



JT File Format Reference

Version 10.6

Rev-A

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Version 10.6 revision summaries

Revision A contains changes made to JT from version 10.5

Errors in the Annex A Object Type Identifiers table have been fixed.

Nine new texture types have been added to Table 21 Texture Vers-1 Texture Type values table.

Newly supported line styles have been added to Table 36 — Line Style Attribute Data Flag values and Table 61 — Polyline Styles.

A scale factor system attribute definition has been added to the XT B-Rep segment.

Hybrid XT B-Rep and XT Facet body descriptions are added to the XT B-Rep segment. Section “11.6.1 Version numbers” has been updated to reflect this addition.

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1 Scope

This reference defines the syntax and semantics of the JT Version 10.6 file format.

The JT format is an industry focused, high-performance, lightweight, flexible file format for capturing and repurposing 3D Product Definition data that enables collaboration, validation and visualization throughout the extended enterprise. JT format is the de-facto standard 3D Visualization format in the automotive industry, and the single most dominant 3D visualization format in Aerospace, Heavy Equipment and other mechanical CAD domains.

The JT format is both robust, and streamable, and contains best-in-class compression for compact and efficient representation. The JT format was designed to be easily integrated into enterprise translation solutions, producing a single set of 3D digital assets that support a full range of downstream processes from lightweight web-based viewing to full product digital mockups.

At its core the JT format is a scene graph with CAD specific node and attributes support. Facet information (triangles), is stored with sophisticated geometry compression techniques. Visual attributes such as lights, textures, materials are supported. Product and Manufacturing Information (PMI), Precise Part definitions (B-Rep) and Metadata as well as a variety of representation configurations are supported by the format. The JT format is also structured to enable support for various delivery methods including asynchronous streaming of content.

Some of the highlights of the JT format include:

- Built-in support for assemblies, sub-assemblies and part constructs
- Flexible partitioning scheme, supporting single or multiple files
- B-Rep, including integrated support for industry standard Parasolid® (XT) format
- Product Manufacturing Information in support of paperless manufacturing initiatives
- Precise and imprecise wireframe
- Discrete purpose-built Levels of Detail
- Triangle sets, Polygon sets, Point sets, Line sets and Implicit Primitive sets (cylinder, cone, sphere, etc...)
- Full array of visual attributes: Materials, Textures, Lights
- Hierarchical Bounding Box and Bounding Spheres
- Advanced data compression that allows producers of JT files to fine tune the tradeoff between compression ratio and fidelity of the data.

Beyond the data contents description of the JT Format, the overall physical structure/organization of the format is also designed to support operations such as:

Offline optimizations of the data contents

- File granularity and flexibility optimized to meet the needs of Enterprise Data Translation Solutions

Asynchronous streaming of content

- Viewing optimizations such as view frustum and occlusion culling and fixed-framerate display modes.

Layers, and Layer Filters.

Along with the pure syntactical definition of the JT Format, there is also series of conventions which although not required to have a reference compliant JT file, have become commonplace within JT format translators. These conventions have been documented in the “Best Practices” section of this JT format reference.

This JT format reference does not specifically address implementation of, nor define, a run-time architecture for viewing and/or processing JT data. This is because although the JT format is closely aligned with a run-time data representation for fast and efficient loading/unloading of data, no interaction behaviour is defined within the format itself, either in the form of specific viewer controls, viewport information, animation behaviour or other event-based interactivity. This exclusion of interaction behaviour from the JT format makes the format more easily reusable for dissimilar application interoperation and also facilitates incremental update, without losing downstream authored data, as the original CAD asset revises.

2 Terms and definitions, abbreviated terms

2.1 Terms and definitions

For the purposes of this document, the following terms apply.

3.1.1

3D visualization

visual presentation on a screen or another media of graphical and textual three dimensional representation of a set of data representing an object, information or results of a computational process in order to facilitate capture of the understanding of the object, for visual information sharing with users and sometimes to promote decision process by a human looking at data visualized in a medium

3.1.2

assembly

related collection of model parts, represented in a JT format logical scene graph as a logical graph branch.

3.1.3

attribute objects associated with nodes in a logical scene graph and specifying one of several appearances, positioning, or visual characteristics of a shape

3.1.4

code text

collection of data in encoded form

3.1.5

coordinate system system which uses one or more numbers, or coordinates, to uniquely determine the position of a point or other geometric element

Note 1 to entry: If not otherwise specified in a data field's description, it is assumed that the data is defined in Local Coordinate System.

3.1.6

degenerated surface

place where a region of the parameter space of the surface is mapped to a single of Cartesian space

Note 1 to entry: This means that there are several (u,v) parameters defining the same 3D point of the surface. In this region, one or both partial derivatives are zero. The tip of a cone or the poles of a sphere are common examples.

3.1.7

directed acyclic graph

graph that consists of a set of nodes and a set of edges that connect the nodes in a tree like structure

Note 1 to entry: A directed graph is one in which every edge has a direction such that edge (u,v), connecting node-u with node-v, is different from edge (v,u).

Note 2 to entry: A directed acyclic graph is a directed graph with no cycles, where a cycle is a path (sequence of edges) from a node to itself.

Note 3 to entry: With a directed acyclic graph, there is no path that can be followed within the graph such that the first node in the path is the same as the last node in the path.

3.1.8

JT enabled application

application which supports reading and/or writing reference compliant JT format files

3.1.9

level of detail

LOD

alternative graphical representation for some model component such as part

3.1.10

local coordinate system

LCS

coordinate system that is used to specify the raw data of the shape geometry with no transforms applied

3.1.11

logical scene graph

LSG

scene graph representing the logical organization of a model

Note 1 to entry: A scene graph contains shapes and attributes representing the model's physical components, properties identifying arbitrary metadata (for example names, semantic roles) of those components, and a hierarchical structure expressing the component relationships.

3.1.12

mipmap

reduced resolution version of a texture map

Note 1 to entry: Mipmaps are used to texture a geometric primitive whose screen resolution differs from the resolution of the source texture map originally applied to the primitive.

3.1.13

model

representation, in JT format, of a physical or virtual product, part, assembly; or collections of such objects

3.1.14

model coordinate system

MCS

local coordinates transformed by any transforms specified as attributes at or above the node

3.1.15

product and manufacturing information

PMI

collection of information created on a 3D/2D CAD model to completely document the product with respect to design, manufacturing, inspection, etc.

Note 1 to entry: This can include data such as:

- dimensions (tolerances for each dimension);
- geometric tolerances of feature (datums, feature control frames);
- manufacturing information (surface finish, welding notations);
- inspection information (key locations points);
- assembly instructions ;
- product information (materials, suppliers, part numbers).

3.1.16

property

object associated with a logical scene graph node and identifying arbitrary application or enterprise specific information (meta-data) related to that node

3.1.17

quantize

constrain something to a discrete set of values, such as an integer or integral multiplier of a common factor, rather than a continuous set of values, such as a real number

3.1.18

scene graph

directed acyclic graph that arranges the logical and often (but not necessarily) spatial representation of a graphical scene

3.1.19

shader

user-definable program, expressed directly in a target assembly language or in a high-level form to be compiled, that calculates colour values at a pixel based upon data such as lighting, surface colour and texture.

Note 1 to entry: A shader program replaces a portion of the otherwise fixed-functionality graphics pipeline with some user-defined function.

Note 2 to entry: At present, hardware manufacturers have made it possible to run a shader for each vertex that is processed or each pixel that is rendered.

3.1.20

streaming

loading from disk based medium only the portions of data that are required by the user to perform the tasks at hand

Note 1 to entry: The motivation for streaming is to more efficiently manage system memory.

Note 2 to entry: Transfer of data in a stream of packets, over the internet on an on-demand basis, where the data is interpreted in real-time by the application as the data packets arrive.

Note 3 to entry: The motivation for streaming is that the user can begin using or interacting with the data almost immediately - no waiting for the entire data file(s) to be transferred before beginning.

Note 4 to entry: The desired end result of streaming is to deliver only the JT data that the user needs, where the user needs it, when the user needs it.

3.1.21

shape

logical scene graph leaf node containing or referencing the geometric shape definition data (such as vertices, polygons and normals) of a model component

3.1.22

texture channel

texture unit plus the texture environment.

Note 1 to entry: The JT format meaning for texture channel is the same as in OpenGL [1].

3.1.23

texture object

named cache that stores texture data, such as the image array, associated mipmaps, and associated texture parameter values: width, height, border width, internal format, resolution of components, minification and magnification filters, wrapping modes, border colour, and texture priority

Note 1 to entry: The JT format meaning for texture object is the same as in OpenGL [1].

3.1.24

texture unit

piece of hardware that takes a sample of a texture.

Note 1 to entry: The JT format meaning for texture unit is the same as in OpenGL [1].

3.1.25

view coordinate system

world coordinates transformed by a view matrix

3.1.26

world coordinate system

WCS

node coordinates transformed by transforms inherited from a node's parent (therefore the coordinate system at the root of the graph)

3.1.27

boundary representation

solid model representation where the solid volume is specified by its surface boundary (both its geometric and topological boundaries)

2.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

| | |
|----------|--|
| Abs | Absolute Value |
| Bbox | Bounding Box |
| B-Rep | Boundary Representation |
| CAD | Computer Aided Design |
| CODEC | Coder-Decoder |
| GD&T | Geometric Dimensioning and Tolerancing |
| GUID | Globally Unique Identifier |
| HSV | Hue, Saturation, Value |
| LsbFirst | Least Significant Byte First |
| Max | Maximum |
| Min | Minimum |
| MsbFirst | Most Significant Byte First |
| N/A | Not Applicable |
| PCS | Parameter Coordinate Space |
| PLM | Product Lifecycle Management |
| RGB | Red, Green, Blue |
| RGBA | Red, Green, Blue, Alpha |






| | |
|------|-----------------------------|
| TOC | Table of Contents |
| VPCS | Viewpoint Coordinate System |
| URL | Uniform Resource Locator |

3 Notational conventions

3.1 Diagrams and field descriptions

Symbolic diagrams are used to describe the structure of the JT file. The symbols used in these diagrams are shown in Table 1 and have the following meaning:

Table 1 — Symbols

| Symbol | Description |
|---|---|
|  | Rectangles represent a data field of one of the standard data types. |
|  | Folders represent a logical collection of one or more of the standard data types. This information is grouped for clarity and the basic data types that compose the group are detailed in following sections of the document. |
|  | Rectangles with extra lines at left and the right sides corners clipped off represent information logical steps that has been compressed. |
|  | Rectangles with the right side corners clipped off represent information that has been compressed. |
|  | Arrows convey the ordering of the information. |

The format used to title the diagram symbols is dependent upon the symbol type as follows:

Diagram “rectangle box” (therefore standard data types) symbols are titled using a format of “Data_Type : Field_Name.” The Data_Type is an abbreviated data type symbol as defined in 3.2 Data Types. In the example shown in Figure 1 the Data_Type is “I32” (a signed 32 bit integer) and Field_Name is “Count.”

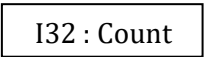


Figure 1 — rectangle box diagram

Diagram “folder” (therefore logical data collections) symbols are simply titled with a collection name. In the example shown in Figure 2 the collection name is “Graph Elements.”

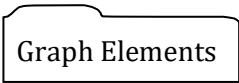


Figure 2 — folder diagram

Diagram “rectangle box with lines at left and right sides” are simply titled with a logic step name. In the example shown in Figure 3 the logic step name is “Recover First Shell Indices”.



Figure 3 — rectangle box with lines at left and right sides diagram

Diagram “rectangle box with clipped right side corners” (therefore compressed/encoded data fields) are titled using one of the following three formats:

Data Type; followed by open brace “{”, number of bits used to store value, closed brace “}”, and a colon “:”; followed by the Field Name. This format for titling the diagram symbol indicates that the data is compressed but not encoded. The compression is achieved by using only a portion of the total bit range of the data type to store the value (for example if a count value can never be larger than the value “63” then only 6 bits are needed to store all possible count values). In the example shown in Figure 4 the Data Type is “U32”, “6” bits are used to store the value, and Field Name is “Count”

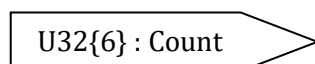


Figure 4 — rectangle box with clipped right side corners

Data Type followed by open brace “{”, compressed data packet type, “,”, Predictor Type, closed brace “}”, and a colon “:”; followed by the field name. This format for titling the diagram indicates that a vector of “Data Type” data (therefore *primal* values) is ran through “Predictor Type” algorithm and the resulting output array of *residual* values is then compressed and encoded into a series of symbols using one of the two supported compressed data packet types.

The two supported compressed data packet types are:

Int32CDP – The Int32CDP (therefore Int32 Compressed Data Packet) represents a third-generation format used to encode/compress a collection of data into a series of Int32 based symbols. This version of the Int32CDP supersedes the two similarly-named ones from the JT 9.5 Specification, and should not be confused with either of its predecessors. A complete description for Int32 Compressed Data Packet can be found in Int32 Compressed Data Packet.

The Int32 Compressed Data Packet type is used for compressing/encoding both “integer” and “float” (through quantization) data.

In the example shown in Figure 5 the Data Type is “VecU32”, Int32 Compressed Data Packet type is used, Lag1 Predictor Type is used, and Field Name is “First Shell Index.”

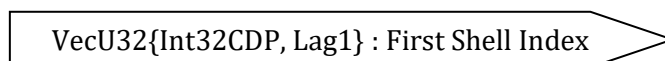


Figure 5 — compressed data packet diagram

As mentioned above (with Predictor Type algorithm), the *primal* input data values are NOT always what is encoded/compressed. This is because the *primal* input data is first run through a Predictor Type algorithm, which produces an output array of residual values (therefore difference from the predicted value), and this resulting output array of *residual* values is the data which is actually encoded/compressed. The JT format supports several Predictor Type algorithms and each use of Int32CDP specifies, using the notation format described above, what Predictor Type algorithm is being used on the data. The JT format supported Predictor Type algorithms are as shown in Table 2 (note that a sample implementation of decoding the predictor *residual* values back into the primal values can be found in the Coding Algorithms Annex.

Table 2 — Predictor Type

| Predictor Type | Description |
|----------------|--|
| Lag1 | Predicts as last value |
| Xor1 | Predict as last, but use XOR instead of subtract to compute residual |
| NULL | No prediction applied |

Each predictor type can be combined with additional processing steps, and in such case the predictor type is prefixed with “Combined:”. For example, “Combined:Lag1” means that predictor type “Lag1” is combined with additional preprocessing steps. Additional description about the processing steps is provided whenever such combined predictor is used.

“Data Type : Field Name” . This format for titling the diagram symbol indicates that the data is both compressed and encoded. The Data_Type is an abbreviated data type symbol as defined in Data Types and usually represent a vector/array of data. How the data is compressed and encoded into the Data Type is indicated by a CODEC type and other information stored before the particular data in the file. In the example shown in Figure 6 the Data_Type is “VecU32” and Field_Name is “CodeText.”

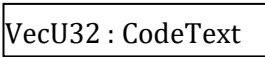


Figure 6 — data type : field name diagram

Note that for some JT file Segment Types there is LZMA compression also applied to all bytes of element data stored in the segment. This LZMA compression applied to all the segment’s data is not indicated in the diagrams through the use of “rectangle box with clipped right side corners”. Instead, one shall examine information stored with the first Element in the file segment to determine if LZMA compression is applied to all data in the segment. A complete description of the JT format data compression and encoding can be found in Data Segment and Data Compression and Encoding.

Following each data collection diagram is detailed descriptions for each entry in the data diagram.

For rectangles this detail includes the abbreviated data type symbol, field name, verbal data description, and compression technique/algorithm where appropriate. If the data field is documented as a collection of flags, then the field is to be treated as a bit mask where the bit mask is formed by combining the flags using the binary OR operator. Each bits usage is documented, and bit ON indicates flag value is TRUE and bit OFF indicates flag value is FALSE. All bits fields that are not defined as in use should be set to “0”.

For folders (therefore data collections), if the collection is not detailed under a sub-section of the particular document section referencing the data collection, then a comment is included following the diagram indicating where in the document the particular data collection is detailed.

If an arrow appears with a branch in its shaft, then there are two or more options for data to be stored in the file. Which data is stored will depend on information previously read from the file. The following example, shown in Figure 7, shows data field A followed by (depending on value of A) either data field B, C, or D.

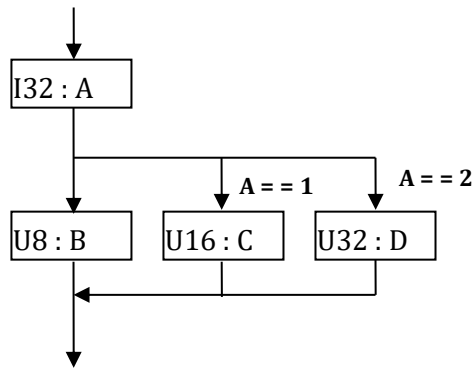


Figure 7 — data filed dependency example

In cases where the same data type repeats, a loop construct is used where the number of iterations appears next to the loop line. There are two forms of this loop construct. The first form is used when the number of iterations is not controlled by some previous read count value. Instead the number of iterations is either a hard coded count (for example always 80 characters) or is indicated by some end-of-list marker in the data itself (thus the count is always minimum of 1). This first form of the loop construct looks as shown in Figure 8:

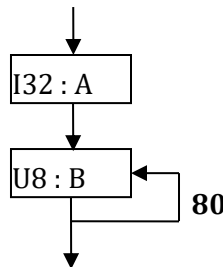


Figure 8 — loop construct example

The second form of this loop construct is used when the number of iterations is based on data (for example count) previously read from the file. In this case it is valid for there to be zero data iterations (zero count). This second form of the loop construct looks as shown in Figure 9 (data field D is repeated C value times).

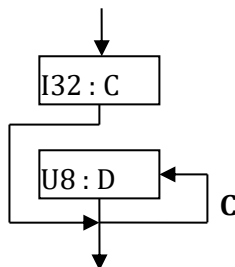


Figure 9 — loop construct with iterations example

3.2 Data Types

The data types that can occur in the JT binary files are listed in the following two tables.

The Basic Data Types table, shown in Table 3, lists the basic/standard data types which can occur in JT file.

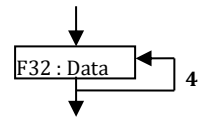
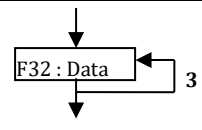
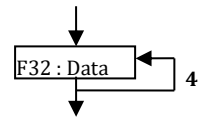
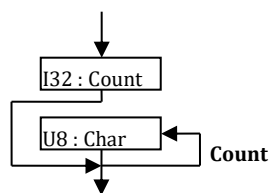
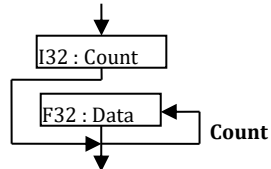
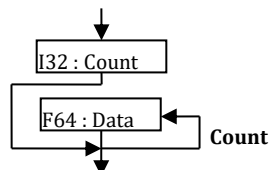
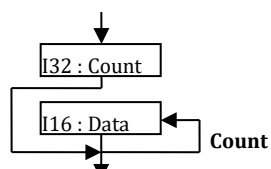
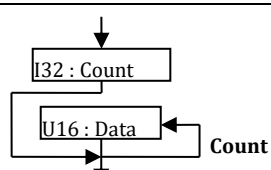
Table 3 — Basic Data Types

| Type | Description |
|-------|---|
| UChar | An unsigned 8-bit byte. |
| U8 | An unsigned 8-bit integer value. |
| U16 | An unsigned 16-bit integer value. |
| U32 | An unsigned 32-bit integer value. |
| U64 | An unsigned 64-bit integer value. |
| | |
| I16 | A signed two's complement 16-bit integer value. |
| I32 | A signed two's complement 32-bit integer value. |
| I64 | A signed two's complement 64-bit integer value. |
| | |
| F32 | An IEEE 32-bit floating point number. |
| F64 | An IEEE 64-bit double precision floating point number |

Table 4 — Composite Data Types, as shown in Table 4, lists some composite data types which are used to represent some frequently occurring groupings of the basic data types (for example Vector, RGBA colour). The composite data types are defined in this reference simply for convenience/brevity in describing the JT file contents.

Table 4 — Composite Data Types

| Type | Description | Symbolic Diagram |
|----------|--|------------------|
| BBoxF32 | The BBoxF32 type defines a bounding box using two CoordF32 types to store the XYZ coordinates for the bounding box minimum and maximum corner points. | |
| CoordF32 | The CoordF32 type defines X, Y, Z coordinate values. So a CoordF32 is made up of three F32 base types. | |
| DirF32 | The DirF32 type defines X, Y, Z components of a direction vector. So a DirF32 is made up of three F32 base types. | |
| GUID | <p>The GUID type is a 16 byte (128-bit) number. GUID is stored/written to the JT file using a four-byte word (U32), 2 two-byte words (U16), and 8 one-byte words (U8) such as:</p> <p>{3F2504E0-4F89-11D3-9A-0C-03-05-E8-2C-33-01}</p> <p>In the JT format GUIDs are used as unique identifiers (for example Data Segment ID, Object Type ID, etc.)</p> | |
| MbString | The MbString type starts with an I32 that defines the number of characters (NumChar) the string contains. The number of bytes of character data is "2 * NumChar" (therefore the strings are written out as multi-byte characters where each character is UTF16 size). | |
| Mx4F32 | Defines a 4-by-4 matrix of F32 values for a total of 16 F32 values. The values are stored in row major order (right most subscript, column varies fastest), that is, the first 4 elements form the first row of the matrix. | |
| Mx4F64 | Defines a 4-by-4 matrix of F64 values for a total of 16 F64 values. The values are stored in row major order (right most subscript, column varies fastest), that is, the first 4 elements form the first row of the matrix. | |
| PlaneF32 | The PlaneF32 type defines a geometric Plane using the General Form of the plane equation ($Ax + By + Cz + D = 0$). The PlaneF32 type is made up of four F32 base types where the first three F32 define the plane unit normal vector (A, B, C) and the last F32 defines the negated perpendicular distance (D), along normal vector, from the origin to the plane. | |

| | | |
|------------|--|---|
| Quaternion | The Quaternion type defines a 3-dimensional orientation (no translation) in quaternion linear combination form ($a + bi + cj + dk$) where the four scalar values (a, b, c, d) are associated with the 4 dimensions of a quaternion (1 real dimension, and 3 imaginary dimensions). So the Quaternion type is made up of four F32 base types. |  |
| RGB | The RGB type defines a colour composed of Red, Green, Blue components, each of which is a F32. So a RGB type is made up of three F32 base types. The Red, Green, Blue colour values typically range from 0.0 to 1.0. |  |
| RGBA | The RGBA type defines a colour composed of Red, Green, Blue, Alpha components, each of which is a F32. So a RGBA type is made up of four F32 base types. The Red, Green, Blue colour values typically range from 0.0 to 1.0. The Alpha value ranges from 0.0 to 1.0 where 1.0 indicates completely opaque. |  |
| String | The String type starts with an I32 that defines the number of characters (NumChar) the string contains. The number of bytes of character data is "NumChar" (therefore the strings are written out as single-byte characters where each character is U8 size). |  |
| VecF32 | The VecF32 type defines a vector/array of F32 base type. The type starts with an I32 that defines the count of following F32 base type data. So a VecF32 is made up of one I32 followed by that number of F32. Note that it is valid for the I32 count number to be equal to "0", indicating no following F32. |  |
| VecF64 | The VecF64 type defines a vector/array of F64 base type. The type starts with an I32 that defines the count of following F64 base type data. So a VecF64 is made up of one I32 followed by that number of F64. Note that it is valid for the I32 count number to be equal to "0", indicating no following F64. |  |
| VecI16 | The VecI16 type defines a vector/array of I16 base type. The type starts with an I32 that defines the count of following I16 base type data. So a VecI16 is made up of one I32 followed by that number of I16. Note that it is valid for the I32 count number to be equal to "0", indicating no following I16. |  |
| VecU16 | The VecU16 type defines a vector/array of U16 base type. The type starts with an I32 that defines the count of following U16 base type data. So a VecU16 is made up of one I32 followed by that number of U16. Note that it is valid for the I32 count number to be equal to "0", indicating no following U16. |  |

| | | |
|--------|--|--|
| VecI32 | The VecI32 type defines a vector/array of I32 base type. The type starts with an I32 that defines the count of following I32 base type data. So a VecI32 is made up of one I32 followed by that number of I32. Note that it is valid for the I32 count number to be equal to “0”, indicating no following I32. | |
| VecU32 | The VecU32 type defines a vector/array of U32 base type. The type starts with an I32 that defines the count of following U32 base type data. So a VecU32 is made up of one I32 followed by that number of U32. Note that it is valid for the I32 count number to be equal to “0”, indicating no following U32. | |

3.3 Empty field

When writing a JT file whose data did not originate from reading a previous JT file, an empty field should be set to a value of “0”.

When writing a JT file whose data originated from reading a previous JT (therefore rewriting a JT file), empty fields should be written with the same value that was read from the originating JT file.

Refer to Empty Field guidelines in the Common Data Conventions and Constructs section

4 File Format

All objects represented in the JT format are assigned an “object identifier” (for example see Base Node Data, or Base Attribute Data Base Attribute Data) and all references from one object to another object are represented in the JT format using the referenced object’s “object identifier”. It is the responsibility of JT format readers/writers to maintain the integrity of these object references by doing appropriate pointer unswizzling/swizzling as JT format data is read into memory or written out to disk. Where “pointer swizzling” refers to the process of converting references based on object identifiers into direct memory pointer references and “pointer unswizzling” is the reverse operation (therefore replacing references based on memory pointers with object identifier references).

All objects stored in a JT file are classified by type and thus include an object type identifier as part of their persisted data.

Object Type Identifiers specifications are defined in Object Type Identifiers Annex A of this document.

4.1 File Structure

An JT file is structured as a sequence of blocks/segments, as shown in Figure 10. The File Header block is always the first block of data in the file. The File Header is followed (in no particular order) by a TOC Segment and a series of other Data Segments. The one Data Segment which shall always exist to have a reference compliant JT file is the LSG Segment. The TOC Segment is located within the file using data stored in the File Header. Within the TOC Segment is information that locates all other Data Segments within the file.

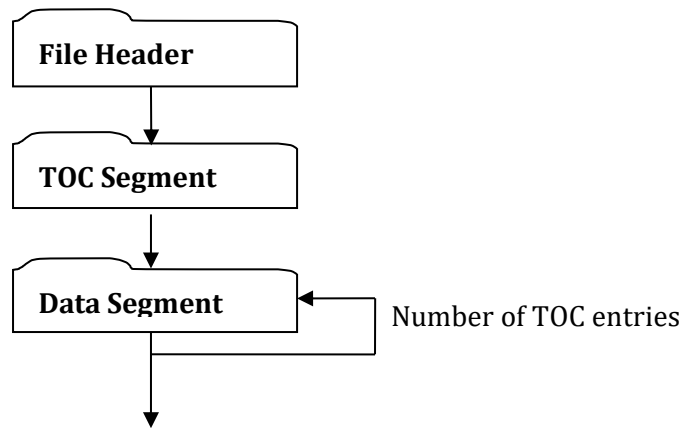


Figure 10 — JT File Structure

4.1.1 File Header

The File Header is always the first block of data in an JT file. The File Header contains information about the JT file version and TOC location, which Loaders use to determine how to read the file. The exact contents of the File Header are as shown in Figure 11:

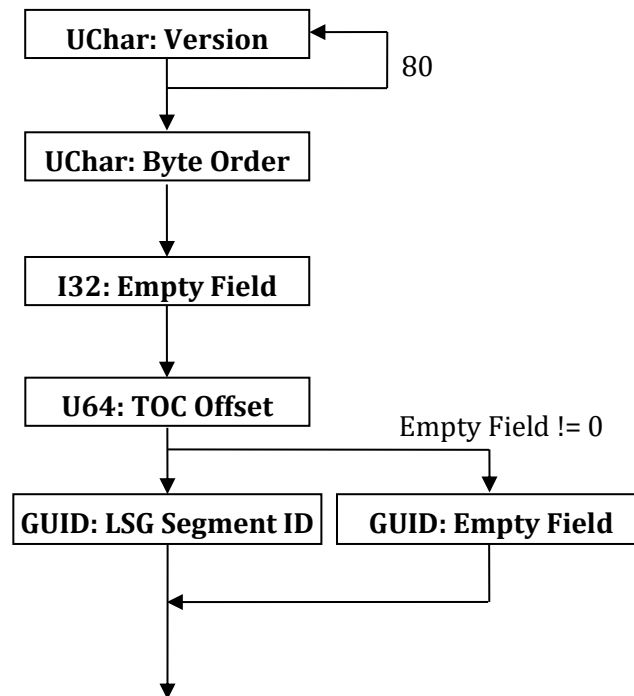


Figure 11 — File Header data collection

UChar: Version

An 80-character version string defining the version of the file format used to write this file. The Version string has the following format:

Version *M.n* Comment

Where *M* is replaced by the major version number, *n* is replaced by the minor version number, and *Comment* provides other information.

The major.minor version description for JT files is 10.6

The version string is padded with spaces to a length of 75 ASCII characters and then the final five characters shall be filled with the following linefeed and carriage return character combination (shown using c-style syntax):

```
Version[75] = ' '
Version[76] = '\n'
Version[77] = '\r'
Version[78] = '\n'
Version[79] = ' '
```

These final 5 characters (shown above and referred to as ASCII/binary translation detection bytes) can be used by JT file readers to validate that the JT files has not been corrupted by ASCII mode FTP transfers.

As an example, for a JT Version 10.6 file this string will look as follows:

“Version 10.6 \n\r\n “

UChar: Byte Order

Defines the file byte order and thus can be used by the loader to determine if there is a mismatch (thus byte swapping required) between the file byte order and the machine (on which the loader is being run) byte order. Valid values for Byte Order are:

0 – Least Significant byte first (LsbFirst)

1 – Most Significant byte first (MsbFirst)

I32: Empty Field

Refer to Common Data Conventions and Constructs Empty Field description.

U64: TOC Offset

Defines the byte offset from the top of the file to the start of the TOC Segment.

GUID: LSG Segment ID

LSG Segment ID specifies the globally unique identifier for the Logical Scene Graph Data Segment in the file. This ID along with the information in the TOC Segment can be used to locate the start of LSG Data Segment in the file. This ID is needed because without it a loader would have no way of knowing the location of the root LSG Data Segment. All other Data Segments shall be accessible from the root LSG Data Segment.

GUID: Empty Field

Refer to Common Data Conventions and Constructs Empty Field description.

4.1.2 TOC Segment

The TOC Segment contains information identifying and locating all individually addressable Data Segments within the file. A TOC Segment is always required to exist somewhere within a JT file. The actual location of the TOC Segment within the file is specified by the File Header segment's "TOC Offset" field. The TOC Segment contains one TOC Entry for each individually addressable Data Segment in the file, as shown in Figure 12.

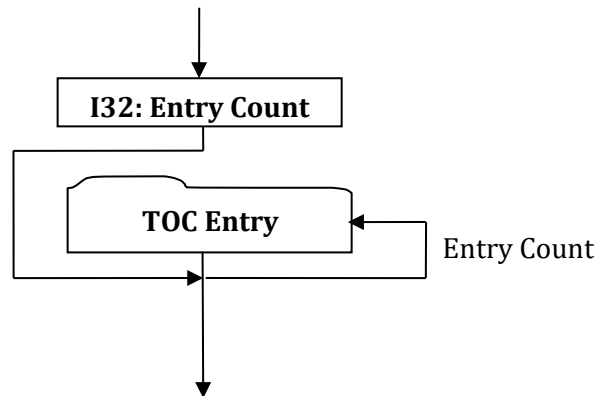


Figure 12 — TOC Segment data collection

I32: Entry Count

Entry Count is the number of entries in the TOC.

TOC Entry

Each TOC Entry represents a Data Segment within the JT File. The essential function of a TOC Entry is to map a Segment ID to an absolute byte offset within the file, as shown in Figure 13.

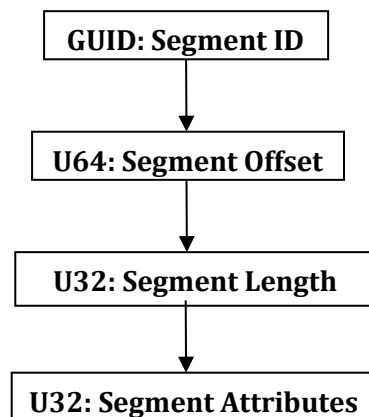


Figure 13 — TOC Entry data collection

GUID: Segment ID

Segment ID is the globally unique identifier for the segment.

U64: Segment Offset

Segment Offset defines the byte offset from the top of the file to start of the segment.

U32: Segment Length

Segment Length is the total size of the segment in bytes.

U32: Segment Attributes

Segment Attributes is a collection of segment information encoded within a single U32 using the following bit allocation, as shown in Table 5.

Table 5 — Segment attributes

| | |
|--------------|--|
| Bits 0 - 23 | Reserved for future use. |
| Bits 24 - 31 | Segment type. Complete list of Segment types can be found in the Segment Types table of this document. |

4.1.3 Data Segment

All data stored in an JT file shall be defined within a Data Segment. Data Segments are “typed” based on the general classification of data they contain. See the Segment Type field description below for a complete list of the segment types.

Beyond specific data field compression/encoding, some Data Segment types also have compression conditionally applied to all the Data bytes of information persisted within the segment. Whether this compression is conditionally applied to a segment’s Data bytes of information is indicated by information stored with the first “Element” in the segment. Also, the Segment Types table has a column indicating whether the Segment Type may have compression applied to its Data bytes.

All Data Segments have the same basic structure, as shown in Figure 14.

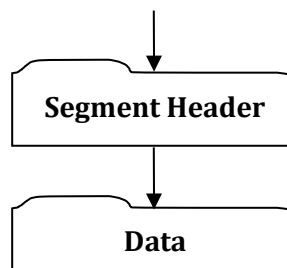


Figure 14 — Data Segment data collection

Segment Header

Segment Header contains information that determines how the remainder of the Segment is interpreted by the loader, as shown in Figure 15.

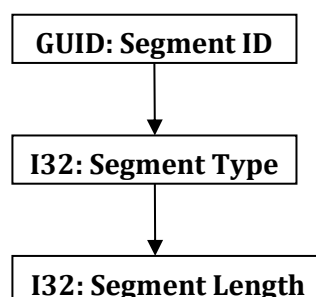


Figure 15 — Segment Header data collection

GUID: Segment ID

Global Unique Identifier for the segment.

I32: Segment Type

Segment Type defines a broad classification of the segment contents. For example, a Segment Type of “1” denotes that the segment contains Logical Scene Graph material; “2” denotes contents of a B-Rep, etc.

The complete list of segment and whether or not they support compression on all Data bytes in the payload is as shown in Table 6:

Table 6 — Segment Types

| Type | Data Contents | Compression |
|------|--------------------------|-------------|
| 1 | Logical Scene Graph | Yes |
| 2 | JT B-Rep | Yes |
| 3 | PMI Data | Yes |
| 4 | Meta Data | Yes |
| 6 | Shape | No |
| 7 | Shape LOD0 | No |
| 8 | Shape LOD1 | No |
| 9 | Shape LOD2 | No |
| 10 | Shape LOD3 | No |
| 11 | Shape LOD4 | No |
| 12 | Shape LOD5 | No |
| 13 | Shape LOD6 | No |
| 14 | Shape LOD7 | No |
| 15 | Shape LOD8 | No |
| 16 | Shape LOD9 | No |
| 17 | XT B-Rep | Yes |
| 18 | Wireframe Representation | Yes |
| 20 | ULP | Yes |
| 23 | STT | Yes |
| 24 | LWPA | Yes |
| 30 | MultiXT B-Rep | Yes |
| 31 | InfoSegment | Yes |
| 33 | STEP B-rep | Yes |

NOTE 1 Segment Types 7-16 all identify the contents as LOD Shape data, where the increasing type number is intended to convey some notion of how high an LOD the specific shape segment represents. The lower the type in this 7-16 range the more detailed the Shape LOD (therefore Segment Type 7 is the most detailed Shape LOD Segment). For the rare case when there are more than 10 LODs, LOD9 and greater are all assigned Segment Type 16.

NOTE 2 The more generic Shape Segment type (therefore Segment Type 6) is used when the Shape Segment has one or more of the following characteristics:

- not a descendant of an LOD node;
- is referenced by (therefore is a child of) more than one LOD node;
- Shape has its own built-in LODs;
- no way to determine what LOD a Shape Segment represents.

NOTE 3 Segment type 33, STEP B-rep, is not defined in this document.

I32: Segment Length

Segment Length is the total size of the segment in bytes. This length value includes all segment Data bytes plus the Segment Header bytes (therefore it is the size of the complete segment) and should be equal to the length value stored with this segment's TOC Entry.

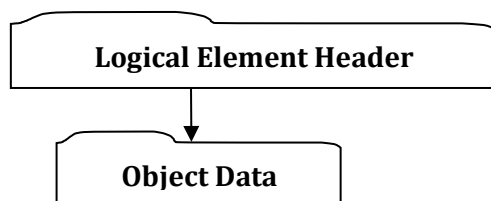
Data

The interpretation of the Data section depends on the Segment Type. See Data Segments for complete description for all Data Segments that may be contained in a JT file.

Although the Data section is Segment Type dependent there is a common structure which often occurs within the Data section. This structure is a list or multiple lists of Elements where each Element has the same basic structure which consists of some fixed length header information describing the type of object contained in the Element, followed by some variable length object type specific data.

Individual data fields of an Element data collection (and its children data collections), shown in Figure 16, may have advanced compression/encoding applied to them as indicated through compression related data values stored as part of the particular Element's storage format. In addition, another level of compression (therefore LZMA compression) may be conditionally applied to all bytes of information stored for all Elements within a particular Segment. Not all Segment types support compression on all Segment data as is indicated Segment Types table. If a particular file Segment is of the type which supports compression on all the Segment data, whether this compression is applied or not is indicated by data values stored in the Logical Element Header Compressed data collection of the first Element within the Segment. An in-depth description of JT file compression/encoding techniques can be found in this document.

For Segment Types that do NOT support compression on all Segment Data.



For Segment Types that DO support compression on all Segment Data.

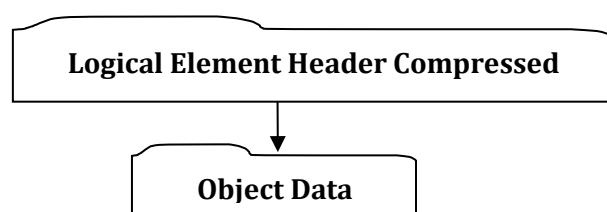


Figure 16 — Data collection

Logical Element Header

Logical Element Header contains data defining the length in bytes of the Element along with the Element Header, shown in Figure 17.

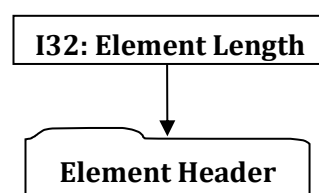


Figure 17 — Logical Element Header data collection

I32: Element Length

Element Length is the total length in bytes of the element Object Data.

Element Header

Element Header contains data describing the object type contained in the Element, shown in Figure 18.

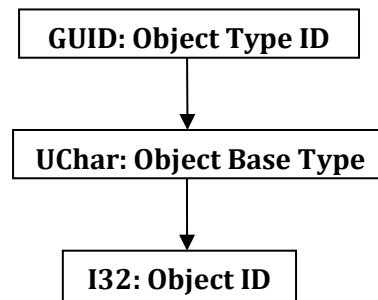


Figure 18 — Element Header data collection

GUID: Object Type ID

Object Type ID is the globally unique identifier for the object type. A complete list of the assigned GUID for all object types stored in an JT file can be found in Annex A. If the GUID is not found in Annex A, the reader should skip Element Length + 1 number of bytes.

UChar: Object Base Type

Object Base Type identifies the base object type. If the Object Base Type is not present in Object Base Types table then the loader should simply skip (read pass) Element Length number of bytes.

Valid Object Base Types, shown in Table 7, include the following:

Table 7 — Object Base Types

| Base Type | Description | Base Type's Data Format |
|-----------|--------------------------------|--|
| 255 | None | None |
| 0 | Base Graph Node Object | Base Node Data |
| 1 | Group Graph Node Object | Group Node Data |
| 2 | Shape Graph Node Object | Base Shape Data |
| 3 | Base Attribute Object | Base Attribute Data |
| 4 | Shape LOD | None |
| 5 | Base Property Object | Base Property Atom Data |
| 6 | JT Object Reference Object | JT Object Reference Property Atom Element without the Logical Element Header Compressed data collection. |
| 8 | JT Late Loaded Property Object | Late Loaded Property Atom Element without the Logical Element Header Compressed data collection. |
| 9 | JtBase (none) | None |

I32: Object ID

Object ID is the identifier for this Object. Other objects referencing this particular object do so using the Object ID.

Object Data

The interpretation of the Object Data section depends upon the Object Type ID stored in the Logical Element Header (see the Logical Element Header description in this document).

Logical Element Header Compressed

Logical Element Header Compressed data collection, shown in Figure 19, is the format of Element Header data used by all Elements within Segment Types that support compression on all data in the Segment. See the Segment Types table for information on whether a particular Segment Type supports compression on all data in the Segment.

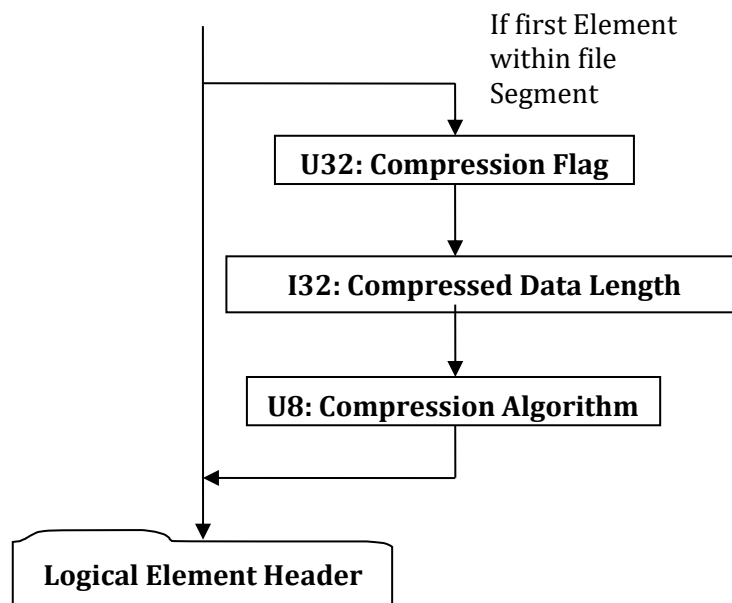


Figure 19 — Logical Element Header Compressed data collection

U32: Compression Flag

Compression Flag is a flag indicating whether compression is ON/OFF for all data elements in the file Segment. Valid values, shown in Table 8, include the following:

Table 8 — Compression flag values

| | |
|------|------------------------|
| = 3 | LZMA compression is ON |
| != 3 | LZMA No Compression |

I32: Compressed Data Length

Compressed Data Length specifies the compressed data length in number of bytes. Note that data field Compression Algorithm is included in this count.

U8: Compression Algorithm

Compression Algorithm specifies the compression algorithm applied to all data in the Segment. Valid values, shown in Table 9, include the following:

Table 9 — Compression algorithm values

| | |
|-----|------------------|
| = 1 | No compression |
| = 3 | LZMA compression |

Logical Element Header

See previous Logical Element Header description. Note that if Compression Flag indicates that compression is ON for all element data in the Segment, then the Logical Element Header data collection is also compressed accordingly.

Object Data

The interpretation of the Object Data section depends upon the Object Type ID stored in the Logical Element Header (see Logical Element Header).

4.2 Data Segments

An JT file consists of the following mandatory segments of data:

- LSG segment contains a collection of objects (therefore elements) connected through directed references to form a directed acyclic graph structure (therefore the LSG). The LSG is the graphical description of the model and contains graphics shapes and attributes representing the model's physical components, properties identifying arbitrary metadata (for example names, semantic roles) of those components, and a hierarchical structure expressing the component relationships.
- Shape LOD segment contains an element that defines the geometric shape definition data (for example vertices, polygons, normals, etc.) for a particular shape level of detail or alternative representation.

In addition to these mandatory segments a set of optional segments for geometry representation, PMI and meta data are available:

For geometry representation:

- XT B-Rep Segment contains an element that defines the recommended precise geometric boundary representation data for a particular part in boundary representation format.
- Multi XT B-Rep Segment contains an element that defines the precise geometric boundary representation data for one or more parts in boundary representation format.
- ULP Segment contains an element that defines the semi-precise geometric boundary representation data for a particular part in JT ULP format.
- LWPA Segment contains an element that defines light weight precise analytic data for a particular part. More specifically LWPA contains the collection of analytic surfaces in the b-rep definition of the part.
- Wireframe Segment contains an element that defines the precise 3D wireframe data for a particular part.

For PMI and metadata:

- Info Segment: contains text strings with authoring information for the JT file it exists in.
- Meta Data Segment is used to store large collections of meta-data in separate addressable segments of the JT File, including PMI. Storing meta-data in a separate addressable segment allows references (from within the JT file) to these segments to be constructed such that the meta-data can be late-loaded.
- STT Segment JT Smart Topology Table (hereafter referred to as STT) Segment contains an Element that defines the lightweight topology description for a particular Part.

For completed information on all the segments of an JT file see the segment descriptions for each segment in their specific sections in this document.

5 LSG Segment

5.1 Segment Overview

LSG Segment contains a collection of objects (therefore Elements) connected through directed references to form a directed acyclic graph structure (therefore the LSG). The LSG is the graphical description of the model and contains graphics shapes and attributes representing the model's physical components, properties identifying arbitrary metadata (for example names, semantic roles) of those components, and a hierarchical structure expressing the component relationships. The "directed" nature of the LSG references implies that there is by default "state/attribute" inheritance from ancestor to descendant (therefore predecessor to successor).

The first Graph Element in a LSG Segment should always be a Partition Node. The LSG Segment type supports compression on all element data, so all elements in LSG Segment use the Logical Element Header Compressed form of element header data. i.e. this means the 3 compression related fields in the Logical Element Header Compressed appear in the first graph element only, shown in Figure 20.

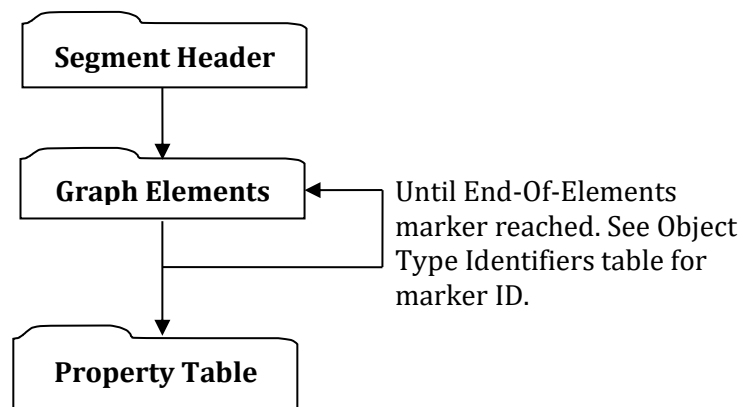


Figure 20 — LSG Segment data collection

Complete description for Segment Header can be found in the Segment Header description found in Data Segment.

5.2 Graph Elements

Graph Elements form the backbone of the LSG directed acyclic graph structure and in doing so serve as the JT model's fundamental description. There are two general classifications of Graph elements, Node Elements and Attribute Elements.

Node Elements are nodes in the LSG and in general can be categorized as either an internal or leaf node. The leaf nodes are typically shape nodes used to represent a model's physical components and as such either contain or reference some graphical representation or geometry. The internal nodes define the hierarchical organization of the leaf nodes, forming both spatial and logical model relationships, and often contain or reference information (for example Attribute Elements) that is inherited down the LSG to all descendant nodes.

Attribute Elements represent graphical data (like appearance characteristics (for example colour), or positional transformations) that can be attached to a node, and inherit down the LSG.

Each of these general Graph Element classifications (therefore Node/Attribute Elements) is sub-typed into specific/concrete types based on data content and implied specialized behaviour. The following sub-sections describe each of the Node and Attribute Element types.

5.3 Node Elements

Node Elements represent the relationships of a model's components. The model's component hierarchy is formed via certain types of Node Elements containing collections of references to other Node Elements who in turn may reference other collections of Node Elements. Node Elements are also the holders (either directly or indirectly) of geometric shape, properties, and other information defining a model's components and representations.

5.3.1 Base Node Element

Object Type ID: 0x10dd1035, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Base Node Element represents the simplest form of a node that can exist within the LSG. The Base Node Element, as shown in Figure 21, has no implied LSG semantic behaviour nor can it contain any children nodes.

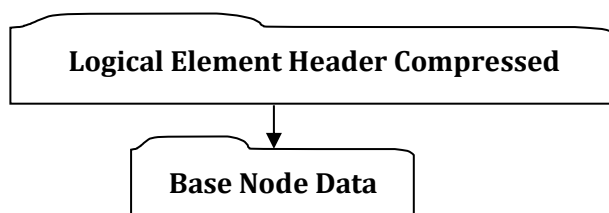


Figure 21 — Base Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data

5.3.2 Base Node Data

An example diagrammatic representation of Base Node Data is shown in Figure 22.

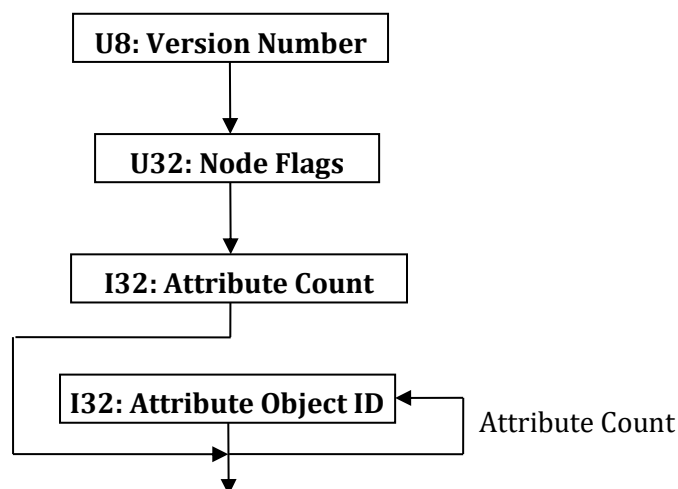


Figure 22 — Base Node Data collection

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U32: Node Flags

Node Flags is a collection of flags. The flags are combined using the binary OR operator. These flags store various state information of the node object. All bits fields that are not defined as in use should be set to “0”, as shown in Table 10.

Table 10 — Node Flag values

| | |
|------------|---|
| 0x00000001 | Ignore Flag = 0 – Algorithms traversing the LSG structure should include/process this node. = 1 – Algorithms traversing the LSG structure should skip the whole subgraph rooted at this node. Essentially the traversal should be pruned. |
|------------|---|

I32: Attribute Count

Attribute Count indicates the number of Attribute Objects referenced by this Node Object. A node may have zero Attribute Object references.

I32: Attribute Object ID

Attribute Object ID is the identifier for a referenced Attribute Object.

5.3.3 Partition Node Element

Object Type ID: 0x10dd103e, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A partition in a JT file must always be either the root or leaf node. A leaf partition node represents an external JT file reference and provides a means to partition a model into multiple physical JT files (for example separate JT file per part in an assembly). An example diagrammatic representation of the Partition Node Element data collection is shown in Figure 23.

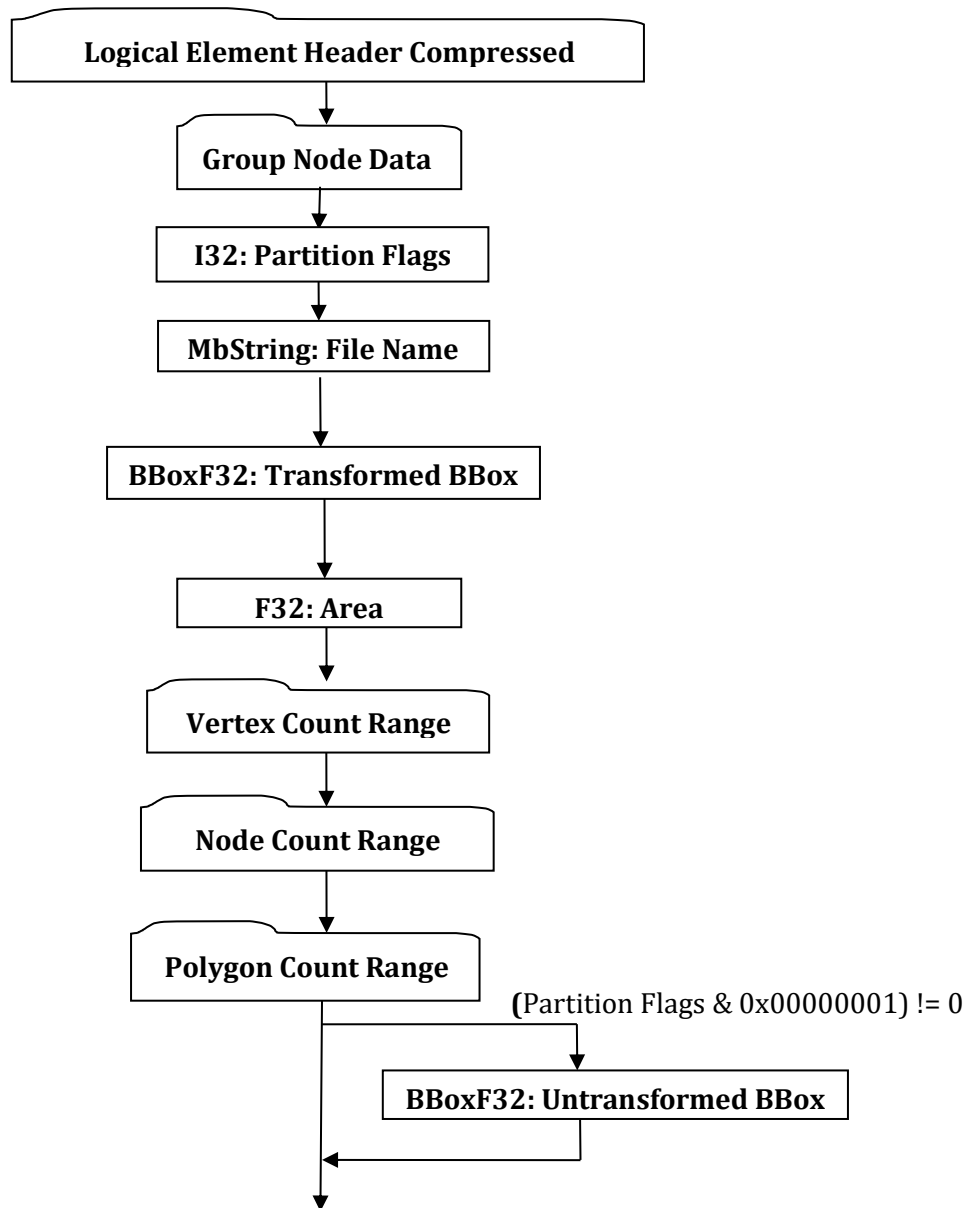


Figure 23 — Partition Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data

Complete description for Group Node Data can be found in Group Node Data.

I32: Partition Flags

Partition Flags is a collection of flags. The flags are combined using the binary OR operator. These flags store various state information of the Partition Node Object, as shown in Table 11, such as indicating the presence of optional data. All bits fields that are not defined as in use should be set to “0”.

Table 11 — Partition flag bits

| | |
|------------|--|
| 0x00000001 | Untransformed bounding box is written. |
|------------|--|

MbString: File Name

File Name is the relative path portion of the Partition’s file location. Where “relative path” should be interpreted to mean the string contains the file name along with any additional path information that locates the partition JT file relative to the location of the referencing JT file.

BBoxF32: Transformed BBox

The Transformed BBox is an MCS axis aligned bounding box and represents the transformed geometry extents for all geometry contained in the Partition Node. This bounding box information may be used by a renderer of JT data to determine whether to load the data contained within the Partition node (therefore is any part of the bounding box within the view frustum).

F32: Area

Area is the total surface area for this node and all of its descendants. This value is stored in MCS coordinate space (therefore values scaled by MCS scaling).

Vertex Count Range

Vertex Count Range, as shown in Figure 24, is the aggregate minimum and maximum vertex count for all descendants of the Partition Node. There is a minimum and maximum value to accommodate descendant branches having LOD nodes, which encompass a range of count values within the branch, and to accommodate nodes that can themselves generate varying representations. The minimum value represents the least vertex count that can be achieved by the Partition Node’s descendants. The maximum value represents the greatest vertex count that can be achieved by the Partition Node’s descendants.

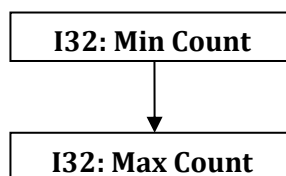


Figure 24 — Vertex Count Range data collection

I32: Min Count

Min Count is the least vertex count that can be achieved by the Partition Node’s descendants.

I32: Max Count

Max Count is the maximum vertex count that can be achieved by the Partition Node’s descendants.

Node Count Range

Node Count Range is the aggregate minimum and maximum count of all node descendants of the Partition Node. There is a minimum and maximum value to accommodate descendant branches having LOD nodes, which encompass a range of descendant node count values within the branch. The minimum value represents the least node count that can be achieved by the Partition Node’s descendants. The maximum value represents the greatest node count that can be achieved by the Partition Node’s descendants.

The data format for Node Count Range is the same as that described in Vertex Count Range.

Polygon Count Range

Polygon Count Range is the aggregate minimum and maximum polygon count for all descendants of the Partition Node. There is a minimum and maximum value to accommodate descendant branches having LOD nodes, which encompass a range of count values within the branch, and to accommodate nodes that can themselves generate varying representations. The minimum value represents the least polygon count that can be achieved by the Partition Node's descendants. The maximum value represents the greatest polygon count that can be achieved by the Partition Node's descendants.

The data format for Polygon Count Range is the same as that described in Vertex Count Range.

BBoxF32: Untransformed BBox

The Untransformed BBox is only present if Bit 0x00000001 of Partition Flags data field is ON. The Untransformed BBox is an LCS axis-aligned bounding box and represents the untransformed geometry extents for all geometry contained in the Partition Node. This bounding box information may be used by a renderer of JT data to determine whether to load the data contained within the Partition node (therefore is any part of the bounding box within the view frustum).

5.3.4 Group Node Element

Object Type ID: 0x10dd101b, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Group Nodes, as shown in Figure 25, contain an ordered list of references to other nodes, called the group's *children*. Group nodes may contain zero or more children; the children may be of any node type. Group nodes may not contain references to themselves or their ancestors.

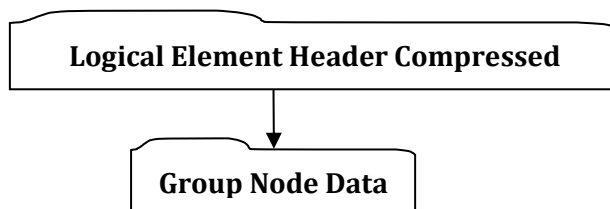


Figure 25 — Group Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data

Group Node Data

An example diagrammatic representation of Group Node Data is shown in Figure 26.

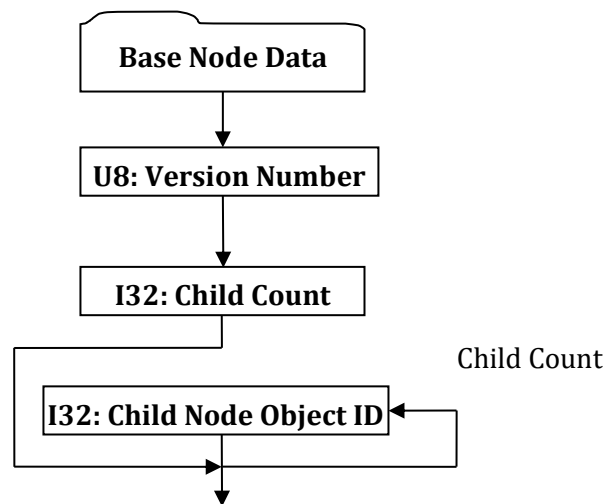


Figure 26 — Group Node Data collection

A complete description of Base Node Data can be found in the LSG Segment section of this document under Base Node Elements in the logical collection describing Base Node Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

I32: Child Count

Child Count indicates the number of child nodes for this Group Node Object. A node may have zero children.

I32: Child Node Object ID

Child Node Object ID is the identifier for the referenced Node Object.

5.3.5 Instance Node Element

Object Type ID: 0x10dd102a, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

An Instance Node, shown in Figure 27, contains a single reference to another node. Their purpose is to allow sharing of nodes and assignment of instance-specific attributes for the instanced node. Instance Nodes may not contain references to themselves or their ancestors.

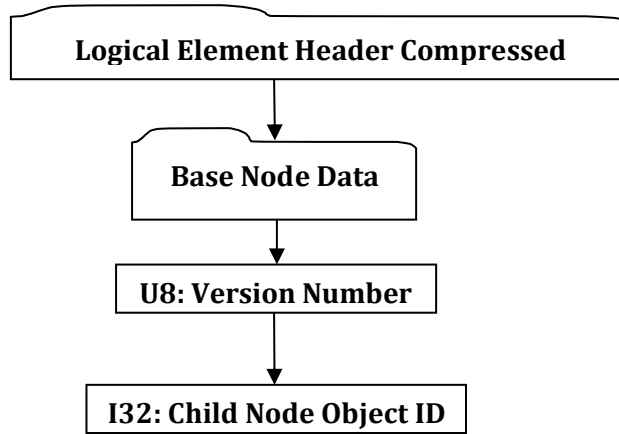


Figure 27 — Instance Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data

A complete description of Base Node Data can be found in the LSG Segment section of this document under Base Node Elements in the logical collection describing Base Node Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

I32: Child Node Object ID

Child Node Object ID is the identifier for the instanced Node Object.

5.3.6 Part Node Element

Object Type ID: 0xce357244, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1

A Part Node Element, shown in Figure 28, represents the root node for a particular Part within a LSG structure. Every unique Part represented within a LSG structure should have a corresponding Part Node Element. A Part Node Element typically references (using Late Loaded Property Atoms) additional Part specific geometric data and/or properties (for example B-Rep data, PMI data).

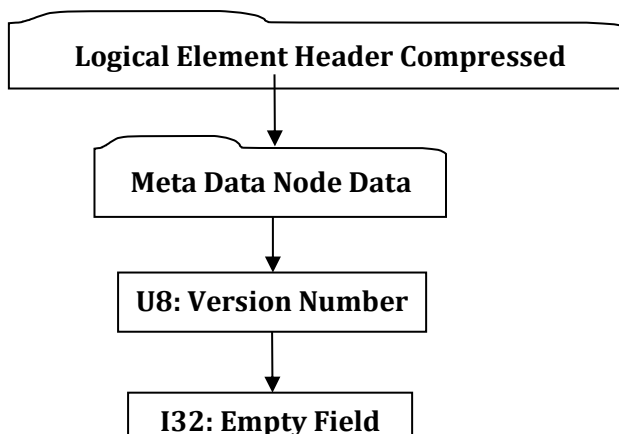


Figure 28 — Part Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data

Complete description for Meta Data Node Data can be found in Meta Data Node Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

I32: Empty Field

Refer to Common Data Conventions and Constructs Empty Field description.

5.3.7 Meta Data Node Element

Object Type ID: 0xce357245, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1

The Meta Data Node Element, shown in Figure 29, is a node type used for storing references to specific “late loaded” meta-data (for example properties, PMI). The referenced meta-data is stored in a separate addressable segment of the JT File (see Meta Data Segment) and thus the use of this Meta Data Node Element is in support of the JT file loader/reader “best practice” of late loading data (therefore storing the referenced meta-data in separate addressable segment of the JT file allows a JT file loader/reader to ignore this node’s meta-data on initial load and instead late-load the node’s meta-data upon demand so that the associated meta-data does not consume memory until needed).

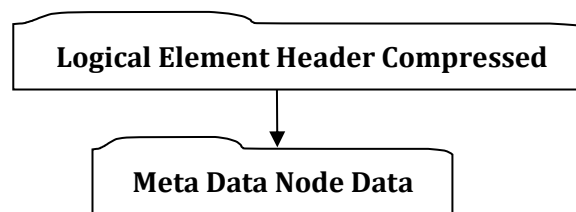


Figure 29 — Meta Data Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data

Meta Data Node Data

A diagrammatic representation of Meta Data Node Data is shown in Figure 30.

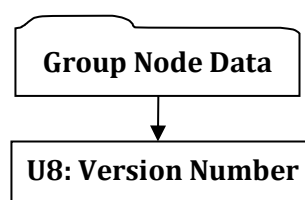


Figure 30 —Meta Data Node Data collection

Complete description for Group Node Data, as shown in Figure 30, can be found in Group Node Data.

U8: Version Number

Version Number is the version identifier for this data. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

5.3.8 LOD Node Element

Object Type ID: 0x10dd102c, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A LOD Node holds a list of alternate representations. The list is represented as the children of a base group node, however, there are no implicit semantics associated with the ordering. Traversers of LSG may apply semantics to the ordering as part of alternative representation selection. A diagrammatic representation of LOD Node Element data is shown in Figure 31.

Each alternative representation could be a sub-assembly where the alternative representation is a group node with an assembly of children.

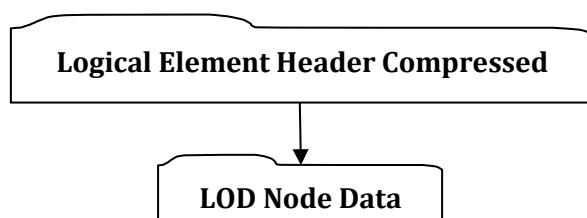


Figure 31 — LOD Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 31, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

LOD Node Data

A diagrammatic representation of LOD Node Data is shown in Figure 32.

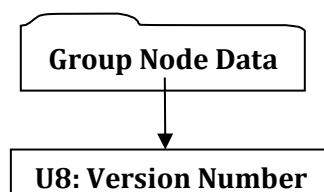


Figure 32 — LOD Node Data collection

Complete description for Group Node Data, as shown in Figure 32, can be found in Group Node Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

5.3.9 Range LOD Node Element

Object Type ID: 0x10dd104c, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Range LOD Nodes, as shown in Figure 33, hold a list of alternate representations and the ranges over which those representations are appropriate. Range Limits indicate the distance between a specified centre point and the eye point, within which the corresponding alternate representation is appropriate. Traversers of LSG consult these range limit values when making an alternative representation selection.

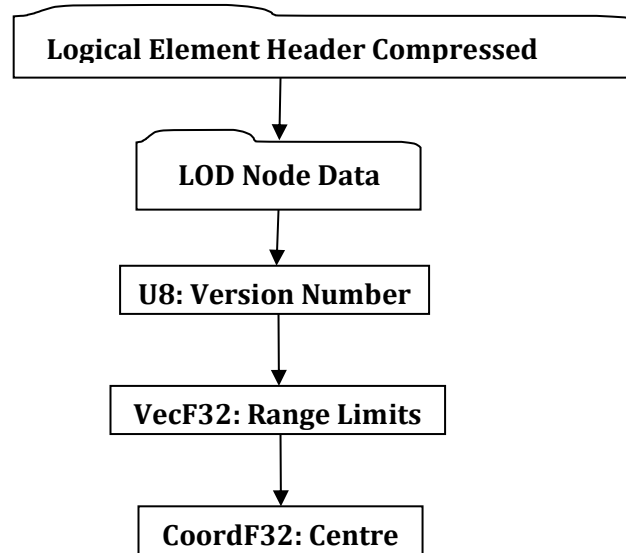


Figure 33 — Range LOD Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 33, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for LOD Node Data can be found in LOD Node Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

VecF32: Range Limits

Range Limits indicate the WCS distance between a specified centre point and the eye point, within which the corresponding alternate representation is appropriate. It is not required that the count of range limits is equivalent to the number of alternative representations. These values are considered “soft values” in that loaders/viewers of JT data are free to throw these values away and compute new values based on their desired LOD selection semantics.

Best practices suggest that LSG traversers apply the following strategy, at Range LOD Nodes, when making alternative representation selection decisions based on Range Limits: The first alternate representation is valid when the distance between the centre and the eye point is less than or equal to the first range limit (and when no range limits are specified). The second alternate representation is valid when the distance is greater than the first limit and less than or equal to the second limit, and so on. The last alternate representation is valid for all distances greater than the last specified limit.

CoordF32: Centre

Centre specifies the X,Y,Z coordinates for the MCS centre point upon which alternative representation selection eye distance computations are based. Typically, this location is the centre of the highest-detail alternative representation. These values are considered “soft values” in that loaders/viewers of JT data are free to throw these values away and compute new values based on their desired LOD selection semantics.

5.3.10 Switch Node Element

Object Type ID: 0x10dd10f3, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

The Switch Node, as shown in Figure 34, is very much like a Group Node in that it contains an ordered list of references to other nodes, called the *children* nodes. The difference is that a Switch Node also contains additional data indicating which child (one or none) a LSG traverser should process/traverse.

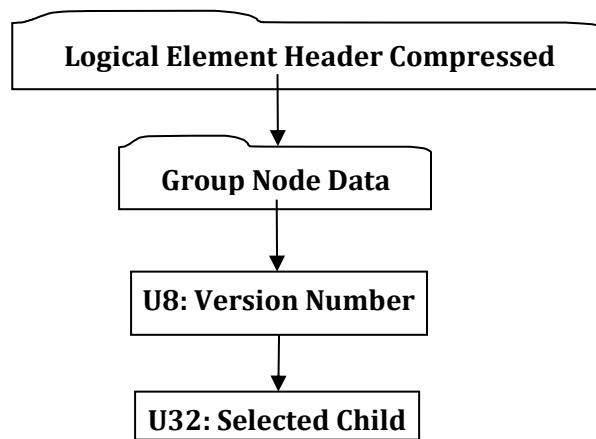


Figure 34 — Switch Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 34, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Group Node Data can be found in Group Node Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U32: Selected Child

Selected Child is the index for the selected child node. Valid Selected Child values reside within the following range: “-1 < Selected Child < Child Count”. Where “-1” indicates that no child is to be selected and “Child Count” is the data field value Group Node Data.

Shape Node Elements

Shape Node Elements are “leaf” nodes within the LSG structure and contain or reference the geometric shape definition data (for example vertices, polygons, normals, etc.).

Typically Shape Node Elements do not directly contain the actual geometric shape definition data, but instead reference (using Late Loaded Property Atoms) Shape LOD Segments within the file for the actual geometric shape definition data. Storing the geometric shape definition data within separate independently addressable data segments in the JT file, allows an JT file reader to be structured to support the “best practice” of delaying the loading/reading of associated data until it is actually needed. Complete descriptions for Late Loaded Property Atom Elements and Shape LOD Segments can be found in Late Loaded Property Atom Element and Property Atom Elements respectively.

There are several types of Shape Node Elements which the JT format supports. The following sub-sections document the various Shape Node Element types.

5.3.11 Base Shape Node Element

Object Type ID: 0x10dd1059, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Base Shape Node Element, shown in Figure 35, represents the simplest form of a shape node that can exist within the LSG.

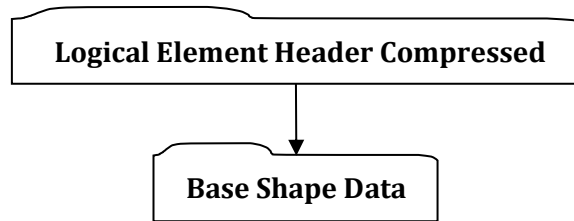


Figure 35 — Base Shape Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 35, can be found in the File Format section of this document under Data Segment in the logical collection describing Data .

Base Shape Data

A diagrammatic representation of Base shape data is shown in Figure 36.

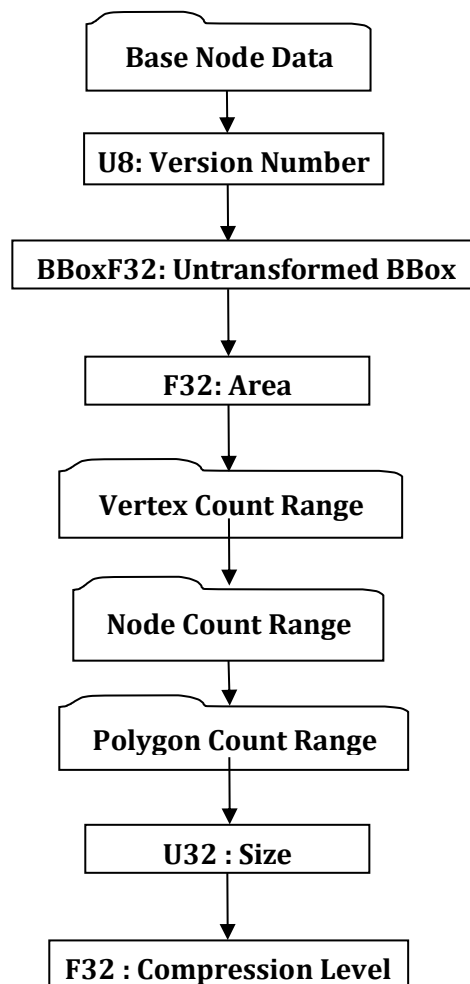


Figure 36 — Base Shape Data collection

A complete description of Base Node Data, as shown in Figure 36, can be found in the LSG Segment section of this document under Base Node Elements in the logical collection describing Base Node Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

BBoxF32: Untransformed BBox

The Untransformed BBox is an axis-aligned LCS bounding box and represents the untransformed geometry extents for all geometry contained in the Shape Node.

F32: Area

Area is the total surface area for this node and all of its descendants. This value is stored in MCS coordinate space (therefore values scaled by MCS scaling).

Vertex Count Range

Vertex Count Range, as shown in Figure 37, is the aggregate minimum and maximum vertex count for this Shape Node. There is a minimum and maximum value to accommodate shape types that can themselves generate varying representations. The minimum value represents the least vertex count that can be achieved by the Shape Node. The maximum value represents the greatest vertex count that can be achieved by the Shape Node.

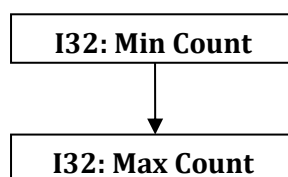


Figure 37 — Vertex Count Range data collection

I32: Min Count

Min Count is the least vertex count that can be achieved by this Shape Node.

I32: Max Count

Max Count is the maximum vertex count that can be achieved by this Shape Node. A value of “-1” indicates maximum vertex count is unknown.

Node Count Range

Node Count Range is the aggregate minimum and maximum count of all node descendants of the Shape Node. The minimum value represents the least node count that can be achieved by the Shape Node’s descendants. The maximum value represents the greatest node count that can be achieved by Shape Node’s descendants. For Shape Nodes the minimum and maximum count values should always be equal to “1”.

Polygon Count Range

Polygon Count Range is the aggregate minimum and maximum polygon count for this Shape Node. There is a minimum and maximum value to accommodate shape types that can themselves generate varying representations. The minimum value represents the least polygon count that can be achieved by the Shape Node. The maximum value represents the greatest polygon count that can be achieved by the Shape Node.

The data format for Polygon Count Range is the same as that described in Vertex Count Range.

U32 : Size

Size specifies the in-memory length in bytes of the associated/referenced Shape LOD Element. This Size value has no relevancy to the on-disk (JT File) size of the associated/referenced Shape LOD Element. A

value of zero indicates that the in-memory size is unknown. See Shape LOD Element for complete description of Shape LOD Elements. JT file loaders/readers can leverage this Size value during late load processing to help pre-determine if there is sufficient memory to load the Shape LOD Element.

F32: Compression Level

Compression Level, as shown in Table 12, specifies the qualitative compression level applied to the associated/referenced Shape LOD Element. See the chapter on Shape LOD Segment for complete description of Shape LOD Elements. This compression level value is a qualitative representation of the compression applied to the Shape LOD Element. The absolute compression (derived from this qualitative level) applied to the Shape LOD Element is physically represented in the JT format by other data stored with both the Shape Node and the Shape LOD Element (for example Quantization Parameters), and thus it's not necessary to understand how to map this qualitative value to absolute compression values in order to uncompress/decode the data.

Table 12 — Compression level values

| | |
|-------|--|
| = 0.0 | "Lossless" compression used. |
| = 0.1 | "Minimally Lossy" compression used. This setting generally results in modest compression ratios with little if any visual difference when compared to the same images rendered from "Lossless" compressed Shape LOD Element. |
| = 0.5 | "Moderate Lossy" compression used. The setting results in more data loss than "Minimally Lossy" and thus higher compression ratio is obtained. Some visual difference will likely be noticeable when compared to the same images rendered from "Lossless" compressed Shape LOD Element. |
| = 1.0 | "Aggressive Lossy" compression used. With this setting as much data as possible will be thrown away, resulting in highest compression ratio, while still maintaining a modestly useable representation of the underlying data. Visual differences may be evident when compared to the same images rendered from "Lossless" compressed Shape LOD Element. |

5.3.12 Vertex Shape Node Element

Object Type ID: 0x10dd107f, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Vertex Shape Node Element represents shapes defined by collections of vertices, as shown in Figure 38.

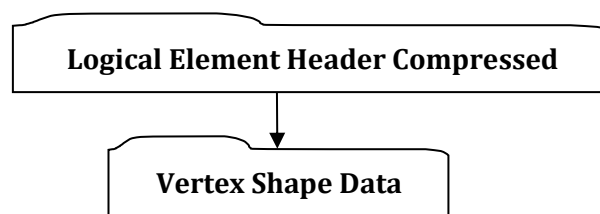


Figure 38 — Vertex Shape Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 38, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Vertex Shape Data

A diagrammatic representation of Vertex Shape Data is shown in Figure 39.

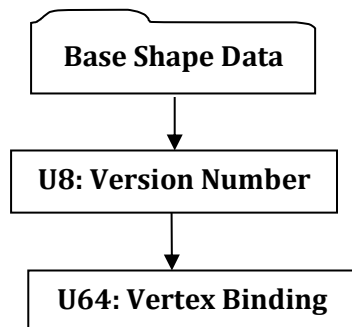


Figure 39 — Vertex Shape Data collection

A complete description of Base Shape Data, as shown in Figure 39, can be found in the LSG Segment section of this document under Base Shape Node Element in the logical collection describing Base Shape Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U64: Vertex Binding

Vertex Bindings is a collection of normal, texture coordinate, and colour binding information encoded within a single U64. All bits fields that are not defined as in use should be set to “0”. For more information see Vertex Shape LOD Data U64 : Vertex Bindings.

5.3.13 Tri-Strip Set Shape Node Element

Object Type ID: 0x10dd1077, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Tri-Strip Set Shape Node Element, as shown in Figure 40, defines a collection of independent and unconnected triangle strips. Each strip constitutes one primitive of the set and is defined by one list of vertex coordinates.

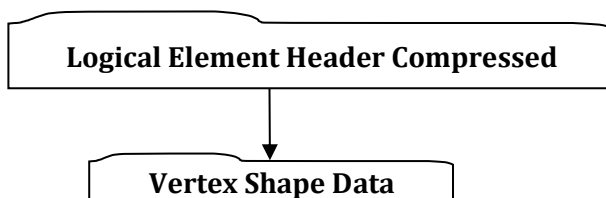


Figure 40 — Tri-Strip Shape Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Vertex Shape Data can be found in the LSG Segment section of this document under Vertex Shape Node Element in the logical collection describing Vertex Shape Data.

5.3.14 Polyline Set Shape Node Element

Object Type ID: 0x10dd1046, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Polyline Set Shape Node Element, as shown in Figure 41, defines a collection of independent and unconnected polylines. Each polyline constitutes one primitive of the set and is defined by one list of vertex coordinates.

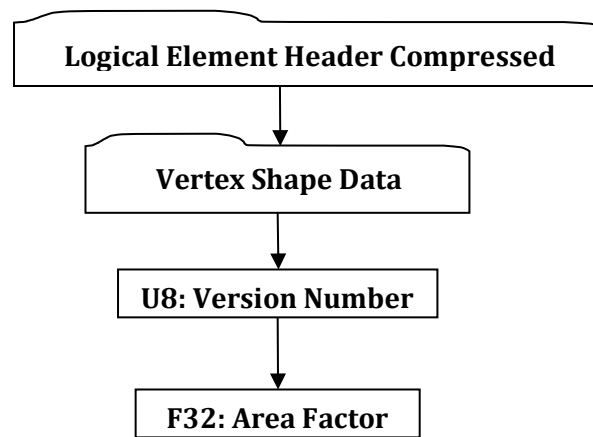


Figure 41 — Polyline Set Shape Node Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Vertex Shape Data can be found in the LSG Segment section of this document under Vertex Shape Node Element in the logical collection describing Vertex Shape Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

F32: Area Factor

Area Factor specifies a multiplier factor applied to a Polyline Set computed surface area. In JT data viewer applications there may be LOD selection semantics that are based on screen coverage calculations. The so-called "surface area" of a polyline is computed as if each line segment were a square. This Area Factor turns each edge into a narrow rectangle. Valid Area Factor values lie in the range [0,1].

5.3.15 Point Set Shape Node Element

Object Type ID: 0x98134716, 0x0010, 0x0818, 0x19, 0x98, 0x08, 0x00, 0x09, 0x83, 0x5d, 0x5a

A Point Set Shape Node Element, as shown in Figure 42, defines a collection of independent and unconnected points. Each point constitutes one primitive of the set and is defined by one vertex coordinate.

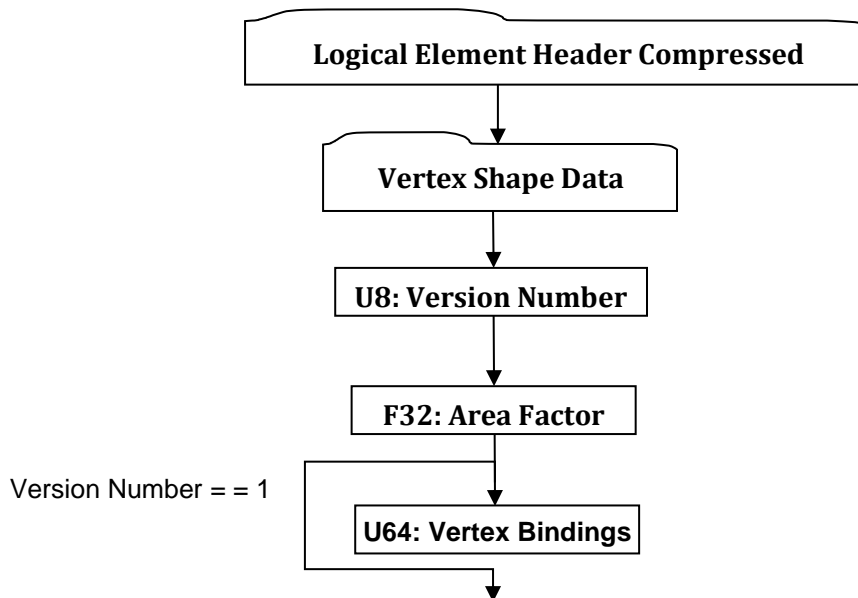


Figure 42 — Point Set Shape Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 42, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Vertex Shape Data can be found in the LSG Segment section of this document under Vertex Shape Node Element in the logical collection describing Vertex Shape Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

F32: Area Factor

Area Factor specifies a multiplier factor applied to the Point Set computed surface area. In JT data viewer applications there may be LOD selection semantics that are based on screen coverage calculations. The computed “surface area” of a Point Set is equal to the larger (therefore whichever is greater) of either the area of the Point Set’s bounding box, or “1.0”. Area Factor scales the result of this “surface area” computation.

U64: Vertex Bindings

Vertex Bindings is a collection of normal, texture coordinate, and colour binding information encoded within a single U64. All bits fields that are not defined as in use should be set to “0”. For more information see Vertex Shape LOD Data U64: Vertex Bindings.

5.3.16 Polygon Set Shape Node Element

Object Type ID: 0x10dd1048, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Polygon Set Shape Node Element, as shown in Figure 43, defines a collection of independent and unconnected polygons. Each polygon constitutes one primitive of the set and is defined by one list of vertex coordinates.

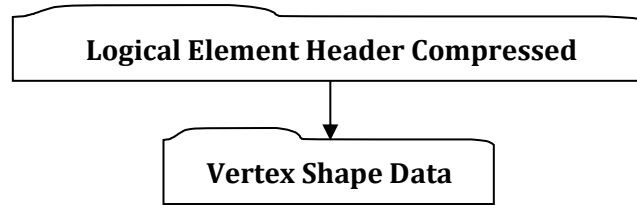


Figure 43 — Polygon Set Shape Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 43, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Vertex Shape Data can be found in the LSG Segment section of this document under Vertex Shape Node Element in the logical collection describing Vertex Shape Data.

5.3.17 NULL Shape Node Element

Object Type ID: 0xd239e7b6, 0xdd77, 0x4289, 0xa0, 0x7d, 0xb0, 0xee, 0x79, 0xf7, 0x94, 0x94

A NULL Shape Node Element, as shown in Figure 44, defines a shape which has no direct geometric primitive representation (therefore it is empty/NULL). NULL Shape Node Elements are often used as “proxy/placeholder” nodes within the serialized LSG when the actual Shape LOD data is run time generated (therefore not persisted).

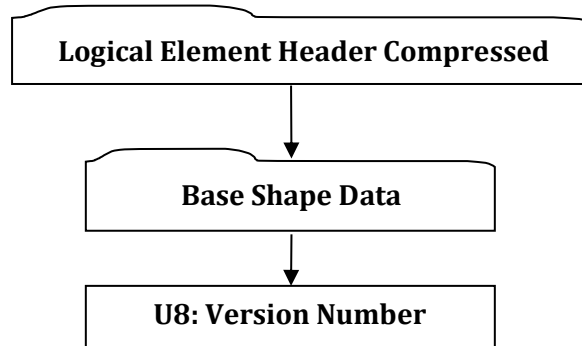


Figure 44 — NULL Shape Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 44, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Shape Data can be found in the LSG Segment section of this document under Base Shape Node Element in the logical collection describing Base Shape Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

5.3.18 Primitive Set Shape Node Element

Object Type ID: 0xe40373c1, 0x1ad9, 0x11d3, 0x9d, 0xaf, 0x0, 0xa0, 0xc9, 0xc7, 0xdd, 0xc2

A Primitive Set Shape Node Element represents a list/set of primitive shapes (for example box, cylinder, sphere, etc.) whose LODs can be procedurally generated. “Procedurally generate” means that the raw geometric shape definition data (for example vertices, polygons, normals, etc.) for LODs is not directly

stored; instead some basic shape information is stored (for example sphere centre and radius) from which LODs can be generated.

Primitive Set Shape Node Elements, as shown in Figure 45, actually do not even directly contain this basic shape definition data, but instead reference (using Late Loaded Property Atoms) Primitive Set Shape Node Element within the file for the actual basic shape definition data. Storing the basic shape definition data within separate independently addressable data segments in the JT file, allows a JT file reader to be structured to support the “best practice” of delaying the loading/reading of associated data until it is actually needed. Complete descriptions for Late Loaded Property Atom Elements and Primitive Set Shape Element can be found in Late Loaded Property Atom Element and Primitive Set Shape Element respectively.

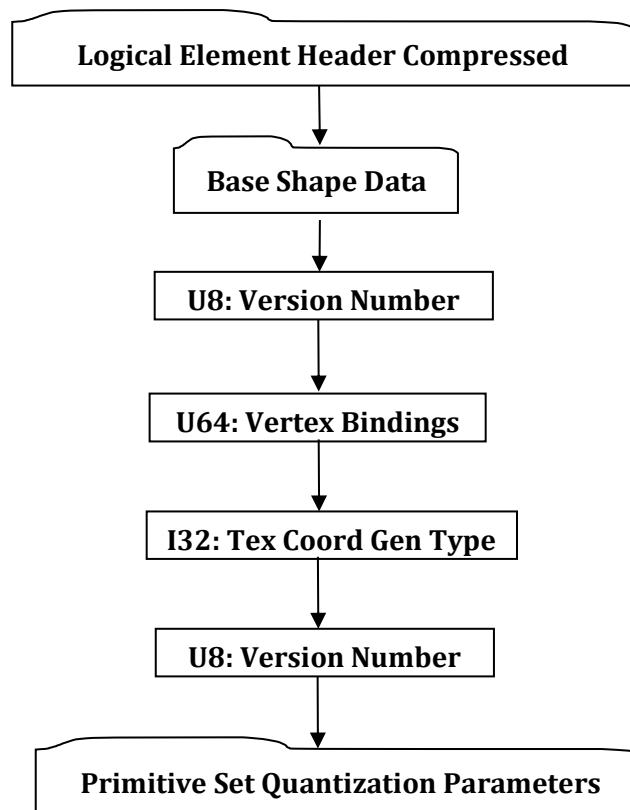


Figure 45 — Primitive Set Shape Node Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 45, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Shape Data can be found in the LSG Segment section of this document under Base Shape Node Element in the logical collection describing Base Shape Data.

U8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U64: Vertex Bindings

Vertex Bindings is a collection of normal, texture coordinate, and colour binding information encoded within a single U64. All bits fields that are not defined as in use should be set to “0”. For more information see Vertex Shape LOD Data U64 : Vertex Bindings.

I32: Tex Coord Gen Type

Texture Coord Gen Type, as shown in Table 13, specifies how a texture is applied to each face of the primitive. Single tile means one copy of the texture will be stretched to fit the face, isotropic means that the texture will be duplicated on the longer dimension of the face in order to maintain the texture's aspect ratio.

Table 13 — Texture Coord Gen Type values

| | |
|-----|---|
| = 0 | Single Tile...Indicates that a single copy of a texture image will be applied to significant primitive features (therefore cube face, cylinder wall, end cap) no matter how eccentrically shaped. |
| = 1 | Isotropic...Implies that multiple copies of a texture image may be mapped onto eccentric surfaces such that a mapped texel stays approximately square. |

U8: Version Number

Version Number, as shown in Table 14, is the version identifier for this element. The value of this Version Number indicates the format of data fields to follow.

Table 14 — Version Number values

| | |
|-----|------------------|
| = 0 | Version 0 Format |
| = 1 | Version 1 Format |

Primitive Set Quantization Parameters

Primitive Set Quantization Parameters, as shown in Figure 46, specifies for the two shape data type grouping (therefore Vertex, Colour) the number of quantization bits used for given qualitative compression level. Although these values are saved in the associated/referenced Shape LOD Element, they are also saved here so that a JT File loader/reader does not have to load the Shape LOD Element in order to determine the Shape quantization level. See Shape LOD Element for complete description of Shape LOD Elements.

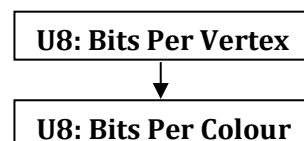


Figure 46 — Primitive Set Quantization Parameters data collection

U8: Bits Per Vertex

Bits Per Vertex specifies the number of quantization bits per vertex coordinate component. Value shall be within range [0:24] inclusive.

U8: Bits Per Colour

Bits Per Colour specifies the number of quantization bits per colour component. Value shall be within range [0:24] inclusive.

5.4 Attribute Elements

Attribute Elements (for example colour, texture, material, lights, etc.) are placed in LSG as objects associated with nodes. Attribute Elements are not nodes themselves, but can be associated with any node.

For applications producing or consuming JT format data, it is important that the JT format semantics of how attributes are meant to be applied and accumulated down the LSG are followed. If not followed, then consistency between the applications in terms of 3D positioning and rendering of LSG model data will not be achieved.

To that end each attribute type defines its own application and accumulation semantics, but in general attributes at lower levels in the LSG take precedence and replace or accumulate with attributes set at higher levels. Nodes without associated attributes inherit those of their parents. Attributes inherit only from their parents, thus a node's attributes do not affect that node's siblings. The root of a partition inherits the attributes in effect at the referring partition node.

In previous version of the JT file format, Attributes held a single “final” bit denoting that no further accumulations were to take place into that attribute type by Attributes of the same type lying below it in the scene graph. JT version 10.6 replaces this single bit with separate “field final” bits for each field within the Attribute. Different Attributes have different fields, and are documented accordingly in the following sections. Only three Attributes define more than one internal field (therefore Material Attribute Element, Texture Image Attribute Element, and Draw Style Attribute Element). All other Attributes merely define a single default field that encompasses their entire state.

In addition to “field final” bits, each Attribute also defines a parallel set of “field inhibit” bits. These bits denote, on a field-by-field basis, whether a field is allowed to accumulate. Said differently, if a field inhibit bit is set to 0, the field accumulates normally; if the bit is set to 1, then the field will not accumulate, and is ignored.

Descendants can explicitly do a one-shot override of “final” using the attribute “force” flag (see Base Attribute Data), but do not by default. Note that “force” does not turn OFF “final” – it is simply a one-shot override of “final” for the specific attribute marked as “forcing.” Note that the “force” flag is attribute-wide – not on a field-by-field basis like field-finals and field-inhibits. An analogy for this “force” and “final” interaction is that “final” is a back-door in the attribute accumulation semantics, and that “force” is a doggy-door in the back-door!

Base Attribute Data

A diagrammatic representation of Base Attribute Data is shown in Figure 47.

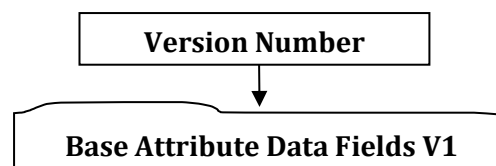


Figure 47 — Base Attribute Data collection

I8: Version Number

Version Number, as shown in Figure 47, can have the value one or two. If the value is two then the Logical Collection Base Attribute Data Fields V2 will be read after each derived attribute type (therefore. Material, Texture etc.) In all cases Base Attribute Data Fields V1 must be read first.

Base Attribute Data Fields V1

A diagrammatic representation of Base Attribute Data Fields V1 is shown in Figure 48.

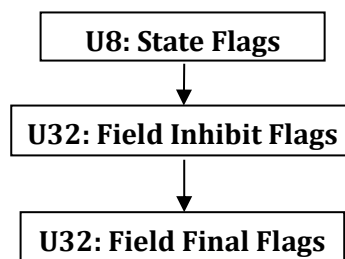


Figure 48 — Base Attribute Data Fields V1

U8: State Flags

State Flags, as shown in Figure 48, is a collection of flags. The flags are combined using the binary OR operator, as shown in Table 15, and store various state information for Attribute Elements; such as indicating that the attributes accumulation is final. All bits fields that are not defined as in use should be set to “0”.

Table 15 — State Flag values

| | |
|------|---|
| 0x01 | Unused |
| 0x02 | Accumulation Force flag. Provides a way to assign nodes in LSG, attributes that shall not be overridden by ancestors. = 0 – Accumulation of this attribute obeys ancestor’s Final flag setting. = 1 – Accumulation of this attribute is forced (overrides ancestor’s Final flag setting) |
| 0x04 | Accumulation Ignore Flag. Provides a way to indicate that the attribute is to be ignored (not accumulated). = 0 – Attribute is to be accumulated normally (subject to values of Force/Final flags) = 1 – Attribute is to be ignored. |
| 0x08 | Attribute Persistable Flag. Provides a way to indicate that the attribute is to be persistable to an JT file. = 0 – Attribute is to be non-persistable. = 1 – Attribute is to be persistable. |

U32: Field Inhibit Flags

Field Inhibit Flags is a collection of flags, each flag corresponding to a collection of state data within a particular Attribute type. Each value (or semantically related set of values) present in an Attribute Element is given a field number ranging from 0 to 31. If the field’s corresponding bit in Inhibit Flags is set, then the field should not participate in attribute accumulation. All bits are reserved.

See each particular Attribute Element (for example Material Attribute Element) for a description of bit field assignments for each attribute value.

U32: Field Final Flags

Field Final Flags is a collection of flags, each flag being parallel to the corresponding flag in the Field Inhibit Flags. If the field’s bit in Field Final Flags is set, then that field within the Attribute will become “final” and will not allow any subsequent accumulation into the specified field. All bits are reserved.

See each particular Attribute Element for a description of bit field assignments for each Attribute value.

Base Attribute Data Fields V2

This logical collection is found in the Attribute Element data descriptions for; Material, Texture Image, Draw Style, Light Set, Line Style, Point Style, Geometric Transform, and Palette Map, as shown in Figure 49

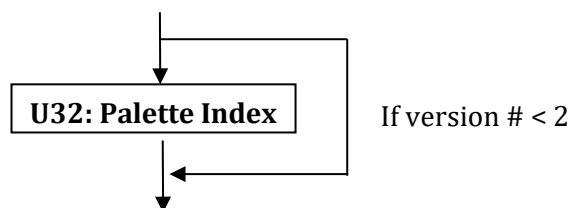


Figure 49 — Base Attribute Data Fields V2

U32: Palette Index

The palette index field, as shown in Figure 49, is used to implicitly create a State Palette that may later be indexed by a PaletteMap attribute. For a full description see the Per Face Group Attribute Annex E in this document.

Palette Index default value is -1

5.4.1 Material Attribute Element

Object Type ID: 0x10dd1030, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Material Attribute Element, as shown in Figure 50, defines the material properties of an object. JT format LSG traversal semantics state that material attributes accumulate down the LSG by replacement.

The Field Inhibit flag (see Base Attribute Data) bit assignments for the Material Attribute Element data fields, are as shown in Table 16:

Table 16 — Material Attribute data field inhibit values

| Field Inhibit Flag Bit | Data Field(s) Bit Applies To |
|------------------------|--|
| 0 | Ambient Common RGB Value, Ambient Colour |
| 1 | Specular Common RGB Value, Specular Colour |
| 2 | Emission Common RGB Value, Emission Colour |
| 3 | Blending Flag, Source Blending Factor, Destination Blending Factor |
| 4 | Override Vertex Colour Flag |
| 5 | Material Reflectivity |
| 6 | Diffuse Colour |
| 7 | Diffuse Alpha |
| 8 | Bumpiness |

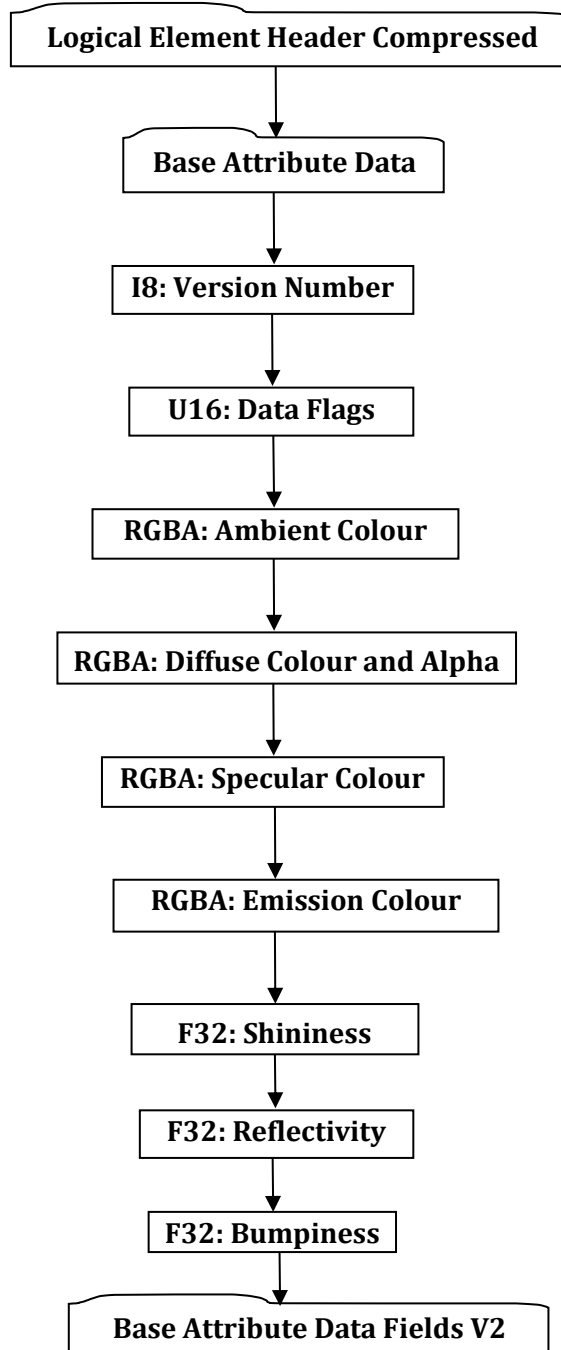


Figure 50 — Material Attribute Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 50, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8: Version Number

Version Number, as shown in Table 17, is the version identifier for this element. The value of this Version Number indicates the format of data fields to follow.

Table 17 — Material Attribute Version number value

| | |
|-----|------------------|
| = 1 | Version-1 Format |
|-----|------------------|

U16: Data Flags

Data Flags, as shown in Table 18, is a collection of flags and factor data. The flags and factor data are combined using the binary OR operator. The flags store information to be used for interpreting how to read subsequent Material data fields. All bits fields that are not defined as in use should be set to “0”.

Table 18 — Material Attribute Data Flag values

| | |
|--------|--|
| 0x0010 | Blending Flag. Blending is a colour combining operation in the graphics pipeline that happens just before writing a colour to the framebuffer. If Blending is ON then incoming fragment RGBA colour values are used (based on Source Blend Factor) and existing framebuffer’s RGBA colour values are used (based on Destination Blend Factor) to blend between the incoming fragment RGBA and the current frame buffer RGBA to arrive at a new RGBA colour to write into the framebuffer. If Blending is OFF then incoming fragment RGBA colour is written directly into framebuffer unmodified (therefore completely overriding existing framebuffer RGBA colour). = 0 – Blending OFF. = 1 – Blending ON |
| 0x0020 | Override Vertex Colours Flag. If ON, then a shape’s per vertex colours are to be overridden by the accumulated Material colour. = 0 – Override OFF = 1 – Override ON |
| 0x07C0 | Source Blend Factor (stored in bits 6 – 10 or in binary notation 0000011111000000). If Blending Flag enabled, this value indicates how the incoming fragment’s (therefore the source) RGBA colour values are to be used to blend with the current framebuffer’s (therefore the destination) RGBA colour values. Additional information on the interpretation of the Blending Factor values and how one might leverage them to render an image can be found in reference [1] listed in the bibliography section. = 0 – Interpret same as OpenGL GL_ZERO Blending Factor = 1 – Interpret same as OpenGL GL_ONE Blending Factor = 2 – Interpret same as OpenGL GL_DST_COLOUR Blending Factor = 3 – Interpret same as OpenGL GL_SRC_COLOUR Blending Factor = 4 – Interpret same as OpenGL GL_ONE_MINUS_DST_COLOUR Blending Factor = 5 – Interpret same as OpenGL GL_ONE_MINUS_SRC_COLOUR Blending Factor = 6 – Interpret same as OpenGL GL_SRC_ALPHA Blending Factor = 7 – Interpret same as OpenGL GL_ONE_MINUS_SRC_ALPHA Blending Factor = 8 – Interpret same as OpenGL GL_DST_ALPHA Blending Factor = 9 – Interpret same as OpenGL GL_ONE_MINUS_DST_ALPHA Blending Factor = 10 – Interpret same as OpenGL GL_SRC_ALPHA_SATURATE Blending Factor |
| 0xF800 | Destination Blend Factor (stored in bits 11 – 15 or in binary notation 1111100000000000).). If Blending Flag enabled, this value indicates how the current framebuffer’s (the destination) RGBA colour values are to be used to blend with the incoming fragment’s (the source) RGBA colour values. Additional information on the interpretation of the Blending Factor values and how one might leverage them to render an image can be found in reference [1] listed the bibliography section. = 0 – Interpret same as OpenGL GL_ZERO Blending Factor = 1 – Interpret same as OpenGL GL_ONE Blending Factor = 2 – Interpret same as OpenGL GL_DST_COLOUR Blending Factor = 3 – Interpret same as OpenGL GL_SRC_COLOUR Blending Factor = 4 – Interpret same as OpenGL GL_ONE_MINUS_DST_COLOUR Blending Factor = 5 – Interpret same as OpenGL GL_ONE_MINUS_SRC_COLOUR Blending Factor = 6 – Interpret same as OpenGL GL_SRC_ALPHA Blending Factor = 7 – Interpret same as OpenGL GL_ONE_MINUS_SRC_ALPHA Blending Factor = 8 – Interpret same as OpenGL GL_DST_ALPHA Blending Factor |

| | |
|--|--|
| | = 9 – Interpret same as OpenGL GL_ONE_MINUS_DST_ALPHA Blending Factor |
| | = 10 – Interpret same as OpenGL GL_SRC_ALPHA_SATURATE Blending Factor |

RGBA: Ambient Colour

Ambient Colour specifies the ambient red, green, blue, alpha colour values of the material.

RGBA: Diffuse Colour and Alpha

Diffuse Colour and Alpha specify the diffuse red, green, blue colour components and alpha value of the material.

RGBA: Specular Colour

Specular Colour specifies the specular red, green, blue, alpha colour values of the material.

RGBA: Emission Colour

Emission Colour specifies the emissive red, green, blue, alpha colour values of the material.

F32: Shininess

Shininess is the exponent associated with specular reflection and highlighting of the Phong specular lighting model. Shininess controls the degree with which the specular highlight decays. Only values in the range [1,128] are valid.

F32: Reflectivity

Reflectivity specifies the material reflectivity of the material. It represents the fraction of light reflected in the mirror direction by the material. Only values in the range [0.0, 1.0] are valid.

F32: Bumpiness

Bumpiness is used to control bump mapping, and specifies the degree to which bump mapping modifies the local normal vector. A value of 1.0 is the default. Values larger than 1.0 are intended to make the shaded object look as if it is more highly embossed; values between 0.0 and 1.0 make it look less so. Negative values are legal and make the object appear to be *engraved* rather than embossed.

Base Attribute Data Fields V2

See the Attribute Elements section on Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 are defined when Base Attribute Version Number is set to two.

5.4.2 Texture Image Attribute Element

Object Type ID: 0x10dd1073, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

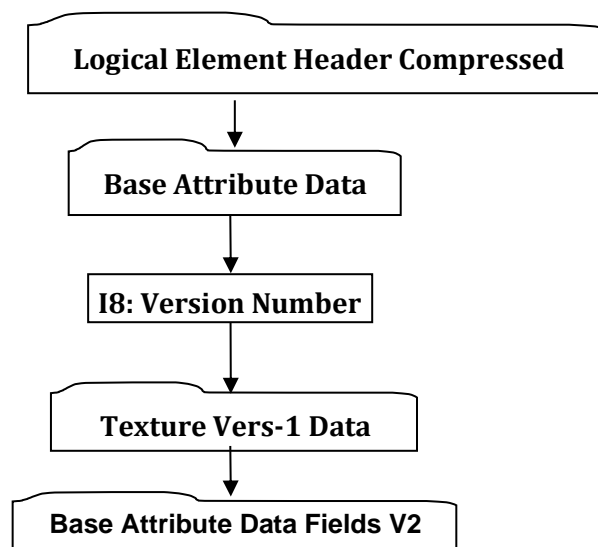
Texture Image Attribute Element, as shown in Figure 51, defines a texture image and its mapping environment. JT format LSG traversal semantics state that texture image attributes accumulate down the LSG by replacement on a *per texture channel* basis. See below for more information on texture image channels.

Note that additional information on the interpretation of the various Texture Image Attribute Element data fields can be found in the OpenGL references listed in the bibliography section [1].

The Field Inhibit and Field Final flag (see Base Attribute Data) bit assignments for the Texture Image Attribute Element data fields, are as shown in Table 19:

Table 19 — Texture Image Attribute data field inhibit values

| Field Inhibit Flag Bit | Data Field(s) Bit Applies To |
|------------------------|--|
| 0 | I32 : Texture Type, Mipmap Image Texel Data, MBString:External Storage Name, Shared Image Flag |
| 1 | Border Mode, Border Colour |
| 2 | Mipmap Minification Filter, Mipmap Magnification Filter |
| 3 | S-Dimen Wrap Mode, T-Dimen Wrap Mode, R-Dimen Wrap Mode |
| 4 | Blend Type, Blend Colour |
| 5 | Texture Transform |
| 6 | Tex Coord Gen Mode, Tex Coord Reference Plane |
| 7 | Internal Compression Level |

**Figure 51 — Texture Image Attribute Element data collection**

A complete description of Logical Element Header Compressed, as shown in Figure 51, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8: Version Number

Version Number is the version identifier for this element. The value of this Version Number, as shown in Table 20, indicates the format of data fields to follow.

Table 20 — Texture Image Version Number values

| | |
|-----|------------------|
| = 1 | Version-1 Format |
|-----|------------------|

When a data element in the JT file is versioned, it is for the purpose of adding a few pieces of new data onto the end of the existing data format. In this way, older viewers and readers of the JT file that do not yet know about higher local versions will naturally read the lower-numbered version blocks and ignore the higher-numbered ones they do not know how to read. At present, this mechanism is not being used in JT 10.6, but experience has shown from previous versions that it probably will become useful at some point.

Texture Vers-1 Data

A diagrammatical representation of Texture Vers-1 Data is shown in Figure 52.

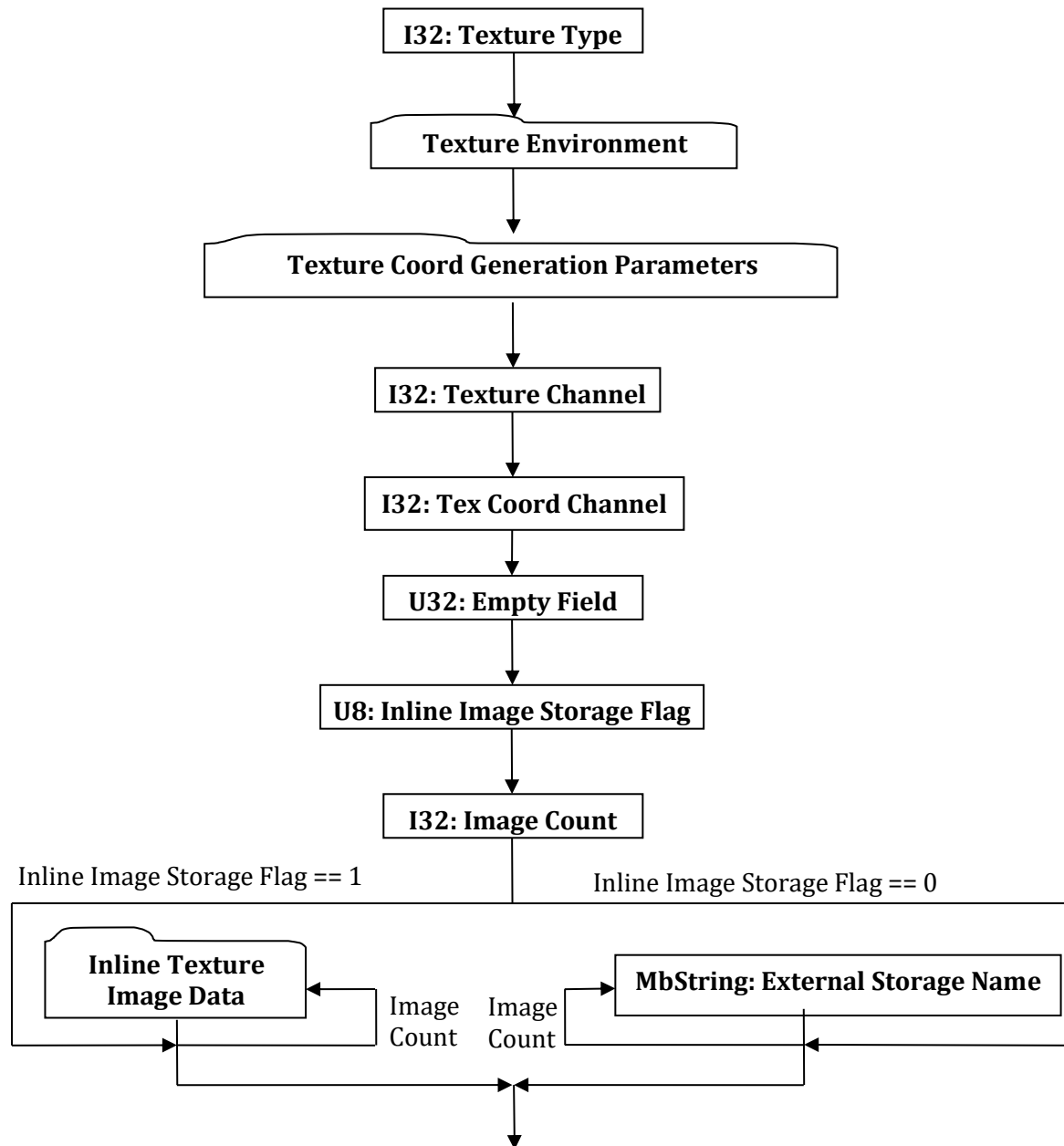


Figure 52 — Texture Vers-1 Data collection

Complete details for Texture Environment, as shown in Figure 52, can be found in Texture Environment.

Complete details for Texture Coord Generation Parameters can be found in Texture Coord Generation Parameters.

Complete details for Inline Texture Image Data can be found in Inline Texture Image Data.

I32: Texture Type

Texture Type, as shown in Table 21, specifies the type of texture. A new texture type, separator texture, is defined in Texture Vers-1 Data to support resetting the texture accumulation state mid-graph. Shadow maps and pre-filtered light maps, however, are a general exception to this rule. In the following list, “image” refers to an image texture, “pre-lit” indicates that the image texture is to be applied before

lighting when rendering the object to which it is applied, and “post-lit” indicates that the image texture is to be applied after lighting. A gloss map is a pre-lit texture that applies itself to the specular material component of lighting instead of the diffuse component. A light map is an environment texture (texture at infinity surrounding the whole model) that serves as a source of illumination during shading calculations.

Table 21 — Texture Vers-1 Texture Type values

| Texture Type | Description | Explicit Channel | Auto Channel |
|--------------|---|------------------|--------------|
| = 0 | None. | N/A | N/A |
| = 1 | One-Dimensional post-lit image texture. | Yes | No |
| = 2 | Two-Dimensional post-lit image texture. | Yes | No |
| = 3 | Three-Dimensional post-lit image texture. | Yes | No |
| = 4 | Two-Dimensional 3-component tangent-space normal map. | No | Yes |
| = 5 | Cube post-lit image texture. | Yes | No |
| = 7 | Cube pre-lit image texture. | Yes | No |
| = 8 | One-Dimensional pre-lit image texture. | Yes | No |
| = 9 | Two-Dimensional pre-lit image texture. | Yes | No |
| = 10 | Three-Dimensional pre-lit image texture. | Yes | No |
| = 11 | Cube environment map. | No | Yes |
| = 12 | One-Dimensional gloss map (specular) texture. | No | Yes |
| = 13 | Two-Dimensional gloss map (specular) texture. | No | Yes |
| = 14 | Three-Dimensional gloss map (specular) texture. | No | Yes |
| = 15 | Cube gloss map (specular) texture. | No | Yes |
| = 16 | Two-Dimensional 1-component bumpmap. | No | Yes |
| = 17 | Two-Dimensional 3-component world-space normal map. | No | Yes |
| = 18 | Two-Dimensional sphere environment map. | No | Yes |
| = 19 | Two-Dimensional latitude/longitude environment map. | No | Yes |
| = 20 | Two-Dimensional spherical diffuse light map. | No | Yes |
| = 21 | Cube diffuse light map. | No | Yes |
| = 22 | Two-Dimensional latitude/longitude diffuse light map. | No | Yes |
| = 23 | Two-Dimensional spherical specular light map. | No | Yes |
| = 24 | Cube specular light map. | No | Yes |
| = 25 | Two-Dimensional latitude/longitude specular light map. | No | Yes |
| = 26 | Resets texture state except shadow map and light maps. | N/A | N/A |
| = 27 | Empty Field | N/A | N/A |
| = 28 | Alpha One Dimensional - neither pre-lit nor post-lit | Yes | Yes |
| = 29 | Alpha Two Dimensional - neither pre-lit nor post-lit | Yes | Yes |
| = 30 | Alpha Three Dimensional - neither pre-lit nor post-lit | Yes | Yes |
| = 31 | Lum One Dimensional -Pre-lit luminance (diffuse) texture | Yes | Yes |
| = 32 | Lum Two Dimensional -Pre-lit luminance (diffuse) texture | Yes | Yes |
| = 33 | Lum Three Dimensional -Pre-lit luminance (diffuse) texture | Yes | Yes |
| = 34 | Luma One Dimensional -Pre-lit luminance (diffuse) texture | Yes | Yes |
| = 35 | Luma Two Dimensional -Pre-lit luminance (diffuse) texture | Yes | Yes |
| = 36 | Luma Three Dimensional -Pre-lit luminance (diffuse) texture | Yes | Yes |

I32: Texture Channel

Texture Channel specifies the texture channel number for the Texture Image Element. For purposes of multi-texturing, the JT concept of a texture channel corresponds to the OpenGL concept of a “texture unit.” The Texture Channel value shall be between -1 and 2,147,483,647 inclusive. The value -1 is accepted to denote a texture whose channel number is to be automatically assigned. This assignment will never displace another texture with an explicit texture channel assignment from its slot. Best practices suggest that a renderer of JT data ignore all but channel-0 if the renderer does not support multi-textured

geometry. Also for purposes of blending, any renderer of JT data should ensure that higher numbered texture channels “blend over” lower numbered ones.

Pre- and post-lit image textures shall specify an explicit texture channel. All other texture types shall specify -1 for their texture channel.

U32: Empty Field

Refer to Common Data Conventions and Constructs Empty Field description.

U8: Inline Image Storage Flag

Inline Image Storage Flag, as shown in Table 22, is a flag that indicates whether the texture image is stored within the JT File (therefore inline) or in some other external file.

Table 22 — Texture Vers-1 Inline Image Storage Flag values

| | |
|-----|--|
| = 0 | Texture image stored in an external file. |
| = 1 | Texture image stored inline in this JT file. |

I32: Image Count

Image Count specifies the number of texture images. A “Cube Map” I32:Texture Type shall have six images while all other Texture Types should only have one image.

MbString: External Storage Name

External Storage Name is a string identifying the name of an external texture image storage. External Storage Name is only present if data field Inline Image Storage Flag equals “0.” If present there will be data field Image Count number of External Storage Name instances. This External Storage Name string is a relative path based name for the texture image file. Where “relative path” should be interpreted to mean the string contains the file name along with any additional path information that locates the texture image file relative to the location of the referencing JT file.

I32: Tex Coord Channel

Tex Coord Channel specifies the channel number for texture coordinate generation. Value shall be within range [-1, 2147483647] inclusive.

Texture Environment

The Texture Environment, as shown in Figure 53, is a collection of data defining various aspects of how a texture image is to be mapped/applied to a surface.

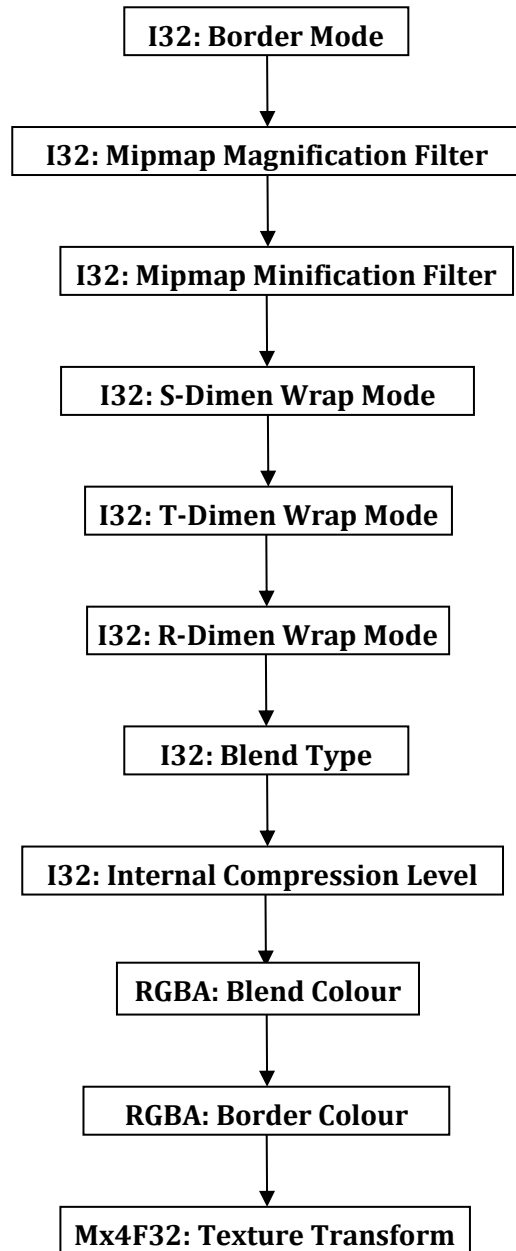


Figure 53 — Texture Environment data collection

I32: Border Mode

Border Mode, as shown in Table 23, specifies the texture border mode.

Table 23 — Texture Vers-1 Texture Environment Border Mode values

| | |
|-----|---|
| = 0 | No border. |
| = 1 | Constant Border Colour. Indicates that the texture has a constant border colour whose value is defined in data field Border Colour. |
| = 2 | Explicit. Indicates that a border texel ring is present in the texture image definition. |

I32: Mipmap Magnification Filter

Mipmap Magnification Filter, as shown in Table 24, specifies the texture filtering method to apply when a single pixel on screen maps to a tiny portion of a texel.

Table 24 — Texture Vers-1 Texture Environment Mipmap Magnification Filter values

| | |
|-----|--|
| = 0 | None. |
| = 1 | Nearest. Texel with coordinates nearest the centre of the pixel is used. |
| = 2 | Linear. A weighted linear average of the 2 x 2 array of texels nearest to the centre of the pixel is used. For one-dimensional texture is average of 2 texels. For three dimensional texel is 2 x 2 x 2 array. |

I32: Mipmap Minification Filter

Mipmap Minification Filter, as shown in Table 25, specifies the texture filtering method to apply when a single pixel on screen maps to a large collection of texels.

Table 25 — Texture Vers-1 Texture Environment Mipmap Minification Filter values

| | |
|-----|---|
| = 0 | None. |
| = 1 | Nearest. Texel with coordinates nearest the centre of the pixel is used. |
| = 2 | Linear. A weighted linear average of the 2 x 2 array of texels nearest to the centre of the pixel is used. For one-dimensional texture is average of 2 texels. For three-dimensional texture is 2 x 2 x 2 array. |
| = 3 | Nearest in Mipmap. Within an individual mipmap, the texel with coordinates nearest the centre of the pixel is used. |
| = 4 | Linear in Mipmap. Within an individual mipmap, a weighted linear average of the 2 x 2 array of texels nearest to the centre of the pixel is used. For one-dimensional texture is average of 2 texels. For three-dimensional texture is 2 x 2 x 2 array |
| = 5 | Nearest between Mipmaps. Within each of the adjacent two mipmaps, selects the texel with coordinates nearest the centre of the pixel and then interpolates linearly between these two selected mipmap values. |
| = 6 | Linear between Mipmaps. Within each of the two adjacent mipmaps, computes value based on a weighted linear average of the 2 x 2 array of texels nearest to the centre of the pixel and then interpolates linearly between these two computed mipmap values. |

I32: S-Dimen Wrap Mode

S-Dimen Wrap Mode, as shown in Table 26, specifies the mode for handling texture coordinates S-Dimension values outside the range [0, 1].

Table 26 — Texture Vers-1 Texture Environment S-Dimen Wrap Mode values

| | |
|-----|--|
| = 0 | None. |
| = 1 | Clamp. Any values greater than 1.0 are set to 1.0; any values less than 0.0 are set to 0.0. |
| = 2 | Repeat Integer parts of the texture coordinates are ignored (therefore retains only the fractional component of texture coordinates greater than 1.0 and only one-minus the fractional component of values less than zero). Resulting in copies of the texture map tiling the surface. |
| = 3 | Mirror Repeat. Like Repeat, except the surface tiles “flip-flop” resulting in an alternating mirror pattern of surface tiles. |
| = 4 | Clamp to Edge. Border is always ignored and instead texel at or near the edge is chosen for coordinates outside the range [0, 1]. Whether the exact nearest edge texel or some average of the nearest edge texels is used is dependent upon the mipmap filtering value. |

| | |
|-----|---|
| = 5 | Clamp to Border. Nearest border texel is chosen for coordinates outside the range [0, 1]. Whether the exact nearest border texel or some average of the nearest border texels is used is dependent upon the mipmap filtering value. |
|-----|---|

I32: T-Dimen Wrap Mode

T-Dimen Wrap Mode specifies the mode for handling texture coordinates T-Dimension values outside the range [0, 1]. Same mode values as documented for S-Dimen Wrap Mode.

I32: R-Dimen Wrap Mode

R-Dimen Wrap Mode specifies the mode for handling texture coordinates R-Dimension values outside the range [0, 1]. Same mode values as documented for S-Dimen Wrap Mode.

I32: Blend Type

Blend Type, as shown in Table 27, contains information indicating how the values in the texture map are to be modulated/combined/blended with the original colour of the surface or some other alternative colour to compute the final colour to be painted on the surface. Additional information on the interpretation of the Blend Type values and how one might leverage them to render an image can be found in reference [1] listed in the bibliography section.

Table 27 — Texture Vers-1 Texture Environment Blend Type values

| | |
|-----|---|
| = 0 | None. |
| = 1 | Decal. Interpret same as OpenGL GL_DECAL environment mode. |
| = 2 | Modulate. Interpret same as OpenGL GL_MODULATE environment mode. |
| = 3 | Replace. Interpret same as OpenGL GL_REPLACE environment mode. |
| = 4 | Blend. Interpret same as OpenGL GL_BLEND environment mode. |
| = 5 | Add. Interpret same as OpenGL GL_ADD environment mode. |
| = 6 | Combine. Interpret same as OpenGL GL_COMBINE environment mode. |

I32: Internal Compression Level

Internal Compression Level, as shown in Table 28, specifies a data compression hint/recommendation that a JT file loader is free to follow for internally (in memory) storing texel data. This setting does not affect how image texel data is actually stored in JT files or other externally referenced files.

Table 28 — Texture Vers-1 Texture Environment Internal Compression Level values

| | |
|-----|---|
| = 0 | None. No compression of texel data. |
| = 1 | Conservative. Lossless compression of texel data. |
| = 2 | Moderate. Texel components truncated to 8-bits each. |
| = 3 | Aggressive. Texel components truncates to 4-bits each (or 5 bits for RGB images). |

RGBA: Blend Colour

Blend Colour specifies the colour to be used for the “Blend” mode of Blend Type operations.

RGBA: Border Colour

Border Colour specifies the constant border colour to use for “Clamp to Border” style wrap modes when the texture itself does not have a border.

Mx4F32: Texture Transform

Texture Transform defines the texture coordinate transformation matrix. A renderer of JT data would typically apply this transform to texture coordinates prior to applying the texture.

Texture Coord Generation Parameters

Texture Coord Generation Parameters, as shown in Figure 54, contains information indicating if and how texture coordinate components should be automatically generated for each of the 4 components (S, T, R, Q) of a texture coordinate.

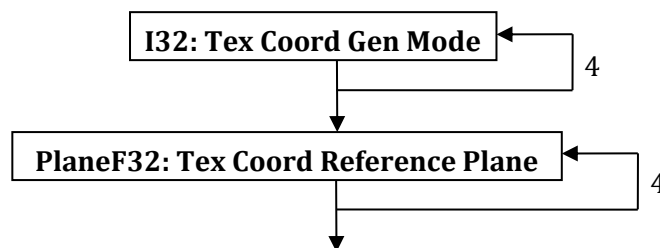


Figure 54 — Texture Coord Generation Parameters data collection

I32: Tex Coord Gen Mode

Tex Coord Gen Mode, as shown in Table 29 , specifies the texture coordinate generation mode for each component (S, T, R, Q) of texture coordinate. There are four mode values stored, one for each component of texture coordinate. The mode values are stored in S, T, R, Q order.

Table 29 — Texture Vers-1 Texture Coord Generation Gen Mode values

| | |
|-----|---|
| = 0 | None. No texture coordinates automatically generated. |
| = 1 | Model Coordinate System Linear. Texture coordinates computed as a distance from a reference plane specified in model coordinates. |
| = 2 | View Coordinate System Linear. Texture coordinates computed as a distance from a reference plane specified in view coordinates. |
| = 3 | Sphere Map. Texture coordinates generated based on spherical environment mapping. |
| = 4 | Reflection Map. Texture coordinates generated based on cubic environment mapping. |
| = 5 | Normal Map. Texture coordinates computed/set by copying vertex normal in view coordinates to S, T, R. |

PlaneF32: Tex Coord Reference Plane

Reference Plane specifies the reference plane used for “Model Coordinate System Linear” and “View Coordinate System Linear” texture coordinate generation modes. There are four Reference Planes stored, one for each component of texture coordinate. The Reference Planes are stored in S, T, R, Q order. Even if a components “Tex Coord Gen Mode” is one that does not require a reference plane, dummy reference planes are still stored in JT file.

Inline Texture Image Data

Inline Texture Image Data, as shown in Figure 55, is a collection of data defining the texture format properties and image texel data for one texture image. Inline Texture Image Data is only present if data field Inline Image Storage Flag equals “1.” If present there will be data field Image Count number of Inline Texture Image Data instances.

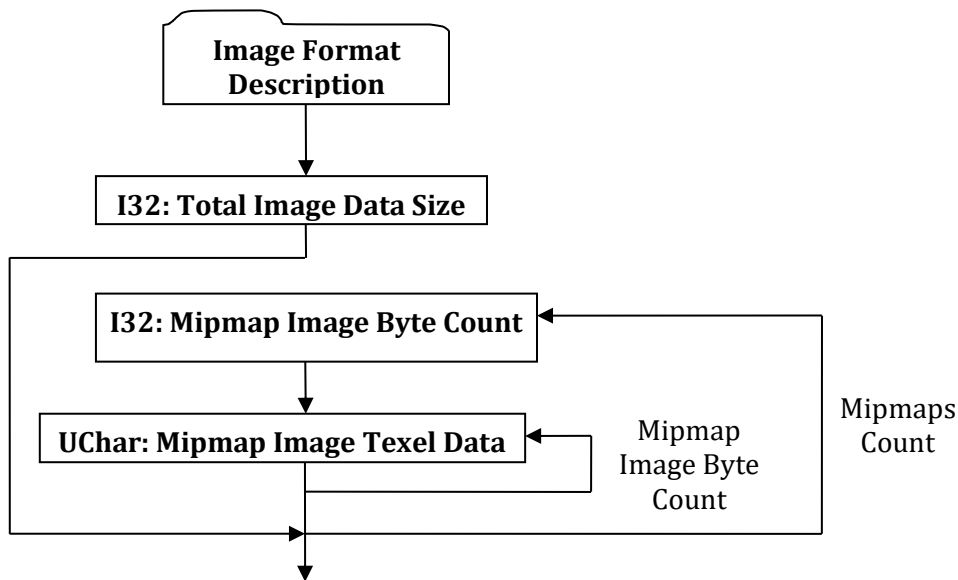


Figure 55 — Inline Texture Image Data collection

Complete description for Image Format Description, as shown in Figure 55, can be found in Image Format Description.

I32: Total Image Data Size

Total Image Data Size specifies the total length, in bytes, of the on-disk representation for all mipmap images. This byte total does not include the I32: Mipmap Image Byte Count data field storage (4 bytes per) for each mipmap.

I32: Mipmap Image Byte Count

Mipmap Image Byte Count specifies the length, in bytes, of the on-disk representation of the next mipmap image.

UChar: Mipmap Image Texel Data

Mipmap Image Texel Data is the mipmap's block of image data. The length of this field in bytes is specified by the value of data field Mipmap Image Byte Count.

Image Format Description

The Image Format Description, as shown in Figure 56, is a collection of data defining the pixel format, data type, size, and other miscellaneous characteristics of the texel image data.

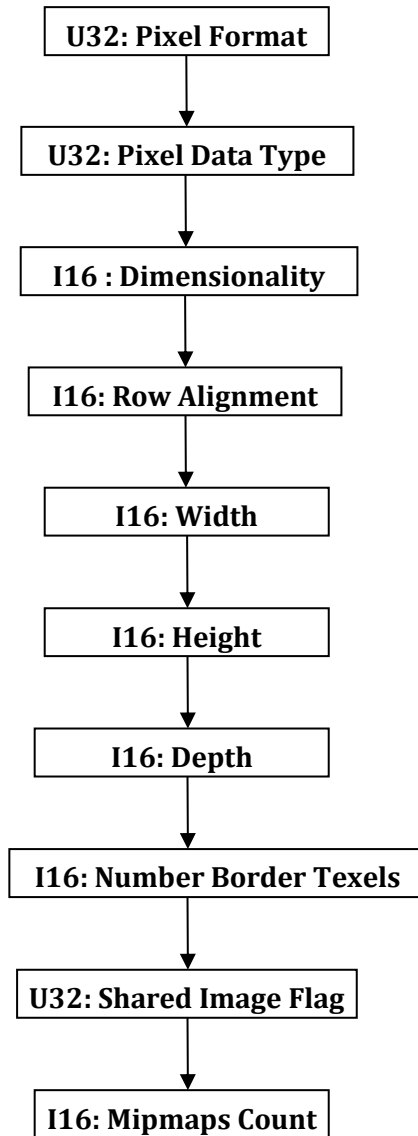


Figure 56 — Image Format Description data collection

U32: Pixel Format

Pixel format, as shown in Table 30, specifies the format of the texture image pixel data. Depending on the format, anywhere from one to four elements of data exists per texel.

Table 30 — Texture Vers-1 Image Format Description Pixel Format values

| | |
|------|---|
| = 0 | No format specified. Texture mapping is not applied. |
| = 1 | RGB: A red colour component followed by green and blue colour components |
| = 2 | RGBA: A red colour component followed by green, blue, and alpha colour components |
| = 3 | LUM: A single luminance component |
| = 4 | LUMA: A luminance component followed by an alpha colour component |
| = 5 | A single stencil index |
| = 6 | A single depth component |
| = 7 | A single red colour component |
| = 8 | A single green colour component |
| = 9 | A single blue colour component |
| = 10 | A single alpha colour component |

| | |
|------|--|
| = 11 | A blue colour component, followed by green and red colour components |
| = 12 | A blue colour component, followed by green, red, and alpha colour components |
| = 13 | A depth component, followed by a stencil component |

U32: Pixel Data Type

Pixel Data Type, as shown in Table 31, specifies the data type used to store the per texel data. If the Pixel Format represents a multi component value (for example red, green, blue) then each value requires the Pixel Data Type number of bytes of storage (for example a Pixel Format Type of “1” with Pixel Data Type of “3” would require 3 bytes of storage for each texel).

Table 31 — Texture Vers-1 Image Format Description Pixel Data values

| | |
|-----|--|
| = 0 | No type specified. Texture mapping is not applied. |
| = 1 | Signed 8-bit integer |
| = 2 | Single-precision 32-bit floating point |
| = 3 | Unsigned 8-bit integer |
| = 4 | Single bits in unsigned 8-bit integers |
| = 5 | Unsigned 16-bit integer |
| = 6 | Signed 16-bit integer |
| = 7 | Unsigned 32-bit integer |
| = 8 | Signed 32-bit integer |
| = 9 | 16-bit floating point according to IEEE-754 format (therefore 1 sign bit, 5 exponent bits, 10 mantissa bits) |

I16 : Dimensionality

Dimensionality, as shown in Table 32, specifies the number of dimensions the texture image has. Valid values include:

Table 32 — Texture Vers-1 Image Format Description Dimensionality values

| | |
|-----|---------------------------|
| = 1 | One-dimensional texture |
| = 2 | Two-dimensional texture |
| = 3 | Three-dimensional texture |

I16: Row Alignment

Row Alignment specifies the byte alignment for image data rows. This data field shall have a value of 1, 2, 4, or 8. If set to 1 then all bytes are used (therefore no bytes are wasted at end of row). If set to 2, then if necessary, an extra wasted byte(s) is/are stored at the end of the row so that the first byte of the next row has an address that is a multiple of 2 (multiple of four for Row Alignment equal 4 and multiple of 8 for row alignment equal 8). The actual formula (using C syntax) to determine number of bytes per row is as follows:

$$\text{BytesPerRow} = (\text{numBytesPerPixel} * \text{ImageWidth} + \text{RowAlignment} - 1) \& \sim(\text{RowAlignment} - 1)$$

I16: Width

Width specifies the width dimension (number of texel columns) of the texture image in number of pixels.

I16: Height

Height specifies the height dimension (number of texel rows) of the texture image in number of pixels. Height is 1 for one-dimensional images.

I16: Depth

Depth specifies the depth dimension (number of texel slices) of the texture image in number of pixels. Depth is 1 for one-dimensional and two-dimensional images.

I16: Number Border Texels

Number Border Texels specifies the number of border texels in the texture image definition. Valid values are 0 and 1.

U32: Shared Image Flag

Shared Image Flag, as shown in Table 33, is a flag indicating whether this texture image is shareable with other Texture Image Element attributes.

Table 33 — Texture Vers-1 Image Format Description Shared Image Flag values

| | |
|-----|---|
| = 0 | Image is not shareable with other Texture Image Elements. |
| = 1 | Image is shareable with other Texture Image Elements. |

I16: Mipmaps Count

Mipmaps Count specifies the number of mipmap images. A value of 1 indicates that no mipmaps are used. A value greater than 1 indicates that mipmaps are present all the way down to a 1-by-1 texel.

Base Attribute Data Fields V2

See section 5.4 Attribute Elements description of Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 are defined when Base Attribute Version Number is set to two.

5.4.3 Draw Style Attribute Element

Object Type ID: 0x10dd1014, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Draw Style Attribute Element, as shown in Figure 57, contains information defining various aspects of the graphics state/style that should be used for rendering associated geometry. JT format LSG traversal semantics state that draw style attributes accumulate down the LSG by replacement.

The Field Inhibit flag (see Base Attribute Data) bit assignments for the Draw Style Attribute Element data fields, are as shown in Table 34:

Table 34 — Draw Style Attribute Field Inhibit flag values

| Field Inhibit Flag Bit | Data Field(s) Bit Applies To |
|------------------------|------------------------------|
| 0 | Two Sided Lighting Flag |
| 1 | Back-face Culling Flag |
| 2 | Outlined Polygons Flag |
| 3 | Lighting Enabled Flag |
| 4 | Flat Shading Flag |
| 5 | Separate Specular Flag |

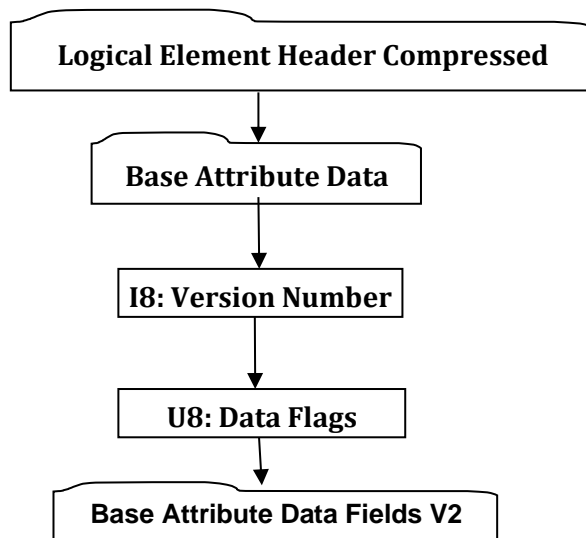


Figure 57 — Draw Style Attribute Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 57, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers. Only version 1 is defined for version 10.6.

U8: Data Flags

Data Flags, as shown in Table 35, is a collection of flags. The flags are combined using the binary OR operator and store various state settings for Draw Style Attribute Elements. All bits fields that are not defined as in use should be set to “0”.

Table 35 — Draw Style Attribute Data Flag values

| | |
|------|---|
| 0x01 | Back-face Culling Flag. Indicates if back-facing polygons should be discarded (culled). = 0 – Back-facing polygons not culled. = 1 – Back-facing polygons culled. |
| 0x02 | Two Sided Lighting Flag. Indicates if two sided lighting should be enabled to insure that polygons are illuminated on both sides. = 0 – Disable two sided lighting. = 1 – Enable two sided lighting. |
| 0x04 | Outlined Polygons Flag. Indicates if polygons should be drawn as “wireframes” therefore not filled. = 0 – Polygons drawn as filled. = 1 – Only polygon’s outline drawn. |
| 0x08 | Lighting Enabled Flag. Indicates if lighting should be enabled. If lighting disabled, then renderer should perform no calculations concerning normals, light sources, material properties, etc. |

| | |
|------|--|
| | = 0 – Disable lighting. = 1 – Enable lighting. |
| 0x10 | Flat Shading Flag. Indicates if the geometry should be rendered with single colour (flat shading) or with many different colour (smooth/Gouraud) shading. = 0 – Disable flat shading (therefore use smooth/Gouraud shading). = 1 – Enable flat shading. |
| 0x20 | Separate Specular Flag. Indicates if the application of the specular colour should be delayed until after texturing. If no texture mapping then this flag setting is irrelevant. = 0 – Apply specular colour contribution before texture mapping. = 1 – Apply specular colour contribution after texture mapping. |

Base Attribute Data Fields V2

See section 5.4 Attribute Elements description of Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 are defined when Base Attribute Version Number is set to two.

Palette Index default value is -1

5.4.4 Light Set Attribute Element

Object Type ID: 0x10dd1096, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Light Set Attribute Element, as shown in Figure 58, holds an unordered list of Lights. JT format LSG traversal semantics state that light set attributes accumulate down the LSG through addition of lights to an attribute list.

Light Set Attribute Element does not have any Field Inhibit flag (see Base Attribute Data) bit assignments.

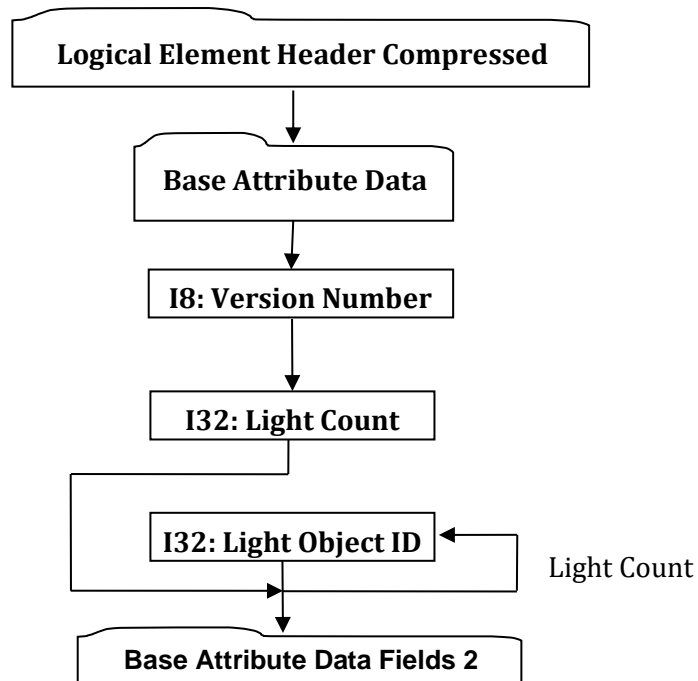


Figure 58 — Light Set Attribute Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 58, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8: Version Number

Version Number is the version identifier for this element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers. Only version 1 is defined for version 10.6.

I32: Light Count

Light Count specifies the number of lights in the Light Set.

I32: Light Object ID

Light Object ID is the identifier for a referenced Light Object.

Base Attribute Data Fields V2

See section 5.4 Attribute Elements description of Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 are defined when Base Attribute Version Number is set to two.

5.4.5 Line Style Attribute Element

Object Type ID: 0x10dd10c4, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Line Style Attribute Element contains information defining the graphical properties to be used for rendering polylines. JT format LSG traversal semantics state that Line Style attributes accumulate down the LSG by replacement.

Line Style Attribute Element, as shown in Figure 59, does not have any Field Inhibit flag (see Base Attribute Data) bit assignments.

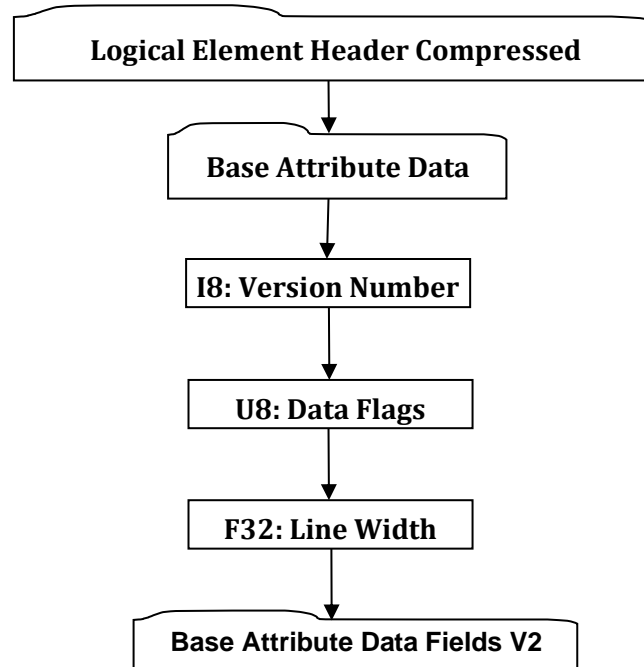


Figure 59 — Line Style Attribute Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8: Version Number


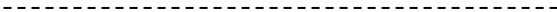











Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U8: Data Flags

Data Flags, as shown in Table 36, is a collection of flags and line type data. The flags and line type data are combined using the binary OR operator and store various polyline rendering attributes.

All bits fields that are not defined as in use should be set to "0".

Table 36 — Line Style Attribute Data Flag values

| | |
|------|--|
| 0x0F | <p>Line Type (stored in bits 0 – 3 or in binary notation 00001111) Line type specifies the polyline rendering stipple-pattern.</p> <p>= 0 - Solid </p> <p>= 1 - Dash </p> <p>= 2 - Dot </p> <p>= 3 - Dash_Dot </p> <p>= 4 - Dash_Dot_Dot </p> <p>= 5 - Long_Dash </p> <p>= 6 - Centre_Dash </p> <p>= 7 - Centre_Dash_Dash </p> <p>= 8 - Invisible</p> <p>= 9 - Long Dash Dot </p> <p>= 10 - Long Dash Double Dot </p> <p>= 11 - Long Dash Triple Dot </p> <p>= 12 - Long Dash Double Short Dash </p> <p>= 13 - Undulate </p> <p>= 14 - Interrupt Zigzag</p> <p>= 15 - Railway</p> |
| 0x10 | <p>Antialiasing Flag (stored in bit 4 or in binary notation 00010000) Indicates if antialiasing should be applied as part of rendering polylines.</p> <p>= 0 - Antialiasing disabled.</p> <p>= 1 - Antialiasing enabled.</p> |

F32: Line Width

Line Width specifies the width in pixels that should be used for rendering polylines. The value of this field shall be greater than 0.0.

Base Attribute Data Fields V2

See section 5.4 Attribute Elements description of Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 are defined when Base Attribute Version Number is set to two.

5.4.6 Point Style Attribute Element

Object Type ID: 0x8d57c010, 0xe5cb, 0x11d4, 0x84, 0xe, 0x00, 0xa0, 0xd2, 0x18, 0x2f, 0x9d

Point Style Attribute Element, as shown in Figure 60, contains information defining the graphical properties that should be used for rendering points. JT format LSG traversal semantics state that Point Style attributes accumulate down the LSG by replacement.

Point Style Attribute Element does not have any Field Inhibit flag (see Base Attribute Data) bit assignments.

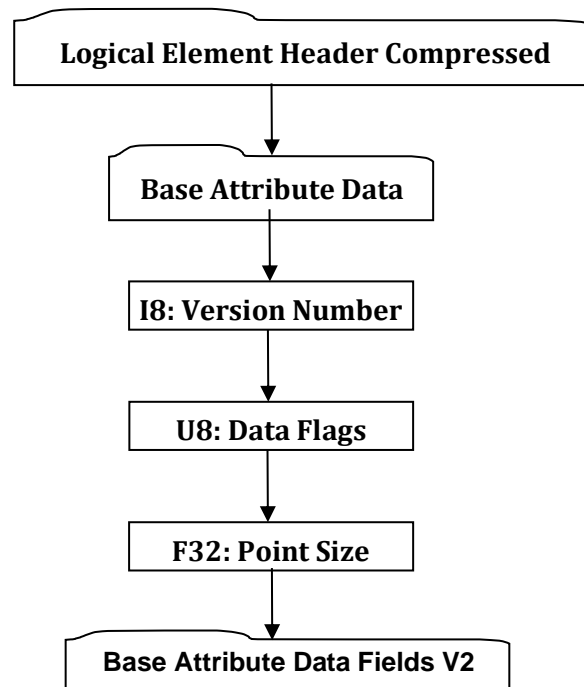


Figure 60 — Point Style Attribute Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8: Version Number

Version Number is the version identifier for this element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U8: Data Flags

Data Flags, as shown in Table 37, is a collection of flags and point type data. The flags and point type data are combined using the binary OR operator and store various point rendering attributes. All bits fields that are not defined as in use should be set to “0”.

Table 37 — Point Style Attribute Data Flag values

| | |
|------|---|
| 0x0F | Point Type (stored in bits 0 – 3 or in binary notation 00001111) These bits are reserved for future expansion of the format to support Point Types. |
| 0x10 | Antialiasing Flag (stored in bit 4 or in binary notation 00010000) Indicates if antialiasing should be applied as part of rendering points. = 0 – Antialiasing disabled. = 1 – Antialiasing enabled. |

F32: Point Size

Point Size specifies the size in pixels that should be used for rendering points. The value shall be greater than 0.0.

Base Attribute Data Fields V2

See section 5.4 Attribute Elements description of Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 are defined when Base Attribute Version Number is set to two.

5.4.7 Geometric Transform Attribute Element

Object Type ID: 0x10dd1083, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Geometric Transform Attribute Element contains a 4x4 homogeneous transformation matrix that positions the associated LSG node's coordinate system relative to its parent LSG node. JT format LSG traversal semantics state that geometric transform attributes accumulate down the LSG through matrix multiplication as follows:

$$p' = pAM$$

Where p is a point of the model, p' is the transformed point, M is the current modelling transformation matrix inherited from ancestor LSG nodes and previous Geometric Transform Attribute Element, and A is the transformation matrix of this Geometric Transform Attribute Element. The matrix is allowed to contain translation, rotation, and uniform- and non-uniform scaling factors, including negative scales. It is not allowed to contain shearing or projective components, or scaling factors of zero (which would make the matrix singular).

Geometric Transform Attribute Element, as shown in Figure 61, does not have any Field Inhibit flag (see Base Attribute Data) bit assignments.

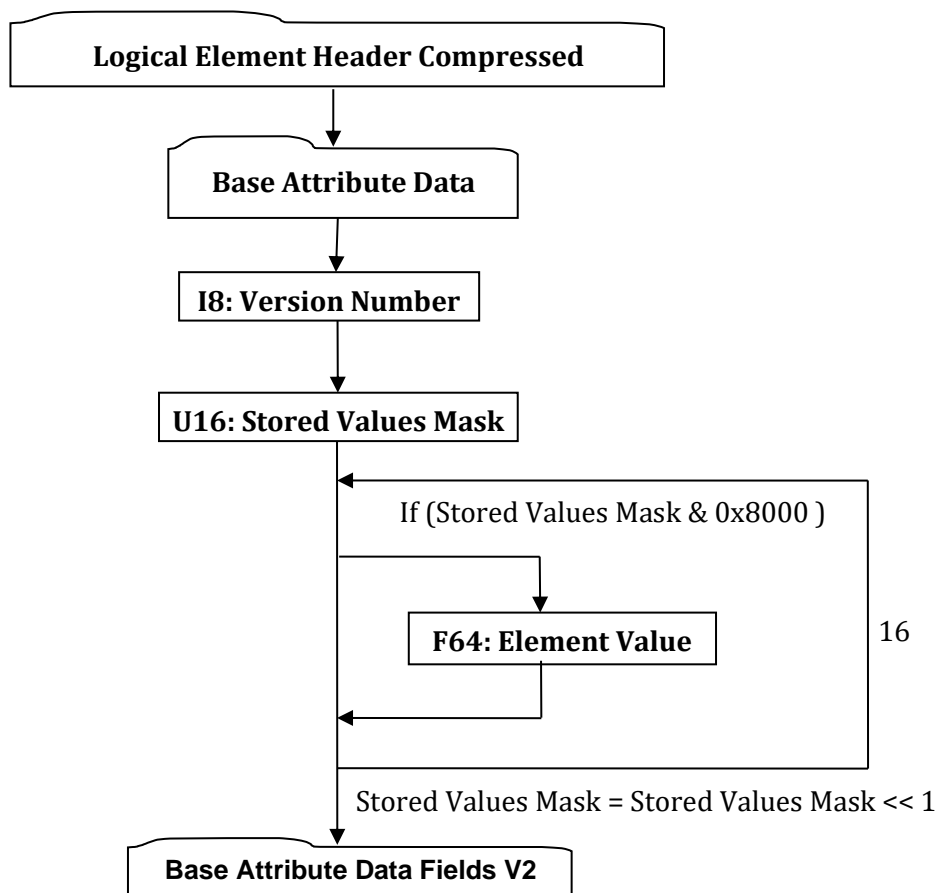


Figure 61 — Geometric Transform Attribute Element data collection

A complete description of Logical Element Header Compressed, as shown in Figure 61, can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8: Version Number

Version Number is the version identifier for this node. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U16: Stored Values Mask

Stored Values mask, as shown in Table 38, is a 16-bit mask where each bit is a flag indicating whether the corresponding element in the matrix is different from the identity matrix. Only elements which are different from the identity matrix are actually stored. The bits are assigned to matrix elements as follows:

Bit15 Bit14 Bit13 Bit12

Bit11 Bit10 Bit9 Bit8

Bit7 Bit6 Bit5 Bit4

Bit3 Bit2 Bit1 Bit0

The individual bit-flag values are interpreted as follows:

Table 38 — Geometric Transform Attribute Stored Value Mask individual bit-flag values

| | |
|-----|--|
| = 0 | Value not stored (matrix value same as corresponding element in identity matrix) |
| = 1 | Value stored |

F64: Element Value

Element Value specifies a particular matrix element value.

Base Attribute Data Fields V2

See section 5.4 Attribute Elements description of Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 are defined when Base Attribute Version Number is set to two.

5.4.8 Palette Map Attribute Element

Object Type ID: 0x10dd1106,0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Palette Map Attribute, as shown in Figure 62, is used on a shape such that any face group can be rendered with a chosen entry from the palette. Each Attribute entry in the palette is inherited down the scene graph independent from any other palette entry. Attributes Elements in the scene graph are able to specify to which palette entry they apply.

For a complete description of per face group attributes and palette map see the Per Face Group Attributes Annex E in this document.

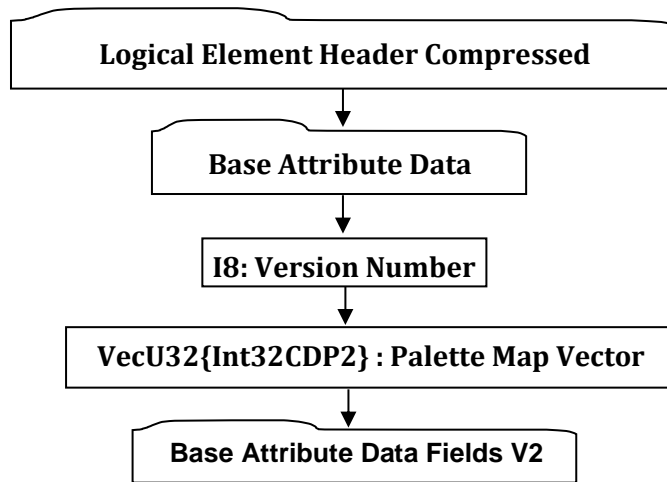


Figure 62 — PaletteMap Attribute Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

A complete description of Base Attribute Data can be found in the LSG Segment section of this document under Attribute Elements in the logical collection describing Base Attribute Data.

I8:Version Number

Version Number is the version identifier for this element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

VecU32{Int32CDP2}: Palette Map Vector

A Palette Map is a set of accumulated states belonging to an instance of a node in the LSG. Each state in a palette is accumulated by different levels and types of attributes with the same palette index.

The Palette Map Vector contains a mapping vector indexed by face group number storing the palette index of the state to be assigned to that face group. A Palette Map entry of -1 indicates that the "fallback" state is to be used for the corresponding face group. A Palette Map entry of -2 indicates that the corresponding face group is to be inhibited entirely, and not rendered at all.

For a complete description of this topic see the Per Face Group Attributes Annex E in this document.

Base Attribute Data Fields V2

See section 5.4 Attribute Elements description of Base Attribute Data for the definition of Base Attribute Data Fields V2.

Base Attribute Data Fields V2 must be set to -1 for the PaletteMap Attribute element.

5.4.9 Sabot Attribute Element

Object Type ID: 0x96603dd3,0x5a0f,0x40f5,0x97,0xcb,0x1e,0x96,0x47,0xcb,0xd3,0x7e);

Sabot Attribute Element as shown in Figure 63 is used to insulate pre JT readers from attributes with non-fallback palette Index attributes in order to preserve forward compatibility.

The Sabot Attribute Element applies for attribute elements containing Base Attribute Data Fields V2 (see the Base Attribute Data Fields V2 description in section 6.2 Attribute Elements of this document).

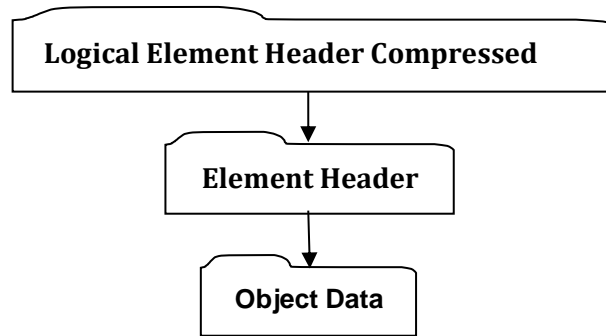


Figure 63 — Sabot Attribute Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

The complete description for Element Header can also be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Object Data

The Object Data contained in the Sabot object is an attribute element. The Sabot object exists only to insulate pre JTreaders from the contained attribute element. The attribute element contained is wrapped in a Sabot attribute because its palette index is not -1. Older readers must ignore such attributes to function as they did with previous version of JT.

Each time a Sabot object is read, the Sabot object must be discarded, and the wrapped attribute read in its place. A Sabot object never appears in the scene graph, only in the persisted JT file.

When writing an JT file, all attributes having Palette Index not set to -1 must be wrapped by a Sabot attribute.

5.4.10 Infinite Light Attribute Element

Object Type ID: 0x10dd1028, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Infinite Light Attribute Element, as shown in Figure 64, specifies a light source emitting un-attenuated light in a single direction from every point on an infinite plane. The infinite location indicates that the rays of light can be considered parallel by the time they reach an object.

JT format LSG traversal semantics state that infinite light attributes accumulate down the LSG through addition of lights to an attribute list.

Infinite Light Attribute Element does not have any Field Inhibit flag (see Base Attribute Data) bit assignments.

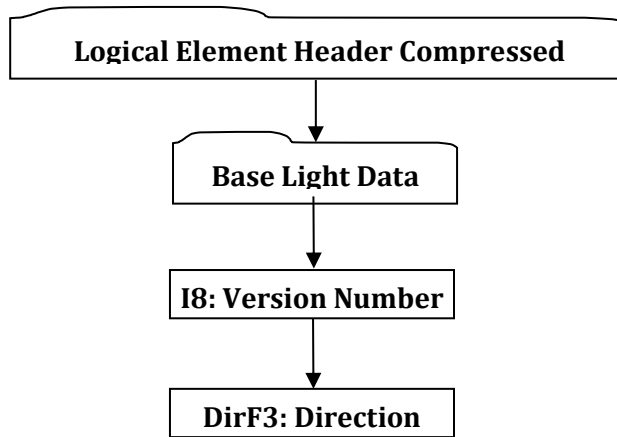


Figure 64 — Infinite Light Attribute Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Light Data can be found in Base Light Data.

I8: Version Number

Version Number, as shown in Table 39, is the version identifier for this element. The value of this Version Number indicates the format of data fields to follow.

Table 39 — Light Set Attribute Version Number values

| | |
|-----|------------------|
| = 1 | Version-1 Format |
|-----|------------------|

DirF3: Direction

Direction specifies the direction the light is pointing in.

Base Light Data

A diagrammatic representation of Base Light Data is shown in Figure 65.

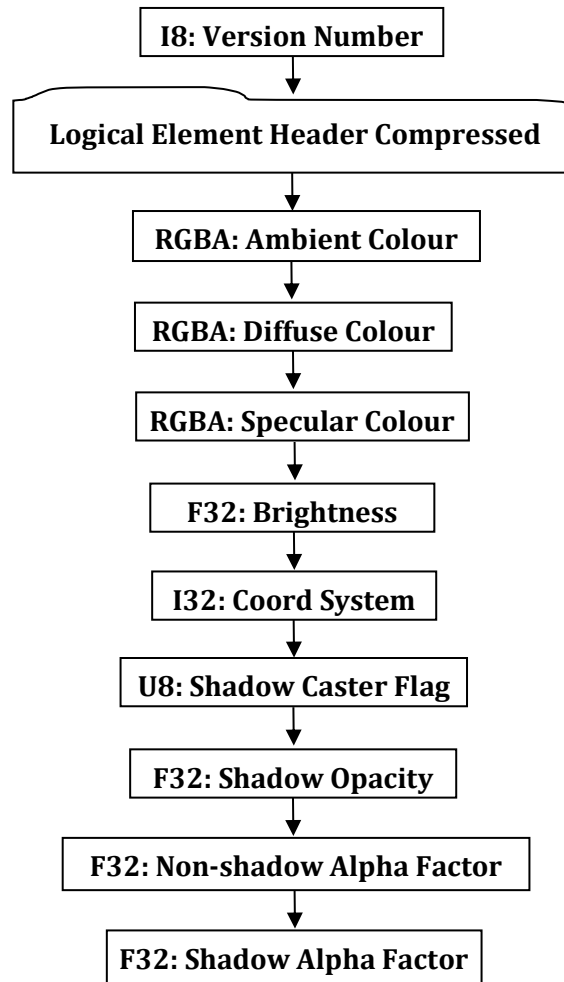


Figure 65 — Base Light Data collection

I8: Version Number

Version number, as shown in Figure 65, is the version identifier for this element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers. Only version 1 is defined for JT.

Logical Element Header

A complete description of Logical Element Header can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

RGBA: Ambient Colour

Ambient Colour specifies the ambient red, green, blue, alpha colour values of the light.

RGBA: Diffuse Colour

Diffuse Colour specifies the diffuse red, green, blue, alpha colour values of the light.

RGBA: Specular Colour

Specular Colour specifies the specular red, green, blue, alpha colour values of the light.

F32: Brightness

Brightness specifies the Light brightness. The Brightness value shall be greater than or equal to “-1”.

I32: Coord System

Coord System, as shown in Table 40, specifies the coordinate space in which Light source is defined. Valid values include the following:

Table 40 — Base Light Data Coord System values

| | |
|-----|--|
| = 1 | Viewpoint Coordinate System. Light source is to move together with the viewpoint. |
| = 2 | Model Coordinate System. Light source is affected by whatever model transforms that are current when the light source is encountered in LSG. |
| = 3 | World Coordinate system. Light source is not affected by model transforms in the LSG. |

U8: Shadow Caster Flag

Shadow Caster Flag, as shown in Table 41, is a flag that indicates whether the light is a shadow caster or not.

Table 41 — Base Light Data Shadow Caster Flag values

| | |
|-----|--------------------------------------|
| = 0 | Light source is not a shadow caster. |
| = 1 | Light source is a shadow caster. |

F32: Shadow Opacity

Shadow Opacity specifies the shadow opacity factor on Light source. Value shall be within range [0.0, 1.0] inclusive. Shadow Opacity is intended to convey how dark a shadow cast by this light source are to be rendered. A value of 1.0 means no light from this light source reaches a shadowed surface, resulting in a black shadow.

F32: Non-shadow Alpha Factor

Non-shadow Alpha Factor is one of a matched pair of fields intended to govern how a shadowing light source (one whose Shadow Caster Flag is set) casts "alpha light" into areas that it directly illuminates (therefore are not in shadow). Those fragments directly lit by this light source will have their alpha values scaled by Non-shadow Alpha Factor. Non-shadow Alpha Factor value shall lie on the range [0.0, 1.0] inclusive.

This field can be used to create "drop shadows" by setting its value to 0. The effect being that all geometry illuminated by the light source will be "burned away," leaving behind only those parts lying in shadow. Naturally, implementing this intended behaviour implies extensive viewer support.

F32: Shadow Alpha Factor

Shadow Alpha Factor is one of a matched pair of fields intended to govern how a shadowing light source (one whose Shadow Caster Flag is set) casts "alpha light" into areas that it does not illuminate (therefore are in shadow). Those fragments in shadow from this light source will have their alpha values scaled by Shadow Alpha Factor. Shadow Alpha Factor value shall lie on the range [0.0, 1.0] inclusive.

This field has the opposite effect of Non-shadow Alpha Factor. If set to a value of 0, for example, it will cause all geometry shadowed from the light source to be burned away, leaving behind only those parts directly illuminated by the light source. Naturally, implementing this intended behaviour implies extensive viewer support.

5.4.11 Point Light Attribute Element

Object Type ID: 0x10dd1045, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Point Light Attribute Element, as shown in Figure 66, specifies a light source emitting light from a specified position, along a specified direction, and with a specified spread angle.

JT format LSG traversal semantics state that point light attributes accumulate down the LSG through addition of lights to an attribute list.

Point Light Attribute Element does not have any Field Inhibit flag (see Base Attribute Data) bit assignments.

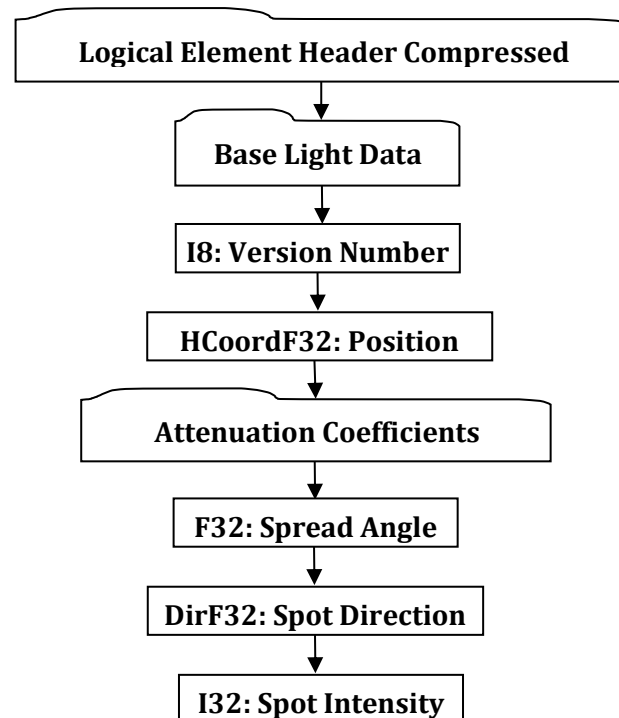


Figure 66 — Point Light Attribute Element data collection

Complete description for Logical Element Header can be found in Logical Element Header.

Complete description for Base Light Data can be found in Base Light Data.

Complete description for Attenuation Coefficients can be found in Attenuation Coefficients.

I8: Version Number

Version Number, as shown in Table 42, is the version identifier for this element. The value of this Version Number indicates the format of data fields to follow.

Table 42 — Point Light Attribute Version Number values

| | |
|-----|------------------|
| = 1 | Version-1 Format |
|-----|------------------|

HCoordF32: Position

Position specifies the light position in homogeneous coordinates.

F32: Spread Angle

Spread Angle, as shown in the Figure 66, with respect to the light cone, specifies in degrees the half angle of the light cone. Valid Spread Angle values are clamped and interpreted as shown in Table 43:

Table 43 — Point Light Attribute Spread Angle values

| | |
|----------------------|--------------------|
| angle == 180.0 | Simple point light |
| 0.0 >= angle <= 90.0 | Spot Light |

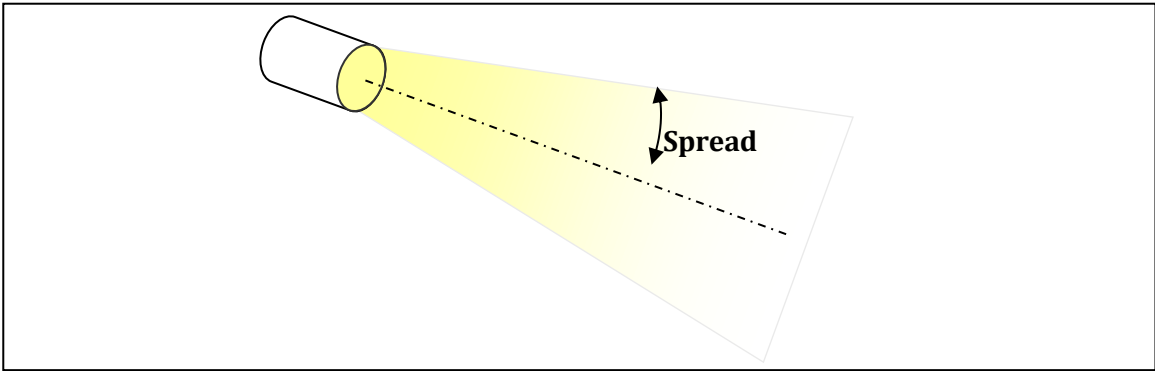


Figure 67 — Spread Angle value with respect to the light cone

DirF32: Spot Direction

Spot Direction specifies the direction the spot light is pointing in.

I32: Spot Intensity

Spot Intensity specifies the intensity distribution of the light within the spot light cone. Spot Intensity is really a “spot exponent” in a lighting equation and indicates how focused the light is at the centre. The larger the value, the more focused the light source. Only non-negative Spot intensity values are valid.

Attenuation Coefficients

Attenuation Coefficients data collection, as shown in Figure 68, contains the coefficients for how light intensity decreases with distance.

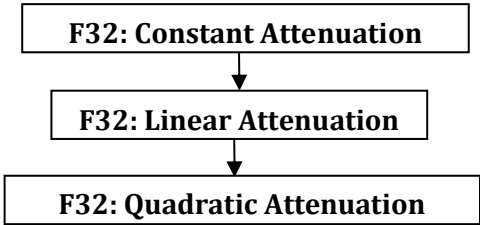


Figure 68 — Attenuation Coefficients data collection

F32: Constant Attenuation

Constant Attenuation specifies the constant coefficient for how light intensity decreases with distance. Value shall be greater than or equal to “0”.

F32: Linear Attenuation

Linear Attenuation specifies the linear coefficient for how light intensity decreases with distance. Value shall be greater than or equal to “0”.

F32: Quadratic Attenuation

Quadratic Attenuation specifies the quadratic coefficient for how light intensity decreases with distance. Value shall be greater than or equal to “0”.

5.5 Property Atom Elements

Property Atom Elements are meta-data objects associated with nodes or Attributes. Property Atom Elements are not nodes or attributes themselves, but can be associated with any node or Attribute to maintain arbitrary application- or enterprise information (meta-data) pertaining to that node or Attribute. Each Node Element or Attribute Element in an LSG may hold zero or more Property Atom Elements and this relationship information is stored within Property Table section of a JT file.

An individual property is specified as a *key/value* Property Atom Element pair, where the *key* identifies the type and meaning of the *value*. The JT format supports many different Property Atom Element key/value object types. The different Property Atom Element key/value object types are documented in the following subsections.

Some “Best Practices” for placing application or enterprise properties/meta-data on Nodes in JT files can be found in Metadata Conventions section of this reference.

5.5.1 Base Property Atom Element

Object Type ID: 0x10dd104b, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Base Property Atom Element, as shown in Figure 69, represents the simplest form of a property that can exist within the LSG and has no type specific value data associated with it.

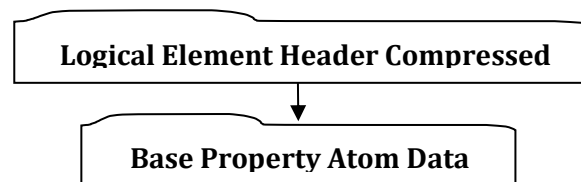


Figure 69 — Base Property Atom Element data collection

Complete description for Logical Element Header Compressed can be found in Logical Element Header Compressed in this document.

Base Property Atom Data

A diagrammatic representation of Base Property Atom Data is shown in Figure 70.

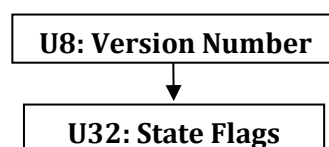


Figure 70 — Base Property Atom Data collection

U8: Version Number

Version Number, as shown in Figure 70, is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U32: State Flags

State Flags is a collection of flags. The flags are combined using the binary OR operator and store various state information for property atoms. Bits 0 – 7 are freely available for an application to store whatever property atom information desired. The topmost 0x40000000 bit must be set to 1 for general viewing support. All other bits are reserved for future expansion of the file format.

5.5.2 String Property Atom Element

Object Type ID: 0x10dd106e, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

String Property Atom Element, as shown in Figure 71, represents a character string property atom.

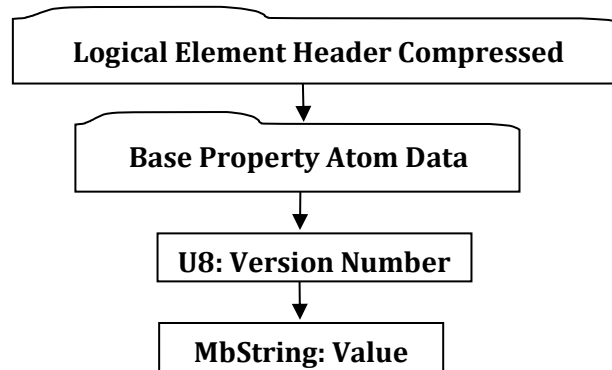


Figure 71 — String Property Atom Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Property Atom Data can be found in Base Property Atom Data.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

MbString: Value

Value contains the character string value for this property atom.

5.5.3 Integer Property Atom Element

Object Type ID: 0x10dd102b, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Integer Property Atom Element, as shown in Figure 72, represents a property atom whose value is of I32 data type.

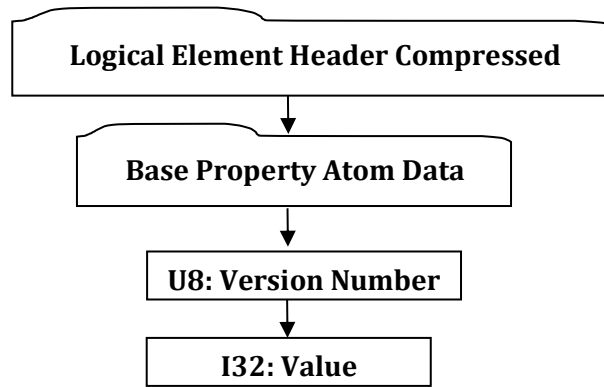


Figure 72 — Integer Property Atom Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Property Atom Data can be found in Base Property Atom Data.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

I32: Value

Value contains the integer value for this property atom.

5.5.4 Floating Point Property Atom Element

Object Type ID: 0x10dd1019, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

Floating Point Property Atom Element, as shown in Figure 73, represents a property atom whose value is of F32 data type.

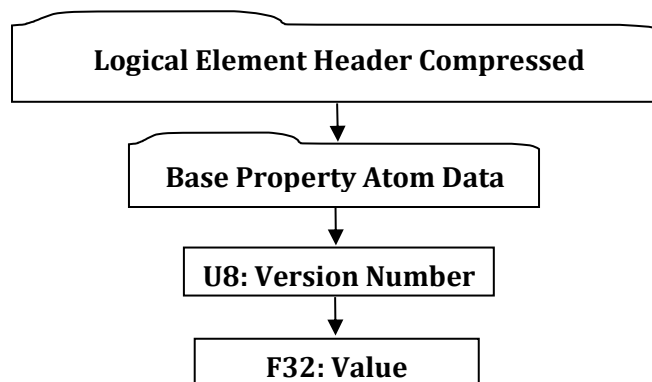


Figure 73 — Floating Point Property Atom Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Property Atom Data can be found in Base Property Atom Data.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

F32: Value

Value contains the floating point value for this property atom.

5.5.5 JT Object Reference Property Atom Element

Object Type ID: 0x10dd1004, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

JT Object Reference Property Atom Element, as shown in Figure 74, represents a property atom whose value is an object ID for another object within the JT file.

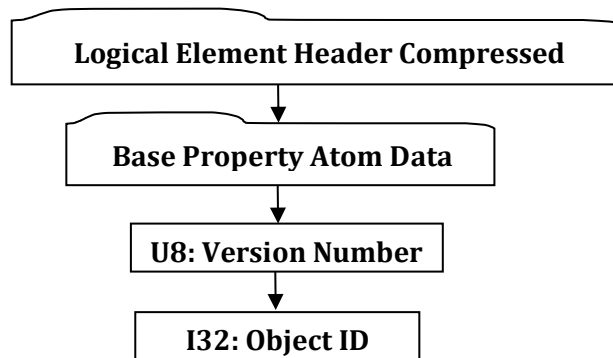


Figure 74 — JT Object Reference Property Atom Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Property Atom Data can be found in Base Property Atom Data.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

I32: Object ID

Object ID specifies the identifier within the JT file for the referenced object.

5.5.6 Date Property Atom Element

Object Type ID: 0xce357246, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1

Date Property Atom Element, as shown in Figure 75, represents a property atom whose value is a “date”.

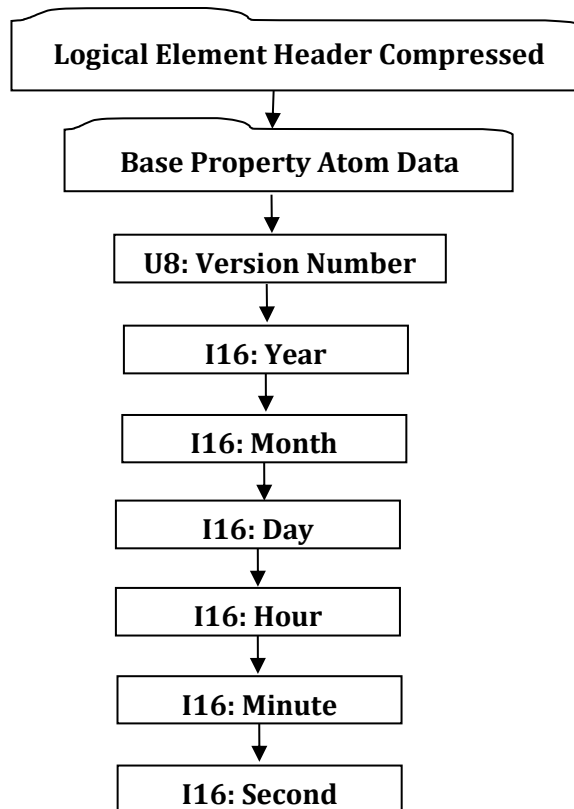


Figure 75 — Date Property Atom Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Property Atom Data can be found in Base Property Atom Data.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

I16: Year

Year specifies the date year value. Valid values are [1900, 2999] inclusive.

I16: Month

Month specifies the date month value. Valid values are [0, 11] inclusive.

I16: Day

Day specifies the date day value. Valid values are [1, 31] inclusive.

I16: Hour

Hour specifies the date hour value. Valid values are [0, 23] inclusive.

I16: Minute

Minute specifies the date minute value. Valid values are [0, 59] inclusive.

I16: Second

Second specifies the date Second value. Valid values are [0, 59] inclusive.

5.5.7 Late Loaded Property Atom Element

Object Type ID: 0xe0b05be5, 0xfbbd, 0x11d1, 0xa3, 0xa7, 0x00, 0xaa, 0x00, 0xd1, 0x09, 0x54

Late Loaded Property Atom Element is a property atom type used to reference an associated piece of atomic data in a separate addressable segment of the JT file. The “Late Loaded” connotation derives from the associated data being stored in a separate addressable segment of the JT file, and thus a JT file reader can be structured to support the “best practice” of delaying the loading/reading of the associated data until it is actually needed.

Late Loaded Property Atom Elements, as shown in Figure 76, are used to store a variety of data, including, but not limited to, Shape LOD Segments and B-Rep Segments (see Shape LOD Element).

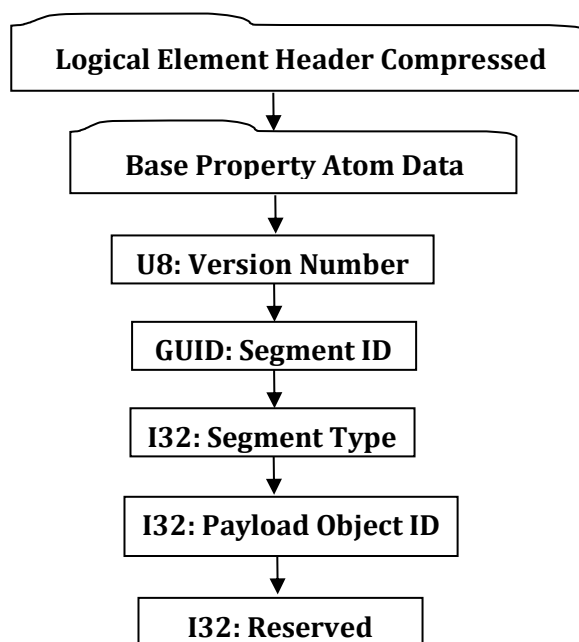


Figure 76 — Late Loaded Property Atom Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Property Atom Data can be found in Base Property Atom Data.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

GUID: Segment ID

Segment ID is the globally unique identifier for the associated data segment in the JT file. See TOC Segment for additional information on how this Segment ID can be used in conjunction with the file TOC Entries to locate the associated data in the JT file.

The complete list of segment types can be found the Segment Types Table.

I32: Segment Type

Segment Type defines a broad classification of the associated data segment contents. For example, a Segment Type of “1” denotes that the segment contains Logical Scene Graph material; “2” denotes contents of a B-Rep, etc.

I32: Payload Object ID

Object ID is the identifier for the payload. Other objects referencing this particular payload will do so using the Object ID.

I32: Reserved

Reserved data field that is guaranteed to always be greater than or equal to 1.

5.5.8 Vector4f Property Atom Element

Object Type ID: 0x2e7db4be, 0xc71a, 0x4b18, 0x9d, 0x7, 0xc7, 0x22, 0x7e, 0x9f, 0xef, 0x76

Vector4f Property Atom Element, as shown in Figure 77, represents a property atom whose value is of VecF32 data type with the length to be equal to 4 .

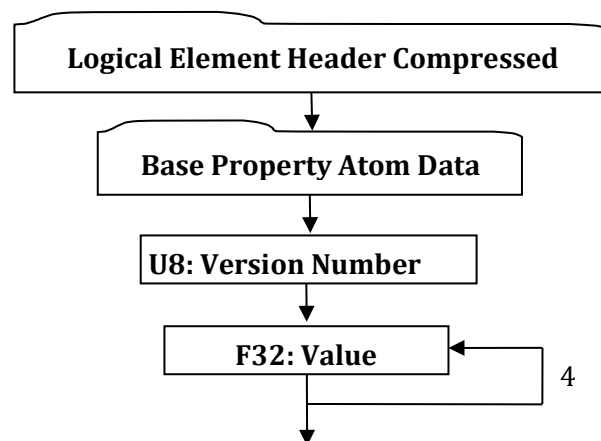


Figure 77 — Vector4f Property Atom Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

Complete description for Base Property Atom Data can be found in Base Property Atom Data.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

F32: Value

Value contains the floating point value for this property atom.

5.6 Property Table

The Property Table, as shown in Figure 78, is where the data connecting Node Elements and Attribute Elements with their associated Properties is stored. The Property Table contains an Element Property Table for each element in the JT File which has associated Properties. An Element Property Table is a list of key/value Property Atom Element pairs for all Properties associated with a particular Node Element Object or Attribute Element Object.

For a reference compliant JT File all Node Elements, Attribute Elements, and Property Atom Elements contained in a JT file should have been read by the time a JT file reader reaches the Property Table section of the file. This means that all Node Objects, Attribute Objects, and Property Atom Objects referenced in the Property Table (through Object IDs), should have already been read, and if not, then the file is corrupt (therefore not reference compliant).

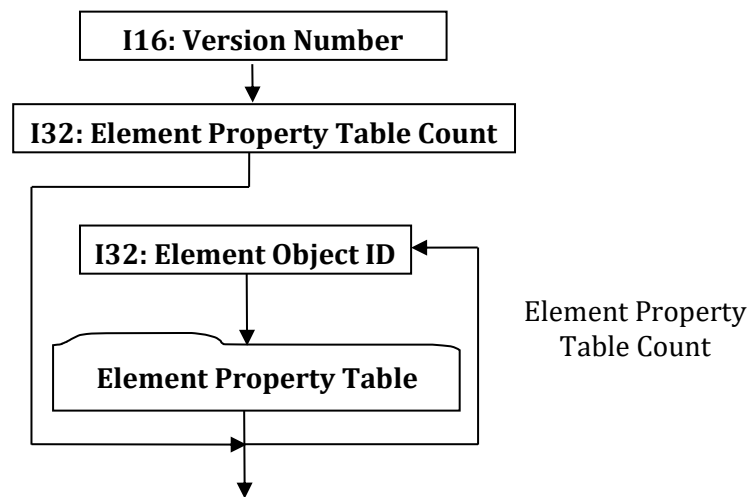


Figure 78 — Property Table data collection

I16: Version Number

Version Number is the version identifier for this Property Table. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

I32: Element Property Table Count

Element Property Table Count specifies the number of Element Property Tables to follow. This value is equivalent to the total number of Node Elements (see Node Elements) and Attribute Elements (see Attribute Elements) that have associated Property Atom Elements (see Property Atom Elements).

I32: Element Object ID

Element Object ID is the identifier for the Node Element object (see Node Elements) or the Attribute Element object (see Attribute Elements) that the following Element Property Table is for (therefore Node Element or Attribute Element that all properties in the following Element Property Table are associated with).

Element Property Table

The Element Property Table, as shown in Figure 79, is a list of key/value Property Atom Element pairs for all properties associated with a particular Node Element Object or Attribute Element Object. The list is terminated by a “0” value for Key Property Atom Object ID.

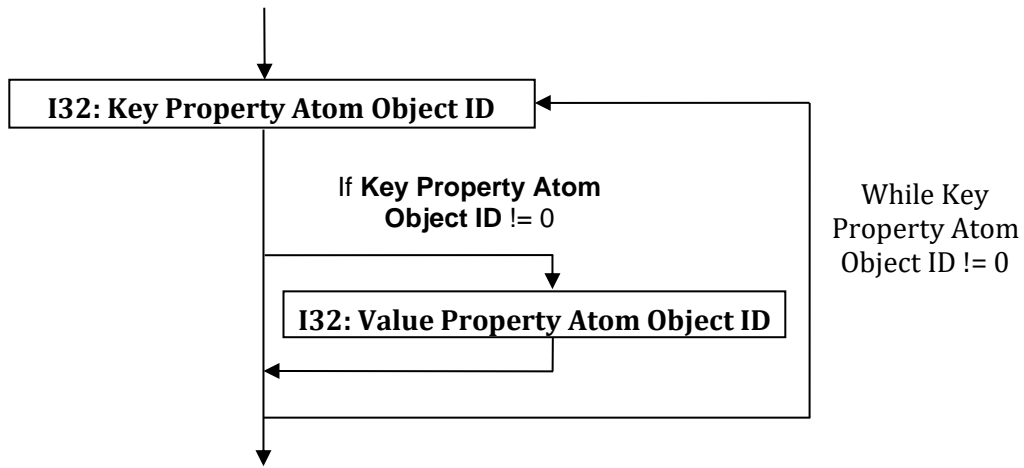


Figure 79 — Element Property Table data collection

I32: Key Property Atom Object ID

Key Property Atom Object ID is the identifier for the Property Atom Element object (see Property Atom Elements) representing the “key” part of the property key/value pair. A value of “0” indicates the end of the Node Property Table.

I32: Value Property Atom Object ID

Value Property Atom Object ID is the identifier for the Property Atom Element object (see Property Atom Elements) representing the “value” part of the property key/value pair. A value is not stored if I32: Key Property Atom Object ID has a value of “0”.

6 Shape LOD Segment

6.1 Shape LOD Segment Overview

Shape LOD Segment, as shown in Figure 80, contains an Element that defines the geometric shape definition data (for example vertices, polygons, normals, etc.) for a particular shape Level Of Detail or alternative representation. Shape LOD Segments are typically referenced by Shape Node Elements using Late Loaded Property Atom Elements (see Shape Node Elements and Late Loaded Property Atom Element respectively).

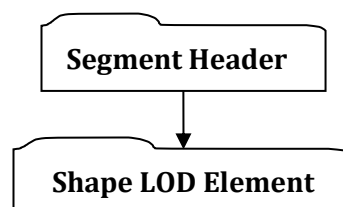


Figure 80 — Shape LOD Segment data collection

Complete description for Segment Header can be found in Segment Header.

Shape LOD Element

- A Shape LOD Element is the holder/container of the geometric shape definition data (for example vertices, polygons, normals, etc.) for a single LOD. Much of the “heavyweight” data contained

within a Shape LOD Element may be optionally compressed and/or encoded. The compression and/or encoding state is indicated through other data stored in each Shape LOD Element.

There are several types of Shape LOD Elements which the JT format supports. The following sub-sections document the various Shape LOD Element types.

6.1.1 Tri-Strip Set Shape LOD Element

Object Type ID: 0x10dd10ab, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Tri-Strip Set Shape LOD Element, as shown in Figure 81, contains the geometric shape definition data (for example vertices, polygons, normals, etc.) for a single LOD of a collection of independent and unconnected triangle strips. Each strip constitutes one primitive of the set and the ordering of the vertices in forming triangles, is the same as OpenGL's triangle strip definition [1].

A Tri-Strip Set Shape LOD Element is typically referenced by a Tri-Strip Set Shape Node Element using Late Loaded Property Atom Elements (see Tri-Strip Set Shape Node Element and Late Loaded Property Atom Element respectively).

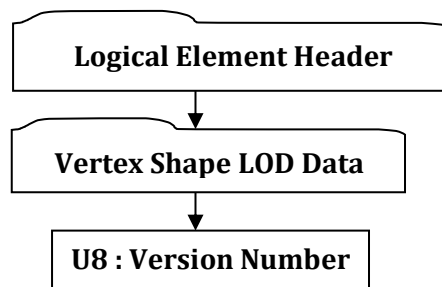


Figure 81 — Tri-Strip Set Shape LOD Element data collection

Complete description for Logical Element Header can be found in Logical Element Header.

Complete description for Vertex Shape LOD Data can be found in Vertex Shape LOD Data.

U8 : Version Number

Version Number is the version identifier for this Tri-Strip Set Shape LOD. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

6.1.2 Polyline Set Shape LOD Element

Object Type ID: 0x10dd10a1, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Polyline Set Shape LOD Element contains the geometric shape definition data (for example vertices, normals, etc.) for a single LOD of a collection of independent and unconnected polylines. Each polyline constitutes one primitive of the set.

A Polyline Set Shape LOD Element, as shown in Figure 82, is typically referenced by a Polyline Set Shape Node Element using Late Loaded Property Atom Elements (see Polyline Set Shape Node Element and Late Loaded Property Atom Element respectively).

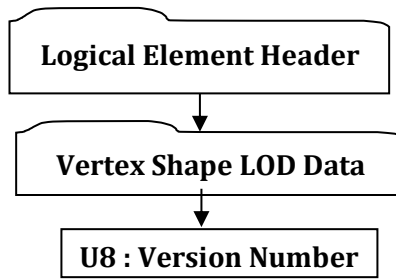


Figure 82 — Polyline Set Shape LOD Element data collection

Complete description for Logical Element Header can be found in Logical Element Header.

Complete description for Vertex Shape LOD Data can be found in Vertex Shape LOD Data.

U8 : Version Number

Version Number is the version identifier for this Polyline Set Shape LOD. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

6.1.3 Point Set Shape LOD Element

Object Type ID: 0x98134716, 0x0011, 0x0818, 0x19, 0x98, 0x08, 0x00, 0x09, 0x83, 0x5d, 0x5a

A Point Set Shape LOD Element, as shown in Figure 83, contains the geometric shape definition data (for example coordinates, normals, etc.) for a collection of independent and unconnected points. Each point constitutes one primitive of the set.

A Point Set Shape LOD Element is typically referenced by a Point Set Shape Node Element using Late Loaded Property Atom Elements (see Point Set Shape Node Element and Late Loaded Property Atom Element respectively).

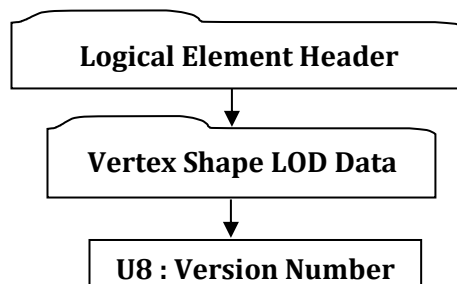


Figure 83 — Point Set Shape LOD Element data collection

Complete description for Logical Element Header can be found in Logical Element Header.

Complete description for Vertex Shape LOD Data can be found in Vertex Shape LOD Data.

U8 : Version Number

Version Number is the version identifier for this Point Set Shape LOD. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

6.1.4 Polygon Set LOD Element

Object Type ID: 0x10dd109f, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Polygon Set LOD Element, as shown in Figure 84, contains the geometric shape definition data (for example vertices, polygons, normals, etc.) for a single LOD of a collection of independent and unconnected polygons. Each polygon constitutes one primitive of the set and the ordering of the vertices in forming polygons, is the same as OpenGL's polygon definition [1].

A Polygon Set LOD Element is typically referenced by a Polygon Set Shape Node Element using Late Loaded Property Atom Elements (see Polygon Set Shape Node Element and Late Loaded Property Atom Element respectively).

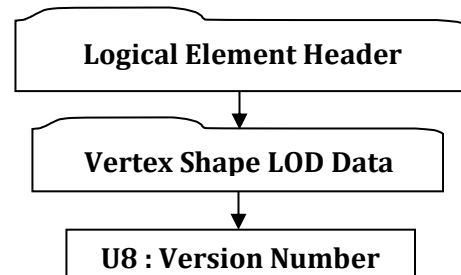


Figure 84 — Polygon Set LOD Element data collection

Complete description for Logical Element Header can be found in Logical Element Header.

U8 : Version Number

Version Number is the version identifier for this Polygon Set LOD Element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

Vertex Shape LOD Data

Vertex Shape LOD Data collection, as shown in Figure 85, is an abstract container for geometric *primitives* such as triangles, line strips, or points, depending on the specific type of Vertex Shape. The set of primitives are further partitioned into so-called "face groups." The Vertex Shape LOD Data also contains the vertex attribute bindings and quantization settings used to store the vertex records referenced by the primitives.

One use for face groups is to establish a correspondence between B-rep faces and their triangle representation. A convention for mapping JT Brep and XT Brep faces to face groups is described in section B-Rep Face Group Associations.

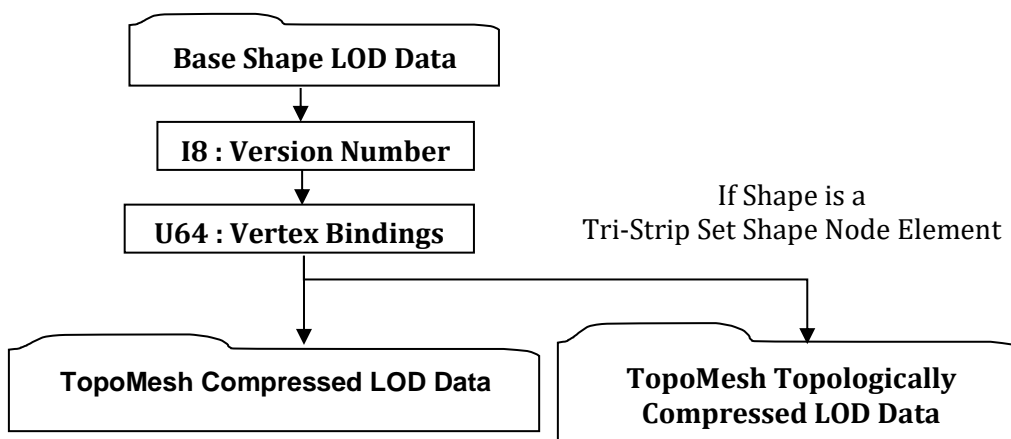


Figure 85 — Vertex Shape LOD Data collection

I8 : Version Number

Version Number is the version identifier for this Vertex Shape LOD Data. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U64 : Vertex Bindings

Binding Attributes, as shown in Table 44, is a collection of normal, texture coordinate, and colour binding information encoded within a single U64 using the following bit allocation. All bits fields that are not defined as in use should be set to “0”.

Table 44 — Vertex Shape LOD Bindings values

| | |
|------------|--|
| Bits 1-3 | Vertex Coordinate Binding. The Vertex Coordinate Binding denotes per vertex coordinate field data is present when one of the bits is set. Bit 1 - 2 Component Vertex Coordinates Bit 2 - 3 Component Vertex Coordinates Bit 3 - 4 Component Vertex Coordinates |
| Bit 4 | Normal Binding. The Normal Binding denotes per vertex normal field data is present when the bit is set. Normal field data is always stored in 3 Component Normals when present. |
| Bits 5 -6 | Colour Binding. The Colour Binding denotes per vertex colour field data is present when one of the bits is set. Bit 5 - 3 Component Colours Bit 6 - 4 Component Colour |
| Bit 7 | Vertex Flag Binding. The Vertex Flag Binding denotes the per vertex flag field is present on the shape when the bit is set. |
| Bits 9-12 | Texture Coordinate 0 Binding. The Texture Coordinate 0 binding denotes per vertex texture coordinates field data is present when one of the bits is set: Bit 9 - 1 Component Texture Coordinates Bit 10 - 2 Component Texture Coordinates Bit 11 - 3 Component Texture Coordinates Bit 12 - 4 Component Texture Coordinates |
| Bits 13-16 | Texture Coordinate 1 Binding. The Texture Coordinate 1 binding denotes per vertex texture coordinates field data is present when one of the bits is set: Bit 13 - 1 Component Texture Coordinates Bit 14 - 2 Component Texture Coordinates Bit 15 - 3 Component Texture Coordinates Bit 16 - 4 Component Texture Coordinates |
| Bits 17-20 | Texture Coordinate 2 Binding. The Texture Coordinate 2 binding denotes per vertex texture coordinates field data is present when one of the bits is set: Bit 17 - 1 Component Texture Coordinates Bit 18 - 2 Component Texture Coordinates Bit 19 - 3 Component Texture Coordinates Bit 20 - 4 Component Texture Coordinates |
| Bits 21-24 | Texture Coordinate 3 Binding. The Texture Coordinate 3 binding denotes per vertex texture coordinates field data is present when one of the bits is set: Bit 21 - 1 Component Texture Coordinates Bit 22 - 2 Component Texture Coordinates Bit 23 - 3 Component Texture Coordinates Bit 24 - 4 Component Texture Coordinates |
| Bits 25-28 | Texture Coordinate 4 Binding. The Texture Coordinate 4 binding denotes per vertex texture coordinates field data is present when one of the bits is set: |

| | |
|------------|--|
| | Bit 25 - 1 Component Texture Coordinates Bit 26 - 2 Component Texture Coordinates Bit 27 - 3 Component Texture Coordinates Bit 28 - 4 Component Texture Coordinates |
| Bits 29-32 | Texture Coordinate 5 Binding. The Texture Coordinate 5 binding denotes per vertex texture coordinates field data is present when one of the bits is set: Bit 29 - 1 Component Texture Coordinates Bit 30 - 2 Component Texture Coordinates Bit 31 - 3 Component Texture Coordinates Bit 32 - 4 Component Texture Coordinates |
| Bits 33-36 | Texture Coordinate 6 Binding. The Texture Coordinate 6 binding denotes per vertex texture coordinates field data is present when one of the bits is set: Bit 33 - 1 Component Texture Coordinates Bit 34 - 2 Component Texture Coordinates Bit 35 - 3 Component Texture Coordinates Bit 36 - 4 Component Texture Coordinates |
| Bits 37-40 | Texture Coordinate 7 Binding. The Texture Coordinate 7 binding denotes per vertex texture coordinates field data is present when one of the bits is set: Bit 37 - 1 Component Texture Coordinates Bit 38 - 2 Component Texture Coordinates Bit 39 - 3 Component Texture Coordinates Bit 40 - 4 Component Texture Coordinates |
| Bits 41-62 | Unused |
| Bit 63 | |
| Bit 64 | Auxiliary Vertex Field Binding. The Auxiliary Vertex Field Binding denotes per vertex auxiliary field data is present on the shape when the bit is set. |

Base Shape LOD Data

Base shape LOD data, as shown in Figure 86, contains the common items to all shape LODs.

I8 : Version Number

Figure 86 — Base Shape LOD Data collection

I8 : Version Number

Version Number is the version identifier for this Base Shape LOD Data. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

TopoMesh Compressed LOD Data

TopoMesh Compressed LOD Data collection, as shown in Figure 87, contains the common items to all TopoMesh Compressed LOD data elements.

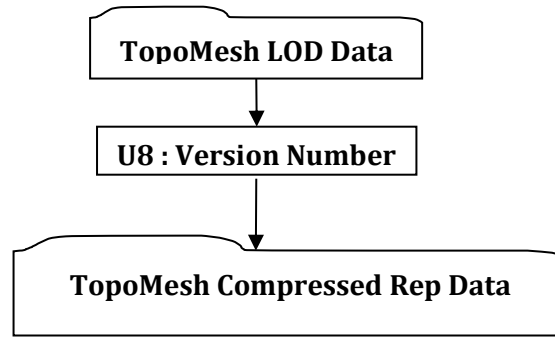


Figure 87 — TopoMesh Compressed LOD Data collection

Complete description for TopoMesh LOD Data, and TopoMesh Compressed Rep Data, can be found in TopoMesh LOD Data, TopoMesh Compressed Rep Data.

U8 : Version Number

Version Number is the version identifier for this TopoMesh Compressed LOD Data. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

TopoMesh LOD Data

TopoMesh LOD Data collection, as shown in Figure 88, contains the common items to all TopoMesh LOD elements.

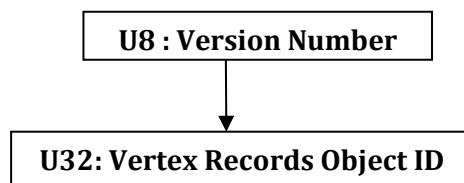


Figure 88 — TopoMesh LOD Data collection

U8 : Version Number

Version Number is the version identifier for this TopoMesh LOD Data. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U32: Vertex Records Object ID

Vertex Records Object ID is the identifier for the vertex records associated with this Object. Other objects referencing these vertex records will do so using this Object ID. It is via this mechanism that multiple TopoMeshes are able to reference the same set of vertex records.

TopoMesh Compressed Rep Data

TopoMesh Compressed Rep Data, as shown in Figure 89, contains the geometric shape definition data (for example vertices, colours, normals, etc.) in a lossy or lossless compressed format. This format is used when the shape type is Polyline Set Shape Node Element, or Point Set Shape Node Element. For Tri-Strip Set Shape Node Element and Polygon Set Shape Node Element, please refer to Topologically Compressed Rep Data.

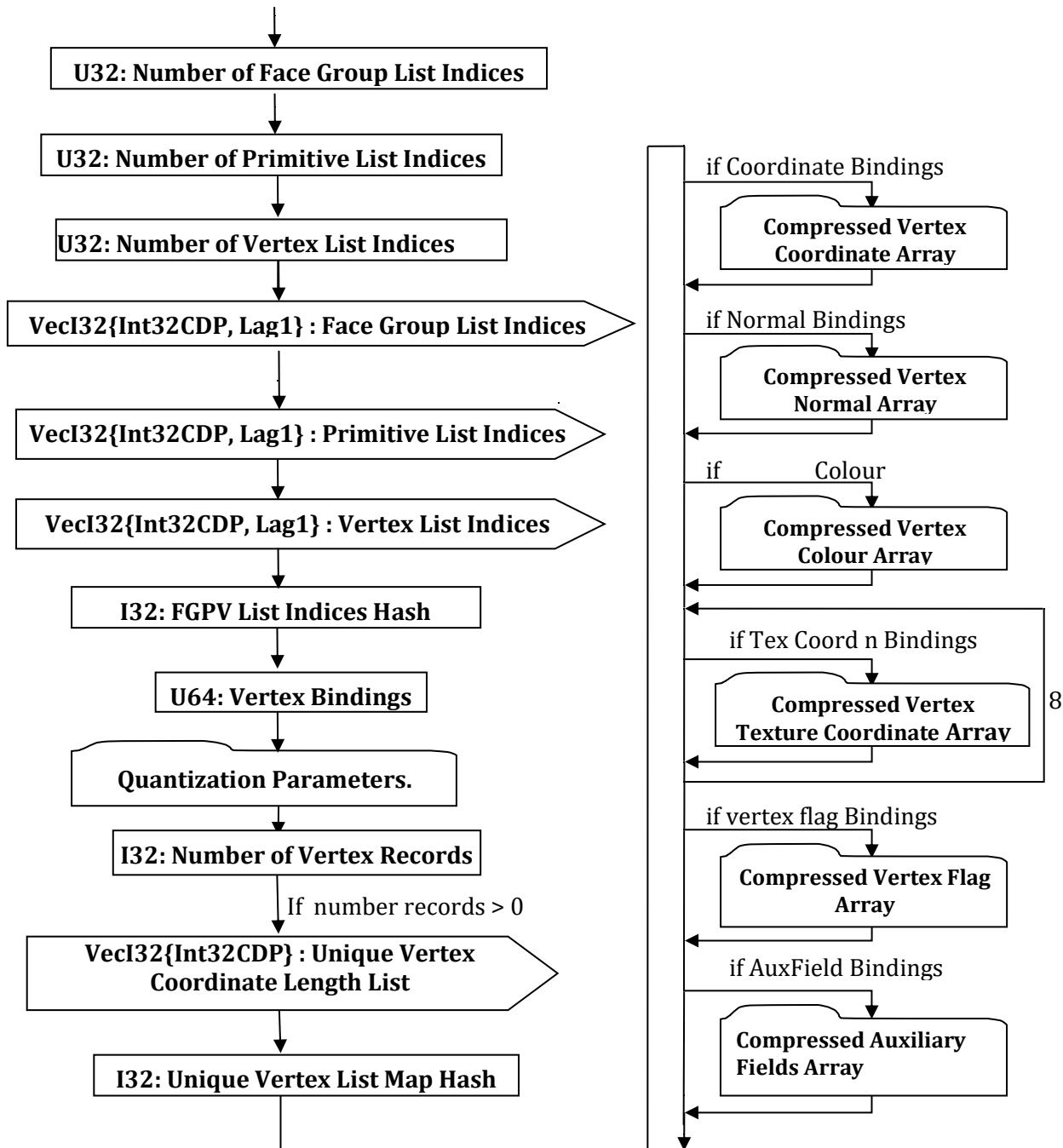


Figure 89 — TopoMesh Compressed Rep Data data collection

Complete description for Compressed Vertex Coordinate Array, Compressed Vertex Normal Array, Compressed Vertex Colour Array, Compressed Vertex Texture Coordinate Array, Compressed Vertex Flag Array and Compressed Vertex Auxiliary Fields Array can be found in Data Compression and Encoding.

U32: Number of Face Group List Indices

Number of Face Group List Indices.

U32: Number of Primitive List Indices

Number of Primitive List Indices.

U32: Number of Vertex List Indices

Number of Vertex List Indices.

VecI32{Int32CDP, Lag1} : Face Group List Indices

Face Group List Indices is a vector of indices into the uncompressed Raw Primitive Data marking the start/beginning of Faces. Face Group List Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1} : Primitive List Indices

Primitive List Indices is a vector of indices into the uncompressed Raw Vertex Data marking the start/beginning of primitives. Primitive List Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1} : Vertex List Indices

Vertex List Indices is a vector of indices (one per vertex) into the uncompressed/dequantized unique vertex data arrays (Vertex Coords, Vertex Normals, Vertex Texture Coords, Vertex Colours) identifying each Vertex's data (therefore for each Vertex there is an index identifying the location within the unique arrays of the particular Vertex's data). The Compressed Vertex Index List uses the Int32 version of the CODEC to compress and encode data.

I32: FGPV List Indices Hash

The FGPV Hash is the combined hash value of the Face Group List Indices (if Polyline), Primitive List Indices, and Vertex List Indices. Refer to section Annex C for a more detailed description on hashing.

```
UInt32 uHash      = 0;
UInt32 nFGIdx     = 0,
      nPrimIdx    = 0,
      nVtxIdx     = 0;
vecI32 vFGIndices, vPrimIndices, vVertexIndices;
...
uHash = hash32( (UInt32*)& vFGIndices, nFGIdx+1, uHash );
uHash = hash32( (UInt32*)& vPrimIndices, nPrimIdx+1, uHash );
uHash = hash32( (UInt32*)& vVertexIndices, nVtxIdx , uHash );
```

U64: Vertex Bindings

Vertex Bindings is a collection of normal, texture coordinate, and colour binding information encoded within a single U64. All bits fields that are not defined as in use should be set to "0". For more information see Vertex Shape LOD Data U64 : Vertex Bindings.

I32: Number of Vertex Records

Number of vertex records.

VecI32{Int32CDP} : Unique Vertex Coordinate Length List

The Unique Vertex Length List contains the number of vertex records containing each of the unique vertex coordinates and should sum to the number of vertex records. When read in the Compressed Vertex Coordinate Array only contains a single value for each unique vertex coordinate value and is therefore parallel to the Unique Vertex Length List. In order to expand its coordinates into the vertex record space it unique coordinate value will need to be smeared out such that each unique vertex coordinate is repeated the number of times specified in the Unique Vertex Length List. The Compressed Vertex Normal, Colour, Texture, and Flag Arrays do not require the same expansion.

I32: Unique Vertex List Map Hash

The Unique Vertex List Map Hash is the hash value of Unique Vertex Coordinate Length List. Refer to section Annex C for a more detailed description on hashing.

```

UInt32 uHash      = 0;
UInt32 nUniqVtx  = 0;
vecF32 vUniqVtxIndices;
...
uHash = hash32( (UInt32*)(&vUniqVtxIndices), nUniqVtx, uHash );

```

Quantization Parameters

Quantization Parameters, as shown in Figure 90, specifies for each shape data type grouping (therefore Vertex, Normal, Texture Coordinates, Colour) the number of quantization bits used for given qualitative compression level. Although these Quantization Parameters values are saved in the associated/referenced Shape LOD Element, they are also saved here so that a JT File loader/reader does not have to load the Shape LOD Element in order to determine the Shape quantization level. See Shape LOD Element for complete description of Shape LOD Elements.

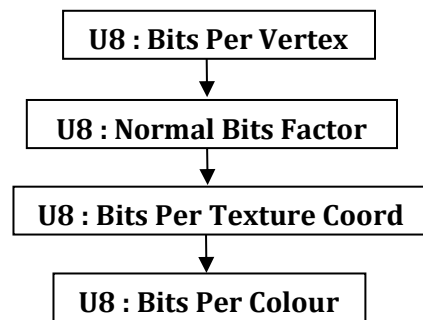


Figure 90 — Quantization Parameters data collection

U8 : Bits Per Vertex

Bits Per Vertex specifies the number of quantization bits per vertex coordinate component. Value shall be within range [0:24] inclusive.

U8 : Normal Bits Factor

Normal Bits Factor is a parameter used to calculate the number of quantization bits for normal vectors. Value shall be within range [0:13] inclusive. The actual number of quantization bits per normal is computed using this factor and the following formula: “BitsPerNormal = 6 + 2 * Normal Bits Factor”.

U8 : Bits Per Texture Coord

Bits Per Texture Coord specifies the number of quantization bits per texture coordinate component. Value shall be within range [0:24] inclusive.

U8 : Bits Per Colour

Bits Per Colour specifies the number of quantization bits per colour component. Value shall be within range [0:24] inclusive.

TopoMesh Topologically Compressed LOD Data

TopoMesh Topologically Compressed LOD Data collection, as shown in Figure 91, contains the common items to all TopoMesh Topologically Compressed LOD data elements such as Tri-Strip Set Shape LOD Element.

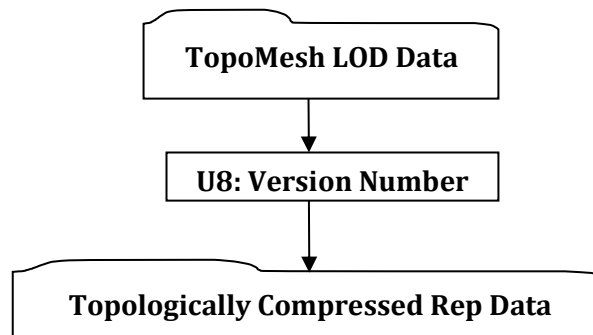


Figure 91 — TopoMesh Topologically Compressed LOD Data collection

Complete description for TopoMesh LOD Data and Topologically Compressed Rep Data can be found in TopoMesh LOD Data and Topologically Compressed Rep Data.

U8: Version Number

Version Number is the version identifier for this TopoMesh Topologically Compressed LOD Data. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

Topologically Compressed Rep Data

This JT specification represents triangle strip data very differently than it does in the JT v8 format. The scheme stores the triangles from a TriStripSet or polygons from a PolygonSet as a topologically-connected mesh. Even though *more* information is stored to the JT file, the additional structure provided by storing the full topological adjacency information actually provides a handsome reduction in the number of bytes needed to encode the triangles or polygons. More importantly, however, the topological information aids us in a more significant respect -- that of only storing the *unique* vertex records used by the TriStripSet or PolygonSet. Combined, these two effects reduce the typical storage footprint of TriStripSet data by approximately half relative to the JT v8 format.

The tristrip information itself is not stored in the JT file -- only the triangles themselves. The reader is expected to re-tristrip (or not) as she sees fit, as tristrips may no longer provide a performance advantage during rendering. There may, however, remain some memory savings for tristripping, and so the decision to tristrip is left to the user.

To begin the decoding process, first read the compressed data fields shown in Figure 91. These fields provide all the information necessary to reconstruct the per face-group organized sets of triangles. The first 22 fields represent the topological information, and the remaining fields constitute the set of unique vertex records to be used. The next step is to run the topological decoder algorithm detailed in provided in the annex on this data to reconstruct the topologically connected representation of the triangle mesh in a so-called "Dual VFMesh." The triangles or polygons in this heavy-weight data structure can then be exported to a lighter-weight form, and the dual VFMesh discarded if desired.

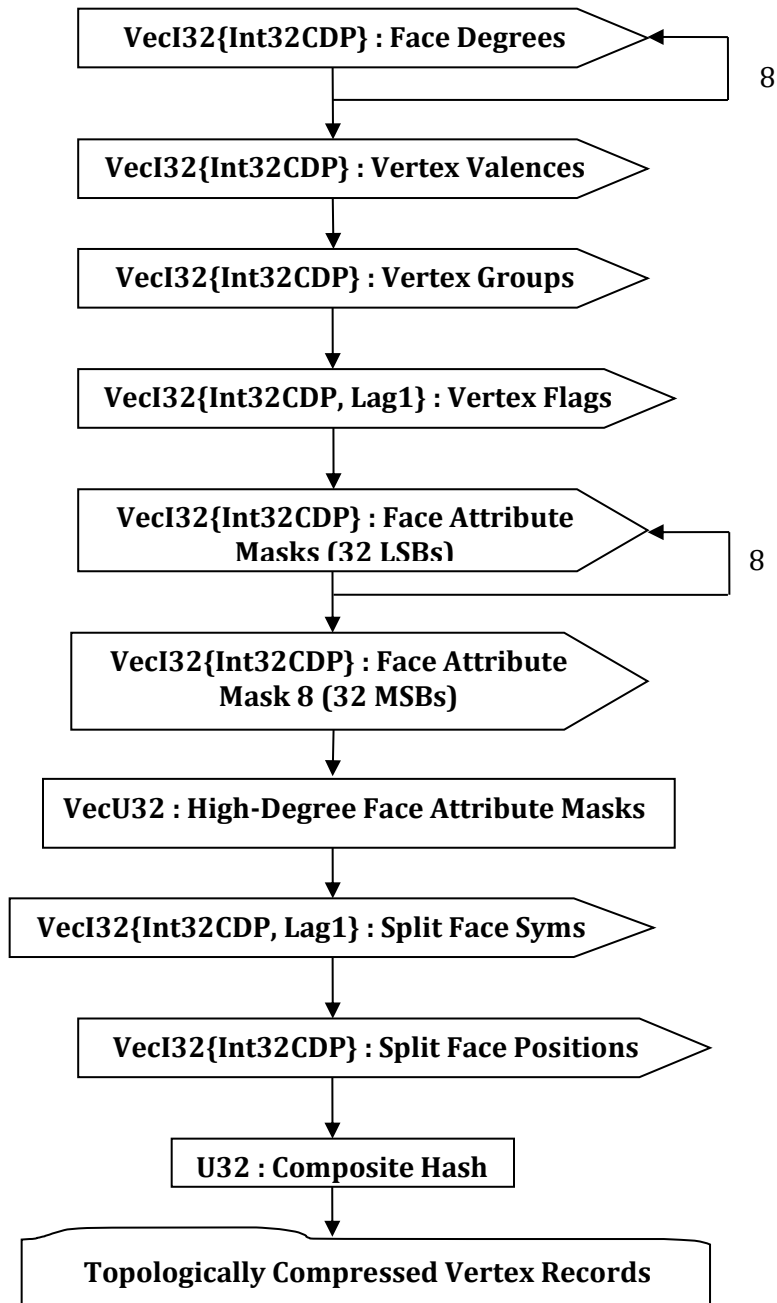


Figure 92 — Topologically Compressed Rep Data Collection

The Topologically Compressed Rep Data Collection structure is diagrammatically represented in Figure 92.

VecI32{Int32CDP} : Face Degrees

Similarly, to the way valences are encoded, the topology encoder emits the *degree* (number of incident vertices) of each face in the order they were visited. The number of face degrees in this array is equal to the number of faces in the mesh.

VecI32{Int32CDP} : Vertex Valences

As the coder visits each vertex in the mesh, it emits the valence (number of incident faces) of each vertex. These valences are collected in the order they were visited into this array. The number of valences in this array is equal to the number of (topological) vertices in the mesh.

VecI32{Int32CDP} : Vertex Groups

This array is parallel to the Vertex Valences array above. As the coder emits the valence of each vertex, it also emits the face group number to which the dual vertex belongs into this array.

VecI32{Int32CDP, Lag1} : Vertex Flags

This array is also parallel to the Vertex Valences array, and contains a value of 0 when the dual face was present in the original triangle mesh, and a value of 1 if the dual face is a *cover face* that was added to artificially close the original mesh.

VecI32{Int32CDP} : Face Attribute Masks (32 LSBs)

This field is written 8 times – once for each of the 8 context groups listed above – and encodes the face attribute bit vector associated with a single face.

VecI32{Int32CDP} : Face Attribute Mask 8 (32 MSBs)

This field encodes the 32 most significant bits of the 8th context group of face attribute bit vectors.

VecU32 : High-Degree Face Attribute Masks

This field encodes all remaining face attribute bit vectors, adjoined end-to-end, and encoded as a single array of unsigned integers.

VecI32{Int32CDP, Lag1} : Split Face Syms

Encodes the list of “split face” ID numbers in the order the coder encountered them.

VecI32{Int32CDP} : Split Face Positions

Encodes the list of “split face” positions in the active vertex queue in the order the code encountered them.

U32 : Composite Hash

This field is a hash value computed on all of the above data using the hash function described in Annex C. It is written into the JT file so that a reader can perform the same hash on the above data and compare against this value in order to guarantee that it has read and decoded correct data from the JT file. It is *highly* encouraged that all readers perform this check, as even a single bit error in the topology information above can have catastrophic consequences on the topology decoder and the resulting mesh. Any writers are *required* to write this field using the method provided so that other readers may validate the data they read.

```

UInt32 uHash          = 0;
UInt32 anDegSyms[8]   = {0},
      nValSyms = 0,
      nVGrpSyms = 0,
      nVtxFlags = 0,
      anAttrMasks[8] = {0},
      nLrgAttrMasks = 0,
      nSplitVtxSyms = 0,
      nSplitVtxPos = 0;
VecI32 vFaceDegreeSymbols[8], vviValenceSymbols, vFaceGroupSyms,
      vvuAttrMasks[8], viSplitVtxSyms, viSplitVtxPos;
VecI16 vFaceFlags;
VecU32 vuTmp, vuAttrMasksLrg;
...
for (i=0 ; i<8 ;i++)
    uHash = hash32((UInt32*) vFaceDegreeSymbols[i].ptr(), anDegSyms[i], uHash );
uHash = hash32((UInt32*) vviValenceSymbols.ptr(), nValSyms, uHash );
uHash = hash32((UInt32*)vVtxGroupSyms.ptr(), nVGrpSyms, uHash );
uHash = hash16((UInt16*)vVtxFlags.ptr(), nFlags, uHash );
for (i=0 ; i<7 ;i++)
    uHash = hash32((UInt32*)vvuAttrMasks[i].ptr(), anAttrMasks[i], uHash );
vuTmp = vvuAttrMasks[7] & 0xffffffff; // Lower 32 bits of each element

```

```

uHash = hash32(vuTmp.ptr(), anAttrMasks[7], uHash );
vuTmp = (vvuAttrMasks[7] >> 32) & 0xffffffff; // Next 32 bits of each element
uHash = hash32(vuTmp.ptr(), anAttrMasks[7], uHash );
uHash = hash32(vuAttrMasksLrg.ptr(), nLrgAttrMasks, uHash );
uHash = hash32((UInt32*)viSplitVtxSyms.ptr(), nSplitVtxSyms, uHash );
uHash = hash32((UInt32*)viSplitVtxPos.ptr(), nSplitVtxPos, uHash );

```

Topologically Compressed Vertex Records

Documented here, as shown in Figure 93, is the format of the vertex data written by the topological encoder found in the annex. Some additional explanation is necessary, however, because only the *unique* vertex coordinates are written to the JT file, while the remaining vertex attributes (normals, colours, texture coordinates, vertex flags) may not be unique.

Vertex coordinates are written to the file in the order that they were visited by the topology encoder. Note that this means that the number of vertex coordinates written is equal to the number of topological vertices in the mesh (therefore all vertex coordinates are unique).

By contrast one set of vertex attribute records is written to the file corresponding to each 1 bit across all encoded dual Face Attribute Masks. The vertex attribute records are written in the order that the topology encoder visited them. The reader shall then use the topology decoder's output to correctly associate each vertex attribute record to the correct vertex coordinate using the dual Face Attribute Masks.

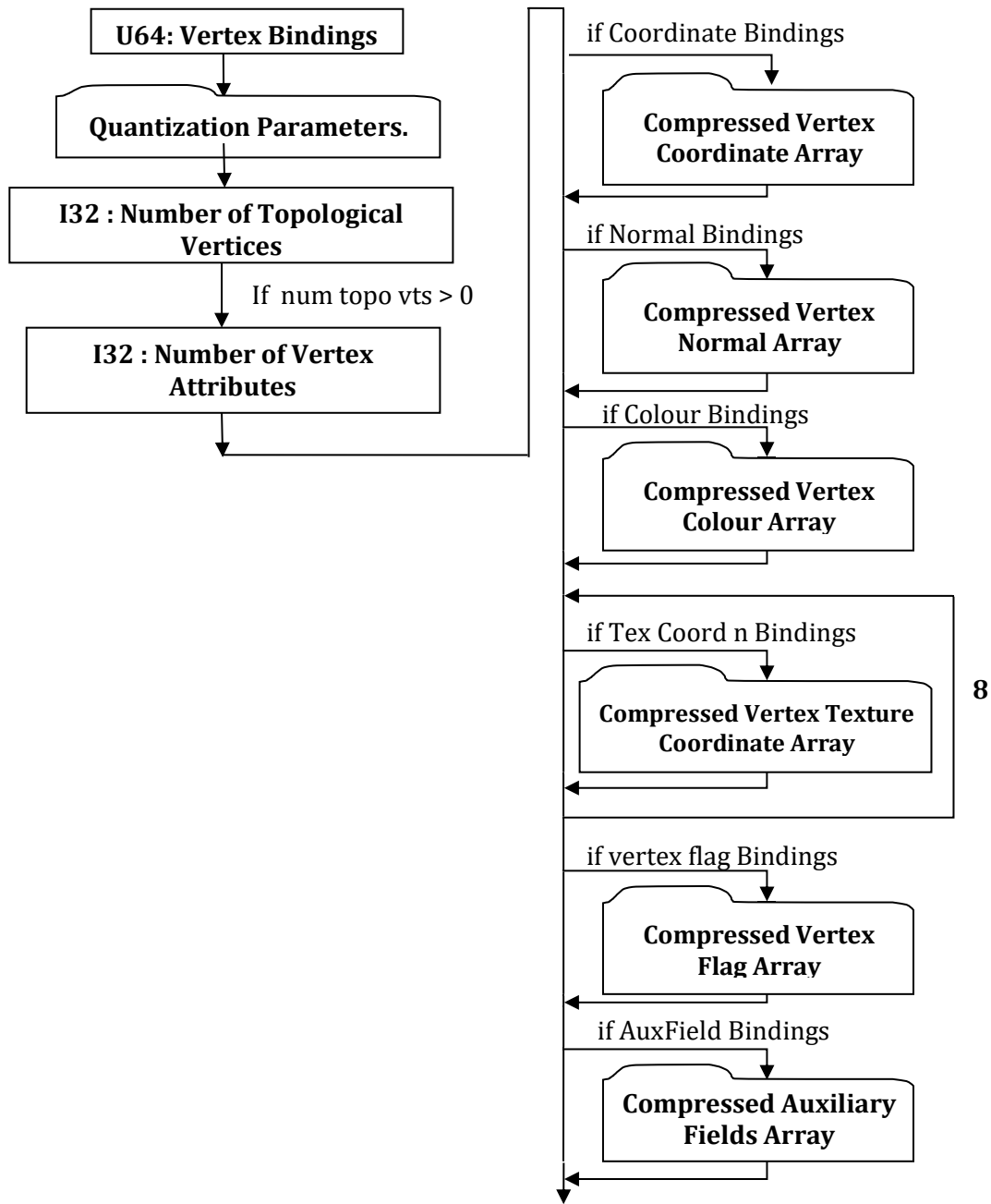


Figure 93 — Topologically Compressed Vertex Records data collection

Complete description for Compressed Vertex Coordinate Array, Compressed Vertex Normal Array, Compressed Vertex Colour Array, Compressed Vertex Texture Coordinate Array, Compressed Vertex Flag Array and Compressed Vertex Auxiliary Fields Array can be found in Data Compression and Encoding.

U64: Vertex Bindings

Vertex Bindings is a collection of normal, texture coordinate, and colour binding information encoded within a single U64. All bit fields that are not defined as in use should be set to “0”. For more information see Vertex Shape LOD Data U64 : Vertex Bindings.

I32 : Number of Topological Vertices

This field is the number of topological vertices encoded by the topology encoder. This is the number of unique vertex coordinates that will be written in the later Compressed Vertex Coordinate Array field.

I32 : Number of Vertex Attributes

One set of vertex attribute records is written to the file corresponding to each 1 bit across all encoded dual Face Attribute Masks. The vertex attribute records are written in the order that the topology encoder visited them. The reader shall then use the topology decoder's output to correctly associate each vertex attribute record to the correct vertex coordinate using the dual Face Attribute Masks.

6.1.5 Null Shape LOD Element

Object Type ID: 0x3e637aed, 0x2a89, 0x41f8, 0xa9, 0xfd, 0x55, 0x37, 0x37, 0x3, 0x96, 0x82

A Null Shape LOD Element, as shown in Figure 94, represents the pseudo geometric shape definition data for a NULL Shape Node Element. Although a NULL Shape Node Element has no real geometric primitive representation (therefore is empty), its usage as a “proxy/placeholder” node within the LSG still supports the concept of having a defined bounding box and thus the existence of this Null Shape LOD Element type.

A Null Shape LOD Element is typically referenced by a NULL Shape Node Element using Late Loaded Property Atom Elements (see NULL Shape Node Element and Late Loaded Property Atom Element respectively).

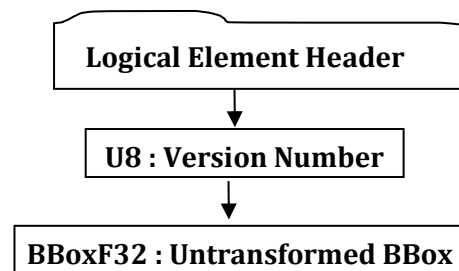


Figure 94 — Null Shape LOD Element data collection

Complete description for Logical Element Header can be found in Logical Element Header.

U8 : Version Number

Version Number is the version identifier for this Null Shape LOD Element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

BBoxF32 : Untransformed BBox

The Untransformed BBox is an axis-aligned LCS bounding box and represents the untransformed extents for this Null Shape LOD Element.

6.1.6 Primitive Set Shape Element

Object Type ID: 0xe40373c2, 0x1ad9, 0x11d3, 0x9d, 0xaf, 0x0, 0xa0, 0xc9, 0xc7, 0xdd, 0xc2

A Primitive Set Shape Element, as shown in Figure 95, defines the minimum data necessary to procedurally generate LODs for a list of primitive shapes (for example box, cylinder, sphere, etc.). “Procedurally generate” means that the raw geometric shape definition data (for example vertices, polygons, normals, etc.) for LODs is not directly stored; instead some basic shape information is stored (for example sphere centre and radius) from which LODs can be generated.

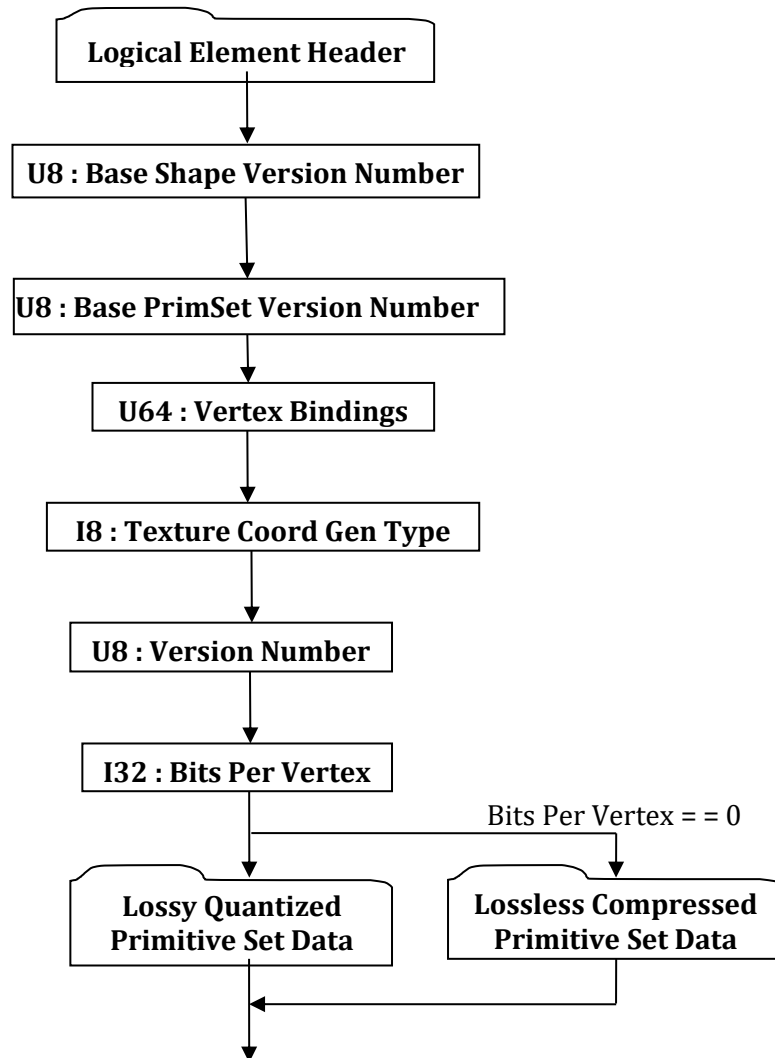


Figure 95 — Primitive Set Shape Element data collection

Complete description for Logical Element Header can be found in Logical Element Header.

U8 : Base Shape Version Number

Base Shape Version Number is the version identifier for the 2-level base class of this element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U8 : Base PrimSet Version Number

Base PrimSet Version Number is the version identifier for the immediate base class of element. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

U64 : Vertex Bindings

Vertex Bindings is a collection of normal, texture coordinate, and colour binding information encoded within a single U64. All bits fields that are not defined as in use should be set to “0”. For more information see Vertex Shape LOD Data U64 : Vertex Bindings.

U8 : Version Number

Version Number, as shown in Table 45, is the version identifier for this element. The value of this Version Number indicates the format of data fields to follow.

Table 45 — Primitive Set Shape Version Number values

| | |
|-----|------------------|
| = 1 | Version-1 Format |
|-----|------------------|

I32 : Bits Per Vertex

Bits Per Vertex specifies the number of quantization bits per vertex coordinate component. Value shall be within range [0:32] inclusive.

I8 : Texture Coord Gen Type

Texture Coord Gen Type, as shown in Table 46, specifies how a texture is applied to each face of the primitive. Single tile means one copy of the texture will be stretched to fit the face, isotropic means that the texture will be duplicated on the longer dimension of the face in order to maintain the texture’s aspect ratio.

Table 46 — Primitive Set Shape Texture Coord Gen Type values

| | |
|-----|---|
| = 0 | Single Tile...Indicates that a single copy of a texture image will be applied to significant primitive features (therefore cube face, cylinder wall, end cap) no matter how eccentrically shaped. |
| = 1 | Isotropic...Implies that multiple copies of a texture image may be mapped onto eccentric surfaces such that a mapped texel stays approximately square. |

Lossless Compressed Primitive Set Data

The Lossless Compressed Primitive Set Data collection, as shown in Figure 96, contains all the per-primitive information stored in a “lossless” compression format for all primitives in the Primitive Set. The Lossless Compressed Primitive Set Data collection is only present when the Bits Per Vertex data field equals “0” (see Primitive Set Shape Element for complete description).

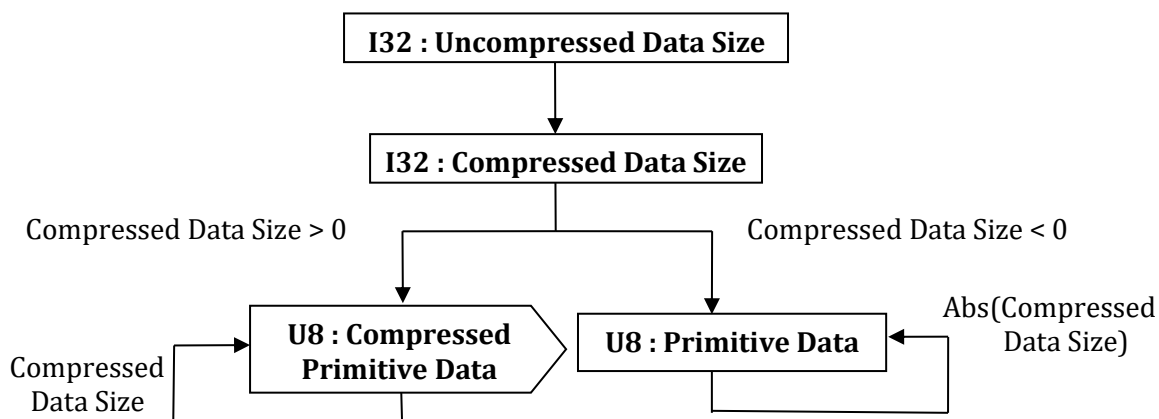


Figure 96 — Lossless Compressed Primitive Set Data collection

I32 : Uncompressed Data Size

Uncompressed Data size specifies the uncompressed size of Primitive Data or Compressed Primitive Data in bytes.

I32 : Compressed Data Size

Compressed Data Size specifies the compressed size of Primitive Data or Compressed Primitive Data in bytes. If the Compressed Data Size is negative, then the Compressed Primitive Data field is not present (therefore data is not compressed) and the absolute value of Compressed Data Size should be equal to Uncompressed Data Size value.

U8 : Primitive Data

The Primitive Data field is a packed array of the raw per primitive data (therefore reserved, params1, params2, params3, colour, type) sequentially for all primitives in the set. The Primitive Data field is only present if Compressed Data Size value is less than zero. The per primitive data is packed into Primitive Data array using an interleaved data schema/format as follows:

{[reserved], [params1], [params2], [params3], [colour], [type]}, ..., **for all primitives**

Where the data elements have the following size and meaning, as shown in Table 47:

Table 47 — Lossless Compressed Primitive Set Data Field values

| Element | Data Type | Description |
|----------|------------|---|
| reserved | I32 | This is a field reserved for future expansion of the JT Format. |
| params1 | CoordF32 | Interpretation is Primitive Type specific (see below table) |
| params2 | DirF32 | Interpretation is Primitive Type specific (see below table) |
| params3 | Quaternion | Interpretation is Primitive Type specific (see below table) |
| Colour | RGB | Red, Green, Blue colour component values |
| Type | I32 | Primitive Type = 0 – Box = 1 – Cylinder = 2 – Pyramid = 3 – Sphere = 4 – Tri-Prism |

Given this format of the Primitive Data, and the previously read size fields, a reader can then implicitly compute the data stride (length of one primitive entry in Primitive Data), and number of primitives.

The interpretation of the three “params#” data fields is primitive type dependent as shown in Table 48:

Table 48 — Primitive Set “params#” Data Fields Interpretation

| Primitive Type | params1 | | | params2 | | | params3 | | | |
|----------------|----------------|----------------|----------------|---------------------|--------------------|-------------------|--------------------------------|----------|-------|-------|
| | [0] | [1] | [2] | [0] | [1] | [2] | [0] | [1] | [2] | [3] |
| Box | min X | min Y | min Z | length X | length Y | length Z | orientation in Quaternion form | | | |
| Cylinder | base centre X | base centre Y | base centre Z | spine X | spine Y | spine Z | radius 1 | radius 2 | N / A | N / A |
| Pyramid | base centre X | base centre Y | base centre Z | length X | length Y | length Z | orientation in Quaternion form | | | |
| Sphere | centre X | centre Y | centre Z | radius | N/A | N/A | N/A | N/A | N / A | N / A |
| Tri-Prism | bottom front X | bottom front Y | bottom front Z | length X (to right) | length Y (to back) | length Z (to top) | orientation in Quaternion form | | | |

U8 : Compressed Primitive Data

The Compressed Primitive Data field represents the same data as documented in Primitive Data field above except that the data is compressed using the general “LZMA” method. The Compressed Primitive Data field is only present if Compressed Data Size value is greater than zero. See Data Compression and Encoding for more details on LZMA compression and LZMA library version used.

Lossy Quantized Primitive Set Data

The Lossy Quantized Primitive Set Data collection, as shown in Figure 97, contains all the per-primitive information (therefore reserved, params1, params2, params3, colour, type) stored in a “lossy” encoding/compression format for all primitives in the Primitive Set. The Lossy Quantized Primitive Set Data collection is only present when the Bits Per Vertex data field is NOT equal to “0” (See Primitive Set Shape Element for complete description).

The interpretation of the three per-primitive “params#” data fields is primitive type dependent. See Table 48 — Primitive Set “params#” Data Fields Interpretation in Lossless Compressed Primitive Set Data for per-primitive type description of the “params#” data fields.

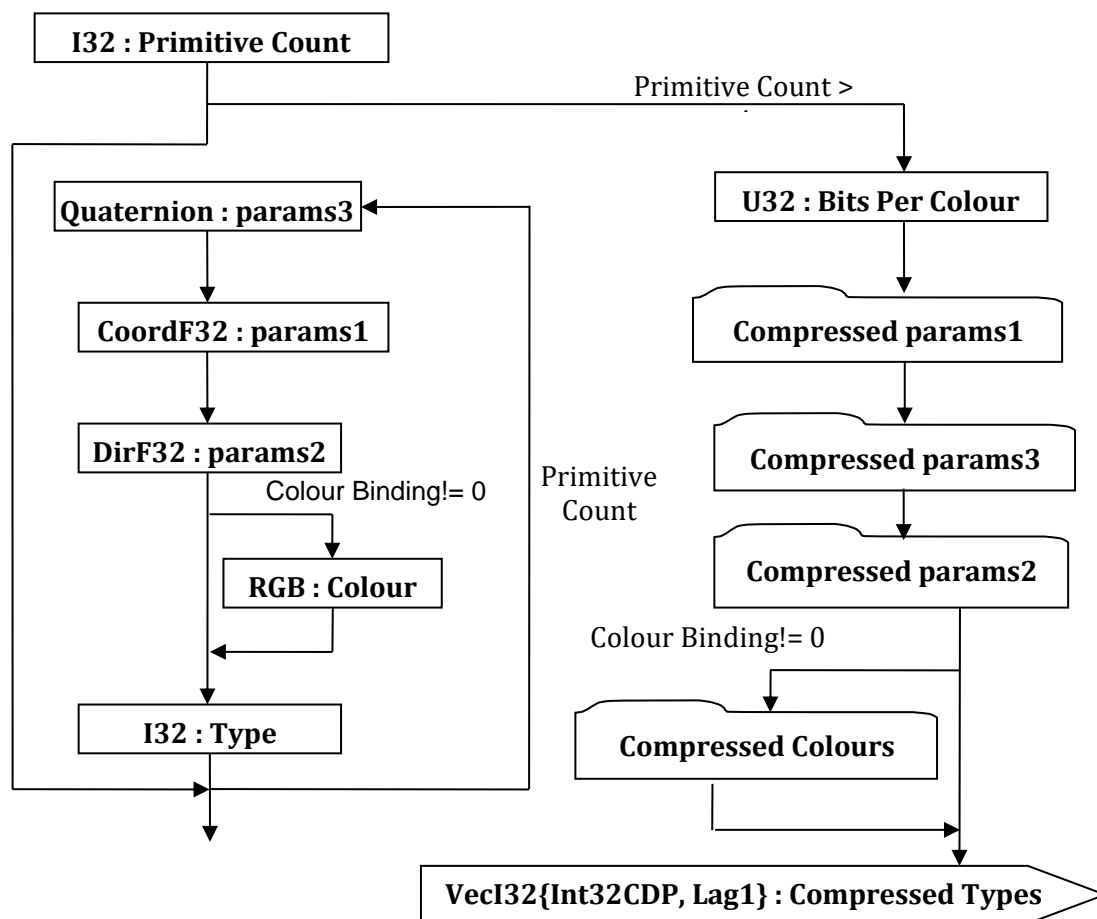


Figure 97 — Lossy Quantized Primitive Set Data collection

I32 : Primitive Count

Primitive Count specifies the number of primitives in the Primitive Set.

Quaternion : params3

Interpretation of params3 data field is primitive Type dependent. See Table for Primitive Set “params#” Data Fields Interpretation in Lossless Compressed Primitive Set Data for per-primitive type description of the params3 data fields.

CoordF32 : params1

Interpretation of params1 data field is primitive Type dependent. See Table for Primitive Set “params#” Data Fields Interpretation in Lossless Compressed Primitive Set Data for per-primitive type description of the params1 data fields.

DirF32 : params2

Interpretation of params1 data field is primitive Type dependent. See Table for Primitive Set “params#” Data Fields Interpretation in Lossless Compressed Primitive Set Data for per-primitive type description of the params1 data fields.

RGB : Colour

Colour specifies the Red, Green Blue colour components for the primitive. This data field is only present if previously read Colour Binding (see Primitive Set Shape Element) is not equal to “0”.

I32 : Type

Type specifies the primitive type. See Table for Lossless Compressed Primitive Set Data Field values in Lossless Compressed Primitive Set Data for valid primitive Type values.

U32 : Bits Per Colour

Bits Per Colour specifies the number of quantization bits per colour component. Value shall be within range [0:32] inclusive.

VecI32{Int32CDP, Lag1} : Compressed Types

The Compressed Types data field is a vector of Type data for all the primitives in the Primitive Set. Compressed Types uses the Int32 version of the CODEC to compress and encode data. In an uncompressed form the valid primitive Type values are as documented in Table for Lossless Compressed Primitive Set Data Field values in Lossless Compressed Primitive Set Data.

Compressed params1

Compressed params1, shown in Figure 98, is the compressed representation of the *params1* data for all the primitives in the Primitive Set. Note that the interpretation of the uncompressed *params1* data is primitive Type dependent. See Table for Primitive Set “params#” Data Fields Interpretation in Lossless Compressed Primitive Set Data for per-primitive type description of the *params1* data fields.

The *params1* data for all primitives in the Primitive Set is compressed/encoded on a per ordinate basis using a separate Uniform Quantizer (with Bits Per Vertex number of quantization bits) for each collection of ordinate values. Since *params1* is of type “CoordF32”, it has three ordinate values (three F32 values), and thus three Uniform Quantizers (where a Uniform Quantizer is a scalar quantizer/encoder whose range is divided into levels of equal spacing). See Data Compression and Encoding for more complete description of Uniform Quantizer.

The JT Format packs all the *params1* data for all primitives into a single array using an ordinate dependent order (as shown below) and then encodes each of the lists of ordinate values using a separate Uniform Quantizer per ordinate list.

```
{prim1 params1[0], prim2 params1[0],...primN params1[0],  
 prim1 params1[1], prim2 params1[1],...primN params1[1],  
 prim1 params1[2], prim2 params1[2],...primN params1[2]}
```

The result of the Uniform Quantizer encoding is a range min and max floating point value pairs for each ordinate value collection, and an integer array of *params1* quantization codes that corresponds to the above described “ordinate dependent order” packed array of *params1* data.

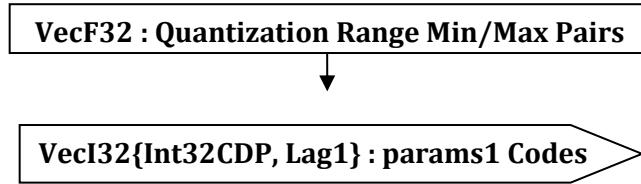


Figure 98 — Compressed params1 data collection

VecF32 : Quantization Range Min/Max Pairs

Quantization Range Min/Max Pairs is a vector of Uniform Quantizer range min/max value pairs. There shall be a min/max pair for each ordinate value collection (therefore each Uniform Quantizer). Thus the length of this vector is “2 * num_ordinates” (so vector length would be “6” for *params1* data).

VecI32{Int32CDP, Lag1} : params1 Codes

The params1 Codes data field is a vector of quantizer “codes” for the *params1* data of all the primitives in the Primitive Set. The params1Codes also uses the Int32 version of the CODEC to compress and encode data.

Compressed params3

Compressed params3 is the compressed representation of the *params3* data for all the primitives in the Primitive Set. Note that the interpretation of the uncompressed *param31* data is primitive Type dependent. See Table 48 — Primitive Set “params#” Data Fields Interpretation in Lossless Compressed Primitive Set Data for per-primitive type description of the *params3* data fields.

The *params3* data for all primitives in the Primitive Set is compressed/encoded on a per ordinate basis using a separate Uniform Quantizer (with Bits Per Vertex number of quantization bits) for each collection of ordinate values. Since *params1* is of type “Quaternion”, it has four ordinate values (four F32 values), and thus four Uniform Quantizers (where a Uniform Quantizer is a scalar quantizer/encoder whose range is divided into levels of equal spacing). See Data Compression and Encoding for more complete description of Uniform Quantizer.

The JT Format packs all the *params3* data for all primitives into a single array using an ordinate dependent order (as shown below) and then encodes each of the lists of ordinate values using a separate Uniform Quantizer per ordinate list.

```

{prim1 params3[0], prim2 params3[0],...primN params3[0],
 prim1 params3[1], prim2 params3[1],...primN params3[1],
 prim1 params3[2], prim2 params3[2],...primN params3[2],
 prim1 params3[3], prim2 params3[3],...primN params3[3]}
  
```

The result of the Uniform Quantizer encoding is a range min and max floating point value pairs for each ordinate value collection, and an integer array of *params3* quantization codes that corresponds to the above described “ordinate dependent order” packed array of *params3* data.

The storage format of Compressed params3 is exactly the same as that documented in Figure 98 for Compressed params1 data collection.

Compressed params2

Compressed params2 is the compressed representation of the *params2* data for all the primitives in the Primitive Set. Note that the interpretation of the uncompressed *params2* data is primitive Type dependent. See Table for Primitive Set “params#” Data Fields Interpretation in Lossless Compressed Primitive Set Data for per-primitive type description of the *params2* data fields.

The *params2* data for all primitives in the Primitive Set is compressed/encoded on a per ordinate basis using a separate Uniform Quantizer (with Bits Per Vertex number of quantization bits) for each collection of ordinate values. Since *params2* is of type “DirF32”, it has three ordinate values (three F32 values), and thus three Uniform Quantizers (where a Uniform Quantizer is a scalar quantizer/encoder whose range is divided into levels of equal spacing). See Data Compression and Encoding for more complete description of Uniform Quantizer.

The JT Format packs all the *params2* data for all primitives into a single array using an ordinate dependent order (as shown below) and then encodes each of the lists of ordinate values using a separate Uniform Quantizer per ordinate list.

```
{prim1 params2[0], prim2 params2[0],...primN params2[0],
 prim1 params2[1], prim2 params2[1],...primN params2[1],
 prim1 params2[2], prim2 params2[2],...primN params2[2]}
```

The result of the Uniform Quantizer encoding is a range min and max floating point value pairs for each ordinate value collection, and an integer array of *params2* quantization codes that corresponds to the above described “ordinate dependent order” packed array of *params2* data.

The storage format of Compressed *params2* is exactly the same as that documented in Figure 98 for Compressed *params1* data collection.

Compressed Colours

Compressed Colours is the compressed representation of the *colour* data for all the primitives in the Primitive Set. This data collection is only present if previously read Colour Binding (see Primitive Set Shape Element) is not equal to “0”.

The *colour* data for all primitives in the Primitive Set is compressed/encoded on a per ordinate basis using a separate Uniform Quantizer (with Bits Per Colour number of quantization bits) for each collection of ordinate values. Since *colour* is of type “RGB”, it has three ordinate values (three F32 values), and thus three Uniform Quantizers (where a Uniform Quantizer is a scalar quantizer/encoder whose range is divided into levels of equal spacing). See Data Compression and Encoding for more complete description of Uniform Quantizer.

The JT Format packs all the *colour* data for all primitives into a single array using an ordinate dependent order (as shown below) and then encodes each of the lists of ordinate values using a separate Uniform Quantizer per ordinate list.

```
{prim1 colour[0], prim2 colour[0],...primN colour[0],
 prim1 colour[1], prim2 colour[1],...primN colour[1],
 prim1 colour[2], prim2 colour[2],...primN colour[2]}
```

The result of the Uniform Quantizer encoding is a range min and max floating point value pairs for each ordinate value collection, and an integer array of *colour* quantization codes that corresponds to the above described “ordinate dependent order” packed array of *colour* data.

The storage format of Compressed Colours is exactly the same as that documented in Figure 98 for Compressed *params1* data collection.

7 Geometry Segments

7.1 Geometry Segments Overview

The Geometry Segments in JT contain Element that define a range of geometry definitions that can be included with a JT file. Complete descriptions for each geometry segment can be found in the Geometry Annexes.

7.2 XT B-Rep Element

XT B-Rep Segment contains an Element that defines the precise geometric Boundary Representation data for a particular Part in XT boundary representation format.

XT B-Rep Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element).

The XT B-Rep Segment type supports LZMA compression on all element data, so all elements in XT B-Rep Segment use the Logical Element Header LZMA form of element header data.

Object Type ID: 0x873a70e0, 0x2ac9, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

See Annex F XT B-rep Segment for a full description of the XT B-Rep Segment.

7.3 JT ULP Segment

The JT ULP Segment contains an Element that defines the lightweight geometric Boundary Representation data for a particular Part in the JT ULP format.

JT ULP Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The JT ULP Segment type supports compression on all element data, so all elements in JT ULP Segment use the Logical Element Header Compressed form of element header data.

Object Type ID: 0xf338a4af, 0xd7d2, 0x41c5, 0xbc, 0xf2, 0xc5, 0x5a, 0x88, 0xb2, 0x1e, 0x73

See Annex G JT ULP Segment for a full description of the legacy ULP segment.

7.4 JT LWPA Segment

JT LWPA Segment contains an Element that defines light weight precise analytic data for a particular part. More specifically LWPA contains the collection of analytic surfaces in the B-Rep definition of the part.

JT LWPA Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The JT LWPA Segment type supports LZMA compression on all element data, so all elements in JT LWPA Segment use the Logical Element Header Compressed form of element header data.

Object Type ID: 0xd67f8ea8, 0xf524, 0x4879, 0x92, 0x8c, 0x4c, 0x3a, 0x56, 0x1f, 0xb9, 0x3a

See Annex I JT LWPA Segment for a full description of the JT LWPA Segment.

7.5 Wireframe Segment

The Wireframe Segment contains an Element that defines the precise 3D wireframe data for a particular Part.

A Wireframe Segment is typically referenced by a Part Node Element using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The Wireframe Segment type supports LZMA compression on all element data, so all elements in Wireframe Segment use the Logical Element Header Compressed form of element header data.

Object Type ID: 0x873a70d0, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

See Annex J Wireframe Segment for a full description of the JT Wireframe Segment.

7.6 JT B-Rep Element (deprecated)

JT B-Rep Element represents a particular Part's precise data in JT boundary representation format.

JT B-Rep Segments are typically referenced by Part Node Elements using Late Loaded Property Atom Elements.

The JT B-Rep Segment type supports LZMA compression on all element data, so all elements in JT B-Rep Segment use the Logical Element Header LZMA form of element header data.

Object Type ID: 0x873a70c0, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

See Annex K JT B-rep Segment for a full description of the JT B-Rep Segment.

NOTE: JT B-Rep is deprecated and should be considered read only for application creation.

8 Meta Data Segment

8.1 Meta Data Segment Overview

Meta Data Segments, shown in Figure 99, are used to store large collections of meta-data in separate addressable segments of the JT File. Storing meta-data in a separate addressable segment allows references (from within the JT file) to these segments to be constructed such that the meta-data can be late-loaded (therefore JT file reader can be structured to support the “best practice” of delaying the loading/reading of the referenced meta-data segment until it is actually needed).

Meta Data Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element).

The Meta Data Segment type supports compression on all element data, so all elements in Meta Data Segment use the Logical Element Header Compressed form of element header data.

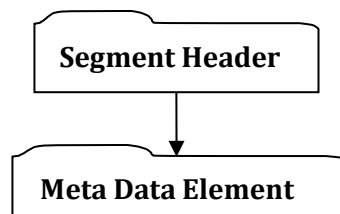


Figure 99 — Meta Data Segment data collection

Complete description for Segment Header can be found in Segment Header.

The following sub-sections document the various Meta Data Element types.

8.2 Property Proxy Meta Data Element

Object Type ID: 0xce357247, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1

A Property Proxy Meta Data Element, shown in Figure 100, serves as a “proxy” for all meta-data properties associated with a particular Meta Data Node Element (see Meta Data Node Element). The proxy is in the form of a list of key/value property pairs where the *key* identifies the type and meaning of the *value*. Although the property *key* is always in the form of a String data type, the *value* can be one of several data types.

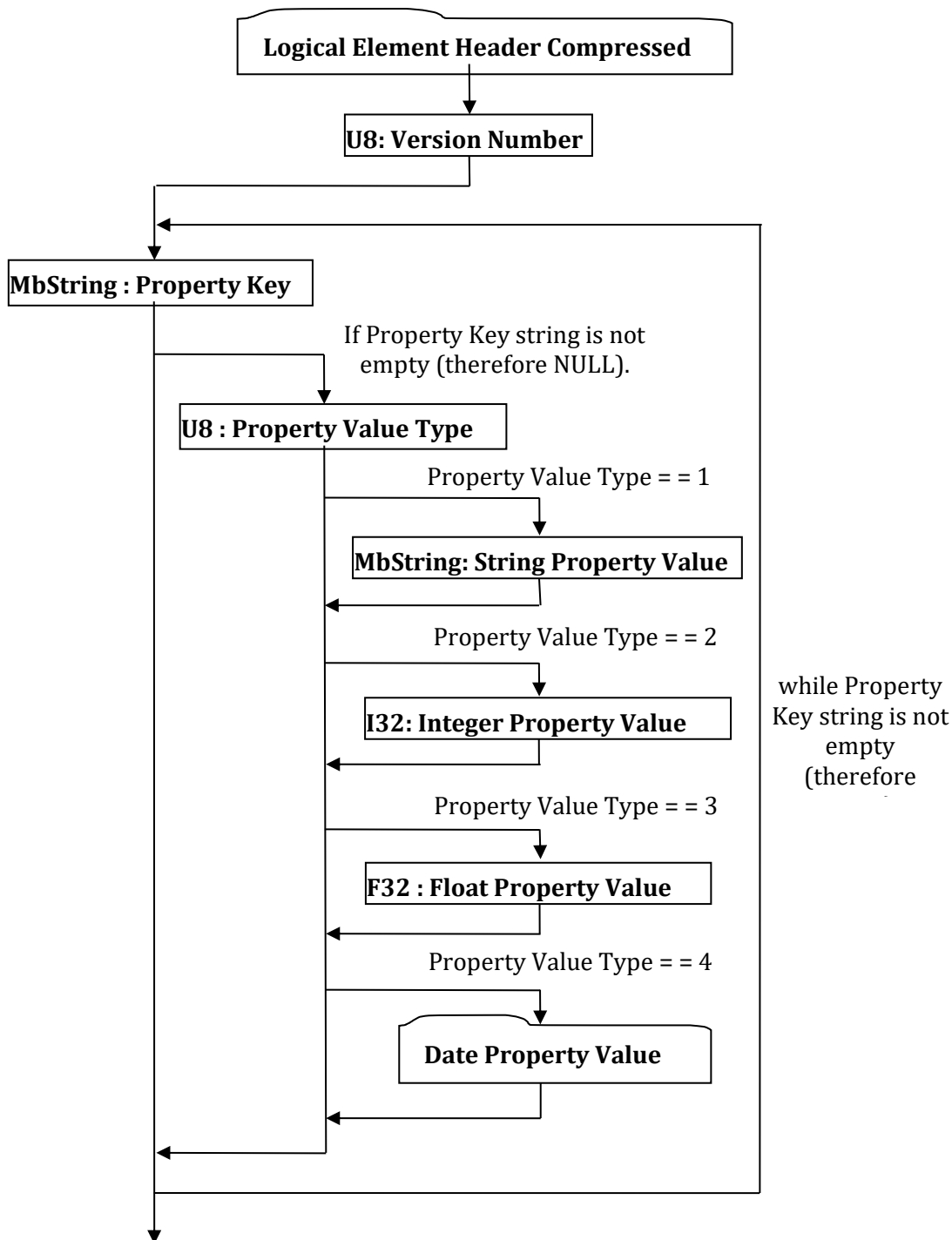


Figure 100 — Property Proxy Meta Data Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

MbString: Property Key

Property Key specifies the *key* string for the property.

U8: Property Value Type

Property Value Type, shown in Table 49, specifies the data type for the Property Value. If the type equals “0” then no Property Value is written. Valid types include the following:

Table 49 — Property Proxy Meta Data Property Value Type values

| | |
|-----|--------------------------|
| = 0 | Unknown |
| = 1 | MbString data type value |
| = 2 | I32 data type value |
| = 3 | F32 data type value |
| = 4 | Date value |

MbString: String Property Value

String Property Value represents the property value when Property Value Type = = 1.

I32: Integer Property Value

Integer Property Value represents the property value when Property Value Type = = 2.

F32: Float Property Value

Float Property Value represents the property value when Property Value Type = = 3.

Date Property Value

Date Property Value, shown in Figure 101, represents the property value when Property Value Type = = 4. Date Property Value data collection represents a date as a combination of year, month, day, hour, minute, and second data fields.

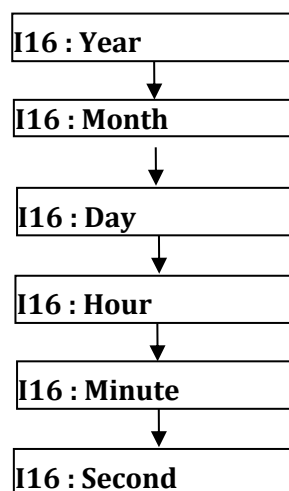


Figure 101 — Date Property Value data collection

I16: Year

Year specifies the date year value.

I16: Month

Month specifies the date month value.

I16: Day

Day specifies the date day value.

I16: Hour

Hour specifies the date hour value.

I16: Minute

Minute specifies the date minute value.

I16: Second

Second specifies the date Second value.

8.3 PMI Manager Meta Data Element

Object Type ID: 0xce357249, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1

The PMI Manager Meta Data Element data collection, shown in Figure 102, is a type of Meta Data Element which contains the Product and Manufacturing Information for a part/assembly.

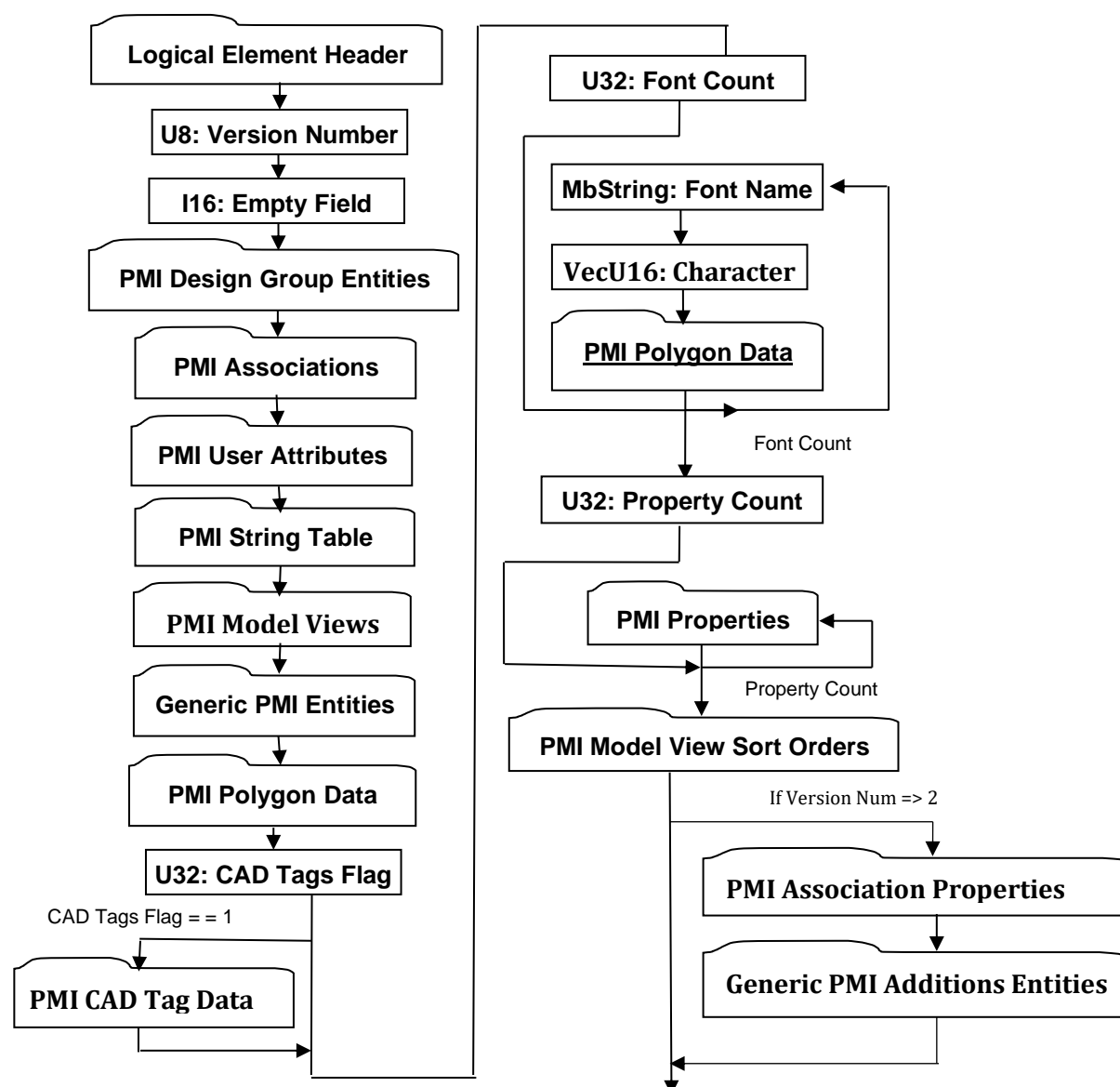


Figure 102 — PMI Manager Meta Data Element data collection

A complete description of Logical Element Header Compressed can be found in the File Format section of this document under Data Segment in the logical collection describing Data.

U8: Version Number

Version Number is the version identifier for this PMI Manager Element. For information on local version numbers see Common Data Conventions and Constructs [Local version numbers](#).

I16: Empty Field

Refer to Common Data Conventions and Constructs Empty Field.

U32: CAD Tags Flag

CAD Tags Flag is a flag indicating whether CAD Tag data exist for the PMI.

U32: Font Count

U32: Font Count specifies the number of sets of glyph definitions. Each set of glyphs represents a single font definition that consists of a name, a character set and polygonal glyph definition for each character in the set.

MbString: Font Name

Font name specifies a representative name for the font set.

VecU16: Character Set

VecU16:Character Set contains the unsigned 16-bit integer identifiers for each character whose symbol is defined in the ensuing PolygonData segment.

U32: Property Count

Property Count specifies the number of PMI Properties

8.3.1 PMI Design Group Entities

The PMI Design Group Entities data collection, shown in Figure 103, defines data for a list of Design Groups. Design Groups are collections of PMI created to organize a model into smaller subsets of information. This organization is achieved via PMI Associations (see PMI Associations), where specific PMI entities are associated as “destinations” to a “source” PMI Design Group.

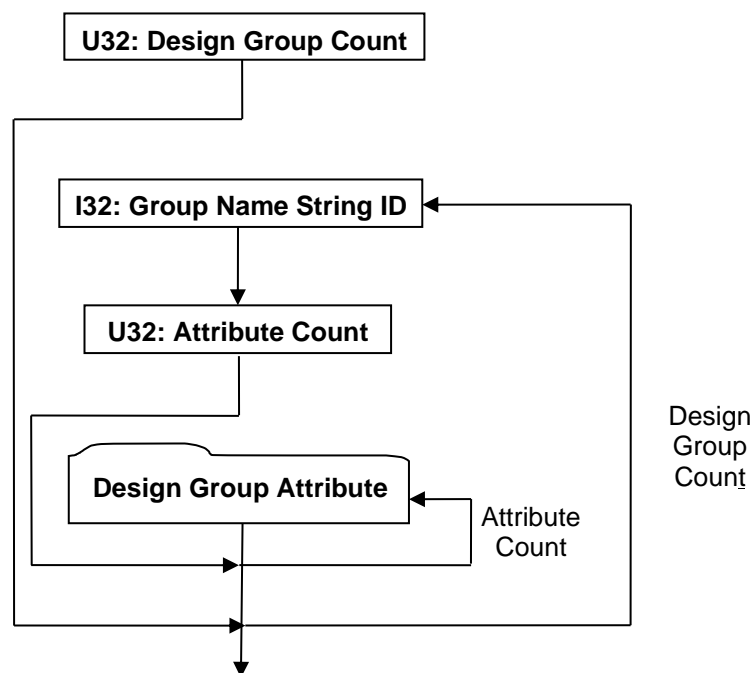


Figure 103 — PMI Design Group Entities data collection

U32: Design Group Count

Design Group Count specifies the number of Design Group entities.

I32: Group Name String ID

Group Name String ID specifies the identifier for the group name character string. This identifier is an index to a particular character string in the PMI String Table. An identifier value of “-1” indicates no string.

U32: Attribute Count

Attribute Count specifies the number of Design Group Attribute data collections.

Design Group Attribute

The Design Group Attribute data collection, shown in Figure 104, defines a group property/attribute.

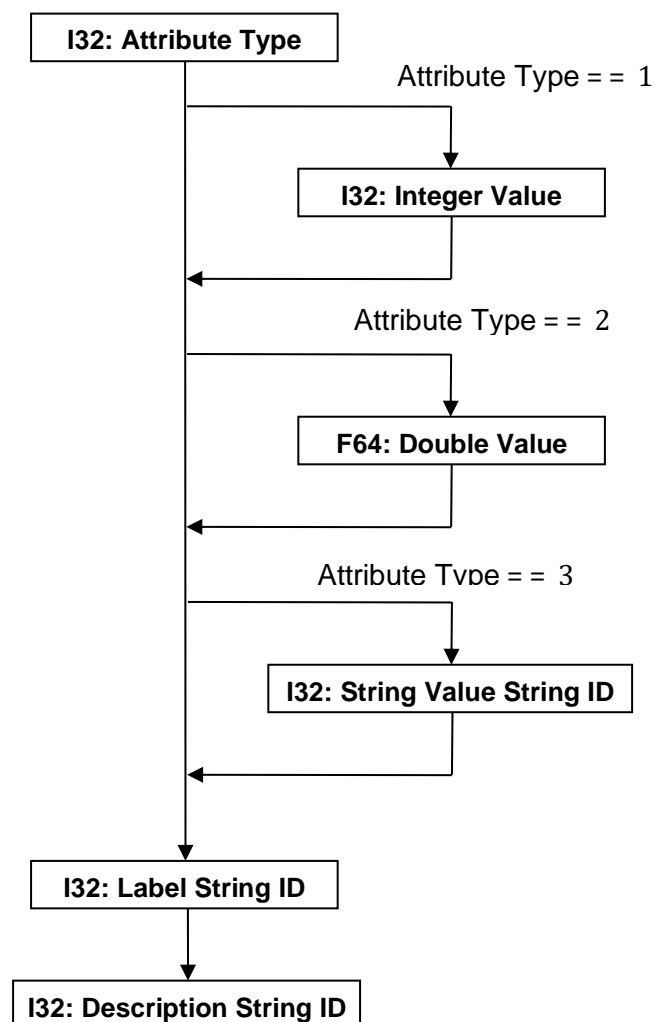


Figure 104 — Design Group Attribute data collection

I32: Attribute Type

Attribute Type, shown in Table 50, specifies the attribute type. Valid types include the following:

Table 50 — PMI Design Group Attribute Type values

| | |
|-----|---------|
| = 1 | Integer |
| = 2 | Double |
| = 3 | String |

I32: Integer Value

Integer Value specifies the value for “integer” Attribute Types.

F64: Double Value

Double Value specifies the value for “double” Attribute Types.

I32: String Value String ID

String Value String ID specifies the string identifier value for “string” Attribute Types. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of “-1” indicates no string.

I32: Label String ID

Label String ID specifies the string identifier for the attribute label. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of “-1” indicates no string.

I32: Description String ID

Description String ID specifies the string identifier for the attribute description. This identifier is an index to a particular character string in the PMI String Table. An identifier value of “-1” indicates no string.

8.3.2 PMI Associations

The PMI Associations data collection, shown in Figure 105, defines data for a list of associations. An association defines a link (“relationship”) between two PMI, B-Rep, or Wireframe Rep entities where one entity is defined as the “source” and the other entity is defined as the “destination”.

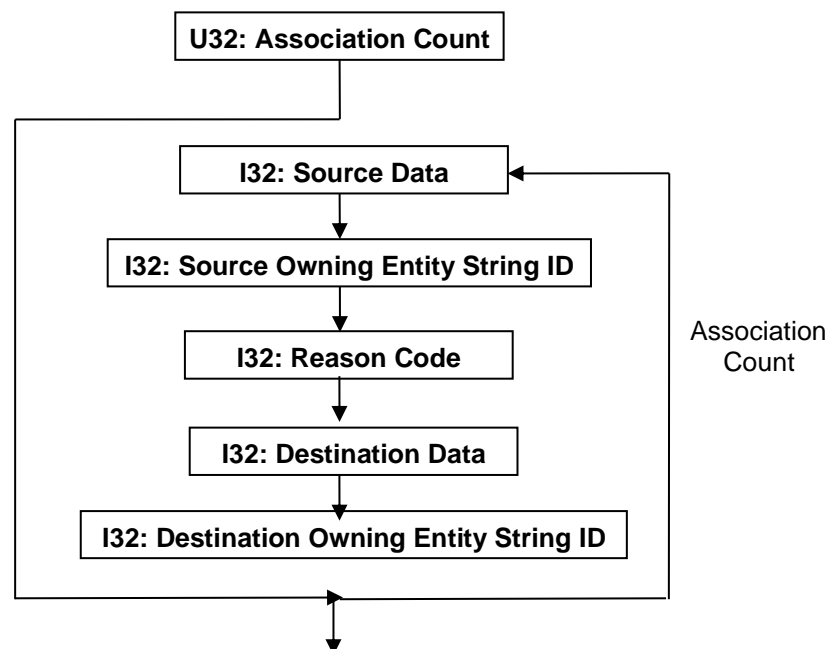


Figure 105 — PMI Associations data collection

U32: Association Count

Association Count specifies the number of associations.

I32: Source Data

Source Data, shown in Table 51, is a collection of source entity information encoded/packed within a single I32 using the following bit allocation. All bits fields that are not defined as in use should be set to “0”.

Table 51 — PMI Associations Source Data values

| | |
|-------------|---|
| Bits 0 - 23 | Source Entity Identifier. The interpretation of this identifier data is dependent upon the value of Bit 31 documented below. |
| Bits 24 -30 | Source Entity PMI or B-Rep type. Valid types include the following: = 0 PMI - Dimension = 1 PMI - Note = 2 PMI - Datum Feature Symbol = 3 PMI - Datum Target = 4 PMI - Feature Control Frame = 5 PMI - Line Weld = 6 PMI - Spot Weld = 7 PMI - Measurement Point = 8 PMI - Surface Finish = 9 PMI - Locator Designator = 10 PMI - Reference Geometry = 11 PMI - Coordinate System = 12 PMI - Design Group = 13 PMI - User Attribute = 14 B-Rep - Vertex = 15 B-Rep - Edge = 16 B-Rep - Face = 17 PMI - Model View = 18 PMI - Generic = 19 Wireframe Rep - Edge = 20 PMI - Unspecified type = 21 Part Instance |
| Bit 31 | Indirect Identifier Flag = 0 – Value in Bits 0-23 is not the actual CAD identifier, instead Bits 0-23 is an index into the source type’s PMI array or index of the edge/face in B-Rep or Wireframe Rep for the source entity. = 1 – Value in Bits 0-23 is not the actual CAD identifier; instead Bits 0-23 is an index into the list of CAD Tags (as documented in PMI CAD Tag Data) identifying the CAD Tag belonging to the particular source entity. |

I32: Source Owning Entity String ID

Source Owning Entity String ID specifies the string identifier for the string which contains the unique CAD identifier of the component (part or assembly) that owns the source PMI or B-Rep entity. This identifier is an index to a particular character string in the PMI String Table. An identifier value of “-1” indicates no string and implies that the entity is to be found on the current node’s PMI/B-Rep/Wireframe-Rep segment. It is valid for the source owning entity to be the same as the destination owning entity (therefore an association between two PMI or B-Rep entities in the same part/assembly).

I32: Reason Code

Reason Code, shown in Table 52, specifies the “reason” for the association. Valid Reason Codes include the following:

Table 52 — PMI Associations Reason Code values

| | |
|-----|---|
| = 0 | Association is to the primary entity being dimensioned. |
| = 1 | Association is to the secondary entity being dimensioned. |

| | |
|-------|--|
| = 2 | Association is to the dimension plane. |
| = 5 | Association is to the entity used to specify the Z-Axis of a coordinate system. |
| = 10 | Association is to an entity "associated" to or "included in" a PMI symbol. |
| = 11 | Association is to an entity used to "attach" a PMI symbol. |
| = 12 | Association is to first entity used to "attach" a PMI symbol. |
| = 13 | Association is to second entity used to "attach" a PMI symbol. |
| = 14 | Specifying PMI grouping, source is PMI/B-Rep entity and destination is design group. |
| = 15 | Association is to a weld line entity. |
| = 16 | Association is to a "hot spot". |
| = 20 | Association is to a PMI B-rep entity contained in a virtual group. Similar to reason code 14 but for a virtual group |
| = 17 | Association is to a child in a PMI stack. |
| = 72 | Association is for PMI miscellaneous relation. |
| = 73 | Association is for PMI related entity. |
| = 78 | Association is to a product instance to cut by a PMI section. Only required for partial scene sectioning |
| = 98 | Association is to show the PMI when associated Model View is selected. Source is the PMI, and destination is Model View. |
| = 99 | Association is to show/select PMI B, if showing/selecting PMI A. Source is PMI A, and destination is PMI B. This is different from an "attached" PMI, where the convention is to show the PMI visibly linked to one another. |
| = 100 | Association is to show all parts except the associated part instance. Source is the part instance, and destination is Model View. |
| =256 | Association is to say cut the selected content that doesn't exist within the regular scene graph (such as a targeted PMI Display) within the given section |
| =257 | Association is to identify that the PMI source content should be part of the MV (Model View) destination with its visibility toggled to off. |

I32: Destination Data

Destination Data is a collection of destination entity information encoded/packed within a single I32. The encoding schema and interpretation of this data is the same as that documented in Source Data.

I32: Destination Owning Entity String ID

Destination Owning Entity String ID specifies the string identifier for the string which contains the unique CAD identifier of the component (part or assembly) that owns the destination PMI or B-Rep entity. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of "-1" indicates no string and implies that the entity is to be found on the current node's PMI/B-Rep/Wireframe-Rep segment. It is valid for the source owning entity to be the same as the destination owning entity (therefore an association between two PMI or B-Rep entities in the same part/assembly).

8.3.3 PMI User Attributes

The PMI User Attributes collection, shown in Figure 106, defines data for a list of user attributes. PMI User Attributes are used to add attribute data to a part/assembly. Each user attribute is composed of key/value pair of strings.

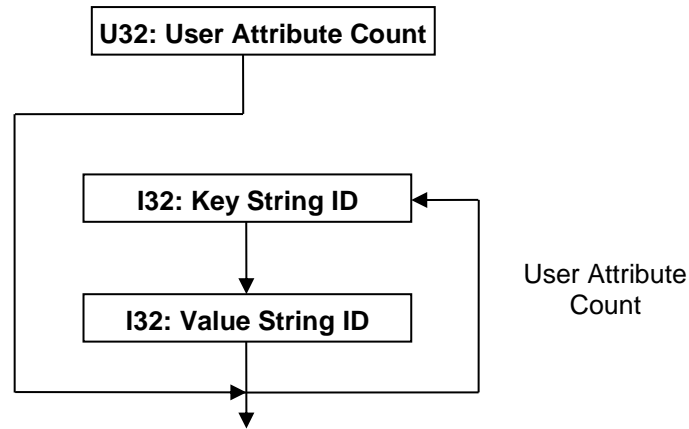


Figure 106 — PMI User Attributes data collection

U32: User Attribute Count

User Attribute Count specifies the number of user attributes.

I32: Key String ID

Key String ID specifies the string identifier for the user attribute key. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of “-1” indicates no string.

I32: Value String ID

Value String ID specifies the string identifier for the user attribute value. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of “-1” indicates no string.

8.3.4 PMI String Table

The PMI String Table data collection, shown in Figure 107, defines data for a list of character strings and serves as a central repository for all character strings used by other PMI Entities within the same PMI Manager Meta Data Element. PMI Entities reference into this list/array of character strings to define usage of a particular character string using a simple list/array “index” (therefore String ID).

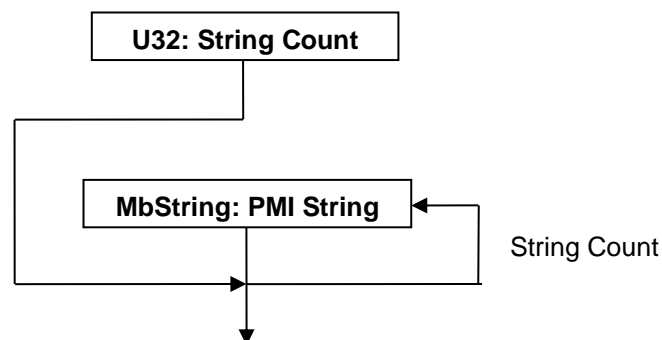


Figure 107 — PMI String Table data collection

U32: String Count

String Count specifies the number of character strings in the string table.

MbString: PMI String

PMI String specifies the character string.

8.3.5 PMI Model Views

The PMI Model Views data collection, shown in Figure 108, defines data for a list of Model Views. A fully annotated part/assembly may contain so much PMI information, that it becomes very difficult to interpret the design intent when viewing a 3D Model (with PMI visible) of the part/assembly. Model Views provide a means to capture and organize PMI information about a 3D model so that the design intent can be clearly interpreted and communicated to others in later stages of the Product Lifecycle Management (PLM) process (for example manufacturing, inspection, assembly). This organization is achieved via PMI Associations (see PMI Associations), where specific PMI entities are associated as “destinations” to a “source” PMI Model View.

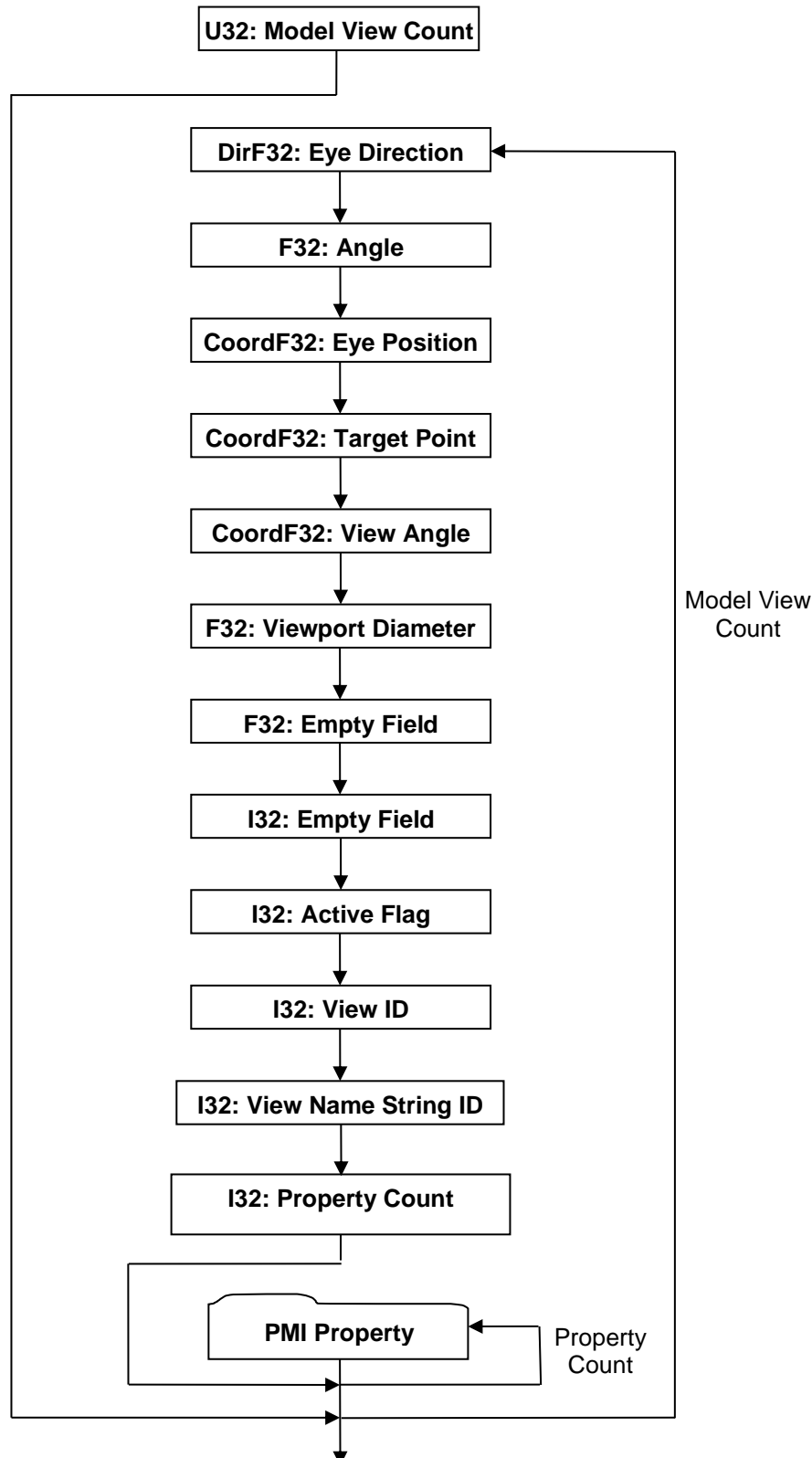


Figure 108 — PMI Model Views data collection

U32: Model View Count

Model View Count specifies the number of Model Views.

DirF32: Eye Direction

Eye Direction specifies the camera direction vector.

F32: Angle

Angle specifies the camera rotation angle (in degrees where positive is counter-clockwise) about the Eye Direction. So this Angle in combination with the Eye Direction is equivalent to specifying a rotation using axis-angle representation.

CoordF32: Eye Position

Eye Position specifies the WCS coordinates of the eye/camera “look from” position.

CoordF32: Target Point

Target Point specifies the WCS coordinates of the eye/camera “look at” position.

CoordF32: View Angle

View angle specifies the X, Y, Z rotation angles (in degrees) of the model’s axis. The rotations are defined with respect to an initial orientation where the model’s axis are aligned with the screen’s axis (therefore +X axis points to right, +Y axis points up, +Z axis points out at you).

F32: Viewport Diameter

Viewport Diameter specifies the diameter in WCS coordinates of the largest possible circle that could be inscribed within viewport. If a large diameter value is specified, the model appears very small in relation to the viewport; whereas if a small diameter value is specified a close-up (“zoomed-in”) view of the model results.

F32: Empty Field

Refer to Common Data Conventions and Constructs Empty Field.

I32: Empty Field

Refer to Common Data Conventions and Constructs Empty Field.

I32: Active Flag

Active Flag, shown in Table 53, is a flag specifying whether this Model View is the “active” view. Valid values include the following:

Table 53 — PMI Model Views Active Flag values

| | |
|-----|-------------------------------|
| = 0 | Is not the active Model View. |
| = 1 | Is the active Model View |

I32: View ID

View ID specifies the Model View unique identifier.

I32: View Name String ID

View Name String ID specifies the string identifier for the Model View’s name. This identifier is an index to a particular character string in the PMI String Table. An identifier value of “-1” indicates no string.

PMI Property

A PMI Property data collection, shown in Figure 109, consists of a key/value pair and is used to describe attributes of Generic PMI Entity or other specific data.

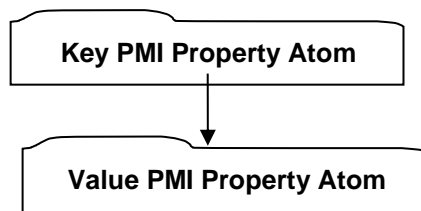


Figure 109 — PMI Property data collection

Both Key and Value have the same format as that documented in Key PMI Property Atom.

For a full description of PMI “Key” strings and “Value” string encoding format descriptions see the PMI Data Segment Annex L in this document.

Key PMI Property Atom

Key PMI Property Atom data collection, shown in Figure 110, represents the data format for both the key and value data of a PMI Property key/value pair.

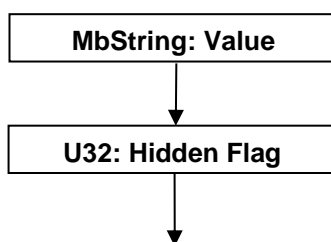


Figure 110 — Key PMI Property Atom data collection

MbString: Value

Value specifies the property atom value encoded into a String. See Sections 11.9, [Metadata Conventions et seq.](#) for encoding formats of the Value string.

U32: Hidden Flag

Hidden Flag, shown in Table 54, specifies if the property is “hidden” or not. An JT file reader could use this flag to control whether read properties should be exposed to the end user of the application reading the JT file. Valid values include the following:

Table 54 — PMI Property Atom Hidden Flag values

| | |
|-----|-------------------------|
| = 0 | Property is not hidden. |
| = 1 | Property is hidden. |

8.3.6 Generic PMI Entities

The Generic PMI Entity data collection, shown in Figure 111, provides a “generic” format for defining various PMI entity types, including user defined types. The generic format defines the data making up the PMI Entity through a combination of the PMI 2D Data collection and a list of PMI Property data collections.

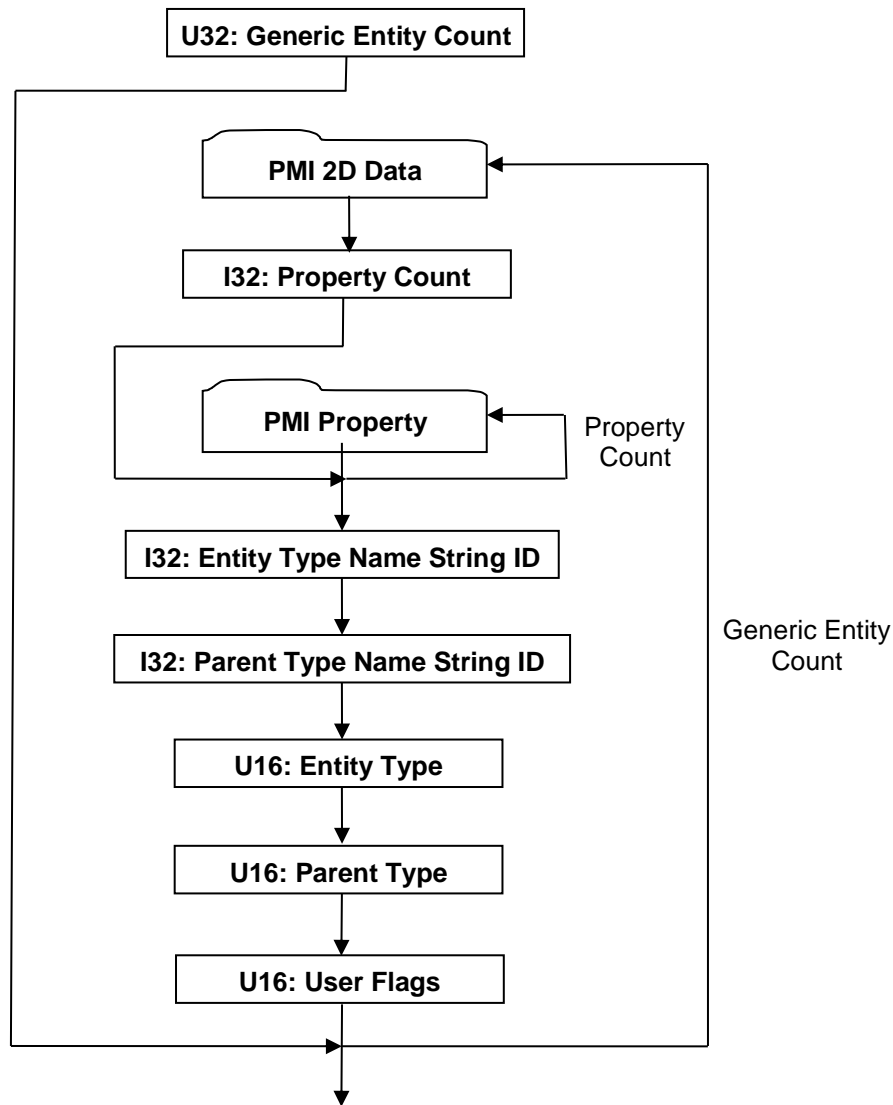


Figure 111 — Generic PMI Entity data collection

Complete description for PMI Property can be found in the logical collection for PMI Property found in PMI Model View.

U32: Generic Entity Count

Generic Entity Count specifies the number of Generic PMI Entities.

I32: Property Count

Property Count specifies the number of PMI Properties.

I32: Entity Type Name String ID

Entity Type Name String ID specifies the string identifier for the name of the Generic PMI Entity Type. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of “-1” indicates no string.

I32: Parent Type Name String ID

Parent Type Name String ID specifies the string identifier for the name of the parent Generic PMI Entity Type. This identifier is an index to a particular character string in the PMI String Table. An identifier value of “-1” indicates no string.

U16: Entity Type

Entity Type, shown in Table 55, specifies the Generic PMI Entity Type. The valid Entity Type values (in hexadecimal format) are documented in the following table. Note that for “user defined” Generic PMI Entities a hexadecimal value of “0x0114” (as documented in table below) should be used.

Table 55 — Generic PMI Entity Type values

| Entity Type | Description |
|-------------|--|
| 0x0001 | PMI (generally only used as a Parent Type) |
| 0x0002 | Weld |
| 0x0004 | Spot Weld |
| 0x0008 | Line Weld |
| 0x0010 | Groove Weld |
| 0x0011 | Fillet Weld |
| 0x0012 | Slot Weld |
| 0x0014 | Edge Weld |
| 0x0018 | Arc Spot Weld |
| 0x0020 | Resistance Spot Weld |
| 0x0021 | Resistance Seam Weld |
| 0x0022 | Structural Adhesive Bead Shaped |
| 0x0024 | Structural Adhesive Tape Shaped |
| 0x0028 | Structural Adhesive Dollop Shaped |
| 0x0040 | Mechanical Clinch Connector |
| 0x0041 | Surface Finish |
| 0x0042 | Measurement Point |
| 0x0044 | Datum Locator |
| 0x0048 | Certification Point |
| 0x0080 | Geometric Dimensioning and Tolerancing |
| 0x0081 | Feature Control Frame |
| 0x0082 | Dimension |
| 0x0084 | Datum Feature Symbol |
| 0x0088 | Datum Target |
| 0x0100 | Note |
| 0x0101 | Face Attribute Note |
| 0x0102 | Model View Label Note |
| 0x0104 | Coordinate System |
| 0x0108 | Reference Geometry |
| 0x0110 | Reference Point |
| 0x0111 | Reference Axis |
| 0x0112 | Reference Plane |
| 0x0114 | User Defined |
| 0x0118 | Measurement Locator |
| 0x0120 | Datum Point |
| 0x0121 | Surface Vector Measurement Point |
| 0x0122 | Hole Vector Measurement Point |
| 0x0124 | Trimmed Sheet Vector Measurement Point |
| 0x0128 | Hem Vector Measurement Point |
| 0x0230 | Fastener PMI |
| 0x0231 | Material specification |
| 0x0232 | Process specification |
| 0x0233 | Part specification |
| 0x0235 | Balloon Note |
| 0x0238 | Circle Centre |
| 0x0239 | Coordinate Note |
| 0x0240 | AttributeNote |
| 0x0241 | Bundle or Dressing Note |

| Entity Type | Description |
|-------------|--|
| 0x0242 | Cutting Plane Symbol |
| 0x0243 | Crosshatch |
| 0x0244 | E Marking (Note) |
| 0x0245 | Organization |
| 0x0246 | Region |
| 0x0305 | Section |
| 0x0306 | Centreline |
| 0x0307 | Fit Designation |
| 0x0308 | Composite Feature Control Frame |
| 0x0309 | Weld Note Type |
| 0x030A | Reference Circle |
| 0x030B | Reference Cylinder |
| 0x030C | Part Transform |
| 0x030D | Callout Dimension Type |
| 0x030E | Parameter Dimension Type (reserved not in use) |
| 0x030F | Chamfer Dimension Type |
| 0x0310 | Model View Style |
| 0x0311 | PMI Table Type |
| 0x0312 | Parameter Fit Designation Type (reserved not in use) |
| 0x0313 | Callout Fit Designation |
| 0x8000 | Feature Type |
| 0x8001 | Feature Thread Type |
| 0x8002 | Feature Arc Weld Type |
| 0x8003 | Feature Datum Type |
| 0x8004 | Feature Discrete Join Type |
| 0x8005 | Feature Resistance Weld Type |
| 0x8006 | Feature Continuous Join Type |
| 0x8007 | Feature Adhesive Fill Type |
| 0x8008 | Feature Surface Weld Type |
| 0x8009 | Feature Measurement Locator Type |
| 0x800A | Feature Grouped Weld |
| 0x800B | Feature Lazer Weld Type |

U16: Parent Type

Parent Type specifies the parent Generic PMI Entity Type. The valid Parent Type values are the same as that documented above for Entity Type. The Parent Type is used to create a class hierarchy of PMI when presenting the PMI contents from a JT file.

U16: User Flags

User Flags, shown in Table 56, is a collection of flags. The flags are combined using the binary OR operator and store various state information for the Generic PMI Entity. All bits fields that are not defined as in use should be set to “0”.

Table 56 — Generic PMI User Flag values

| | |
|--------|--|
| 0x0001 | Show PMI Entity “flat to screen only” flag = 0 – Allow PMI display plane to rotate with model. = 1 – Display PMI entity in the plane of the screen, so that it does not rotate with model. |
|--------|--|

PMI 2D Data

The PMI 2D Data collection, shown in Figure 112, defines a data format common to all 2D based PMI entities.

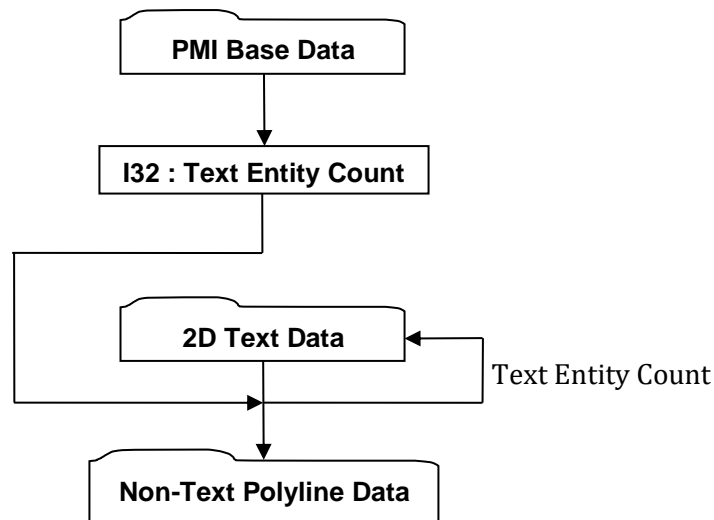


Figure 112 — PMI 2D Data collection

I32: Text Entity Count

Text Entity Count specifies the number of Text entities in the particular PMI entity.

When working with JT version 10.6 and greater the **Text Entity Count** is used again when reading additional 2D Text Data . See the figure titled **V105 2D Text Data collection** in this section of the document.

PMI Base Data

The PMI Base Data collection, shown in Figure 113, defines the basic/common data that every 2D and 3D PMI entity.

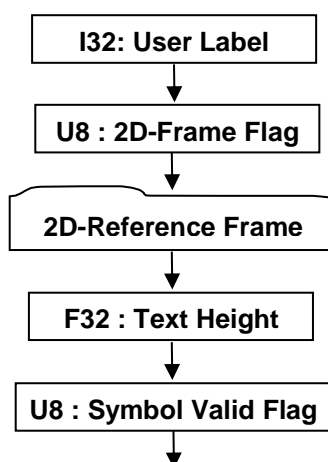


Figure 113 — PMI Base Data collection

I32: User Label

User Label specifies the particular PMI entity identifier.

U8: 2D-Frame Flag

2D-Frame Flag is a flag specifying whether 2D-Reference Frame data is stored. If 2D-Frame Flag has a non-zero value then 2D-Reference Frame data is included. If 2D-Frame Flag has a value of “2”, then dummy (therefore all zeros) 2D-Reference Frame data is written. The “2D-Frame Flag = 2” case is used

by Generic PMI Entities because for Generic PMI Entities all the Non-Text Polyline Data is already in 3D form (therefore XYZ coordinate data).

F32: Text Height

Text Height specifies the PMI text height in WCS.

U8: Symbol Valid Flag

Symbol Valid Flag is a flag specifying whether the particular PMI entity is valid. If Symbol Valid Flag has a non-zero value then PMI entity is valid.

2D-Reference Frame

The 2D-Reference Frame data collection, as shown in Figure 114, defines a reference frame (2D coordinate system) where the PMI entity is displayed in 3D space. All the PMI entity's 2D and 3D polyline data is assumed to lie on the defined plane.

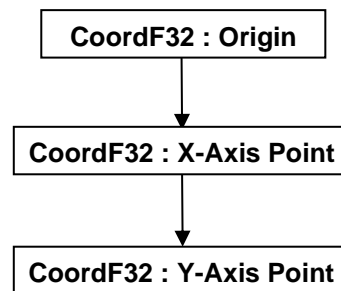


Figure 114— 2D-Reference Frame data collection

CoordF32: Origin

Origin defines the origin (min-corner) of the 2D coordinate system.

CoordF32: X-Axis Point

X-Axis Point defines a point along the X-Axis of the 2D coordinate system.

CoordF32: Y-Axis Point

Y-Axis Point defines a point along the Y-Axis of the 2D coordinate system.

2D Text Data

The 2D Text Data collection, as shown in Figure 115, defines a 2D text entity/primitive.

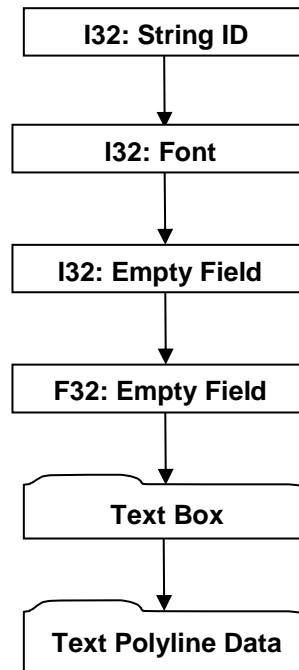


Figure 115 — 2D Text Data collection

I32: String ID

String ID specifies the identifier for the character string. This identifier is an index to a particular character string in the PMI String Table. An identifier value of “-1” indicates no string.

I32: Font

Font, shown in Table 57, identifies the font to be used for this text. Valid values include the following:

Table 57 — PMI 2D Base Data Font values

| | |
|-------|--|
| = 1 | Simplex |
| = 2 | Din |
| = 3 | Military |
| = 4 | ISO |
| = 5 | Lightline |
| = 6 | IGES 1001 |
| = 7 | Century |
| = 8 | IGES 1002 |
| = 9 | IGES 1003 |
| = 101 | Japanese JISX 0208 coded character set |
| = 102 | Japanese Extended Unix Codes JISX 0208 coded character set |
| = 103 | Chinese GB 2312.1980 Simplified coded character set |
| = 104 | Korean KSC 5601 coded character set |
| = 105 | Chinese Big5 Traditional coded character set |

I32: Empty Field

Refer to Common Data Conventions and Constructs Empty Field.

F32: Empty Field

Refer to Common Data Conventions and Constructs Empty Field.

Text Box

The Text Box data collection, shown in Figure 116, specifies a 2D box that particular text fits within. All values are with respect to 2D-Reference Frame documented in 2D-Reference Frame.

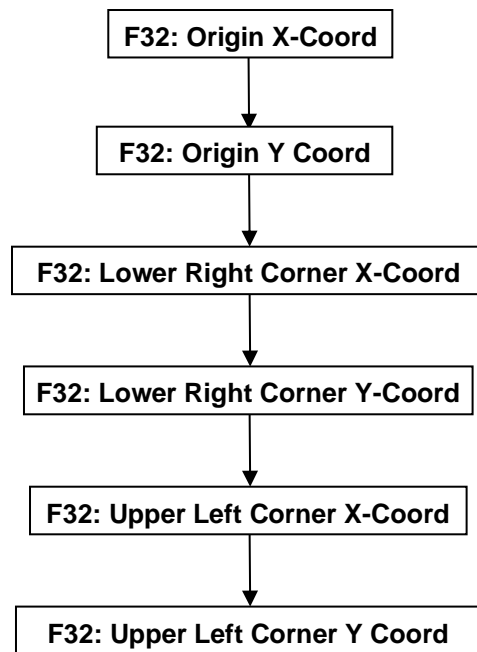


Figure 116 — Text Box data collection

F32: Origin X-Coord

Origin X-Coord defines the 2D X-coordinate of the text origin with respect to 2D-Reference Frame.

F32: Origin Y Coord

Origin Y-Coord defines the 2D Y-coordinate of the text origin with respect to 2D-Reference Frame.

F32: Lower Right Corner X-Coord

Lower Right Corner X-Coord defines the 2D X-coordinate of the lower right corner of the text with respect to 2D-Reference Frame.

F32: Lower Right Corner Y-Coord

Lower Right Corner Y-Coord defines the 2D Y-coordinate of the lower right corner of the text with respect to 2D-Reference Frame.

F32: Upper Left Corner X-Coord

Upper Left Corner X-Coord defines the 2D X-coordinate of the upper left corner of the text with respect to 2D-Reference Frame.

F32: Upper Left Corner Y Coord

Upper Left Corner Y-Coord defines the 2D Y-coordinate of the upper left corner of the text with respect to 2D-Reference Frame.

Text Polyline Data

The Text Polyline Data collection, shown in Figure 117, defines any polyline segments which are part of the text representation. This existence of this polyline data is conditional (therefore not all text has it) and is made up of an array of indices into an array of polyline segments packed as 2D vertex coordinates, specifying where each polyline segment begins and ends. Polyline segments are constructed from these arrays of data as follows:

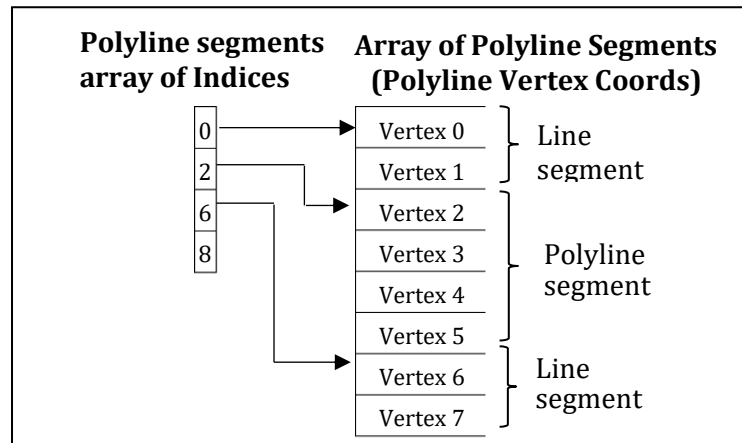


Figure 117 — Constructing Text Polyline Data from data arrays

This data is represented in JT file in the following format, as shown in Figure 118:

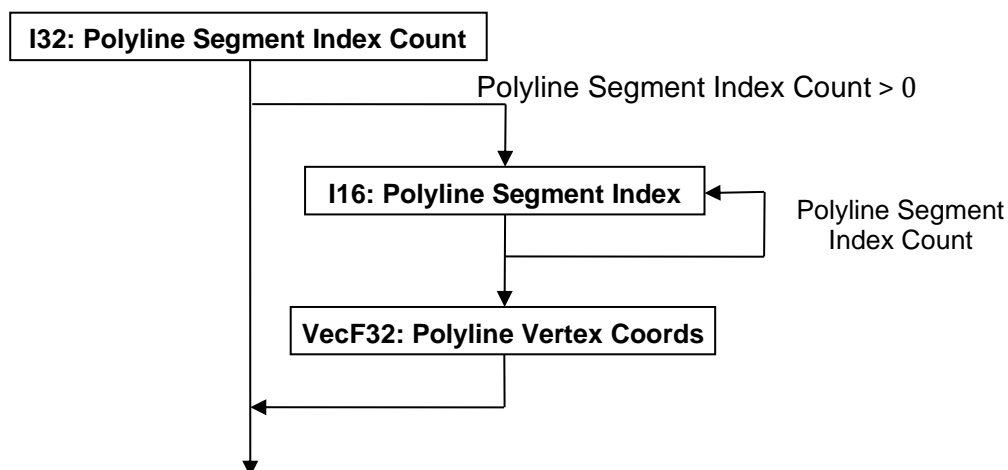


Figure 118 — Text Polyline Data collection

I32: Polyline Segment Index Count

Polyline Segment Index Count specifies the number of polyline segment indices.

I16: Polyline Segment Index

Polyline Segment Index is an index into the Polyline Vertex Coords array specifying where polyline segment begins or ends. This index is a vertex coordinate index so the absolute index into the Polyline Vertex Coords array is computed by multiplying the index value by “2” (therefore for 2D coordinates).

VecF32: Polyline Vertex Coords

Polyline Vertex Coords is an array of polyline segments packed as 2D point coordinates. These 2D point coordinates are with respect to the 2D-Reference Frame documented in 2D-Reference Frame.

Non-Text Polyline Data

The Non-Text Polyline Data collection, as shown in Figure 120, contains all the non-text polylines making up the particular PMI entity. Examples of non-text polylines include line attachments, text boxes, symbol box dividers, etc. The Non-Text Polyline Data collection is made up of an array of indices into an array of polyline segments packed as either 2D or 3D vertex coordinates, specifying where each polyline segment begins and ends. Whether vertex coordinates are 2D or 3D is dependent upon the PMI entity type using this data collection. If it is a Generic PMI Entities type then the packed coordinate data is 3D; for all other PMI entity types the packed coordinate data is 2D. Two arrays of values that sequentially specify the polyline type and width in the polyline segments array are included.

The Figure 119, titled Constructing Non-Text Polylines from packed 2D data arrays, shows how Polylines are constructed from these arrays of data for the packed 2D coordinates case. The packed 3D coordinates case is interpreted the same except that the coordinates array includes a Z component and is thus packed as “[XYZ][XYZ][XYZ]...”

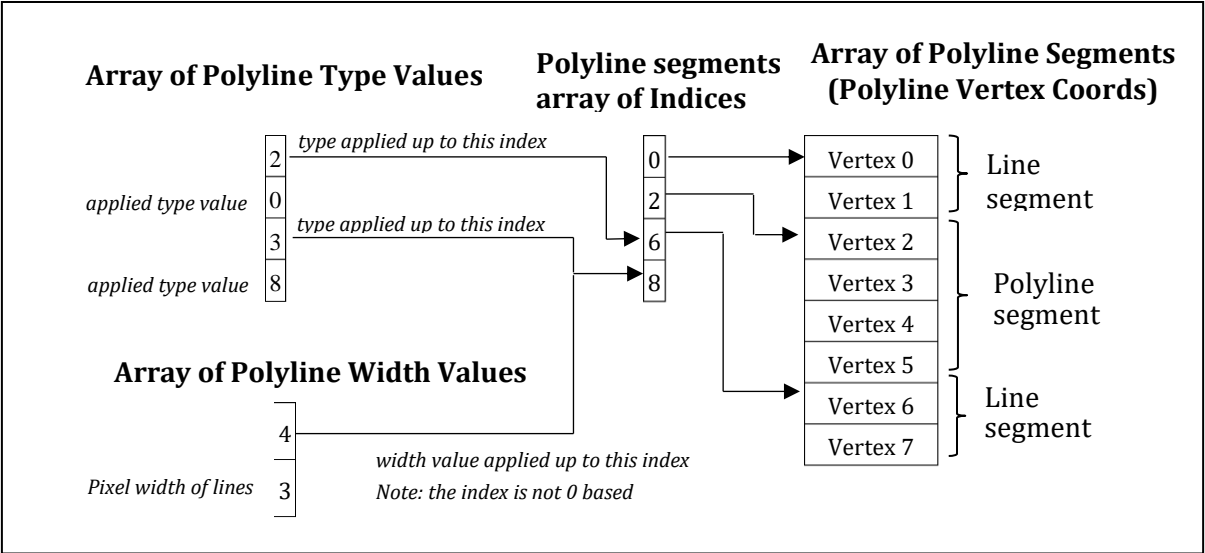


Figure 119 — Constructing Non-Text Polylines from packed 2D data arrays

This data is represented in the JT format as shown in Figure 120:

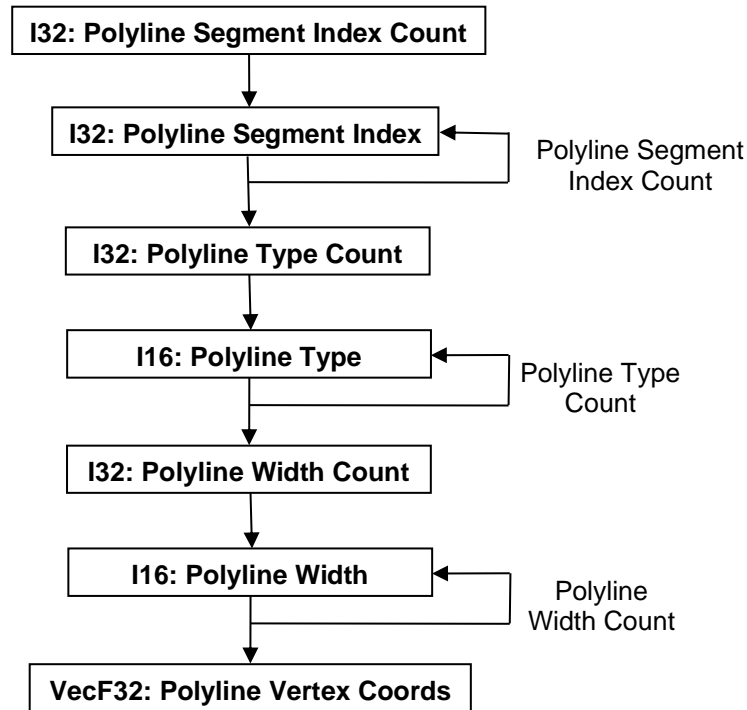


Figure 120 — Non-Text Polyline Data collection

I32: Polyline Segment Index Count

Polyline Segment Index Count specifies the number of polyline segment indices.

I32: Polyline Segment Index

Polyline Segment Index is an index into the Polyline Vertex Coords array specifying where polyline segment begins or ends. This index is a vertex/coordinate index so the absolute index into the Polyline Vertex Coords array is computed by multiplying the index value by “2” (therefore for 2D coordinates).

I32: Polyline Type Count

Polyline Type Count specifies the number of polyline type values.

I16: Polyline Type

Polyline Type, as shown in Table 58, specifies the type of the polyline segments in the Polyline Vertex Coords array. See Figure titled — Constructing Non-Text Polylines from packed 2D data arrays for interpretation of this array of type values relative to the defined polylines. Valid values include the following:

Table 58 — PMI 2D Non-Text Polyline Type values

| | |
|-----|--|
| = 0 | General line |
| = 1 | General arrow |
| = 2 | General circle |
| = 3 | General arc |
| = 4 | Extended line 1 |
| = 5 | Extended line 2 |
| = 6 | Extended arc |
| = 7 | Extended circle |
| = 8 | Text line (used in text boxes and symbol box dividers) |
| = 9 | Text string |

I32: Polyline Width Count

Polyline Width Count specifies the number of polyline width values.

I16: Polyline Width

Polyline Width specifies the width of polyline segment in Polyline Vertex Coords array. See Figure 119 — Constructing Non-Text Polylines from packed 2D data arrays for interpretation of this array of width values relative to the defined polylines.

VecF32: Polyline Vertex Coords

Polyline Vertex Coords is an array of polyline segments packed as 2D point coordinates. These 2D point coordinates are with respect to the 2D-Reference Frame documented in 2D-Reference Frame.

8.3.7 PMI CAD Tag Data

The PMI CAD Tag Data collection, as shown in Figure 121, contains the list of persistent IDs, as defined in the CAD System, to uniquely identify individual PMI entities. The existence of this PMI CAD Tag Data collection is dependent upon the value of previously read data field CAD Tags Flag as documented in J.3.2 PMI Manager Meta Data Element.

If the PMI CAD Tag Data collection is present, there will be a CAD Tag for each PMI entity as specified by the below documented CAD Tag Index Count formula.

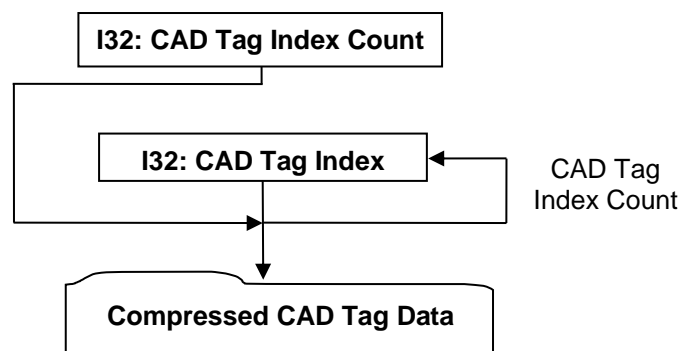


Figure 121 — PMI CAD Tag Data collection

Complete description for Compressed CAD Tag Data can be found in Compressed CAD Tag Data.

I32: CAD Tag Index Count

CAD Tag Index Count specifies the total number of CAD Tag indices. This value shall be equal to the summation of the previously read count values for all the PMI entities supporting CAD Tags. The formula is the sum of the following:

- Line Weld Count
- Spot Weld Count
- SF Count
- MP Count
- Reference Geometry Count
- Datum Target Count
- FCF Count
- Locator Count

- Dimension Count
- DFS Count
- Note Count
- Model View Count
- Design Group Count
- Coord Sys Count
- Generic Entity Count

I32: CAD Tag Index

CAD Tag Index specifies an index into a list of CAD Tags, identifying the CAD Tag belonging to a particular PMI entity. There will be a total of CAD Tag Index Count number of CAD Tag Indices and the order of the indices will be as defined by the above documented CAD Tag Index Count formula (therefore Line Weld CAD Tag Indices are first, followed by the Spot Weld CAD Tag Indices, followed by the Surface Finish CAD Tag Indices, etc.).

8.3.8 PMI Polygon Data

The PMI Polygon Data collection, as shown in Figure 122, contains a list of vertices classified as polygonal primitives. Each block of PMI PolygonData contains a list of 0 or more PolygonData elements. Empty PolygonData elements are written with 0 vertices and no additional fields.

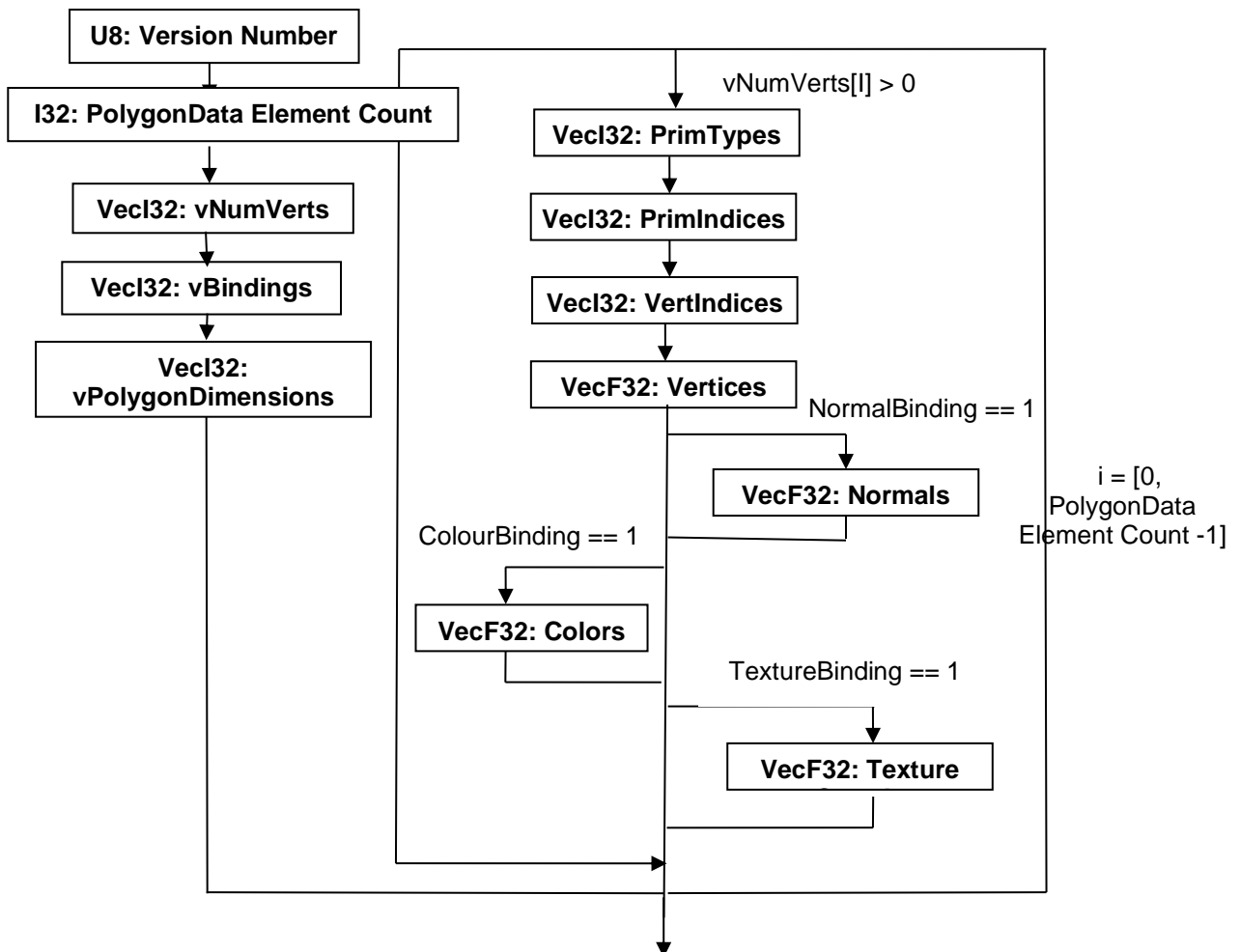


Figure 122 — PMI Polygon Data Collection

U8: Version Number

Version number is the version identifier for this PMI Polygon Data. For information on local version numbers see Common Data Conventions and Constructs [Local version numbers](#).

I32: PolygonData Element Count

PolygonData Element Count specifies the number of PolygonData elements.

VecI32: vNumVerts

An integer vector is used to record the number of vertices in each polygon data element. The length of this vector is equal to PolygonData Element Count written in this block of PMI PolygonData. The presence of additional data fields in each PolygonData element is hinged upon that element having more than 0 vertices recorded in this vector.

Retrieve next vertCount from vNumVerts

If the next element in the vNumVerts vector is non-zero, proceed to read other fields that make up a single PMI PolygonData element. Otherwise, skip reading more data for this element and loop back to seek the next element in the vector.

VecI32: vBindings

An integer vector used to record the bindings of all non-zero polygon data elements. This vector has three entries for each such element. The first entry is the color binding, followed by the normal binding, followed by the texture binding. These map to the non-zero polygon data elements in order.

For example:

```
If vNumVerts = {10, 0, 10, 0, 12}
vBindings = {1,0,0, 1,0,0, 1,0,0}
Then
Polygon data element 0: {Color binding = 1; Normal binding = 0; Texture binding = 0}
Polygon data element 1: there are no entries in this array since numVerts[1] = 0
Polygon data element 2: {Color binding = 1; Normal binding = 0; Texture binding = 0}
Polygon data element 3: there are no entries in this array since numVerts[3] = 0
Polygon data element4: {Color binding = 1; Normal binding = 0; Texture binding = 0}
```

VecI32: vPolygonDimensions:

An integer vector used to record the dimensions of all non-zero polygon data elements. The vector has one entry for each such element. These map to the non-zero polygon data elements in order.

For example:

```
If vNumVerts = {10, 0, 10, 0, 12}
vPolygonDimensions = {3, 3, 3}
Then
Polygon data element 0: {PolygonDimension = 3}
Polygon data element 1: there are no entries in this array since numVerts[1] = 0
Polygon data element 2: {PolygonDimension = 3}

Polygon data element 3: there are no entries in this array since numVerts[3] = 0
Polygon data element4: {PolygonDimension = 3}
```

iNumVerts

Number of vertices for the ith PolygonData element.

I32: ColorBinding

A Boolean value that indicates if there are colors present along with the list of coordinates at each vertex.

I32: NormalBinding

A Boolean value that indicates if there are normals present along with the list of coordinates at each vertex.

I32: TextureBinding

A Boolean value that indicates if there are Texture Coordinates present along with the list of coordinates at each vertex.

I32: PolygonDimension

Indicates the dimension of vertex coordinates.

VecI32: PrimTypes

An array indicating the type of each of the primitive stored in the PrimIndices array. Adjacent numbers in the array form tuples of the form [PrimIndex, PrimType]. All primitives to the left of the PrimIndex are of type PrimType unless they are already to the left of an earlier PrimIndex in this array.

VecI32: PrimIndices

Indices of vertices that form a single primitive. The difference between two adjacent values in this array determines the length of the primitive. An extra element is stored at the end of this array to identify the length of the last primitive. Values in this array are indices into the VertIndices array.

VecI32: VertIndices

An array of indices into the Vertices array. This index array eliminates the need to duplicate floating point vertices that are shared by multiple primitives.

VecF32: Vertices

The list of vertex coordinates. Each vertex is made of PolygonDimension coordinates. The length of this list is equal to number of vertices multiplied by PolygonDimension.

VecF32: Normals

An optional list of Normals for each vertex. Presence of this list is indicated by the NormalBinding flag. Each normal consists of PolygonDimension components. The size of this list is equal to number of vertices multiplied by PolygonDimension.

VecF32: Colors

An optional list of Colours for each vertex. Presence of this list is indicated by the ColorBinding flag. Each color consists of PolygonDimension components. The size of this list is equal to number of vertices multiplied by PolygonDimension.

VecF32: Texture Coords

An optional list of Texture coordinates for each vertex. Presence of this list is indicated by the TexCoordBinding flag. Each TexCoord consists of 2 components. The size of this list is equal to number of vertices multiplied by 2.

8.3.9 PMI Properties

The PMI data segment itself can contain a list of PMI Properties to hold special semantic information. See PMI Property for the data description. There are no pre-defined properties for the PMI data segment itself.

8.3.10 PMI Model View Sort Orders

The PMI Model View Sort Orders collection, as shown in Figure 123, defines data for a list of model view sort orders. Each model view sort order is composed of key/value pair of strings.

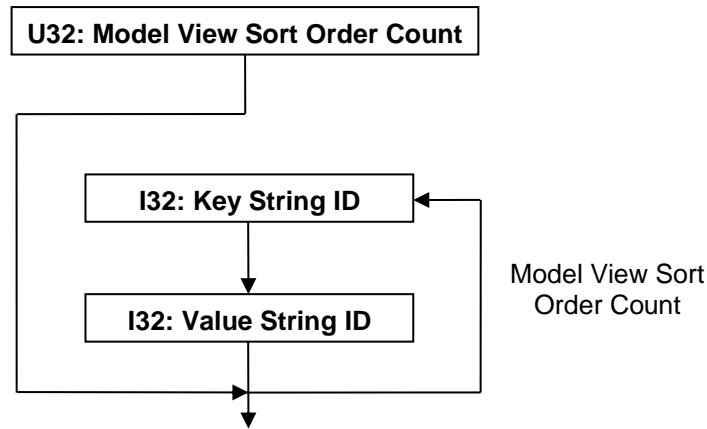


Figure 123 — PMI Model View Sort Orders data collection

U32: Model View Sort Order Count

Model View Sort Order Count specifies the number of model view sort orders.

I32: Key String ID

Key String ID specifies the string identifier for the key of model view sort order. This identifier is an index to a particular character string in the PMI String Table. An identifier value of “-1” indicates no string.

I32: Value String ID

Value String ID specifies the string identifier for the value of model view sort order. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of “-1” indicates no string.

8.3.11 PMI Association Properties

The PMI Associations Properties, as shown in Figure 124, define the data for a list of associations that are found in version 10.6 and beyond JT files.

An association defines a link (“relationship”) between two PMI, B-Rep, or Wireframe Rep entities where one entity is defined as the “source” and the other entity is defined as the “destination”.

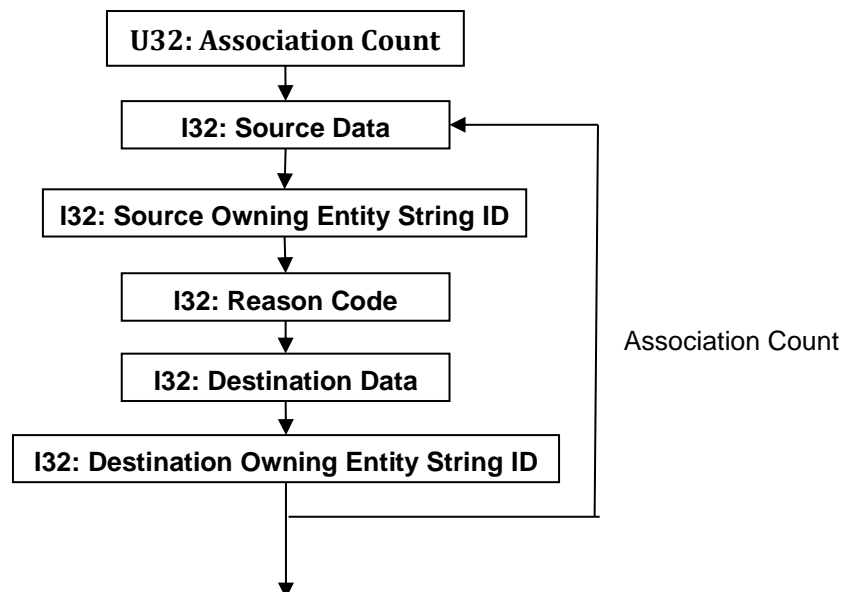


Figure 124 — Association Properties data collection

U32: Association Count

Association Count specifies the number of associations.

I32: Source Data

Source Data, shown in Table 59, is a collection of source entity information encoded/packed within a single I32 using the following bit allocation. All bits fields that are not defined as in use should be set to "0".

Table 59 — PMI Associations Source Data values

| | |
|-------------|--|
| Bits 24 -30 | Source Entity PMI or B-Rep type. Valid types include the following: = 22 B-rep body = 23 Group |
|-------------|--|

I32: Source Owning Entity String ID

Source Owning Entity String ID specifies the string identifier for the string which contains the unique CAD identifier of the component (part or assembly) that owns the source PMI or B-Rep entity. This identifier is an index to a particular character string in the PMI String Table. An identifier value of "-1" indicates no string and implies that the entity is to be found on the current node's PMI/B-Rep/Wireframe-Rep segment. It is valid for the source owning entity to be the same as the destination owning entity (therefore an association between two PMI or B-Rep entities in the same part/assembly).

I32: Reason Code

The Reason Code specifies the "reason" for the association.

The **PMI Associations Reason Code values** table can be found in the **PMI Associations** data collection section of this document

I32: Destination Data

Destination Data is a collection of destination entity information encoded/packed within a single I32. The encoding schema and interpretation of this data is the same as that documented in [Source Data](#).

I32: Destination Owning Entity String ID

Destination Owning Entity String ID specifies the string identifier for the string which contains the unique CAD identifier of the component (part or assembly) that owns the destination PMI or B-Rep entity. This identifier is an index to a particular character string in the PMI String Table as defined in PMI String Table. An identifier value of "-1" indicates no string and implies that the entity is to be found on the current node's PMI/B-Rep/Wireframe-Rep segment. It is valid for the source owning entity to be the same as the destination owning entity (therefore an association between two PMI or B-Rep entities in the same part/assembly).

8.3.12 Generic PMI Additions

The Generic PMI Entity data collection, as shown in Figure 125, is additive to the previously read Generic PMI Entity data collection. It contains information that applies to JT version 10.6 and forward JT files. This data cannot exist independent of a Generic PMI Entity description.

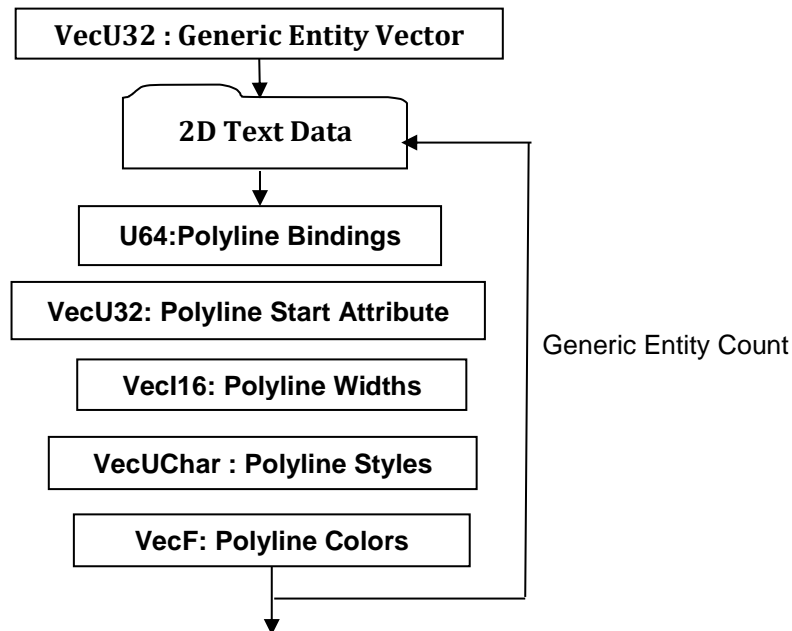


Figure 125 — Generic PMI Entity data collection

VecU32: Generic Entity Count:

Array of unsigned integers defining the amount of Generic PMI information to overlay into the already loaded PMI Generic Entities. As Generic Entity Count is looped, information in processed it should be overlaid onto the already loaded PMI Generic Entity

U64: Polyline Bindings

Polyline bindings, as shown in Table 60, are a collection of width, style and colour information encoded within a single U64 value using the following bit allocation. All bits fields that are not defined as in use should be set to “0”.

Table 60 — PMI Attribute Bindings

| | |
|----------|--|
| Bits 1 | Width binding status. Bit-1 Width information present |
| Bit 2 | Style binding status. Bit-2 Style information present |
| Bits 3-4 | Colour Binding status. Bit-3 RGB colour information present. Bit-4 RGBA colour information present. Cannot used in conjunction. |
| Bit 5 | Spacing binding status Bit-5 not currently in use |

VecU32: Polyline Start Attribute

If polylineBindings is non zero, a Polyline Start Attribute vector must be defined. The vector defines where attributes (such as; widths, styles, colours) apply within the Generic PMI data for version 10.6 and forward.

In Figure 126, titled Constructing Text Polyline Attribute data arrays, the first entry in the subsequent vectors applies up to the line identified by the first polyline start attribute vector entry. The Polyline Start Attribute vector is not zero based, the first value is 1.

Polyline start array defines the boundary in term of the already read line segments (refer to the Figure titled Constructing Non-Text Polylines from packed 2D data arrays)

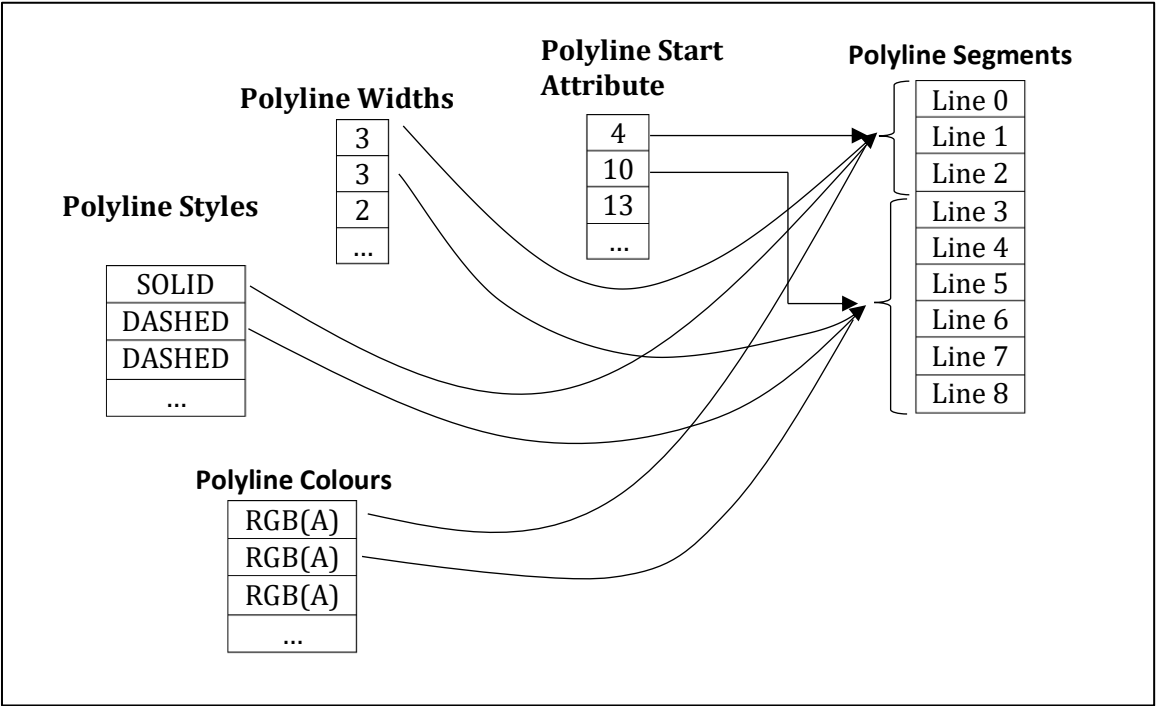


Figure 126 — Constructing Text Polyline Attribute data arrays

Vec16: Polyline Widths


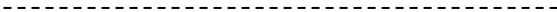











When Bit-1 is defined in the polyline binding this vector should be of equal length to polyline Start Attribute vector. This information supersedes the polyline width array read from Generic PMI Entity description. It defines the width to apply to the lines within the polyline data in pixels.

VecUChar: Polyline Styles

When Bit 2 is defined in the polyline binding this vector should be of equal length to polyline Start Attribute **vector**.

It is an vector of byte data representing the Line Style to apply to the lines within the polyline data as described in Table 61, titled Polyline Styles.

Table 61 — Polyline Styles

| | |
|------------------------------------|--|
| 0x0F | Line Type (stored in bits 0 – 3 or in binary notation 00001111) Line type specifies the polyline rendering stipple-pattern. |
| = 0 - Solid |  |
| = 1 - Dash |  |
| = 2 - Dot |  |
| = 3 - Dash_Dot |  |
| = 4 - Dash_Dot_Dot |  |
| = 5 - Long_Dash |  |
| = 6 - Centre_Dash |  |
| = 7 - Centre_Dash_Dash |  |
| = 8 - Invisible | |
| = 9 - Long Dash Dot |  |
| = 10 - Long Dash Double Dot |  |
| = 11 - Long Dash Triple Dot |  |
| = 12 - Long Dash Double Short Dash |  |
| = 13 - Undulate |  |
| = 14 - Interrupt Zigzag | |
| = 15 - Railway | |

VecF: Polyline Colors

When Bit 3 or 4 is defined in the polyline binding this vector should be of equal length to polyline Start Attribute vector when multiplied by the implied number of colour components. When Colour3 binding is in use the data is RGB. When colour 4 binding is in use the data is packed RGBA

The values should be between 0 and 1, the Alpha follows the JT format convention such that 1 is opaque.

2D Text Data

2D Text Data is additive to the previous text data definitions. The number of elements in the data collection is determined by subtracting the **Text Entity Index** from the **Text Entity Count** previously read from the **2D Text Data** collection

U32: 2D Text Entity Index

The Text Entity Index, as shown in Figure 127, is used as a count to overlay the V102 Text Entities into the existing 2D Text Data collection. The data should be processed such that this information is overlayed into the pre-existing read text data. The data is applied from the start index to the end of the Generic Entity 2D text.

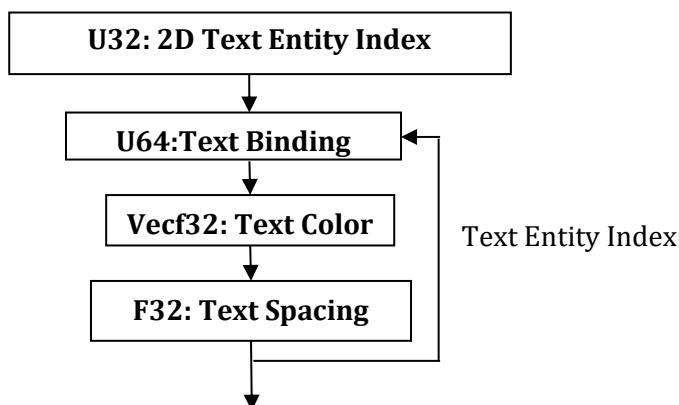


Figure 127 — 2D Text Data collection

U64: Text Binding

The Text Binding, shown in Table 62, indicates what additional v102 data is overlaid on Generic Entity 2D text already read.

Table 62 —Supported Values

| | |
|----------|--|
| Bits 1 | NA |
| Bit 2 | NA |
| Bits 3-4 | Colour Binding status. Bit-3 RGB colour information present. Bit-4 RGBA colour information present. Cannot used in conjunction. |
| Bit 5 | Spacing binding status |

Vecf32: Text Color

The **colour of this** text. When Bit 3 binding in use the data is RGB. When Bit 4 binding in use the data is packed RGBA

The values should be between 0 and 1 and the Alpha follows the JT format convention such that 1 is opaque.

F32: Text Spacing

Bit 5 is used to define the spacing between the text characters. This field is not being populated in JT files supporting up to version 10.6, this value should be left as zero or whatever it is read as.

9 Info Segment

The info segment, shown in Figure 128, is made up of text strings that may contain information on the system(s) used to author the file it exists in. The information contained in the Info Segment does not pertain to, modify, or supplement the file content existing outside of the Info Segment itself.

The Info Segment must not be used to add to existing, or define new, data constructs in an JT file.

The Info Segment does not share a “pointer swizzling” namespace with the remainder of the JT file. It uses the Logical Element Header Compression form of element header data.

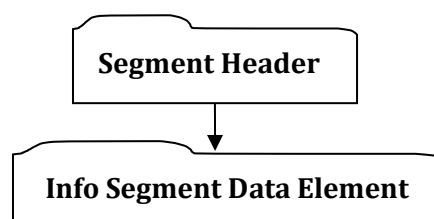


Figure 128 — Info Segment data collection

Complete description for Segment Header can be found in this document.

Info Segment Data Element

Object Type ID: 0x84c2112a, 0x0001, 0x11e7, 0x80, 0x00, 0xa4, 0x24, 0x9a, 0x27, 0x47, 0x70

A diagrammatic representation of Property Proxy Meta Data Element is shown in Figure 129.

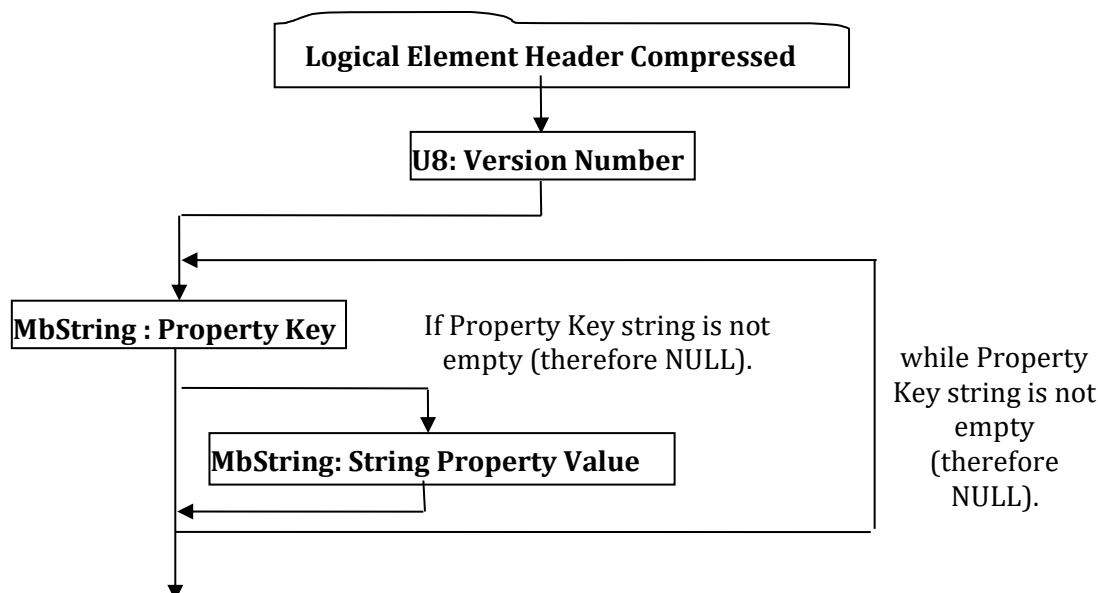


Figure 129 — Property Proxy Meta Data Element data collection

A complete description for Logical Element Header Compressed, shown in Figure 129, can be found in this document.

U8: Version Number

Version Number is the version identifier for this data collection. For information on local version numbers see Common Data Conventions and Constructs Local version numbers.

MbString: Property Key

Property Key specifies the *key* string for the property.

MbString: String Property Value

String Property Value represents the property value when Property Value Type = 1.

10 Data Compression and Encoding

10.1 Data Compression and Encoding Overview

The JT File format utilizes best-in-class compression and encoding algorithms to produce compact and efficient representations of data. The types of compression algorithms supported by the JT format vary from standard data type agnostic LZMA dictionary compression to entropy coding algorithms that exploit knowledge of the characteristics of the data types they are compressing. Some of the JT format data collections are always stored in a compressed format, whereas other data collections support multiple compression storage formats that qualitatively vary from “lossless” compression to more aggressive strategies that employ “lossy” compression. This support by the JT format of varying qualitative levels of compression allows producers of JT data to fine tune the trade-off between compression ratio and fidelity of the data.

In some instances, data may be encoded/compressed using multiple techniques applied on top of one another in a serial fashion (therefore encoding applied to the output of another encoder). One common example of this multiple encoding is when an array/vector of floating point data is first quantized into some integer codes and then these resulting integer codes are further compressed/encoded using an Arithmetic or BitLength CODEC (see Encoding Algorithms).

Beyond the data collection specific compression/encoding, some JT format Data Segment types (see) also support having LZMA compression conditionally applied to all the bytes of information persisted within

the segment. So individual fields or collections of data may first have data type specific encoding/compression algorithms applied to them, and then if their Data Segment type supports it, the resulting data may be additionally compressed using LZMA.

Whether, and at what qualitative level, a particular Data Segment's data is compressed/encoded is indicated through compression related data values stored as part of the particular Data Segment storage format. In general, aggressive application of advanced compression/encoding techniques is reserved for the heavy-weight renderable geometric data (for example triangles and wireframe lines) which can exist in a JT File.

The following sections document the format of the data compression/encoding within the JT file. Along with documenting the format, a technical description of the various compression/encoding algorithms is included and an example implementation of the decoding portion of the algorithms can be found within Annex B.

10.2 Common Compression Data Collection Formats

For convenience and brevity in documenting the JT format, this section of the reference documents the format for several common "data compression/encoding" related data collections that can exist in the JT format. You will find references to these common compression data collections in the Data Segments section of the document.

10.2.1 Int32 Compressed Data Packet

The Int32CDP (therefore Int32 Compressed Data Packet), as shown in Figure 130, represents a third-generation format used to encode/compress a collection of data into a series of Int32 based symbols. This version of the Int32CDP supersedes the two similarly-named ones from the 9.5 Specification, and should not be confused with either of its predecessors. Note that the Int32 Compressed Data Packet collection can in itself contain another nested Int32 Compressed Data Packet collection in some cases.

Four distinct CODECs are available for use within the Int32 Compressed Data Packet, depending on the nature of the data to be compressed.

The Arithmetic CODEC is a so-called "entropy coder" because it can exploit the statistics present in the relative frequencies of the values being encoded. Basically, the more often a value is present the fewer bits it takes to represent that value in the compressed code text. Values that occur too infrequently to take advantage of this property are written *aside* into the "out-of-band data" array to be encoded separately. An "escape" symbol is encoded in their place as a placeholder in the primal CODEC (note, see "Symbol" data field definition in Int32 Compressed Data Packet for further details on the representation of "escape" symbol).

Essentially the "out-of-band data" is the high-entropy residue left over after the CODEC has squeezed all the advantage out of the original data stream that it can. However, this "out-of-band data" is sent back around for another pass because sometimes there are *new* or *different* statistics to be exploited.

The *Chopper* pseudo-CODEC's is used to identify fields of bits in a sequence of otherwise incompressible data that may be hiding low-entropy statistics that can be profitably exploited. In other words, it "chops" the input data up into bit fields, and then encodes them separately using the other CODECs, or in some cases, another round of chopping. The Chopper also removes *value bias* from the original input data array. Some input data arrays may contain values that are clustered around a certain central value. In these cases, it is profitable to first subtract out a *bias value* from the original input data. In some cases, this simple expedient may dramatically reduce the apparent field width necessary to code the variation in the original sequence.

In some cases, all values may be written as "out of band" when the Codec cannot perform any useful compression. In this case, the encoded CodeText Length field will be 0, and the I32: Out-of-Band Value Count will be equal to I32: Value Count. The implied action in this case is to merely copy the Out-Of-Band value data into the output Value Element array instead of invoking the Codec.

The Move-to-Front pseudo-CODEC is useful for data that exhibits spatial coherence (therefore if a given value is likely to be used again in the near future). It decomposes the incoming data stream into two streams called “values” and “offsets”. Each time a new value is observed in the data stream, it is added to a small “cache” or “window” of the most recently seen few values (16 in this case), the value emitted to the “values” array and an “escape” emitted into the “offsets” array. When a value is seen that is already in the cache, then only its offset into the window is emitted, and the value is moved to the front of the window (hence the name). Runs and clusters are thus more efficiently represented by the values/offsets arrays. These arrays in turn are subjected to a different CODEC to finish the job – most likely the Arithmetic or Bitlength.

When all other coding options have been exhausted, the Bitlength CODEC is invoked. The Bitlength CODEC directly encodes all values given to it, does not require a probability context, and hence never produces additional “out-of-band data”. The byte stops there, in other words.

Note that in the Figure 130, encoding can loop back recursively for Out-Of-Band data and chopper fields. For JT files compliant with this specification, the maximum recursion depth may not exceed eight.

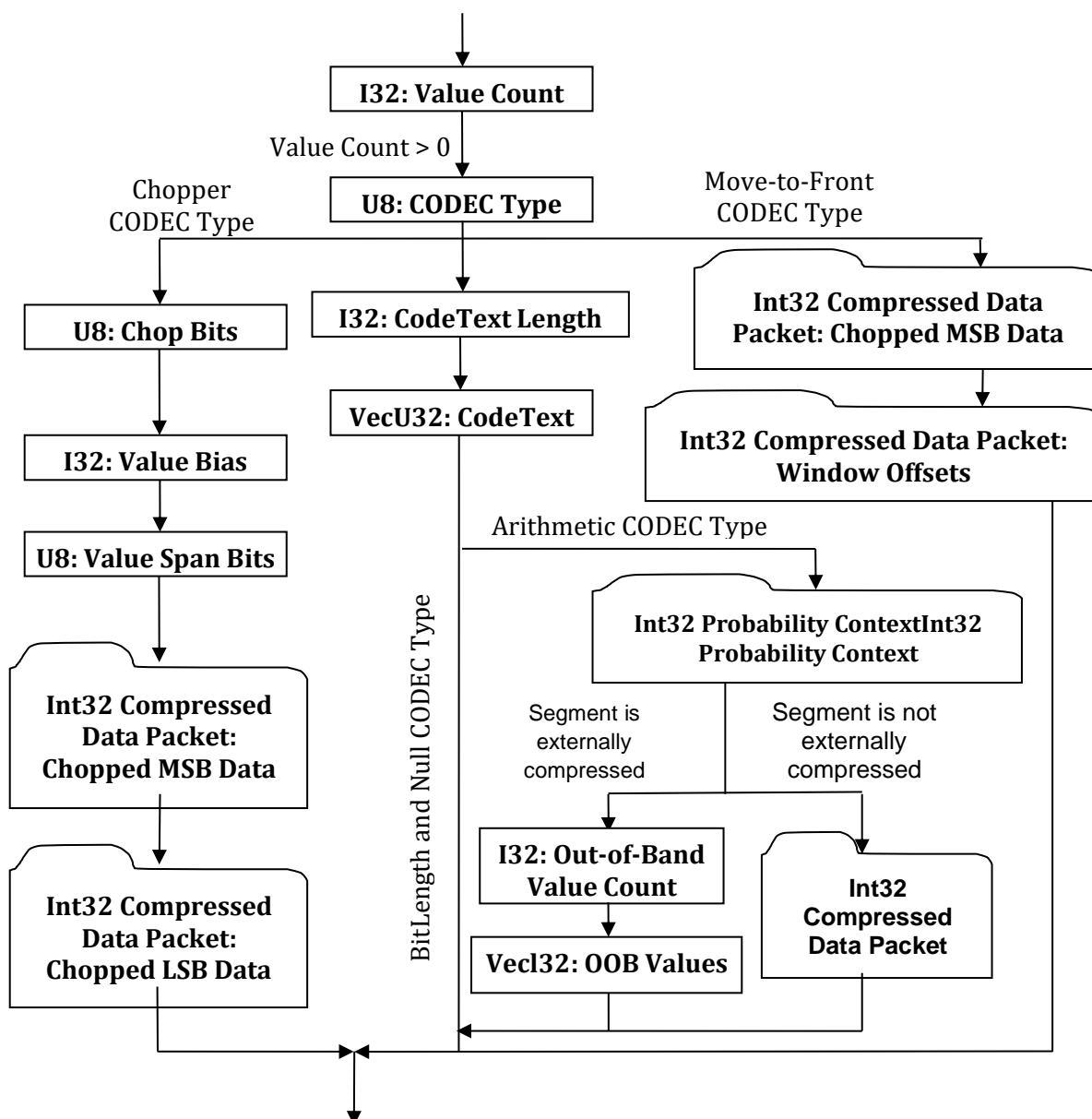


Figure 130 — Int32 Compressed Data Packet data collection

I32: Value Count

Value Count specifies the number of values that the CODEC is expected to decode (therefore it's like the "length" field written if you're just writing out a vector of integers). Upon completion of decoding the CodeText data field below, the number of decoded Values should be equal to Value Count. When only a single Probability Context Table is used, Value Count will also be equal to the number of Symbols decoded upon completion of decoding.

U8: CODEC Type

CODEC Type, shown in Table 63, specifies the algorithm used to encode/decode the data. See the section on Encoding Algorithms in this document for complete explanation of each of the encoding algorithms.

Table 63 — Int32 Probability Contexts CODEC Type values

| | |
|-----|---------------------|
| = 0 | Null CODEC |
| = 1 | Bitlength CODEC |
| = 2 | Illegal value |
| = 3 | Arithmetic CODEC |
| = 4 | Chopper CODEC |
| = 5 | Move-to-front CODEC |

I32: CodeText Length

CodeText specifies the total number of bits of CodeTextdata.

VecU32: CodeText

CodeText is the array/vector of encoded symbols. For CODEC Type not equal to "Null CODEC", the total number of bits of encoded data in this array is indicated by the previously described CodeText Length data field.

U8: Chop Bits

Chop Bits specifies the number of high-order bits "chopped off" from the *biased* input data array and coded separately from the low-order bits. Repeated applications of the Chopper pseudo-CODEC can expose low-entropy bit fields that would be inaccessible by directly coding the data array. Chop Bits is the number of bits coded into the Chopped MSB Data field. The number of Chop Bits is always greater than 0, and less than 32.

I32: Value Bias

Value Bias is the (signed) number that is subtracted from the original input data array elements *before* computing Value Span Bits and Chop Bits. See Chopped LSB Data below for a full explanation of how to reconstitute the original data values using Value Bias and the two chopped fields.

U8: Value Span Bits

Value Span Bits specifies the total bit width of the *biased* input data array. Note that Value Span Bits minus Chop Bits is the number of low-order bits present in the Value Bias and the two chopped fields.

Int32 Compressed Data Packet: Chopped MSB Data

This field contains the separately compressed most significant bits of the *biased* input data array, whose elements contain Value Span Bits bits of significance. In other words, this field contains the bit field from

the *biased* data array beginning at bit number ValueSpan-ChopBits and ending at bit number ValueSpan-1 inclusive. This field may contain negative numbers.

Int32 Compressed Data Packet: Chopped LSB Data

This field contains the separately compressed most significant bits of the original input data array, whose elements contain Value Span Bits bits of significance. In other words, this field contains the bit field from the original data array beginning at bit number 0 and ending at bit number ValueSpan-ChopBits-1 inclusive. This field may only contain positive numbers; all bits above this range shall encode to 0. A pseudo-code representation of the re-constituting the original data values is as follows:

$$\text{OrigValue}[i] = (\text{LSBValue}[i] \mid (\text{MSBValue}[i] \ll (\text{ValSpanBits} - \text{ChopBits}))) + \text{ValueBias};$$

I32: Out-of-Band Value Count

This field encodes the number of out-of-band values associated with the Arithmetic CODEC.

VecI32: OOB Values

This field encodes the out-of-band Int32 values associated with the Arithmetic CODEC.

Int32 Compressed Data Packet: Window Values

Used by the move to pseudo codec, reference Move-To-Front pseudo CODEC.

Int32 Compressed Data Packet: Window Offsets

Used by the move to pseudo codec, reference Move-To-Front pseudo CODEC.

Int32 Probability Context

Int32 Probability Context data collection, shown in Figure 131, encodes a Probability Context Table, and is present only for the Arithmetic CODEC Type. A Probability Context Table is a trimmed and scaled histogram of the input values. It tallies the frequencies of the several most frequently occurring values. It is central to the operation of the Arithmetic CODEC.

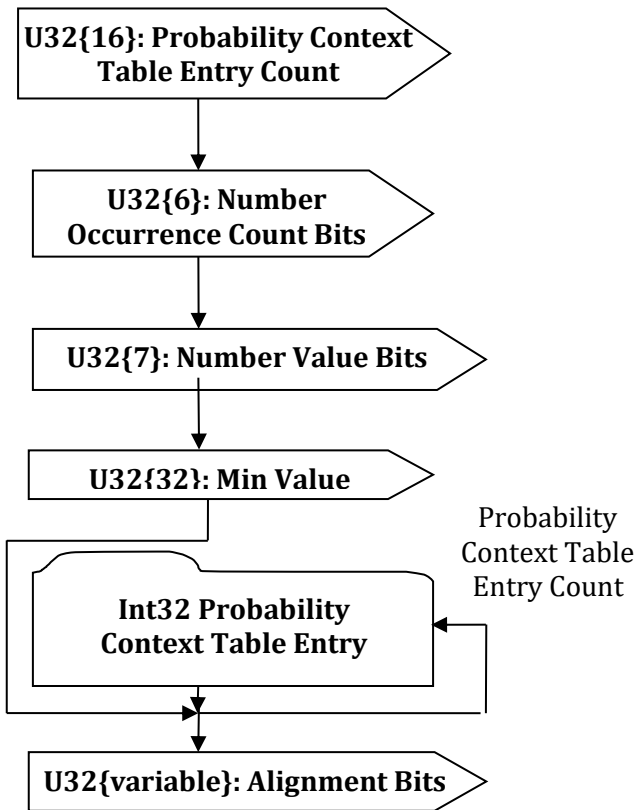


Figure 131 — Int32 Probability Context data collection

U32{16}: Probability Context Table Entry Count

Probability Context Table Entry Count specifies the number of entries in this Probability Context Table.

U32{6}: Number Occurrence Count Bits

Number Occurrence Count Bits specifies the number of bits used to encode the Occurrence Count range.

U32{7}: Number Value Bits

Number Value Bits specifies the number of bits used to encode the Associated Value range. Note that Number Value Bits is only specified in the JT file for the *first* Probability Context Table. If a second Probability Context Table is present, the Number Value Bits from the first should be used for the second as well.

U32{32}: Min Value

Min Value specifies the minimum of all Associated Values (therefore one per table entry) stored in this Probability Context Table. This value is used to compute the real Associated Value for a Probability Context Table Entry. See Associated Value description in Int32 Probability Context Table Entry.

U32{variable}: Alignment Bits

Alignment Bits represents the number of additional padding bits stored to arrive at the next even multiple of 8 bits. Values of “0” are stored in the alignment bits.

Note: Data written into a JT file is always aligned on bytes. Therefore after reading in a block of bit data such as the probability context tables it is necessary to discard any remaining bits on the last byte that is read in. This is represented by the “Alignment Bits” entry.

Int32 Probability Context Table Entry

A diagrammatical representation of the Int32 Probability Context Table Entry is shown in Figure 132.

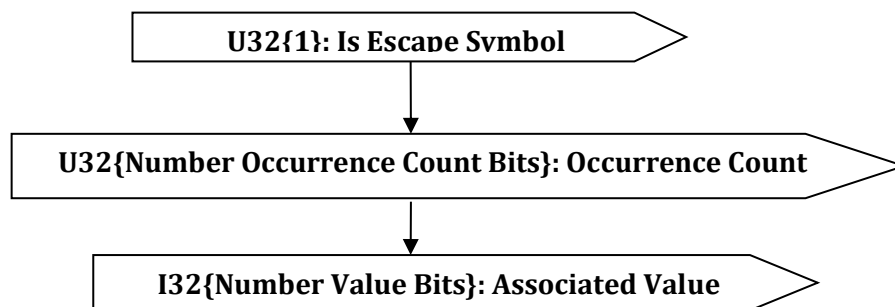


Figure 132 — Int32 Probability Context Table Entry data collection

U32{1}: Is Escape Symbol

This Boolean flag denotes whether the context entry is the escape symbol entry. At most one entry will have this flag set to true in any context.

U32{Number Occurrence Count Bits}: Occurrence Count

Occurrence Count specifies the relative frequency of the value. Complete description for Number Occurrence Count Bits can be found in Int32 Probability Context.

Note: Occurrence Counts for all symbols are normalized (converted to a relative frequency) during the write process in order to ensure the minimum amount of bits possible is used to write them while closely approximating their actual frequency.

This has several implications the reader should be aware of:

The sum of all Occurrence Counts is not guaranteed to equal the number of symbols to be decoded (see I32: Value Count for number of symbols to be decoded).

During Arithmetic decoding

pDriver->numSymbolsToRead() – Refers to the total number of symbols to be decoded (therefore I32: Value Count).

pCurrContext->totalCount() – Refers to the sum of the “Occurrence Count” values for all the symbols associated with a Probability Context.

I32{Number Value Bits}: Associated Value

Associated Value is the value (from the input data) that the symbol represents. The CODECs don’t directly encode values, they encode symbols. Symbols, then, are associated with specific values, so when the CODEC decodes an array of symbols, you can reconstruct the array of values that was intended by looking up the symbols in the Probability Context Table. This value is stored with “Min Value” subtracted from the value. Complete descriptions for “Min Value” and Number Value Bits can be found in Int32 Probability Context.

Note: The associated value for an escape symbol is undefined and therefore can be any valid U32 number.

10.2.2 Int64 Compressed Data Packet

The Int64CDP (therefore Int64 Compressed Data Packet), shown in Figure 133, represents a format used to encode/compress a collection of data into a series of Int64 based symbols. Int64CDP shares the same encoding and compression logic as Int32CDP (therefore Int32 Compressed Data Packet), except the data being compressed consists of an array of Int64 numbers instead of Int32 numbers.

Any scalar field (for example the “MinValue” field in an Int64 Probability Context) that is longer than 32 bits is written with the low-order 32 bits first in the stream, then followed by the remaining bits.

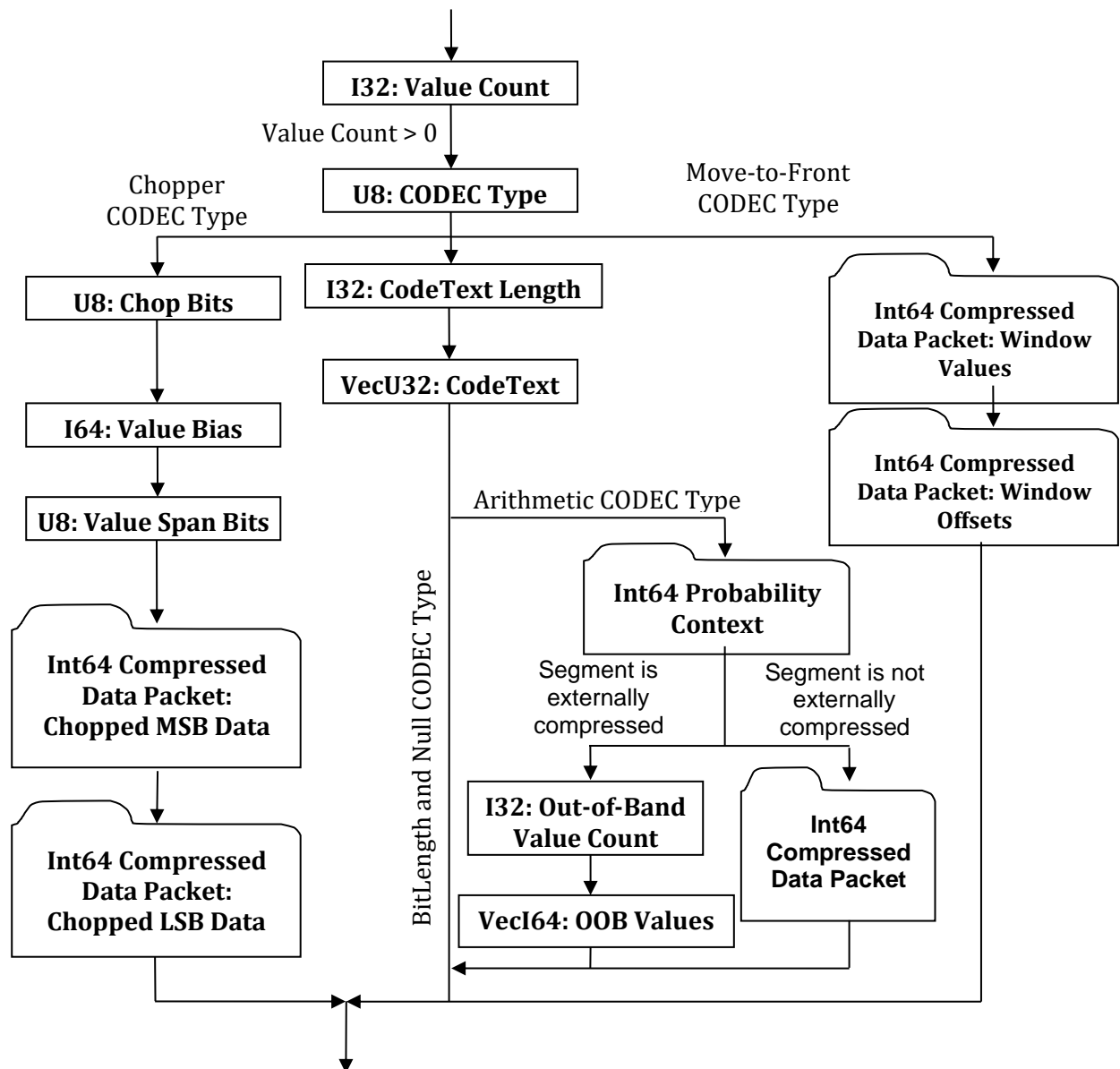


Figure 133 — Int64 Compressed Data Packet data collection

VecI64: OOB Values

This field encodes the out-of-band Int64 values associated with the Arithmetic CODEC.

I64: Value Bias

The meaning of this field is the same as I32: Value Bias except the data type is Int64 instead of Int32.

Int64 Compressed Data Packet: Chopped MSB Data

The meaning of this field is the same as Int32 Compressed Data Packet: Chopped MSB Data except the data type is Int64 instead of Int32.

Int64 Compressed Data Packet: Chopped LSB Data

The meaning of this field is the same as Int32 Compressed Data Packet: Chopped LSB Data except the data type is Int64 instead of Int32.

Int64 Compressed Data Packet: Window Values

The meaning of this field is the same as Int32 Compressed Data Packet: Chopped MSB Data except the data type is Int64 instead of Int32.

Int64 Compressed Data Packet: Window Offsets

The meaning of this field is the same as Int32 Compressed Data Packet: Window Offsets except the data type is Int64 instead of Int32.

Int64 Probability Context

Int64 Probability Context data collection, shown in Figure 134, encodes a Probability Context Table, and is present only for the Arithmetic CODEC Type. Int64 Probability Context is the same as Int32 Probability Context, except the data element is of type Int64 instead of Int32.

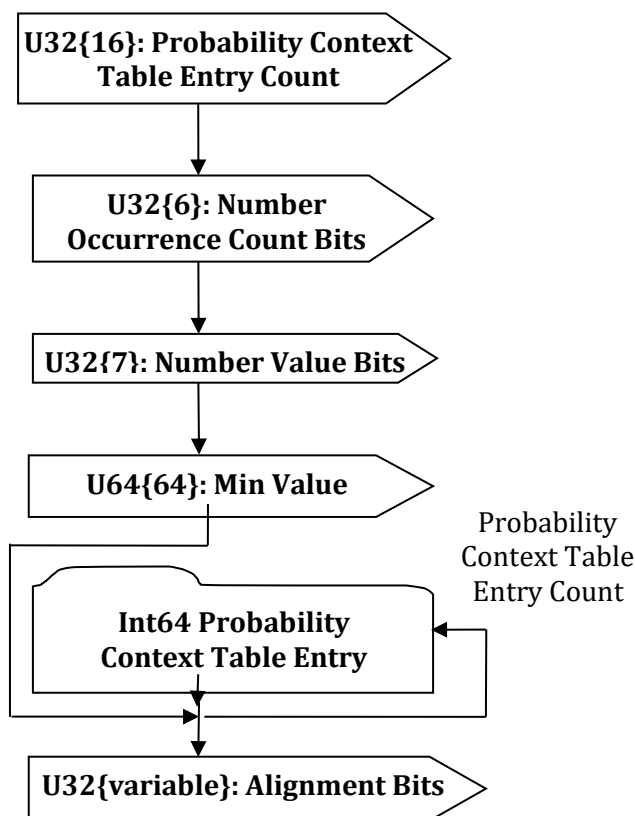


Figure 134 — Int64 Probability Context data collection

U64{64}: Min Value

Min Value specifies the minimum of all Associated Values (therefore one per table entry) stored in this Probability Context Table. This value is used to compute the real Associated Value for a Probability Context Table Entry. See Associated Value description in Int64 Probability Context Table Entry.

Int64 Probability Context Table Entry

A diagrammatical representation of the Int64 Probability Context Table Entry is shown in Figure 135.

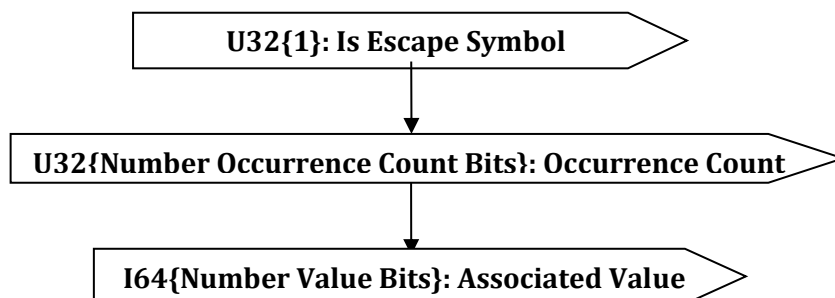


Figure 135 — Int64 Probability Context Table Entry data collection

I64{Number Value Bits}: Associated Value

Similar to I32{Number Value Bits}: Associated Value, I64{Number Value Bits}: Associated Value is the value (from the input data) that the symbol represents. This value is stored with “Min Value” subtracted from the value. Complete descriptions for “Min Value” and Number Value Bits can be found in Int64 Probability Context.

10.2.3 Compressed Vertex Coordinate Array

The Compressed Vertex Coordinate Array data collection, shown in Figure 136, contains the quantization data/representation for a set of vertex coordinates.

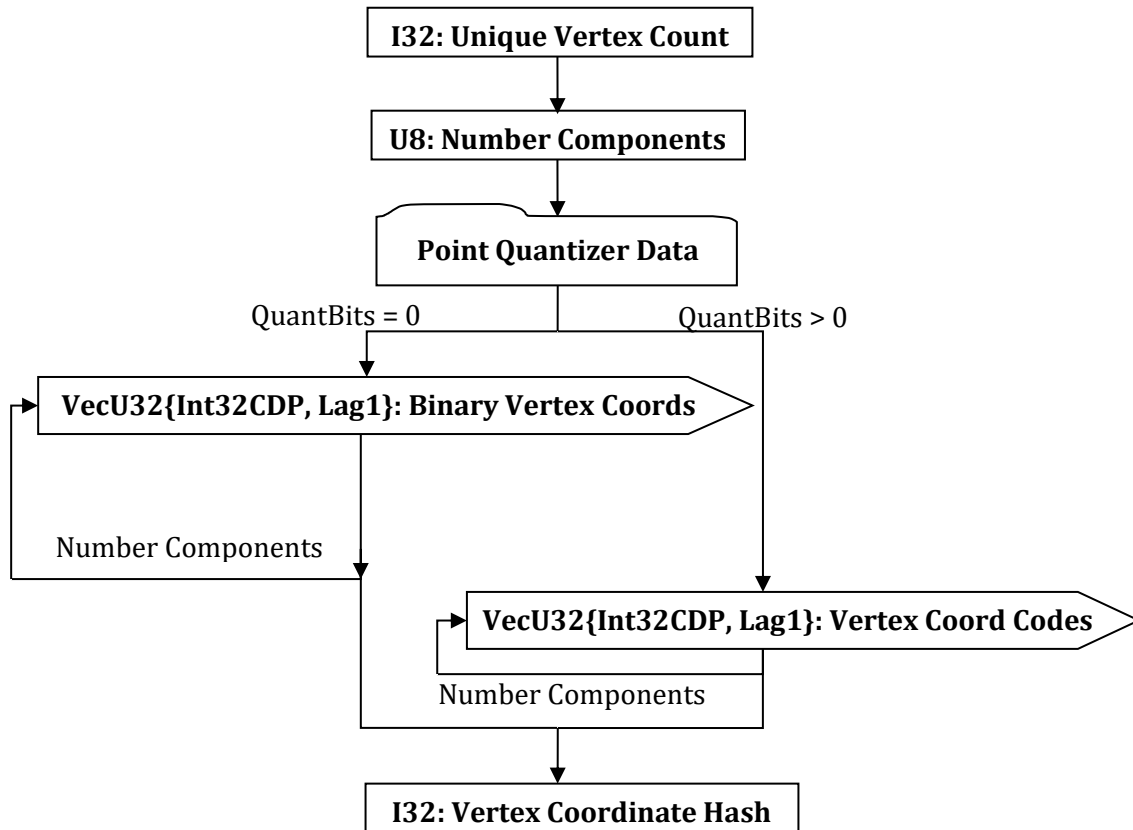


Figure 136 — Compressed Vertex Coordinate Array data collection

Complete description for Point Quantizer Data can be found in Point Quantizer Data.

The above predicates “QuantBits = 0” and “QuantBits > 0” refer to the value of the field U8: Number Of Bits stored in the three components of Point Quantizer Data. All three of these fields are required to be equal.

I32: Unique Vertex Count

Vertex Count specifies the count (number of unique) vertices in the Vertex Codes arrays. Identical values are only stored once therefore it may be necessary to smear out the vertices as described in TopoMesh Compressed Rep Data and TopoMesh Topologically Compressed LOD Data.

U8: Number Components

Number Components specifies the number of vertex components present for each vertex record in the set of vertex records. The only legal value for this field is 3.

VecU32{Int32CDP, Lag1}: Binary Vertex Coords

Binary Vertex Coords is a vector of the *i*th component values of a set of vertex coordinates *interpreted* as integers. That is to say, the binary IEEE-754 floating point representation of the coordinates is fed *directly* into the Lag1 predictor as if they were integers.

VecU32{Int32CDP, Lag1}: Vertex Coord Codes

Vertex Coord Codes is a vector of quantizer “codes” for all the *i*th component values of a set of vertex coordinates. Vertex Coord Codes uses the Int32 version of the CODEC to compress and encode data.

I32: Vertex Coordinate Hash

The Vertex Coordinate Hash is the combined hash of the unique vertex coordinate records. If the number of quantization bits is equal to zero the hash value is equal to the combined hash of the vertex coordinate values for each of the component arrays. If the number of quantization bits is greater than 0 the hash value is equal to the combined hash of the vertex coordinates codes for each of the component arrays. Refer to the Hashing Annex C for a more detailed description on hashing.

```
UInt32 uHash      = 0;
uInt32 nUniqVtx   = 0;
vecF32 vCoord[nUniqVtx][3];
vecU32 vCodes[3];
...
if ( uQuantBits == 0 ) {
    for ( int i=0 ; i<nComp ; i++ ) {
        for ( int j=0 ; j<nUniqVtx ; j++ ) {
            uHash = hash32( (const UInt32*)&vCoord[j][i], 1, uHash );
        }
    }
} else {
    for ( int i=0 ; i<nComp ; i++ ) {
        uHash = hash32( &vCodes[i], nUniqVtx, uHash );
    }
}
```

10.2.4 Compressed Vertex Normal Array

The Compressed Vertex Normal Array data collection, shown in Figure 137, contains the compressed data/representation for a set of vertex normals. Compressed Vertex Normal Array data collection is only present if previously read vertex bindings denote normals are present (see Vertex Shape LOD Data U64 : Vertex Bindings for complete explanation of the vertex bindings).

A variation of the CODEC developed by Michael Deering at Sun Microsystems is used to encode the normals when quantization is enabled. The variation being that the “Sextants” are arranged differently than in Deering’s scheme [4], for better delta encoding. See Deering Normal CODEC for a complete explanation on the Deering CODEC used.

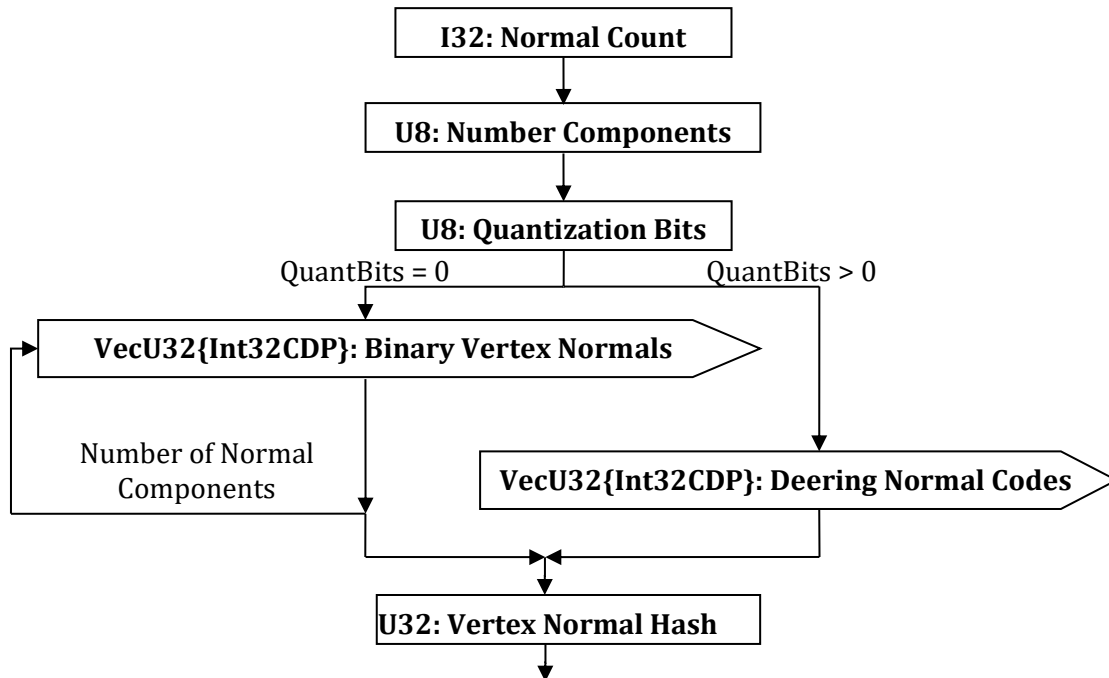


Figure 137 — Compressed Vertex Normal Array data collection

I32: Normal Count

Normal count specifies the number of normals. This number should equal the total number of vertex records.

U8: Number Components

Number Components specifies the number of normal components present for each vertex record in the set of vertex records.

U8: Quantization Bits

The number of bits used when the Deering Normal CODEC if quantization is enabled. A value of 0 denotes that quantization is disabled. The maximum value for this field is 13 (so that the resulting Deering normal codes are of at most 32 bits).

VecU32{Int32CDP}: Binary Vertex Normals

Binary Vertex Normals is a vector of the *i*th component values of a set of vertex normals *interpreted* as integers. That is to say, the binary IEEE-754 floating point representation of the coordinates is fed *directly* into the Lag1 predictor as if they were integers.

VecU32{Int32CDP}: Deering Normal Codes

Deering Normal Codes is a vector of “codes” (one per normal) for a set of normals produced by the Deering Normal Codec (q.v.). Deering Normal Codes uses the Int32 version of the CODEC to compress and encode data.

U32: Vertex Normal Hash

The Vertex Normal Hash is the combined hash of the vertex normals. If the number of quantization bits is equal to zero the hash value is equal to the combined hash of the vertex normal values for each of the component arrays. If the number of quantization bits is greater than 0 the hash value is equal to the combined hash of the Sextant, Octant, Theta, and Psi Codes for all vertex records.

```

UInt32 uHash    = 0;
UInt32 nVtxRec  = 0;
vecF32 vNorm[nVtxRec][3];
vecU32 vDeeringCodes;
...
if ( uQuantBits == 0 ) {
    for ( int i=0 ; i<nComp ; i++ ) {

```

```

for ( int j=0 ; j<nVtxRec ; j++) {
    uHash = hash32( (UInt32*)&vNorm[j][i]), 1, uHash );
}
} else {
    uHash = hash32( &vDeeringCodes, nVtxRec, uHash );
}

```

10.2.5 Compressed Vertex Texture Coordinate Array

The Compressed Vertex Texture Coordinate Array data collection, shown in Figure 138, contains the quantization data/representation for a set of vertex texture coordinates. Compressed Vertex Texture Coordinate Array data collection is only present if previously read vertex bindings denote texture coordinates are presents (See Vertex Shape LOD Data U64 : Vertex Bindings for complete explanation of the vertex bindings).

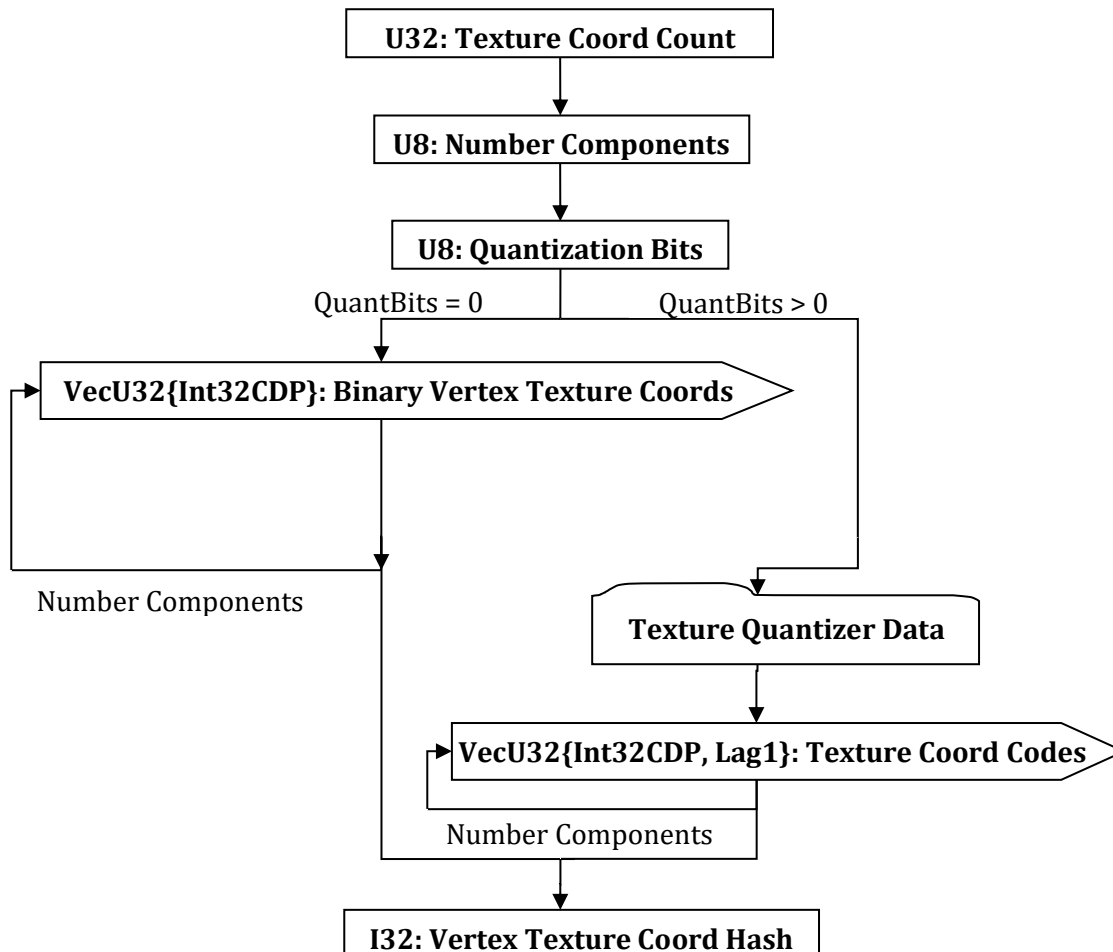


Figure 138 — Compressed Vertex Texture Coordinate Array data collection

Complete description for Texture Quantizer Data can be found in this document.

U32: Texture Coord Count

Coord Count specifies the number of Texture Coordinates. This number should equal the total number of vertex records.

U8: Number Components

Number Components specifies the number of Texture Coordinate components present for each vertex record in the set of vertex records.

U8: Quantization Bits

Number of Bits specifies the quantized size (therefore the number of bits of precision) for each of the components. The actual number of quantization bits used is specified within Texture Quantizer Data. Value shall be within range [0:24] inclusive.

VecU32{Int32CDP}: Binary Vertex Texture Coords

Binary Vertex Texture Coordinates is a vector of the *i*th component values of a set of texture coordinates *interpreted* as integers. That is to say, the binary IEEE-754 floating point representation of the coordinates is fed *directly* into the Lag1 predictor as if they were integers.

VecU32{Int32CDP, Lag1}: Texture Coord Codes

Texture Coord Codes is a vector of quantizer “codes” for all the *n*th-component of a set of vertex texture coordinates. Texture Coord Codes uses the Int32 version of the CODEC to compress and encode data.

I32: Vertex Texture Coord Hash

The Vertex Texture Coord Hash is the combined hash of the Vertex Texture Coordinates. If the number of quantization bits is equal to zero the hash value is equal to the combined hash of the vertex texture coordinate values for each of the component arrays. If the number of quantization bits is greater than 0 the hash value is equal to the combined hash of the vertex texture coordinates codes for each of the component arrays.

```
UInt32 uHash      = 0;
uInt32 nVtxRec    = 0;
vecF32 vTexCoord[nVtxRec][4];
vecU32 vCodes[4];
...
if ( uQuantBits == 0 ) {
    for ( int i=0 ; i<nComp ; i++ ) {
        for ( int j=0 ; j<nVtxRec ; j++ ) {
            uHash = hash32( (UInt32*)&vTexCoord[j][i]), 1, uHash );
        }
    }
} else {
    for ( int i=0 ; i<nComp ; i++ ) {
        uHash = hash32( &vCodes[i], nVtxRec, uHash );
    }
}
```

10.2.6 Compressed Vertex Colour Array

The Compressed Vertex Colour Array data collection, shown in Figure 139, contains the quantization data/representation for a set of vertex colours. Compressed Vertex Colour Array data collection is only present if previously read Colour Binding value is not equal to zero (See Vertex Shape LOD Data for complete explanation of Colour Binding data field).

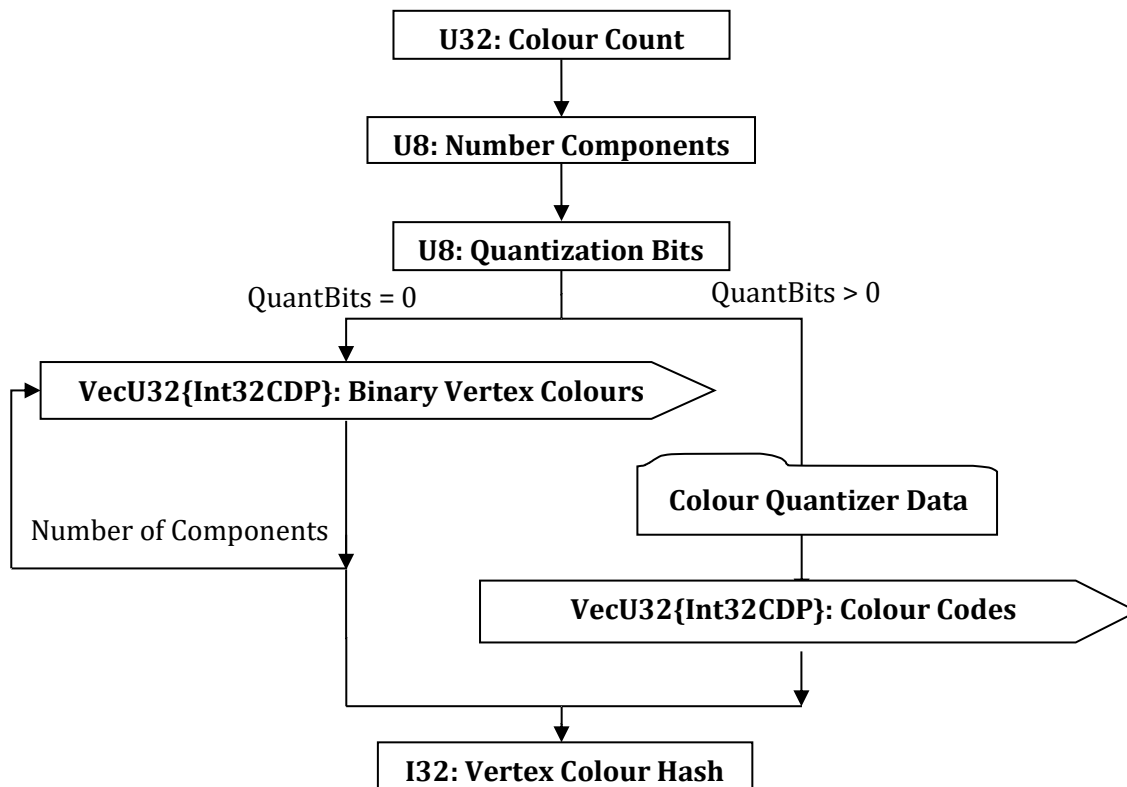


Figure 139 — Compressed Vertex Colour Array data collection

Complete description for Colour Quantizer Data can be found in Colour Quantizer Data.

U32: Colour Count

Colour count specifies the number of colour records. This number should equal the total number of vertex records.

U8: Number Components

Number Components specifies the number of Colour components present for each vertex record in the set of vertex records.

U8: Quantization Bits

Number of Bits specifies the quantized size (therefore the number of bits of precision) for each of the 3 or 4 colour components. This value shall satisfy the following condition: “0 <= Number Of Bits <= 8”.

VecU32{Int32CDP}: Binary Vertex Colours

Binary Vertex Colours is a vector of the *i*th component values of a set of texture coordinates *interpreted* as integers. That is to say, the binary IEEE-754 floating point representation of the coordinates is fed *directly* into the Lag1 predictor as if they were integers.

VecU32{Int32CDP}: Colour Codes

Colour Codes is a vector of quantizer “codes” for all the vertex colours. Each Colour Code contains up to four bit fields representing the RGBA or HSVA encoded colour. The width of each field is set by the corresponding data in Colour Quantizer Data. The alpha field lies in the least significant bits, the B/V field lies immediately to the left of the alpha field, the G/S field lies immediately to the left of B/V field, and so on toward the more significant bits.

I32: Vertex Colour Hash

The Vertex Colour Hash is the combined hash of the vertex colours. If the number of quantization bits is equal to zero the hash value is equal to the combined hash of the vertex colour values for each of the component arrays. If the number of quantization bits is greater than 0 the hash value is equal to the hash of the Colour Codes vector.

```

UInt32 uHash      = 0;
uInt32 nVtxRec = 0;
vecF32 vCol[nVtxRec][3];
vecU32 vColorCodes;
...
if ( uQuantBits == 0 ) {
    for ( int i=0 ; i<nComp ; i++ ) {
        for ( int j=0 ; j<nVtxRec ; j++ ) {
            uHash = hash32( (UInt32*)&vCol[j][i], nVtxRec, uHash );
        }
    }
} else {
    uHash = hash32( &vColorCodes, nVtxRec, uHash );
}

```

10.2.7 Compressed Vertex Flag Array

The Compressed Vertex Flag Array data collection, shown in Figure 140, contains the quantization data/representation for per vertex flags. Compressed Vertex Flag Array data collection is only present if previously read Vertex Flag Binding value is not equal to zero.

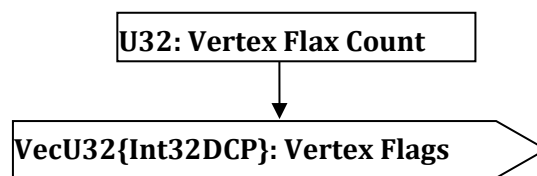


Figure 140 —Compressed Vertex Flag Array data collection

U32: Vertex Flag Count

Vertex flag count specifies the number of vertex flags. This number should be equal to the total number of vertex records.

VecU32{Int32CDP}: Vertex Flags

Vertex Flags is a vector of per vertex bit flags encoded as integers with valid values of either 0 (false) or 1 (true). Vertex Flags uses the Int32 version of the CODEC to compress and encode data.

10.2.8 Compressed Auxiliary Fields Array

Compressed Auxiliary Fields Array data, as shown in Figure 141, contains additional geometric shape data (auxiliary vertex fields) that may be associated with each vertex record defined in TopoMesh Compressed LOD Data. Each Auxiliary field contains data that is parallel to the existing vertex record fields in order capture additional information about each vertex (for example Vertex Identifiers, Weights, or other information). Importantly, each datum in the Auxiliary field may have a single value (of the specified type), or *may have many values* (called „steps“). Again, each data collection may have multiple Auxiliary fields, each of which contains one datum per vertex record in the TopoMesh Compressed LOD Data, each datum containing 1 or more values (steps).

Each Auxiliary field has a GUID tag (unique to the fields in the current TopoMesh Compressed LOD Data record), and a field data type that allows the user to store a variety of different data types. It is not intended that Auxiliary fields be required to directly participate in rendering – that is the province of the vertex attributes defined in TopoMesh Compressed LOD Data.

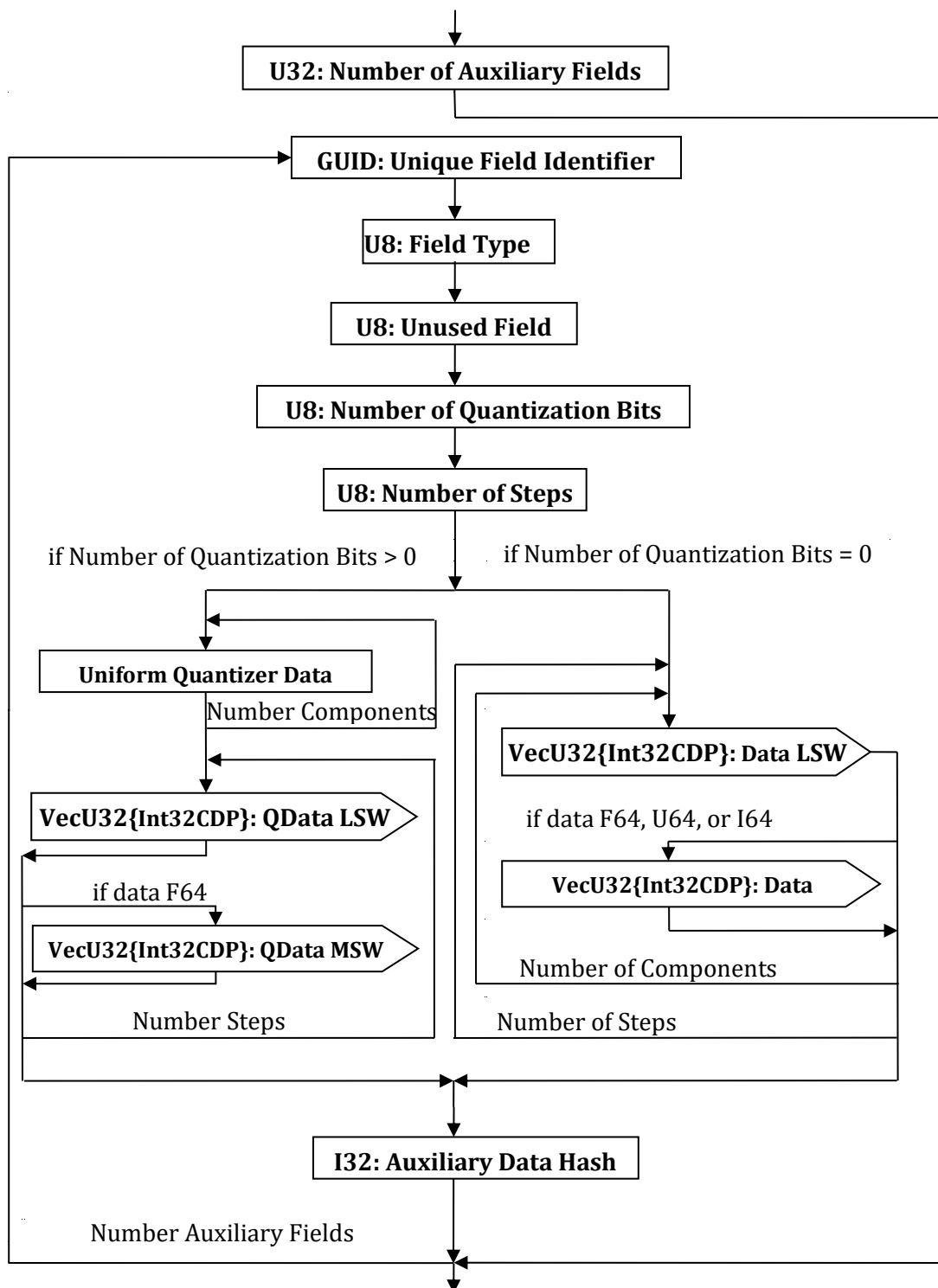


Figure 141 — Compressed Auxiliary Fields Array data collection

U32: Number of Auxiliary Fields

The number of auxiliary vertex fields included in the data collection.

GUID: Unique Field Identifier

Each Auxiliary Vertex Field is associated with Unique Field Identifier to denote the usage of the contained data. This field is intended to be user defined. Any valid GUID, as defined in Table 4, can be used as a Unique Field Identifier.

U8: Field Type

Defines the number of components and type of data contained within the auxiliary field based upon the values shown in Table 64.

Table 64 — TopoMesh Compressed Rep Data V2 Field Type values

| Type | Data | Components | Type | Data | Components |
|------|------|------------|------|------|------------|
| 1 | U8 | 1 | 24 | I32 | 4 |
| 2 | U8 | 2 | 25 | U64 | 1 |
| 3 | U8 | 3 | 26 | U64 | 2 |
| 4 | U8 | 4 | 27 | U64 | 3 |
| 5 | I8 | 1 | 28 | U64 | 4 |
| 6 | I8 | 2 | 29 | I64 | 1 |
| 7 | I8 | 3 | 30 | I64 | 2 |
| 8 | I8 | 4 | 31 | I64 | 3 |
| 9 | U16 | 1 | 32 | I64 | 4 |
| 10 | U16 | 2 | 33 | F32 | 1 |
| 11 | U16 | 3 | 34 | F32 | 2 |
| 12 | U16 | 4 | 35 | F32 | 3 |
| 13 | I16 | 1 | 36 | F32 | 4 |
| 14 | I16 | 2 | 37 | F32 | 2x2 |
| 15 | I16 | 3 | 38 | F32 | 3x3 |
| 16 | I16 | 4 | 39 | F32 | 4x4 |
| 17 | U32 | 1 | 40 | F64 | 1 |
| 18 | U32 | 2 | 41 | F64 | 2 |
| 19 | U32 | 3 | 42 | F64 | 3 |
| 20 | U32 | 4 | 43 | F64 | 4 |
| 21 | I32 | 1 | 44 | F64 | 2x2 |
| 22 | I32 | 2 | 45 | F64 | 3x3 |
| 23 | I32 | 3 | 46 | F64 | 4x4 |

U8: Unused Field

This field is unused.

U8: Number of Quantization Bits

Each Auxiliary field can be lossily or losslessly compressed. A value of 0 in this field means that that field data are to be losslessly compressed. This field must be 0 for all integer field types (therefore lossy compression is not defined for integer field types). Only floating-point field types may be lossily compressed. A value between 1 and 32, or between 1 and 64 for double precision floating point typed fields, indicates that the data are quantized to the indicated number of bits of significance.

U8: Number of Steps

This field represents the number of “steps” present with each vertex record for the given Auxiliary field. The field must be a number greater than 0. All vertex records have the same number of “steps.” One or more steps, called “suppressed steps”, may contain no auxiliary data. At least one step must be not suppressed for any auxiliary field.

VecU32{Int32CDP}: Data LSW

Data LSW is an array of the low order 32 bits of the vector formed from all steps, components, and vertex records of a single Auxiliary Data field. The data is laid out by cycling through vertex records first, then components, and steps last so that adjacent vertex records for the same step and component are contiguous (therefore in “stepwise-major, component semi-major” order). For U8, I8, U16, I16, U32, I32 and lossless F32 data types this contains all bits. For U64, I64, and lossless F64 data types it contains bits 0 through 31. Data LSW uses the Int32 version of the CODEC to compress and encode data. In the case when the data is a zero length vector, it means that no auxiliary data exists on any vertex record for this component in this step. In addition, if no auxiliary data exists for one component in a particular step then it is guaranteed that no auxiliary data exists for all the other components in the same step.

VecU32{Int32CDP}: Data MSW

Data MSW is an array of the low order 32 bits of the vector formed from all steps, components, and vertex records of a single Auxiliary Data field. The data is laid out by cycling through vertex records first, then components, and steps last so that adjacent vertex records for the same step and component are contiguous (therefore in “stepwise-major, component semi-major” order). For U64, I64, and lossless F64 data types it contains bits 32 through 63. Data MSW uses the Int32 version of the CODEC to compress and encode data. In the case when the data is a zero length vector, it means that no auxiliary data exists on any vertex record for this component in this step. In addition, if no auxiliary data exists for one component in a particular step then it is guaranteed that no auxiliary data exists for all the other components in the same step.

VecU32{Int32CDP}: QData LSW

QData LSW is an array of the low order 32 bits of the vector formed from all components and vertex records of a single Auxiliary Data field. The data is laid out by cycling through vertex records first, then components so that adjacent vertex records for the same step are contiguous (therefore in “stepwise-major” order) For the F32 data type this field contains all bits. For F64 the data type it contains bits 0 through 31. QData LSW uses the Int32 version of the CODEC to compress and encode data. Note that there is one QData LSW packet for each step in the Auxfield rather than a single unified packet as with Data LSW. In the case when the data is a zero length vector, it means that no auxiliary data exists on any vertex record for this component in this step. In addition, if no auxiliary data exists for one component in a particular step then it is guaranteed that no auxiliary data exists for all the other components in the same step.

VecU32{Int32CDP}: QData MSW

QData MSW is an array of the low order 32 bits of the vector formed from all steps, components, and vertex records of a single Auxiliary Data field. The data is laid out by cycling through vertex records first, then components, and steps last so that adjacent vertex records for the same step and component are contiguous (therefore in “stepwise-major, component semi-major” order). For U64, I64, and lossless F64 data types it contains bits 32 through 63. QData MSW uses the Int32 version of the CODEC to compress and encode data. Note that there is one QData MSW packet for each step in the Auxfield rather than a single unified packet as with Data MSW. In the case when the data is a zero length vector, it means that no auxiliary data exists on any vertex record for this component in this step. In addition, if no auxiliary data exists for one component in a particular step then it is guaranteed that no auxiliary data exists for all the other components in the same step.

I32: Auxiliary Data Hash

The Auxiliary Data Hash is the combined hash of auxiliary field data arrays.

```
UInt32 uHash          = 0;
UInt32 nVtxRec        = 0, // Number of vertex records
nComp                = 0, // Number of components in current Auxfield
nSteps               = 0; // Number of steps in current Auxfield
vecU32 vDataLSW [nSteps][nComp],
vDataMSW [nSteps][nComp],
vQDataLSW[nSteps],
vQDataMSW[nSteps];
...
if (nQuantBits == 0) {
    if ( bU8 || bI8 || bU16 || bI16 || bU32 || bI32 || bF32 ) {
        for ( int i=0 ; i<nSteps ; i++ )
            for ( int j=0 ; j<nComp ; j++ )
                uHash = hash32( vDataLSW[i][j], nVtxRec, uHash );
    }
    else { // bU64 || bI64
        for ( int i=0 ; i<nSteps ; i++ ) {
            for ( int j=0 ; j<nComp ; j++ ) {
                uHash = hash32( vDataLSW[i][j], nVtxRec, uHash );
                uHash = hash32( vDataMSW[i][j], nVtxRec, uHash );
            }
        }
    }
} else {
    if (bF32) {
```

```

    for ( int i=0 ; i<nSteps ; i++ )
        uHash = hash32( vQDataLSW[i], nVtxRec * nComp, uHash );
}
else {    // bF64
    for ( int i=0 ; i<nSteps ; i++ ) {
        uHash = hash32( vQDataLSW[i], nVtxRec * nComp, uHash );
        uHash = hash32( vQDataMSW[i], nVtxRec * nComp, uHash );
    }
}
}

```

10.2.9 Point Quantizer Data

A Point Quantizer Data collection, as shown in Figure 142, is made up of three Uniform Quantizer Data collections; there is a separate Uniform Quantizer Data collection for the X, Y, and Z values of point coordinates.

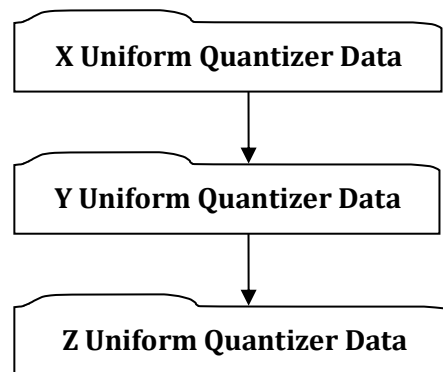


Figure 142 — Point Quantizer Data collection

Complete description for X Uniform Quantizer Data, Y Uniform Quantizer Data and Z Uniform Quantizer Data can be found in Uniform Quantizer Data.

10.2.10 Texture Quantizer Data

A Texture Quantizer Data collection, as shown in Figure 143, is made up of n Uniform Quantizer Data collections; there is a separate Uniform Quantizer Data collection for each component of the texture coordinates. The number of components is not specified within the quantizer, but rather is determined by the number of texture components present in the underlying data (See Compressed Vertex Texture Coordinate Arrays U8: Number Components)..

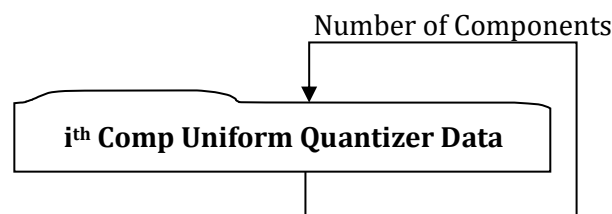


Figure 143 — Texture Quantizer Data collection

Complete description for U Uniform Quantizer Data and V Uniform Quantizer Data can be found in Uniform Quantizer Data.

10.2.11 Colour Quantizer Data

A Colour Quantizer Data collection, as shown in Figure 144, contains the quantizer information for each of the colour components. The Colour Quantizer utilizes a separate Uniform Quantizer Data collection for each of the 4 colour components, as shown in Table 65, however if the HSV colour model is being used, then it is not necessary to store a complete Uniform Quantizer Data Collection.

For the HSV model, since the range values for each colour component are constant, only the Number of Bits of precision for each colour component's Uniform Quantizer is stored. The Uniform Quantizer range values for the HSV colour components should always be assumed to be the following:

Table 65 — Colour Quantizer values

| Component | Quantizer Range | |
|------------|-----------------|-----|
| | Min | Max |
| Hue | 0.0 | 6.0 |
| Saturation | 0.0 | 1.0 |
| Value | 0.0 | 1.0 |
| Alpha | 0.0 | 1.0 |

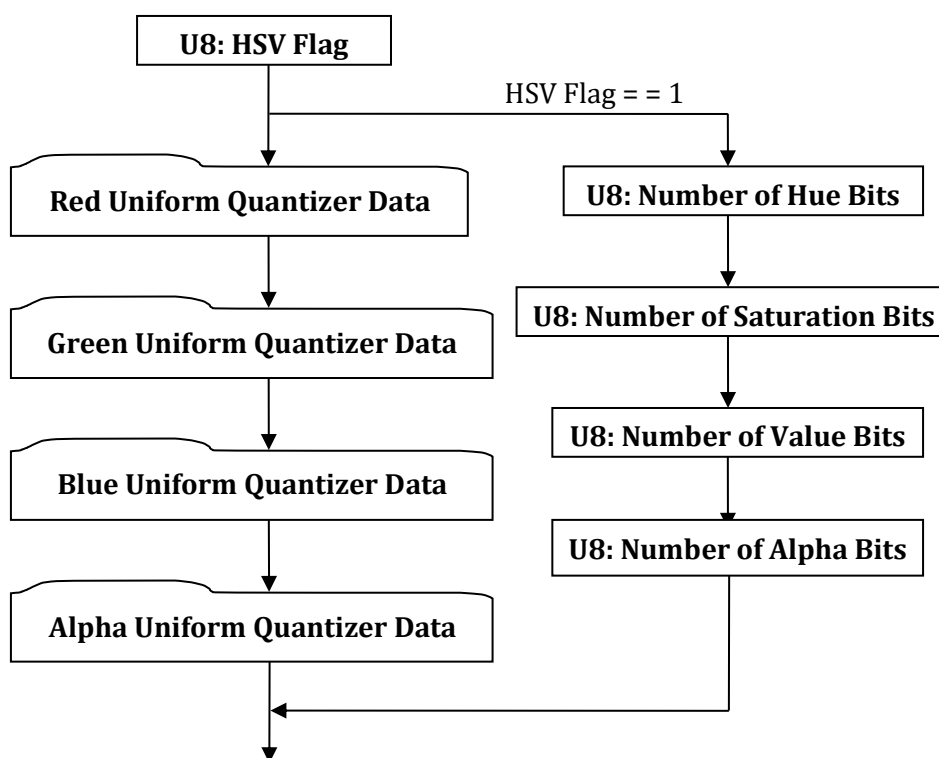


Figure 144 — Colour Quantizer Data collection

Complete descriptions for Red Uniform Quantizer Data, Green Uniform Quantizer Data, Blue Uniform Quantizer Data and Alpha Uniform Quantizer Data can be found in Uniform Quantizer Data. These four Uniform Quantizer Data collections are only present when data field HSV Flag = 0.

U8: HSV Flag

HSV Flag is a flag indicating whether colour component data is stored in HSV colour model form, as shown in Table 66.

Table 66 — Colour Quantizer HSV Flag values

| | |
|-----|--|
| = 0 | Colour component data stored in RGB colour model form. |
| = 1 | Colour component data stored in HSV colour model form. |

U8: Number of Hue Bits

Number of Hue Bits specifies the quantized size (therefore the number of bits of precision) for the Hue component of the colour. Number of Hue Bits data is only present when data field HSV Flag = 1.

U8: Number of Saturation Bits

Number of Saturation Bits specifies the quantized size (therefore the number of bits of precision) for the Saturation component of the colour. Number of Saturation Bits data is only present when data field HSV Flag = 1.

U8: Number of Value Bits

Number of Value Bits specifies the quantized size (therefore the number of bits of precision) for the Value component of the colour. Number of Value Bits data is only present when data field HSV Flag = 1.

U8: Number of Alpha Bits

Number of Alpha Bits specifies the quantized size (therefore the number of bits of precision) for the Alpha component of the colour. Number of Alpha Bits data is only present when data field HSV Flag = 1.

10.2.12 Uniform Quantizer Data

The Uniform Quantizer Data collection, as shown in Figure 145, contains information that defines a scalar quantizer/dequantizer (encoder/decoder) whose range is divided into levels of equal spacing.

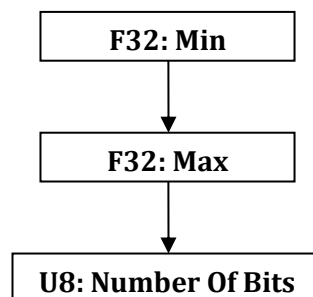


Figure 145 — Uniform Quantizer Data collection

F32: Min

Min specifies the minimum of the quantized range.

F32: Max

Max specifies the maximum of the quantized range.

U8: Number Of Bits

Number of Bits specifies the quantized size (therefore the number of bits of precision). In general, this value shall satisfy the following condition: “0 <= Number Of Bits <= 32”.

10.2.13 Compressed Entity List for Non-Trivial Knot Vector

Compressed Entity List for Non-Trivial Knot Vector data collection specifies index identifiers (therefore indices to particular entities within a list of entities) for a set of entities that contain Non-Trivial Knot Vectors. The entity types which can contain non-trivial knot vectors include:

JT B-Rep NURBS Surfaces

JT B-Rep PCS NURBS Curves

JT B-Rep MCS NURBS Curves

Wireframe MCS NURBS Curves

Note that any one occurrence of Compressed Entity List for Non-Trivial Knot Vector data collection will only contain index identifiers for one particular type of the above listed entities. The entity type is inferred based on the data collection which includes/references the Compressed Entity List for Non-Trivial Knot Vector.

A trivial knot vector is one which completely satisfies all conditions of at least one of the following cases:

Case-1 for trivial knot vector:

- Number of knots is an even number.
- Knot vector has a [0:1] knot range.
- There are no interior knots (therefore $\text{NumberKnots} = 2 * (\text{NurbsEntityDegree} + 1)$).

Case-2 for trivial knot vector:

- Number of knots is an even number.
- Knot vector has a [0:1] knot range.
- $\text{NurbsEntityDegree} < 3$.
- Difference between successive non-repeating knots (therefore KnotDelta) is:
 - $\text{KnotDelta} = 2.0 / (\text{NumberKnots} - (2.0 * \text{NurbsEntityDegree}))$.

Any knot vector which does not satisfy one of the above cases for “trivial knot vector” is classified as a “non-trivial knot vector”, as shown in Figure 146.

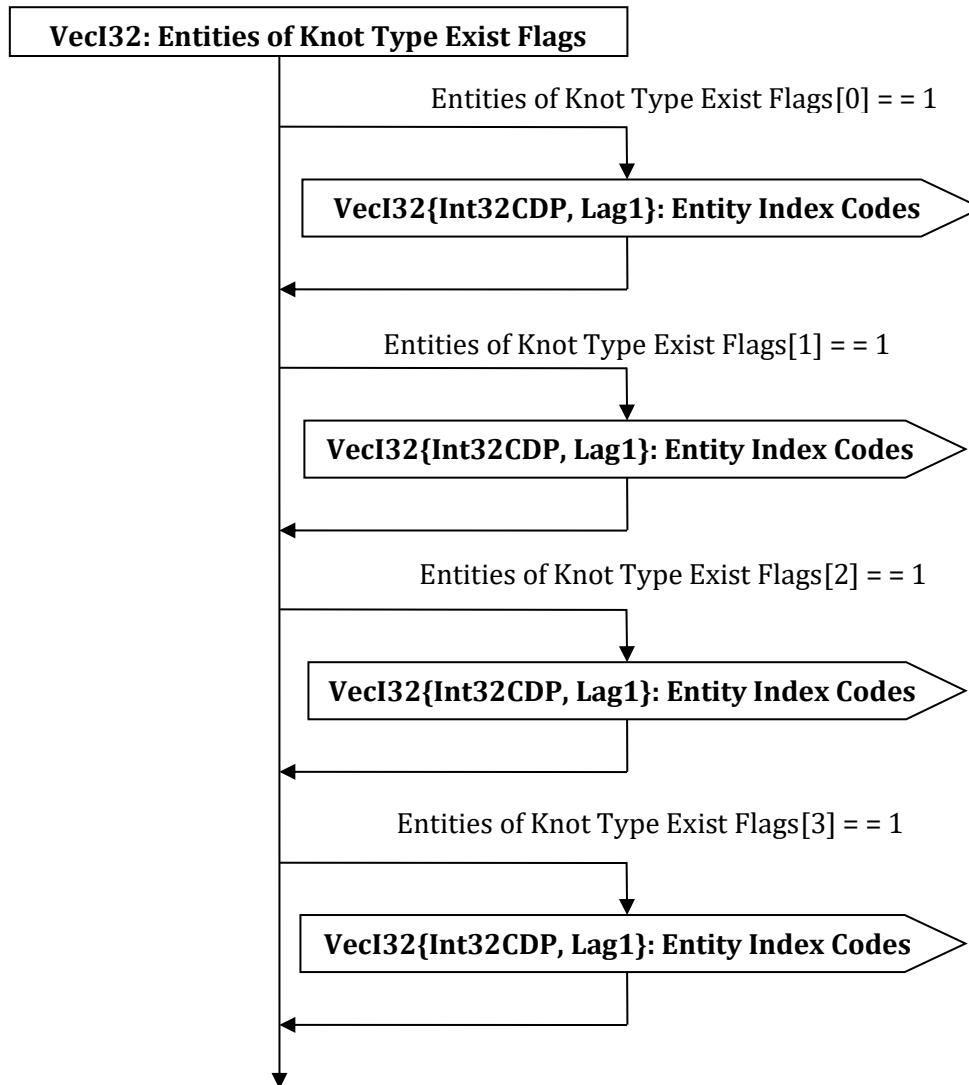


Figure 146 — Compressed Entity List for Non-Trivial Knot Vector data collection

VecI32: Entities of Knot Type Exist Flags

Entities of Knot Type Exist Flags is a vector of flags indicating for each knot vector type whether Entity Index ID data collections exist/follow for that knot vector type. Knot Vectors are categorized into types based on the following characteristics: whether internal knots occur in *adjacent pairs* and whether the knot range is $[0:1]$ or some other $[x_1:x_2]$ range.

Currently there are four knot vector types, so this Entities of Knot Type Exist Flags vector should be of length four. The four flags have the following meaning, as shown in Table 67:

Table 67 — Knot Type Exist Flag values

| | |
|-----|--|
| [0] | Flag indicating whether Entity IDs data collection exists for “Even Count $[0:1]$ Range” knot type. Knots in this category have their knot range on $[0:1]$, internal knots occur in <i>adjacent pairs</i> , <i>except</i> when there are no internal knots, in which case Type = 1 instead. = 0 – No Entity IDs data collection exists. = 1 – Entity IDs data collection exists. |
| [1] | Flag indicating whether Entity IDs data collection exists for “Even Count $[x_1:x_2]$ Range” knot type. Knots in this category have their knot range on $[x_1:x_2]$, and internal knots occur in <i>adjacent pairs</i> . = 0 – No Entity IDs data collection exists. = 1 – Entity IDs data collection exists. |

| | |
|-----|--|
| [2] | Flag indicating whether Entity IDs data collection exists for “Odd Count [0:1] Range” knot type. Knots of this type have their knot range on [0:1], and are not Type 0. = 0 – No Entity IDs data collection exists. = 1 – Entity IDs data collection exists. |
| [3] | Flag indicating whether Entity IDs data collection exists for “Odd Count [x ₁ :x ₂] Range” knot type. Knots of this type have their knot range on [x ₁ :x ₂], and are not Type 1. = 0 – No Entity IDs data collection exists. = 1 – Entity IDs data collection exists. |

Examples of knot vectors of Type 0:

```
0 0 X X 1 1
0 0 X X Y Y 1 1
0 0 X X Y Y Z Z 1 1
```

Examples of knot vectors of Type 1:

```
0 0 1 1          (Note: This is the exception to Type 0)
X X Y Y
X X Y Y Z Z
X X Y Y Z Z W W
```

Examples of knot vectors of Type 2:

```
0 0 X 1 1
0 0 X Y 1 1
0 0 X Y Z 1 1
0 0 X X X 1 1
0 0 X X Y Z Z 1 1
```

Examples of knot vectors of Type 3:

```
X X Y Z Z
X X Y Z W W
```

With this information in hand, the reader is able to reconstruct complete knot vectors in the following manner. When reconstructing the knot vector, you only take just enough values from the decoded knot value array. This may be as few as one. All the other values are inferred. Here's a sketch of the reconstruction algorithm:

```
// Number of knots in the knot vector
cNumKnots = numCtlPts + degree + 1;
// Necessary knot multiplicity at both ends of the knot vector
cClamping = degree + 1;
switch (knotType) {
    // Clamping is 0..1, internal knots occur in ADJACENT PAIRS
    // *EXCEPT* when there are no internal knots, in which case
    // Type = 1 instead.
    case 0: numVals = (cNumKnots - 2 * cClamping)/2;
    // Clamping is X1..X2, internal knots occur in ADJACENT PAIRS
    case 1: numVals = (cNumKnots - 2 * cClamping)/2 + 2;
    // Clamping is 0..1, and not Type 0
    case 2: numVals = (cNumKnots - 2 * cClamping);
    // Clamping is X1..X2, and not Type 1
    case 3: numVals = (cNumKnots - 2 * cClamping) + 2;
}
// numVals is the number of non-inferable knot values needed
// Let vVals be the knot vector value array
// vKnot will be the final output knot vector
if (knotType is either 0 or 2)
    Set vKnot[0 .. cClamping-1] to 0
    Set vKnot[cNumKnots-cClamping .. cNumKnots-1] to 1
else
    Set vKnot[0 .. cClamping-1] to vVals[0]
    Set vKnot[cNumKnots-cClamping .. cNumKnots-1] to vVals[numVals-1]
Set vKnot[cClamping .. cNumKnots-cClamping-1] from vVals[1 .. numVals-2]
VecI32{Int32CDP, Lag1}: Entity Index Codes
```


Entity Index Codes is a vector of quantizer “codes” representing entity index identifiers for a set of entities (therefore indices to particular entities within a list of entities). Entity Index Codes uses the Int32 version of the CODEC to compress and encode data.

10.2.14 Compressed Control Point Weights Data

Compressed Control Point Weights Data collection, as shown in Figure 147, is the compressed and/or encoded representation of weight data for some set of Control Points. All NURBS based geometry use this data collection to compress/encode Control Point Weight data.

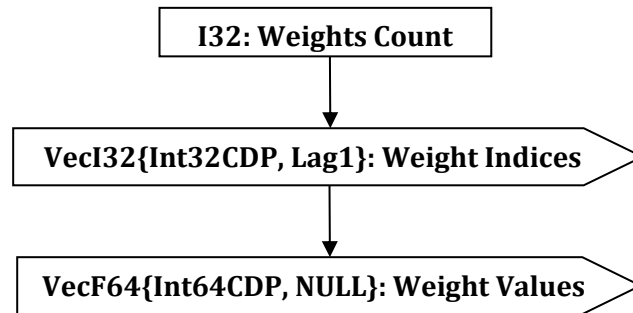


Figure 147 — Compressed Control Point Weights Data collection

I32: Weights Count

Weights Count specifies the total number of Weights. This count can differ from the Control Point count (see A.1.4.1.3 NURBS Surface Control Point Counts) because if the Control Point Dimensionality is non-rational (see data field), then no Weight values are stored for the particular Control Point. Weights Count value also does not necessarily equate to the actual number of Weights stored, since if a particular Control Point’s Weight values is “1”, then no actual Weight value is stored (therefore JT file loaders/readers can infer that the Weight Value is “1” for Control Points that don’t have a Weight value stored).

VecI32{Int32CDP, Lag1}: Weight Indices

Weight Indices is a vector of indices representing the index identifiers for the conditional set of weights for which an actual Weight Values is stored in Weight Values. Weight Indices uses the Int32 version of the CODEC to compress and encode data.

VecF64{Int64CDP, NULL}: Weight Values

Weight Values is a vector of weight values for the conditional set of weights. Weight Values uses the Int64 version of the CODEC to compress and encode data. Each deserialized 64 bit integer number should be converted to bit wise equivalent 64 bit floating number.

10.2.15 Compressed Curve Data

Compressed Curve Data collection, as shown in Figure 148, contains JT B-Rep or Wireframe Rep compressed/encoded geometric Curve data. Currently only NURBS Curve types are supported as part of this data collection. Complete documentation for JT B-Rep and Wireframe Rep can be found in the sections on JT B-Rep Element and Wireframe Rep Element respectively.

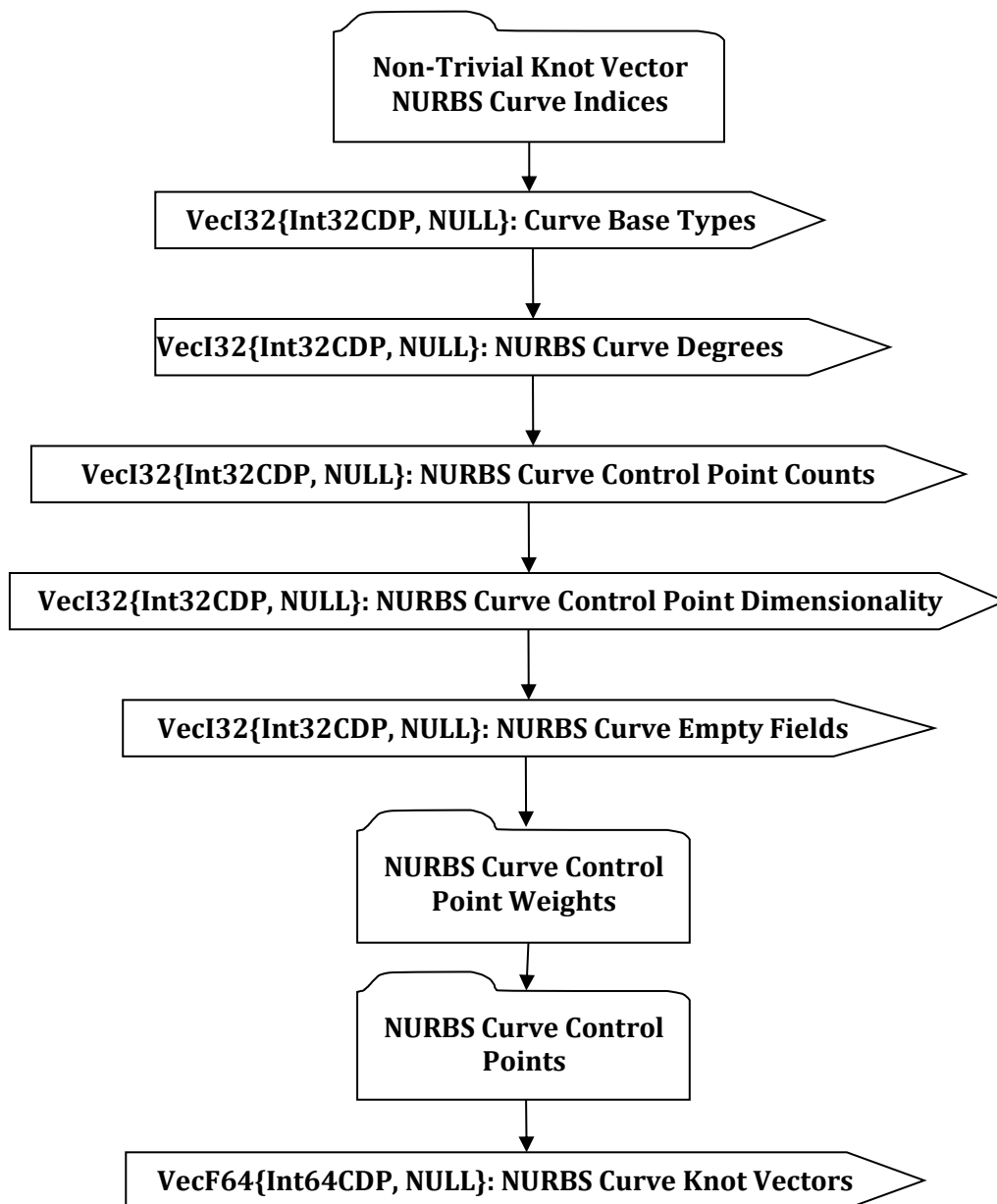


Figure 148 — Compressed Curve Data collection

VecI32{Int32CDP, NULL}: Curve Base Types

Each Curve is assigned a base type identifier. Curve Base Types is a vector of base type identifiers for each Curve in a list of Curves. Currently only NURBS Curve Base Type is supported, but a type identifier is still included in the specification to allow for future expansion of the JT Format to support other curve types.

In an uncompressed/decoded form the Curves base type identifier values have the following meaning, as shown in Table 68:

Table 68 — Compressed Curve Base Type values

| | |
|-----|------------------------|
| = 1 | Curve is a NURBS curve |
|-----|------------------------|

Curve Base Types uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: NURBS Curve Degrees

NURBS Curve Degrees is a vector of Curve degree values for each NURBS Curve in a list of Curves (there is a stored value for each NURBS Curve in the list). NURBS Curve Degrees uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: NURBS Curve Control Point Counts

NURBS Curve Control Point Counts is a vector of control point counts for each NURBS Curve in a list of curves (there is a stored value for each NURBS Curve in the list). NURBS Curve Control Point Counts uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: NURBS Curve Control Point Dimensionality

NURBS Curve Control Point Dimensionality is a vector of control point dimensionality values for each NURBS Curve in a list of Curves (therefore there is a stored values for each NURBS Curve in the list).

In an uncompressed/decoded form the control point dimensionality values meaning is dependent upon the NURBS Entity type.

For NURBS UV Curve entities the dimensionality value has the following definition, as shown in Table 69:

Table 69 — NURB UV Curve entity dimensionality values

| | |
|-----|---|
| = 2 | Non-Rational (each control point has 2 coordinates) |
| = 3 | Rational (each control point has 3 coordinates) |

For NURBS XYZ Curve entities the dimensionality value has the following definition, as shown in Table 70:

Table 70 — NURB XYZ Curve entity dimensionality values

| | |
|-----|---|
| = 3 | Non-Rational (each control point has 3 coordinates) |
| = 4 | Rational (each control point has 4 coordinates) |

NURBS Curve Control Point Dimensionality uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: NURBS Curve Empty Fields

NURBS Curve Empty Fields is a vector of data. Each NURBS Curve in a list of Curves has one reserved data field entry in this NURBS Curve Empty Fields vector. NURBS Curve Empty Fields uses the Int32 version of the CODEC to compress and encode data. Refer to Common Data Conventions and Constructs, Empty Field.

VecF64{Int64CDP, NULL}: NURBS Curve Knot Vectors

NURBS Curve Knot Vectors is a list of knot vector values for each NURBS Curve having non-trivial knot vectors in a list of Curves (therefore there are stored values for each non-trivial knot vector NURBS Curve in the list). All these NURBS Curve non-trivial knot vectors are accumulated into this single list in the same order as the Curve appears in the Curve list (therefore Curve-N Non-Trivial Knot Vector, Curve-M Non-Trivial Knot Vector, etc.). The NURBS Curves for which knot vectors are stored (therefore those containing non-trivial knot vectors) are identified in data collection Non-Trivial Knot Vector NURBS Curve Indices documented in Non-Trivial Knot Vector NURBS Curve Indices. NURBS Curve Knot Vectors uses the Int64 version of the CODEC to compress and encode data. Each deserialized 64 bit integer number should be converted to bit wise equivalent 64 bit floating number.

Non-Trivial Knot Vector NURBS Curve Indices

Non-Trivial Knot Vector NURBS Curve Indices data collection, as shown in Figure 149, specifies the Curve index identifiers (therefore indices to particular NURBS Curves within a list of Curves) for all NURBS Curves containing non-trivial knot vectors. A description/definition for “non-trivial knot vector” can be found in Compressed Entity List for Non-Trivial Knot Vector.

This Curve index data is stored in a compressed format.



Figure 149 — Non-Trivial Knot Vector NURBS Curve Indices data collection

Complete description for Compressed Entity List for Non-Trivial Knot Vector, as shown in Figure 149, can be found in Compressed Entity List for Non-Trivial Knot Vector.

NURBS Curve Control Point Weights

NURBS Curve Control Point Weights data collection defines the Weight values for a conditional set of Control Points for a list of NURBS Curves. The storing of the Weight value for a particular Control Point is conditional, because if NURBS Curve Control Point Dimension is “non-rational” or the actual Control Point’s Weight value is “1”, then no Weight value is stored for the Control Point (therefore Weight value can be inferred to be “1”).

The NURBS Curve Control Point Weights data, as shown in Figure 150, is stored in a compressed format.



Figure 150 — NURBS Curve Control Point Weights data collection

Complete description for Compressed Control Point Weights Data can be found in Compressed Control Point Weights Data.

NURBS Curve Control Points NURBS Curve Control Points, as shown in Figure 151, is the compressed and/or encoded representation of the Control Point coordinates for each NURBS Curve in a list of Curves (therefore there are stored values for each NURBS Curve in the list). Note that these are non-homogeneous coordinates (therefore Control Point coordinates have been divided by the corresponding Control Point Weight values).



Figure 151 — NURBS Curve Control Points data collection

VecF64{Int64CDP, NULL}: Control Points

Control Points is a vector of Control Point coordinates for all the NURBS Curves in a list of Curves. All the NURBS Curve Control Point coordinates are accumulated into this single vector in the same order as the Curve appears in the Curve list (therefore Curve-1 Control Points, Curve-2 Control Points, etc.). Control Points uses the Int64 version of the CODEC to compress and encode data in a “lossless” manner. Each deserialized 64 bit integer number should be converted to bit wise equivalent 64 bit floating number.

10.2.16 Compressed CAD Tag Data

The Compressed CAD Tag Data collection, as shown in Figure 152, contains the persistent IDs, as defined in the CAD System, to uniquely identify individual CAD entities (for example Faces and Edges of a JT B-Rep, PMI, etc.). Exactly what CAD entity types have CAD Tags and what order they are stored in Compressed CAD Tag Data is defined by users of this data collection.

What constitutes a CAD Tag is outside the scope of the JT File format and is indeed part of the CAD system. The JT File format simply provides a way to store any kind of CAD Tag as provided by the CAD system which produced the CAD entity.

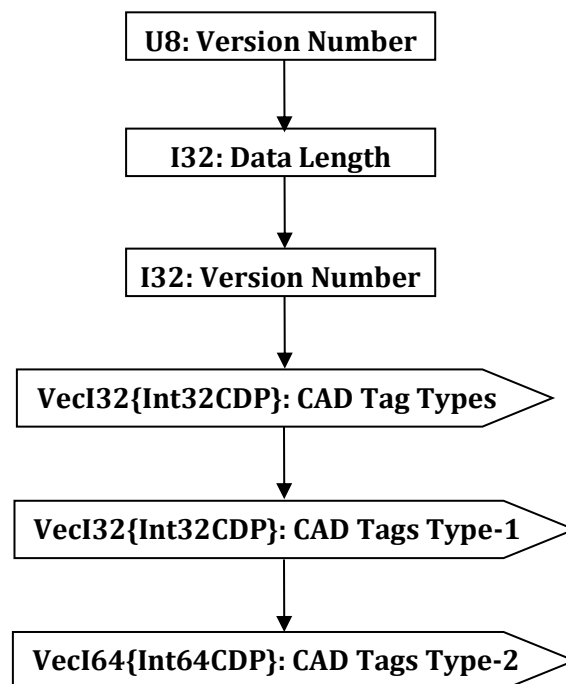


Figure 152 — Compressed CAD Tag Data collection

U8: Version Number

Version Number is the version identifier for the CADTag element. For information on local version numbers see Common Data Conventions and Constructs, Local version numbers.

I32: Data Length

Data Length specifies the length in bytes of the Compressed CAD Tag Data collection. A JT file loader/reader may use this information to compute the end position of the Compressed CAD Tag Data within the JT file and thus skip reading the remaining Compressed CAD Tag Data.

I32: Version Number

Version Number is the local version identifier for the Compressed CAD Tag Data. For information on local version numbers see Common Data Conventions and Constructs, Local version numbers.

VecI32{Int32CDP}: CAD Tag Types

CAD Tag Types is a vector of type identifiers for a list of CAD Tags (where each CAD Tag in the list has a type identifier value).

In an uncompressed/decoded form the CAD Tag type identifier values have the following meaning, as shown in Table 71:

Table 71 — Compressed CAD Tag Type values

| | |
|-----|-----------------------------|
| = 1 | 32 Bit Integer CAD Tag Type |
| = 2 | 64 Bit Integer CAD Tag Type |

CAD Tag Types uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP}: CAD Tags Type-1

CAD Tags Type-1 is a vector of the Type-1 (therefore 32 Bit Integer Type) CAD Tags for a list of CAD Tags. CAD Tags Type-1 uses the Int32 version of the CODEC to compress and encode data. CAD Tags Type-1 is only present if there are Type-1 CAD Tags in the CAD Tag Types vector.

VecI64{Int64CDP}: CAD Tags Type-2

CAD Tags Type-2 is a vector of the Type-2 (therefore 64 Bit integer Type) CAD Tag data for a list of CAD Tags. CAD Tags Type-2 uses the Int64 version of the CODEC to compress and encode data. CAD Tags Type-2 is only present if there are Type-2 CAD Tags in the CAD Tag Types vector.

10.3 Encoding Algorithms

The following sections give a brief technical overview/descriptions of the various encoding algorithms used in the JT format. A sample implementation of the encoding and decoding portion of each algorithm can be found in this document Annex B.

10.3.1 Uniform Data Quantization

Uniform Data Quantization is a lossy encoding technique in which a continuous set of input values (floating point data) is approximated with integral multiples (therefore integers) of a common factor. How close the quantization output approximates the original input data is dependent upon the quantization data range and the number of bits specified to hold the resulting integer value.

The quantization is considered “uniform” because the algorithm divides the data input range into levels of equal spacing (therefore a uniform scale). The form of Uniform Data Quantization used by the JT format is also considered scalar in nature, in that each input value is treated separately in producing the output integer value.

Given the following definitions:

```
inputVal:           Input floating point data to quantize
outputVal:          Resulting quantized output integer value
minInputRange:      Specified minimum value of input data range
maxInputRange:      Specified maximum value of input data range
nBits:              Specified number of bits of precision (quantized size)
The basic algorithm (using C++ style syntax) for Uniform Data Quantization is as follows:
UInt32 iMaxCode = (nBits < 32) ? (0x1 << nBits) - 1 : 0xffffffff;
Float64 encodeMultiplier = Float64(iMaxCode) / (maxInputRange - minInputRange);
UInt32 outputVal = UInt32( (inputVal - minInputRange) * encodeMultiplier + 0.5 );
```

Note: For reasons of robustness, “outputVal” shall also be explicitly clamped to the range [0,iMaxCode]. This is because floating-point roundoff error in the calculation of “encodeMultiplier” can otherwise cause “outputVal” to sometimes come out equal to “iMaxCode + 1”.

Note that all compression algorithms in the following sections operate on quantized integer data.

10.3.2 Bitlength CODEC

This is a very simple compression algorithm that runs either a fixed-width or adaptive-width bit field encoding for each value. It is used whenever none of the more sophisticated CODECs are able to extract any compression advantage. In essence, the Bitlength CODEC takes advantage of the fact that most of the values will require less than 32 bits to represent, and so can be written as bitfields narrower than 32 bits. In some cases, the best answer is to choose a fixed field width that can represent all values in the array. In other cases, a little more compression can be had by using an adjustable-width coding scheme.

When using the variable-width scheme, as each input value is encountered, the number of bits needed to represent it is calculated and compared to the current “field width”. The current field width is then adjusted upwards or downwards by a constant “step_size” number of bits (therefore 2 bits for the JT format) to accommodate the input value storage. This increment or decrement of the current field width is indicated for each encoded value by a prefix code stored with each value.

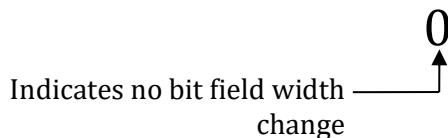
The prefix code will be one of the following two forms:

A single '0' bit to denote the same (therefore current) field width is to be used for the next value.

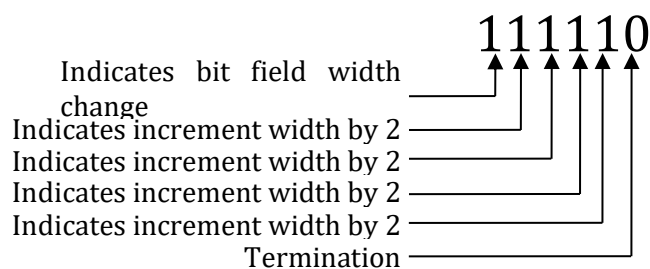
A '1' bit followed by a series of one or more bits where each bit indicates whether the field width is to be incremented (a '1' bit) or decremented (a '0' bit) by the field step_size, followed by a single terminator bit (which is complement of the previous increment/decrement bit). Note that there can only be increments or decrements in a given prefix code, never both, and that is why the prefix code terminator bit can be recognized as bits are read by simply looking for the complement of the previous increment/decrement bit.

Some examples of prefix codes and their interpretation are as follows:

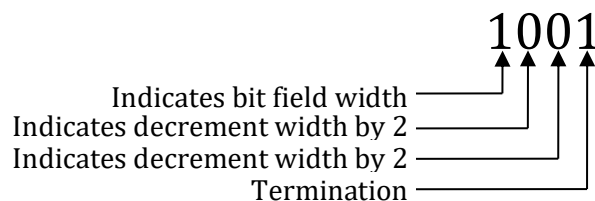
Example 1: Prefix code to maintain same (current) field width.



Example 2: Prefix code to increment field width four times (8 bits).



Example 3: Prefix code to decrement field width two times.



A pseudo-code sample implementation of bit length decoding is available in the Annex B.

10.3.3 Arithmetic CODEC

In 1948, Claude Shannon of Bell Laboratories published his seminal paper “A mathematical theory of communication” that launched the new field of Information Theory. In that same year, two Doctoral students at the Massachusetts Institute of Technology (MIT) made breakthroughs in the coding of information. The first to press was David Huffman, whose coding scheme we now know as Huffman Coding. In that same class with Huffman was Peter Elias who reportedly developed the first articulation of arithmetic coding, but it lay unpublished until 1976, when Jorma Rissanen and Richard Pasco, of IBM, refined it into a practically useful algorithm.

Arithmetic encoding is a so-called “entropy coding” algorithm that replaces an input stream of symbols or bytes with a single fixed point output number (therefore only the mantissa bits to the right of the binary point are output from MSB to LSB). The total number of bits needed in the output number is dependent upon the length and statistical properties of the input message (therefore the longer the input message the more bits needed in the output number). This single fixed point number output from an arithmetic encoding process shall be uniquely decodable to create the exact stream of input symbols that were used to create it.

Initially all symbols being encoded have a probability value assigned to them based on the likelihood that the symbol will occur next in the input stream (therefore the frequency of the symbol in the input stream). Given probability value assignments, each individual symbol is then assigned an interval range along a nominal 0 to 1 “probability line”, where the size of each range corresponds to the symbol’s probability value. Note that a particular symbol owns all values within its assigned range up to, but not including, the range high value, and that it does not matter which symbols are assigned which segment of the range as long it is done in the same manner by both the encoder and the decoder.

Given the above described input stream probability and interval range assignments, a high level description of the arithmetic encoding process is as follows:

Begin with a “current interval” initialized to $[0,1)$. Note, that in interval range notation (therefore “ $[0,1)$ ”), the “[” symbol indicates inclusive of the interval low limit and “)” symbol indicates exclusive of the interval high limit.

Sequentially for each symbol of the input stream, perform two steps.

Subdivide the current interval into subintervals based on the input stream symbol probability values as described above.

Select the subinterval corresponding to the current input stream symbol being sequentially processed and make it the new “current interval”.

After all input stream symbols have been sequentially processed; output enough bits to distinguish the final “current interval” from all other possible final intervals.

In pseudo code form, the algorithm to accomplish the above described arithmetic encoding for an input stream message of any length could look as follows:

```
Set low to 0.0
Set high to 1.0
While there are still input symbols do
    cur_symbol = get next input symbol
    range = high - low
    high = low + range * high_range(cur_symbol)
    low = low + range * low_range(cur_symbol)
End of While
Output low
```

So the arithmetic encoding process is simply one in which we narrow the range of possible numbers with every new sequentially processed input symbol; where the new narrowed range is proportional to the predefined probability values assigned to each symbol in the input stream.

The arithmetic decoding process is the inverse procedure; where the range is expanded in proportion to the probability of each symbol as it is extracted. For the arithmetic decoding process we find the first symbol in the message by seeing which symbol owns the interval range that our encoded message falls in. Then, since we know the low and high range limit values of the first symbol we can remove their effects by reversing the process that put them in.

In pseudo code form, the algorithm for decoding the incoming number could look as follows:

```
Get encoded_number
Do
    find symbol whose range straddles the encoded_number
    output the symbol
    range = symbol_high_value - symbol_low_value
    encoded_number = encoded_number - symbol_low_value
    encoded_number = encoded_number / range
until no more symbols
```

Example

Following is an example to demonstrate in practice the basic principles of arithmetic coding.

Suppose you want to compress, using arithmetic coding, the following sequence/array of integer data:

{2, 9, 12, 12, 0, 7, 1, 20, 5, 19}

For this input stream of data, the assigned probability values will be as shown in Table 72:

Table 72 — Example assigned probability values

| Number | Probability |
|--------|-------------|
| 0 | 1/10 |
| 1 | 1/10 |
| 2 | 1/10 |
| 5 | 1/10 |
| 7 | 1/10 |
| 9 | 1/10 |
| 12 | 2/10 |
| 19 | 1/10 |
| 20 | 1/10 |

Then based on each input numbers probability value, an interval range along a 0 to 1 “probability line” can be assigned to each input number as shown in Table 73::

Table 73 — Example “probability line” values

| Number | Probability | Range |
|--------|-------------|--------------|
| 0 | 1/10 | [0.00, 0.10) |
| 1 | 1/10 | [0.10, 0.20) |
| 2 | 1/10 | [0.20, 0.30) |
| 5 | 1/10 | [0.30, 0.40) |
| 7 | 1/10 | [0.40, 0.50) |
| 9 | 1/10 | [0.50, 0.60) |
| 12 | 2/10 | [0.60, 0.80) |
| 19 | 1/10 | [0.80, 0.90) |
| 20 | 1/10 | [0.90, 1.00) |

Now proceeding with encoding the example input integer sequence {2, 9, 12, 12, 0, 7, 1, 20, 5, 19}, the first number to be encoded is “2”; so the final encoded value will be a number that is greater than or equal to 0.20 and less than 0.30. Now as each subsequent number in the input stream is sequentially processed for encoding, the possible range of the output number is further restricted. In our example the next number to be encoded is “9” which owns the range [0.50, 0.60) within the new sub-range of [0.20, 0.30); which now further restricts our output number to the range [0.25, 0.26). If we continue this logic for the complete input integer sequence we end up with the following, as shown in Table 74:

Table 74 — Example input integer sequence values

| New integer number | Low value | High value |
|--------------------|---------------------|--------------|
| | 0.0 | 1.0 |
| 2 | 0.2 | 0.3 |
| 9 | 0.25 | 0.26 |
| 12 | 0.256 | 0.258 |
| 12 | 0.2572 | 0.2576 |
| 0 | 0.25720 | 0.25724 |
| 7 | 0.257216 | 0.257220 |
| 1 | 0.2572164 | 0.2572168 |
| 20 | 0.25721676 | 0.2572168 |
| 5 | 0.257216772 | 0.257216776 |
| 19 | 0.2572167752 | 0.2572167756 |

From the above table, the final low value is “0.2572167752” which is the output number that uniquely encodes the integer number sequence {2, 9, 12, 12, 0, 7, 1, 20, 5, 19}.

Given this encoding scheme, the decoding would simply follow the process previously described. We find the first number in the sequence by looking up in the probability range for the value, whose range, our encoded number “0.2572167752” falls within. In our example this equates to the value “2” and so our first decoded value shall be “2”. Then we apply the previously described decoding subtraction and division steps to arrive at a new encoded value of “0.572167752”. Using this new “0.572167752” encoded value and the same logic of the first step, the second decoded value will be “9”. We continue this process until there are no more numbers to decode.

In practice, due to floating point size (therefore number of bits) restrictions and possible differences in floating point formats on machines, arithmetic encoding is best implemented using 16 bit or 32 bit integer math. Using 16 bit or 32 bit integer math, an incremental transmission scheme can be implemented, where fixed size integer state variables receive new bits in at the low end and shift them out the high end, forming a single number that can be as many bits long as are available on the computer’s storage medium.

Using our example as a guide, define the starting range [0.0, 1.0) to instead be 0 to 0.999 (which is .111 in binary). Then in order to use integer registers to store these numbers, justify the values so that the implied decimal point is at the left hand side of the word. Now load the initial range values based on the word size we are using. In the case of a 16 bit implementation the initial range values will be low equals 0x0000 and high equals 0xFFFF. Since we know these values will go on forever (for example 0.999... will continue with FFs) we can shift those extra bits in as needed with no detrimental effects.

Going back to our example and using a 5 digit register, we start with the range:

High: 99999

Low: 00000

Applying the previously described encoding algorithm we first calculate the range between the low and high values; which in this case is 100000 (not 9999 since we assume the high value has an infinite number of 9’s). Next, we calculate the new high value which in this example will be 30000. But before we store the new high value we shall decrement it to account for the implied digits appended to it; so new high value will be 29999. Applying similar logic to computing the new low value results in a new range of:

High: 29999 (999...)

Low: 20000 (000...)

In looking at the newly computed high and low range values, it can be seen that the most significant digits of high and low match. A property of arithmetic coding is that as this encoding process continues, the high and low values will continue to get closer, but will never match exactly. Given this property, once the most

significant digit of high and low match, it will never change, and thus we can output this most significant digit as the first number in the coded word and continue working with just 16 bit high and low values. This output process is accomplished by shifting both the high and low values left by one digit and shifting in a “9” in the least significant digit of the high value.

Applying the previously described encoding algorithm and continuing the above described process of shifting out most significant digit into the coded word as high and low continually grow closer together looks as shown in Table 75 for encoding our example integer number sequence {2, 9, 12, 12, 0, 7, 1, 20, 5, 19}:

Table 75 — Example integer number sequence values

| | High | Low | Range | Cumulative output |
|------------------------|-------|-------|--------|-------------------|
| Initial State | 99999 | 00000 | 100000 | |
| Encode “2” [0.2, 0.3) | 29999 | 20000 | | |
| Shift out 2 | 99999 | 00000 | 100000 | .2 |
| Encode “9” [0.5, 0.6) | 59999 | 50000 | | .2 |
| Shift out 5 | 99999 | 00000 | 100000 | .25 |
| Encode “12” [0.6, 0.8) | 79999 | 60000 | 20000 | .25 |
| Encode “12” [0.6, 0.8) | 75999 | 72000 | | .25 |
| Shift out 7 | 59999 | 20000 | 40000 | .257 |
| Encode “0” [0.0, 0.1) | 23999 | 20000 | | .257 |
| Shift out 2 | 39999 | 00000 | 40000 | .2572 |
| Encode “7” [0.4, 0.5) | 19999 | 16000 | | .2572 |
| Shift out 1 | 99999 | 60000 | 40000 | .25721 |
| Encode “1” [0.1, 0.2) | 67999 | 64000 | | .25721 |
| Shift out 6 | 79999 | 40000 | 40000 | .257216 |
| Encode “20” [0.9, 1.0) | 79999 | 76000 | | .257216 |
| Shift out 7 | 99999 | 60000 | 40000 | .2572167 |
| Encode “5” [0.3, 0.4) | 75999 | 72000 | | .2572167 |
| Shift out 7 | 59999 | 20000 | 40000 | .25721677 |
| Encode “19” [0.8, 0.9) | 55999 | 52000 | | .25721677 |
| Shift out 5 | 59999 | 20000 | 40000 | .257216775 |
| Shift out 2 | | | | .2572167752 |
| Shift out 0 | | | | .25721677520 |

As can be seen in the above table, after all values in the input stream have been encoded and any final matching most significant digit has been output, the arithmetic coding algorithm requires that two extra digits be shifted out of either the high or low value to finish up the cumulative output word.

Although the above example incrementally encodes very nicely with the arithmetic coding algorithm, there are certain cases where the computed high and low values get closer, but never actually converge to one value in the most significant digit (for example High = 0.300001, Low = 0.299992). Thus after a few iterations the difference between high and low becomes so small that 16 bits is not sufficient to represent any difference between the values (therefore all calculations return the same values). This conditions is known as “underflow” and special logic shall added to the arithmetic coding algorithm to recognize that “underflow” is occurring and thus head it off before the computations reach an impasse.

The additional logic for recognizing that “underflow” is occurring would be executed after each recalculation of High and Low value set, and in pseudo code form this logic would look as follows:

```
underflow = FALSE
if( (High and Low value's significant digits don't match but are on adjacent numbers) &&
    (2nd MSDMSD of High is "0" and the 2nd MSDMSD of low is "9") )
{
    underflow = TRUE
}
```

When/If it is identified that “underflow” is occurring, the encoding algorithm shall perform the following steps to stop the current “underflow”:

Delete the 2nd most significant digit from both the High and Low value.

Shift the other digits (those to the right of the deleted 2nd digit) to the left to fill up the space (note that the most significant digit stays in place).

Increment a counter to remember that we threw away a digit and don’t know whether it was going to converge to “0” or “9”.

A before and after example of performing the above steps to the High and Low values when ‘underflow’ occurs is as follows:

| | <u>Before</u> | <u>After</u> |
|-------------------|---------------|--------------|
| High | 40344 | 43449 |
| Low | 39810 | 38100 |
| Underflow_counter | 0 | 1 |

Now as the encoding algorithm continues and the most significant digit of High and Low values once again converge to a common value, then that value shall be output to the coded word along with “Underflow_counter” number of “underflow” digits that were previously deleted. The underflow digits output to the coded word will either be all 9s or 0s, depending on whether the High and Low value converged to the higher or lower value.

A pseudo-code sample implementation of arithmetic decoding is available in the annex.

10.3.4 Deering Normal CODEC

Michael Deering first published his work on geometry compression in 1995 [2] and later helped present a course on the subject at SIGGRAPH’99 [3]. Although Deering’s approach to geometric compression involves compression of vertices, colours and normals, the description detailed here will focus solely on compression of normals since this is the only component of Deering’s approach used in the JT format.

Through both theoretical examination and empirical testing, Deering found that an angular density of 0.01 radians between normals (about 100,000 normalized normals distributed over unit sphere) gave results that were not visually distinguishable from results obtained from finer normal representations. This observation reduced the problem of having to “exactly” represent any general surface normal, to only having to represent about 100,000 specific normals (therefore general surface normal replaced by the appropriate one of the 100,000 specific normals).

If there were no run-time memory concerns and no concerns for on disk footprint size, these specific 100,000 normals could be simply represented in a table that is indexed into, to reference a particular normal. Instead, Deering’s approach leverages symmetrical properties of the unit sphere to reduce the size of the table and allow any normal to be represented by, at max, an 18 bit index as summarized below:

- All normals are normalized (therefore can be represented as points on the surface of the unit sphere).
- Unit sphere is divided into eight symmetrical octants based on sign bits of normal’s X,Y,Z rectilinear representation (see Figure 153).
- Using three bits to represent the three sign bits of the normals XYZ components reduces the problem space to one eighth of the unit sphere.
- Each octant of the unit sphere is divided into six identical sextants by folding about the planes of symmetry; $x=y$, $x=z$, and $y=z$ (see Figure 153)

- The particular sextant can be encoded using another three bits. So now unit sphere is divided into 48 identically shaped triangle patches reducing the normal look-up table to about 2000 entries (therefore $100000/48$).
- Then, a local rectangular orthogonal two dimensional grid is created on the sextant and all normals within the sextant are represented as two n-bit angular addresses (therefore a quantization of two angular values along the unit sphere) where “n” is in the range from 0 to 6 bits.
- Resulting in a max grand total of 18 bits ($3 + 3 + 6 + 6$) to represent any normal on the unit sphere.

In the Figure 153, the sphere is divided into eight octants and each octant is divided into six sextants. Each sextant is assigned an identifying three bit code.

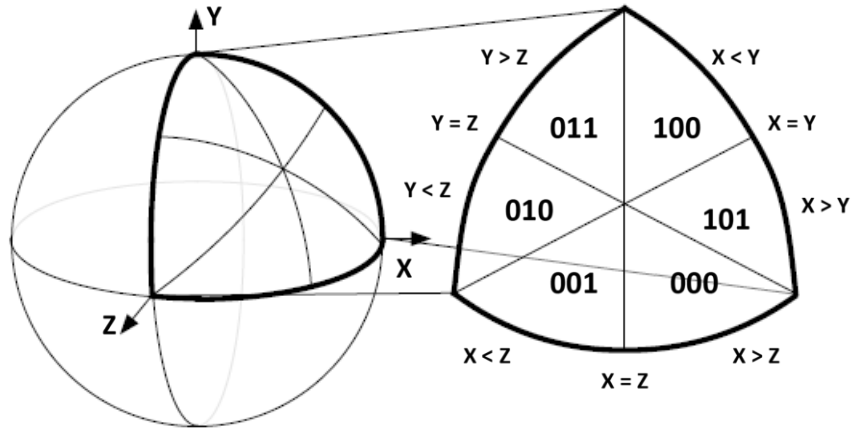


Figure 153 — Sextant Coding on the Sphere

Note that the sextant three bit code assignments used by the JT format, as seen in Figure 153, are slightly modified from the original assignments as specified by Deering.

The representation of all normals within a sextant by two n-bit angular addresses, as summarized above, is based on the following:

- In spherical coordinates, points on a unit sphere can be parameterized by two angles, θ and φ ; where θ is the angle about the y axis and φ is the longitudinal angle from the $y=0$ plane.
- Mapping between rectangular and spherical coordinates is:

$$x = \cos\theta * \cos\varphi \quad y = \sin\varphi \quad z = \sin\theta * \cos\varphi.$$

- All encoding takes place in the positive octant.
- Angles θ and φ can be quantized into two n-bit integers θ'_n and φ'_n (where “n” is in the range of 0 to 6) and the relationship between these n-bit integers and angles θ and φ for a given “n” is:

$$\theta(\theta'_n) = \arcsin \tan(\varphi_{\max} * (n - \theta'_n) / 2n)$$

$$\varphi(\varphi'_n) = \varphi_{\max} * \varphi'_n / 2n.$$

Thus to encode (therefore quantize) a given normal **N** into θ'_n and φ'_n :

- **N** shall be first represented (see
- Figure 153) in the positive octant and appropriate sextant within that octant, resulting in **N'**.

- Then N' shall be dotted with all quantized normals in the sextant.
- For a fixed “ n ”, the corresponding θ'_n and φ'_n values of the quantized sextant normal that result in the largest (nearest unity) dot product defines the proper θ'_n and φ'_n encoding of N .

With this encoding of normal N into θ'_n and φ'_n n -bit integers the complete bit representation of normal N can now be defined as follows:

- Uppermost three bits specify the octant.
- Next three bits specify the sextant code as defined in Figure 153.
- Next two n -bit fields specify θ'_n and φ'_n values respectively.

10.4 LZMA compression

LZMA is a (lossless) dictionary-based data compression algorithm and is essentially the same as that in 7-Zip. Implementers of this specification should consider using XZ Utils for compressing and decompressing JT data. XZ Utils is free general-purpose data compression software. XZ Utils are the successor to LZMA Utils.

The core of the XZ Utils compression code is based on LZMA SDK, but it has been modified quite a lot to be suitable for XZ Utils. The primary compression algorithm is currently LZMA2, which is used inside the .xz container format. Typically, XZ Utils create 30 % smaller output than gzip and 15 % smaller output than bzip2.

Entry points from the liblzma API, used when compressing and decompressing JT files using XZ utils, are listed here;

lzma_code

lzma_easy_encoder

lzma_end

lzma_stream_decoder

The compression and decompression XZ Utils are freely available and in the public domain. For complete description and source code visit <http://tukaani.org/xz/>.

11 Common Data Conventions and Constructs

11.1 Overview

The proceeding sections of this specification specify the mandatory clauses for creating a reference compliant JT file. This section documents format conventions that should be followed to promote consistency in JT.

11.2 Late-Loading Data

The JT format was designed and structured to load entities from a JT file on a deferred or as-needed basis. This concept is referred to within this specification as “late-loading data”. The JT format has many structures in support of this; writers/loaders of JT data may leverage these capabilities.

Initial loading of a JT file shall require the Table of Contents and the LSG segments.

All Meta Data Node Elements, JT B-Rep Elements, XT B-Rep Elements, Wireframe Rep Elements, PMI Manager Meta Data Elements, JT ULP Elements, JT LWPA Elements, and Shape LOD Elements may be ignored until they are actually needed. These Late-Loaded data containers are accessed via a Late Loaded Property Atom Element which appears in a LSG Node's Property list. Contained in this Property is the GUID associated with the segment to be loaded. This GUID can be looked up in the TOC Segment, which will give the location in the JT from which to load the actual Element via the Data Segment convention.

11.3 TOC Segment Location

The TOC Segment should be located within the JT file immediately following the file header.

11.4 Bit Fields

All bits fields that are not defined as in use shall be set to "0".

11.5 Empty Field

In the File Format section of this reference some data fields may be named/documented as "Empty Field" (e.g. LOD Node Data "Empty Field" field). These fields should be treated as follows:

If you are writing a JT file whose data did not originate from reading a previous JT file, then Empty Fields should be set to a value a "0" when writing the field to a JT file.

If you are writing a JT file whose data originated from reading a previous JT file (therefore rewriting a JT File), then "Empty Fields" should be written with the same value that was read from the originating JT file.

11.6 Local version numbers

The version numbers seen throughout the data collections are version numbers local to those data types. They provide a simple means by which those data collections can be extended. All version information for 10.6 JT data is included within this document.

For each data collection, data for each local version should be written in sequence. When reading the data, the local version number allows readers to read up to the maximum local version they support and then use the segment length that was read in the Segment Header to skip over additional data. For example when version one and two data is present the user can choose to read only the version one data or additionally read the version two data as required.

Local version numbers are used for conditional branching as depicted in the element figures.

11.6.1 Version numbers

"0x02"

Base Property Atom Element,

String Property Atom Element,

Integer Property Atom Element,

Floating Point Property Atom Element,

JT Object Reference Property Atom Element,

Date Property Atom Element,

Late Loaded Property Atom Element,

Vector4f Property Atom Element

PMI Manager Meta Data Element

Lines styles contain a type >= 9

XT facet body

“0x03”

Hybrid XT B-Rep

“0x05”

JT B-Rep Element

11.7 Hash Value

Hashing is a means by which a large chunk of values can be represented by single value through the use of a mathematical function that provides a distinctive value for each unique set of ordered values. The hash function used within this format was published by Bob Jenkins in Dr Dobbs Journal in 1997. Its implementation is provided in Annex C. It is the same implementation that was used in JT v9.5.

The hash function takes a pointer to a set of values, the number of values, and a seed hash value. It returns the resulting hash value. Initially the seed value is set to 0, however when hashing multiple data fields together the hash of previous data field is used as the seed hash value of the next data field:

```
UInt32 uHash = 0;
uHash = hash32( pVal0, nVal0, uHash );
uHash = hash32( pVal1, nVal1, uHash );
```

The order that individual fields are hashed is extremely important since readers for this format should assert that the stored hash value matches the calculated hash value of the corresponding fields after reading in all the corresponding data. To this end each hash value stored within this recommendation's format carefully documents which fields it encompasses and the order in which they should be hashed.

11.8 Scene graph construction

The following guidelines apply for scene graph construction:

1. use a Meta Data Node Element to denote a CAD “Assembly”,
2. use a Part Node Element to denote a CAD “part”.

Below is an example of a fully-fleshed out small assembly of a three-wheeled motorcycle:

| | | |
|--------------------------|--|--|
| Partition | (Partition Node Element) | Root node of JT file |
| MetaDataNode | (Meta Data Node Element) | “Three-wheeler” Top-level assembly |
| Instance | (Instance Node Element) | “Front wheel” assembly |
| Partition | (Partition Node Element) | External reference to JT file for “Wheel” part |
| PartNode | (Part Node Element) | “Wheel” generic part |
| RangeLOD | (Range LOD Node Element) | Level-of-detail node |
| Group | (Group Node Element) | High-LOD group node |
| TriStripSet | (Tri-Strip Set Shape LOD Element) | Rim geometry |
| TriStripSet | (Tri-Strip Set Shape LOD Element) | Tire geometry |
| TriStripSet | (Tri-Strip Set Shape LOD Element) | Low-LOD geometry |
| MetaDataNode | (Meta Data Node Element) | “Rear Axle” assembly |
| Instance | (Instance Node Element) | “Left rear wheel” assembly |
| [“Wheel” PartNode above] | This instance node's child is same as the one above. | |
| Instance | (6.1.1.4 Instance Node Element) | “Right rear wheel” assembly |
| [“Wheel” PartNode above] | This instance node's child is same as the one above. | |

Instance Node Elements are used when referring to an *instanced* part but are not fundamentally different from a Group Node Element having only one child.

11.9 Metadata Conventions

Although there are not limits to what Meta Data (therefore properties) may be attached to nodes in the LSG, the following conventions should be followed in industry when translating CAD data to the JT file format. See the Property Atom Elements section of this document for complete description of the file Elements used to attach this property information to nodes.

11.9.1 Property Key Naming Conventions

Properties in JT are named value pairs constructed of keys and values as defined in Property Proxy Meta Data Element. Properties are used to provide information to downstream applications and processes. In order to enable different applications to read and interpret properties correctly, a common understanding and treatment for naming of keys should be followed.

11.9.1.1 Uniqueness of Property Keys

No duplicate property keys are allowed in the same scene graph node.

It is allowed to create two properties with identical keys if one of them is defined as visible and the other as hidden as described below. This is possible since the visible state changes the property key string by appending a double colon.

This definition of duplicate properties using visible and hidden should be avoided.

11.9.1.2 Hidden Properties

Properties are used for a range of purposes in a JT file; some are relevant to visual interrogation by users and some not. To enable applications with the ability to differentiate properties a convention for naming key strings should be followed. The key string pattern that is used to denote the visibility of a property is a double colon ("::"). The double colon is appended to the end of the name in the property key as shown below.

"property" = "hidden"

"property::" = "visible"

The objective of the "hidden" concept is to indicate to a viewing application that a user should not see the property in an application user interface.

For example:

The property with the key "Name::" will list the value "body_4465" in a viewing application when property display is selected.

Property type="STRING" key="Name::" value="body_4465"

The property SUBNODE will not be listed by a viewing application.

Property type="STRING" key="SUBNODE" value="1"

Definition of key names with "::" included in the key name shall not affect visibility of that property when parsing of the JT data; therefore, "hidden" shall not be interpreted as "encrypted" or "secure" with respect to JT data.

11.9.1.3 Case-sensitivity of Property Keys

Property keys are case-sensitive; therefore “ud_CAD_MASS” and “UD_CAD_MASS” are considered two separate properties.

11.9.1.4 Blanks (white spaces) in Property Keys

Property keys are strings, spaces are allowed. Converting blank spaces to underscores should not be followed as a convention or recommended practice.

11.9.1.5 Special Characters in Property Keys and Property Values

All strings in JT files, including property keys, are stored as Unicode (UCS-2) strings. As such, “special characters” supported by Unicode are allowed.

11.9.1.6 Maximum Length of Property Keys and Property Values

Since property keys are strings, the maximum length is theoretically 2^{31} (about 2.1 billion) bytes; therefore 2^{30} characters. Keys this large should not be created. Applications writing or reading JT files have a significantly lower limit for the maximum property key length. The definition of overly large property keys may lead to data exchange issues.

11.9.1.7 Properties with an empty Value

Properties in JT are always <key, value>. Since blanks are valid values, the value can be an empty string. Such properties have to be handled properly by the consuming applications and shall not be ignored.

11.9.2 PMI Properties

A complete list of Product Manufacturing Information (PMI) String Property Atom Element values is made available as an Excel spread sheet titled; “PMIPropertiesStrings_alphabetic_list.xlsx”.

The “PMIPropertiesStrings_alphabetic_list.xlsx” spreadsheet can be download from the same Siemens website this document.

The tables provide a list of properties that can be found in JT parts that contain Generic PMI Entities .

Tables are provided for each “Generic PMI Entity type”. A full list of Generic PMI Entity Types can be found in the “Generic PMI Entities” logical collection description from the “PMI Manager Meta Data Element”.

Each table lists the property keys that are valid for the specific Generic PMI entity Type. For example, all valid PMI properties for Dimensions can be found in the table PMI_DIM_TYPE (0x0082). In some cases, a Generic Entity type shares a common set of Property keys. In these cases more than one Generic PMI Entity Type is listed for the table. For example, PMI_SPOT_WELD_TYPE (0x0004), PMI_ARC_SPOT_WELD_TYPE (0x0018), PMI_RES_SPOT_WELD_TYPE (0x0020), PMI_DOLLOP_TYPE (0x0028), PMI_CLINCH_TYPE (0x0040) all share the same property keys.

There are four columns in each table;

“Key” Property Atom Value String – the string value found in the “Key PMI Property Atom” as described in “PMI Property”. A full description of “PMI Property” can be found in the “PMI Model Views” logical collection.

“Value” Property Atom Value String Encoding Format - the string value found in “Value PMI Property Atom” as described in “PMI Property”. A full description of “PMI Property” can be found in the “PMI Model Views” logical collection.

“Prequist Key” – keys required for the proper use of the listed property key

“Additional Note” – additional information for the property key

The PMI Properties table makes use of C programming string format specifiers in order to describe the content expected by the property key as all properties are natively stored as UTF16 encoded strings. For example “%.16g” indicates an encoded double value, “%s” a string and “%d” an integer.

Note: The following comment applies for all properties where the value format is “0x00%02x%02x%02x” such that the values of blue, green and red for the colour are encoded in the string

- This defines an hexadecimal integer representing RGB colour where value has “0x00bbgrr” form. The low-order byte contains a value for the relative intensity of red; the second byte contains a value for the relative intensity of green; and the third byte contains a value for the relative intensity of blue. The high-order byte shall be zero. The maximum value for a single byte is 0xFF (therefore intensity value is in the range [0:255]).

Note: Implementers should use the descriptions found in PMI Manager Meta Data Element as opposed to working with PMI Data Segment.

11.9.3 CAD Properties

The CAD Properties table, as shown in Table 76, provides a description for properties that CAD data translators should follow when placing CAD information in a JT file as properties on various LSG nodes.

Table 76 — CAD Properties

| JT Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values | Required / Optional |
|-----------------------|---|-------------------|-------------------|-------------------------------------|------------------------|
| CAD_CENTER_OF_GRAVITY | Center of gravity of solids within part | String | F64 | 3 space separated numeric values | Optional See Note * |
| CAD_FORCE_UNITS | Defines the units for forces | String | MbString | MilliNewton Newton PoundForce | Optional |
| CAD_DENSITY | Density of solids within part | String | F64 | numeric | Optional See Note * |
| CAD_MASS | Mass or weight of solids within part | String | F64 | numeric | Optional See Note * |

| JT Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values | Required / Optional |
|-----------------------------|--------------------------------------|-------------------|-------------------|--|------------------------|
| CAD_MASS_UNITS | Defines the Units of mass | String | MbString | micrograms milligrams grams kilograms ounces pounds | Required |
| CAD_MOMENT_OF_INERTIA | Moment of inertia value | String | F64 | 6 space separated numeric values ;xx,yy,zz, xy,xz,yz | Optional See Note * |
| CAD_PART_NAME | Component name from translator | String | MbString | | Optional |
| CAD_PROP_MATERIAL_THICKNESS | Sheet thickness within part | String | F64 | numeric | Optional |
| CAD_PROP_YOUNGS_MODULUS | Youngs Modulus value | String | F64 | numeric | Optional |
| CAD_SOURCE | CAD program the Part originated from | String | MbString | | Optional |
| CAD_SURFACE_AREA | Surface area of solids within part. | String | F64 | numeric | Optional See Note * |
| CAD_VOLUME | Volume of solids within part | String | F64 | numeric | Optional See Note * |

| JT Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values | Required / Optional |
|---------------------------|---|-------------------|-------------------|---|--------------------------|
| JT_PROP_MEASUREMENT_UNITS | <p>Defines the Model Units and is therefore relevant for the reading and interpretation of the Geometry and LOD data.</p> <p>Note: Must be present as a hidden property using.</p> <p>If the property is in the scene graph twice on different nodes, then the definition that is the lowest (last along a specific path through the graph) takes precedence.</p> | String | MbString | millimeters centimeters meters inches feet yards micrometers decimeters kilometers mils miles | Required See Note |

Note * : These properties contain calculated values which are typically taken from the origin CAD system during conversion.

Note: CAD properties may appear with prefix “UD_”. These values are specified by the JT content harmonization group in order to allow users to pass user defined values independent on some CAD measurements.

Note: JT 9.5 states the JT_PROP_MEASUREMENT_UNIT property value is in lowercase. It may occur that the property is given in mixed case, upper case for the first letter. In this situation, some tools might interpret the JT_PROP_MEASUREMENT_UNITS property as unknown or not defined. Implementors should check for this property value with the first letter in both upper and lower case.

11.9.3.1 Required Properties

The CAD unit properties are required to properly interpret numeric data for analysis operations (for example measurement) and support the building of assemblies when reading JT files with disparate units.

The JT_PROP_MEASUREMENT_UNITS property is required to define model dimensions. It is relevant to the interpretation of geometrical values, such as coordinates of B-Rep and LOD data as well as certain properties. To avoid ambiguous interpretation, the property should appear only once per JT Part. If the property exists for two different nodes in the scene graph, the property of the lowest (last) node along a given path takes precedence.

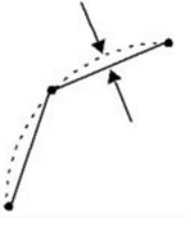
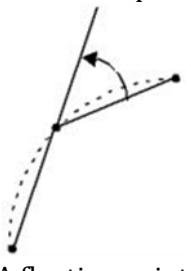
By convention, the property JT_PROP_MEASUREMENT_UNITS is defined as a hidden property.

11.9.4 Tessellation Properties

The faceted graphical representations in JT are present as LODs. Three properties may be stored on Part Node Elements to indicate the tessellation tolerances used to generate each LOD. These properties are defined in Table 77, Tessellation Property Values.

Note: Tessellation properties should not be defined as late-loaded but with the visible specifier included in their property keys.

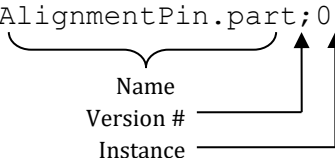
Table 77 — Tessellation Property values

| JT Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values |
|-----------------|---|-------------------|--|--------------|
| Chordal | <p>Chordal deviation tessellation tolerance in MCS units for each LOD. The Measure of maximum allowable distance a linear approximation for a curve/surface may deviate from the true curve/surface.</p>  <p>A floating point value in the range [0.0,1.0] for relative interpretation, arbitrary range for absolute interpretation.</p> | MbString | space separated F32 values Number of values will be defined by the number of LODs | Numeric |
| Angular | <p>Angular tessellation tolerance for each LOD in degrees. Two consecutive segments in a linear approximation of a curve/surface form an angle; this value specifies the maximum angle allowed.</p>  <p>A floating point value in the range [0.0,90.0].</p> | MbString | space separated F32 values Number of values will be defined by the number of LODs | Numeric |
| SegLength | <p>The maximum absolute length of (tessellated) line segments in a curve approximation. A floating point value of arbitrary range</p> | MbString | F32 | Numeric |

11.9.5 Miscellaneous Properties

The Table 78 documents some miscellaneous properties often placed on various nodes in the LSG to communicate specific information about the node or its contents.

Table 78 — Miscellaneous Property values

| JT Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values |
|------------------------------|---|-------------------|-------------------|--------------------------------|
| PMI_TYPE_TABLE | May be attached to Part Node Element to indicate the list of PMI type values and associated names for all PMI types (basically equivalent to the Entity Type field documented in Generic PMI Entities). The string is a "." and "," delimited string of the following form: "10.Groove Weld,11.Fillet Weld,12.Plug/Slot Weld,14.Edge Weld" | MbString | <string> | |
| JT_PROP_SHAPE_DATA_TYPE | May be attached to Shape Node Elements to indicate what geometry type the shape data represents. | MbString | <string> | "Surface" "Wire" |
| JT_PROP_ORIGINATING_BREPTYPE | May be attached to Part Node Element to indicate the type of B-Rep associated with the Part. | MbString | <string> | "None" "JtBrep" "XTBrep" |
| JT_PROP_NAME | May be attached to any form of node or attribute with which one wants to associate a textual name (for example Part/Assembly/Instance name, Material name, Light Set name, etc.). For Part/Assembly/Instance names this string has the following encoded form where ";" is a delimiter and ":" is a terminator: <div style="text-align: center;"> "AlignmentPin.part;0" <div style="display: flex; justify-content: center; align-items: center; margin-top: 10px;"> <div style="text-align: center; margin-right: 20px;"> Name Version # Instance </div> <div style="text-align: center;">  </div> </div> </div> For attribute names this string has the following encoded form: <div style="text-align: center;"> "Chrome material" <div style="display: flex; justify-content: center; align-items: center; margin-top: 10px;"> <div style="text-align: center;"> Name </div> </div> </div> | MbString | <string> | |

11.9.6 The SUBNODE property and Reference Sets

A SUBNODE property can be defined on a part or assembly node in a JT file. By convention, the node which has the property defined is considered to be part of the parent as opposed to being a normal node entity in an assembly, as shown in Figure 154. SUBNODE properties can be used to represent a number of CAD constructs in JT files including reference sets.

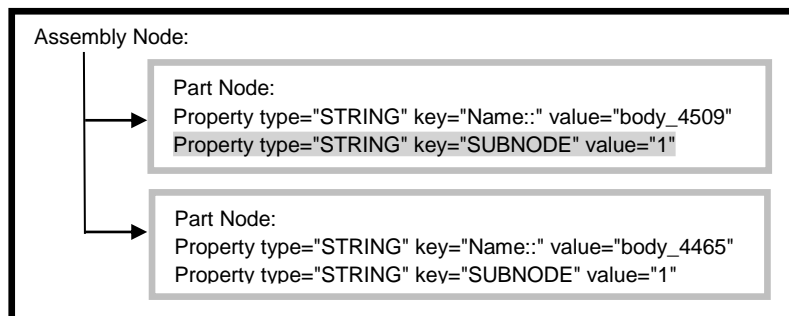


Figure 154 — Assembly node with SUBNODE

A diagrammatic representation of Assembly node without SUBNODE is shown in Figure 155.

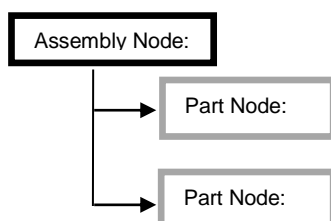


Figure 155 — Assembly node without SUBNODE

JT viewing systems by default do not display the trees structure for a node containing sub node definitions expanded, as shown in Figure 156.

A diagrammatic representation Displaying Nodes that have SUBNODE properties is shown is shown in Figure 156.

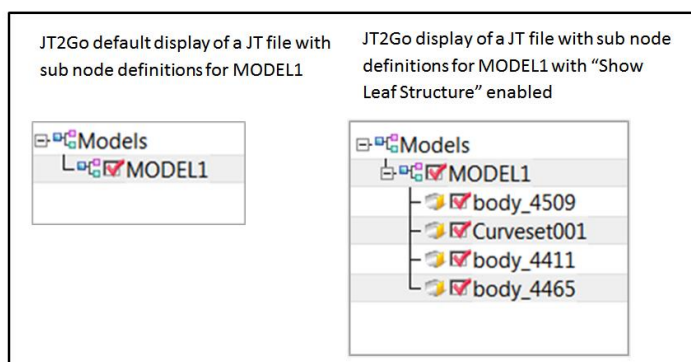


Figure 156 — Displaying Nodes that have SUBNODE properties

The node containing the SUBNODE property, as shown in Figure 156, can be either a part node or an assembly node.

The value assigned to the SUBNODE property has no specific meaning, as shown in Table 79. Implementers should set the value for the property to a string value of "1". Parts that contain the SUBNODE property must contain a string property with a name for the part.

Table 79 — SUBNODE Property

| JT Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values |
|-----------------|---|-------------------|-------------------|--------------|
| SUBNODE | Specifies the node as being a sub node of the parent assembly | MbString | <string> | 0 or 1 |

Reference Sets and the Reference Set Property

Many CAD systems are able to create a modeled construct whereby a single CAD part can contain a user defined substructure of geometry and PMI. A CAD part constructed this way is said to have reference sets or reference geometry. In JT a CAD part constructed this way, by convention, is referred to as a CAD component.

A JT CAD component is a unique assembly structure whereby the top level part in the assembly is the CAD Component and the part(s) that make up the assembly are sub nodes. When this arrangement exists in a JT file the CAD Component is said to contain Reference Sets. Reference Set definitions, as shown in Figure 157, are an JT convention made up of assembly nodes, part nodes and properties. The part or assembly nodes defined in the CAD Component assembly are the actual reference set definitions.

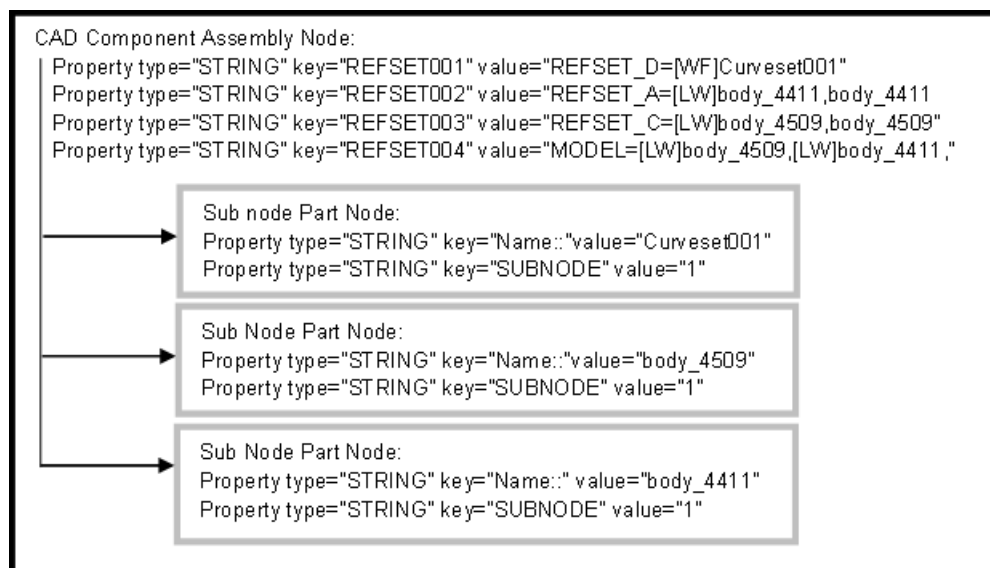


Figure 157 — CAD Component with Reference sets

This representation of the CAD Component structure is achieved through the use of the REFSET<XXX> property in the CAD Component part and the SUBNODE property in the parts that contain the reference set definitions.

The reference set property key has the form REFSETXXX with the XXX being a three digit incrementing number starting at 001. The numbers must be assigned concurrently. Up to 999 references set properties can be assigned for a CAD component. A reference set property is a comma delimited string of part names and hints. These parts can contain geometry such as solid bodies, wireframe or points that represent content relevant to the owning CAD component. To facilitate identification of the reference set content, hint strings can be combined with the part names. There are four reserved hint strings for reference sets: PMI, PT (point cloud), WF (wireframe) and LW (light weight, facet only).

Reference set encoding conventions

- Reference set names are not case sensitive

- The values = , and \ need to be escaped within the values of the property keys if they are in a part name or reference set name

The Reference Set Properties table, as shown in Table 80, provides a description of the Reference set property values.

Table 80 — Reference Set Properties

| Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values |
|--------------|--|-------------------|-------------------|--|
| REFSETXXX | <p>Specifies the string of part names that are included in the reference set. The property value defines the reference set name that is displayed in viewing systems</p> <p>therefore;</p> <p>type="STRING" key="REFSET<XXX>" value="REFSET_A_D=[WF]<ref set name>,[LW]<ref set name>,[PT]<ref set name>,<ref set name>,[PMI]"</p> <p>There are 3 reserved strings that can be added as prefixes to the JT part names included on the reference set string. They are;</p> <p>[PT] : precedes the referenced part name(s) that contain point cloud geometry</p> <p>[WF] : precedes the referenced part name(s) that contain wireframe geometry</p> <p>[LW] : precedes the referenced part name(s) that contain only facet geometry representations. B-Rep is not present.</p> <p>The reference hint string [PMI] is included without part names. When the [PMI] hint is included corresponding PMI entities with the JT_TK_MULTICAD_REFSET property may exist. See table 81</p> | MbString | <string> | Comma delimited string of part names and hints |

The Properties table, related to the use of Reference Sets, as shown in Table 81, provides a list of additional properties that assist applications with using and displaying reference sets.

Table 81 — Properties related to the use of Reference Sets

| Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values |
|----------------------|--|-------------------|-------------------|------------------------|
| REFSET_META | <p>Contains a comma delimited list of aliased reference sets via the following convention; REFSET_META="alias_1=name_1,alias_2=name_2"</p> <p>An aliased reference sets is a reference set definition used to record a group of reference sets that crosses multiple CAD Components.</p> | MbString | <string> | Comma delimited string |
| JTTK_MULTICAD_REFSET | <p>This property must be set on the PMI.</p> <p>To have PMI visible within a reference it must have a JTTK_MULTICAD_REFSET property defined.</p> <p>The property is a string of Reference Set names that the PMI will be visible in.</p> <p>therefore</p> <p>type="STRING" key="JTTK_MULTICAD_REFSET" value="<refset name>, <refset name>"</p> | MbString | <string> | Comma delimited string |

The REFSET_CURRENT property, as shown in Table 82, is defined in instance nodes that are instances of a CAD Component. The property contains a string value that is the name of a reference set that exists in the CAD Component that has been instantiated. Best practice is to use this property to determine the reference set that will become active if the model is set to the "as saved" state.

Table 82 — REFSET_CURRENT property

| Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values |
|----------------|--|-------------------|-------------------|------------------------|
| REFSET_CURRENT | <p>Defines which reference set will be displayed in an instance node</p> <p>therefore</p> <p>type="STRING" key="REFSET_CURRENT" value =<refset name></p> | MbString | <string> | Comma delimited string |

11.10 LSG Attribute Accumulation Semantics

For applications producing or consuming JT format data, it is important that the JT format semantics of how attributes are meant to be applied and accumulated down the LSG are followed. If not followed, then consistency between the applications in terms of 3D positioning and rendering of LSG model data will not be achievable.

Although each attribute type defines its own application and accumulation LSG semantics (the details of which can be found in each attribute type sub-section under Attribute Elements), there are some general rules which apply:

Attributes at lower level in the LSG take precedence and replace or accumulate with attributes set at higher levels. When multiple Attributes of the same type are present on a Node, they accumulate in the order they are specified (therefore from the front of the Attribute list toward the back).

Nodes with no associated attributes inherit those of their parents.

Attributes are inherited only from a node's parents. Thus a given node's attributes do not affect those on the node's siblings.

The root of a partition inherits the attributes in effect at the referring partition node.

Attributes can be marked "final", which terminates accumulation of that attribute type at that marked attribute and propagates the accumulated value at that point to all descendants of the associated node. Descendants can override a "final" attribute using the "force" flag. Note that "force" does not turn OFF "final" – it is simply a one-shot override of "final" for the specific attribute marked as "forcing." Multiple attributes of the same type may be marked as "forcing" and in this case, the last one wins. Both of these flags are OFF by default. An analogy for this "force" and "final" interaction is that "final" is a back-door in the attribute accumulation semantics and that "force" is the doggy-door in the back-door!

11.11 LSG Part Structure

The JT Format Reference does not mandate that a particular node hierarchy be used for modeling physical Parts within a LSG structure. In fact there are many node hierarchies for representing Parts in LSG that will function correctly in most JT enabled applications. Still, there is a convention that most JT translators follow (and some JT enabled applications may assume exists) for modeling Parts within a LSG. The convention is to model each Part within a LSG structure with the following node hierarchy, as shown in Figure 158:

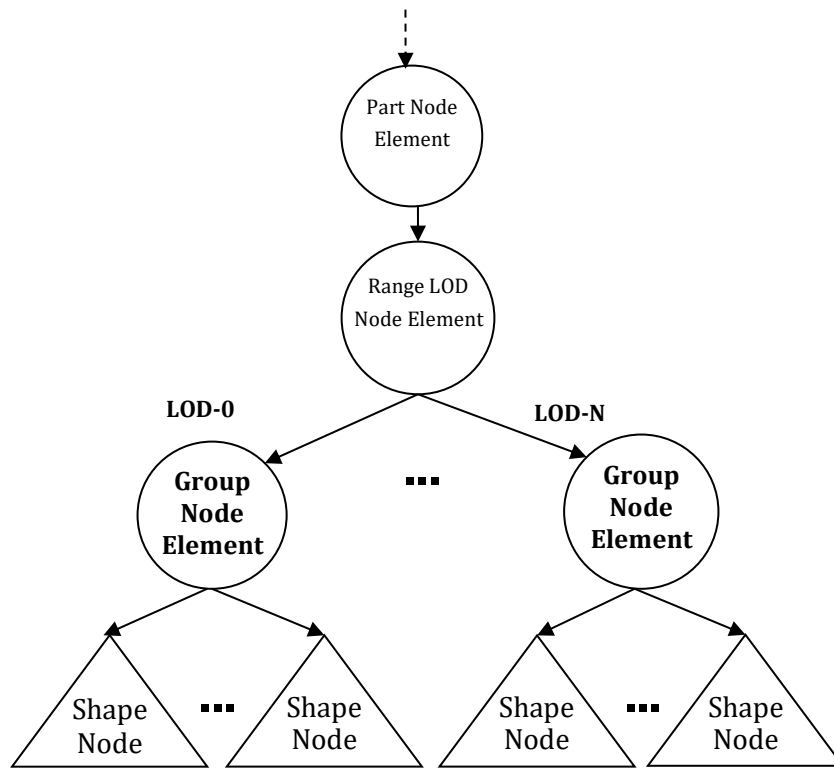


Figure 158 — JT Format Convention for Modeling each Part in LSG

11.12 Range LOD Node Alternative Rep Selection

Best practices suggest that LSG traversers apply the following strategy, at Range LOD Nodes (see Range LOD Node Element), when making alternative representation selection decisions based on Range Limits: The first alternate representation is valid when the world coordinate distance between the centre and the eye point is less than or equal to the first range limit (and when no range limits are specified). The second alternate representation is valid when the distance is greater than the first limit and less than or equal to the second limit, and so on. The last alternate representation is valid for all distances greater than the last specified limit.

11.13 B-Rep Face Group Associations

The original purpose of the face group concept was to provide associativity between B-Rep faces and geometry. Exactly how a B-Rep face associates to a face group number is the topic of this section. An implicit scheme has been chosen for face group associativity, rather than storing some kind of explicit data on either the Vertex Shape LOD Data or the B-Rep. The primary motivation for this implicit scheme is to keep the JT files simple and small; additional association information would not only be redundant, but also wasteful. Tessellators shall exercise this policy when producing Vertex Shape LOD Data from B-Reps, grouping the triangles into face groups according to its rules. Tristrips may not cross face groups. Applications shall be able to count on this policy so that, for example, they can map a picking action back to its corresponding B-Rep face reliably.

JT B-Rep/ULP: In the case of JT B-Rep and ULP reps, the mapping is simple. These Reps have a consistent sequential index origin-0 numbering scheme for their regions, shells, and faces. So the B-Rep faces are simply assigned sequentially to face group by increasing region and shell. For example, suppose we have a JT B-Rep with 2 regions, each with 2 shells, each with 2 faces. The Face Group \Leftrightarrow Region/Shell/Face mapping will be as follows:

FG0 \Leftrightarrow R0 S0 F0
 FG1 \Leftrightarrow R0 S0 F1

```

FG2 ⇔ R0 S1 F0
FG3 ⇔ R0 S1 F1
FG4 ⇔ R1 S0 F0
FG5 ⇔ R1 S0 F1
FG6 ⇔ R1 S1 F0
FG7 ⇔ R1 S1 F1

```

XT B-Rep: In the case of XT B-Rep, the mapping is based on an identifier of each XT face that is persisted on disk. The identifier is unique within each XT body, but it is not an index. XT B-Rep maintains a zero-based contiguous index of XT face based on increasing identifier value within the same XT body. In the case when multiple bodies are present in XT B-Rep, face index is assigned sequentially by increasing XT body index. For example, suppose we have a XT B-Rep with 2 bodies, each with 2 faces, then the Face Group to Body/Face mapping will be as follows:

```

FG0 ⇔ B0 F0
FG1 ⇔ B0 F1
FG2 ⇔ B1 F0
FG3 ⇔ B1 F1

```

11.14 JT Smart Topology Table (STT) Segment

JT Smart Topology Table (hereafter referred to as STT) Segment contains an Element that defines the lightweight topology description for a particular Part.

JT STT Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The JT STT Segment type supports compression on all element data, so all elements in JT STT Segment use the Logical Element Header Compressed form of element header data.

Object Type ID: 0xca7e6f89, 0x97c8, 0x47f0, 0x9f, 0xca, 0x16, 0x99, 0xc, 0xfb, 0xe2, 0x17

See Annex H JT Smart Topology Table (STT) Segment for a full description of the STT Segment.

11.15 Watermark Image

A watermark image can be added to a JT file as a texture. Textures are stored as Attribute Elements in JT. Attribute Elements are placed in the Logical Scene Graph (LSG) as objects associated with nodes. For more information on Attribute Elements, see Attribute Elements.

Use of a JT texture to represent a watermark is implementation de-pendent. When a texture contains specific properties, an application shall display the texture image on top of any other graphics, effectively displaying it as a watermark.

This implementation requires properties that follow a defined convention, as shown in Table 83. These properties alert the application that the texture information should be displayed in a unique way and at which locations on the display screen the texture should appear. Properties on textures are defined as Property Atom Elements. These properties are meta-data objects associated with attributes. Each attribute element in an LSG may hold zero or more property atom elements.

Table 83 — Texture watermark properties

| Property Key | Meaning | JT File Data Type | Encoded Data Type | Valid Values |
|--------------|---------|-------------------|-------------------|--------------|
| | | | | |

| | | | | |
|------------------------------|---|---------|-----------|-----------|
| WATERMARK / Watermark (*) | Alerts to the application that the texture containing this property is meant to be displayed as a watermark | String | MbString | Watermark |
| LOCATION / Location (*) | Defines a region on the display for the watermark to appear top left = 1, top center = 2, top right = 3, mid left = 4, mid center = 5, mid right = 6, bottom left = 7, bottom center = 8, bottom right = 9 | Integer | Integer | 1-9 |
| Y_DPI | DPI for the output image in Y direction | Float | F32 value | |
| X_DPI | DPI for the output image in X direction | Float | F32 value | |

(*) Property key may appear in upper case or camel style.

11.16 State Flags

State Flags are defined within the Base Property Atom Element definition this way;

State Flags are a collection of flags. The flags are combined using the binary OR operator and store various state information for property atoms. Bits 0 – 7 are freely available for an application to store whatever property atom information desired. All other bits are reserved for future expansion of the file format.

Tests have shown that there are problems with interoperability when Bits 0-7 are freely used. State Flags bits 0-7 shall be defaulted to 0x40000000.

Annex A

Object Type Identifiers

All objects stored in an JT file are classified by type and thus include an object type identifier as part of their persisted data, as shown in Table A.1. The data format for these Object Type identifiers is a GUID. These Object Type identifiers are consistent for all objects, of a particular type.

Table A.1—Object Type Identifiers

| GUID | Object Type |
|--|---------------------------------------|
| 0xffffffff, 0xffff, 0xffff, 0xff, 0xff, 0xff, 0xff, 0xff, 0xff, 0xff | Identifier to signal End-Of-Elements. |
| Types Stored Within LSG Segment (Segment Type = 1) | |
| 0x10dd1035, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Base Node Element |
| 0x10dd101b, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Group Node Element |
| 0x10dd102a, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Instance Node Element |
| 0x10dd102c, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | LOD Node Element |
| 0xce357245, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1 | Meta Data Node Element |
| 0xd239e7b6, 0xdd77, 0x4289, 0xa0, 0x7d, 0xb0, 0xee, 0x79, 0xf7, 0x94, 0x94 | NULL Shape Node Element |
| 0xce357244, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1 | Part Node Element |
| 0x10dd103e, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Partition Node Element |
| 0x10dd104c, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Range LOD Node Element |
| 0x10dd10f3, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Switch Node Element |
| 0x10dd1059, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Base Shape Node Element |
| 0x98134716, 0x0010, 0x0818, 0x19, 0x98, 0x08, 0x00, 0x09, 0x83, 0x5d, 0x5a | Point Set Shape Node Element |
| 0x10dd1048, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Polygon Set Shape Node Element |
| 0x10dd1046, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Polyline Set Shape Node Element |
| 0xe40373c1, 0x1ad9, 0x11d3, 0x9d, 0xaf, 0x0, 0xa0, 0xc9, 0xc7, 0xdd, 0xc2 | Primitive Set Shape Node Element |
| 0x10dd1077, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Tri-Strip Set Shape Node Element |
| 0x10dd107f, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Vertex Shape Node Element |
| 0x10dd1001, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Base Attribute Data |
| 0x10dd1014, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Draw Style Attribute Element |

| GUID | Object Type |
|--|--|
| 0x10dd1083, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Geometric Transform Attribute Element |
| 0x10dd1028, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Infinite Light Attribute Element |
| 0x10dd1096, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Light Set Attribute Element |
| 0x10dd10c4, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Linestyle Attribute Element |
| 0x10dd1030, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Material Attribute Element |
| 0x10dd1045, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Point Light Attribute Element |
| 0x8d57c010, 0xe5cb, 0x11d4, 0x84, 0xe, 0x00, 0xa0, 0xd2, 0x18, 0x2f, 0x9d | Pointstyle Attribute Element |
| 0x10dd1073, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Texture Image Attribute Element |
| 0xaa1b831d, 0x6e47, 0x4fee, 0xa8, 0x65, 0xcd, 0x7e, 0x1f, 0x2f, 0x39, 0xdc | Texture Coordinate Generator Attribute Element |
| 0x10dd1106, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | PaletteMap Attribute Element |
| 0xa3cfb921, 0xbdeb, 0x48d7, 0xb3, 0x96, 0x8b, 0x8d, 0xe, 0xf4, 0x85, 0xa0 | Mapping Plane Element |
| 0x3e70739d, 0x8cb0, 0x41ef, 0x84, 0x5c, 0xa1, 0x98, 0xd4, 0x0, 0x3b, 0x3f | Mapping Cylinder Element |
| 0x72475fd1, 0x2823, 0x4219, 0xa0, 0x6c, 0xd9, 0xe6, 0xe3, 0x9a, 0x45, 0xc1 | Mapping Sphere Element |
| 0x92f5b094, 0x6499, 0x4d2d, 0x92, 0xaa, 0x60, 0xd0, 0x5a, 0x44, 0x32, 0xcf | Mapping TriPlanar Element |
| 0x10dd104b, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Base Property Atom Element |
| 0xce357246, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1 | Date Property Atom Element |
| 0x10dd102b, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Integer Property Atom Element |
| 0x10dd1019, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Floating Point Property Atom Element |
| 0xe0b05be5, 0xfbbd, 0x11d1, 0xa3, 0xa7, 0x00, 0xaa, 0x00, 0xd1, 0x09, 0x54 | Late Loaded Property Atom Element |
| 0x10dd1004, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Object Reference Property Atom Element |
| 0x10dd106e, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | String Property Atom Element |
| Types Stored Within JT B-Rep Segment (Segment Type = 2) | |
| 0x873a70c0, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | JT B-Rep Element |
| Types Stored Within Meta Data Segment (Segment Type = 4) | |
| 0xce357249, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1 | PMI Manager Meta Data Element |
| 0xce357247, 0x38fb, 0x11d1, 0xa5, 0x6, 0x0, 0x60, 0x97, 0xbd, 0xc6, 0xe1 | Property Proxy Meta Data Element |
| Types Stored Within Shape LOD Segment (Segment Type = 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16) | |

| GUID | Object Type |
|--|---------------------------------|
| 0x3e637aed, 0x2a89, 0x41f8, 0xa9, 0xfd, 0x55, 0x37, 0x37, 0x3, 0x96, 0x82 | Null Shape LOD Element |
| 0x98134716, 0x0011, 0x0818, 0x19, 0x98, 0x08, 0x00, 0x09, 0x83, 0x5d, 0x5a | Point Set Shape LOD Element |
| 0x10dd10a1, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Polyline Set Shape LOD Element |
| 0xe40373c2, 0x1ad9, 0x11d3, 0x9d, 0xaf, 0x0, 0xa0, 0xc9, 0xc7, 0xdd, 0xc2 | Primitive Set Shape Element |
| 0x10dd10ab, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Tri-Strip Set Shape LOD Element |
| 0x10dd109f, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Polygon Set LOD Element |
| 0x10dd10b0, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Vertex Shape LOD Element |
| Types Stored Within XT B-Rep Segment (Segment Type = 17) | |
| 0x873a70e0, 0x2ac9, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | XT B-Rep Element |
| Types Stored Within Wireframe Segment (Segment Type = 18) | |
| 0x873a70d0, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97 | Wireframe Rep Element |
| Types Stored Within ULP Segment (Segment Type = 20) | |
| 0xf338a4af, 0xd7d2, 0x41c5, 0xbc, 0xf2, 0xc5, 0x5a, 0x88, 0xb2, 0x1e, 0x73 | ULP Element |
| Type Stored Within STT (Segment Type = 23) | |
| 0xca7e6f89, 0x97c8, 0x47f0, 0x9f, 0xca, 0x16, 0x99, 0xc, 0xfb, 0xe2, 0x17 | STT Element |
| Types Stored Within LWPA Segment (Segment Type = 24) | |
| 0xd67f8ea8, 0xf524, 0x4879, 0x92, 0x8c, 0x4c, 0x3a, 0x56, 0x1f, 0xb9, 0x3a | LWPA Element |
| Type Stored Within MultiXT B-Rep (Segment Type = 30) | |
| 0x49829521, 0x1835, 0x49c3, 0x8b, 0xef, 0xdd, 0xc4, 0x3b, 0xfe, 0x5e, 0x88 | MultiXT B-Rep |
| Type Stored Within Info Segment (Segment Type = 31) | |
| 0x84c2112a, 0x0001, 0x11e7, 0x80, 0x00, 0xa4, 0x24, 0x9a, 0x27, 0x47, 0x70 | Info Element |
| Type Stored Within STEP-B-Rep Segment (Segment Type = 33) | |
| 0x869c7d53, 0xccb0, 0x451b, 0xb2, 0x3, 0xd1, 0x42, 0x81, 0x56, 0x14, 0x56 | STEP B-Rep Element |

Annex B

Coding Algorithms – An Implementation

This Appendix provides a sample C++ implementation for the encoding and decoding portion of the various compression CODECs used in the JT format. This sample code is not intended to be fully functional encoder/decoder class implementations but is instead intended to demonstrate the fundamentals of implementing the encoding/decoding portion of the CODEC algorithms used in the JT format.

B.1 Common classes

The following sub-sections define some general classes used by all the coding algorithms.

B.1.1 CntxEntryBase class

```
//
// Type used to build probability context tables.
// Used by ProbabilityContext class.
//
class CntxEntryBase
{
public:

    // ----- Housekeeping -----
    CntxEntryBase() : _bIsEscape(false), _cCount(-1), _cCumCount(-1) {};
    CntxEntryBase(Bool bIsEsc, Int32 cCount)
        : _bIsEscape(bIsEsc), _cCount(cCount), _cCumCount(-1) {};
    CntxEntryBase(const CntxEntryBase &rhs) { *this = rhs; }
    ~CntxEntryBase() {};
    CntxEntryBase &operator=(const CntxEntryBase &rhs)
    {
        _bIsEscape = rhs._bIsEscape;
        _cCount = rhs._cCount;
        _cCumCount = rhs._cCumCount;
        return *this;
    }

    // ----- Operations Interface -----
    Bool isEscape() const
    { return _bIsEscape; }
    Int32 operator==(const CntxEntryBase2 &rhs) const
    { return (_iSym == rhs._iSym); };

public:

    // ----- Member Variables -----
    Int32      _cCount;      // Number of occurrences
    Int32      _cCumCount;  // Cumulative number of occurrences
    Bool       _bIsEscape;  // True if this symbol is the escape symbol
};

template <class ValueType>

class CntxEntry : public CntxEntryBase
{
public:

    // ----- Housekeeping -----
    CntxEntry() : CntxEntryBase(), _val(ValueType()) {};

    CntxEntry( Bool bIsEsc, Int32 cCount, const ValueType &val ) :
        CntxEntryBase(bIsEsc, cCount), _val(val) {};

    CntxEntry( const CntxEntry &rhs ) { *this = rhs; }
    ~CntxEntry() {};
    CntxEntry &operator=(const CntxEntry &rhs)
    {
        _val = rhs._val;
    }
};
```

```

        CntxEntryBase::operator= (rhs);
        return *this;
    }
    Int32 operator==(const CntxEntry &rhs) const
    { return (_iSym == rhs._iSym); };

public:

    // ----- Member Variables -----
    ValueType          _val;          // Associated value
};

```

B.1.2 ProbContext class

```

//
// Type used to build probability context tables.
// Used by CodecDriver class.
//
template <class ValueType>
class ProbContext
{
public:
    typedef CntxEntry< ValueType > CntxEntryV;

    // ----- Housekeeping -----
    ProbContext();
    ProbContext(const ProbContext &rhs);
    ~ProbContext();
    ProbContext &operator=(const ProbContext &rhs);
    Bool operator==(const ProbContext &rhs) const;
    enum { cMaxCntxCnt = 8192 };

    // ----- Accessor Interface -----
    Int32 totalCount() const
    { return _cTotalCount; }
    Int32 numEntries() const
    { return _vEntries.length(); }
    Bool getEntry(Int32 iEntry, const CntxEntryBase *&rpEntry) const
    { const CntxEntryV *aEntries = _vEntries.ptr();
      rpEntry = &aEntries[iEntry]; return True; }
    Bool getEntryV(Int32 iEntry, const CntxEntryV *&rpEntry) const
    { const CntxEntryV *aEntries = _vEntries.ptr();
      rpEntry = &aEntries[iEntry]; return True; }
    Bool getEntryV(Int32 iEntry, CntxEntryV *&rpEntry)
    { CntxEntryV *aEntries = _vEntries.ptr();
      rpEntry = &aEntries[iEntry]; return True; }

    // ----- Lookup Interface -----
    Bool lookupValue(const ValueType &rValue, const CntxEntryV *&opCntxEntry) const;
    Bool lookupEntryByCumCount(Int32 iCount, const CntxEntryV *&opCntxEntry) const;

    // ----- Reorganizing Interface -----
    Bool accumulateCounts();
    Bool sortByValue();

protected:
    Vec< CntxEntryV > _vEntries;
    Int32 _cTotalCount;
    Int32 _iEscPosCache;

    static int _compareCounts(const void *pVal1,
                             const void *pVal2,
                             const void *uData);
};

template <class ValueType>
Bool ProbContext::lookupValue( const ValueType &rValue,
                             const CntxEntryV *&opCntxEntry ) const
{
    // If we do not find the value, then return NULL for the entry
    opCntxEntry = NULL;
}

```

```

// If the escape position is not cached, sort the context by value
// and then set it. Then, we can binary search for values. We do
// this because translateValuesToSymbols() will call this method in
// a tight loop. Anything is better than linear search!
ProbContext *pThis = (ProbContext*) this;
CntxEntryV *pEntries = pThis->_vEntries.ptr();
Int32 nEntries = _vEntries.length();
if (_iEscPosCache == -1) {
    // Search for the escape symbol
    Bool bFoundEsc = False;
    for (Int32 i = 0 ; i < nEntries ; i++) {
        if (pEntries[i].isEscape()) {
            // Move the escape symbol to context slot 0
            ::swap(pEntries[0], pEntries[i]);
            bFoundEsc = True;
            break;
        }
    }
    // Sort by value
    if (bFoundEsc) {
        // Sort by value _except_ leave the escape symbol in slot 0
        ::sort(&pEntries[1], nEntries-1, FtorCntxValue<ValueType>());
        pThis->accumulateCounts();
        pThis->_iEscPosCache = 0;
    }
    else {
        pThis->sortByValue();
        pThis->_iEscPosCache = -2;
    }
}

// Binary search for rValue!
Int32 l = (_iEscPosCache == 0),
      h = nEntries - 1,
      m;
while (l <= h) {
    m = (l + h) >> 1;
    if (pEntries[m]._val == rValue) {
        opCntxEntry = &pEntries[m];
        return True;
    }
    else if (pEntries[m]._val < rValue)
        l = m + 1;
    else
        h = m - 1;
}

// If we don't find the value, then we return the position of
// the escape symbol.
if (_iEscPosCache >= 0)
    opCntxEntry = &pEntries[_iEscPosCache];

return True;
}

template <class ValueType>
Bool ProbContext2::lookupEntryByCumCount(Int32 iCount, const CntxEntryV *&opCntxEntry )
const
{
    const CntxEntryV *aEntries = _vEntries.ptr();
    const Int32      nEntries = _vEntries.length();

    const Int32      seqSearchLen = 4;
    Int32 ii=0;
    opCntxEntry = NULL;

    // For short lists, do sequential search
    if ( nEntries <= (seqSearchLen*2) ) {
        ii = 0;
        while ((iCount>=(aEntries[ii]._cCumCount + aEntries[ii]._cCount)) &&
              (ii<nEntries))
        {
            ii++;

```

```

    }

    if ( ii >= nEntries ) {
        Assert( 0 && "Bad probability table" );
    }
    opCntxEntry = &aEntries[ii];
}

// For long lists, do a short sequential searches through most likely
// elements, then do a binary search through the rest.
else {
    for (ii=0; ii<seqSearchLen; ii++) {
        if (iCount < (aEntries[ii]._cCumCount + aEntries[ii]._cCount)) {
            opCntxEntry = &aEntries[ii];
            return True;
        }
    }

    Int32 low=ii, high=nEntries-1, mid;
    while(1) {
        if ( high < low ) {
            break;
        }
        mid = low + ((high-low)>>1);

        if ( iCount < aEntries[mid]._cCumCount ) {
            high = mid-1;
            continue;
        }
        if ( iCount >= (aEntries[mid]._cCumCount + aEntries[mid]._cCount) ) {
            low = mid+1;
            continue;
        }

        opCntxEntry = &aEntries[mid];
        return True;
    }
    Assert( 0 && "Bad probability table" );
}

return True;
}

template <class ValueType>
Bool ProbContext2::accumulateCounts()
{
    // Check for zero length context
    CntxEntryV *aEntries = _vEntries.ptr();
    Int32 nEntries = _vEntries.length();
    if ( nEntries == 0 ) {
        _cTotalCount = 0;
        return True;
    }

    // Accumulate counts in _cCumCount for entries 1 and higher
    aEntries[0]._cCumCount = 0;
    Int32 ii;
    for ( ii=1 ; ii<nEntries ; ii++ ) {
        aEntries[ii]._cCumCount = aEntries[ii-1]._cCount + aEntries[ii-1]._cCumCount;
    }

    // Set the total count for the context
    _cTotalCount = aEntries[ii-1]._cCount + aEntries[ii-1]._cCumCount;

    return True;
}

template <class ValueType>
struct FtorCntxValue
{
    Bool operator () (const CntxEntry<ValueType>& l, const CntxEntry<ValueType>& r) const
    { return (l._val < r._val); }
};

```

```

template <class ValueType>
Bool ProbContext2::sortByValue()
{
    // Sort the entries in order of values from smallest to largest
    ProbContextV *pThis = (ProbContextV*) this;
    sort( _vEntries.ptr(), (size_t)( _vEntries.length()), FtorCntxValue<ValueType>() );

    pThis->_iEscPosCache = -1;
    pThis->accumulateCounts();

    return True;
}

```

B.1.3 CodecDriver class

```

//
// A class that deals with the conversions from SYMBOL to VALUE and
// provides end-consumer APIs for using the codecs.
//
template <class ValueType>
class CodecDriver
{
public:

    // ----- Internal Types -----
    typedef enum {
        CodecNull          = 0,    // Null Codec
        CodecBitLength      = 1,    // Bitlength Codec
        CodecArithmetic     = 3,    // Arithmetic Codec
        CodecChopper        = 4,    // Chopper Pseudo-codec
        CodecMTF            = 5,    // Move-to-front Pseudo-codec
    } CodecType;
    // Type of value predictor
    typedef enum {
        PredLag1           = 0,    // Predicts as last values
        PredXor1           = 1,    // Predict as last, but use xor instead of subtract
        PredNULL           = 2,    // No prediction.
    } PredictorType;

    static Bool unpackResiduals(const Veci    &rvResidual,
                               Veci          &rvVals,
                               PredictorType  ePredType);
    static Bool unpackResiduals(const Vecu    &rvResidual,
                               Vecu          &rvVals,
                               PredictorType  ePredType);

    static Float64 log2( Float64 x ) { return (log(x) / 0.6931471805599453); }

    ///////////////////////////////////////////////////
    // Convenience Methods
    ///////////////////////////////////////////////////

protected:
    static Int32 _predictValue( const Int32 *vVal, Int32 iIndex,
                               PredictorType ePredType );
};

Bool CodecDriver::unpackResiduals( const Veci    &rvResidual,
                                   Veci          &rvVals,
                                   PredictorType  ePredType )
{
    const Int32 len = rvResidual.length();
    Int32 iPredicted;
    rvVals.setLength(len);
    Int32 *aVals = rvVals.ptr();
    const Int32 *aResidual = rvResidual.ptr();
    for ( Int32 i = 0 ; i < len ; i++ ) {
        if ( i < 4 ) {
            // The first four values are just primers
            aVals[i] = aResidual[i];
        } else {
            // Get a predicted value

```

```

        iPredicted = _predictValue(rvVals.ptr(), i, ePredType);

        if (ePredType == PredXor1) {
            // Encode the residual as the current value XOR predicted
            aVals[i] = aResidual[i] ^ iPredicted;
        } else {
            // Encode the residual as the current value plus predicted
            aVals[i] = aResidual[i] + iPredicted;
        }
    }
}

return True;
}

Bool
CodecDriver2::unpackResiduals( const Vecu      &rvResidual,
                               Vecu           &rvVals,
                               PredictorType   ePredType )
{
    return unpackResiduals(*((const Veci*)&rvResidual),
                           *((Veci*) &rvVals),
                           ePredType);
}

Int32
CodecDriver2::_predictValue( const Int32*   paVals,
                             Int32         iIndex,
                             PredictorType  ePredType )
{
    Int32 iPredicted = 0;
    switch (ePredType) {

        default:
        case PredLag1:      // Predicts as last value
        case PredXor1:      // Predicts as last value
            iPredicted     = paVals[iIndex-1];
            break;
    }

    return iPredicted;
}

```

B.2 Bitlength decoding class

The following sub-section contains a sample implementation of the decoding portion of the Bitlength CODEC algorithm. A summary technical explanation of the Bitlength CODEC can be found in the Encoding Algorithms section of this document under Bitlength Codec.

B.2.1 BitLengthCodec class

```

template <class ValueType>
class BitLengthCodec : public Codec<ValueType>
{
public:
    typedef Vec< ValueType >          VecValue;
    typedef ProbContext< ValueType >  ProbContextV;
    typedef CodecDataCntx< ValueType > CodecDataCntxV;

    Bool encode( const VecValue &vValues,
                 VecValue       &ovOOBValues,
                 Vecu           &ovCodeText,
                 Int32          &onBitsCodeText,
                 ProbContextV   *pProbCntx      );

    Bool decode( Int32          nValues,
                 VecValue       &ovOOBValues,
                 const Vecu     &vCodeText,
                 Int32          nBitsCodeText,
                 VecValue       &ovValues,
                 ProbContextV   *pProbCntx      );
}

```



```

protected:
    Int32 _nBitsInSymbol(Int32 iSymbol) const;
    Bool getNextCodeText (UInt32 &uCodeText, Int32 &nBits);

    Vecu      *_pvCodeText;
    Int32      *_pcCodeTextLen;
    Int32      _iCurCodeText;
    Vecus      _vnValBits;
};

template <class ValueType> void
BitLengthCodec3T<ValueType>::GetSignedBits(Int32 &iOut, UInt32 n)
{
    GetUnsignedBits(*((UInt32*)&iOut),n);
    iOut <=> (32 - n);
    iOut >>= (32 - n);
}

template <class ValueType> void
BitLengthCodec3T<ValueType>::GetUnsignedBits(UInt32 &uOut, UInt32 n)
{
    if (n == 0) uOut = 0;
    else if (_nValBits >= n) {
        uOut = _uVal >> (32 - n);
        _uVal <=> n;
        _uVal &= (n==32)-1;
        _nValBits -= n;
        _nBits += n;
    }
    else {
        Int32 _nLBits = _nValBits;
        uOut = _uVal >> (32 - n);
        _nBits += _nLBits;
        getNextCodeText (_uVal, _nValBits);
        Int32 _nRBits = (n - _nLBits);
        uOut |= _uVal >> (32 - _nRBits);
        _uVal <=> _nRBits;
        _uVal &= (_nRBits==32)-1;
        _nValBits -= _nRBits;
        _nBits += _nRBits;
    }
}

template <class ValueType> void
BitLengthCodec3T<ValueType>::GetUnsignedBits(UInt64 &ulOut, UInt32 n)
{
    UInt32 low32 = 0, high32 = 0;
    GetUnsignedBits(low32, ::min(n, (UInt32)32));
    GetUnsignedBits(high32, ::max((Int32)n-32, (Int32)0));
    UInt64 ulHigh32 = high32;
    ulHigh32 <=> 32;
    ulOut = ulHigh32 | low32;
}

template <class ValueType> void
BitLengthCodec3T<ValueType>::GetSignedBits(Int64 &lOut, UInt32 n)
{
    GetUnsignedBits(*((UInt64*)&lOut),n);
    lOut <=> (64 - n);
    lOut >>= (64 - n);
}

template <class ValueType> void
BitLengthCodec3T<ValueType>::nibblerEmit(UInt32 iVal)
{
    return _nibblerEmit(iVal, ::bitsize(iVal));
}

template <class ValueType> void
BitLengthCodec3T<ValueType>::nibblerEmit(Int32 iVal)
{
    return _nibblerEmit(*(const UInt32*)&iVal, ::bitsize(iVal));
}

```

```

template <class ValueType> void
BitLengthCodec3T<ValueType>::_nibblerEmit(UInt32 uVal, UInt32 nBits)
{
    //uVal &= ((1 << nBits) - 1);    // Eliminate any upper bits
    while (nBits > 0) {
        addCodeText(uVal, cNibbleWidth);
        UInt32 n = min(UInt32(cNibbleWidth), nBits);
        uVal >>= n;
        nBits -= n;
        addCodeText((nBits > 0), 1);    // 1 if more bits, 0 if not
    }
    return;
}

```

```

template <class ValueType> void
BitLengthCodec3T<ValueType>::nibblerGet(UInt32 &oiVal)
{
    oiVal = 0;
    UInt32 bMoreBits, uTmp, cNibbles = 0;
    do {
        GetUnsignedBits(uTmp, cNibbleWidth);
        uTmp <= cNibbles * UInt32(cNibbleWidth);
        oiVal |= uTmp;
        GetUnsignedBits(bMoreBits, 1);
        cNibbles++;
    } while (bMoreBits);
    return;
}

```

```

template <class ValueType> void
BitLengthCodec3T<ValueType>::nibblerGet(Int32 &oiVal)
{
    oiVal = 0;
    UInt32 bMoreBits, uTmp, cNibbles = 0;
    do {
        GetUnsignedBits(uTmp, cNibbleWidth);
        uTmp <= cNibbles * UInt32(cNibbleWidth);
        oiVal |= uTmp;
        GetUnsignedBits(bMoreBits, 1);
        cNibbles++;
    } while (bMoreBits);
    // Sign-extend the resulting bits
    UInt32 sw = cNibbles * UInt32(cNibbleWidth);
    if (sw < 32) {
        oiVal <= 32 - sw;
        oiVal >>= 32 - sw;
    }
    return;
}

```

```

// Simply write out all the bits for 64 bit
template <class ValueType> void
BitLengthCodec3T<ValueType>::nibblerEmit(Int64 lVal)
{
#ifdef 1
    addCodeText(*(const UInt64*)&lVal, 64);
#else
    _nibblerEmit(*(const UInt64*)&(lVal), ::bitsize(lVal));
#endif
}

```

```

template <class ValueType> void
BitLengthCodec3T<ValueType>::nibblerGet(Int64 &olVal)
{
#ifdef 1
    GetUnsignedBits(*(UInt64*)&olVal, 64);
#else
    olVal = 0;
    UInt32 bMoreBits, cNibbles = 0;
    UInt64 uTmp, uTmp64;
    do {
        GetUnsignedBits(uTmp, cNibbleWidth);

```

```

        uTmp64 = uTmp;
        uTmp64 <=<= cNibbles * UInt32(cNibbleWidth);
        olVal |= uTmp64;
        GetUnsignedBits(bMoreBits, 1);
        cNibbles++;
    } while (bMoreBits);
    // Sign-extend the resulting bits
    UInt32 sw = cNibbles * UInt32(cNibbleWidth);
    if (sw < 64) {
        olVal <=<= 64 - sw;
        olVal >>= 64 - sw;
    }
#endif
}

template <class ValueType> void
BitLengthCodec3T<ValueType>::_nibblerEmit(UInt64 uVal, UInt32 nBits)
{
    while (nBits > 0) {
        addCodeText(uVal, cNibbleWidth);
        UInt32 n = min(UInt32(cNibbleWidth), nBits);
        uVal >>= n;
        nBits -= n;
        addCodeText((nBits > 0), 1);    // 1 if more bits, 0 if not
    }
    return;
}

Template <class ValueType>
Bool BitLengthCodec::encode(const VecValue    &vValues,
                           VecValue          &ovOOBValues,
                           Vecu              &ovCodeText,
                           Int32             &onBitsCodeText,
                           ProbContextV      *)
{
    Int32 i, j, k;
    Int32 iSymbol;           // Symbol value to encode
    Int32 cSymBits = 0,      // Number of bits in iSymbol
        nValues;            // Number of values to encode
    // Initialize output state
    ovOOBValues.setLength(0);
    ovCodeText.setLength(0);
    onBitsCodeText = 0;
    _pvCodeText = &ovCodeText;
    _pcCodeTextLen = &onBitsCodeText;

    // Short circuit for null array of values
    nValues = vValues.length();
    if (nValues <= 0)
        return True;

    _vnValBits.setLength(nValues);
    UInt16 *paiSymBits = _vnValBits.ptr();
    const ValueType *paiValues = vValues.ptr();
    // Find the minimum value and compute how many bits each value takes
    ValueType iMinSymbol = Limits<ValueType>::maxValue();
    ValueType iMaxSymbol = Limits<ValueType>::maxNegValue();
    Float64 fMean = 0.0;
    for (i = 0 ; i < nValues ; i++) {
        iMinSymbol = ::min(iMinSymbol, paiValues[i]);
        iMaxSymbol = ::max(iMaxSymbol, paiValues[i]);
        fMean += Float64(paiValues[i]);
    }
    fMean /= nValues;
    ValueType iMean = Int32(fMean);
    for (i = 0 ; i < nValues ; i++) {
        paiSymBits[i] = bitsize(paiValues[i] - iMean);
    }
    // A "block" is: 3 bits of number of bits (repeats while value is either 3 or -4 for
    larger width changes)
    //
    // 4 bits of block length
    Int32 cBlkLenBits = 4; // Number of bits used to express a block length. 0 means 0.

```

```

Int32 cBlkValBits = 4; // *Delta* number of bits to express the current field width
Int32 cBlkHdrBits = cBlkLenBits + cBlkValBits;
Bool bMerged;
// Block-forming: Merge Down/Up blocks
do {
    bMerged = JtFalse;
    Int32 iPrevRunPos = 0,
        iCurRunPos = 0,
        iNextRunPos = 0;
    while (iCurRunPos < nValues - 1) {
        // Advance the next run
        iNextRunPos++;
        while (iNextRunPos < nValues - 1 &&
            paiSymBits[iNextRunPos] == paiSymBits[iNextRunPos-1])
        {
            iNextRunPos++;
        }
        if (iNextRunPos >= nValues)
            break;
        Int32 wab = (iCurRunPos - iPrevRunPos),
            wbc = (iNextRunPos - iCurRunPos);
        if (wab == 0) {
            iCurRunPos = iNextRunPos;
            continue;
        }
        else if (wbc == 0) {
            continue;
        }
        // If we've bitten off more than one block's worth of data
        // we must start a new block. Length 0 is allowed because
        // we may need to insert multiple consecutive block headers
        // in order to change the field width more bits than can be
        // represented in cBlkValBits.
        if (wab > (1 << cBlkLenBits)) {
            iPrevRunPos += (1 << cBlkLenBits);
        }
        else if (wab == (1 << cBlkLenBits)) {
            iPrevRunPos = iCurRunPos;
            iCurRunPos = iNextRunPos;
            continue;
        }
        UInt16 &ua = paiSymBits[iPrevRunPos],
            &ub = paiSymBits[iCurRunPos],
            &uc = paiSymBits[iNextRunPos];
        // If the runs go "down-up"
        if (ua > ub && ub < uc) {
            // Test if we should increase ub to the lesser of ua and uc
            if (ua < uc) {
                // Test if we should increase ub to ua
                if (wbc * (ua - ub) <= cBlkHdrBits) {
                    for (j = iCurRunPos ; j < iNextRunPos ; j++)
                        paiSymBits[j] = ua;
                    iCurRunPos = iNextRunPos;
                    continue;
                }
            }
            else if (ua > uc) {
                // Test if we should increase ub to uc
                if (wbc * (uc - ub) <= cBlkHdrBits) {
                    for (j = iCurRunPos ; j < iNextRunPos ; j++)
                        paiSymBits[j] = uc;
                    iNextRunPos = iCurRunPos;
                    bMerged = True;
                    continue;
                }
            }
        }
        else { // ua == uc
            // Test if we should increase ub to ua/uc
            if (wbc * (ua - ub) <= 2 * cBlkHdrBits) {
                for (j = iCurRunPos ; j < iNextRunPos ; j++)
                    paiSymBits[j] = ua;
                iCurRunPos = iPrevRunPos;
                iNextRunPos = iPrevRunPos;
            }
        }
    }
}

```

```

        bMerged = True;
        continue;
    }
}

// Shift down the runs
iPrevRunPos = iCurRunPos;
iCurRunPos = iNextRunPos;
}
} while (bMerged);
// Block forming: Merge down/down and up/up runs
do {
    bMerged = JtFalse;
    Int32 iPrevRunPos = 0,
        iCurRunPos = 0,
        iNextRunPos = 0;
    while (iCurRunPos < nValues - 1) {
        // Advance the next run
        iNextRunPos++;
        while (iNextRunPos < nValues - 1 &&
            paiSymBits[iNextRunPos] == paiSymBits[iNextRunPos-1])
        {
            iNextRunPos++;
        }
        if (iNextRunPos >= nValues)
            break;
        Int32 wab = (iCurRunPos - iPrevRunPos),
            wbc = (iNextRunPos - iCurRunPos);
        if (wab == 0) {
            iCurRunPos = iNextRunPos;
            continue;
        }
        else if (wbc == 0) {
            continue;
        }
        // If we've bitten off more than one block's worth of data
        // we must start a new block. Length 0 is allowed because
        // we may need to insert multiple consecutive block headers
        // in order to change the field width more bits than can be
        // represented in cBlkValBits.
        if (wab > (1 << cBlkLenBits)) {
            iPrevRunPos += (1 << cBlkLenBits);
        }
        else if (wab == (1 << cBlkLenBits)) {
            iPrevRunPos = iCurRunPos;
            iCurRunPos = iNextRunPos;
            continue;
        }
        UInt16 &ua = paiSymBits[iPrevRunPos],
            &ub = paiSymBits[iCurRunPos],
            &uc = paiSymBits[iNextRunPos];
        // If the runs go "up-up"
        if (ua < ub && ub < uc) {
            // Test if we should increase ua to ub
            if (wab * (ub - ua) < cBlkHdrBits) {
                for (j = iPrevRunPos ; j < iCurRunPos ; j++)
                    paiSymBits[j] = ub;
                iCurRunPos = iNextRunPos;
                bMerged = True;
                continue;
            }
            // Test if we should increase ub to uc
            else if (wbc * (uc - ub) < cBlkHdrBits) {
                for (j = iCurRunPos ; j < iNextRunPos ; j++)
                    paiSymBits[j] = uc;
                iNextRunPos = iCurRunPos;
                bMerged = True;
                continue;
            }
        }
        // If the runs go "down-down"
        else if (ua > ub && ub > uc) {

```

```

        // Test if we should increase ub to ua
        if (wbc * (ua - ub) < cBlkHdrBits) {
            for (j = iCurRunPos ; j < iNextRunPos ; j++)
                paiSymBits[j] = ua;
            iCurRunPos = iNextRunPos;
            continue;
        }
    }

    // Shift down the runs
    iPrevRunPos = iCurRunPos;
    iCurRunPos = iNextRunPos;
}
} while (bMerged);

// Compute the total bits
UInt32 cMaxBlkLen = (1 << cBlkLenBits) - 1;
UInt32 iLastRunPos = 0;
Int32 cTotalBits = paiSymBits[0] + cBlkHdrBits;
for (UInt32 iCurRunPos = 1 ; iCurRunPos < nValues ; iCurRunPos++) {
    cTotalBits += paiSymBits[iCurRunPos];
    if (paiSymBits[iCurRunPos] != paiSymBits[iCurRunPos - 1]) {
        UInt32 cNumBlks = ((iCurRunPos - iLastRunPos) + (cMaxBlkLen - 1)) / cMaxBlkLen;
        cTotalBits += cNumBlks * cBlkHdrBits;
        iLastRunPos = iCurRunPos;
    }
}
}
UInt32 cValSpanBits = bitsize(UInt32(iMaxSymbol - iMinSymbol));
UInt32 cFixedWidBits = nValues * cValSpanBits + (13 + 2 * (cValSpanBits + 1));

/////
// If the fixed-width total bits are better, then write out the values
// in a single fixed-width format.
/////
if (cFixedWidBits < cTotalBits) {
    // Write the fixed-width tag
    addCodeText(0, 1);

    // Write the min and max symbols into the stream
    nibblerEmit (iMinSymbol);
    nibblerEmit (iMaxSymbol);

    // Iterate over the remaining symbols
    UInt32 uCodeText = 0;
    for (Int32 i = 0; i < nValues; i++) {

        // Get the next symbol
        iSymbol = paiValues[i];

        // Write it
        uCodeText = iSymbol - iMinSymbol;
        addCodeText(uCodeText, cValSpanBits);
    }
}
/////
// Otherwise, encode with variable-length fields
/////
else {
    // Write the variable-width tag
    addCodeText(1, 1);

    // Write out the mean value
    nibblerEmit(iMean);

    // Set the initial field-width
    Int32 cMaxFieldDecr = -(1 << (cBlkValBits - 1)), // -ve number
        cMaxFieldIncr = (1 << (cBlkValBits - 1)) - 1; // +ve number
    Int32 cCurFieldWidth = 0;
    Int32 cTargFieldWidth;
    for (Int32 ii = 0 ; ii < nValues ; ) {
        // Adjust the current field width to the target field width
        cTargFieldWidth = paiSymBits[ii];
        {

```

```

        if (cCurFieldWidth <= cTargFieldWidth) {
            while (cTargFieldWidth - cCurFieldWidth >= cMaxFieldIncr) {
                addCodeText(cMaxFieldIncr, cBlkValBits);
                cCurFieldWidth += cMaxFieldIncr;
            }
        }
        else {
            while (cTargFieldWidth - cCurFieldWidth <= cMaxFieldDecr) {
                addCodeText(cMaxFieldDecr, cBlkValBits);
                cCurFieldWidth += cMaxFieldDecr;
            }
        }
        addCodeText(cTargFieldWidth - cCurFieldWidth, cBlkValBits);
        cCurFieldWidth = cTargFieldWidth;
    }

    // Write out the run length
    for (j = ii+1 ; j < ii + (1 << cBlkLenBits) - 1 && j < nValues ; j++)
        if (paiSymBits[ii] != paiSymBits[j])
            break;
    addCodeText(j - ii, cBlkLenBits);

    // Write out the data bits for the run
    for (k = ii ; k < j ; k++)
        addCodeText(paiValues[k] - iMean, cCurFieldWidth);

    // Advance to the end of the run
    ii = j;
}

}

return True;
}

template <class ValueType>
Bool BitLengthCodec2::decode( Int32          nValues,
                             const VecValue &,
                             const Vecu    &vCodeText,
                             Int32          nBitsCodeText,
                             VecValue      &ovValues,
                             ProbContextV   *)
{
    Int32 nTotalBits = 0;    // Total number of codetext bits expected
    ValueType iSymbol;      // Decoded symbol value
    Int32 cNumCurBits = 0;  // Current field width in bits
    ValueType iMinSymbol = 0; // The minimum symbol value. Used as bias.
    ValueType iMaxSymbol = 0; // The maximum symbol value. Used as bias.
    Int32 nSyms = 0;        // Number of symbols read so far
    ValueType *paiValues;    // Pointer into ovValues where we write decoded values

    // Get codetext from the driver and loop over it until it's gone!
    ovValues.setLength(nValues);
    paiValues = ovValues.ptr();

    _iCurCodeText = 0;
    _pvCodeText = (Vecu*) &vCodeText;
    _pcCodeTextLen = &nBitsCodeText;

    /////
    // If the fixed-width total bits are better, then write out the values
    // in a single fixed-width format.
    /////
    // Read the variable-width tag
    Int32 iTmp;
    GetUnsignedBits(iTmp, 1); // 0 = Fixed-width, 1 = Variable width
    if (iTmp == 0) {
        // Read the min and max symbols from the stream
        nibblerGet(iMinSymbol);
        nibblerGet(iMaxSymbol);
        cNumCurBits = bitsize(UInt32(iMaxSymbol - iMinSymbol));

        // Read each fixed-width field and output the value
        while (nBits < nTotalBits || nSyms < nValues) {

```

```

        GetUnsignedBits(iSymbol, cNumCurBits);
        iSymbol += iMinSymbol;
        *paiValues++ = iSymbol;
        nSyms++;
    }
}
/////
// Otherwise, encode with variable-length fields
/////
else {
    // Write out the mean value
    ValueType iMean;
    nibblerGet(iMean);

    // Set the initial field-width
    Int32 cMaxFieldDecr = -(1 << (cBlkValBits - 1)),      // -ve number
        cMaxFieldIncr = (1 << (cBlkValBits - 1)) - 1;    // +ve number
    UInt32 cCurFieldWidth = 0, cRunLen, k;
    Int32 cDeltaFieldWidth;
    ValueType iTmp;
    for (Int32 ii = 0 ; ii < nValues ;) {
        // Adjust the current field width to the target field width
        do {
            GetSignedBits(cDeltaFieldWidth, cBlkValBits);
            cCurFieldWidth += cDeltaFieldWidth;
        } while (cDeltaFieldWidth == cMaxFieldDecr || cDeltaFieldWidth ==
cMaxFieldIncr);

        // Read in the run length
        GetUnsignedBits(cRunLen, cBlkLenBits);

        // Read in the data bits for the run
        for (k = ii ; k < ii + cRunLen ; k++) {
            GetSignedBits(iTmp, cCurFieldWidth);
            *paiValues++ = iTmp + iMean;
        }

        // Advance to the end of the run
        ii += cRunLen;
    }
}

// Assert that we have consumed exactly all of the bits
Assert(nValBits == 0);
Assert(uVal == 0);

return True;
}

// Number of bits necessary to encode a SIGNED integer
UInt32 bitsize(Int32 x) const
{
    x = x ^ (x >> 31);
    return 33 - nlz(UInt32(x));
}

// Number of bits necessary to encode an UNsigned integer
UInt32 bitsize(UInt32 x) const
{
    return 32 - nlz(x);
}

// Number of Leading Zeros
UInt32 nlz(UInt32 x)
{
    x = x | (x >> 1);
    x = x | (x >> 2);
    x = x | (x >> 4);
    x = x | (x >> 8);
    x = x | (x >> 16);
    return popcnt(~x);
}

```



```

// Population count - # of 1 bits in x
UInt32 popcnt(UInt32 x)
{
    x = x - ((x >> 1) & 0x55555555);
    x = (x & 0x33333333) + ((x >> 2) & 0x33333333);
    x = (x + (x >> 4)) & 0x0f0f0f0f;
    x = x + (x >> 8);
    x = x + (x >> 16);
    return x & 0x3f;
}

Bool BitLengthCodec2::getNextCodeText (UInt32 &uCodeText, Int32 &nBits)
{
    uCodeText = _pvCodeText->value(_iCurCodeText);
    nBits = ::min(32, *_pcCodeTextLen - 32 * _iCurCodeText);
    _iCurCodeText++;
    return True;
}

```

B.3 Arithmetic decoding classes

The following sub-sections contain a sample implementation of the decoding portion of the Arithmetic CODEC algorithm. A summary technical explanation of the Arithmetic CODEC can be found in can be found in the Encoding Algorithms section of this document under Arithmetic CODEC.

B.3.1 ArithmeticCodec class

```

template <class ValueType>
class ArithmeticCodec: public Codec
{
public:
    Bool encode( const VecValue &vValues,
                  VecValue      &ovOOBValues,
                  Vecu          &ovCodeText,
                  Int32         &onBitsCodeText,
                  ProbContextV   *pProbCntx      );
    Bool decode( Int32          nValues,
                  VecValue      &ovOOBValues,
                  const Vecu    &vCodeText,
                  Int32         nBitsCodeText,
                  VecValue      &ovValues,
                  ProbContextV   *pProbCntx      );

protected:
    Bool _encodeSymbol(UInt16 uLowCt, UInt16 uHighCt, UInt16 uScale );
    Bool _flushEncoder();
    Bool _removeSymbolFromStream( UInt16 uLowCt, UInt16 uHighCt, UInt16 uScale );
    Bool _flushDecoder();

    Bool getNextCodeText (UInt32 &uCodeText, Int32 &nBits);

    UInt16 _code;           // Present input code value, for decoding only
    UInt16 _low;            // Start of the current code range
    UInt16 _high;           // End of the current code range
    Int32  _nUnderflowBits; // Number of underflow bits pending

    Vecu   *_pvCodeText;
    Int32   *_pcCodeTextLen;
    Int32   _iCurCodeText;

    UInt32  _uBitBuff;
    Int32   _nBitBuff;
};

// Reads a bit and places it into ouBit
#define ReadBit(ouBit) \
    if (_nBitBuff==0) { \
        getNextCodeText(_uBitBuff, _nBitBuff); \
    } \
    ouBit = (_uBitBuff >> 31); \
    _uBitBuff <<= 1; \

```

```

    _nBitBuff--;

// Reads a bit and ORs it into bit 0 of ouBit
#define ReadBit0(ouBit) \
    if ( _nBitBuff==0) { \
        getNextCodeText(_uBitBuff, _nBitBuff); \
    } \
    ouBit |= ( _uBitBuff >> 31); \
    _uBitBuff <<= 1; \
    _nBitBuff--;
// Writes bit 0 of uBit
#define WriteBit(uBit) \
    if ( _nBitBuff==32) { \
        addCodeText(_uBitBuff, 32); \
        _uBitBuff = _nBitBuff = 0; \
    } \
    _uBitBuff <<= 1; \
    _uBitBuff |= (UInt32(uBit) & 0x1); \
    _nBitBuff++;

Bool ArithmeticCodec::encode(const VecValue &vValues,
                             Veci          &ovOOBValues,
                             Vecu          &ovCodeText,
                             Int32         &onBitsCodeText,
                             ProbContextV  *pProbCntx)
{
    // Initialize output state
    ovOOBValues.setLength(0);
    ovCodeText.setLength(0);
    onBitsCodeText = 0;
    _pvCodeText = &ovCodeText;
    _pcCodeTextLen = &onBitsCodeText;

    // Initialize the encoder state
    _low = 0x0000;
    _high = 0xffff;
    _nUnderflowBits = 0;

    // Prime the bit buffer
    _uBitBuff = 0;
    _nBitBuff = 0;

    const ValueType *paiValues = vValues.ptr();
    const CntxEntry *pEntry;
    Int32 nValues = vValues.length();
    Int32 cTotalCount = pProbCntx->totalCount();
    for (Int32 i = 0; i < nValues; i++ ) {
        // Look up the value in the prob context
        pProbCntx->lookupValue(paiValues[i], pEntry );

        // If this is not the null context, then we emit an escape symbol,
        // move the context it specifies, and restart the translation of
        // the same value. Thus, a value may emit more than one symbol.
        if (pEntry->isEscape()) {
            ovOOBValues.append(paiValues[i]);
        }

        _encodeSymbol(pEntry->_cCumCount,
                     pEntry->_cCumCount + pEntry->_cCount,
                     cTotalCount);
    }

    _flushEncoder();

    return True;
}

Bool ArithmeticCodec2::_encodeSymbol(UInt16 uLowCt, UInt16 uHighCt, UInt16 uScale )
{
    // These three lines rescale _high and _low for the new symbol.
    UInt32 uRange = UInt32(_high - _low) + 1;
    _high = _low + (uRange * uHighCt) / uScale - 1;
    _low = _low + (uRange * uLowCt) / uScale;
}

```

```

// This loop turns out new bits until _high and _low are far enough
// apart to have stabilized.
for (;;) {
    // If this test passes, it means that the most signif digits match,
    // and can be sent to the output stream.
    if ( (_high & 0x8000) == (_low & 0x8000) )
    {
        // Flush the bit buff if the MSB and underflow bits
        // won't all fit in what's left
        if (1+_nUnderflowBits > 32 - _nBitBuff) {
            addCodeText(_uBitBuff, _nBitBuff);
            _uBitBuff = 0;
            _nBitBuff = 0;
        }
        // Write the MSB and all uflow bits at once
        if (1+_nUnderflowBits <= 32 - _nBitBuff) {
            _uBitBuff <= (1 + _nUnderflowBits);
            _uBitBuff |= (1 << _nUnderflowBits)
                + (Int32(Int16(~_high)) >> 15);
            _nBitBuff += 1 + _nUnderflowBits;
            _nUnderflowBits = 0;
        }
        else {
            // We're writing more than 32 bits!
            _uBitBuff = (1 << 31)
                + (Int32(Int16(~_high)) >> 15);
            addCodeText(_uBitBuff, 32);
            _nBitBuff = 0;
            _nUnderflowBits -= 31;
            // Emit the rest of the underflow bits
            _uBitBuff = (_uBitBuff << 1) | (_uBitBuff & 1);
            while (_nUnderflowBits >= 32) {
                addCodeText(_uBitBuff, 32);
                _nUnderflowBits -= 32;
            }
            addCodeText(_uBitBuff, _nUnderflowBits);
            _nUnderflowBits = 0;
            _uBitBuff = 0;
        }
    }

    // If this test passes, the numbers are in danger of underflow, because
    // the most sigif digits don't match, and the 2nd digits are just one apart.
    //
    // _low = 01... and _high = 10...
    else if ( ( _low & 0x4000 ) && !( _high & 0x4000 ) )
    {
        _nUnderflowBits++;
        _low &= 0x3fff;
        _high |= 0x4000;
    }
    else
        break;

    //Shift all bits left. Move 0 into _low and 1 into _high.
    _low <<= 1;
    _high <<= 1;
    _high |= 1;
}

return True;
}

Bool ArithmeticCodec2::_flushEncoder()
{
    // Write out some underflow bits and misc.
    WriteBit((_low & 0x4000)>>14)
    _nUnderflowBits++;
    while ( _nUnderflowBits-- > 0)
        WriteBit((~_low & 0x4000)>>14)

    //Need 16 zeros at the end, for this decoding algorithm

```

```

    UInt32 zeroBit = 0x0000;
    for (Int32 ii=0; ii<16; ii++) {
        WriteBit(zeroBit)
    }

    // Flush out the local buffer
    addCodeText(_uBitBuff, _nBitBuff);

    return True;
}

template <class ValueType>
Bool ArithmeticCodec2::decode( Int32          nValues,
                               const VecValue &vOOBValues,
                               const Vecu      &vCodeText,
                               Int32          nBitsCodeText,
                               Veci            &ovValues,
                               ProbContextV    *pProbCntx      )
{
    ovValues.setLength(0);
    const ValueType *paiOOBValues = vOOBValues.ptr();
    ovValues.setLength(nValues);
    ValueType *paiValues = ovValues.ptr();
    Int32 cSymbolsCurrCtx = pProbCntx->totalCount();
    const CntxEntryV *pCntxEntry = 0;

    // Initialize the arithmetic decoder state
    _iCurCodeText = 0;
    _pvCodeText = (Vecu*) &vCodeText;
    _pcCodeTextLen = &nBitsCodeText;
    getNextCodeText(_uBitBuff, _nBitBuff);
    _low = 0;
    _high = 0xffff;
    _code = (_uBitBuff >> 16);
    _uBitBuff <<= 16;
    _nBitBuff -= 16;

    // Decode each symbol
    for (Int32 i = 0 ; i < nValues ; i++) {
        // Scale the current "code" into the range of counts presented by
        // the probcontext so we can look up the code.
        UInt16 rescaledCode = (((UInt32)(_code - _low) + 1) * (UInt32)cSymbolsCurrCtx -
1)
            / ((UInt32)(_high - _low) + 1);
        pProbCntx->lookupEntryByCumCount( (Int32)rescaledCode, pCntxEntry );

        // Emit the value corresponding to the symbol we just decoded
        if (!pCntxEntry->isEscape())
            *paiValues++ = pCntxEntry->_val;
        else
            *paiValues++ = *paiOOBValues++;

        // Set up the symbol's range and adjust the decoder state
        // to "remove" it.
        _removeSymbolFromStream( pCntxEntry->_cCumCount,
                                pCntxEntry->_cCumCount + pCntxEntry->_cCount,
                                cSymbolsCurrCtx );
    }

    _flushDecoder();

    return True;
}

Bool ArithmeticCodec2::_flushDecoder()
{
    UInt32 dummyBit;
    ReadBit(dummyBit)
    ReadBit(dummyBit)

    Assert( _uBitBuff == 0 );
    _nBitBuff = 0;
}

```

```

        return True;
    }

Bool ArithmeticCodec2::_removeSymbolFromStream( UInt16 uLowCt, UInt16 uHighCt, UInt16
uScale )
{
    // First, the range is expanded to account for the symbol removal.
    UInt32 uRange = UInt32(_high - _low) + 1;
    _high = _low + (UInt32)((uRange * uHighCt) / uScale - 1);
    _low = _low + (UInt32)((uRange * uLowCt) / uScale);

    //Next, any possible bits are shipped out.
    for (;;) {
        // If the most signif digits match, the bits will be shifted out.
        if (UInt16(~(_high ^ _low)) >> 15){
        }
        // Else, if underflow is threatening, shift out the 2nd most signif digit.
        //else if ((_low & 0x4000) && !(_high & 0x4000))
        // If high=10xx and low=01xx
        else if (((_low >> 14) == 1) & ((_high >> 14) == 2)) {
            _code ^= 0x4000;
            _low &= 0x3fff;
            _high |= 0x4000;
        }
        // Otherwise, nothing can be shifted out, so return.
        else {
            return True;
        }

        _low <<= 1;
        _high <<= 1;
        _high |= 1;
        _code <<= 1;

        ReadBit0( _code )
    }
}

```

B.4 Deering Normal decoding classes

The following sub-sections contain a sample implementation of the decoding portion of the Deering Normal CODEC algorithm. A summary technical explanation of the Deering Normal CODEC can be found in the Encoding Algorithms section of this document under Deering Normal CODEC.

B.4.1 DeeringNormalLookupTable class

The DeeringNormalLookupTable class represents a lookup table used by the DeeringNormalCodec class for faster conversion from the compressed normal representation to the standard 3-float representation. The tables hold precomputed results of the trig functions called during conversion.

```

class DeeringNormalLookupTable
{
public:
    DeeringNormalLookupTable();

    // Lookup and return the result of converting iTheta and iPsi to
    // real angles and taking the sine and cosine of both. This gives
    // a slight speedup for normal decoding.
    Bool lookupThetaPsi(Int32 iTheta,
                        Int32 iPsi,
                        UInt32 numberBits,
                        Float32 outCosTheta,
                        Float32 outSinTheta,
                        Float32 outCosPsi,
                        Float32 outSinPsi );

    UInt32 numBitsPerAngle() {return nBits;}
}

```

```

private:
    UInt32 nBits;
    Vector vCosTheta;
    Vector vSinTheta;
    Vector vCosPsi;
    Vector vSinPsi;
};

DeeringNormalLookupTable::DeeringNormalLookupTable()
{
    UInt32 numberbits = 8;
    nBits = min(numberbits, (UInt32)31);

    Int32 tableSize = (1 << nBits);

    vCosTheta.setLength(tableSize+1);
    vSinTheta.setLength(tableSize+1);
    vCosPsi.setLength(tableSize+1);
    vSinPsi.setLength(tableSize+1);

    Float32 fPsiMax = 0.615479709;
    Float32 fTableSize = (Float32)tableSize;

    for( Int32 ii = 0; ii <= tableSize; ii++ )
    {
        Float32 fTheta =
            asin(tan(fPsiMax * Float32(tableSize - ii) / fTableSize));

        Float32 fPsi = fPsiMax * ((Float32)ii) / fTableSize;
        vCosTheta[ii] = cos(fTheta);
        vSinTheta[ii] = sin(fTheta);
        vCosPsi[ii] = cos(fPsi);
        vSinPsi[ii] = sin(fPsi);
    }
}

Bool DeeringNormalLookupTable::lookupThetaPsi(Int32 iTheta,
                                                iPsi,
                                                numberBits,
                                                Float32 outCosTheta,
                                                Float32 outSinTheta,
                                                Float32 outCosPsi,
                                                Float32 outSinPsi)
{
    Int32 offset = nBits - numberBits;

    outCosTheta = vCosTheta[iTheta << offset];
    outSinTheta = vSinTheta[iTheta << offset];
    outCosPsi = vCosPsi[iPsi << offset];
    outSinPsi = vSinPsi[iPsi << offset];

    return True;
}

```

B.4.2 DeeringNormalCodec class

The `DeeringNormalCodec` class converts a normal vector to and from the standard 3-float representation and a lower-precision representation. The precision can be adjusted using the `nbits` parameter.

```

class DeeringNormalCodec
{
public:
    DeeringNormalCodec(Int32 numberbits = 6)
    {
        numBits = numberbits;
    }

    // Converts a compressed normal into a vector.
    Bool convertCodeToVec(UInt32 code, Vector& outVec);
}

```

```

// Converts a compressed normal into a vector.
Bool convertCodeToVec (UInt32 iSextant,
                      UInt32 iOctant,
                      UInt32 iTheta,
                      UInt32 iPsi,
                      Vector& outVec);

// Separates an encoded normal into its 4 pieces
Bool unpackCode (UInt32 code,
                 UInt32& outSextant,
                 UInt32& outOctant,
                 UInt32& outTheta,
                 UInt32& outPsi );

private:
    Int32 numBits;
}

Bool DeeringNormalCodec::convertCodeToVec(UInt32 code, Vector& outVec)
{
    UInt32 s=0, o=0, t=0, p=0;
    unpackCode(code, s, o, t, p);
    convertCodeToVec(s, o, t, p, outVec);
    return True;
}

Bool DeeringNormalCode::convertCodeToVec(UInt32 iSextant,
                                           UInt32
iOctant,
                                           UInt32
iTheta,
                                           UInt32 iPsi,
                                           Vector&
outVec)
{
    // Size of code = 6+2*numBits, and max code size is 32 bits,
    // so numBits shall be <= 13.

    // Code layout: [sextant:3][octant:3][theta:numBits][psi:numBits]

    outVec.setValues(0,0,0);
    Float32 fPsiMax = 0.615479709;

    UInt32 iBitRange = 1<<numBits;
    Float32 fBitRange = Float32(iBitRange);

    // For sextants 1, 3, and 5, iTheta needs to be incremented
    iTheta += (iSextant & 1);

    Float32 fCosTheta, fSinTheta, fCosPsi, fSinPsi;

    DeeringNormalLookupTable LookupTable;

    if( (LookupTable.numBitsPerAngle() < (UInt32)numBits) ||
        !LookupTable.lookupThetaPsi(iTheta, iPsi, numBits,
                                     fCosTheta, fSinTheta,
                                     fCosPsi, fSinPsi) )
    {
        Float32 fTheta = asin(tan(fPsiMax * Float32(iBitRange - iTheta) /
                                                    fBitRange));

        Float32 fPsi = fPsiMax * (iPsi / fBitRange);
        fCosTheta = cos(fTheta);
        fSinTheta = sin(fTheta);
        fCosPsi = cos(fPsi);
        fSinPsi = sin(fPsi);
    }

    Float32 x,y,z;
    Float32 xx = x = fCosTheta * fCosPsi;
    Float32 yy = y = fSinPsi;
    Float32 zz = z = fSinTheta * fCosPsi;
}

```

```

//Change coordinates based on the sextant
switch( iSextant )
{
    case 0:      // No op
        break;

    case 1:      // Mirror about x=z plane
        z = xx;
        x = zz;
        break;

    case 2:      // Rotate CW
        z = xx;
        x = yy;
        y = zz;
        break;

    case 3:      // Mirror about x=y plane
        y = xx;
        x = yy;
        break;

    case 4:      // Rotate CCW
        y = xx;
        z = yy;
        x = zz;
        break;

    case 5:      // Mirror about y=z plane
        z = yy;
        y = zz;
        break;
};

//Change some more based on the octant

//if first bit is 0, negate x component
if( !(iOctant & 0x4) )
    x = -x;

//if second bit is 0, negate y component
if( !(iOctant & 0x2) )
    y = -y;

//if third bit is 0, negate z component
if( !(iOctant & 0x1) )
    z = -z;

outVec.setValues(x,y,z);

return True;
}

Bool DeeringNormalCodec::unpackCode(UInt32 code,
                                     UInt32&
outSextant,
                                     UInt32&
outOctant,
                                     UInt32& outTheta,
                                     UInt32& outPsi)
{
    UInt32 mask = (1<<numBits)-1;

    outSextant = (code >> (numBits+numBits+3)) & 0x7;
    outOctant  = (code >> (numBits+numBits))   & 0x7;
    outTheta   = (code >> (numBits))           & mask;
    outPsi     = (code)                       & mask;

    return True;
}

```


Annex C

Hashing – An Implementation

This Appendix provides a sample C++ implementation for the creation of hash values (as detailed in Encoding Algorithms) used in the JT format.

```
unsigned int hash32( const unsigned int *pWords,
                    int nWords,
                    unsigned int uSeedHashValue )
{ return hash2(pWords, nWords, uSeedHashValue); }
```

```
unsigned int jthash16(const unsigned short *pBytes,
                    int nShort,
                    unsigned int uSeedHashValue)
{ return hash3(pBytes, nShort, uSeedHashValue); }
```

```
//-----
// mix -- mix 3 32-bit values reversibly.
// For every delta with one or two bit set, and the deltas of all three
// high bits or all three low bits, whether the original value of a,b,c
// is almost all zero or is uniformly distributed,
// * If mix() is run forward or backward, at least 32 bits in a,b,c
// have at least 1/4 probability of changing.
// * If mix() is run forward, every bit of c will change between 1/3 and
// 2/3 of the time. (Well, 22/100 and 78/100 for some 2-bit deltas.)
// mix() was built out of 36 single-cycle latency instructions in a
// structure that could supported 2x parallelism, like so:
//     a -= b;
//     a -= c; x = (c>>13);
//     b -= c; a ^= x;
//     b -= a; x = (a<<8);
//     c -= a; b ^= x;
//     c -= b; x = (b>>13);
//     ...
// Unfortunately, superscalar Pentiums and Sparcs can't take advantage
// of that parallelism. They've also turned some of those single-cycle
// latency instructions into multi-cycle latency instructions. Still,
// this is the fastest good hash I could find. There were about 2^^68
// to choose from. I only looked at a billion or so.
//-----

#define mix(a,b,c) \
{ \
    a -= b; a -= c; a ^= (c>>13); \
    b -= c; b -= a; b ^= (a<<8); \
    c -= a; c -= b; c ^= (b>>13); \
    a -= b; a -= c; a ^= (c>>12); \
    b -= c; b -= a; b ^= (a<<16); \
    c -= a; c -= b; c ^= (b>>5); \
    a -= b; a -= c; a ^= (c>>3); \
    b -= c; b -= a; b ^= (a<<10); \
    c -= a; c -= b; c ^= (b>>15); \
}
```

```
//-----
// hash() -- hash a variable-length key into a 32-bit value
//   k      : the key (the unaligned variable-length array of bytes)
//   len    : the length of the key, counting by bytes
//   level  : can be any 4-byte value
// Returns a 32-bit value. Every bit of the key affects every bit of
// the return value. Every 1-bit and 2-bit delta achieves avalanche.
// About 36+6len instructions.

// The best hash table sizes are powers of 2. There is no need to do
// mod a prime (mod is sooo slow!). If you need less than 32 bits,
// use a bitmask. For example, if you need only 10 bits, do
//   h = (h & hashmask(10));
// In which case, the hash table should have hashsize(10) elements.
```

```

//
// If you are hashing n strings (JtUInt8 **)k, do it like this:
//   for (i=0, h=0; i<n; ++i) h = hash( k[i], len[i], h);
//
// By Bob Jenkins, 1996.  bob_jenkins@burtleburtle.net.  You may use this
// code any way you wish, private, educational, or commercial.  It's free.
//
// See http://burtleburtle.net/bob/                // 2010/02/12
// See http://burtleburtle.net/bob/hash/doobs.html  // 2010/02/12
//
// Use for hash table lookup, or anything where one collision in 2^32 is
// acceptable.  Do NOT use for cryptographic purposes.
//-----

//-----
// This works on all machines.  hash2() is identical to hash() on
// little-endian machines, except that the length has to be measured
// in ub4s instead of bytes.  It is much faster than hash().  It
// requires
// -- that the key be an array of UInt32's, and
// -- that all your machines have the same endianness, and
// -- that the length be the number of UInt32's in the key
//-----
unsigned int hash(const unsigned char *k,          // key
                  unsigned int      length,       // length of the key
                  unsigned int      initval)      // prev hash, or an arbitrary value
{
    register unsigned int a,b,c,len;

    /* Set up the internal state */
    len = length;
    a = b = 0x9e3779b9; /* the golden ratio; an arbitrary value */
    c = initval;        /* the previous hash value */
    /*----- handle most of the key */
    while (len >= 12) {
        a += (k[0] + ((UInt32)k[1]<<8) + ((UInt32)k[2]<<16) + ((UInt32)k[3]<<24));
        b += (k[4] + ((UInt32)k[5]<<8) + ((UInt32)k[6]<<16) + ((UInt32)k[7]<<24));
        c += (k[8] + ((UInt32)k[9]<<8) + ((UInt32)k[10]<<16) + ((UInt32)k[11]<<24));
        mix(a,b,c);
        k += 12; len -= 12;
    }
    /*----- handle the last 11 bytes */
    c += length;
    switch(len) { /* all the case statements fall through */
        case 11: c+=((UInt32)k[10]<<24);
        case 10: c+=((UInt32)k[9]<<16);
        case 9 : c+=((UInt32)k[8]<<8);
        /* the first byte of c is reserved for the length */
        case 8 : b+=((UInt32)k[7]<<24);
        case 7 : b+=((UInt32)k[6]<<16);
        case 6 : b+=((UInt32)k[5]<<8);
        case 5 : b+=k[4];
        case 4 : a+=((UInt32)k[3]<<24);
        case 3 : a+=((UInt32)k[2]<<16);
        case 2 : a+=((UInt32)k[1]<<8);
        case 1 : a+=k[0];
        /* case 0: nothing left to add */
    }
    mix(a,b,c);
    /*----- report the result */
    return c;
}

unsigned int hash3(const unsigned short *k,        /* the key */
                   unsigned int      length,       /* the length of the key */
                   unsigned int      initval)      /* the previous hash, or an arbitrary
value */
{
    unsigned int a,b,c,len;

    /* Set up the internal state */
    len = length;
    a = b = 0x9e3779b9; /* the golden ratio; an arbitrary value */

```

```

c = initval;          /* the previous hash value */

/*----- handle most of the key */
while (len >= 6)
{
    a += (k[0] + (UInt32(k[1]) << 16));
    b += (k[2] + (UInt32(k[3]) << 16));
    c += (k[4] + (UInt32(k[5]) << 16));
    mix(a,b,c);
    k += 6; len -= 6;
}

/*----- handle the last 2 uint32s */
c += length;
switch(len)           /* all the case statements fall through */
{
    case 5 : c+=(UInt32(k[4]) << 16);
    /* c is reserved for the length */
    case 4 : b+=(UInt32(k[3]) << 16);
    case 3 : b+=k[2];
    case 2 : a+=(UInt32(k[1]) << 16);
    case 1 : a+=k[0];
    /* case 0: nothing left to add */
}
mix(a,b,c);
/*----- report the result */
return c;
}

```

Annex D

Polygon Mesh Topology Coder

The topology coding algorithm described here is used to code the dual of the desired mesh. Thus, for example, the reader will need to take the dual of the decoded mesh in order to obtain the original primal mesh. Presented below are classes suitable for representing the dual of a polygon mesh and the dual topology decoding algorithm.

At a high level, the topology coder works by traversing the dual mesh to be encoded one vertex and one face at a time. The coder maintains a queue of faces to be processed; the initial queue is created using the valence of an arbitrary vertex of the mesh followed by the degrees of the faces adjacent to that vertex, and adds the adjacent faces to the face queue. Each time it visits a face, it encodes the degree of that face and emits any incident vertices that have not yet been visited. Each time the coder visits a vertex, it encodes the valence of the vertex (usually 3 in the current case), and emits any incident faces that have not yet been visited. It works its way through the mesh in this fashion until all vertices and faces have been encoded. Thus, the primary output from the topology coder is a list of vertex valences and face degrees. These two fields plus two more encoding so-called split faces, coupled with the exact coder implementation completely encode the mesh topology in a very compact manner¹.

In addition to these two basic fields are added a number of other fields that organize the dual vertices into vertex groups, and also encode the vertex attributes (e.g. normals, colours, and texture coordinates) around each dual face's degree ring.

The topological coder can only encode closed, manifold meshes. It cannot encode boundaries; it can only encode edges with exactly two incident faces. But, as we know, real-world data is chock full of meshes with boundaries. In order to encode these types of meshes, it is necessary to add cover faces incident to all boundary loops whose sole job is to turn the mesh into a closed mesh. It is the dual of this closed, manifold mesh that is actually encoded. Thus, most meshes encoded in JT files contain a few cover faces. These faces may be of arbitrarily high degree, and they represent the only exceptions to the general rule that the numbers in the dual vertex valence array are usually three. It is necessary to flag all such artificially introduced cover faces so that they can be removed by the loader. These flags are encoded below in the Face Flags array. Primal faces are flagged with zero, while cover faces are flagged with one.

Now, let us make the connection between topological vertices and how vertex attributes relate to them. Several faces may be incident on the same topological mesh vertex. While this topological vertex has only a single 3D coordinate, it may have a different set of vertex attributes for each incident face. Vertex attributes include colour, normal, and texture coordinates. An important observation in real-world data is that adjacent faces tend to share the same vertex attributes. Thus, a natural way to encode which vertex attributes map to which faces within a given valence ring (the counter-clockwise ordered set of faces incident on a given vertex) is by way of a bit vector. The bit vector begins at the first face the coder encounters that is incident to the vertex, and proceeds counter clockwise around the vertex, allocating one bit per incident face. A value of 0 is assigned to the bit if all vertex attributes for the face are the same as the face immediately clockwise. A value of 1 is assigned if the vertex attributes for the face are different. Recall that these bits from the original primal mesh are encoded as face attributes in the dual mesh.

Thus, at the end of the coding process, there will be one such bit vector per topological vertex in the mesh. These bit vectors will be of disparate lengths because all vertex valences are not the same. Though there is no theoretical limit to the valence of any given vertex, in practice, the vertex valences seldom rise above six, and only rarely rise into the dozens. As a matter of practicality, then, we break this list of bit vectors into those of length 64 and smaller into one group, and all others into a list of so-called “high-valence” bit vectors. The low-valence bit vectors are encoded into two fields of 32 bits each. The high-valence bit

¹ Similar methods of topology coding are described in [24] and US patent # 7,098,916. The topology coding algorithm described herein differs from such methods in that while they utilize a queue of active *vertices*, the instant algorithm utilizes a queue of active *faces*. Other differences include the tracking of face group numbers and per-vertex attributes such as normals, colours, and texture coordinates.

vectors are adjoined end-to-end into a single long bit vector, and encoded as a single array of integers. As an additional optimization, the low-valence bit vectors are grouped into 8 “context groups” depending on the valence of the vertex being coded. This is done in order to improve compression performance because the valence bit vectors in each of the most common groups typically share similar statistics. Context group number 8 is the only one that encodes valence rings up to valence 64. Again, recall that these attribute bits from the original primal mesh are encoded as face attribute bits in the dual mesh.

D.1 DualVFMesh

The DualVFMesh (Dual Vertex-Facet Mesh) is a support class paired with the topology decoder itself, and represents a closed two-manifold polygon mesh. The topology decoder reconstructs the encoded dual mesh into a DualVFMesh, building it one vertex and one facet at a time. When the decoder is finished, it will have visited each vertex and each face of the dual mesh exactly once. DualVFMesh is not intended as a work-horse in-memory storage container because its way of encoding the topological connections between faces and vertices is memory-intensive.

```
class DualVFMesh
{
public:
    // ===== Housekeeping Interface =====
    DualVFMesh();
    DualVFMesh (const DualVFMesh &rhs);
    DualVFMesh &operator=(const DualVFMesh &rhs);

    // ===== Topology Interface =====

    // Vtx creation
    bool        isValidVtx  (Int32  iVtx) const;
    bool        newVtx      (Int32  iVtx,
                            Int32  iValence,
                            UInt16 uFlags = 0);
    bool        setVtxFlags (Int32  iVtx,
                            UInt16 uFlags);
    bool        setVtxGrp   (Int32  iVtx,
                            Int32  iVGrp);
    UInt16      vtxFlags    (Int32  iVtx) const;
    Int32       vtxGrp      (Int32  iVtx) const;

    // Face creation
    bool        isValidFace (Int32  iFace) const;
    bool        newFace     (Int32  iFace,
                            Int32  cDegree,
                            Int32  cFaceAttrs = 0,
                            UInt64 uFaceAttrMask = 0,
                            UInt16 uFlags = 0);
    bool        newFace     (Int32  iFace,
                            Int32  cDegree,
                            Int32  cFaceAttrs,
                            const BitVec *pvbFaceAttrMask,
                            UInt16 uFlags);
    bool        setFaceFlags (Int32  iFace,
                            UInt16 uFlags);
    UInt16      faceFlags    (Int32  iVtx) const;
    bool        setFaceAttr  (Int32  iFace,
                            Int32  iAttrSlot,
                            Int32  iFaceAttr);
    Int32       faceAttr     (Int32  iFace,
                            Int32  iAttrSlot) const;

    // Topology connection
    bool        setVtxFace  (Int32  iVtx,
                            Int32  iFaceSlot,
                            Int32  iFace);
    bool        setFaceVtx  (Int32  iFace,
                            Int32  iVtxSlot,
                            Int32  iVtx);

    // Queries
```

```

Int32      valence      (Int32 iVtx) const
{ return _vVtxEnts[iVtx].cVal; }
Int32      degree      (Int32 iFace ) const
{ return _vFaceEnts[iFace].cDeg; }
Int32      face        (Int32 iVtx,
                        Int32 iFaceSlot) const
{ return _viVtxFaceIndices[_vVtxEnts[iVtx].iVFI + iFaceSlot]; }
Int32      vtx         (Int32 iFace,
                        Int32 iVtxSlot) const
{ return _viFaceVtxIndices[_vFaceEnts[iFace].iFVI + iVtxSlot]; }
Int32      numVts       () const
{ return _vVtxEnts.length(); }
Int32      numFaces     () const
{ return _vFaceEnts.length(); }
Int32      numAttrs     () const
{ return _viFaceAttrIndices.length(); }
Int32      numAttrs     (Int32 iFace) const
{ return _vFaceEnts[iFace].cFaceAttrs; }
UInt64     attrMask     (Int32 iFace) const
{ return _vFaceEnts[iFace].u.uAttrMask; }
const BitVec *attrMaskV (Int32 iFace) const
{ return _vFaceEnts[iFace].u.pvbAttrMask; }
Int32      findVtxSlot  (Int32 iFace,
                        Int32 iTargVtx) const;
Int32      findFaceSlot (Int32 iVtx,
                        Int32 iTargFace) const;
Int32      emptyFaceSlots (Int32 iFace) const
{ return _vFaceEnts[iFace].cEmptyDeg; }

// ===== VFMesh Data Members =====
public:
class VtxEnt {
public:
    VtxEnt() : cVal(0), uFlags(0), iVGrp(-1), iVFI(-1) {}
    UInt16    cVal;    // Vtx valence
    UInt16    uFlags;  // User flags
    Int32     iVGrp;   // Vtx group
    Int32     iVFI;    // Idx into _viVtxFaceIndices of cVal incident faces
};

// Number of optimized mask bits.
static const Int32 cMBits = 64;

class FaceEnt {
public:
    FaceEnt() : cDeg(0), uFlags(0), cEmptyDeg(0),
               cFaceAttrs(0), iFVI(-1), iFAI(-1) { u.uAttrMask = 0; }
    FaceEnt(const FaceEnt &rhs) : cDeg(rhs.cDeg), cEmptyDeg(rhs.cEmptyDeg),
                                  cFaceAttrs(rhs.cFaceAttrs), iFVI(rhs.iFVI),
                                  iFAI(rhs.iFAI)
    {
        if (cDeg <= cMBits)
            u.uAttrMask = rhs.u.uAttrMask;
        else
            JtWrapNew(u.pvbAttrMask, new BitVec(*rhs.u.pvbAttrMask));
    }
    ~FaceEnt() { if (cDeg > cMBits && u.pvbAttrMask) delete u.pvbAttrMask; }
    UInt16    cDeg;    // Face degree
    UInt16    cEmptyDeg; // Empty degrees (opt for emptyFaceSlots())
    UInt16    cFaceAttrs; // Number of face attributes
    UInt16    uFlags;   // User flags
    union {
        UInt64 uAttrMask;    // Degree-ring attr mask as a UInt64
        BitVec *pvbAttrMask; // Degree-ring attr mask as a BitVec
    } u;
    Int32     iFVI; // Idx into _viFaceVtxIndices of cDeg incident vts
    Int32     iFAI; // Idx into _viFaceAttrIndices of cAttr attributes
};

protected:
// Subscripted by atom number, the entry contains the vtx valence and
// points to the location in _viVtxFaceIndices of valence consecutive
// integers that in turn contain the indices of the incident faces

```

```

// in _vFaceRecs to the vtx.
JtVec<VtxEnt> _vVtxEnts;

// Subscripted by unique vertex record number, the entry contains the
// face degree and points to the location in _viFaceVtxIndices of
// cDeg consecutive integers that in turn contain the indices of the
// vertices indicent upon the face, in CCW order, in _vVtxRecs.
JtVec<FaceEnt> _vFaceEnts;

// Combined storage for all vtxs.
JtVeci _viVtxFaceIndices;

// Combined storage for all faces.
JtVeci _viFaceVtxIndices;

// Combined storage for all face attribute record identifiers
JtVeci _viFaceAttrIndices;
};

bool
DualVFMesh::isValidVtx(Int32 iVtx) const
{
    bool bRet = JtFalse;
    if (iVtx >= 0 && iVtx < _vVtxEnts.length()) {
        const VtxEnt &rFE = _vVtxEnts[iVtx];
        bRet = (rFE.cVal != 0);
    }
    return bRet;
}

bool
DualVFMesh::newVtx(Int32 iVtx,
                   Int32 iValence,
                   UInt16 uFlags)
{
    VtxEnt &rFE = _vVtxEnts[iVtx];
    if (rFE.cVal != iValence) {
        rFE.cVal = iValence;
        rFE.uFlags = uFlags;
        rFE.iVFI = _viVtxFaceIndices.length();
        _viVtxFaceIndices.verify(rFE.iVFI + iValence - 1);
        for (Int32 i = rFE.iVFI ; i < rFE.iVFI + iValence ; i++)
            _viVtxFaceIndices[i] = -1;
    }
    return true;
}

bool
DualVFMesh::setVtxGrp(Int32 iVtx,
                      Int32 iVGrp)
{
    VtxEnt &rFE = _vVtxEnts[iVtx];
    rFE.iVGrp = iVGrp;
    return true;
}

bool
DualVFMesh::setVtxFlags(Int32 iVtx,
                        UInt16 uFlags)
{
    VtxEnt &rFE = _vVtxEnts[iVtx];
    rFE.uFlags = uFlags;
    return true;
}

Int32
DualVFMesh::vtxGrp (Int32 iVtx) const
{
    Int32 u = -1;
    if (iVtx >= 0 && iVtx < _vVtxEnts.length()) {
        const VtxEnt &rFE = _vVtxEnts[iVtx];
        u = rFE.iVGrp;
    }
}

```



```

        return u;
    }

UInt16
DualVFMesh::vtxFlags (Int32 iVtx) const
{
    UInt16 u = 0;
    if (iVtx >= 0 && iVtx < _vVtxEnts.length()) {
        const VtxEnt &rFE = _vVtxEnts[iVtx];
        u = rFE.uFlags;
    }
    return u;
}

bool
DualVFMesh::isValidFace(Int32 iFace) const
{
    bool bRet = JtFalse;
    if (iFace >= 0 && iFace < _vFaceEnts.length()) {
        const FaceEnt &rVE = _vFaceEnts[iFace];
        bRet = (rVE.cDeg != 0);
    }
    return bRet;
}

bool
DualVFMesh::newFace(Int32 iFace,
                    Int32 cDegree,
                    Int32 cFaceAttrs,
                    UInt64 uFaceAttrMask,
                    UInt16 uFlags)
{
    FaceEnt &rVE = _vFaceEnts[iFace];
    if (rVE.cDeg != cDegree) {
        rVE.cDeg = cDegree;
        rVE.cEmptyDeg = cDegree;
        rVE.cFaceAttrs = cFaceAttrs;
        rVE.uFlags = uFlags;
        rVE.u.uAttrMask = uFaceAttrMask;
        rVE.iFVI = _viFaceVtxIndices.length();
        rVE.iFAI = _viFaceAttrIndices.length();
        _viFaceVtxIndices.verify(rVE.iFVI + cDegree - 1);
        if (cFaceAttrs > 0)
            _viFaceAttrIndices.verify(rVE.iFAI + cFaceAttrs - 1);
        for (Int32 i = rVE.iFVI ; i < rVE.iFVI + cDegree ; i++)
            _viFaceVtxIndices[i] = -1;
        for (Int32 i = rVE.iFAI ; i < rVE.iFAI + cFaceAttrs ; i++)
            _viFaceAttrIndices[i] = -1;
    }
    return true;
}

bool
DualVFMesh::newFace(Int32 iFace,
                    Int32 cDegree,
                    Int32 cFaceAttrs,
                    const BitVec *pvbFaceAttrMask,
                    UInt16 uFlags)
{
    FaceEnt &rVE = _vFaceEnts[iFace];
    if (rVE.cDeg != cDegree) {
        rVE.cDeg = cDegree;
        rVE.cEmptyDeg = cDegree;
        rVE.cFaceAttrs = cFaceAttrs;
        rVE.uFlags = uFlags;
        rVE.u.pvbAttrMask = new BitVec(*pvbFaceAttrMask);
        rVE.iFVI = _viFaceVtxIndices.length();
        rVE.iFAI = _viFaceAttrIndices.length();
        _viFaceVtxIndices.verify(rVE.iFVI + cDegree - 1);
        if (cFaceAttrs > 0)
            _viFaceAttrIndices.verify(rVE.iFAI + cFaceAttrs - 1);
        for (Int32 i = rVE.iFVI ; i < rVE.iFVI + cDegree ; i++)

```

```

        _viFaceVtxIndices[i] = -1;
        for (Int32 i = rVE.iFAI ; i < rVE.iFAI + cFaceAttrs ; i++)
            _viFaceAttrIndices[i] = -1;
    }
    return true;
}

bool
DualVFMesh::setFaceFlags(Int32 iFace,
                        UInt16 uFlags)
{
    FaceEnt &rVE = _vFaceEnts[iFace];
    rVE.uFlags = uFlags;
    return true;
}

UInt16
DualVFMesh::faceFlags (Int32 iFace) const
{
    UInt16 u = 0;
    if (iFace >= 0 && iFace < _vFaceEnts.length()) {
        const FaceEnt &rVE = _vFaceEnts[iFace];
        u = rVE.uFlags;
    }
    return u;
}

bool
DualVFMesh::setFaceAttr(Int32 iFace,
                        Int32 iAttrSlot,
                        Int32 iFaceAttr)
{
    FaceEnt &rVE = _vFaceEnts[iFace];
    Int32 *paiFAI = _viFaceAttrIndices.ptr();
    paiFAI[rVE.iFAI + iAttrSlot] = iFaceAttr;
    return true;
}

Int32
DualVFMesh::faceAttr(Int32 iFace,
                    Int32 iAttrSlot) const
{
    Int32 u = 0;
    if (iFace >= 0 && iFace < _vFaceEnts.length()) {
        const FaceEnt &rVE = _vFaceEnts[iFace];
        if (iAttrSlot >= 0 && iAttrSlot < rVE.cDeg) {
            const Int32 *paiFAI = _viFaceAttrIndices.ptr();
            u = paiFAI[rVE.iFAI + iAttrSlot];
        }
    }
    return u;
}

// Attaches VF face iFace to VF vertex iVtx in the vertex's
// face slot iFaceSlot
bool
DualVFMesh::setVtxFace(Int32 iVtx,
                      Int32 iFaceSlot,
                      Int32 iFace)
{
    VtxEnt &rFE = _vVtxEnts[iVtx];
    _viVtxFaceIndices[rFE.iVFI + iFaceSlot] = iFace;
    return true;
}

// Attaches VF vertex iVtx to VF face iFace in the face's
// vertex slot iVtxSlot
bool
DualVFMesh::setFaceVtx(Int32 iFace,
                      Int32 iVtxSlot,
                      Int32 iVtx)
{
    FaceEnt &rVE = _vFaceEnts[iFace];

```

```

    Int32 *paiFVI = _viFaceVtxIndices.ptr();
    rVE.cEmptyDeg -= (paiFVI[rVE.iFVI + iVtxSlot] != iVtx);
    paiFVI[rVE.iFVI + iVtxSlot] = iVtx;
    return true;
}

// Searches the list of incident vts to face iFace for
// iTargVtx and returns the vtx slot at which it is found
// or -1 if iTargVtx is not found.
Int32
DualVFMesh::findVtxSlot(Int32 iFace,
                        Int32 iTargVtx) const
{
    const FaceEnt &rVE = _vFaceEnts[iFace];
    const Int32 *const pFaceVtxIndices = _viFaceVtxIndices.ptr() + rVE.iFVI;
    Int32 cDeg = rVE.cDeg;
    Int32 iSlot = -1;
    for (Int32 iVtxSlot = 0 ; iVtxSlot < cDeg ; iVtxSlot++) {
        if (pFaceVtxIndices[iVtxSlot] == iTargVtx) {
            iSlot = iVtxSlot;
            break;
        }
    }
    return iSlot;
}

// Searches the list of incident faces to vertex iVtx for
// iTargFace and returns the face slot at which it is found
// or -1 if iTargFace is not found.
Int32
DualVFMesh::findFaceSlot (Int32 iVtx,
                        Int32 iTargFace) const
{
    const VtxEnt &rFE = _vVtxEnts[iVtx];
    const Int32 *const pVtxFaceIndices = _viVtxFaceIndices.ptr() + rFE.iVFI;
    for (Int32 iFaceSlot = 0 ; iFaceSlot < rFE.cVal ; iFaceSlot++) {
        if (pVtxFaceIndices[iFaceSlot] == iTargFace) {
            return iFaceSlot;
        }
    }
    return -1;
}

```

D.2 Topology Decoder

Partial implementations of three classes are given here for MeshCoderDriver, MeshCodec, and MeshDecoder. MeshCodec contains the abstract implementation of the topology coder. MeshDecoder implements the functionality needed to decode a mesh from the input data read from an JT file (see Topologically Compressed Rep Data). MeshCoderDriver manages the input data, the output VFMesh, and the MeshDecoder itself, providing a simple three-step API.

D.2.1 MeshCoderDriver class

```

// This class serves as a coordinating driver for mesh coding and decoding.
class MeshCoderDriver
{
public:
    MeshCoderDriver ();

    // ===== Operations Interface =====
    void      setInputData(const Veci      vviOutValSyms[/*8*/],
                           const Veci      &viOutDegSyms,
                           const Veci      &viOutFGrpSyms,
                           const Vecus     &vuOutFaceFlags,
                           const Vecclu    vvuOutAttrMasks[/*8*/],
                           const Vecu      &vuOutAttrMasksLrg,
                           const Veci      &viOutSplitVtxSyms,
                           const Veci      &viOutSplitPosSyms)

```

```

        { /* Copy into 22 fields below */ }

void      decode();
VFMesh   *vfm() const { return _pOutVFM; }

// ===== Utility Methods =====
Int32     _nextDegSymbol      (Int32 iCCntx);
Int32     _nextValSymbol      ();
Int32     _nextFGrpSymbol     ();
UInt16    _nextVtxFlagSymbol  ();
UInt64    _nextAttrMaskSymbol(Int32 iCCntx);    // <= 64-bit attrmask
void      _nextAttrMaskSymbol(BitVec *iopvbAttrMask,
                               Int32  cDegree);  // > 64 bit attrmask

Int32     _nextSplitFaceSymbol();
Int32     _nextSplitPosSymbol();
Int32     _faceCntxt(Int32 iVtx, JtDualVFMesh *pVFM);

// ===== Member Data =====
protected:
SharedPtr<MeshCodec>    _pMC;        // The mesh coder or decoder being used
SharedPtr<JtDualVFMesh> _pOutVFM;    // Back-end VFMesh built by decoder
SharedPtr<MeshDecoder> _pMeshDecoder;

// Coding symbols generated by encoding operation, auxiliary data such as
// offsets, etc.
Veci      _vviOutDegSyms[8]; // Face degree + SPLIT symbols for multiple contexts
Veci      _viOutValSyms;     // Vtx valence symbols
Veci      _viOutVGrpSyms;    // Vtx group of each encoded vtx
Vecus     _vuOutVtxFlags;    // Vtx flags; parallel to _viOutValSyms.
Vecclu    _vvuOutAttrMasks[8]; // Attribute bitmasks per face for multiple
contexts.

// One per non-split entry in _viOutValSyms.
Vecu      _vuOutAttrMasksLrg; // > 64-bit attrmasks
Veci      _viOutSplitFaceSyms; // Split face offsets
Veci      _viOutSplitPosSyms; // Split face vtx slots

// The next symbol to be consumed by _next*Symbol()
Int32     _iValReadPos[8];
Int32     _iDegReadPos;
Int32     _iVGrpReadPos;
Int32     _iFFlagReadPos;
Int32     _iAttrMaskReadPos[8];
Int32     _iAttrMaskLrgReadPos;
Int32     _iSplitFaceReadPos;
Int32     _iSplitPosReadPos;
};

void MeshCoderDriver::decode()
{
    // Allocate a coder
    if (!_pMeshDecoder) {
        _pMeshDecoder = new MeshDecoder(this);
    }
    _pMC = _pMeshDecoder;
    _pMC->setTopoDualMeshCoder(this);

    // Reset the symbol counters
    for (Int32 i = 0 ; i < 8 ; i++) {
        _iValReadPos[i] = 0;
        _iAttrMaskReadPos[i] = 0;
    }
    _iDegReadPos = 0;
    _iVGrpReadPos = 0;
    _iFFlagReadPos = 0;
    _iAttrMaskLrgReadPos = 0;
    _iSplitFaceReadPos = 0;
    _iSplitPosReadPos = 0;

    // Run the decoder
    _pMC->run();

    // Assert that ALL symbols have been consumed
    for (Int32 i = 0 ; i < 8 ; i++) {
        Assert(_iValReadPos[i] == _vviOutDegSyms[i].length());
    }
}

```

```

        Assert(_iAttrMaskReadPos[i] == _vvuOutAttrMasks[i].length());
    }
    Assert(_iDegReadPos == _viOutValSyms.length());
    Assert(_iVGrpReadPos == _viOutVGrpSyms.length());
    Assert(_iFFlagReadPos == _vuOutVtxFlags.length());
    Assert(_iAttrMaskLrgReadPos == _vuOutAttrMasksLrg.length());
    Assert(_iSplitFaceReadPos == _viOutSplitFaceSyms.length());
    Assert(_iSplitPosReadPos == _viOutSplitPosSyms.length());

    // Set output VFMesh
    _pOutVFM = _pMC->vfm();
}

Int32 MeshCoderDriver::_nextDegSymbol (Int32 iCCntx)
{
    Int32 eSym = -1;
    if (_iValReadPos[iCCntx] < _vviOutDegSyms[iCCntx].length())
        eSym = _vviOutDegSyms[iCCntx].value(_iValReadPos[iCCntx]++);
    return eSym;
}

Int32
MeshCoderDriver::_nextValSymbol ()
{
    Int32 eSym = -1;
    if (_iDegReadPos < _viOutValSyms.length())
        eSym = _viOutValSyms.value(_iDegReadPos++);
    return eSym;
}

Int32 MeshCoderDriver::_nextFGrpSymbol()
{
    Int32 eSym = -1;
    if (_iVGrpReadPos < _viOutVGrpSyms.length())
        eSym = _viOutVGrpSyms.value(_iVGrpReadPos++);
    return eSym;
}

UInt16 MeshCoderDriver::_nextVtxFlagSymbol ()
{
    UInt16 eSym = 0;
    if (_iFFlagReadPos < _vuOutVtxFlags.length())
        eSym = _vuOutVtxFlags.value(_iFFlagReadPos++);
    return eSym;
}

UInt64 MeshCoderDriver::_nextAttrMaskSymbol (Int32 iCCntx)
{
    UInt64 eSym = 0;
    if (_iAttrMaskReadPos[iCCntx] < _vvuOutAttrMasks[iCCntx].length())
        eSym = _vvuOutAttrMasks[iCCntx].value(_iAttrMaskReadPos[iCCntx]++);
    return eSym;
}

void MeshCoderDriver::_nextAttrMaskSymbol(BitVec *iopvbAttrMask, Int32 cDegree)
{
    if (_iAttrMaskLrgReadPos < _vuOutAttrMasksLrg.length()) {
        iopvbAttrMask->setLength(cDegree);
        UInt32 *pu = iopvbAttrMask->ptr();
        Int32 nWords = (cDegree + BitVec::cWordBits - 1) >> BitVec::cBitsLog2;
        memcpy(pu, &_vuOutAttrMasksLrg.value(_iAttrMaskLrgReadPos), nWords *
sizeof(UInt32));
        _iAttrMaskLrgReadPos += nWords;
    }
    else {
        iopvbAttrMask->setLength(0);
    }
}

Int32 MeshCoderDriver::_nextSplitFaceSymbol ()
{
    Int32 eSym = -1;
    if (_iSplitFaceReadPos < _viOutSplitFaceSyms.length())

```

```

        eSym = _viOutSplitFaceSyms.value(_iSplitFaceReadPos++);
    return eSym;
}

Int32 MeshCoderDriver::_nextSplitPosSymbol ()
{
    Int32 eSym = -1;
    if (_iSplitPosReadPos < _viOutSplitPosSyms.length())
        eSym = _viOutSplitPosSyms.value(_iSplitPosReadPos++);
    return eSym;
}

// Computes a "compression context" from 0 to 7 inclusive for
// faces on vertex iVtx. The context is based on the vertex's
// valence, and the total _known_ degree of already-coded
// faces on the vertex at the time of the call.
Int32 MeshCoderDriver::_faceCntxt(JtInt32 iVtx, JtDualVFMesh *pVFM)
{
    // Here, we are going to gather data to be used to determine a
    // compression contest for the face degree.
    JtInt32 cVal = pVFM->valence(iVtx);
    JtInt32 nKnownFaces = 0;
    JtInt32 cKnownTotDeg = 0;
    for (JtInt32 i = 0 ; i < cVal ; i++) {
        JtInt32 iTmpFace = pVFM->face(iVtx, i);
        if (!pVFM->isValidFace(iTmpFace))
            continue;
        nKnownFaces++;
        cKnownTotDeg += pVFM->degree(iTmpFace);
    }
    JtInt32 iCCntxt = 0;
    if (cVal == 3) {
        // Regular trisrip-like meshes tend to have degree 6 faces
        iCCntxt = (cKnownTotDeg < nKnownFaces * 6) ? 0 :
            (cKnownTotDeg == nKnownFaces * 6) ? 1 : 2;
    }
    else if (cVal == 4) {
        // Regular quadstrip-like meshes tend to have degree 4 faces
        iCCntxt = (cKnownTotDeg < nKnownFaces * 4) ? 3 :
            (cKnownTotDeg == nKnownFaces * 4) ? 4 : 5;
    }
    else if (cVal == 5)
        // Pentagons are all lumped into context 6
        iCCntxt = 6;
    else
        // All other polygons are lumped into context 7
        iCCntxt = 7;

    return iCCntxt;
}

```

D.2.2 MeshCodec class

```

// This class serves as the abstract base class from which two concrete classes
// are derived to implement the core operations for a polygonal
// mesh coder or decoder. An instance of this object is used by the
// MeshCoderDriver to encode and decode polygonal meshes.
//
// This class makes extensive use of DualVFMesh objects as the primary source and
// destination mesh topology storage data structures. This mediating data
// structure is necessary because the mesh coding scheme is deeply cooperative
// with and dependent upon such a vertex-facet data structure. Please refer to
// DualVFMesh for more information.
class MeshCodec {
public:
    // ===== Housekeeping Interface =====
    MeshCodec (MeshCoderDriver *pTMC = NULL);
protected:
    virtual ~MeshCodec() {}
public:

    // ===== Setup and Apply Interface =====
    void setMeshCoderDriver(MeshCoderDriver *pTMC) { _pTMC = pTMC; }
    JtDualVFMesh *vfm() const { return _pDstVFM; }
}

```

```

void run();

// ===== Generic encode/decode Driver Chain =====
void clear();
void runComponent(bool &obFoundComponent);
void initNewComponent(bool &obFoundComponent);
void completeV(Int32 iFace);
Int32 activateV(Int32 iVtx, Int32 iVSlot);
Int32 activateF(Int32 iFace, Int32 iFSlot);
void completeF(Int32 iVtx, Int32 jFSlot);
void addVtxToFace (Int32 iVtx, Int32 iVSlot,
                  Int32 iFace, Int32 iFSlot);

// Active face list management
void addActiveFace(Int32 iFace);
Int32 nextActiveFace();
void removeActiveFace(Int32 iFace);
Int32 activeFaceOffset(Int32 iFace) const;

private:
// ===== Polymorphic I/O Interface =====
virtual Int32 ioVtxInit () = 0;
virtual Int32 ioVtx (Int32 iFace, Int32 jFSlot) = 0;
virtual Int32 ioFace (Int32 iVtx, Int32 iVSlot) = 0;
virtual Int32 ioSplitFace (Int32 iVtx, Int32 iVSlot) = 0;
virtual Int32 ioSplitPos (Int32 iVtx, Int32 iVSlot) = 0;

// ===== Member Data =====
protected:
MeshCoderDriver *_pTMC; // TopoDualMeshCoder this codec is attached
to
SharedPtr<JtDualVFMesh> _pSrcVFM; // Input VFMesh
SharedPtr<JtDualVFMesh> _pDstVFM; // Output VFMesh
Veci _viActiveFaces; // Stack of incomplete "active faces"
BitVec _vbRemovedActiveFaces; // Helper bitvec parallel to above
// Used by decoder to assign running attr indices
Int32 _iFaceAttrCtr;
};

// Runs the mesh encoder/decoder machine.
// If decoding is being performed, it consumes the mesh
// coding symbols from pre-filled member variables to produce
// the output VFMesh _pDstVFM.
void MeshCodec::run()
{
    // Assert state is consistent and ready to co/dec
    if (!_pDstVFM)
        _pDstVFM = new JtDualVFMesh();
    Assert(_pDstVFM);
    _pDstVFM->clear();
    clear();

    // Co/dec connected mesh components one at a time
    bool bFoundComponent = JtTrue;
    while (bFoundComponent) {
        Bool bRetVal = runComponent(bFoundComponent);
        Assert (bRetVal);
    }
}

void MeshCodec::clear()
{
    // Setup
    _viActiveFaces.setLength(0);
    _vbRemovedActiveFaces.setLength(0);
    _iFaceAttrCtr = 0;
}

// Decodes one "connected component" (contiguous group of polygons) into
// _pDstVFM. Because the polygonal model may be formed of multiple
// disconnected mesh components, it may be necessary for run() to call this
// method multiple times. This method returns obFoundComponent = True

```

```

// if it actually encoded a new mesh component, and obFoundComponent = False
// if it did not.
void MeshCodec::runComponent(bool &obFoundComponent)
{
    Int32 iFace;
    initNewComponent(obFoundComponent);
    if (!obFoundComponent)
        return;
    while ((iFace = nextActiveFace()) != -1) {
        completeF(iFace);
        removeActiveFace(iFace);
    }
}

// Locates an unencoded vertex and begins the encoding
// process for the newly-found mesh component.
void MeshCodec::initNewComponent(bool &obFoundComponent)
{
    obFoundComponent = JtTrue;

    // Call ioVtxInit() to start us off with the seed face
    // from a new "connected component" of polygons.
    Int32 iVtx, i;
    if ((iVtx = ioVtxInit()) == -1) {
        obFoundComponent = JtFalse; // All vtxs are processed
        return;
    }
    Int32 cVal = _pDstVFM->valence(iVtx);
    for (i = 0 ; i < cVal ; i++) {
        Int32 iFace = activateF(iVtx, i); // Process all faces
        if (iFace == -2) {
            Assert(0 && "Mesh traversal failed");
            return false;
        }
    }
}

// Completes the VFMesh face iFace on _pDstVFM by calling activateV() and
// completeV() for each as-yet inactive incident vertexes in the face's
// degree ring.
void MeshCodec::completeF(Int32 iFace)
{
    // While there is an empty vtx slot on the face
    Int32 jVtxSlot, iVtx;
    Int32 iVSlot = 0;
    while ((jVtxSlot = _pDstVFM->findVtxSlot(iFace, -1)) != -1) {
        // Create and return a vtx iVtx, attaching it to iFace at vtx
        // slot jVtxSlot.
        iVtx = activateV(iFace, jVtxSlot);

        // Assert FV consistency
        Assert(_pDstVFM->vtx (iFace, jVtxSlot) == iVtx &&
            _pDstVFM->face(iVtx, iVSlot) == iFace );

        // Process the faces of iVtx starting from face slot
        // jVtxSlot where iVtx is incident on iFace.
        completeV(iVtx, jVtxSlot);

        // Invariant "VF": vtx(iVtx).face(iVSlot) == iFace &&
        // face(iFace).vtx(jVtxSlot) == iVtx
    }
}

// "Activates" the VFMesh face, on _pDstVFM, at face iFace vertex slot iVSlot
// by calling ioFace() to obtain a new vertex number and hooking it up to the
// topological structure. If the face is a SPLIT face, then call
// ioSplitFace() and ioSplitPos() to get the information necessary to connect
// to an already-active face. Note that we use the term "activate" here to
// mean "read" for mesh decoding.
Int32 MeshCodec::activateF(Int32 iVtx, Int32 iVSlot)
{
    Int32 jFSlot;
    // ioFace might return -2 as an error condition

```



```

    Int32 iFace = ioFace(iVtx, iVSlot);
    if (iFace >= 0) { // If a new active face
        if (!_pDstVFM->setVtxFace(iVtx, iVSlot, iFace) ||
            !_pDstVFM->setFaceVtx(iFace, 0, iVtx) ||
            !addActiveFace(iFace) )
        {
            return -2;
        }
    }
    else if (iFace == -1) { // Face already exists, so Split
        iFace = ioSplitFace(iVtx, iVSlot); // v's index in ActiveSet, returns v
        jFSlot = ioSplitPos(iVtx, iVSlot); // Position of iVtx in v
        if (iFace == -2 || iVSlot == -1)
            return -2;
        _pDstVFM->setVtxFace(iVtx, iVSlot, iFace);
        addVtxToFace(iVtx, iVSlot, iFace, jFSlot);
    }
    return iFace;
}

// "Activates" the VFMesh vertex, on _pDstVFM, at face iFace vertex slot iVSlot
// by calling ioFace() to obtain a new face number and hooking it up to the
// topological structure. Note that we use the term "activate" here to
// mean "read" for mesh decoding.
Int32 MeshCodec::activateV(Int32 iFace, Int32 iVSlot)
{
    Int32 iVtx = ioVtx(iFace, iVSlot); // I/O valence; create a vtx
    _pDstVFM->setVtxFace(iVtx, 0, iFace);
    addVtxToFace (iVtx, 0, iFace, iVSlot);
    return iVtx;
}

// Completes the vertex iVtx on _pDstVFM by activating all inactive faces
// incident upon it. As an optimization, the user shall also pass in iVSlot
// which is the vertex slot on face 0 of iVtx where iVtx is located. This
// method begins its examination of iVtx's faces at face 0 by working its
// way around the vertex in both CCW and CW directions, checking to see if there
// are any faces that can be hooked into iVtx without calling activateF().
// This can happen when a face is completed by a nearby vertex before coming
// here. The situation can be detected by traversing the topology of the
// _pDstVFM over to the neighboring vertex and checking if it already has a
// face number for the corresponding face entry on iVtx. If so, then
// iVtx and the already completed face are connected together, and the
// next face around iVtx is examined. When the process can go no further,
// this method calls _activateF() on the remaining unresolved span of faces
// around the vertex.
void MeshCodec::completeF(Int32 iVtx, Int32 iVSlot)
{
    JtDualVFMesh *pDstVFM = _pDstVFM;
    Int32 i, vp, vn, jp, jn,
        iVtx2,
        cVal = pDstVFM->valence(iVtx);

    // Walk CCW from face slot 0, attempting to link in as many
    // already-reachable faces as possible until we reach one
    // that is inactive.
    vp = pDstVFM->face(iVtx, 0);
    jp = iVSlot;
    i = 1;
    JtDebugOnly(_assertParallelValRings(vp));
    while ((vn = pDstVFM->face(iVtx, i)) != -1) { // Forces "FV" in the "next" direction
        DecModN(jp, pDstVFM->degree(vp));
        iVtx2 = pDstVFM->vtx(vp, jp);
        if (iVtx2 == -1)
            break;
        jn = pDstVFM->findVtxSlot(vn, iVtx2);
        Assert(jn > -1);
        DecModN(jn, pDstVFM->degree(vn));
        addVtxToFace(iVtx, i, vn, jn);
        vp = vn;
        jp = jn;
        i++;
        if (i >= cVal)

```

```

        return;
    }

    // Walk CW from face slot 0, attempting to link in as many
    // already-reachable faces as possible until we reach one
    // that is inactive.
    Int32 ilast = i;
    vp = pDstVFM->face(iVtx, 0);
    jp = iVSlot;
    i = pDstVFM->valence(iVtx) - 1;
    while ((vn = pDstVFM->face(iVtx, i)) != -1) { // Forces "VF" in "prev" direction
        IncModN(jp, pDstVFM->degree(vp));
        iVtx2 = pDstVFM->vtx(vp, jp);
        if (iVtx2 == -1)
            break;
        jn = pDstVFM->findVtxSlot(vn, iVtx2);
        Assert(jn > -1);
        IncModN(jn, pDstVFM->degree(vn));
        addVtxToFace(iVtx, i, vn, jn);
        vp = vn;
        jp = jn;
        i--;
        if (i < ilast)
            return;
    }

    // Activate the remaining faces on iVtx that cannot be deduced from
    // the already-assembled topology in the destination VFMesh.
    for (; ilast <= i ; ilast++) {
        Int32 iFace = activateV(iVtx, ilast);
        JtDemandState(iFace >= -1);
    }
}

// This method connects vertex iVtx into the topology of
// _pDstVFM at and around iFace. First, it connects iVtx
// to iFace's degree ring at position iVSlot. Next, it
// will connect iVtx into the faces at the other ends of
// the shared edges between iVtx and the next vertices CS and
// CCW about iFace if necessary.
void MeshCodec::addVtxToFace (Int32 iVtx, Int32 jFSlot,
                             Int32 iFace, Int32 iVSlot)
{
    Int32 iVSlotCW = iVSlot,
          iVSlotCCW = iVSlot,
          fp, ip,
          fn, in;
    JtDualVFMesh *pDstVFM = _pDstVFM;
    IncModN(iVSlotCCW, pDstVFM->degree(iFace));
    DecModN(iVSlotCW, pDstVFM->degree(iFace));

    // Connect iVtx to iFace/iVSlot
    JtRethrow(pDstVFM->setFaceVtx(iFace, iVSlot, iVtx));

    // Connect iVtx across the shared edge between iVtx and the vtx CW
    // from iVtx at iFace. Connect iVtx into the face at the other
    // end of this edge if it is not already connected there.
    if ((fp = pDstVFM->vtx(iFace, iVSlotCW)) != -1) {
        ip = pDstVFM->findFaceSlot(fp, iFace);
        Int32 iVSlotCCW = jFSlot;
        IncModN(iVSlotCCW, pDstVFM->valence(iVtx));
        if (pDstVFM->face(iVtx, iVSlotCCW) == -1) {
            DecModN(ip, pDstVFM->valence(fp));
            pDstVFM->setVtxFace(iVtx, iVSlotCCW, pDstVFM->face(fp, ip));
        }
    }

    // Connect iVtx across the shared edge between iVtx and the vtx CCW
    // from iVtx at iFace. Connect iVtx into the face at the other
    // end of this edge if it is not already connected there.
    if ((fn = pDstVFM->vtx(iFace, iVSlotCCW)) != -1) {
        in = pDstVFM->findFaceSlot(fn, iFace);
        Int32 iVSlotCW = jFSlot;

```

```

        DecModN(iVSlotCW, pDstVFM->valence (iVtx));
        if (pDstVFM->face(iVtx, iVSlotCW) == -1) {
            IncModN(in, pDstVFM->valence(fn));
            pDstVFM->setVtxFace(iVtx, iVSlotCW, pDstVFM->face(fn, in));
        }
    }
}

void MeshCodec::addActiveFace(Int32 iFace)
{
    JtRethrow(_viActiveFaces.pushBack(iFace));
}

// Returns a face from the active queue to be completed. This needn't be the
// one at the end of the queue, because the choice of the next active face
// can affect how many SPLIT symbols are produced. This method employs a
// fairly simple scheme of searching the most recent 16 active faces for the
// first one with the smallest number of incomplete slots in its degree ring.
Int32 MeshCodec::nextActiveFace()
{
    Int32 iFace = -1;
    // Search the 16 face record at the end of the
    // queue for the one with lowest remaining degree.
    while (_viActiveFaces.length() > 0 &&
        _vbRemovedActiveFaces.test(_viActiveFaces.back()))
        _viActiveFaces.popBack();
    Int32 cLowestEmptyDegree = 9999999;
    Int32 i, iFace0, cEmptyDeg;
    const Int32 cWidth = 16;
    JtDualVFMesh *pDstVFM = _pDstVFM;
    for (i = _viActiveFaces.length() - 1 ;
        i >= ::jtmax(0, _viActiveFaces.length() - cWidth) ;
        i--)
    {
        iFace0 = _viActiveFaces[i];
        if (_vbRemovedActiveFaces.test(iFace0)) {
            _viActiveFaces.remove(i); // TOXIC: O(N^2)
            continue;
        }
        cEmptyDeg = pDstVFM->emptyFaceSlots(iFace0);
        if (cEmptyDeg < cLowestEmptyDegree) {
            cLowestEmptyDegree = cEmptyDeg;
            iFace = iFace0;
        }
    }

    // Return the selected active face
    return iFace;
}

// Removes iFace from the active face queue.
void MeshCodec::removeActiveFace(Int32 iFace)
{
    _vbRemovedActiveFaces.set(iFace);
}

// Searches the active face queue for iFace and returns
// its index position from the _end_ of the queue. This is
// needed by the ioFace() method when encoding a SPLIT
// symbol.
Int32 MeshCodec::activeFaceOffset(Int32 iFace) const
{
    Int32 iOffset = -1;
    Int32 i, cLen = _viActiveFaces.length();
    const Int32 *paiActiveFaces = _viActiveFaces.ptr();
    for (i = cLen - 1 ; i >= 0 ; i--) {
        if (paiActiveFaces[i] == iFace) {
            // The offset is how far FROM THE END of the active
            // face list we found iFace. This serves to make
            // the iOffset a much smaller number, which is better
            // for compression!
            iOffset = cLen - i;
            break;
        }
    }
}

```

```

    }
}
return iOffset;
}

```

D.2.3 MeshDecoder class

// This class implements the five abstract methods from
// MeshCodec to realize a mesh decoder.

```

class MeshDecoder : public MeshCodec {
public:
    // ===== Housekeeping Interface =====
    MeshDecoder (MeshCoderDriver *pTMC = NULL);
protected:
    virtual ~MeshDecoder() {}

private:
    // ===== Polymorphic I/O Interface =====
    virtual Int32 ioVtxInit  () ;
    virtual Int32 ioVtx      (Int32 iFace, Int32 iVSlot);
    virtual Int32 ioFace     (Int32 iVtx , Int32 jFSlot);
    virtual Int32 ioSplitFace(Int32 iVtx , Int32 jFSlot);
    virtual Int32 ioSplitPos (Int32 iVtx , Int32 jFSlot);
};

// Begins decoding a new connected mesh component by calling
// ioVtx() to read the next vertex from the symbol stream.
Int32 MeshDecoder::ioVtxInit()
{
    return ioVtx(-1, -1);
}

// Read a vertex valence symbol, vertex group number, and vertex
// flags from the input symbols stream. Create a new vertex
// on _pDstVFM with this data, and return the new vertex number.
// It is this method's responsibility to detect the end of
// the input symbol stream by returning -1 when that happens.
Int32 MeshDecoder::ioVtx (Int32 /*iFace*/ , Int32 /*iVSlot*/)
{
    // Obtain a VERTEX VALENCE symbol
    Int32 eSym = _pTMC->_nextValSymbol();
    Int32 iVtxVal, iVtx = -1;
    if (eSym > -1) {
        // Create a new vtxt on the VFMesh
        iVtx = _pDstVFM->numVts();
        iVtxVal = eSym;
        _pDstVFM->newVtx      (iVtx, iVtxVal);
        _pDstVFM->setVtxGrp   (iVtx, _pTMC->_nextFGrpSymbol());
        _pDstVFM->setVtxFlags(iVtx, _pTMC->_nextVtxFlagSymbol());
    }

    return iVtx;
}

// Read a face degree symbol, and attribute mask bit
// vector, create a new DualVFMesh face, initialize the
// face attribute record numbers from a running counter,
// and return the new face number. If the degree symbol
// read from the input symbol stream is 0, signify this by
// returning -1.
Int32
MeshDecoder::ioFace      (Int32 iVtx, Int32 /*jFSlot*/)
{
    // Obtain a FACE DEGREE symbol
    Int32 iCntxt = _pTMC->_faceCntxt(iVtx, _pDstVFM);
    Int32 eSym = _pTMC->_nextDegSymbol(iCntxt);
    Int32 cDeg, iFace = -1;
    if (eSym != 0) {
        // Create a new face on the VFMesh
        iFace = _pDstVFM->numFaces();
        cDeg = eSym;
        Int32 nFaceAttrs = 0;
        if (cDeg <= JtDualVFMesh::cMBits) {

```

```

        UInt64 uAttrMask = _pTMC-
>_nextAttrMaskSymbol(/*iCntxt*/::jtmin(7,::jtmax(0,cDeg-2)));
        for (UInt64 uMask = uAttrMask ; uMask ; nFaceAttrs += (uMask & 1), uMask >>=
1);
        _pDstVFM->newFace(iFace, cDeg, nFaceAttrs, uAttrMask);
    }
    else {
        BitVec vbAttrMask;
        _pTMC->_nextAttrMaskSymbol(&vbAttrMask, cDeg);
        for (Int32 i = 0 ; i < cDeg ; i++) {
            if (vbAttrMask.test(i))
                nFaceAttrs++;
        }
        _pDstVFM->newFace(iFace, cDeg, nFaceAttrs, &vbAttrMask, 0);
    }

    // Error check for a corrupt degree or attrmask
    if (nFaceAttrs > cDeg) {
        Assert (nFaceAttrs <= cDeg);
        return -2;
    }

    // Set up the face attributes
    for (Int32 iAttrSlot = 0 ; iAttrSlot < nFaceAttrs ; iAttrSlot++) {
        _pDstVFM->setFaceAttr(iFace, iAttrSlot, _iFaceAttrCtr++);
    }
}

}

// Consumes a split offset symbol from the SPLIT offset
// symbol stream, and determines the face number referenced
// by the offset. Returns the referenced face number.
Int32 MeshDecoder::ioSplitFace(Int32 /*iVtx*/, Int32 /*jFSlot*/)
{
    // Obtain a SPLITFACE symbol
    Int32 eSym = _pTMC->_nextSplitFaceSymbol();
    Assert(eSym >= -1);
    Int32 iOffset = -1, iFace = -1;
    if (eSym > -1) {
        // Use the offset to index into the active face queue
        // to determine the actual face number.
        iOffset = eSym;
        Int32 cLen = _viActiveFaces.length();
        // Error check for a corrupt offset
        if (iOffset <= 0 || iOffset > cLen) {
            Assert(iOffset > 0 && iOffset <= cLen);
            return -2;
        }
        iFace = _viActiveFaces[cLen - iOffset];
    }
    return iFace;
}

// Consumes a split position symbol from the associated symbol
// stream, and returns the vertex slot number on the current
// split face at which the topological split/merge occurred.
Int32 MeshDecoder::ioSplitPos (Int32 /*iVtx*/, Int32 /*jFSlot*/)
{
    // Obtain a SPLITVTX symbol
    Int32 eSym = _pTMC->_nextSplitPosSymbol();
    Assert(eSym >= -1);
    Int32 iVSlot = -1;
    if (eSym > -1) {
        // Return the vtx slot number
        iVSlot = eSym;
    }
    return iVSlot;
}

```

Annex E

Per Face Group Attributes

With JT the ability to apply attributes, such as material and texture image, to a group of faces in the Logical Scene Graph (LSG) is introduced, as shown in Figure E.1. This is referred to as per face group attributes. An Attribute Element in the logical scene graph (LSG) may be scoped so that it applies only to the geometry contained in a specific subset of grouped faces. Previous versions of the JT file format were capable of only applying Attributes to an entire Shape node.

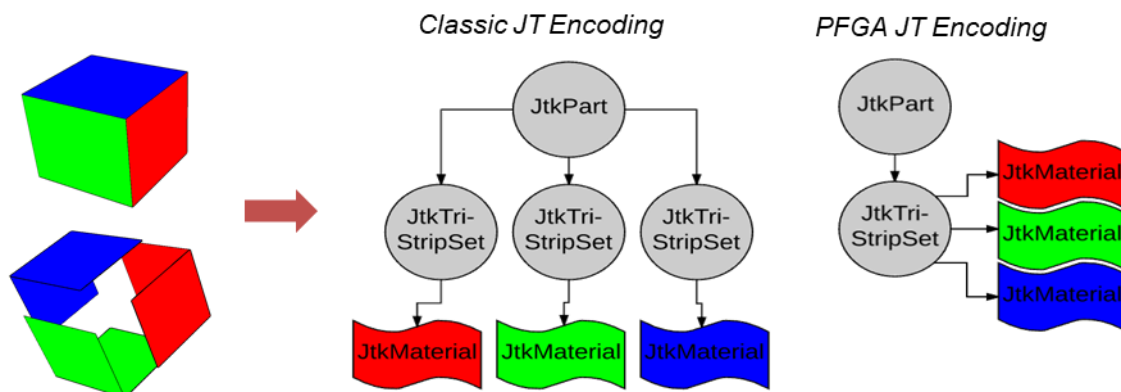


Figure E.1 — Classic versus PFGA Encoding

A Palette Map Attribute is used on a shape such that any face group can be rendered with a chosen entry from the palette. Each Attribute entry in the palette is inherited down the scene graph independent from any other palette entry. Attributes Elements in the scene graph are able to specify to which palette entry they apply.

There are two pieces of information involved in scoping a Palette Map Attribute Element to a face group: The U32:Palette Index field in the Base Attribute Data Fields V2 logical collection, and the PaletteMap Attribute Element.

E.1 U32:Palette Index field description

The U32:Palette Index field is used to implicitly create a State Palette that may later be indexed by a PaletteMap Attribute.

Three rules are used to accumulate the state for each explicitly mentioned palette index:

- Rule 1: The palette index value -1 is regarded as the "fallback palette entry". All Attributes are by default created with palette index -1.
- Rule 2: All Attributes sharing the same Palette Index value are accumulated separately, and constitute an entry in the State Palette.
- Rule 3: The fallback palette entry serves as the initial basis for each other distinct palette entry when the first Attribute of a given Palette Index is encountered during Attribute accumulation.

Rule 3 is best understood by example.

With the example case a user has a scene graph consisting of three nodes organized vertically in a depth 3 scene graph, each bearing various Attributes. The three attribute types are chosen because each accumulates differently in the scene graph.

- N is used to number the nodes, as the type of node is immaterial,

- N2 is the child of N1,
- N3 is the child of N2.
- M represents a Material attribute,
- X represents a Geometric Transform attribute,
- T represents a Texture Image attribute.
- PI denotes the Palette Index setting on an Attribute.
- TC denotes the Texture Channel index on a Texture Image.

N1: JtPartition - M1 (PI:-1), X1 (PI:-1), T0 (PI:-1, TC:0)

N2: VisPartNode - M2 (PI:0), M3 (PI:1), X2 (PI:1), X4(PI:3), T1 (PI:0, TC:1), T2 (PI:0, TC:2)

N3: TriStripSet - M4 (PI:2), M5(PI:0), X3 (PI:2), T3(PI:1, TC:1), T4 (PI:2, TC:0)

The Table E.1 shows the accumulated State Palette at node N3 in the example. Each row in the table represents the full accumulated state for a single palette entry

Table E.1— N3: Tristrip Set Accumulation

N3: TriStripSet - M4 (PI:2), M5 (PI:0), X3 (PI:2), T3(PI:1, TC:1), T4 (PI:2, TC:0)

| Palette Index | Material | Transform | Texture(s) |
|---------------|----------|-----------|-------------------------------------|
| -1 (Fallback) | M1 | X1 | T0 (TC:0) |
| 0 | M5 | X1 | T0 (TC:0) T1 (TC:1) T2 (TC:2) |
| 1 | M3 | X1*X2 | T0 (TC:0) T3 (TC:1) |
| 2 | M4 | X1*X3 | T4 (TC:0) |
| 3 | M1 | X1*X4 | T0 (TC:0) |

The table entries are obtained the following way:

Palette Entry -1 (the fallback): this entry comes directly from the two attributes on node N1 (i.e. M1 and X1). Since there are no other Attributes in the scene graph bearing palette index -1 below them, these two attributes stand as the fallback state on all three nodes. (Rule 1)

Transform state for palette entry 0: Because there is no Transform tagged with Palette Index 0 at or below N1, the fallback entry's Transform state also stands for this palette entry. (Rule 3).

Material state for palette entry 0: The Material attributes involved in this entry are M1, M2, and M5. M1 is a fallback (PI = -1) and so by Rule 3 serves as the basis for all material palette entries. M2 and M5 are explicitly tagged with PI=0 (Rule 2). Since Material attributes accumulate via replacement, M5 is left as the surviving Material. All other Material and Transform entries in the table follow this same logic.

Texture Image accumulation is slightly more subtle because it involves the independent concept of Texture Channel. Palette Index is conceptually similar to the way that multiple Texture Images accumulate via their Texture Channel, however, the two concepts are orthogonal to one another. Each entry in the State Palette can have a set of accumulated Texture Images.

Now draw special attention to Rule 1 above (this rule specifies how an Attribute with Palette Index -1 is accumulated). How would adding Material M6 (PI:-1) to Node N3 affect the State Palette at N3? The

answer is that M6 would replace the previously accumulated Material entries in all palette entries. This addition would result in the palette described in Table E.2.

Table E.2 — N3: Tristrip Set Accumulation Updated

N3: TriStripSet - M4 (PI:2), M5 (PI:0), X3 (PI:2), T3(PI:1, TC:1), T4 (PI:2, TC:0), M6 (PI: -1)

| Palette Index | Material | Transform | Texture(s) |
|---------------|----------|-----------|-------------------------------------|
| -1 (Fallback) | M6 | X1 | T0 (TC:0) |
| 0 | M6 | X1 | T0 (TC:0) T1 (TC:1) T2 (TC:2) |
| 1 | M6 | X1*X2 | T0 (TC:0) T3 (TC:1) |

This is how a default-constructed Attribute behaves. A default/fallback Attribute is assertive with respect to any specific palettized state above it in the scene graph.

As a final example of this behavior, it is important to emphasize that a fallback does not override the state that came before it, but rather asserts itself into the normal accumulation mechanism. To illustrate this point, consider the addition of a Transform X5 (PI:-1) to node N2 after the existing attributes:

N1: JtPartition: M1 (PI:-1), X1 (PI:-1), T0 (PI:-1, TC:0)

N2: VisPartNode: M2(PI:0), M3(PI:1), X2(PI:1), X4(PI:3), T1(PI:0,TC:1), T2(PI:0,TC:2), X5 (PI:-1)

N3: TriStripSet: M4 (PI:2), M5(PI:0), X3 (PI:2), T3(PI:1, TC:1), T4 (PI:2, TC:0)

In this case, the new State Palette would appear as shown in Table E.3:

Table E.3 — N2 Accumulation Updated

N2: VisPartNode: M2(PI:0), M3(PI:1), X2(PI:1), X4(PI:3), T1(PI:0,TC:1), T2(PI:0,TC:2), X5 (PI:-1)

| Palette Index | Material (M) | Transform | Texture(s) |
|---------------|--------------|-----------|-------------------------------------|
| -1 (Fallback) | M1 | X1*X5 | T0 (TC:0) |
| 0 | M5 | X1*X5 | T0 (TC:0) T1 (TC:1) T2 (TC:2) |
| 1 | M3 | X1*X2*X5 | T0 (TC:0) |

| | | | |
|---|----|----------|-----------|
| | | | T3 (TC:1) |
| 2 | M4 | X1*X5*X3 | T4 (TC:0) |
| 3 | M1 | X1*X4*X5 | T0 (TC:0) |

E.2 PaletteMap Attribute

The PaletteMap attribute maps some or all of the Palette Entries onto the facegroups of a Shape.

Note that even though the PaletteMap is an attribute, its own Palette Index is ignored and must have a value of -1.

Also note that a PaletteMap attribute accumulates (by replacement) down the logical scene graph just like other Attributes. As such it need not be attached directly to a Shape node. It can be placed higher up in the scene graph, for example on a Part Node where all Shapes below it are expected to have the same number of facegroups.

The palette mapping vector is indexed by facegroup number, and contains a Palette Index. The face group geometry will be rendered with the Attribute state obtained by indexing the State Palette with this retrieved Palette Index.

The length of the Palette Map vector must be exactly equal to the number of facegroups in the Shape to which it is applied. If this is not the case, then the PaletteMap is ignored, and the Shape will be rendered using the fallback state as if the PaletteMap did not exist.

- Two values have special significance in the palette mapping vector.
- The value -1 refers to the fallback state.

The value -2 is used to denote that a given facegroup should be inhibited and not rendered at all.

The render-inhibit value affects nothing other than rendering. It does not make the facegroup unpickable, nor does it cause any change to the Node's bounding box, vertex count, or any other quantity.

E.3 Additional information on per face group attributes

Field-final flags, field-inhibit flags, and the force flag all behave as normal for palettized Attributes.

E.4 Addressing Forward Compatibility

To deal with proper forward compatibility as it relates to scenegraph attributes the attribute Sabot is introduced with JT V10.6. See Sabot definition in this document for full details

Annex F

XT B- Rep data segment

The XT B-Rep Segment contains Elements that define the precise geometric Boundary Representation data for a particular Part in XT boundary representation format.

XT B-Rep segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The XT B-Rep Segment type supports LZMA compression on all element data, so all elements in XT B-Rep Segment use the Logical Element Header Compressed form of element header data, as shown in Figure F.1.

F.1XT B-Rep Element

Object Type ID: 0x873a70e0, 0x2ac9, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

XT B-Rep Element represents a particular part's precise data in XT boundary representation format.

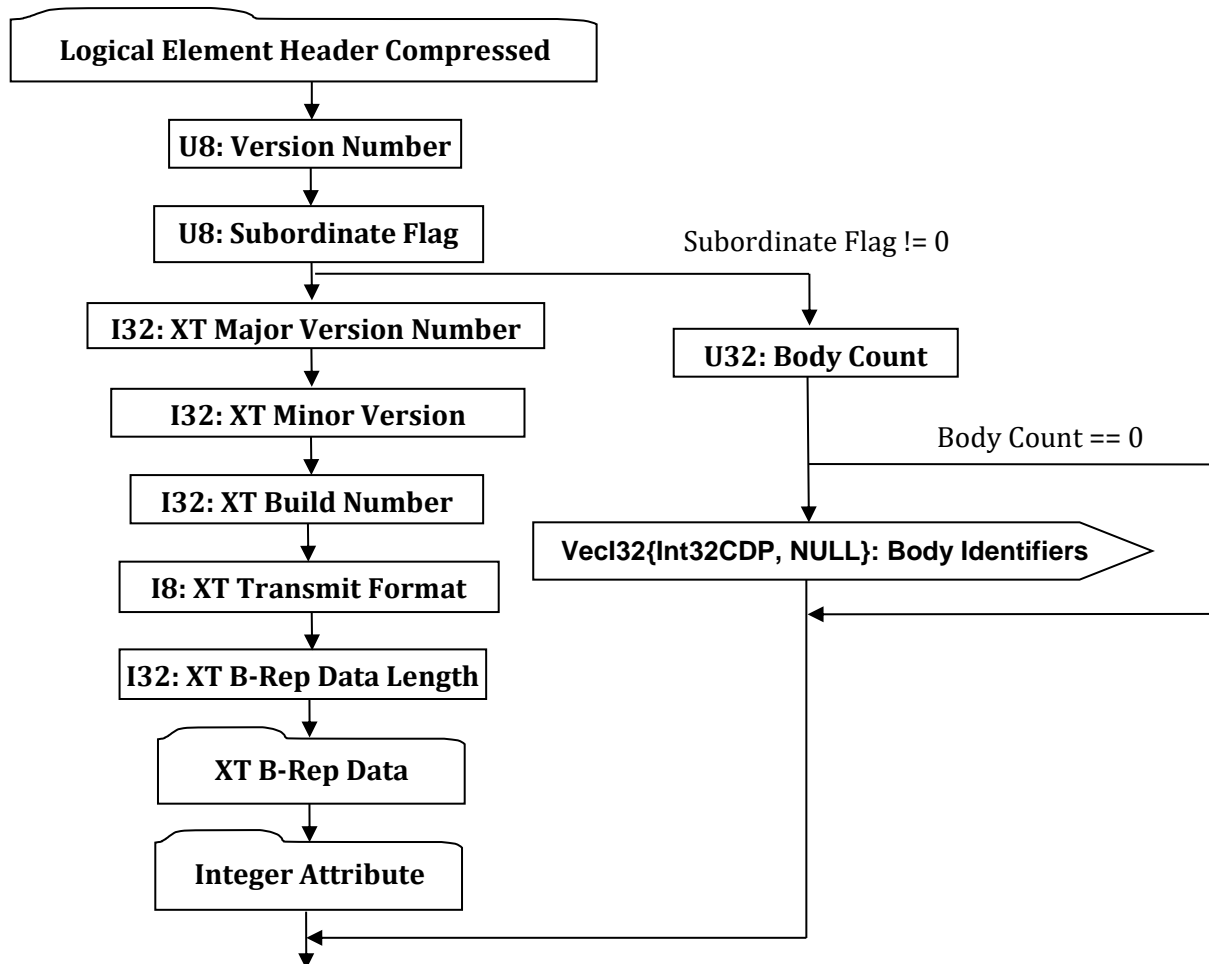


Figure F.1— XT B-Rep Element data collection

Logical Element Header Compressed

A complete description for Logical Element Header Compressed can be found in the File Header section of Base Format Description under Data Segment, Data.

U8: Version Number

Version Number is the version identifier for this XT B-Rep Element. For information on local version numbers see Common Data Conventions and Construct Local version numbers.

U8: Subordinate Flag

The Subordinate Flag indicates if this XT B-Rep Element is subordinate to a MultiXT B-Rep Element. If its value is set to 0, then the segment contains a complete Parasolid data representation and is not subordinate to a MutliXT B-Rep Element description. If the flag is not equal to 0 the XT B-rep description for this segment is defined as a MultiXT B-Rep Element description.

A MultiXT B-Rep Element has a unique Object Type ID and definition. See the MultiXT B-Rep Element data collection definition for the complete description.

I32: XT Major Version Number

XT Major Version Number specifies the major version number for the XT B-Rep data in the JT File. Major version number is an informative field which can be set to 0 without negative impact to implementation.

I32: XT Minor Version Number

XT Minor Version Number specifies the minor version number for the XT B-Rep data in the JT File. Minor version number is an informative field which can be set to 0 without negative impact to implementation.

I32: XT Build Number

XT Build Number specifies the build number for the XT B-Rep data in the JT File. XT build number is an informative field which can be set to 0 without negative impact to implementation.

I8: XT Transmit Format

XT Transmit Format specifies the XT segment transmit format. The XT segment in JT files can only exist as Neutral Binary. To denote Neutral Binary format the XT Transmit Format value must be set to 0.

I32: XT B-Rep Data Length

XT B-Rep Data Length specifies the length in bytes of the XT B-Rep Element collection. An JT file loader/reader may use this information to compute the end position of the XT B-Rep Data within the JT file and thus skip (for whatever reason) reading the remaining XT B-Rep Data.

U32: Body Count

If a subordinate flag is specified the Body Count provides the number of XT bodies in the MultiXT B-Rep Element.

VecI32{Int32CDP, NULL}: Body Identifiers

Body Identifiers is an integer array with its length equal to Body Count. The value of each element in this array represents the persisted identifier of a corresponding XT entity.

This array is a subset of the Body Identifiers array described in MultiXT B-Rep Element, and is used to indicate which XT bodies in the MultiXT B-Rep Element belong to this XT B-Rep Element

XT B-Rep Data

The XT B-Rep Data collection specifies the raw stream of bytes used to represent a Part's XT B-Rep Body(s). For the full description of this stream see the XT B-Rep Data Description in this Annex.

Integer Attribute Data

Integer Attribute Data, as shown in Figure F.2, represents the collection of integer values that may be associated with each face and edge in the XT B-Rep representation.

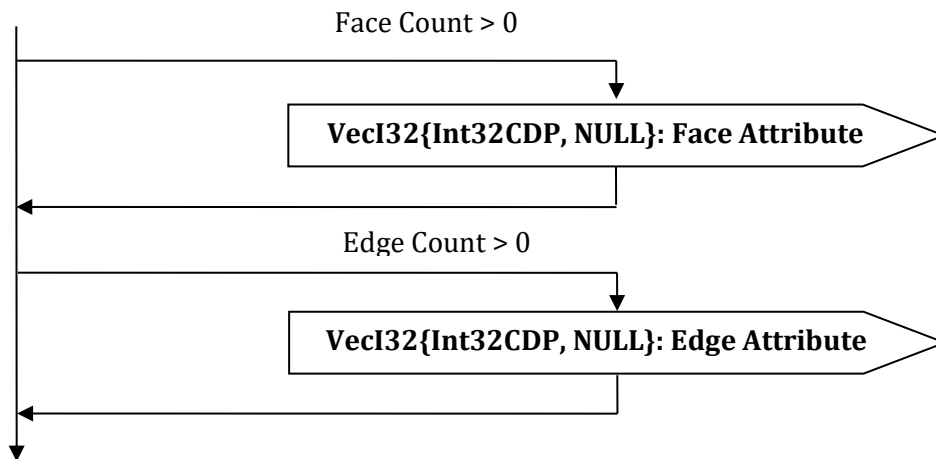


Figure F.2— Integer Attribute Data collection

F.2MultiXT B-Rep-Element

Object Type ID: 0x49829521, 0x1835, 0x49c3, 0x8b, 0xef, 0xdd, 0xc4, 0x3b, 0xfe, 0x5e, 0x88

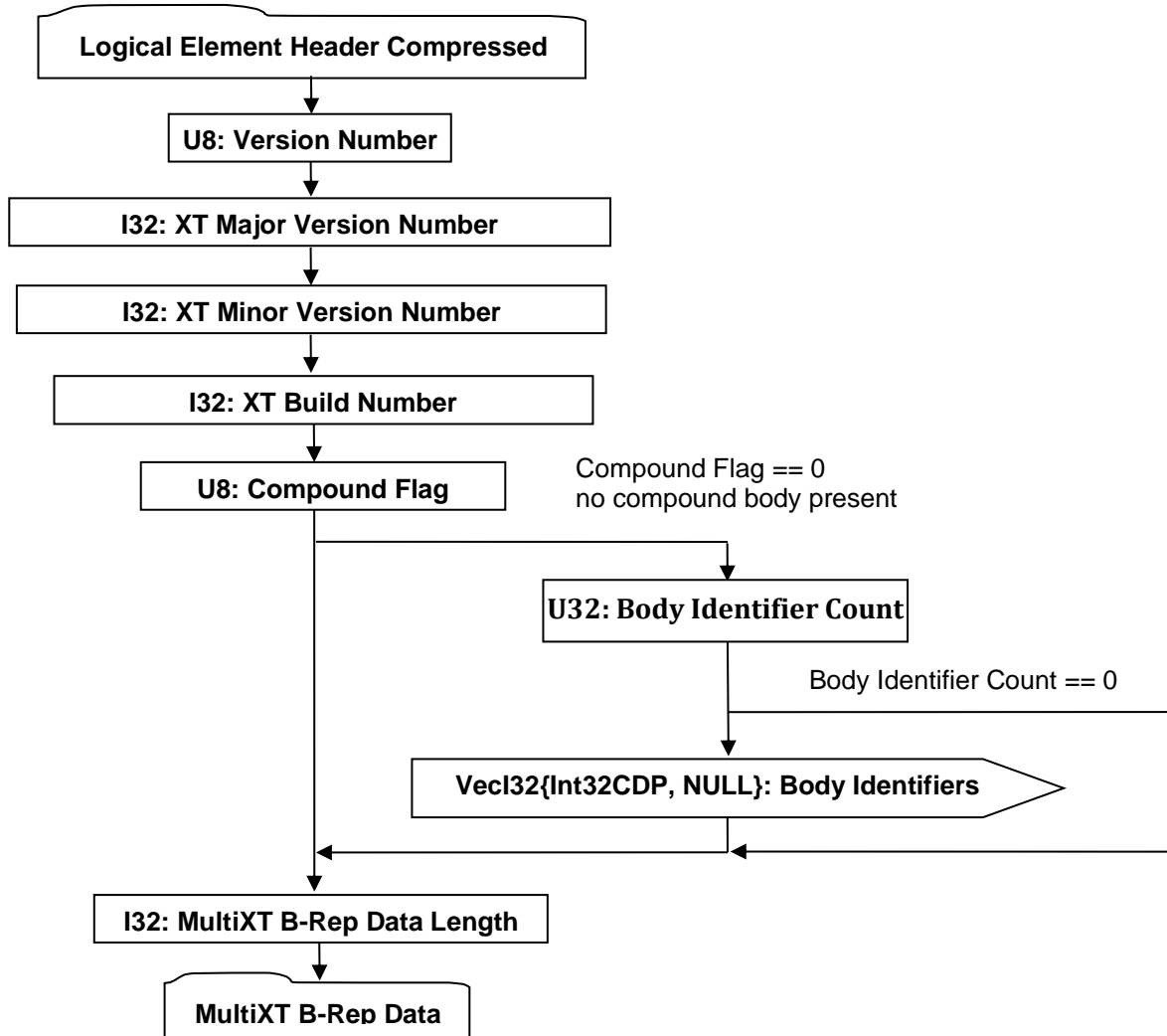
The MultiXT B-Rep Element defines a B-Rep data container for one or more the precise geometric Boundary Representations, from multiple Parts, in XT boundary representation format. The child bodies are expected to be related in some way such that they are able to share some physical aspects.

A MultiXT B-Rep Element includes these child bodies either in a compound body, providing for a more compact file size, or in a body array. In the case of a body array each element is identical to a standard body. Its subordinate XT B-Reps, associated with the Parts, include their associated body identifiers. These body identifiers can be used to acquire their child bodies in the MultiXT B-Rep Element.

MultiXT B-Rep Elements can be referenced by all Part Node Elements (see Part Node Element) that refer to them using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element).

The MultiXT B-Rep Segment type supports LZMA compression on all element data, so all elements in MultiXT B-Rep Segment use the Logical Element Header Compressed form of element header data, as shown in Figure F.3.

Figure F.3— MultiXT B-Rep Element data collection



Logical Element Header Compressed

A complete description for Logical Element Header Compressed can be found in the File Header section of Base Format Description under Data Segment, Data.

U8: Version Number

Version Number is the version identifier for this XT B-Rep Element. For information on local version numbers see Common Data Conventions and Construct Local version numbers.

I32: XT Major Version Number

XT Major Version Number specifies the major version number for the for the XT B-Rep data in the JT File. Major version number is an informative field which can be set to 0 without negative impact to implementation.

I32: XT Minor Version Number

XT Minor Version Number specifies the minor version number for the XT B-Rep data in the JT File. Minor version number is an informative field which can be set to 0 without negative impact to implementation.

I32: XT Build Number

XT Build Number specifies the build number for the XT B-Rep data in the JT File. XT build number is an informative field which can be set to 0 without negative impact to implementation.

U8: Compound Flag

The Compound Flag specifies if the XT Boundary Representation is a compound body.

If the compound flag is not zero, then the XT B-Rep data in MultiXT B-Rep is stored in a compound body. Its child bodies and the associated body identifiers can be retrieved from the compound body. See the Model Structure section found in the XT B-Rep Data Description of this document for a complete description.

If the compound flag is zero, the XT B-Rep data in MultiXT B-Rep is represented in a body array, which is parallel to the body identifier array. Its subordinate XT B-Reps can retrieve their XT B-Rep bodies from MultiXT B-Rep based on the body identifiers found in that array.

U32: Body Identifier Count

Body Identifier Count specifies the number of entity identifiers in this MultiXT B-Rep Element.

VecI32{Int32CDP, NULL} : Body Identifiers

Body Identifiers is an integer array with its length equal to Body Identifier Count. The array is parallel to the XT B-Rep Body array read from MultiXT B-Rep Data, and each element specifies the identifier for the corresponding XT body.

I32: MultiXT B-Rep Data Length

MultiXT B-Rep Data Length specifies the length in bytes of the MultiXT B-Rep Data collection. An JT file loader/reader may use this information to compute the end position of the MultiXT B-Rep Data within the JT file and thus skip (for whatever reason) reading the remaining MultiXT B-Rep Data.

MultiXT B-Rep Data

The MultiXT B-Rep Data collection specifies the raw stream of bytes used to represent XT B-Rep body(s).

If the compound flag is not zero, a compound body is used to represent all the XT B-Rep bodies in the MultiXT B-Rep element. A compound body is a container for child bodies that are expected to have related geometry such that they are able to share physical aspects.

If the compound flag is zero, the MultiXT B-Rep is in split mode and the XT B-Rep bodies are represented in the body array.

For the full description of this stream see the XT B-Rep Data Description in this Annex.

F.3XT B-Rep Data Segment Description

The XT B-Rep data segment in a JT file is a neutral binary definition of the solid body. A proprietary kernel is not required to read the XT B-Rep data segment. The model definition in the XT B-Rep data segment of a JT file is a fully described geometric and topological representation.

F.3.1 Logical Layout

The logical layout of a XT B- Rep data segment is:

- A short flag sequence describing the data format, followed by modeller identification information and user field size.
 - The various flag sequences (mixtures of text and numbers) are documented under 'Physical layout'.
 - The content of the modeller identification information is:
The version of the Parasolid Kernel (if applicable) used to write the data, as a text string of the form:

SCH_3210000_32101

This example above denotes XT data written by the Parasolid Kernel V32.1.00 using schema number 32101.
 - The user field size is a simple integer.
- The objects (known as 'nodes') in the XT data in an unordered sequence, followed by a terminator.
 - Every node in the XT data is assigned an integer index from 1 upwards (some indices may not be used). Pointer fields are output as these indices, or as zero for a null pointer.
 - Each node entry begins with the node type. If the node is of variable length (see below), this is followed by the length of the variable field. The index of the node is then output, followed by the fields of the node.
 - The terminator which follows the sequence of nodes is a two-byte integer with value 1, followed by an index with value 0. The index is output as a 2-byte integer with value 1 in binary XT data.
 - The node with index 1 is the root node of the data as shown in Table F.1:

Table F.1 — Object Nodes

| Contents of XT data | Type of root node |
|---------------------|-------------------|
| Body | BODY |
| Assembly | ASSEMBLY |
| Array of parts | POINTER_LIS_BLOCK |
| Partition | WORLD |

Schema

XT permanent structures are defined in a language akin to C which generates the appropriate files for a C compiler, the runtime information used by the Parasolid Kernel, along with an optional schema file that can be used during transmit and receive. The schema file for version 32100 is named SCH_3210000_32101 and is distributed with the Parasolid kernel. However, it is not necessary for applications reading and writing XT data directly to have a copy of this schema file to understand the XT.

Embedded schemas

XT parts, partitions and deltas can be transmitted with extra information that is intended to replace the schema used to describe the data layout. This information contains the differences between its schema and a defined base schema. The only fields that are included in this information are those which can be referenced in a cut-down version of the schema pertaining only to the XT part data that is present.

Specifically, a full schema definition can contain fields that are not relevant in the context of the transmitted data and these fields are excluded.

Fields that are included are referred to as effective fields, and are either transmittable (`xmt_code == 1`) or have variable-length (`n_elts == 1`).

- Physical layout

Most of the XT data are composed of integers, logical flags, and strings, but are of restricted ranges and so transmitted specially in binary format. The binary representation is given in bold type, such as “integer (byte)”. This is relevant to applications that attempt to read or write XT data directly. Two important elements are

- short strings

These are transmitted as an integer length (byte) followed by the characters (without trailing zero).

- positive integers

These are transmitted similarly to the pointer indices which link individual objects together, therefore, small values 0..32766 are transmitted as a single **short** integer, larger ones encoded into two.

- XT format

Presence of the new format is indicated by a change to the standard header: the archive name is extended by the number of the base schema, for example, SCH_3100000_31000_13006, and then the maximum number of node types is inserted (short).

Transmission then continues as normal, except that when transmitting the first node of any particular type, extra information is inserted between the nodetype and the variable-length, index data as follows:

- The arrays of effective fields in the base schema node and the current schema node are assembled.
- If the nodetype does not exist in the base schema then it is output as follows:
 - number of fields (byte),
 - name and description (short strings), and
 - fields one by one as shown in the Table .F.2, titled “Field types in order by one”

Table F.2 — Field types in order one by one

| Name | Short String | Notes |
|-----------|------------------|---|
| name | pointer | |
| ptr_class | short | |
| n_elts | positive integer | |
| type | short string | The field type. Allowed values are described in “Field types”, below. Omitted if ptr_class non-zero |
| xmt_code | logical (byte) | Omitted for fixed-length (<code>n_elts != 1</code>) |

- If the two arrays match (equal length and all fields match in name, xmt_code, ptr_class, n_elts and type) then output the flag value 255 (byte 0xff).
- If the two arrays do not match, output the number of effective fields in the current schema (byte), and an edit sequence as follows:
 - Initialize pointers to the first base field and first current field, then while there are still unprocessed base and current fields, output a sequence of Copy, Delete and Insert instructions.
 - If the base field matches the current field, output 'C' (char) to indicate an unchanged (Copied) field and advance to the next base and current fields.
 - If the base field does not match any unprocessed current field, output 'D' (char) to indicate a Deleted field and advance to the next base field.
 - Otherwise, output 'I' (char) to indicate an Inserted field, followed by the current field in the above format, and advance to the next current field.
 - If there are any unprocessed current fields, then output an Append sequence, each instruction being 'A' (**char**) followed by the field.
- Finally, output 'Z' (**char**) to signal the end.

- Field types

The XT format is not itself a binary protocol, and so does not define data sizes; the only requirement is that a runtime implementation has sufficient room for the information. The available implementations run with 8bit ASCII characters, 8bit unsigned bytes (0..255), 16bit short integers (0..65535 or -32768..32767), 32bit integers (0..4G-1, -2G..2G-1) and IEEE reals. The implementation used in the given binary XT data is specified by the "PS<code>" at the start of the XT data. See the chapter on "Physical Layout" for more information.

The full list of field types used in XT segment data is as follows:

```

u    unsigned byte 0-255
c    char
l    unsigned byte 0-1 (i.e. logical)
      [1]          typedef char logical;
n    short int
w    unicode character, output as a short int
d    Int
p    pointer-index
      Small indices (less than 32767) are treated specially in binary XT
      data to save space. See the section below on binary format.
f    double
i    These correspond to a region of the real line:
      typedef struct { double low, high; } interval;

v    array [3] of doubles
      These correspond to a 3-space position or direction:
      typedef struct { double x,y,z; } vector;

b    array [6] of doubles
      These correspond to a 3-space region:
      typedef struct { interval x,y,z; } box;

h    array [3] of doubles
      These represent points of intersection between two surfaces; only
      the position vector is written to the XT data. The structure is
      documented further in the section on intersection curves.
```

- Variable-length nodes

Variable-length nodes differ from fixed-length nodes in that their last field is of variable length, therefore different nodes of the same type may have different lengths.

The number of entries in each such node is indicated by an integer in the XT data between its nodetype and index, so an example might be

83 3 15 1 2 3

- Unresolved indices

In some cases a node will contain an index field which does not correspond to a node in the XT data, in this case the index is to be interpreted as zero.

F.3.2 Physical Layout

Binary

The flag sequence is followed by the length of the modeller version as a 2-byte integer, the characters of the modeller version, the length of the schema version as a 4-byte integer, the characters of the schema version, and finally the userfield size as a 4-byte integer.

There are two special numeric values (-32764 for integral values, -3.14158e13 for floating point) which are used to mark an 'unset' or 'null' value.

- Neutral Binary

In the XT Segment neutral binary, data is represented in big-endian format, with IEEE floating point numbers and ASCII characters. The flag sequence is the 4-byte sequence "PS" followed by two zero bytes, therefore, 'P' 'S' '\0' '\0'. The initial letters are ASCII, thus '\120' '\123'. The nodetype at the start of a node is a 2-byte integer, the variable length which may follow it is a 4-byte integer.

Logical values (0,1) are represented as themselves in 1 byte.

Small pointer indices (in the range 0-32766) are implemented as a 2-byte integer, larger indices are represented as a pair, thus:

```
if (index < 32767)
{
    op_short( index + 1 );           // case: small index
    // offset so is > 0
}
else
{
    op_short( -(index % 32767 + 1) ); // case: big index
    // remainder: add 1 so > 0
    op_short( index / 32767 );       // nonzero quotient
}
```

where op_short outputs a 2-byte integer.

The inverse is performed on reading:

```
short q = 0, r;
ip_short( &r );
if (r < 0)
{
    ip_short( &q );
    r = -r;
}
index = q * 32767 + r - 1;
```

where ip_short reads a 2-byte integer.

F.3.3 Model Structure

F.3.3.1 Topology

This section describes the XT Topology model, it gives an overview of how the nodes in the XT data are joined together.

The topological representation allows for:

- non-manifold solids,
- solids with internal partitions,
- bodies of mixed dimension (therefore with wire, sheet, and solid 'bits'),
- pure wire-frame bodies,
- disconnected bodies
- compound bodies
- child bodies
- standard bodies.

Compound bodies are containers for child bodies that are expected to be related in some way such that they are able to share some physical aspects. Within compound bodies, a **child body** is used to define one representation of a part. **Standard** bodies are the basic “unit” of modelling used in XT B-Rep data. A child body is identical to a standard body except that it can share geometry where appropriate with other child bodies within the compound body.

Each entity is described, and its properties and links to other entities given.

F.3.3.2 General points

In this section a set is called finite if it can be enclosed in a ball of finite radius - not that it has a finite number of members.

A set of points in 3-dimensional space is called open if it does not contain its boundary.

Back-pointers, next and previous pointers in a chain, and derived pointers are not described explicitly here. For information on this see the following description of the schema-level model.

Linear and angular resolution

XT data structures use fixed accuracies called linear resolution and angular resolution, which can be described as shown in Table F.3:

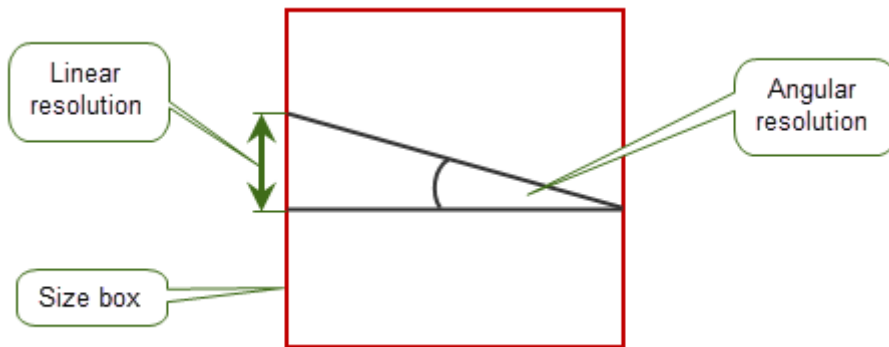
Table F.3 — Description of resolutions

| Resolution | Description |
|--------------------|---|
| Linear resolution | The linear precision. Distances less than this value are considered to be zero and distances that differ by no more than this value are considered to be equal. |
| Angular resolution | The smallest angle (in radians) that is considered to be different from zero. Angles less than this value are considered to be zero and angles that differ by no more than this value are treated as equal. |

By default, in XT data points are not considered coincident unless they are less than $1.0\text{e-}8$ units apart (linear resolution). Directions are considered to be parallel if they differ by less than $1.0\text{e-}11$ radians (angular resolution). You are recommended not to change these values when authoring XT data.

All parts of a body must be within a box called the **size box**, as shown in the figure below, whose size is 1000 by 1000 by 1000 and is centered at the origin.

To handle the angular resolution of arcs correctly, the radius used when representing an arc must be less than a factor of 10 times the dimension of the size box.



F.3.3.3 Entity definitions

Assembly

An assembly is a collection of instances of bodies or assemblies. It may also contain construction geometry. An assembly has the following fields:

- a set of instances, and
- a set of geometry (surfaces, curves and points).

Instance

An instance is a reference to a body or an assembly, with an optional transform:

- Body or assembly.
- Transform. If null, the identity transform is assumed.

Body

A body is a collection of faces, edges and vertices, together with the 3-dimensional connected regions into which space is divided by these entities. Each region is either **solid** or **void** (indicating whether it represents material or not).

The point-set represented by the body is the disjoint union of the point-sets represented by its solid regions, faces, edges, and vertices. This point-set need not be connected, but it shall be finite.

A body has the following fields:

- A set of regions.
A body has one or more regions. These, together with their boundaries, make up the whole of 3-space, and do not overlap, except at their boundaries. One region in the body is distinguished as the exterior region, which shall be infinite; all other regions in the body shall be finite.
- A set of geometry (surfaces, curve and/or points).
- A body-type. This may be wire, sheet, solid or general.

Region

A region is an open connected subset of 3-dimensional space whose boundary is a collection of vertices, edges, and oriented faces.

Regions are either solid or void, and they may be non-manifold. A solid region contributes to the point-set of its owning body; a void region does not (although its boundary will).

Two regions may share a face, one on each side.

A region may be infinite, but a body shall have exactly one infinite region. The infinite region of a body shall be void.

A region has the following fields:

- A logical indicating whether the region is solid.
- A set of shells. The positive shell of a region, if it has one, is not distinguished.

The shells of a region do not overlap or share faces, edges or vertices.

A region may have no shells, in which case it represents all space (and will be the only region in its body, which will have no faces, edges or vertices).

Shell

A shell is a connected component of the boundary of a region. As such it will be defined by a collection of faces, each used by the shell on one 'side', or on both sides; and some edges and vertices.

A shell has the following fields:

- A set of (face, logical) pairs.

Each pair represents one side of a face (where true indicates the front of the face, therefore the side towards which the face normal points), and means that the region to which the shell belongs lies on that side of the face. The same face may appear twice in the shell (once with each orientation), in which case the face is a 2-dimensional cut subtracted from the region which owns the shell.

- A set of wireframe edges.

Edges are called **wireframe** if they do not bound any faces, and so represent 1-dimensional cuts in the shell's region. These edges are not shared by other shells.

- A vertex.

This is only non-null if the shell is an **acorn** shell, therefore it represents a 0-dimensional hole in its region, and has one vertex, no edges and no faces.

A shell shall contain at least one vertex, edge, or face.

Face

A face is an open finite connected subset of a surface, whose boundary is a collection of edges and vertices. It is the 2-dimensional analogy of a region.

A face has the following fields:

- A set of loops. A face may have zero loops (for example a full spherical face), or any number.

- Surface. This may be null, and may be used by other faces.
- Sense. This logical indicates whether the normal to the face is aligned with or opposed to that of the surface.

Loop

A loop is a connected component of the boundary of a face. It is the 2-dimensional analogy of a shell. As such it will be defined by a collection of fins and a collection of vertices.

A loop has the following fields:

- An ordered ring of fins.

Each fin represents the oriented use of an edge by a loop. The sense of the fin indicates whether the loop direction and the edge direction agree or disagree. A loop may not contain the same edge more than once in each direction.

The ordering of the fins represents the way in which their owning edges are connected to each other via common vertices in the loop (therefore nose to tail, taking the sense of each fin into account).

The loop direction is such that the face is locally on the left of the loop, as seen from above the face and looking in the direction of the loop.

- A vertex.

This is only non-null if the loop is an isolated loop, therefore has no fins and represents a 0-dimensional hole in the face.

Consequently, a loop shall consist either of:

- A single fin whose owning ring edge has no vertices, or
- At least one fin and at least one vertex, or
- A single vertex.

Fin

A fin represents the oriented use of an edge by a loop.

A fin has the following fields:

- A logical **sense** indicating whether the fin's orientation (and thus the orientation of its owning loop) is the same as that of its owning edge, or different.
- A curve. This is only non-null if the fin's edge is tolerant, in which case every fin of that edge will reference a trimmed SP-curve. The underlying surface of the SP-curve shall be the same as that of the corresponding face. The curve shall not deviate by more than the edge tolerance from curves on other fins of the edge, and its ends shall be within vertex tolerance of the corresponding vertices.

Edge

An edge is an open finite connected subset of a curve; its boundary is a collection of zero, one or two vertices. It is the 1-dimensional analogy of a region.

An edge has the following fields:

- Start vertex.
- End vertex. If one vertex is null, then so is the other; the edge will then be called a **ring** edge.
- An ordered ring of distinct fins.
- The ordering of the fins represents the spatial ordering of their owning faces about the edge (with a right-hand screw rule, therefore looking in the direction of the edge the fin ordering is clockwise). The edge may have zero or any number of fins; if it has none, it is called a **wireframe** edge.
- A curve. This will be null if the edge has a tolerance. Otherwise, the vertices shall lie within vertex tolerance of this curve, and if it is a Trimmed Curve, they shall lie within vertex tolerance of the corresponding ends of the curve. The curve shall also lie in the surfaces of the faces of the edge, to within modeller resolution.
- Sense. This logical indicates whether the direction of the edge (start to end) is the same as that of the curve.
- A tolerance. If this is null-double, the edge is **accurate** and is regarded as having a tolerance of half the modeller linear resolution, otherwise the edge is called **tolerant**.

Vertex

A vertex represents a point in space. It is the 0-dimensional analogy of a region.

A vertex has the following fields:

- A geometric point.
- A tolerance. If this is null-double, the vertex is **accurate** and is regarded as having a tolerance of half the modeller linear resolution.

Attributes

An attribute is an entity which contains data, and which can be attached to any other entity except attributes, fins, lists, transforms or attribute definitions. An attribute has the following fields:

- Definition. An attribute definition is an entity which defines the number and type of the data fields in a specific type of attribute, which entities may have such an attribute attached, and what happens to the attribute when its owning entity is changed. XT data shall not contain duplicate attribute definitions. Each attribute of a given type should reference the same instance of the attribute definition for that type. It is incorrect, for example, to create a copy of an attribute definition for each instance of the attribute of that type. Only those attribute definitions referenced by attributes in the part occur in the data.
- Owner.
- Fields. These are data fields consisting of one or more integers, doubles, vectors etc.

There are a number of system attribute definitions which may be present in the XT data. These are documented in the section 'System Attribute Definitions'. User attribute definitions can also be created. These are included in the XT data along with any attributes that use them.

Groups

A group is a collection of entities in the same part. Groups in assemblies may contain instances, surfaces, curves and points. Groups in bodies may contain regions, faces, edges, vertices, surfaces, curves and points, loops and other groups. Groups have:

- Owing part.
- A set of member entities.
- Type. The type of the group specifies the allowed type of its members, for example a ‘face’ group in a body may only contain faces, whereas a ‘mixed’ group may have any valid members.

Node-ids

All entities in a part, other than fins and 2D B-curves referenced by SP-curves, have a non-zero integer node-id. All non-zero integer identifiers are unique within a part. This is intended to enable the entity to be identified within the XT data.

F.3.3.4 Entity matrix

Thus the relations between entities can be represented in matrix form as follows in Table F.4. The numbers represent the number of distinct entities connected (either directly or indirectly) to the given one.

Table F.4 — Entity Matrix relations

| | Body | Region | Shell | Face | Loop | Fin | Edge | Vertex |
|--------|------|--------|-------|------|------|-----|------|--------|
| Body | - | >0 | any | any | any | any | any | any |
| Region | 1 | - | any | any | any | any | any | any |
| Shell | 1 | 1 | - | any | any | any | any | any |
| Face | 1 | 1-2 | 1-2 | - | any | any | any | any |
| Loop | 1 | 1-2 | 1-2 | 1 | - | any | any | any |
| Fin | 1 | 1-2 | 1-2 | 1 | 1 | - | 1 | 0-2 |
| Edge | 1 | any | any | any | any | any | any | any |
| Vertex | 1 | any | any | any | any | any | any | - |

F.3.3.5 Representation of manifold bodies

Body types

XT bodies have a field `body_type` which takes values from an enumeration indicating whether the body is:

- **solid**, representing a manifold 3-dimensional volume, possibly with internal voids. It need not be connected;
- **sheet**, representing a 2-dimensional subset of 3-space which is either manifold or manifold with boundary (certain cases are not strictly manifold – see below for details). It need not be connected;
- **wire**, representing a 1-dimensional subset of 3-space which is either manifold or manifold with boundary, and which need not be connected. An **acorn** body, which represents a single 0-dimensional point in space, also has body-type wire;
- **general** - none of the above.

A general body is not necessarily non-manifold, but at the same time it is not constrained to be manifold, connected, or of a particular dimensionality (indeed, it may be of mixed dimensionality).

Restrictions on entity relationships for manifold body types

Solid, sheet, and wire bodies are best regarded as special cases of the topological model; for convenience we call them the manifold body types (although as stated above, a general body may also be manifold).

In particular, bodies of these manifold types shall obey the following constraints:

- An acorn body shall consist of a single void region with a single shell consisting of a single vertex.
- A wire body shall consist of a single void region, with one or more shells, consisting of one or more wireframe edges and zero or more vertices (and no faces). Every vertex in the body shall be used by exactly one or two of the edges (so, in particular, there are no acorn vertices).
- So each connected component will be either: closed, where every vertex has exactly two edges; or open, where all but two vertices have exactly two edges each.
- A wire is called open if all its components are open, and closed if all its components are closed
- Solid and sheet bodies shall each contain at least one face; they may not contain any wireframe edges or acorn vertices.
- A solid body shall consist of at least two regions; at least one of its regions shall be solid. Every face in a solid body shall have a solid region on its negative side and a void region on its positive side (in other words, every face forms part of the boundary of the solid, and the face normals always point away from the solid).
- Every edge in a solid body shall have exactly two fins, which will have opposite senses. Every vertex in a solid body shall either belong to a single isolated loop, or belong to one or more edges; in the latter case, the faces which use those edges shall form a single edgewise-connected set (when considering only connections via the edges which meet at the vertex).
- These constraints ensure that the solid is manifold.
- All the regions of a sheet body shall be void. It is known as an open sheet if it has one region, and a closed sheet if it has no boundary.
- Every edge in a sheet body shall have exactly one or two fins; if it has two, these shall have opposite senses. In a closed sheet body, all the edges will have exactly two fins. Every vertex in a sheet body shall either belong to a single isolated loop, or belong to one or more edges; in the latter case, the faces which use those edges shall either form a single edgewise-connected set where all the edges involved have exactly two fins, or any number of edgewise-connected sets, each of which shall involve exactly two edges with one fin each (again, considering only connections via the edges which meet at the vertex).

Note that, although the constraints on edges and vertices in a sheet body are very similar to those which apply to a solid, in this case they do not guarantee that the body will be manifold; indeed, the rather complicated rules about vertices in an open sheet body specifically allow bodies which are non-manifold (such as a body consisting of two square faces which share a single corner vertex).

F.3.3.6 Schema Definition

Underlying types

```
union CURVE_OWNER_u
{
    struct EDGE_s          *edge;
    struct FIN_s           *fin;
    struct BODY_s          *body;
    struct ASSEMBLY_s      *assembly;
    struct WORLD_s         *world;
};

union SURFACE_OWNER_u
{
    struct FACE_s          *face;
    struct BODY_s          *body;
    struct ASSEMBLY_s      *assembly;
    struct WORLD_s         *world;
};

union ATTRIB_GROUP_u
{
    struct ATTRIBUTE_s     *attribute;
    struct GROUP_s         *group;
};
```

```

        struct MEMBER_OF_GROUP_s      *member_of_group;
    };
typedef union ATTRIB_GROUP_u  ATTRIB_GROUP;

```

F.3.4 Geometry

```

union CURVE_u
{
    struct LINE_s          *line;
    struct CIRCLE_s        *circle;
    struct ELLIPSE_s        *ellipse;
    struct INTERSECTION_s  *intersection;
    struct TRIMMED_CURVE_s *trimmed_curve;
    struct PE_CURVE_s       *pe_curve;
    struct B_CURVE_s        *b_curve;
    struct SP_CURVE_s       *sp_curve;
    struct POLYLINE_s       *polyline;
};
typedef union CURVE_u      CURVE;

union SURFACE_u
{
    struct PLANE_s          *plane;
    struct CYLINDER_s       *cylinder;
    struct CONE_s           *cone;
    struct SPHERE_s         *sphere;
    struct TORUS_s          *torus;
    struct BLENDED_EDGE_s   *blended_edge;
    struct BLEND_BOUND_s    *blend_bound;
    struct OFFSET_SURF_s    *offset_surf;
    struct SWEEP_SURF_s     *sweep_surf;
    struct SPUN_SURF_s      *spun_surf;
    struct PE_SURF_s        *pe_surf;
    struct B_SURFACE_s      *b_surface;
    struct MESH_s           *mesh;
};
typedef union SURFACE_u    SURFACE;

union GEOMETRY_u
{
    union SURFACE_u          surface;
    union CURVE_u            curve;
    struct POINT_s           *point;
    struct TRANSFORM_s       *transform;
};
typedef union GEOMETRY_u   GEOMETRY;

```

F.3.4.1 Curves

In the following field tables, ‘pointer0’ means a reference to another node which may be null. ‘pointer’ means a non-null reference.

All curve nodes share the following common fields, as shown in Table F.5:

Table F.5 — Curve node common fields

| Field name | Data type | Description |
|-------------------|-----------|---|
| node_id | int | Integer value unique to curve in part |
| attributes_groups | pointer0 | Attributes and groups associated with curve |
| owner | pointer0 | topological owner |
| next | pointer0 | next curve in geometry chain |

| | | |
|-----------------|----------|--|
| previous | pointer0 | previous curve in geometry chain |
| geometric_owner | pointer0 | geometric owner node |
| sense | char | sense of curve: '+' or '-' (see end of Geometry section) |

```

struct ANY_CURVE_s          // Any Curve
{
    int                     node_id;                // $d
    union ATTRIB_GROUP_u    attributes_groups;      // $p
    union CURVE_OWNER_u     owner;                  // $p
    union CURVE_u           next;                   // $p
    union CURVE_u           previous;               // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;      // $p
    char                    sense;                  // $c
};
typedef struct ANY_CURVE_s *ANY_CURVE;

```

- Line

A straight line, as represented in Table F.6, has a parametric representation of the form:

$$R(t) = P + t D$$

where

- P is a point on the line.
- D is its direction.

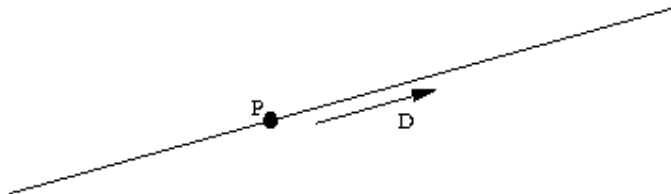


Table F.6 — Line Fields

| Field name | Data type | Description |
|------------|-----------|---------------------------------------|
| pvec | vector | point on the line |
| direction | vector | direction of the line (a unit vector) |

```

struct LINE_s == ANY_CURVE_s    // Straight line
{
    int                     node_id;                // $d
    union ATTRIB_GROUP_u    attributes_groups;      // $p
    union CURVE_OWNER_u     owner;                  // $p
    union CURVE_u           next;                   // $p
    union CURVE_u           previous;               // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;      // $p
    char                    sense;                  // $c
    vector                  pvec;                   // $v
    vector                  direction;              // $v
};
typedef struct LINE_s          *LINE;

```

- Circle

A circle, as represented in Table F.7, has a parametric representation of the form

$$R(t) = C + r X \cos(t) + r Y \sin(t)$$

Where

- C is the centre of the circle.
- r is the radius of the circle.
- X and Y are the axes in the plane of the circle.

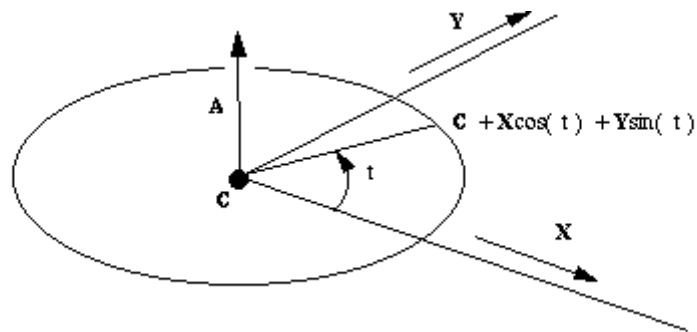


Table F.7 — Circle fields

| Field name | Data type | Description |
|------------|-----------|---|
| centre | vector | Centre of circle |
| normal | vector | Normal to the plane containing the circle (a unit vector) |
| x_axis | vector | X axis in the plane of the circle (a unit vector) |
| radius | double | Radius of circle |

The Y axis in the definition above is the vector cross product of the normal and x_axis.

```
struct CIRCLE_s == ANY_CURVE_s // Circle
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    union CURVE_OWNER_u owner; // $p
    union CURVE_u next; // $p
    union CURVE_u previous; // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    char sense; // $c
    vector centre; // $v
    vector normal; // $v
    vector x_axis; // $v
    double radius; // $f
};
typedef struct CIRCLE_s *CIRCLE;
```

- Ellipse

An ellipse, as represented in Table F.8, has a parametric representation of the form

$$R(t) = C + a X \cos(t) + b Y \sin(t)$$

where

- C is the centre of the circle.
- X is the major axis.
- r is the major radius.
- Y and b are the minor axis and minor radius respectively.

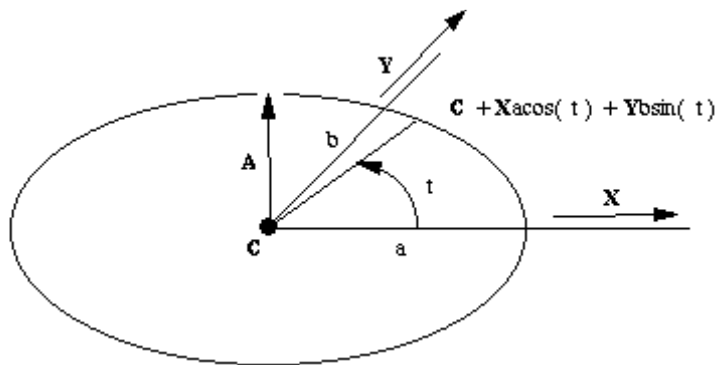


Table F.8 — Ellipse fields

| Field name | Data type | Description |
|--------------|-----------|--|
| centre | Vector | Centre of ellipse |
| normal | Vector | Normal to the plane containing the ellipse (a unit vector) |
| x_axis | Vector | major axis in the plane of the ellipse (a unit vector) |
| major_radius | Double | major radius |
| minor_radius | Double | minor radius |

The minor axis (Y) in the definition above is the vector cross product of the normal and x_axis.

```

struct ELLIPSE_s == ANY_CURVE_s      // Ellipse
{
    int          node_id;              // $d
    union ATTRIB_GROUP_u      attributes_groups; // $p
    union CURVE_OWNER_u      owner;    // $p
    union CURVE_u      next;          // $p
    union CURVE_u      previous;      // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    vector      centre;              // $v
    char        sense;              // $c
    vector      normal;              // $v
    vector      x_axis;              // $v
    double      major_radius;        // $f
    double      minor_radius;        // $f
};
typedef struct ELLIPSE_s      *ELLIPSE;

```

- B_CURVE (B-spline curve)

XT supports B spline curves in full NURBS format. The mathematical description of these curves is:

- Non Uniform Rational B-splines as (NURBS), and

$$P(t) = \frac{\sum_{i=0}^{n-1} b_i(t)w_iV_i}{\sum_{i=0}^{n-1} b_i(t)w_i}$$

— the more simple Non Uniform B-spline

$$P(t) = \sum_{i=0}^{n-1} b_i(t)V_i$$

— Where:

n = number of vertices ($n_vertices$ in the PK standard form)

$V_0 \dots V_{n-1}$ are the B-spline vertices

$w_0 \dots w_{n-1}$ are the weights

$b_i(t), i = 0 \dots n-1$ are the B-spline basis functions

Knot Vectors

The parameter t above is global. The user supplies an ordered set of values of t at specific points. The points are called knots and the set of values of t is called the knot vector. Each successive value in the set shall be greater than or equal to its predecessor. Where two or more such values are the same we say that the knots are coincident, or that the knot has multiplicity greater than 1. In this case it is best to think of the knot set as containing a null or zero length span. The principal use of coincident knots is to allow the curve to have less continuity at that point than is formally required for a spline. A curve with a knot of multiplicity equal to its *degree* can have a discontinuity of first derivative and hence of tangent direction. This is the highest permitted multiplicity except at the first or last knot where it can go as high as $(degree+1)$.

In order to avoid problems associated, for example with rounding errors in the knot set, XT stores an array of distinct values and an array of integer multiplicities.

Most algorithms in the literature, and the following discussion refer to the expanded knot set in which a knot of multiplicity n appears explicitly n times.

The Number of Knots and Vertices

The knot set determines a set of basis functions which are bell shaped, and non-zero over a span of $(degree+1)$ intervals. One basis function starts at each knot, and each one finishes $(degree + 1)$ knots higher. The control vectors are the coefficients applied to these basis functions in a linear sum to obtain positions on the curve. Thus it can be seen that we require the number of knots $n_knots = n_vertices + degree + 1$.

The Valid Range of the B-curve

So if the knot set is numbered $\{t_0$ to $t_{n_knots-1}\}$ it can be seen then that it is only after t_{degree} that sufficient $(degree + 1)$ basis functions are present for the curve to be fully defined, and that the B-curve ceases to be fully defined after $t_{n_knots - 1 - degree}$.

The first *degree* knots and the last *degree* knots are known as the imaginary knots because their parameter values are outside the defined range of the B-curve.

Periodic B-curves

When the end of a B-curve meets its start sufficiently smoothly XT allows it to be defined to have periodic parametrization. That is to say that if the valid range were from t_{degree} to $t_{n_knots} - 1 - \text{degree}$ then the difference between these values is called the period and the curve can continue to be evaluated with the same point reoccurring every period.

The minimal smoothness requirement for periodic curves in XT is tangent continuity, but we strongly recommend $C_{\text{degree}-1}$, or continuity in the $(\text{degree}-1)^{\text{th}}$ derivative. This in turn is best achieved by repeating the first *degree* vertices at the end, and by matching knot intervals so that counting from the start of the defined range, t_{degree} , the first *degree* intervals between knots match the last *degree* intervals, and similarly matching the last *degree* knot intervals before the end of the defined range to the first *degree* intervals.

Closed B-curves

A periodic B-curve shall also be closed, but is permitted to have a closed Bcurve that is not periodic.

In this case the rules for continuity are relaxed so that only C_0 or positional continuity is required between the start and end. Such closed non-periodic curves are not able to be attached to topology.

Rational B-curve

In the rational form of the curve, each vertex is associated with a weight, which increases or decreases the effect of the vertex without changing the curve hull. To ensure that the convex hull property is retained, the curve equation is divided by a denominator which makes the coefficients of the vertices sum to one.

$$P(t) = \frac{\sum_{i=0}^{n-1} b_i(t)w_iV_i}{\sum_{i=0}^{n-1} b_i(t)w_i}$$

Where $w_0 \dots w_{n-1}$ are weights.

Each weight may take any positive value, and the larger the value, the greater the effect of the associated vertex. However, it is the relative sizes of the weights which is important, as may be seen from the fact that in the equation given above, all the weights may be multiplied by a constant without changing the equation.

In XT the weights are stored with the vertices by treating these as having an extra dimension. In the usual case of a curve in 3-d cartesian space this means that vertex_dim is 4, the x, y, z values are multiplied through by the corresponding weight and the 4th value is the weight itself.

```
struct B_CURVE_s == ANY_CURVE_s // B curve
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    union CURVE_OWNER_u owner; // $p
    union CURVE_u next; // $p
    union CURVE_u previous; // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    char sense; // $c
    struct NURBS_CURVE_s *nurbs; // $p
    struct CURVE_DATA_s *data; // $p
};
typedef struct B_CURVE_s *B_CURVE;
```

The data stored in the XT data for a NURBS_CURVE is shown in Table F.9:

Table F.9 — NURB curve fields

| Field name | Data type | Description |
|------------------|-----------|--------------------------------------|
| degree | Short | degree of the curve |
| n_vertices | Int | number of control vertices ('poles') |
| vertex_dim | Short | dimension of control vertices |
| n_knots | Int | number of distinct knots |
| knot_type | Byte | form of knot vector |
| periodic | Logical | true if curve is periodic |
| closed | Logical | true if curve is closed |
| rational | Logical | true if curve is rational |
| curve_form | Byte | shape of curve, if special |
| bspline_vertices | Pointer | control vertices node |
| knot_mult | Pointer | knot multiplicities node |
| knots | Pointer | knots node |

The knot_type enum is used to describe whether or not the knot vector has a certain regular spacing or other common property:

```
typedef enum
{
    SCH_unset = 1,           // Unknown
    SCH_non_uniform = 2,     // Known to be not special
    SCH_uniform = 3,         // Uniform knot set
    SCH_quasi_uniform = 4,   // Uniform apart from bezier ends
    SCH_piecewise_bezier = 5, // Internal multiplicity of order-1
    SCH_bezier_ends = 6     // Bezier ends, no other property
}
SCH_knot_type_t;
```

A uniform knot set is one where all the knots are of multiplicity one and are equally spaced. A curve has bezier ends if the first and last knots both have multiplicity 'order'.

The curve_form enum describes the geometric shape of the curve. The parameterization of the curve is not relevant.

```
typedef enum
{
    SCH_unset = 1,           // Form is not known
    SCH_arbitrary = 2,       // Known to be of no particular shape
    SCH_polyline = 3,
    SCH_circular_arc = 4,
    SCH_elliptic_arc = 5,
    SCH_parabolic_arc = 6,
    SCH_hyperbolic_arc = 7
}
SCH_curve_form_t;

struct NURBS_CURVE_s           // NURBS curve
{
```



```

short          degree;                // $n
int            n_vertices;            // $d
short          vertex_dim;            // $n
int            n_knots;               // $d
SCH_knot_type_t knot_type;            // $u
logical        periodic;              // $l
logical        closed;                // $l
logical        rational;              // $l
SCH_curve_form_t curve_form;          // $u
struct BSPLINE_VERTICES_s *bspline_vertices; // $p
struct KNOT_MULT_s *knot_mult;        // $p
struct KNOT_SET_s *knots;             // $p
};
typedef struct NURBS_CURVE_s *NURBS_CURVE;

```

The bspline vertices node is simply an array of doubles; 'vertex_dim' doubles together define one control vertex. Thus the length of the array is $n_vertices * vertex_dim$.

```

struct BSPLINE_VERTICES_s          // B-spline vertices
{
    double          vertices[ 1 ];    // $f[]
};
typedef struct BSPLINE_VERTICES_s *BSPLINE_VERTICES;

```

The knot vector of the NURBS_CURVE is stored as an array of distinct knots and an array describing the multiplicity of each distinct knot. Hence the two nodes

```

struct KNOT_SET_s                  // Knot set
{
    double          knots[ 1 ];       // $f[]
};
typedef struct KNOT_SET_s *KNOT_SET;

```

and

```

struct KNOT_MULT_s                // Knot multiplicities
{
    short          mult[ 1 ];         // $n[]
};
typedef struct KNOT_MULT_s *KNOT_MULT;

```

The data stored in the XT data for a CURVE_DATA node is:

```

typedef enum
{
    SCH_unset = 1,                // check has not been performed
    SCH_no_self_intersections = 2, // passed checks
    SCH_self_intersects = 3,       // fails checks
    SCH_checked_ok_in_old_version = 4 // see below
}
SCH_self_int_t;

struct CURVE_DATA_s              // curve_data
{
    SCH_self_int_t          self_int;          // $u
    Struct HELIX_CU_FORM_s *analytic_form      // $p
};
typedef struct CURVE_DATA_s *CURVE_DATA;

```

The self-intersection enum describes whether or not the geometry has been checked for self-intersections, and whether such self-intersections were found to exist:

If the `analytic_form` field is not null, it will point to a `HELIX_CU_FORM` node, which indicates that the curve has a helical shape, as follows:

```
struct HELIX_CU_FORM_s
{
    vector          axis_pt          // $v
    vector          axis_dir         // $v
    vector          point            // $v
    char            hand              // $c
    interval        turns            // $i
    double          pitch            // $f
    double          tol              // $f
};
typedef struct HELIX_CU_FORM_s *HELIX_CU_FORM;
```

The `axis_pt` and `axis_dir` fields define the axis of the helix. The `hand` field is '+' for a right-handed and '-' for a left-handed helix. A representative point on the helix is at turn position zero. The `turns` field gives the extent of the helix relative to the point. For instance, an interval [0 10] indicates a start position at the point and an end 10 turns along the axis. Pitch is the distance travelled along the axis in one turn. Tol is the accuracy to which the owning bcurve fits this specification.

- Intersection

An intersection curve is one of the branches of a surface / surface intersection. XT represents these curves exactly; the information held in an intersection curve node is sufficient to identify the particular intersection branch involved, to identify the behaviour of the curve at its ends, and to evaluate precisely at any point in the curve. Specifically, the data is:

- The two surfaces involved in the intersection.
- The two ends of the intersection curve. These are referred to as the 'limits' of the curve. They identify the particular branch involved.
- An ordered array of points along the curve. This array is referred to as the 'chart' of the curve. It defines the parameterisation of the curve, which increases as the array index increases.
- The natural tangent to the curve at any point (therefore in the increasing parameter direction) is given by the vector cross-product of the surface normals at that point, taking into account the senses of the surfaces.

Singular points where the cross-product of the surface normals is zero, or where one of the surfaces is degenerate, are called terminators. Intersection curves do not contain terminators in their interior. At terminators, the tangent to the curve is defined by the limit of the curve tangent as the curve parameter approaches the terminating value.

| Field Name | Data Type | Description |
|-------------------|-------------------|---|
| surface | pointer array [2] | surfaces of intersection curve |
| chart | Pointer | array of hvecs on the curve – see below |
| start | Pointer | start limit of the curve |
| end | Pointer | end limit of the curve |
| intersection_data | Pointer | Optional structure for storing additional information associated with an intersection curve |

```

struct INTERSECTION_s == ANY_CURVE_s // Intersection
{
int node_id;                // $d
union ATTRIB_GROUP_u        attributes_groups;        // $p
union CURVE_OWNER_u         owner;                    // $p
union CURVE_unext;           // $p
union CURVE_uprevious;       // $p
struct GEOMETRIC_OWNER_s    *geometric_owner;         // $p
char sense;                 // $c
union SURFACE_u             surface[ 2 ];              // $p[2]
struct CHART_s              *chart;                   // $p
struct LIMIT_s              *start;                   // $p
struct LIMIT_s              *end;                     // $p
nolog struct INTERSECTION_DATA *intersection_data      // $p
};
typedef struct INTERSECTION_s *INTERSECTION;

```

A point on an intersection curve is stored in a data structure called an hvec (hepta-vec, or 7- vector):

```

typedef struct hvec_s        // hepta_vec
{
vector          Pvec;        //position

double double    u[2];       //surface parameters
                  v[2];

vector          Tangent;     //curve tangent

double          t;          //curve parameter
} hvec;

```

Where

- pvec is a point common to both surfaces;
- u[] and v[] are the u and v parameters of the pvec on each of the surfaces;
- tangent is the tangent to the curve at pvec. This will be equal to the (normalized) vector cross product of the surface normals at pvec, when this cross product is non-zero. These surface normals take account of the surface sense fields;
- t is the parameter of the pvec on the curve.

Note: Only the pvec part of an hvec is actually transmitted.

The chart data structure essentially describes a piecewise-linear (chordal) approximation to the true curve. As well as containing the ordered array of hvecs defining this approximation, it contains extra information pertaining to the accuracy of the approximation:

```

struct CHART_s              //Chart
{
double                    Base_parameter;              // $f
double                    Base_scale;                  // $f
int                       Chart_count;                 // $d
double                    Chordal_error;               // $f
double                    Angular_error;               // $f
double                    Parameter_error[2];          // $f[2]
hvec                      Hvec[ 1 ];                  // $h[]
};
typedef struct CHART_s *CHART;

```

Where

- base_parameter is the parameter of the first hvec in the chart;
- base_scale determines the scale of the parameterization (see below);

- `chart_count` is the length of the `hvec` array;
- `chordal_error` is an estimate of the maximum deviation of the curve from the piecewise- linear approximation given by the `hvec` array. It may be null;
- `angular_error` is the maximum angle between the tangents of two sequential `hvecs`. It may be null;
- `parameter_error[]` is always `[null, null]`;
- `hvec[]` is the ordered array of `hvecs`.

The limits of the intersection curve are stored in the following data structure:

```
struct LIMIT_s                                // Limit
{
    Char type;                                // $c
    Hvec hvec[1];                             // $h[]
};
typedef struct LIMIT_s *LIMIT;
```

The 'type' field may take one of the following values

```
const char SCH_help          = 'H';           // help hvec
const char SCH_terminator    = 'T';           // terminator
const char SCH_limit         = 'L';           // arbitrary limit
const char SCH_boundary      = 'B';           // spine boundary
```

The length of the `hvec` array depends on the type of the limit

- a `SCH_help` limit is an arbitrary point on a closed intersection curve. There will be one `hvec` in the `hvec` array, locating the curve.
- a `SCH_terminator` limit is a point where one of the surface normals is degenerate, or where their cross-product is zero. Typically, there will be more than one branch of intersection between the two surfaces at these singularities. There will be two values in the `hvec` array. The first will be the exact position of the singularity, and the second will be a point on the curve a small distance away from the terminator. This 'branch point' identifies which branch relates to the curve in question. The branch point is the one which appears in the chart, at the corresponding end – so the singularity lies just outside the parameter range of the chart.
- a `SCH_limit` limit is an artificial boundary of an intersection curve on an otherwise potentially infinite branch. The single `hvec` describes the end of the curve.
- a `SCH_boundary` limit is used to describe the end of a degenerate rolling-ball blend. It is not relevant to intersection curves.

The parameterisation of the curve is given as follows. If the chart points are P_i , $i = 0$ to n , with parameters t_i , and natural tangent vectors T_i , then define

$$C_i = | P_{i+1} - P_i |$$

$$\cos(a_i) = T_i \cdot (P_{i+1} - P_i) / C_i$$

$$\cos(b_i) = T_i \cdot (P_i - P_{i-1}) / C_{i-1}$$

Then at any chart point P_i the angles a_i and b_i are the deviations between the tangent at the chart point and the next and previous chords respectively.

```
Let f0 = base_scale
    fi = (cos(bi) / cos(ai)) fi-1
Then t0 = base_parameter
    ti = ti-1 + Ci-1 fi-1
```

The factors f_i are chosen so that the parameterisation is C1. The parameter of a point between two chart points is given by projecting the point onto the chord between the previous and next chart point. The point on the intersection curve corresponding to a given parameter is defined as follows:

- For a parameter equal to that of a chart point, it is the position of the chart point.
- For a parameter interior to the chart, it is the local point of intersection of three surfaces: the two surfaces of the intersection, and a plane defined by the chart. If the parameter t lies between chart parameters t_i, t_{i+1} , then the chord point corresponding to t lies at

$$(t_{i+1} - t) / (t_{i+1} - t_i) P_i + (t - t_i) / (t_{i+1} - t_i) P_{i+1}$$

The plane lies through this point and is orthogonal to the chord (P_{i+1}, P_i) .

For a parameter between a branch chart point and a terminator, it is the local point of intersection of three surfaces: one of the intersection surfaces and two planes. Surface[0] is used unless it is singular at the terminator and surface[1] is not singular at the terminator. The first plane contains the chord between the branch and the terminator, and the normal of the chosen intersection surface at the terminator or the curve tangent at the branch chart point if the surface normal cannot be defined. The second plane is the plane orthogonal to the chord between the branch and terminator points through the chord point as calculated above.

The `intersection_data` node is an optional structure for storing surface uv parameters from hvecs that are associated with an intersection curve.

Note: The `intersection_data` must match the hvecs.

```
logged struct INTERSECTION_DATA_s          //Intersection data
{
SCH_intersection_uv_type_t uv_type;      //$u
double values [1]; ---$f[]
};
typedef struct INTERSECTION_DATA_s*INTERSECTION_DATA;
inline double *SCH_INTERSECTION_DATA_values(INTERSECTION_DATA self)
{
return self -> values;
}
SCH_define_init_fn_m(INTERSECTION_DATA_s, self,
                    self -> uv_type = SCH_intersection_uv_none;
                    double*values    = SCH_INTERSECTION_DATA_values(self);
                    for (int i = 0; i< n_variable; ++i)
                        values [i] = null;
)
```

The `intersection_data` node contains an enum value and a variable length double array. The enum value specifies the uv values stored in the values array and is set based on the following:

```
typedef short short enum
{
SCH_intersection_uv_none =1,
SCH_intersection_uv_first =2,
SCH_intersection_uv_second=3,
SCH_intersection_uv_both=4,
}
SCH_intersection_uv_type_t;
char *SCH_intersection_uv_type_sprintf
```

The uv values are converted to the number of parameters which are stored for each chart hvec as follows:

- If SCH_intersection_uv_none, the number of parameters is 0
- If SCH_intersection_uv_first or SCH_intersection_uv_second, the number of parameters is 2
- If SCH_intersection_uv_both, the number of parameters is 4

The variable length double array contains these parameters, and the start and end limits. The values for the start and end limits can be found in the variable length arrays in the LIMIT start, and LIMIT end fields of the INTERSECTION node.

The number of values in the double array is calculated as:

(The number of chart points + The number of terminator limits) * (The number of parameters per hvec)

For each terminator present in the array the number of values will increase by 0, 2, or 4 depending on the intersection_uv_type field. For example, if both the start and the end limits are terminators and the intersection_uv_type is set to SCH_intersection_uv_both the value will increase by 8.

The order of values in the array is as follows:

If the start limit is a terminator:

| If the intersection_uv_type is... | The order of values in array is... |
|-----------------------------------|---|
| SCH_intersection_uv_first or | intersection node ->start->hvec[0].u[0] |
| SCH_intersection_uv_both | intersection node ->start->hvec[0].v[0] |
| SCH_intersection_uv_second or | intersection node ->start->hvec[0].u[1] |
| SCH_intersection_uv_both | intersection node ->start->hvec[0].v[1] |

For each hvec in the chart:

| If the intersection_uv_type is... | The order of values in array is... |
|-----------------------------------|--|
| SCH_intersection_uv_first or | intersection node->chart->hvec[i].u[0] |
| SCH_intersection_uv_both | intersection node->chart->hvec[i].v[0] |
| SCH_intersection_uv_second or | intersection node->chart->hvec[i].u[1] |
| SCH_intersection_uv_both | intersection node->chart->hvec[i].v[1] |

chart hvecs are wrapped in a loop where i = 0 to the (number of chart hvecs -1).If end limit is a terminator:

| If the intersection_uv_type is... | The order of values in array is... |
|-----------------------------------|--------------------------------------|
| SCH_intersection_uv_first or | intersection node->end->hvec[0].u[0] |
| SCH_intersection_uv_both | intersection node->end->hvec[0].v[0] |
| SCH_intersection_uv_second or | intersection node->end->hvec[0].u[1] |
| SCH_intersection_uv_both | intersection node->end->hvec[0].v[1] |

- Trimmed curve

A trimmed curve is a bounded region of another curve, referred to as its basis curve. It is defined by the basis curve and two points and their corresponding parameters. Trimmed curves are most commonly attached to fins (fins) of tolerant edges in order to specify which portion of the underlying basis curve corresponds to the tolerant edge. They are necessary since the tolerant vertices of the edge do not necessarily lie exactly on the basis curve; the 'point' fields of the trimmed curve lie exactly on the basis curve, and within tolerance of the relevant vertex.

The rules governing the parameter fields and points are:

- point_1 and point_2 correspond to parm_1 and parm_2 respectively.
- If the basis curve has positive sense, $\text{parm}_2 > \text{parm}_1$.
- If the basis curve has negative sense, $\text{parm}_2 < \text{parm}_1$.

In addition,

For open basis curves.

- Both parm_1 and parm_2 shall be in the parameter range of the basis curve.
- point_1 and point_2 shall not be equal.

For periodic basis curves.

- parm_1 shall lie in the base range of the basis curve.
- If the whole basis curve is required then parm_1 and parm_2 should be a period apart and point_1 = point_2. Equality of parm_1 and parm_2 is not permitted.
- parm_1 and parm_2 shall not be more than a period apart.

For closed but non-periodic basis curves.

- Both parm_1 and parm_2 shall be in the parameter range of the basis curve.
- If the whole of the basis curve is required, parm_1 and parm_2 shall lie close enough to each end of the valid parameter range in order that point_1 and point_2 are coincident to XT tolerance (1.0e-8 by default).

The sense of a trimmed curve is positive, as shown in Table F.10.

Table F.10 — Trimmed curve fields

| Field name | Data type | Description |
|-------------|-----------|---|
| basis_curve | pointer | Basis curve |
| point_1 | vector | start of trimmed portion |
| point_2 | vector | end of trimmed portion |
| parm_1 | double | parameter on basis curve corresponding to point_1 |
| parm_2 | double | parameter on basis curve corresponding to point_2 |

```

struct TRIMMED_CURVE_s == ANY_CURVE_s           // Trimmed Curve
{
    int node_id;                                // $d
    union ATTRIB_GROUP_u attributes_groups;      // $p
    union CURVE_OWNER_u owner;                  // $p
    union CURVE_u next;                          // $p
    union CURVE_u previous;                      // $p
}

```

```

    struct GEOMETRIC_OWNER_s      *geometric_owner;           // $p
    char                          sense;                        // $c
    union CURVE_u                  basis_curve;                // $p
    vector                        point_1;                      // $v
    vector                        point_2;                      // $v
    double                        parm_1;                       // $f
    double                        parm_2;                       // $f
};
typedef struct TRIMMED_CURVE_s    *TRIMMED_CURVE;

```

- SP_curve

An SP curve is the 3D curve resulting from embedding a 2D curve in the parameter space of a surface.

The 2D curve shall be a 2D BCURVE; that is it shall either be a rational B curve with a vertex dimensionality of 3, or a non-rational B curve with a vertex dimensionality of 2, as shown in Table F.11.

Table F.11 — SP curve fields

| Field name | Data type | Description |
|-----------------------|-----------|-------------|
| surface | pointer | surface |
| b_curve | pointer | 2D Bcurve |
| original | pointer0 | not used |
| tolerance_to_original | double | not used |

```

struct    SP_CURVE_s == ANY_CURVE_s                                // SP curve
{
    int          node_id;                                           // $d
    union ATTRIB_GROUP_u      attributes_groups;                   // $p
    union CURVE_OWNER_u       owner;                                // $p
    union CURVE_u              next;                                 // $p
    union CURVE_u              previous;                             // $p
    struct GEOMETRIC_OWNER_s   *geometric_owner;                   // $p
    char            sense;                                           // $c
    union SURFACE_u            surface;                              // $p
    struct B_CURVE_s           *b_curve;                             // $p
    union CURVE_u              original;                             // $p
    double                  tolerance_to_original;                   // $f
};
typedef struct SP_CURVE_s     *SP_CURVE;

```

- Polyline

A polyline describes a connected chain of linear segments. It takes the following additional field, as shown in Table F.12:

Table F.12 — Polyline Field

| Field name | Data | Description |
|------------|---------|--|
| data | pointer | contains the data information of the polyline. |

```

struct POLYLINE_s == ANY_CURVE_s ---Polyline
{

```



```

int                node_id;                ---$d
union ATTRIB_u     attributes_s;           ---$p
union CURVE_OWNER_u owner;                 ---$p
union CURVE_u      next;                   ---$p
union CURVE_u      previous;               ---$p
struct GEOMETRIC_OWNER_s *geometric_owner; ---$p
char               sense;                  ---$c
struct POLYLINE_DATA_s *data;              ---$p
}
typedef struct POLYLINE_s *POLYLINE;

```

The data stored in the XT data for a POLYLINE is as follows:

```

logged struct POLYLINE_DATA_s ---Polyline data
{
    int      n_pvecs;                ---$d
    logical  closed;                 ---$I
    double   base_parm;              ---$f
    struct POINT_VALUES_s*pvec;      ---$p
};
typedef struct POLYLINE_DATA_s*POLYLINE_DATA;

```

Where:

| Field name | Data type | Description |
|------------|-----------|---|
| n_pvecs | integer | number of point vectors |
| closed | logical | true if polyline is closed |
| base_parm | double | the parameter of the first pvec in the polyline |
| pvec | pointer | point vectors that describe the shape of the polyline |

F.3.4.2 Surfaces

All surface nodes share the following common fields, as shown in Table F.13:

Table F.13 — Surface node fields

| Field name | Data type | Description |
|-------------------|-----------|---|
| node_id | int | Integer value unique to surface in part |
| attributes_groups | pointer0 | Attributes and groups associated with surface |
| owner | pointer | topological owner |
| next | pointer0 | next surface in geometry chain |
| previous | pointer0 | previous surface in geometry chain |
| geometric_owner | pointer0 | geometric owner node |
| sense | char | sense of surface: '+' or '-'(see end of Geometry section) |

```

struct ANY_SURF_s                                     // Any Surface
{
    int                node_id;                        // $d
    union ATTRIB_GROUP_u attributes_groups;           // $p
    union SURFACE_OWNER_u owner;                      // $p
    union SURFACE_u     next;                          // $p
    union SURFACE_u     previous;                      // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;        // $p
    char               sense;                          // $c
};
typedef struct ANY_SURF_s *ANY_SURF;

```

- Plane

A plane, as represented in Table F.14, has a parametric representation of the form

$R(u, v) = P + uX + vY$

where

- P is a point on the plan.
- X and Y are axes in the plane.

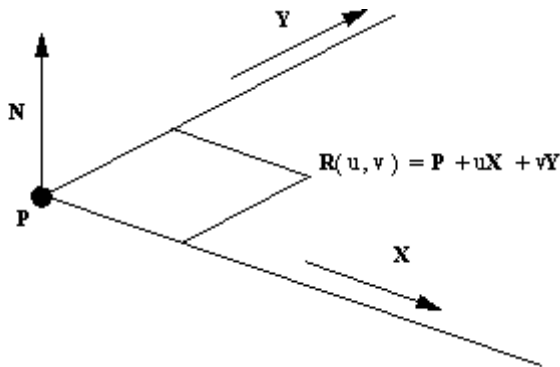


Table F.14 — Plane fields

| Field name | Data type | Description |
|------------|-----------|-------------------------------------|
| pvec | vector | point on the plane |
| normal | vector | normal to the plane (a unit vector) |
| x_axis | vector | X axis of the plane (a unit vector) |

The Y axis in the definition above is the vector cross product of the normal and x_axis.

```
struct PLANE_s == ANY_SURF_s // Plane
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    union SURFACE_OWNER_u owner; // $p
    union SURFACE_u next; // $p
    union SURFACE_u previous; // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    char sense; // $c
    vector pvec; // $v
    vector normal; // $v
    vector x_axis; // $v
};
typedef struct PLANE_s *PLANE;
```

- Cylinder

A cylinder, as represented in Table F.15, has a parametric representation of the form:

$R(u,v) = P + rXcos(u) + rYsin(u) + vA$

where

- P is a point on the cylinder axis.
- r is the cylinder radius.
- A is the cylinder axis.

— X and Y are unit vectors such that A, X and Y form an orthonormal set.

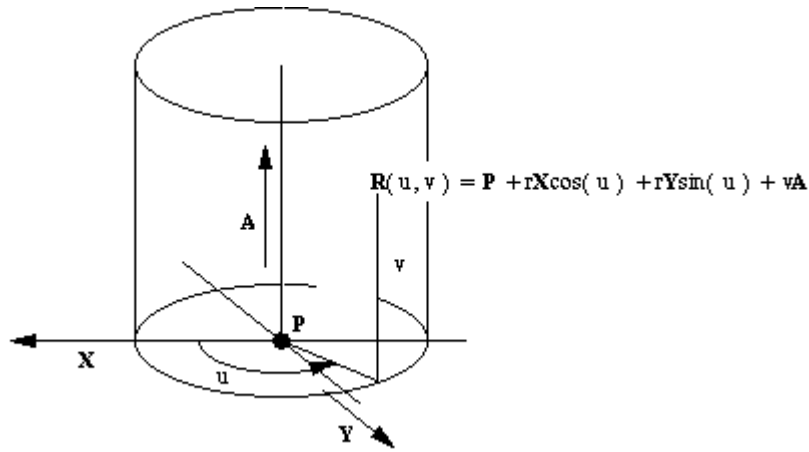


Table F.15 — Cylinder fields

| Field name | Data type | Description |
|------------|-----------|--|
| pvec | vector | point on the cylinder axis |
| axis | vector | direction of the cylinder axis (a unit vector) |
| radius | double | radius of cylinder |
| x_axis | vector | X axis of the cylinder (a unit vector) |

The Y axis in the definition above is the vector cross product of the axis and x_axis.

```

struct CYLINDER_s == ANY_SURF_s                                // Cylinder
{
    int                node_id;                                // $d
    union ATTRIB_GROUP_u    attributes_groups;                // $p
    union SURFACE_OWNER_u    owner;                            // $p
    union SURFACE_u          next;                             // $p
    union SURFACE_u          previous;                         // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;                // $p
    char                  sense;                                // $c
    vector                pvec;                                 // $v
    vector                axis;                                 // $v
    double                radius;                               // $f
    vector                x_axis;                               // $v
};
typedef struct CYLINDER_s *CYLINDER;

```

- Cone

A cone, in XT, as represented in Table F.16, is only half of a mathematical cone. By convention, the cone axis points away from the half of the cone in use. A cone has a parametric representation of the form:

$R(u, v) = P - vA + (X\cos(u) + Y\sin(u))(r + v\tan(a))$
 where

- P is a point on the cone axis.
- r is the cone radius at the point P.
- A is the cone axis.

- X and Y are unit vectors such that A, X and Y form an orthonormal set, therefore $Y = A \times X$.
- a is the cone half angle.

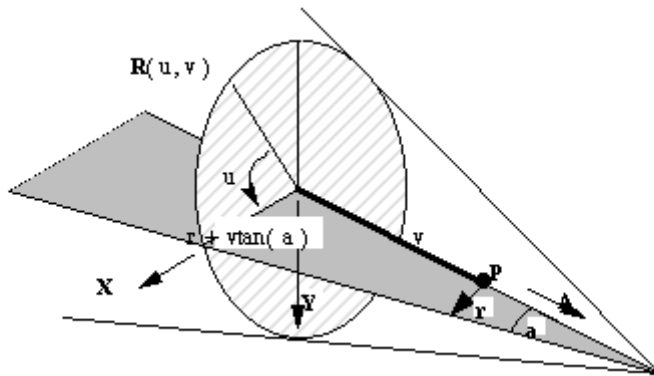


Table F.16 — Cone fields

| Field name | Data type | Description |
|----------------|-----------|--|
| pvec | vector | point on the cone axis |
| axis | vector | direction of the cone axis (a unit vector) |
| radius | double | radius of the cone at its pvec |
| sin_half_angle | double | sine of the cone's half angle |
| cos_half_angle | double | cosine of the cone's half angle |
| x_axis | vector | X axis of the cone (a unit vector) |

The Y axis in the definition above is the vector cross product of the axis and x_axis.

```

struct CONE_s == ANY_SURF_s                                // Cone
{
    int                node_id;                             // $d
    union ATTRIB_GROUP_u attributes_groups;                 // $p
    union SURFACE_OWNER_u owner;                            // $p
    union SURFACE_u    next;                                // $p
    union SURFACE_u    previous;                             // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;              // $p
    char                sense;                               // $c
    vector              pvec;                                 // $v
    vector              axis;                                 // $v
    double              radius;                              // $f
    double              sin_half_angle;                       // $f
    double              cos_half_angle;                       // $f
    vector              x_axis;                               // $v
};

typedef struct CONE_s  *CONE;

```

- Sphere

A sphere, as represented in Table F.17, has a parametric representation of the form:

$R(u, v) = C + (X\cos(u) + Y\sin(u)) r\cos(v) + r\sin(v)$
 where

- C is centre of the sphere.
- r is the sphere radius.
- A, X and Y form an orthonormal axis set.

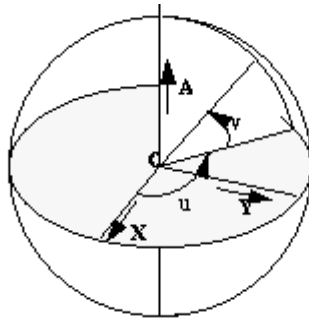


Table F.17 — Sphere fields

| Field name | Data type | Description |
|------------|-----------|--------------------------------------|
| Centre | vector | centre of the sphere |
| Radius | double | radius of the sphere |
| Axis | vector | A axis of the sphere (a unit vector) |
| x_axis | vector | X axis of the sphere (a unit vector) |

The Y axis of the sphere is the vector cross product of its A and X axes.

```

struct SPHERE_s == ANY_SURF_s                                // Sphere
{
    int node_id;                                              // $d
    union ATTRIB_GROUP_u attributes_groups;                  // $p
    union SURFACE_OWNER_u owner;                             // $p
    union SURFACE_u next;                                     // $p
    union SURFACE_u previous;                                 // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;               // $p
    char sense;                                               // $c
    vector centre;                                            // $v
    double radius;                                            // $f
    vector axis;                                              // $v
    vector x_axis;                                            // $v
};

typedef struct SPHERE_s *SPHERE;

```

- Torus

A torus, as represented in Table F.18, has a parametric representation of the form

$R(u, v) = C + (X \cos(u) + Y \sin(u))(a + b \cos(v)) + b A \sin(v)$
 where

- C is centre of the torus.
- A is the torus axis.
- a is the major radius.
- b is the minor radius.

— X and Y are unit vectors such that A, X and Y form an orthonormal set.

In XT, there are three types of torus:

Doughnut - the torus is not self-intersecting ($a > b$)

Apple - the outer part of a self-intersecting torus ($a \leq b, a > 0$)

Lemon - the inner part of a self-intersecting torus ($a < 0, |a| < b$)

The limiting case $a = b$ is allowed; it is called an ‘osculating apple’, but there is no ‘lemon’ surface corresponding to this case.

The limiting case $a = 0$ cannot be represented as a torus; this is a sphere.

Table F.18 — Torus fields

| Field name | Data type | Description |
|--------------|-----------|-------------------------------------|
| centre | vector | centre of the torus |
| axis | vector | axis of the torus (a unit vector) |
| major_radius | double | major radius |
| minor_radius | double | minor radius |
| x_axis | vector | X axis of the torus (a unit vector) |

The Y axis in the definition above is the vector cross product of the axis of the torus and the x_axis.

```

struct TORUS_s == ANY_SURF_s                                // Torus
{
    int                node_id;                               // $d
    union ATTRIB_GROUP_u attributes_groups;                   // $p
    union SURFACE_OWNER_u owner;                             // $p
    union SURFACE_u     next;                                 // $p
    union SURFACE_u     previous;                             // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;                // $p
    char                sense;                                 // $c
    vector              centre;                                // $v
    vector              axis;                                  // $v
    double              major_radius;                          // $f
    double              minor_radius;                          // $f
    vector              x_axis;                                // $v
};

typedef struct TORUS_s    *TORUS;

```

- Blended_Edge (Rolling Ball Blend)

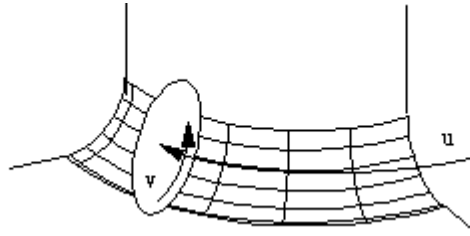
XT supports exact rolling ball blends, as represented in Table F.19. They have a parametric representation of the form

$$R(u, v) = C(u) + rX(u)\cos(v a(u)) + rY(u)\sin(v a(u))$$

where

- $C(u)$ is the spine curve.
- r is the blend radius.

- $X(u)$ and $Y(u)$ are unit vectors such that $C'(u) \cdot X(u) = C'(u) \cdot Y(u) = 0$.
- $a(u)$ is the angle subtended by points on the boundary curves at the spine.



X , Y and a are expressed as functions of u , as their values change with u .

The spine of the rolling ball blend is the centre line of the blend; therefore the path along which the centre of the ball moves.

Table F.19 — Blended edge fields

| Field name | Data type | Description |
|--------------|-------------|---|
| type | char | type of blend: 'R' or 'E' |
| surface | pointer[2] | supporting surfaces (adjacent to original edge) |
| spine | pointer | spine of blend |
| range | double[2] | offsets to be applied to surfaces |
| thumb_weight | double[2] | always [1,1] |
| boundary | pointer0[2] | always [0, 0] |
| start | pointer0 | Start LIMIT in certain degenerate cases |
| end | pointer0 | End LIMIT in certain degenerate cases |

```

struct BLENDED_EDGE_s == ANY_SURF_s                                // Blended edge
{
    int                    node_id;                                // $d
    union ATTRIB_GROUP_u   attributes_groups;                     // $p
    union SURFACE_OWNER_u  owner;                                  // $p
    union SURFACE_u        next;                                   // $p
    union SURFACE_u        previous;                               // $p
    struct GEOMETRIC_OWNER_s *geometric_owner;                    // $p
    char                   sense;                                   // $c
    char                   blend_type;                              // $c
    union SURFACE_u        surface[2];                             // $p[2]
    union CURVE_u          spine;                                   // $p
    double                 range[2];                                // $f[2]
    double                 thumb_weight[2];                        // $f[2]
    union SURFACE_u        boundary[2];                            // $p[2]
    struct LIMIT_s         *start;                                 // $p
    struct LIMIT_s         *end;                                   // $p
};
typedef struct BLENDED_EDGE_s *BLENDED_EDGE;

```

The parameterization of the blend is as follows. The u parameter is inherited from the spine, the constant u lines being circles perpendicular to the spine curve. The v parameter is zero at the blend boundary on the first surface, and one on the blend boundary on the second surface; unless the sense of the spine curve

is negative, in which case it is the other way round. The v parameter is proportional to the angle around the circle.

XT data can contain blends of the following types:

```
const char SCH_rolling_ball = 'R';      // rolling ball blend
const char SCH_cliff_edge   = 'E';      // cliff edge blend
```

For rolling ball blends, the spine curve will be the intersection of the two surfaces obtained by offsetting the supporting surfaces by an amount given by the respective entry in `range[]`. Note that the offsets to be applied may be positive or negative, and that the sense of the surface is significant; therefore the offset vector is the natural unit surface normal, times the range, times -1 if the sense is negative.

For cliff edge blends, one of the surfaces will be a `blended_edge` with a range of $[0,0]$; its spine will be the cliff edge curve, and its supporting surfaces will be the surfaces of the faces adjacent to the cliff edge. Its type will be `R`.

The limit fields will only be non-null if the spine curve is periodic but the edge curve being blended has terminators – for example if the spine is elliptical but the blend degenerates. In this case the two `LIMIT` nodes, of type `L`, determine the extent of the spine.

- Blend_bound (Blend boundary surface)

A `blend_bound` surface is a construction surface, used to define the boundary curve where a blend becomes tangential to its supporting surface. It is an implicit surface defined internally so that it intersects one of the supporting surfaces along the boundary curve. It is orthogonal to the blend and the supporting surface along this boundary curve. The supporting surface corresponding to the `blend_bound` is

```
Blend_bound -> blend.blended_edge -> surface[1-blend_bound->boundary]
```

Blend boundary surfaces have no parameterization, but are defined by the distance function

$$f(X) = f_0(X + r_1 * \text{grad}_{f_1}(X)) - r_0$$

Where

- f_0 is the surface distance function of the supporting surface corresponding to the `blend_bound`.
- r_0 is the blend radius corresponding to that supporting surface.
- f_1 is the surface distance function of the other supporting surface of the blend.
- r_1 is the blend radius corresponding to the other supporting surface.

Blend boundary surfaces, as shown in Table F.20, are most commonly referenced by the intersection curve representing the boundary curve of the blend.

The data stored in the XT data for a `blend_bound` is only that necessary to identify the relevant blend and supporting surface:

Table F.20 — Blend boundary surface fields

| Field name | Data type | Description |
|------------|-----------|-------------------------------------|
| boundary | short | index into supporting surface array |
| blend | pointer | corresponding blend surface |

```
struct BLEND_BOUND_s == ANY_SURF_s      // Blend boundary
{
    int                                node_id;                // $d
```



```

union  ATTRIB_GROUP_u      attributes_groups;    // $p
union  SURFACE_OWNER_u     owner;                // $p
union  SURFACE_u           next;                 // $p
union  SURFACE_u           previous;             // $p
struct GEOMETRIC_OWNER_s   *geometric_owner;    // $p
char    sense;              // $c
short   boundary;          // $n
union  SURFACE_u           blend;               // $p
};
typedef struct BLEND_BOUND_s *BLEND_BOUND;

```

The supporting surface corresponding to the blend_bound is

```
blend_bound->blend.blended_edge->surface[1 - blend_bound->boundary].
```

- Offset_surf

An offset surface, as shown in Table F.21, is the result of offsetting a surface a certain distance along its normal, taking into account the surface sense. It inherits the parameterization of this underlying surface.

Table F.21 — Offset surface fields

| Field name | Data type | Description |
|-------------|-----------|--|
| Check | char | check status |
| true_offset | logical | not used |
| surface | pointer | underlying surface |
| offset | double | signed offset distance |
| scale | double | for internal use only – may be set to null |

```

struct OFFSET_SURF_s == ANY_SURF_s      // Offset surface
{
    int          node_id;                // $d
    union  ATTRIB_GROUP_u      attributes_groups;    // $p
    union  SURFACE_OWNER_u     owner;                // $p
    union  SURFACE_u           next;                 // $p
    union  SURFACE_u           previous;             // $p
    struct GEOMETRIC_OWNER_s   *geometric_owner;    // $p
    char    sense;              // $c
    char    check;              // $c
    logical  true_offset;       // $l
    union  SURFACE_u           surface;              // $p
    double  offset;             // $f
    double  scale;              // $f
};
typedef struct OFFSET_SURF_s *OFFSET_SURF;

```

The offset surface is subject to the following restrictions:

- The offset distance shall not be within modeller linear resolution of zero.
- The sense of the offset surface shall be the same as that of the underlying surface.
- Offset surfaces may not share a common underlying surface.

The 'check' field may take one of the following values:

```

const char SCH_valid      = 'V';          // valid
const char SCH_invalid    = 'I';          // invalid
const char SCH_unchecked  = 'U';          // has not been checked

```

- B_surface

XT supports B spline surfaces in full NURBS format.

B-surface definition

$$P(u, v) = \frac{\sum_{i=0}^{n-1} \sum_{j=0}^{m-1} b_i(u) b_j(v) w_{ij}}{\sum_{i=0}^{n-1} \sum_{j=0}^{m-1} b_i(u) b_j(v) w_{ij}}$$

The B-surface definition, as shown in Table F.22, is best thought of as an extension of the B-curve definition into two parameters, usually called u and v . Two knot sets are required and the number of control vertices is the product of the number that would be required for a curve using each knot vector. The rules for periodicity and closure given in the B-curve documentation are extended to surfaces in an obvious way.

For attachment to topology a B-surface is required to have G_1 continuity. That is to say that the surface normal direction shall be continuous.

Surfaces that are self-intersecting or contain cusps are not permitted to be attached to topology.

Table F.22 — B-Surface fields

| Field name | Data type | Description |
|--------------|-----------------|------------------------------|
| nurbs | pointer | Geometric definition |
| data | pointer0 | Auxiliary information |

```

struct B_SURFACE_s == ANY_SURF_s // B surface
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    union SURFACE_OWNER_u owner; // $p
    union SURFACE_u next; // $p
    union SURFACE_u previous; // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    char sense; // $c
    struct NURBS_SURF_s *nurbs; // $p
    struct SURFACE_DATA_s *data; // $p
};
typedef struct B_SURFACE_s *B_SURFACE;

```

The data stored in the XT data for a NURBS surface is described in Table F.23.

Table F.23 — NURB Surface fields

| Field name | Data type | Description |
|-------------------|-----------|--|
| u_periodic | logical | true if surface is periodic in u parameter |
| v_periodic | logical | true if surface is periodic in v parameter |

| | | |
|------------------|---------|---|
| u_degree | short | u degree of the surface |
| v_degree | short | v degree of the surface |
| n_u_vertices | int | number of control vertices ('poles') in u direction |
| n_v_vertices | int | number of control vertices ('poles') in v direction |
| u_knot_type | byte | form of u knot vector – see “B curve” |
| v_knot_type | byte | form of v knot vector |
| n_u_knots | int | number of distinct u knots |
| n_v_knots | int | number of distinct v knots |
| Rational | logical | true if surface is rational |
| u_closed | logical | true if surface is closed in u |
| v_closed | logical | true if surface is closed in v |
| surface_form | byte | shape of surface, if special |
| vertex_dim | short | dimension of control vertices |
| bspline_vertices | pointer | control vertices (poles) node |
| u_knot_mult | pointer | multiplicities of u knot vector |
| v_knot_mult | pointer | multiplicities of v knot vector |
| u_knots | pointer | u knot vector |
| v_knots | pointer | v knot vector |

The surface form enum is defined below.

```
typedef enum
{
    SCH_unset = 1,                // Unknown
    SCH_arbitrary = 2,            // No particular shape
    SCH_planar = 3,
    SCH_cylindrical = 4,
    SCH_conical = 5,
    SCH_spherical = 6,
    SCH_toroidal = 7,
    SCH_surf_of_revolution = 8,
    SCH_ruled = 9,
    SCH_quadric = 10,
    SCH_swept = 11
}
SCH_surface_form_t;

struct NURBS_SURF_s                // NURBS surface
{
    logical    u_periodic;          // $1
    logical    v_periodic;          // $1
    short      u_degree;            // $n
    short      v_degree;            // $n
}
```

```

int                n_u_vertices;                // $d
int                n_v_vertices;                // $d
SCH_knot_type_t    u_knot_type;                // $u
SCH_knot_type_t    v_knot_type;                // $u
int                n_u_knots;                   // $d
int                n_v_knots;                   // $d
logical            rational;                    // $l
logical            u_closed;                    // $l
logical            v_closed;                    // $l
SCH_surface_form_t surface_form;                // $u
short              vertex_dim;                  // $n
struct BSPLINE_VERTICES_s *bspline_vertices;    // $p
struct KNOT_MULT_s *u_knot_mult;                // $p
struct KNOT_MULT_s *v_knot_mult;                // $p
struct KNOT_SET_s *u_knots;                     // $p
struct KNOT_SET_s *v_knots;                     // $p
};
typedef struct NURBS_SURF_s *NURBS_SURF;

```

The 'bspline_vertices', 'knot_set' and 'knot_mult' nodes and the 'knot_type' enum are described in the documentation for B_CURVE.

The 'surface data' field in a B surface node is a structure designed to hold auxiliary or 'derived' data about the surface: it is not a necessary part of the definition of the B surface. It may be null, or the majority of its individual fields may be null.

```

struct SURFACE_DATA_s // auxiliary surface data
{
    interval    original_uint;                // $i
    interval    original_vint;                // $i
    interval    extended_uint;                // $i
    interval    extended_vint;                // $i
    SCH_self_int_t self_int;                  // $u
    char        original_u_start;              // $c
    char        original_u_end;                // $c
    char        original_v_start;              // $c
    char        original_v_end;                // $c
    char        extended_u_start;              // $c
    char        extended_u_end;                // $c
    char        extended_v_start;              // $c
    char        extended_v_end;                // $c
    char        analytic_form_type;            // $c
    char        swept_form_type;               // $c
    char        spun_form_type;                // $c
    char        blend_form_type;               // $c
    void        *analytic_form;                // $p
    void        *swept_form;                   // $p
    void        *spun_form;                    // $p
    void        *blend_form;                   // $p
};
typedef struct SURFACE_DATA_s *SURFACE_DATA;

```

The 'original_' and 'extended_' parameter intervals and corresponding character fields original_u_start etc. are all connected with the ability to extend B surfaces when necessary – functionality which is commonly exploited in "local operation" algorithms for example. This is done automatically without the need for user intervention.

In cases where the required extension can be performed by adding rows or columns of control points, then the nurbs data will be modified accordingly – this is referred to as an 'explicit' extension. In some rational B surface cases, explicit extension is not possible - in these cases, the surface will be 'implicitly' extended. When a B surface is implicitly extended, the nurbs data is not changed, but it will be treated as being larger by allowing out-of-range evaluations on the surface. Whenever an explicit or implicit extension takes place, it is reflected in the following fields:

- “original_u_int” and “original_v_int” are the original valid parameter ranges for a B surface before it was extended.
- “extended_u_int” and “extended_v_int” are the valid parameter ranges for a B surface once it has been extended.

The character fields ‘original_u_start’ etc. all refer to the status of the corresponding parameter boundary of the surface before or after an extension has taken place. For B surfaces, the character can have one of the following values:

```
const char SCH_degenerate = 'D';      // Degenerate edge
const char SCH_periodic   = 'P';      // Periodic parameterization
const char SCH_bounded    = 'B';      // Parameterization bounded
const char SCH_closed     = 'C';      // Closed, but not periodic
```

The separate fields original_u_start and extended_u_start etc. are necessary because an extension may cause the corresponding parameter boundary to become degenerate.

If the surface_data node is present, then the original_u_int, original_v_int, original_u_start, original_u_end, original_v_start and original_v_end fields should be set to their appropriate values. If the surface has not been extended, the extended_u_int and extended_v_int fields should contain null, and the extended_u_start etc. fields should contain

```
const char SCH_unset_char = '?'; // generic uninvestigated value
```

As soon as any parameter boundary of the surface is extended, all the fields should be set, regardless of whether the corresponding boundary has been affected by the extension.

The SCH_self_int_t enum is documented in the corresponding curve_data structure under B curve.

The ‘swept_form_type’, ‘spun_form_type’ and ‘blend_form_type’ characters and the corresponding pointers swept_form, spun_form and blend_form, are not implemented in XT. The character fields should be set to SCH_unset_char (?) and the pointers should be set to null pointer.

If the analytic_form field is not null, it will point to a HELIX_SU_FORM node, which indicates that the surface has a helical shape. In this case the analytic_form_type field will be set to ‘H’.

```
struct HELIX_SU_FORM_s
{
    vector          axis_pt           // $v
    vector          axis_dir          // $v
    char            hand              // $c
    interval        turns             // $i
    double          pitch             // $f
    double          gap               // $f
    double          tol               // $f
};
typedef struct HELIX_SU_FORM_s *HELIX_SU_FORM;
```

The axis_pt and axis_dir fields define the axis of the helix. The hand field is ‘+’ for a right-handed and ‘-’ for a left-handed helix. The turns field gives the extent of the helix relative to the profile curve which was used to generate the surface. For instance, an interval [0 10] indicates a start position at the profile curve and an end 10 turns along the axis. Pitch is the distance travelled along the axis in one turn. Tol is the accuracy to which the owning bsurface fits this specification. Gap is for future expansion and will currently be zero. The v parameter increases in the direction of the axis.

- Swept_surf

A swept surface, as represented in Table F.24, has a parametric representation of the form:

$$R(u, v) = C(u) + vD$$

where

- $C(u)$ is the section curve.
- D is the sweep direction (unit vector).
- C shall not be an intersection curve or a trimmed curve.

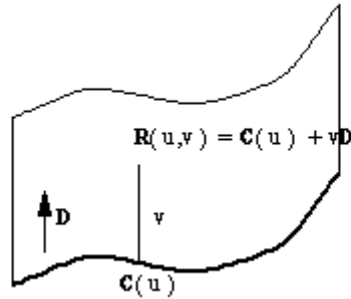


Table F.24 — Swept surface fields

| Field name | Data type | Description |
|------------|-----------|--|
| section | pointer | section curve |
| sweep | vector | sweep direction (a unit vector) |
| scale | double | for internal use only – may be set to null |

```

struct SWEPT_SURF_s == ANY_SURF_s           // Swept surface
{
    int node_id;                             // $d
    union ATTRIB_GROUP_u attributes_groups;  // $p
    union SURFACE_OWNER_u owner;             // $p
    union SURFACE_u next;                    // $p
    union SURFACE_u previous;                // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    char sense;                              // $c
    union CURVE_u section;                   // $p
    vector sweep;                            // $v
    double scale;                            // $f
};
typedef struct SWEPT_SURF_s *SWEPT_SURF;

```

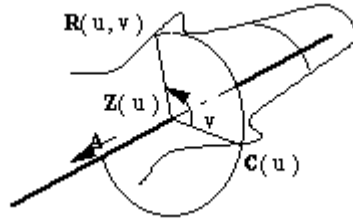
- Spun_surf

A spun surface, as represented in Table F.25, has a parametric representation of the form:

$$R(u, v) = Z(u) + (C(u) - Z(u))\cos(v) + A \times (C(u) - Z(u)) \sin(v)$$

where

- $C(u)$ is the profile curve
- $Z(u)$ is the projection of $C(u)$ onto the spin axis.
- A is the spin axis direction (unit vector).
- C shall not be an intersection curve or a trimmed curve.



NOTE: $Z(u) = P + ((C(u) - P) \cdot A)A$ where P is a reference point on the axis.

Table F.25 — Spun surface fields

| Field name | Data type | Description |
|-------------|-----------|---|
| profile | pointer | profile curve |
| base | vector | point on spin axis |
| axis | vector | spin axis direction (a unit vector) |
| start | vector | position of degeneracy at low u (may be null) |
| end | vector | position of degeneracy at low v (may be null) |
| start_param | double | curve parameter at low u degeneracy (may be null) |
| end_param | double | curve parameter at high u degeneracy (may be null) |
| x_axis | vector | unit vector in profile plane if common with spin axis |
| scale | double | for internal use only – may be set to null |

```

struct SPUN_SURF_s == ANY_SURF_s // Spun surface
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    union SURFACE_OWNER_u owner; // $p
    union SURFACE_u next; // $p
    union SURFACE_u previous; // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    char sense; // $c
    union CURVE_u profile; // $p
    vector base; // $v
    vector axis; // $v
    vector start; // $v
    vector end; // $v
    double start_param; // $f
    double end_param; // $f
    vector x_axis; // $v
    double scale; // $f
};
typedef struct SPUN_SURF_s *SPUN_SURF;

```

The 'start' and 'end' vectors correspond to physical degeneracies on the spun surface caused by the profile curve crossing the spin axis at that point. The values start_param and end_param are the corresponding parameters on the curve. These parameter values define the valid range for the u parameter of the surface. If either value is null, then the valid range for u is infinite in that direction. For example, for a

straight line profile curve intersecting the spin axis at the parameter $t=1$, values of null for start_param and 1 for end_param would define a cone with u parameterization $(-\infty, 1]$.

If the profile curve lies in a plane containing the spin axis, then x_axis shall be set to a vector perpendicular to the spin axis and in the plane of the profile, pointing from the spin axis to a point on the profile curve in the valid range. If the profile curve is not planar, or its plane does not contain the spin axis, then x_axis should be set to null.

- Mesh Surfaces

Each MESH surface node, as shown in Table F.26, references a PSM_MESH node containing facet data. Meshes cannot be shared by more than one face of a body.

Table F.26 — Description of Mesh surface fields

| Field name | Data type | Description |
|------------|-----------|---|
| mesh_box | box | may contain an axis-aligned box bounding the mesh |
| transform | pointer0 | transform applied |
| rcv_key | pointer | key of XMM file containing PSM mesh data. This field is not used |
| rcv_index | int | unique integer value corresponding to the index of the PSM_MESH in the POINTER_LIS_BLOCK used as the root node in the corresponding XT mesh data file, if used. |
| psm_imesh | pointer0 | a pointer to the PSM_MESH node when mesh data is embedded in the XT part or partition file. |
| pff_imesh | pointer0 | debug mesh format, unused |

```

struct MESH_s          // Mesh
{
    int                 node_id;                // $d
    union ATTRIB_FEAT_u attributes_features;    // $p
    union SURFACE_OWNER_U owner;               // $p
    union SURFACE_U     next;                  // $p
    union SURFACE_U     previous;              // $p
    struct GEOMETRIC_OWNER_s *geometric_owner; // $p
    char                 sense;                // $c
    box                  mesh_box;             // $b
    struct TRANSFORM_s   *transform;           // $p
    union MESH_KEY_u     rcv_key;              // $p
    int                 rcv_index;            // $d
    struct PSM_MESH_s    *psm_imesh           // $p
    struct PFF_MESH_s    *pff_imesh           // $p
};
typedef struct MESH_s *MESH;

```

The rcv_key field is not used and must always be set to null pointer.

The PSM mesh data may be embedded in the XT part or partition file, or stored in an associated XT mesh data file. The definition of the PSM mesh data is identical in both cases. When PSM mesh data is stored in an associated XT mesh data file the psm_imesh field must be set to null pointer.

-PSM mesh

Mesh data is stored in a PSM_MESH node, which is referenced by the MESH node.

The mesh data is described using the following fields as shown in Table F.27:

Table F.27—Description of PSM mesh fields

| Field name | Data type | Description |
|------------------|-----------|--|
| precision | byte | Number format used to store the mesh data |
| owner | pointer0 | mesh data owner |
| position_pool | pointer | array of positions. |
| normal_pool | pointer0 | array of directions stored in polar coordinates. |
| position_indices | pointer | array of 3N indices into the position pool, where N is the number of facets. |
| normal_type | byte | form of mesh normals |
| normal_indices | pointer0 | array of 3N indices into the normal pool, where N is the number of facets. |

```
typedef enum
{
    SCH_mesh_normal_none                =1,
    SCH_mesh_normal_per_vertex          =2,
    SCH_mesh_normal_per_facet           =3,
}
SCH_mesh_normal_type_t;
typedef enum
{
    SCH_mesh_precision_double           =1
    SCH_mesh_precision_single           =2
}
SCH_mesh_precision_t;
struct PSM_MESH_s //PSM Mesh
{
    SCH_mesh_precision_t                precision;           //$u

    struct MESH_s                       *owner;              //$p
    struct VECTOR_COMB_s                 *position_pool;     //p
    struct VECTOR_COMB_s                 *normal_pool;       //$p
    struct INTEGER_COMB_s                 *position_indices;  //$p
    SCH_mesh_normal_type_t                normal_type;        //$u
    struct INTEGER_COMB_s                 *normal_indices;    //$p
};
```

The owner field is reserved for future use and must be set to null pointer.

The precision field is reserved for future use and must be set to 1, therefore double precision.

The normal_type defines whether normals are stored, and if so, whether storage is on a per-facet or per-vertex basis. See the section in this document on Normal indices for more information.

-Position pool

The position pool is an indexed point cloud. The vector array is stored using “comb” nodes, each of which consists of a “spine” array containing pointers to “tooth” arrays. Each tooth array contains the vector information. All the teeth have the same length, which is a power of 2.

-Position indices

The mesh is defined by each facet specifying 3 positions from the position pool. The indices for these positions are stored in an integer comb, similar to the vector comb.

-Normal pool

The normal pool is an indexed cloud of normals, therefore unit vectors. These are stored in double-precision spherical polar coordinates.

The normal pool is optional, so need not exist at all.

-Normal indices

If normals are stored with the mesh they must be stored for each vertex of each facet. The type of normal storage used by the mesh data is specified by the normal_type field.

- If no normals are stored, normal indices are not needed and must be set to null pointer.
- If the normals are per-facet, then the number of normal indices is the same as the number of position indices, and the normal indices and position indices are parallel arrays.
- Normal storage per-vertex is not implemented.

F.3.4.3 Point

A table of Point field data is shown in Table F.28

Table F.28 — Point fields

| Field name | Data type | Description |
|-------------------|-----------|---|
| node_id | int | integer unique within part |
| attributes_groups | pointer0 | attributes and groups associated with point |
| owner | pointer | Owner |
| next | pointer0 | next point in chain |
| previous | pointer0 | previous point in chain |
| pvec | vector | position of point |

```

union POINT_OWNER_u
{
    struct VERTEX_s          *vertex;
    struct BODY_s            *body;
    struct ASSEMBLY_s        *assembly;
    struct WORLD_s           *world;
};

struct POINT_s                // Point
{
    int                        node_id;                // $d
    union ATTRIB_GROUP_u      attributes_groups;        // $p
    union POINT_OWNER_u       owner;                   // $p
    struct POINT_s            *next;                   // $p
    struct POINT_s            *previous;                // $p
    vector                    pvec;                    // $v
};
typedef struct POINT_s        *POINT;

```

F.3.4.4 Transform

A table of Transform fields data is shown in Table F.29.

Table F.29 — Transform fields

| Field name | Data type | Description |
|------------|-----------|----------------------------|
| node_id | int | integer unique within part |

| | | |
|--------------------|--------------|--|
| owner | pointer | owning instance or world |
| next | pointer0 | next transform in chain |
| previous | pointer0 | previous pointer in chain |
| rotation_matrix | double[3][3] | rotation component |
| translation_vector | vector | translation component |
| scale | double | scaling factor |
| flag | byte | binary flags indicating non-trivial components |
| perspective_vector | vector | perspective vector (always null vector) |
| precision | pointer0 | Additional precision data for the transform |

The transform acts as

$$x' = (\text{rotation_matrix} \cdot x + \text{translation_vector}) * \text{scale}$$

The 'flag' field contains various bit flags, as shown in Table F.30, which identify the components of the transformation:

Table F.30 — Transform action fields

| Flag Name | Binary Value | Description |
|----------------|--------------|--|
| translation | 00001 | set if translation vector non-zero |
| rotation | 00010 | set if rotation matrix is not the identity |
| scaling | 00100 | set if scaling component is not 1.0 |
| reflection | 01000 | set if determinant of rotation matrix is negative |
| general affine | 10000 | set if the rotation_matrix is not a rigid rotation |

```
union TRANSFORM_OWNER_u
{
    struct INSTANCE_s      *instance;
    struct WORLD_s         *world;
};
```

```
struct TRANSFORM_s // Transformation
```

| | | |
|-------------------------|------------------------|-----------|
| | | |
| int | node id; | // \$d |
| union TRANSFORM_OWNER_u | owner; | // \$p |
| struct TRANSFORM_s | *next; | // \$p |
| struct TRANSFORM_s | *previous; | // \$p |
| double | rotation_matrix[3][3]; | // \$f[9] |
| vector | translation_vector; | // \$v |
| double | scale; | // \$f |
| unsigned | flag; | // \$d |
| vector | perspective_vector; | // \$v |

| | | |
|---------------------------------|-------------|-------|
| struct TRANSFORM_PRECISION_s | *precision; | //\$p |
| }; | | |

typedef struct TRANSFORM_s *TRANSFORM;

F.3.4.5 Curve and Surface Senses

The 'natural' tangent to a curve is that in the increasing parameter direction, and the 'natural' normal to a surface is in the direction of the cross-product of dP/du and dP/dv . For some purposes these are modified by the curve and surfaces senses, respectively – for example in the definition of blend surfaces, offset surfaces and intersection curves.

In the XT format, this orientation information resides in the curves, surfaces and faces as follows:

The edge/curve orientation is stored in the curve->sense field. The face/surface orientation is a combination of sense flags stored in the face->sense and surface->sense fields, so the face/surface orientation is true (therefore the face normal is parallel to the natural surface normal) if neither, or both, of the face and surface senses are positive.

F.3.4.6 Geometric_owner

Where geometry has dependents, the dependents point back to the referencing geometry by means of Geometric Owner nodes. Each geometric node points to a doubly-linked ring of Geometric Owner nodes which identify its referencing geometry. Referenced geometry is as follows:

| | |
|-----------------|--|
| Intersection: | 2 surfaces |
| SP-curve: | Surface |
| Trimmed curve: | basis curve |
| Blended edge: | 2 supporting surfaces, 2 blend_bound surfaces, 1 spine curve |
| Blend bound: | blend surface |
| Offset surface: | underlying surface |
| Swept surface: | section curve |
| Spun surface: | profile curve |

Note that the 2D B-curve referenced by an SP-curve is not a dependent in this sense, and does not need a geometric owner node, as shown in Table F.31.

Table F.31 — Geometry owner fields

| Field name | Data type | Description |
|-----------------|-----------|---|
| owner | pointer | referencing geometry |
| next | pointer | next in ring of geometric owners referring to the same geometry |
| previous | pointer | previous in above ring |
| shared_geometry | pointer | referenced (dependent) geometry |

```

struct GEOMETRIC_OWNER_s          // geometric owner of geometry
{
    union GEOMETRY_u              owner;          // $p
    struct GEOMETRIC_OWNER_s      *next;          // $p
    struct GEOMETRIC_OWNER_s      *previous;      // $p
    union GEOMETRY_u              shared_geometry; // $p
};
typedef struct GEOMETRIC_OWNER_s *GEOMETRIC_OWNER;

```

F.3.5 Topology

In the following tables, as shown in Table F.32, Table F.33, Table F.34, Table F.35, Table F.36, Table F.37, Table F.38, Table F.39, Table F.40, Table F.41, Table F.42 and Table F.43, ‘ignore’ means this may be set to null (zero) and should be ignored.

Unless otherwise stated, all chains of nodes are doubly-linked and null-terminated.

- World

Table F.32 — World topology fields

| Field name | Type | Description |
|------------|----------|--|
| assembly | pointer0 | Head of chain of assemblies |
| attribute | pointer0 | Ignore |
| body | pointer0 | Head of chain of bodies. This chain contains standard and compound bodies but does not contain any child bodies. |
| transform | pointer0 | Head of chain of transforms |
| surface | pointer0 | Head of chain of surfaces |
| curve | pointer0 | Head of chain of curves |
| point | pointer0 | Head of chain of points |
| mesh | pointer0 | Head of chain of meshes |
| polyline | pointer0 | Head of chain of polylines |
| alive | logical | True unless partition is at initial pmark |
| attrib_def | pointer0 | Head of chain of attribute definitions |
| highest_id | int | Highest pmark id in partition |
| current_id | int | Id of current pmark |

| | | |
|----------------------|----------|---|
| index_map_offset | int | Shall be set to 0 |
| index_map | pointer0 | Shall be set to null |
| schema_embedding_map | pointer0 | Shall be set to null |
| mesh_offset_data | pointer0 | Data for embedded meshes. If the XT file does not contain embedded meshes, the field must be set to null. |

The World node is only used when a partition is transmitted. Because some of the attribute definitions may be referenced by nodes which have been deleted, but which may reappear on rollback, the attribute definitions are chained off the World node rather than simply being referenced by attributes.

The fields index_map_offset, index_map, and schema_embedding_map are used for Indexed Transmit; applications writing XT data shall set them to 0 and null.

The mesh_offset_data field is used for embedding mesh data.

```

struct WORLD_s                                     // World
{
    struct ASSEMBLY_s          *assembly;          // $p
    struct ATTRIBUTE_s         *attribute;          // $p
    struct BODY_s              *body;              // $p
    struct TRANSFORM_s         *transform;          // $p
    union SURFACE_u            surface;             // $p
    union CURVE_u              curve;               // $p
    struct POINT_s             *point;             // $p
    union SURFACE_u            mesh;                // $p
    union CURVE_u              polyline;           // $p
    logical                    alive;               // $l
    struct ATTRIB_DEF_s        *attrib_def;         // $p
    int                        highest_id;          // $d
    int                        current_id;          // $d
    int                        index_map_offset;     // $d
    struct INT_VALUES_s        *index_map;          // $p
    struct INT_VALUES_s        *schema_embedding_map; // $p
    struct MESH_OFFSET_DATA_s  *mesh_offset_data;   // $p
};
typedef struct WORLD_s  *WORLD;

```

- Assembly

Table F.33 — Assembly fields

| | | |
|-------------------|----------|--|
| highest_node_id | int | Highest node-id in assembly |
| attributes_groups | pointer0 | Head of chain of attributes of, and groups in, assembly |
| attribute_chains | pointer0 | List of attributes, one for each attribute definition used in the assembly |
| list | pointer0 | Null |
| surface | pointer0 | Head of construction surface chain |
| curve | pointer0 | Head of construction curve chain |

| | | |
|------------------|----------|---|
| point | pointer0 | Head of construction point chain |
| mesh | pointer0 | Head of construction mesh chain |
| polyline | pointer0 | Head of construction polyline chain |
| key | pointer0 | Ignore |
| res_size | double | Value of 'size box' when transmitted (normally 1000) |
| res_linear | double | Value of modeller linear precision when transmitted (normally 1.0e-8). |
| ref_instance | pointer0 | Head of chain of instances referencing this assembly |
| next | pointer0 | Ignore |
| previous | pointer0 | Ignore |
| state | byte | Set to 1. |
| owner | pointer0 | Ignore |
| type | byte | Always 1. |
| sub_instance | pointer0 | Head of chain of instances in assembly |
| mesh_offset_data | pointer0 | Data for embedded meshes. If the XT files does not contain embedded meshes, this field must be set to null. |

The value of the 'state' field should be ignored, as should any nodes of type 'KEY' referenced by the assembly. If XT data is constructed without use of the Parasolid Kernel, the state field should be set to 1, and the key to null.

The highest_node_id gives the highest node-id of any node in the assembly. Certain nodes within the assembly (namely instances, transforms, geometry, attributes and groups) have unique node-ids which are non-zero integers.

The mesh_offset_data field is used for embedded mesh data.

```
typedef enum
{
    SCH_collective_assembly = 1,
    SCH_conjunctive_assembly = 2,
    SCH_disjunctive_assembly = 3
}
SCH_assembly_type;

typedef enum
{
    SCH_new_part = 1,
    SCH_stored_part = 2,
    SCH_modified_part = 3,
    SCH_anonymous_part = 4,
    SCH_unloaded_part = 5
}
SCH_part_state;

struct ASSEMBLY_s // Assembly
{
    int highest_node_id; // $d
```

```

union ATTRIB_GROUP_u      attributes_groups;           // $p
struct LIST_s             *attribute_chains;           // $p
struct LIST_s             *list;                      // $p
union SURFACE_u           surface;                    // $p
union CURVE_u             curve;                      // $p
struct POINT_s            *point;                    // $p
union SURFACE_u           mesh;                      // $p
union CURVE_u             polyline;                   // $p
struct KEY_s              *key;                      // $p
double                   res_size;                    // $f
double                   res_linear;                  // $f
struct INSTANCE_s         *ref_instance;              // $p
struct ASSEMBLY_s         *next;                     // $p
struct ASSEMBLY_s         *previous;                 // $p
SCH_part_state            state;                      // $u
struct WORLD_s            *owner;                    // $p
SCH_assembly_type         type;                      // $u
struct INSTANCE_s         *sub_instance;             // $p
struct MESH_OFFSET_DATA_s *mesh_offset_data;         // $p
};
typedef struct ASSEMBLY_s *ASSEMBLY;
struct KEY_s              // Key
{
    string[1];            char                // $c[]
};
typedef struct KEY_s *KEY;

```

- Instance

Table F.34 — Instance fields

| Field name | Type | Description |
|-------------------|----------|--|
| node_id | int | Node-id |
| attributes_groups | pointer0 | Head of chain of attributes of instance and member_of_groups of instance |
| type | byte | Always 1 |
| part | pointer | Part referenced by instance |
| transform | pointer0 | Transform of instance |
| assembly | pointer | Assembly in which instance lies |
| next_in_part | pointer0 | Next instance in assembly |
| prev_in_part | pointer0 | Previous instance in assembly |
| next_of_part | pointer0 | Next instance of instance->part |
| prev_of_part | pointer0 | Previous instance of instance->part |

```

typedef enum
{
    SCH_positive_instance = 1,
    SCH_negative_instance = 2
}
SCH_instance_type;

```

```

union PART_u

```



```

{
    struct BODY_s          *body;
    struct ASSEMBLY_s      *assembly;
};
typedef union PART_u      PART;

struct INSTANCE_s          // Instance
{
    int                     node_id;                // $d
    union ATTRIB_GROUP_u    attributes_groups;       // $p
    SCH_instance_type       type;                    // $u
    union PART_u            part;                    // $p
    struct TRANSFORM_s      *transform;              // $p
    struct ASSEMBLY_s       *assembly;               // $p
    struct INSTANCE_s       *next_in_part;           // $p
    struct INSTANCE_s       *prev_in_part;           // $p
    struct INSTANCE_s       *next_of_part;           // $p
    struct INSTANCE_s       *prev_of_part;           // $p
};
typedef struct INSTANCE_s *INSTANCE;

```

- Body

Table F.35 — Body fields

| Field name | Type | Description |
|-------------------|----------|---|
| highest_node_id | int | <p>Highest node-id in body. For compound bodies, this is the highest identifier, including entities in child bodies.</p> <p>For child bodies, this is the identifier of the child body itself. It is also the highest unique identifier of the entities which were in the child body when it was added to its parent compound body.</p> |
| attributes_groups | pointer0 | Head of chain of attributes of, and groups in, body. All features in a compound body and its children are chained off this regardless of their contents. |
| attribute_chains | pointer0 | <p>List of attributes, one for each attribute definition used in the body.</p> <p>For compound bodies, all attributes within the compound body and its children appear in the attribute_chains list for the compound body, except those attributes that are directly attached to the child bodies. These attributes appear in the attribute_chains list of their relevant child body.</p> |
| surface | pointer0 | Head of construction surface chain. For a child body, these fields are always null. |
| curve | pointer0 | Head of construction curve chain. For a child body, these fields are always null. |

| | | |
|------------------|----------|--|
| point | pointer0 | Head of construction point chain. For a child body, these fields are always null. |
| mesh | pointer0 | Head of construction mesh chain. For a child body, these fields are always null. |
| polyline | pointer0 | Head of construction polyline chain. For a child body, these fields are always null. |
| key | pointer0 | Ignore |
| res_size | double | Value of 'size box' when transmitted (normally 1000) |
| res_linear | double | Value of modeller linear precision when transmitted (normally 1.0e-8) |
| ref_instance | pointer0 | Head of chain of instances referencing this part |
| next | pointer0 | Ignore |
| previous | pointer0 | Ignore |
| state | byte | Set to 1 (see below) |
| owner | pointer0 | Ignore |
| body_type | byte | Body type. If children of a compound body have the same body_type, then this will also be the body_type of the compound body. Otherwise, the body_type of the compound will be general. |
| nom_geom_state | byte | Set to 1 (not documented) |
| shell | pointer0 | For general bodies: null For solid bodies: the first shell in one of the solid regions For other bodies: the first shell in one of the regions This field is obsolete, and should be ignored by applications reading XT data. When writing XT data, it shall be set as above. |
| boundary_surface | pointer0 | Head of chain of surfaces attached directly or indirectly to faces or edges or fins |
| boundary_curve | pointer0 | Head of chain of curves attached directly or indirectly to edges or faces or fins |
| boundary_point | pointer0 | Head of chain of points attached to vertices |

| | | |
|----------------------|----------|---|
| region | pointer | Head of chain of regions in body; this is the infinite region. For a compound body, this is the head of chain of regions comprising of all the regions of all the child bodies. The regions of each child body are contiguous in this chain and the order of the regions corresponds to the order of the children. For a child body, this field points to the first region of the child. For an empty compound body (therefore one without any children), this field is null |
| edge | pointer0 | Head of chain of all non-wireframe edges in body. For a compound body, this is the head of a chain of all non-wireframe edges in all the children. For a child body, this field is null. |
| vertex | pointer0 | Head of chain of all vertices in body. For a compound body, this is the head of a chain of all vertices in all the children. For a child body, this field is null. |
| index_map_offset | int | Shall be set to 0 |
| index_map | pointer0 | Shall be set to null |
| node_id_index_map | pointer0 | Shall be set to null |
| schema_embedding_map | pointer0 | Shall be set to null |

The value of the 'state' field should be ignored, as should any nodes of type 'KEY' referenced by the body. If the XT data is constructed without using the Parasolid Kernel, the state field should be set to 1, and the key to null.

The highest_node_id gives the highest node of any node in this body. Most nodes in a body have node-ids, which are non-zero integers unique to that node within the body. Applications writing XT data shall ensure that node-ids are present and distinct. The details of which nodes have node ids are given in an appendix.

The fields index_map_offset, index_map, node_id_index_map, and schema_embedding_map are used for Indexed Transmit; applications writing XT data shall ensure that these fields are set to 0 and null.

```
typedef enum
{
    SCH_solid_body      = 1,
    SCH_wire_body       = 2,
    SCH_sheet_body      = 3,
    SCH_general_body    = 6
}
SCH_body_type;

typedef short short enum
{
    SCH_nom_geom_off = 1,          --- Entirely off
    SCH_nom_geom_on  = 2          --- Entirely on
}
SCH_nom_geom_state_t;
```

```

struct BODY_s // Body
{
    int highest_node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    struct LIST_s *attribute_chains; // $p
    union SURFACE_u surface; // $p
    union CURVE_u curve; // $p
    struct POINT_s *point; // $p
    union SURFACE_u mesh; // $p
    union CURVE_u polyline; // $p
    struct KEY_s *key; // $p
    double res_size; // $f
    double res_linear; // $f
    struct INSTANCE_s *ref_instance; // $p
    struct BODY_s *next; // $p
    struct BODY_s *previous; // $p
    SCH_part_state state; // $u
    struct WORLD_s *owner; // $p
    SCH_body_type body_type; // $u
    SCH_nom_geom_state_t nom_geom_state; // $u
    struct SHELL_s *shell; // $p
    union SURFACE_u boundary_surface; // $p
    union CURVE_u boundary_curve; // $p
    struct POINT_s *boundary_point; // $p
    union SURFACE_u boundary_mesh; // $p
    union CURVE_u boundary_polyline; // $p
    struct REGION_s *region; // $p
    struct EDGE_s *edge; // $p
    struct VERTEX_s *vertex; // $p
    int index_map_offset; // $d
    struct INT_VALUES_s *index_map; // $p
    struct INT_VALUES_s *node_id_index_map; // $p
    struct INT_VALUES_s *schema_embedding_map; // $p
    struct MESH_OFFSET_data_s *mesh_offset_data; // $p
};

typedef struct BODY_s *BODY;

```

Attaching Geometry to Topology

The faces which reference a surface are chained together, surface->owner is the head of this chain. Similarly the edges which reference the same curve are chained together. Fins do not share curves.

Geometry in parts may be chained into one of the three boundary geometry chains, or one of the three construction geometry chains. A geometric node will fall into one of the following cases:

Table F.36 — Geometry to Topology attachment

| Geometry | Owner | Whether chained |
|--|------------------|---|
| Attached to face | face | In boundary_surface chain |
| Attached to edge or fin | edge or fin | In boundary_curve chain |
| Attached to vertex | vertex | In boundary_point chain |
| Indirectly attached to face or edge or fin | body | In boundary_surface chain or boundary_curve chain |
| Construction geometry | body or assembly | In surface, curve or point chain |

| | | |
|------------------------|------|-------------|
| 2D B-curve in SP-curve | null | Not chained |
|------------------------|------|-------------|

Here ‘indirectly attached’ means geometry which is a dependent of a dependent of (... etc.) of geometry attached to an edge, face or fin.

Geometry in a construction chain may reference geometry in a boundary chain, but not vice-versa.

- Region

Table F.37 — Region fields

| Field name | Type | Description |
|-------------------|----------|---|
| node_id | int | Node-id |
| attributes_groups | pointer0 | Head of chain of attributes of region and member_of_groups of region |
| body | pointer | Body of region. For a region in a child body, this field references the parent compound body. |
| next | pointer0 | Next region in body |
| prev | pointer0 | Previous region in body |
| shell | pointer0 | Head of singly-linked chain of shells in region |
| type | char | Region type – solid ('S') or void ('V') |

```

struct REGION_s                                     // Region
{
    int node_id;                                     // $d
    union ATTRIB_GROUP_u attributes_groups;         // $p
    struct BODY_s *body;                             // $p
    struct REGION_s *next;                           // $p
    struct REGION_s *previous;                       // $p
    struct SHELL_s *shell;                           // $p
    char type;                                       // $c
};
typedef struct REGION_s *REGION;

```

- Shell

Table F.38 — Shell fields

| Field name | Type | Description |
|-------------------|----------|--------------------------------------|
| node_id | int | Node-id |
| attributes_groups | pointer0 | Head of chain of attributes of shell |

| | | |
|------------|----------|--|
| body | pointer0 | For shells in wire and sheet bodies, and for shells bounding a solid region of a solid body, this is set to the body of the shell. For shells in general bodies, or void shells in solid bodies, it is null. This field is obsolete, and should be ignored by applications reading XT data. When writing XT data, it shall be set as above. |
| next | pointer0 | Next shell in region |
| face | pointer0 | Head of chain of back-faces of shell (therefore faces with face normal pointing out of region of shell). |
| edge | pointer0 | Head of chain of wire-frame edges of shell |
| vertex | pointer0 | If shell consists of a single vertex, this is it; else null |
| region | pointer | Region of shell |
| front_face | pointer0 | Head of chain of front-faces of shell (therefore faces with face normal pointing into region of shell) |

```

struct SHELL_s                                     //  Shell
{
    int                                             node_id;                               //  $d
    union ATTRIB_GROUP_u                          attributes_groups;                          //  $p
    struct BODY_s                                 *body;                               //  $p
    struct SHELL_s                               *next;                               //  $p
    struct FACE_s                                *face;                               //  $p
    struct EDGE_s                                 *edge;                               //  $p
    struct VERTEX_s                               *vertex;                             //  $p
    struct REGION_s                               *region;                             //  $p
    struct FACE_s                                 *front_face;                         //  $p
};
typedef struct SHELL_s    *SHELL;

```

- Face

Table F.39 — Face fields

| Field name | Type | Description |
|-------------------|----------|--|
| node_id | int | Node-id |
| attributes_groups | pointer0 | Head of chain of attributes of face and member_of_groups of face |
| tolerance | double | Not used (null double) |
| next | pointer0 | Next back-face in shell |
| previous | pointer0 | Previous back-face in shell |
| loop | pointer0 | Head of singly-linked chain of loops |
| shell | pointer | Shell of which this is a back-face |

| | | |
|---------------------|----------|---|
| surface | pointer0 | Surface of face |
| sense | char | Face sense – positive ('+') or negative ('-') |
| next_on_surface | pointer0 | Next in chain of faces sharing the surface of this face |
| previous_on_surface | pointer0 | Previous in chain of faces sharing the surface of this face |
| next_front | pointer0 | Next front-face in shell |
| previous_front | pointer0 | Previous front-face in shell |
| front_shell | pointer | Shell of which this is a front-face |

```

struct FACE_s // Face
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    double tolerance; // $f
    struct FACE_s *next; // $p
    struct FACE_s *previous; // $p
    struct LOOP_s *loop; // $p
    struct SHELL_s *shell; // $p
    union SURFACE_u surface; // $p
    char sense; // $c
    struct FACE_s *next_on_surface; // $p
    struct FACE_s *previous_on_surface; // $p
    struct FACE_s *next_front; // $p
    struct FACE_s *previous_front; // $p
    struct SHELL_s *front_shell; // $p
};
typedef struct FACE_s *FACE;

```

- Loop

Table F.40 — Loop fields

| Field name | Type | Description |
|-------------------|----------|-------------------------------------|
| node_id | int | Node-id |
| attributes_groups | pointer0 | Head of chain of attributes of loop |
| fin | pointer | One of ring of fins of loop |
| face | pointer | Face of loop |
| next | pointer0 | Next loop in face |

Isolated loops

An isolated loop (one consisting of a single vertex) does not refer directly to a vertex, but points to a fin which refers to that vertex. This isolated fin has fin->forward = fin->backward = fin, and fin->other = fin->curve = fin->edge = null. Its sense is not significant. The fin is chained into the chain of fins referencing the isolated vertex.

```

struct LOOP_s // Loop
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    struct FIN_s *fin; // $p
    struct FACE_s *face; // $p
    struct LOOP_s *next; // $p
};
typedef struct LOOP_s *LOOP;

```

- Fin

Table F.41 — Fin fields

| Field name | Type | Description |
|-------------------|----------|--|
| attributes_groups | pointer0 | Head of chain of attributes of fin |
| loop | pointer0 | Loop of fin |
| forward | pointer0 | Next fin around loop |
| backward | pointer0 | Previous fin around loop |
| vertex | pointer0 | Forward vertex of fin |
| other | pointer0 | Next fin around edge, clockwise looking along edge |
| edge | pointer0 | Edge of fin |
| curve | pointer0 | For a non-dummy fin of a tolerant edge, this will be a trimmed SP-curve, otherwise null. |
| next_at_vx | pointer0 | Next fin referencing the vertex of this fin |
| sense | char | Positive ('+') if the fin direction is parallel to that of its edge, else negative ('-') |

Dummy fins

An application will see edges as having any number of fins, including zero. However internally, they have at least two. This is so that the forward and backward vertices of an edge can always be found as edge->fin->vertex and edge->fin->other->vertex respectively - the first one being a positive fin, the second a negative fin. If an edge does not have both a positive and a negative externally-visible fin, dummy fins will exist for this purpose. Dummy fins have fin->loop = fin->forward = fin->backward = fin->curve = fin->next_at_vx = null. For example the boundaries of a sheet always have one dummy fin.

```

struct FIN_s // Fin
{
    union ATTRIB_GROUP_u attributes_groups; // $p
    struct LOOP_s *loop; // $p
    struct FIN_s *forward; // $p
    struct FIN_s *backward; // $p
    struct VERTEX_s *vertex; // $p
    struct FIN_s *other; // $p
    struct EDGE_s *edge; // $p
    union CURVE_u curve; // $p
    struct FIN_s *next_at_vx; // $p
    char sense; // $c
};

```



```
};
typedef struct FIN_s *FIN;
```

- Vertex

Table F.42 — Vertex fields

| Field name | Type | Description |
|-------------------|----------|--|
| node_id | int | Node-id |
| attributes_groups | pointer0 | Head of chain of attributes of vertex and member_of_groups of vertex |
| fin | pointer0 | Head of singly-linked chain of fins referencing this vertex |
| previous | pointer0 | Previous vertex in body |
| next | pointer0 | Next vertex in body |
| point | pointer | Point of vertex |
| tolerance | double | Tolerance of vertex (null-double for accurate vertex) |
| owner | pointer | Owning body (for non-acorn vertices) or shell (for acorn vertices) |

```
union SHELL_OR_BODY_u
{
    struct BODY_s          *body;
    struct SHELL_s         *shell;
};
typedef union SHELL_OR_BODY_u SHELL_OR_BODY;

struct VERTEX_s // Vertex
{
    int                node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    struct FIN_s       *fin; // $p
    struct VERTEX_s     *previous; // $p
    struct VERTEX_s     *next; // $p
    struct POINT_s      *point; // $p
    double              tolerance; // $f
    union SHELL_OR_BODY_u owner; // $p
};
typedef struct VERTEX_s *VERTEX;
```

- Edge

Table F.43 — Edge fields

| Field name | Type | Description |
|------------|------|-------------|
| node_id | int | Node-id |

| | | |
|-------------------|----------|--|
| attributes_groups | pointer0 | Head of chain of attributes of edge and member_of_groups of edge |
| tolerance | double | Tolerance of edge (null-double for accurate edges) |
| fin | pointer | One of singly-linked ring of fins around edge |
| previous | pointer0 | Previous edge in body or shell |
| next | pointer0 | Next edge in body or shell |
| curve | pointer0 | Curve of edge, zero for tolerant edge. If edge is accurate, but any of its vertices are tolerant, this will be a trimmed curve |
| next_on_curve | pointer0 | Next in chain of edges sharing the curve of this edge |
| previous_on_curve | pointer0 | Previous in chain of edges sharing the curve of this edge |
| owner | pointer | Owning body (for non-wireframe edges) or shell (for wireframe edges) |

```

struct EDGE_s // Edge
{
    int node_id; // $d
    union ATTRIB_GROUP_u attributes_groups; // $p
    double tolerance; // $f
    struct FIN_s *fin; // $p
    struct EDGE_s *previous; // $p
    struct EDGE_s *next; // $p
    union CURVE_u curve; // $p
    struct EDGE_s *next_on_curve; // $p
    struct EDGE_s *previous_on_curve; // $p
    union SHELL_OR_BODY_u owner; // $p
};
typedef struct EDGE_s *EDGE;

```

F.3.5.1 Associated Data

- List

Table F.44 — Associated List

| Field name | Type | Description |
|------------|---------|-------------|
| node_id | int | Zero |
| list_type | byte | Always 4 |
| notransmit | logical | Ignore |
| owner | pointer | Owning part |

| | | |
|---------------|----------|--|
| next | pointer0 | Ignore |
| previous | pointer0 | Ignore |
| list_length | int | Length of list (≥ 0) |
| block_length | int | Length of each block of list. Always 20 |
| size_of_entry | int | Ignore |
| finger_index | int | Any integer between 1 and list->list_length (set to 1 if length is zero). Ignore |
| finger_block | pointer | Any block for example the first one. Ignore |
| list_block | pointer | Head of singly-linked chain of pointer list blocks |

Lists, as shown in Table F.44, only occur in part data as the list of attributes referenced by a part.

```
typedef enum
{
    LIS_pointer      = 4
}
LIS_type_t;

union LIS_BLOCK_u
{
    struct POINTER_LIS_BLOCK_s      *pointer_block;
};
typedef union LIS_BLOCK_u          LIS_BLOCK;

union LIST_OWNER_u
{
    struct BODY_s                  *body;
    struct ASSEMBLY_s              *assembly;
    struct WORLD_s                 *world;
};
typedef union LIST_OWNER_u LIST_OWNER;

struct LIST_s                      // List Header
{
    int                            node_id;                // $d
    LIS_type_t                     list_type;              // $u
    logical                        notransmit;             // $l
    union LIST_OWNER_u             owner;                  // $p
    struct LIST_s                  *next;                  // $p
    struct LIST_s                  *previous;              // $p
    int                            list_length;            // $d
    int                            block_length;           // $d
    int                            size_of_entry;          // $d
    int                            finger_index;           // $d
    union LIS_BLOCK_u              finger_block;          // $p
    union LIS_BLOCK_u              list_block;            // $p
};
typedef struct LIST_s *LIST;
```

Pointer_lis_block

Table F.45 — Pointer List Block

| Field name | Type | Description |
|------------|------|-------------|
|------------|------|-------------|

| | | |
|------------------|----------|--|
| n_entries | int | Number of entries in this block (0 <= n_entries <= 20). Only the first block may have n_entries = 0. |
| index_map_offset | int | Shall be set to 0 |
| next_block | pointer0 | Next pointer list block in chain |
| Entries[20] | pointer0 | Pointers in block, those beyond n_entries shall be zero |

When the pointer_lis_block, as shown in Table F.45, is used as the root node in XT data containing more than one part, the restriction n_entries <= 20 does not apply.

The index_map_offset field is used for Indexed Transmit; applications writing XT data shall ensure this field is set to 0.

```

struct POINTER_LIS_BLOCK_s // Pointer List
{
    int n_entries; // $d
    int index_map_offset // $d
    struct POINTER_LIS_BLOCK_s *next_block; // $p
    void *entries[ 1 ]; // $p[]
};
typedef struct POINTER_LIS_BLOCK_s *POINTER_LIS_BLOCK;

```

Att_def_id

Table F.46 — Attribute Definition ID

| Field name | Type | Description |
|------------|------|---|
| string[] | char | String name for example "SDL/TYSA_COLOUR" |

```

struct ATT_DEF_ID_s // name field type for attrib def.
{
    char String[1]; // $c[]
};
typedef struct ATT_DEF_ID_s *ATT_DEF_ID;

```

Field_names

Table F.47 — Field Names

| Field name | Type | Description |
|------------|---------|--|
| names[] | pointer | Array of field names – unicode or char |

```

typedef union FIELD_NAME_u
{
    struct CHAR_VALUES_s *name
    struct UNICODE_VALUES_s *uname
};
FIELD_NAME_t;

```

```

struct FIELD_NAME_s          // attribute field name
{
    union FIELD_NAME_u      names[1];          // $p[]
};
typedef struct FIELD_NAME_s *FIELD_NAME;

```

Attrib_def

Table F.48 — Attribute definition

| Field name | Type | Description |
|------------------|--------------|---|
| next | pointer 0 | Next attribute definition. This can be ignored, except in partition data. |
| identifier | pointer | Pointer to string name |
| type_id | int | Numeric id, for example 8001 for colour. 9000 for user-defined attribute definitions |
| actions[8] | byte | Required actions on various events |
| field_names | pointer 0 | Names of fields (unicode or char) |
| legal_owners[14] | logical | Allowed owner types |
| fields[] | byte | Array of field types. Note that the number of fields is given by the length of the variable length part of this node, therefore the integer following the node type in the XT data. |

The legal_owners array is an array of logicals determining which node types may own this type of attribute.

For example if faces are allowed attrib_def -> legal_owners [SCH_fa_owner] = true.

Note that if the XT data contains user fields, the 'fields' field of an attribute definition may contain extra values, set to zero. These are to be ignored.

The 'actions' field in an attribute definition defines the behaviour of the attribute when an event (rotate, scale, translate, reflect, split, merge, transfer, change) occurs. The actions are in Table F.49:

Table F.49 — Attribute definition action fields

| Action | Explanation |
|------------|---|
| do_nothing | Leave attribute as it is |
| delete | Delete the attribute |
| transform | Transform the transformable fields (point, vector, direction, axis) by appropriate part of transformation |

| | |
|-------------------|--|
| propagate | Copy attribute onto split-off node |
| keep_sub_dominant | Move attribute(s) from deleted node onto surviving node in a merge, but any such attributes already on the surviving node are deleted. |
| keep_if_equal | Keep attribute if present on both nodes being merged, with the same field values. |
| combine | Move attribute(s) from deleted node onto surviving node, in a merge |

The XT attribute classes 1-7 correspond as shown in Table F.50:

Table F.50 — Corresponding attribute classes

| | split | merge | transfer | change | Rotate | scale | translate | reflect |
|---------|-----------|------------|------------|------------|------------|------------|------------|------------|
| class 1 | propagate | keep_equal | do_nothing | do_nothing | do_nothing | do_nothing | do_nothing | do_nothing |
| class 2 | delete | delete | delete | delete | do_nothing | delete | do_nothing | do_nothing |
| class 3 | delete | delete | delete | delete | Delete | delete | delete | delete |
| class 4 | propagate | keep_equal | do_nothing | do_nothing | Transform | transform | transform | transform |
| class 5 | delete | delete | delete | delete | Transform | transform | transform | transform |
| class 6 | propagate | combine | do_nothing | do_nothing | do_nothing | do_nothing | do_nothing | do_nothing |
| class 7 | propagate | combine | do_nothing | do_nothing | Transform | transform | transform | transform |

```
typedef enum
{
    SCH_rotate      = 0,
    SCH_scale       = 1,
    SCH_translate   = 2,
    SCH_reflect     = 3,
    SCH_split       = 4,
    SCH_merge       = 5,
    SCH_transfer    = 6,
    SCH_change      = 7,
    SCH_max_logged_event // last entry; value in $d[] code for
                        actions
}
SCH_logged_event_t;

typedef enum
{
    SCH_do_nothing   = 0,
    SCH_delete       = 1,
    SCH_transform    = 2,
    SCH_propagate    = 3,
    SCH_keep_sub_dominant = 4,
    SCH_keep_if_equal = 5,
    SCH_combine      = 6
}
SCH_action_on_fields_t;

typedef enum
```

```

{
SCH_as_owner   = 0,
SCH_in_owner   = 1,
SCH_by_owner   = 2,
SCH_sh_owner   = 3,
SCH_fa_owner   = 4,
SCH_lo_owner   = 5,
SCH_ed_owner   = 6,
SCH_vx_owner   = 7,
SCH_fe_owner   = 8,
SCH_sf_owner   = 9,
SCH_cu_owner   = 10,
SCH_pt_owner   = 11,
SCH_rg_owner   = 12,
SCH_fn_owner   = 13,
SCH_max_owner   // last entry; value in $l[] for
                  .legal_owners
} SCH_attrib_owners_t;

typedef enum
{
SCH_int_field      = 1,
SCH_real_field     = 2,
SCH_char_field     = 3,
SCH_point_field    = 4,
SCH_vector_field   = 5,
SCH_direction_field = 6,
SCH_axis_field     = 7,
SCH_tag_field      = 8,
SCH_pointer_field  = 9,
SCH_unicode_field  = 10
} SCH_field_type_t;

struct ATTRIB_DEF_s // attribute definition
{
struct ATTRIB_DEF_s *next; // $p
struct ATT_DEF_ID_s *identifier; // $p
int type_id; // $d
SCH_action_on_fields_t actions // $u[8]
[(int)SCH_max_logged_event];

struct FIELD_NAMES_s *field_names // $p
logical legal_owners // $l[14]
[(int)SCH_max_owner];

SCH_field_type_t fields[1]; // $u[]
};
typedef struct ATTRIB_DEF_s *ATTRIB_DEF;

```

- Attribute

Table F.51 — Attribute fields

| Field name | Type | Description |
|--------------|----------|---|
| node_id | int | Node-id |
| definition | pointer | Attribute definition |
| owner | pointer | Attribute owner |
| next | pointer0 | Next attribute, group, or member_of_group |
| previous | pointer0 | Previous ditto |
| next_of_type | pointer0 | Next attribute of this type in this part |

| | | |
|------------------|----------|---|
| previous_of_type | pointer0 | Previous attribute of this type in this part |
| fields[] | pointer | Fields, of type int_values etc. The number of fields is given by the length of the variable part of the node. There may be no fields. |

The attributes of a node, as shown in Table F.51, are chained using the next and previous pointers in the attribute. The attribute_groups pointer in the node points to the head of this chain. This chain also contains the member_of_groups of the node.

Attributes within the same part, with the same attribute definition, are chained together by the next_of_type and previous_of_type pointers. The part points to the head of this chain as follows. The attribute_chains pointer in the part points to a list which contains the heads of these attribute chains, one for each attribute definition which has attributes in the part. The list may be null.

Note that the attributes_groups chains in parts, groups and nodes contain the following types of node:

Part: attributes and groups

Group: attributes

Node: attributes and member_of_groups

```
union ATTRIBUTE_OWNER_u
{
    struct ASSEMBLY_s      *assembly;
    struct INSTANCE_s      *instance;
    struct BODY_s          *body;
    struct SHELL_s         *shell;
    struct REGION_s        *region;
    struct FACE_s          *face;
    struct LOOP_s          *loop;
    struct EDGE_s          *edge;
    struct FIN_s           *fin;
    struct VERTEX_s        *vertex;
    union SURFACE_u        Surface;
    union CURVE_u          Curve;
    struct POINT_s         *point;
    struct GROUP_s         *group;
};
typedef union ATTRIBUTE_OWNER_u ATTRIBUTE_OWNER;

union FIELD_VALUES_u
{
    struct INT_VALUES_s      *int_values;
    struct REAL_VALUES_s     *real_values;
    struct CHAR_VALUES_s     *char_values;
    struct POINT_VALUES_s    *point_values;
    struct VECTOR_VALUES_s   *vector_values;
    struct DIRECTION_VALUES_s *direction_values;
    struct AXIS_VALUES_s     *axis_values;
    struct TAG_VALUES_s      *tag_values;
    struct UNICODE_VALUES_s  *unicode_values;
};
typedef union FIELD_VALUES_u FIELD_VALUES;

struct ATTRIBUTE_s // Attribute
{
    int node_id; // $d
    struct ATTRIB_DEF_s *definition; // $p
    union ATTRIBUTE_OWNER_u owner; // $p
    union ATTRIB_GROUP_u next; // $p
    union ATTRIB_GROUP_u previous; // $p
    struct ATTRIBUTE_s *next_of_type; // $p
    struct ATTRIBUTE_s *previous_of_type; // $p
}
```



```

        union FIELD_VALUES_u                fields[1];                // $p[]
    };
typedef struct ATTRIBUTE_s *ATTRIBUTE;

```

- Int_values

Table F.52 — Integer values

| Field name | Type | Description |
|------------|------|----------------|
| values[] | int | Integer values |

```

struct INT_VALUES_s                // Int values
{
    int                values[1];                // $d[]
};
typedef struct INT_VALUES_s *INT_VALUES;

```

- Real_values

Table F.53 — Real values

| Field name | Type | Description |
|------------|--------|-------------|
| values[] | double | Real values |

```

struct REAL_VALUES_s                // Real values
{
    double                values[1];                // $f[]
};
typedef struct REAL_VALUES_s *REAL_VALUES;

```

- Char_values

Table F.54 — Character values

| Field name | Type | Description |
|------------|------|------------------|
| values[] | char | Character values |

```

struct CHAR_VALUES_s                // Character values
{
    char                values[1];                // $c[]
};
typedef struct CHAR_VALUES_s *CHAR_VALUES;

```

- Unicode_values

Table F.55 — Unicode values

| Field name | Type | Description |
|------------|-------|--------------------------|
| values[] | short | Unicode character values |

```

struct UNICODE_VALUES_s                                // Unicode character values
{
    short                values[1];                    // $w[]
};
typedef struct UNICODE_VALUES_s *UNICODE_VALUES;

```

- Point_values**Table F.56 — Point values**

| Field name | Type | Description |
|------------|--------|--------------|
| values[] | vector | Point values |

```

struct POINT_VALUES_s                                // Point values
{
    vector                values[1];                    // $v[]
};
typedef struct POINT_VALUES_s *POINT_VALUES;

```

- Vector_values**Table F.57 — Vector values**

| Field name | Type | Description |
|------------|--------|---------------|
| values[] | vector | Vector values |

```

struct VECTOR_VALUES_s                                // Vector values
{
    vector                values[1];                    // $v[]
};
typedef struct VECTOR_VALUES_s *VECTOR_VALUES;

```

- Direction_values**Table F.58 — Direction values**

| Field name | Type | Description |
|------------|--------|------------------|
| values[] | vector | Direction values |

```

struct DIRECTION_VALUES_s                            // Direction values
{

```

```

        vector                values[1];                // $v[]
    };
typedef struct DIRECTION_VALUES_s *DIRECTION_VALUES;

```

- Axis_values

Table F.59 — Axis values

| Field name | Type | Description |
|------------|--------|-------------|
| values[] | vector | Axis values |

Note that an axis takes up two vectors.

```

struct AXIS_VALUES_s                // Axis values
{
    vector                values[1];                // $v[]
};
typedef struct AXIS_VALUES_s *AXIS_VALUES;

```

- Tag_values

Table F.60 — Tag values

| Field name | Type | Description |
|------------|------|--------------------|
| values[] | int | Integer tag values |

The tag field type and the tag_values node are not available for use in user-defined attributes, they occur only in certain system attributes.

```

struct TAG_VALUES_s                // Tag values
{
    int                values[1];                // $t[]
};
typedef struct TAG_VALUES_s *TAG_VALUES;

```

Group

Table F.61 — Group fields

| Field name | Type | Description |
|-------------------|----------|---|
| node_id | int | Node-id |
| attributes_groups | pointer0 | Head of chain of attributes of this group |
| owner | pointer | Owning part |
| next | pointer0 | Next group or attribute |
| previous | pointer0 | Previous group or attribute |
| type | byte | Type of node allowed in group |

| | | |
|--------------|----------|---|
| first_member | pointer0 | Head of chain of member_of_group nodes in group |
|--------------|----------|---|

The groups in a part, as shown in Table F.61, are chained by the next and previous pointers in a group. The attributes_groups pointer in the part points to the head of the chain. This chain also contains the attributes attached directly to the part - groups and attributes are intermingled in this chain, the order is not significant.

Each group has a chain of member_of_groups. These are chained together using the next_member and previous_member pointers. The first_member pointer in the group points to the head of the chain. Each member_of_group has an owning_group pointer which points back to the group.

Each member_of_group has an owner pointer which points to a node. Thus the group references its member nodes via the member_of_groups.

The member_of_groups which refer to a particular node are chained using the next and previous pointers in the member_of_group. The attributes_groups pointer in the node points to the head of this chain. This chain also contains the attributes attached to the node.

```
typedef enum
{
    SCH_instance_fe    = 1,
    SCH_face_fe        = 2,
    SCH_loop_fe        = 3,
    SCH_edge_fe        = 4,
    SCH_vertex_fe      = 5,
    SCH_surface_fe     = 6,
    SCH_curve_fe       = 7,
    SCH_point_fe       = 8,
    SCH_mixed_fe       = 9,
    SCH_region_fe      = 10
} SCH_group_type_t;

struct GROUP_s          // Group
{
    int                  node_id;                // $d
    union ATTRIB_GROUP_u attributes_groups;      // $p
    union PART_u         owner;                  // $p
    union ATTRIB_GROUP_u next;                   // $p
    union ATTRIB_GROUP_u previous;              // $p
    SCH_group_type_t     type;                   // $u
    struct MEMBER_OF_GROUP_s *first_member;      // $p
};
typedef struct GROUP_s *GROUP;
```

- Member_of_group

Table F.62 — Group member fields

| Field name | Type | Description |
|---------------|----------|--|
| dummy_node_id | int | Entity label |
| owning_group | pointer | Owning group |
| owner | pointer | Referenced member of group |
| next | pointer0 | Next attribute, group or member_of_group |
| previous | pointer0 | Previous ditto |

| | | |
|-----------------|----------|------------------------------------|
| next_member | pointer0 | Next member_of_group in this group |
| previous_member | pointer0 | Previous ditto |

```

union GROUP_MEMBER_u
{
    struct INSTANCE_s      *instance;
    struct FACE_s          *face;
    struct REGION_s        *region;
    struct LOOP_s          *loop;
    struct EDGE_s          *edge;
    struct VERTEX_s        *vertex;
    union SURFACE_u        surface;
    union CURVE_u          curve;
    struct POINT_s         *point;
};
typedef union GROUP_MEMBER_u GROUP_MEMBER;

struct MEMBER_OF_GROUP_s // Member of group
{
    int dummy_node_id; // $d
    struct GROUP_s *owning_group; // $p
    union GROUP_MEMBER_u owner; // $p
    union ATTRIB_GROUP_u next; // $p
    union ATTRIB_GROUP_u previous; // $p
    struct MEMBER_OF_GROUP_s *next_member; // $p
    struct MEMBER_OF_GROUP_s *previous_member; // $p
};
typedef struct MEMBER_OF_GROUP_s *MEMBER_OF_GROUP;

```

- Part_XMT_block

Table F.63 — Description of fields in Part_XMT_block

| Field name | Type | Description |
|----------------------|----------|--|
| n_entries | int | Number of entries in this block (n_entries >1) |
| index_map_offset | int | Must be set to 0 |
| index_map | pointer0 | Must be set to null |
| schema_embedding_map | pointer0 | Must be set to null |
| mesh_offset_data | pointer0 | Data for embedded meshes. If the XT file does not contain embedded meshes, this field must be set to null. |
| entries[] | pointer0 | Pointers in block |

The PART_XMT_BLOCK, as shown in Table F.63, must be the root node in XT data containing more than one part,

The fields index_map_offset, index_map, and schema_embedding_map are used for Indexed Transmit.

The mesh_offset_data field is used for embedded mesh data.

```

struct PART_XMT_BLOCK_s          //Part List

{
    int                n_entries;                // $d
    unsigned            index_map_offset;        // $d
    struct INT_VALUES_s *index_map;              // $p
    struct INT_VALUES_s *schema_embedding_map;   // $p
    struct MESH_OFFSET_DATA_s *mesh_offset_data; // $p
    union PART_u_       entries [1];            // $p[]
};

typedef struct PART_XMT_BLOCK_s    *PART_XMT_BLOCK;

```

-Mesh_offset_data

The MESH_OFFSET_DATA node, as shown in Table F.64, is used for embedded mesh data. It is the second node in an XT file with embedded meshes. At most, there can only be one MESH_OFFSET_DATA node.

Table F.64 — Description of MESH_OFFSET_DATA fields

| Field name | Type | Description |
|-------------------------|----------|---|
| mesh_index_map | pointer0 | Must be set to an offset_values node |
| schema_data | pointer0 | See Schema data section for information |
| schema_data_offset_high | int | Must be present |
| schema_data_offset_low | int | Must be present |

The schema_data field must be present if the XT data contains embedded schema information, otherwise it must be set to null.

The schema_data_offset_high and schema_data_offset_low fields must be present and indicate either the offset of the schema_data node (if present), or the offset of the terminator.

```

struct MESH_OFFSET_DATA_s        //Mesh offset data

{
    struct OFFSET_VALUE_s         *mesh_index_map;                // $p
    struct SCHEMA_DATA_s         *schema_data;                  // $p
    unsigned                      *schema_data_offset_high;      // $d
    unsigned                      *schema_data_offset_low ;      // $d
};

typedef struct MESH_OFFSET_DATA_s *MESH_OFFSET_DATA;

```

-Offset_values

The OFFSET_VALUES node, as shown in Table F.65, contains the offset values of each PSM_MESH node. These offset values must be in the same order as the PSM_MESH nodes in the XT data. If this node is present, it must be the third node in the XT data.

Table F.65 — Description of OFFSET_VALUES fields

| Field name | Type | Description |
|------------|------|-------------------------------------|
| values[] | int | Offset values in high and low pairs |

```

struct OFFSET_VALUES_s      //Offset values
{
    unsigned    values[1];          //$d[]
}
typedef struct OFFSET_VALUES_s  *OFFSET_VALUES;

```

-Schema_data

The SCHEMA_DATA node must be present if the XT data contains embedded schema information. The SCHEMA_DATA node chains one NODE_MAP node per node type used in the mesh data section of the XT data (i.e. between the first PSM_MESH node and the last node before the SCHEMA_DATA node).

There is a NEW_NODE_MAP node defining the following node types:

- PSM_MESH
- INTEGER_TOOTH
- INTEGER_COMB
- VECTOR_TOOTH
- VECTOR_COMB

These node types are relative to the defined base schema.

```

struct SCHEMA_DATA_s //Schema data
{
    union NODE_MAP_u    node_map;          //$p
};
typedef struct SCHEMA_DATA_s *SCHEMA_DATA;

```

The SCHEMA_DATA node is followed by the NODE_MAP, FIELD_MAP, and SCHEMA_CHAR_VALUES nodes. These nodes will always be at the end of the embedded mesh file and indicate whether an embedded mesh file was saved using an embedded schema.

-Node_map union

```

union NODE_MAP_u
{
    struct ANY_NODE_MAP_s          *any;
    struct NEW_NODE_MAP_s          *new;
    struct MOD_NODE_MAP_s          *mod;
    struct OLD_NODE_MAP_s          *old;
};
typedef union NODE_MAP_u NODE_MAP;

```

-Node map nodes

All node map nodes share the following common fields, as shown in Table F.66:

Table F.66 — Node map nodes

| Field name | Type | Description |
|----------------------|----------|------------------------|
| next | pointer0 | Next node map in chain |
| exemplar_offset_high | int | Must be present |
| exemplar_offset_low | int | Must be present |
| node_types | short | Node type |

-Any_node_map

```
struct ANY_NODE_MAP_s //Any node map
{
    union NODE_MAP_u
    {
        unsigned int next; // $p
        unsigned int exemplar_offset_high; // $d
        unsigned int exemplar_offset_low; // $d
        short node_type; // $n
    };
};
typedef struct ANY_NODE_MAP_s *ANY_NODE_MAP;
```

-Old_node_map

```
struct OLD_NODE_MAP_s == ANY_NODE_MAP_s //Unchanged node map
{
    union NODE_MAP_u
    {
        unsigned int next; // $p
        unsigned int exemplar_offset_high; // $d
        unsigned int exemplar_offset_low; // $d
        short node_type; // $n
    };
};
typedef struct OLD_NODE_MAP_s *OLD_NODE_MAP;
```

-New_node_map

Table F.67 — New node map

| Field name | Type | Description |
|--------------------|---------|--|
| vla_field_xmt_code | logical | Whether the variable length array field (if present) should be saved to XT. If this field is not present, the value is set to false. |
| name | pointer | Points to the schema character values node that contain the node name. |
| description | pointer | Points to the schema character values node that contain the description. |
| field_maps [1] | pointer | Array of new field maps |

```
struct NEW_NODE_MAP_s == ANY_NODE_MAP_s //New node map
{
    union NODE_MAP_u
    {
        unsigned int next; // $p
        unsigned int exemplar_offset_high; // $d
        unsigned int exemplar_offset_low; // $d
        short node_type; // $n
        logical vla_field_xmt_code; // $l
    };
    struct SCHEMA_CHAR_VALUES_s *name; // $p
    struct SCHEMA_CHAR_VALUES_s *description; // $p
    struct NEW_FIELD_MAP_s *field_map [1]; // $p[1]
};
typedef struct NEW_NODE_MAP_s *NEW_NODE_MAP;
```

-Modified_node_map

Table F.68 — Modified node map

| Field name | Type | Description |
|--------------------|---------|--|
| vla_field_xmt_code | logical | Whether the variable length array field (if present) should be saved to XT. If this field is not present, the value is set to false. |
| field_maps [1] | pointer | Array of new field maps |

```

struct NEW_NODE_MAP_s == ANY_NODE_MAP_s //New node map
{
    union NODE_MAP_u
    {
        unsigned    next;                // $p
        unsigned    exemplar_offset_high; // $d
        unsigned    exemplar_offset_low;  // $d
        short       node_type;            // $n
        logical     vla_field_xmt_code;    // $1
        struct SCHEMA_CHAR_VALUES_s *name // $p
        struct SCHEMA_CHAR_VALUES_s *description // $p
        struct NEW_FIELD_MAP_s *field_map [1]; // $p[]
    };
};
typedef struct NEW_NODE_MAP_s *NEW_NODE_MAP;

```

-Field_map union

```

union FIELD_MAP_u
{
    struct NEW_FIELD_MAP_s *new;
    struct OLD_FIELD_MAP_s *old;
};
typedef union FIELD_MAP_u FIELD_MAP;

```

-Old_field_map**Table F.69 — Old Field Map**

| Field name | Type | Description |
|------------|------|--|
| base_index | byte | The field number this field used to be in the baseline schema. |

```

struct OLD_FIELD_MAP_s //Old field map
{
    SCH_byte_t base_index; // $u
};
typedef struct OLD_FIELD_MAP_s *OLD_FIELD_MAP;

```

-New_field_map**Table F.70 — New Field Map**

| Field name | Type | Description |
|------------|---------|--|
| name | pointer | Points to the schema character values node that contains the field name. |

| | | |
|-----------|---------|--|
| ptr_class | short | Node type or class of the field if it is a pointer field |
| n_elts | int | Number of elements for that field |
| type | pointer | Points to a schema character values node that contains the field type. |

```

struct NEW_FIELD_MAP_s //New field map
{
    struct SCHEMA_CHAR_VALUES_s    *name                // $p
    short                          ptr_class;            // $n
    int                            n_elts;               // $d
    struct SCHEMA_CHAR_VALUES_s    *type;               // $p
};
typedef struct NEW_FIELD_MAP_s    *NEW_FIELD_MAP;

```

-Schema_char_values

Table F.71 — Schema Char Values

| Field name | Data Type | Description |
|------------|-----------|------------------|
| values[] | char | Character values |

```

struct SCHEMA_CHAR_VALUES_s //Schema character values
{
    char values[1];          // $c[ ]
}
typedef struct SCHEMA_CHAR_VALUES_s *SCHEMA_CHAR_VALUES;

```

F.3.6 Nodes and Classes

Node Types

Table F.72 — Node types

| Node Name | Node Type | Has Node-ID |
|--------------|-----------|-------------|
| ASSEMBLY | 10 | No |
| INSTANCE | 11 | Yes |
| BODY | 12 | No |
| SHELL | 13 | Yes |
| FACE | 14 | Yes |
| LOOP | 15 | Yes |
| EDGE | 16 | Yes |
| FIN | 17 | No |
| VERTEX | 18 | Yes |
| REGION | 19 | Yes |
| POINT | 29 | Yes |
| LINE | 30 | Yes |
| CIRCLE | 31 | Yes |
| ELLIPSE | 32 | Yes |
| INTERSECTION | 33 | Yes |
| CHART | 40 | |
| LIMIT | 41 | |

| | | |
|-------------------|----|-----|
| BSPLINE_VERTICES | 45 | |
| PLANE | 50 | Yes |
| CYLINDER | 51 | Yes |
| CONE | 52 | Yes |
| SPHERE | 53 | Yes |
| TORUS | 54 | Yes |
| BLENDED_EDGE | 56 | Yes |
| BLEND_BOUND | 59 | |
| OFFSET_SURF | 60 | Yes |
| SWEPT_SURF | 67 | Yes |
| SPUN_SURF | 68 | Yes |
| LIST | 70 | Yes |
| POINTER_LIS_BLOCK | 74 | |
| ATT_DEF_ID | 79 | |
| ATTRIB_DEF | 80 | No |

Node Names

Table F.73 — Node Types Continued

| Node Name | Node Type | Has Node-ID |
|------------------|-----------|-------------|
| ATTRIBUTE | 81 | Yes |
| INT_VALUES | 82 | |
| REAL_VALUES | 83 | |
| CHAR_VALUES | 84 | |
| POINT_VALUES | 85 | |
| VECTOR_VALUES | 86 | |
| AXIS_VALUES | 87 | |
| TAG_VALUES | 88 | |
| DIRECTION_VALUES | 89 | |
| GROUP | 90 | Yes |
| MEMBER_OF_GROUP | 91 | |
| UNICODE_VALUES | 98 | |
| FIELD_NAMES | 99 | |
| TRANSFORM | 100 | No |
| WORLD | 101 | |
| KEY | 102 | |
| PE_SURF | 120 | Yes |
| INT_PE_DATA | 121 | |
| EXT_PE_DATA | 122 | |
| B_SURFACE | 124 | No |
| SURFACE_DATA | 125 | |
| NURBS_SURF | 126 | |
| KNOT_MULT | 127 | |
| KNOT_SET | 128 | |
| PE_CURVE | 130 | Yes |
| TRIMMED_CURVE | 133 | Yes |
| B_CURVE | 134 | Yes |
| CURVE_DATA | 135 | |
| NURBS_CURVE | 136 | |
| SP_CURVE | 137 | Yes |
| GEOMETRIC_OWNER | 141 | |
| HELIX_SU_FORM | 163 | |
| PART_XMT_BLOCK | 176 | |
| HELIX_CU_FORM | 184 | |
| POLYLINE | 200 | Yes |

| | | |
|---------------------|-----|-----|
| MESH | 201 | Yes |
| INTERSECTION_DATA | 204 | No |
| OFFSET_VALUES | 205 | |
| MESH_OFFSET_DATA | 206 | |
| SCHEMA_CHAR_VALUES | 207 | |
| NEW_NODE_MAP | 208 | |
| MOD_NODE_MAP | 209 | |
| NEW_FIELD_MAP | 210 | |
| SCHEMA_DATA | 211 | |
| OLD_NODE_MAP | 212 | |
| OLD_FIELD_MAP | 213 | |
| REAL_TOOTH | 220 | |
| REAL_COMB | 221 | |
| GRAPH_COMPACT | 224 | |
| TRANSFORM_PRECISION | 229 | |

Node Classes

| Node Class Name | Node Class |
|---------------------|------------|
| GEOMETRY | 1003 |
| PART | 1005 |
| SURFACE | 1006 |
| SURFACE_OWNER | 1007 |
| CURVE | 1008 |
| CURVE_OWNER | 1010 |
| POINT_OWNER | 1011 |
| LIS_BLOCK | 1012 |
| LIST_OWNER | 1013 |
| ATTRIBUTE_OWNER | 1015 |
| FEATUREGROUP_OWNER | 1016 |
| FEATUREGROUP_MEMBER | 1017 |
| FIELD_VALUES | 1018 |
| ATTRIB_FEATUREGROUP | 1019 |
| TRANSFORM_OWNER | 1023 |
| PE_DATA | 1027 |
| PE_INT_GEOM | 1028 |
| SHELL_OR_BODY | 1029 |
| FIELD_NAME | 1037 |
| BODY_OWNER | 1040 |
| COMB | 1042 |
| NODE_MAP | 1043 |
| FIELD_MAP | 1044 |

F.3.7 System Attribute Definitions

All system attribute definitions are of class 1.

F.3.7.1 Colour

Table F.74 — Colour

| | |
|---------------------|-----------------|
| Identifier | SDL/TYSA_COLOUR |
| Token | 8001 |
| Entity types | face edge |

| | | | |
|--------|------|-------------|--|
| Fields | real | Red value | These three values should be in the range 0.0 to 1.0 |
| | | Green value | |
| | | Blue value | |
| Set by | | Application | |

F.3.7.2 Colour 2

Table F.75 — Colour 2

| | | | |
|--------------------|--------------------------|-------------|--|
| Identifier | SDL/TYSA_COLOUR_2 | | |
| Token | 8040 | | |
| Legal Owner | body, instance, assembly | | |
| Fields | real | Red value | These three values should be in the range 0.0 to 1.0 |
| | | Green value | |
| | | Blue value | |

F.3.7.3 Density Attributes

There are density attributes for each of regions, faces, edges and vertices in addition to the system attribute for density of a body.

The region/face/edge/vertex attributes will be taken into account when finding the mass, centre of gravity and moment of inertia of a body or of the entity to which the attribute is attached:

- The mass of a region will not include that of any of its faces or edges, and the same applies to faces and edges and their boundaries.
- A void region will always have zero mass whatever its density and a solid region will inherit its density from the body if it does not have a density of its own.
- The default density for faces, edges and vertices is always zero.

- Density (of a body)

Table F.76 — Body Density

| | | |
|---------------------|------------------|---------|
| Identifier | SDL/TYSA_DENSITY | |
| Type_id | 8004 | |
| Entity types | body | |
| Fields | real | Density |
| | string | Units |
| Set by | Application | |

A body without a density attribute is taken to have, by default, a density of 1.0.

The character field units can be set and read by the application.

- Region Density

Table F.77 — Region Density

| | | |
|---------------------|-------------------------|-------------------|
| Identifier | SDL/TYSA_REGION_DENSITY | |
| Type_id | 8023 | |
| Entity types | region | |
| Fields | real | Density of region |
| | string | Units |
| Set by | Application | |

This attribute only makes sense for solid regions; void regions always have a mass of zero.

A solid region without a density attribute is taken to have, by default, the same density as its owning body.

The character field units can be set and read by the user.

- Face Density

Table F.78 — Face Density

| | | |
|---------------------|-----------------------|-----------------|
| Identifier | SDL/TYSA_FACE_DENSITY | |
| Type_id | 8024 | |
| Entity types | face | |
| Fields | real | Density of face |
| | string | Units |
| Set by | Application | |

The value of this attribute is treated as a mass per unit area.

A mass will be calculated for a face only when a face possesses this attribute. In all other cases the mass of a face is not defined.

The character field units can be set and read by the user.

- Edge Density

Table F.79 — Edge Density

| | | |
|-------------------|-----------------------|--|
| Identifier | SDL/TYSA_EDGE_DENSITY | |
| Type_id | 8025 | |

| | | |
|---------------------|-------------|-----------------|
| Entity types | edge | |
| Fields | real | Density of edge |
| | string | Units |
| Set by | Application | |

The value of this attribute is treated as a mass per unit length.

A mass will be calculated for an edge only when an edge possesses this attribute. In all other cases the mass of an edge is not defined

The character field units can be set and read by the user.

- Vertex Density

Table F.80 — Vertex Density

| | | |
|---------------------|-------------------------|----------------|
| Identifier | SDL/TYSA_VERTEX_DENSITY | |
| Type_id | 8026 | |
| Entity types | vertex | |
| Fields | real | Mass of vertex |
| | string | Units |
| Set by | Application | |

The value of this attribute is treated as a point mass.

A mass will be calculated for a vertex only when a vertex possesses this attribute. In all other cases the mass of a vertex is not defined.

The character field units can be set and read by the user.

F.3.7.4 Hatching Attributes

- Hatching

Table F.81 — Hatching

| | | |
|---------------------|-------------------|---------------|
| Identifier | SDL/TYSA_HATCHING | |
| Type_id | 8003 | |
| Entity types | face | |
| Fields | real | real 1 |
| | | real 2 |
| | | real 3 |
| | | real 4 |
| | integer | Hatching type |
| Set by | Application | |

For planar hatching - the four real values define the hatch orientation as a vector and a spacing between consecutive planes.

For radial hatching - the first three real values define the spacing of the hatch lines. The fourth value is not used.

For parametric hatching - the first two real values define the spacing in u and v respectively. The last two values are not used.

- Planar Hatch

Table F.82 — Planar Hatch

| | | | | |
|--------------|-----------------------|-----------------------|-----------------------------|-----------------|
| Identifier | SDL/TYSA_PLANAR_HATCH | | | |
| Type_id | 8021 | | | |
| Entity types | face | | | |
| Fields | real | x component | 'direction' or plane normal | |
| | | y component | | |
| | | z component | | |
| | | 'pitch' or separation | | position vector |
| | | x component | | |
| | | y component | | |
| | | z component | | |
| Set by | Application | | | |

For planar hatching, an attribute with this definition takes precedence over an attribute with the SDL/TYSA_HATCHING definition, if a face has both types of attribute attached.

- Radial Hatch

Table F.83 — Radial Hatch

| | |
|-------------------|-----------------------|
| Identifier | SDL/TYSA_RADIAL_HATCH |
| Type_id | 8027 |

| | | |
|---------------------|-------------|---------------------|
| Entity types | face | |
| Fields | real | radial around |
| | | radial along |
| | | radial about |
| | | radial around start |
| | | radial along start |
| | | radial about start |
| Set by | Application | |

For radial hatching, an attribute with this definition takes precedence over an attribute with the SDL/TYSA_HATCHING definition, if a face has both types of attribute attached.

- Parametric Hatch

Table F.84 — Parametric Hatch

| | | |
|---------------------|----------------------|-----------|
| Identifier | SDL/TYSA_PARAM_HATCH | |
| Type_id | 8028 | |
| Entity types | face | |
| Fields | real | u spacing |
| | | v spacing |
| | | u start |
| | | v start |
| Set by | Application | |

For parametric hatching, an attribute with this definition takes precedence over an attribute with the SDL/TYSA_HATCHING definition, if a face has both types of attribute attached.

F.3.7.5 Name

Table F.85 — Name

| | | |
|---------------------|---|----------------|
| Identifier | SDL/TYSA_NAME | |
| Token | 8017 | |
| Entity types | assembly, body, instance, shell, face, loop, edge, vertex, group, surface, curve, point | |
| Fields | string | Name of entity |
| Set by | Application | |

F.3.7.6 Reflectivity

Table F.86 — Reflectivity

| | | |
|---------------------|-----------------------|--|
| Identifier | SDL/TYSA_REFLECTIVITY | |
| Token | 8014 | |
| Entity types | face | |
| Fields | real | Coefficient of specular reflection |
| | | Proportion of coloured light in highlights |

| | | |
|---------------|-------------|-----------------------------------|
| | | Coefficient of diffuse reflection |
| | | Coefficient of ambient reflection |
| | integer | Reflection power |
| Set by | Application | |

F.3.7.7 Translucency

Table F.87 — Translucency

| | | | |
|---------------------|-----------------------|--------------------------|--|
| Identifier | SDL/TYSA_TRANSLUCENCY | | |
| Token | 8015 | | |
| Entity types | face | | |
| Fields | real | Transparency coefficient | range 0.0 to 1.0, where 0 is opaque and 1 is transparent |
| Set by | Application | | |

F.3.7.8 Transparency

Table F.88 — Transparency

| | | |
|---------------------|-----------------------|--|
| Identifier | SDL/TYSA_TRANSPARENCY | |
| Token | 8029 | |
| Entity types | Body, face | |
| Fields | integer | Non-zero transparency coefficient value is transparent |
| Set by | Application | |

F.3.7.9 Unicode name

Table F.89 — Unicode name

| | | |
|---------------------|--|----------------|
| Identifier | SDL/TYSA_UNAME | |
| Token | 8038 | |
| Entity types | assembly, body, instance, shell, face, loop, edge, vertex, group, surf, curve, point, region | |
| Fields | ustring | Name of entity |
| Set by | Application | |

If a group has an attribute of this definition attached, it indicates that alternative behaviour should be used if an entity in the group is merged with an entity not in that group.

F.3.7.10 Group merge behaviour

Table F.90 — Group merge behaviour

| | | |
|---------------------|----------------------|--|
| Identifier | SDL/TYSA_GROUP_MERGE | |
| Token | 8037 | |
| Entity types | group | |

| | | |
|---------------|-------------|--------|
| | | |
| Fields | string | Unused |
| Set by | Application | |

F.3.7.11 Non-mergeable edges

Table F.91 — Non-mergeable edges

| | | |
|---------------------|-------------------|--------|
| Identifier | SDL/TYSA_NO_MERGE | |
| Token | 8032 | |
| Entity types | edge | |
| Fields | string | Unused |
| Set by | Application | |

F.3.7.12 Region

Table F.92 — Region

| | | |
|---------------------|-----------------|--------|
| Identifier | SDL/TYSA_REGION | |
| Type_id | 8013 | |
| Entity types | face | |
| Fields | string | Unused |
| Set by | Application | |

Regional data will allow the application to analyze a hidden-line picture for distinct regions in the 2D view.

F.3.7.13 Scale factor

Table F.93 — Scale factor

| | | |
|---------------------|-----------------------|---|
| Identifier | SDL/TYSA_SCALE_FACTOR | |
| Type_id | 8051 | |
| Entity types | assembly, body | |
| Fields | integer | Order of magnitude (factor of 10) from a base scale |
| Set by | Application | |

This attribute definition represents the scale factor of a part.

F.4XT Moniker Attributes

In order to allow design in context based on JT files, it is mandatory to provide a stable possibility to recognize a particular B-Rep element, especially faces, for external links.

Consider a design change as shown in the Figure F.4:

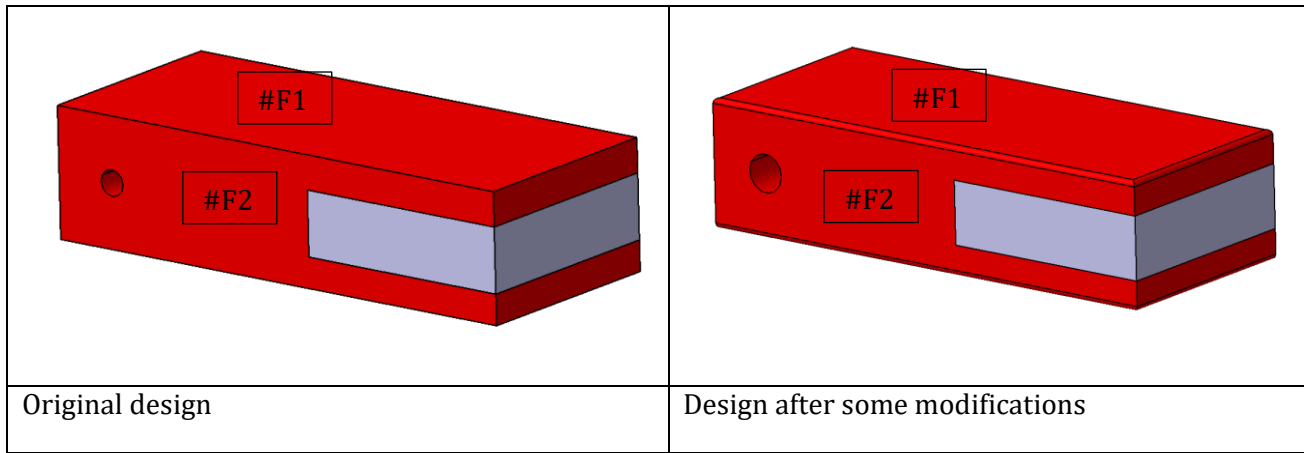


Figure F.4 Design change consideration

In case of an external reference to one of the faces, therefore the top face #F1, it must be possible to reconsider the proper face when replacing the part. Otherwise, the external link requires an interactive reassignment.

Internally, CAD systems typically maintain names or identifiers for B-Rep entities that persist across modelling operations. These persistent names are called “Moniker IDs” in context of JT.

Note: Moniker IDs are not 100% reliable in any CAD system. If a very extensive design change is performed, some of the Moniker IDs may not be preserved.

This kind of mechanism can only work when the two JT files (original and modified designed) have been converted with the same convertor (and settings) or at least the same algorithm for adding the Moniker ID. Furthermore, it must be possible to retrieve a stable persistent ID from the original CAD system.

Moniker IDs

Moniker attributes were created to enable JT adopters with the ability to keep track of design changes made to the solid bodies stored in the XT segment of a JT file. For example, a CAD system that imports JT data that is generated from an updated version of an existing CAD model can use moniker data to determine which bodies in the XT segment of the JT file have changed. These attributes are defined to enable consistent use of JT with XT geometry for data exchange. Moniker attributes must be uniquely defined and persisted to be effective.

Moniker attributes follow the standard convention for creation of attributes in the XT segment of JT. For detailed information on Attributes in the XT segment of JT files see the Attributes section of this Annex.

MONIKER/GUID_TABLE_ATTRIB and MONIKER/MONIKER_DATA_ATTRIB

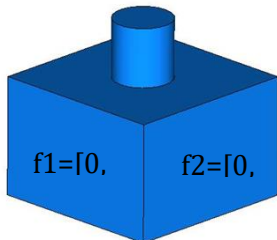
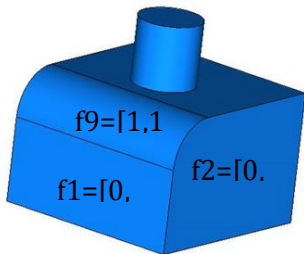
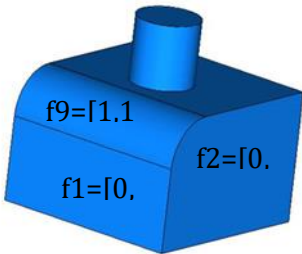
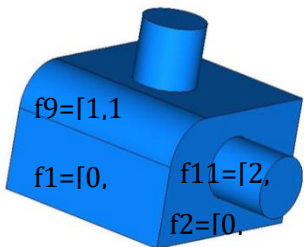
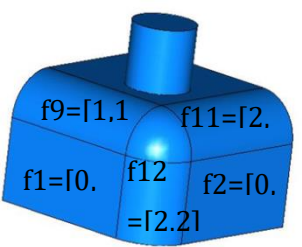
The MONIKER/GUID_TABLE_ATTRIB and MONIKER/MONIKER_DATA_ATTRIB attributes are used to store data in the XT segment of a JT file that records unique identifiers for XT faces and bodies with index values to link them together.

Unique identifiers for bodies are assigned as GUID strings for each version of a body. Unique identifiers for faces are assigned as 32-bit integers. An index field is used to tie the identifier of a body to the identifier of a face. For every version of a body, a set of MONIKER/GUID_TABLE_ATTRIB and MONIKER/MONIKER_DATA_ATTRIB attributes will be defined to record that version’s identifiers. For example, a model might start with a body that has 6 faces. That body will have one MONIKER/GUID_TABLE_ATTRIB attributes and 6 MONIKER/MONIKER_DATA_ATTRIB attributes. If a change is made that adds one face to the body, that body then will have a new version. There will be 2 MONIKER/GUID_TABLE_ATTRIB attributes and 7 MONIKER/MONIKER_DATA_ATTRIB attributes. The information in these attributes is used to form an indexed table of values for bodies and faces. The indices

in the first body version will relate 6 faces to that version's GUID string. The index value in the second version of the body will tie one face ID to that version's GUID string.

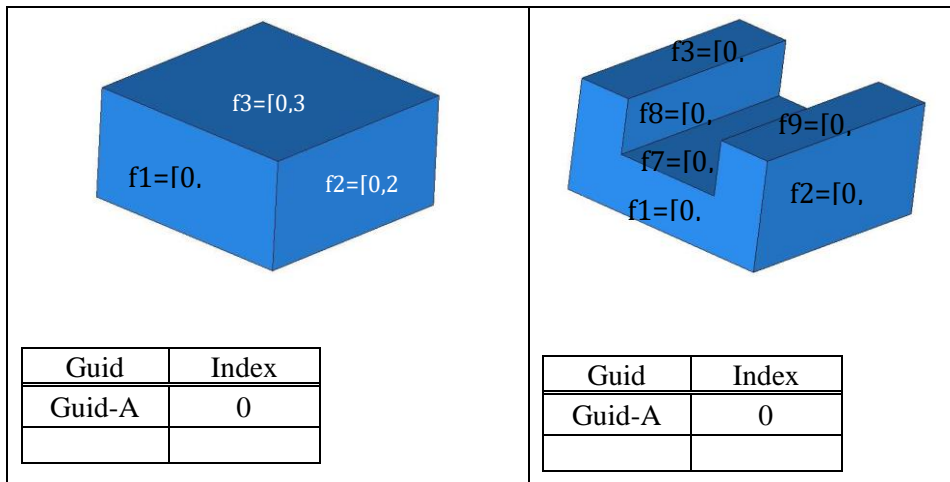
Table F.94 — Moniker attribute use example shows how moniker attributes are used. Each version of a body has a unique GUID. The face identifiers reflect their GUID and index values.

Table F.94 — Moniker attribute use example

| Operation | Application X | Application Y | Operation | | | | | | | | | | | | | | | | |
|---|---------------|---------------|-----------|---|--------|---|--|---|---|--|---|--------|-------|--------|---|--------|---|--------|---|
| <p>Application X constructs initial model.</p> <p>Single entry in GUID table</p> <p>Part 1.0</p> <table><tr><th>GUID</th><th>Index</th></tr><tr><td>GUID-A</td><td>0</td></tr><tr><td></td><td></td></tr></table> | GUID | Index | GUID-A | 0 | | |  | | | | | | | | | | | | |
| GUID | Index | | | | | | | | | | | | | | | | | | |
| GUID-A | 0 | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| <p>Application X modifies model with blend</p> <p>Adds entry in GUID Table</p> <p>New f9 moniker on blend Face uses new GUID index.</p> <p>Part 1.1</p> <table><tr><th>GUID</th><th>Index</th></tr><tr><td>GUID-A</td><td>0</td></tr><tr><td>GUID-B</td><td>1</td></tr></table> | GUID | Index | GUID-A | 0 | GUID-B | 1 |  |  | <p>Part imported into Application Y</p> <p>Monikers are unchanged on imported part.</p> <p>Part 2.0</p> <table><tr><th>GUID</th><th>Index</th></tr><tr><td>GUID-A</td><td>0</td></tr><tr><td>GUID-B</td><td>1</td></tr></table> | GUID | Index | GUID-A | 0 | GUID-B | 1 | | | | |
| GUID | Index | | | | | | | | | | | | | | | | | | |
| GUID-A | 0 | | | | | | | | | | | | | | | | | | |
| GUID-B | 1 | | | | | | | | | | | | | | | | | | |
| GUID | Index | | | | | | | | | | | | | | | | | | |
| GUID-A | 0 | | | | | | | | | | | | | | | | | | |
| GUID-B | 1 | | | | | | | | | | | | | | | | | | |
| <p>Application X adds a boss.</p> <p>New entry in GUID table is unique. New boss faces reference new GUID index</p> <p>Part 1.2</p> <table><tr><th>GUID</th><th>Index</th></tr><tr><td>GUID-A</td><td>0</td></tr><tr><td>GUID-B</td><td>1</td></tr><tr><td>GUID-C</td><td>2</td></tr></table> | GUID | Index | GUID-A | 0 | GUID-B | 1 | GUID-C | 2 |  |  | <p>Application Y adds 2 blends.</p> <p>New entry in GUID table is unique.</p> <p>New blend face monikers reference new GUID</p> <p>Part 2.1</p> <table><tr><th>GUID</th><th>Index</th></tr><tr><td>GUID-A</td><td>0</td></tr><tr><td>GUID-B</td><td>1</td></tr><tr><td>GUID-D</td><td>2</td></tr></table> | GUID | Index | GUID-A | 0 | GUID-B | 1 | GUID-D | 2 |
| GUID | Index | | | | | | | | | | | | | | | | | | |
| GUID-A | 0 | | | | | | | | | | | | | | | | | | |
| GUID-B | 1 | | | | | | | | | | | | | | | | | | |
| GUID-C | 2 | | | | | | | | | | | | | | | | | | |
| GUID | Index | | | | | | | | | | | | | | | | | | |
| GUID-A | 0 | | | | | | | | | | | | | | | | | | |
| GUID-B | 1 | | | | | | | | | | | | | | | | | | |
| GUID-D | 2 | | | | | | | | | | | | | | | | | | |

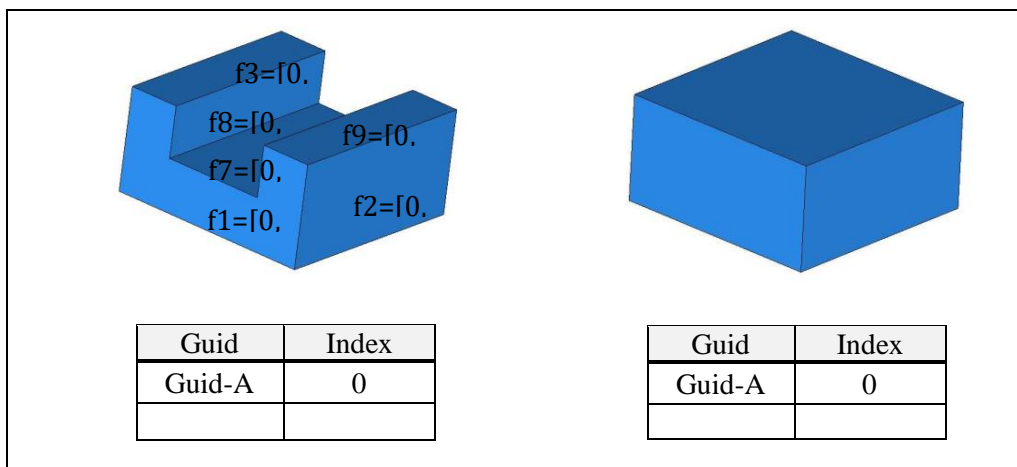
If during a modelling operation a moniker bearing face is split into multiple faces then the moniker attribute is carried over to all the resulting faces (see Figure F.5 — Split a face).

Figure F. 5 — Split a face



When multiple entities get merged in a modelling operation, the moniker attributes from both entities are copied to the new entity. The moniker data from the input faces should not match (see Figure F.6 — Merge faces)

Figure F. 6 — Merge faces



The MONIKER/GUID_TABLE_ATTRIB and MONIKER/MONIKER_DATA_ATTRIB table provides attribute data descriptions, as shown in Table F.95.

Table F.95 — MONIKER/GUID_TABLE_ATTRIB and MONIKER/MONIKER_DATA_ATTRIB

| XT Attribute name | Description |
|-----------------------------|--|
| MONIKER/GUID_TABLE_ATTRIB | <p>An XT body can have multiple occurrences of this attribute.</p> <p>This attribute contains 3 fields:</p> <ol style="list-style-type: none"> 1. GUID string – GUID (Globally Unique Identifier). Each version of an XT body will have a GUID string. The string consists of a series of hexadecimal values separated by a “-”. The GUID string syntax appears this way when using the C printf convention for strings; “{%08x-%04x-%04x-%02x%02x-%02x%02x%02x%02x%02x%02x}” 2. Index – a 32 bit integer. Corresponds with the index field value in MONIKER/MONIKER_DATA_ATTRIB. 3. Application name string – optional string used to record the application that authored the attribute |
| MONIKER/MONIKER_DATA_ATTRIB | <p>Each face can have in an XT segment can have this attribute.</p> <p>Each attribute contains 3 fields:</p> <ol style="list-style-type: none"> 1. Index – a 32 bit integer. Correspond with the index field value in MONIKER/GUID_TABLE_ATTRIB. 2. Entity Id - a 32 bit integer face identifier. 3. Label string – optional string for face specific information. |

MONIKER/BODY_ID_ATTRIB

MONIKER/BODY_ID_ATTRIB is a standalone attribute with no dependencies to the MONIKER/GUID_TABLE_ATTRIB or MONIKER/MONIKER_DATA_ATTRIB attributes. It is created for each version of an XT body in the XT segment of an JT file. An XT body can have multiple occurrences of this attribute, each with an id for that version of the body. It is valid for an XT segment of a JT file to contain all three moniker attributes as different CAD systems will use one or the other constructs, as shown in Table F.96.

Table F.96 — MONIKER/BODY_ID_ATTRIB

| XT Attribute name | Description |
|------------------------|--|
| MONIKER/BODY_ID_ATTRIB | <p>This attribute is created for each version of an XT body in the XT segment of a JT file. It is used to uniquely identify an XT body in the XT segment of a JT file. The Entity Id field is populated with an incrementing integer typically utilized by CAD authoring systems.</p> <p>This attribute consists of 2 fields:</p> <ol style="list-style-type: none"> 1. Entity Id - 32 bit integer 2. Application name string – optional string used to record the application that authored the attribute |

Annex G

JT ULP Segment

JT ULP Segment contains an Element that defines the semi-precise geometric Boundary Representation data for a particular Part in JT ULP format.

JT ULP Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The JT ULP Segment type supports compression on all element data, so all elements in JT ULP Segment use the Logical Element Header Compressed form of element header data, as shown in Figure G.1.

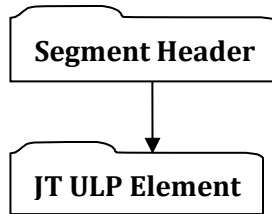


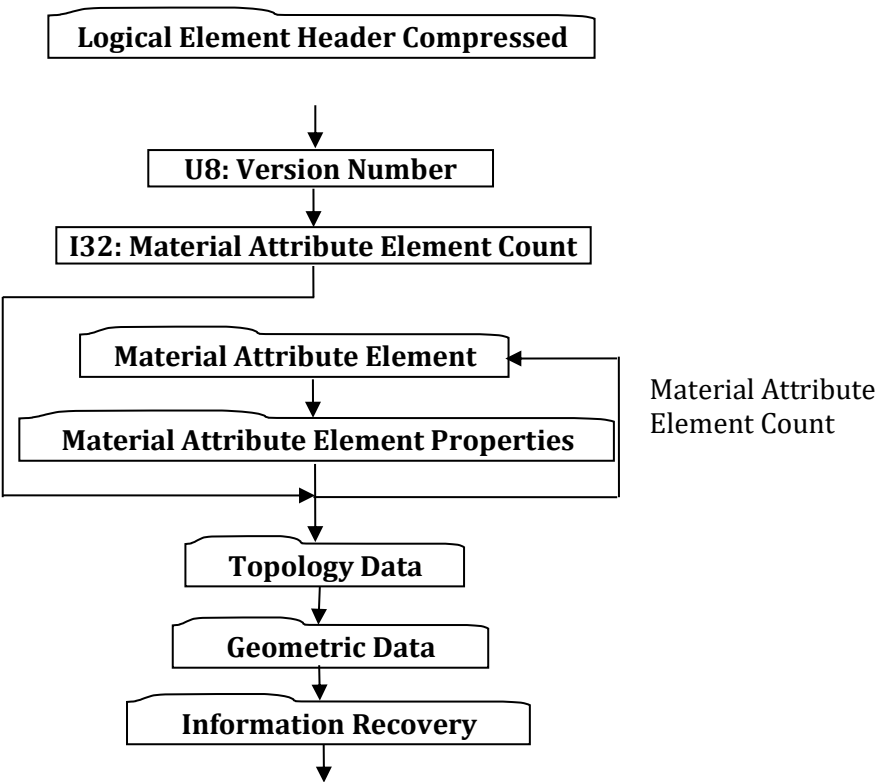
Figure G.1 — JT ULP Segment data collection

Complete description for Segment Header can be found in the File Header section of Base Format Description under Data Segment.

G.1 JT ULP Element

Object Type ID: 0xf338a4af, 0xd7d2, 0x41c5, 0xbc, 0xf2, 0xc5, 0x5a, 0x88, 0xb2, 0x1e, 0x73

JT ULP Element, as shown in Figure G.2, represents a particular Part’s ultra-lightweight semi-precise B-Rep data. Like JT B-Rep Element or XT B-Rep Element, JT ULP Element contains all the topological and geometric information that describes the shape of a part. The difference is that the size of JT ULP Element is typically around 10% of a typical JT file with B-Rep and LODs, and this is achieved by sophisticated compression techniques. In addition, JT ULP Element is semi-precise meaning that its geometric description is not as precise as either JT B-Rep Element or XT B-Rep Element. The precision loss of JT ULP Element, however, is carefully controlled to be equal to or better than 0.01% of the part size or 0.1mm,



whichever is smaller.

Figure G.2 — JT ULP Element data collection

Complete description for Logical Element Header Compressed, as shown in Figure G.2, can be found in the File Header section of

Base Format Description under Data Segment, Data.

U8: Version Number

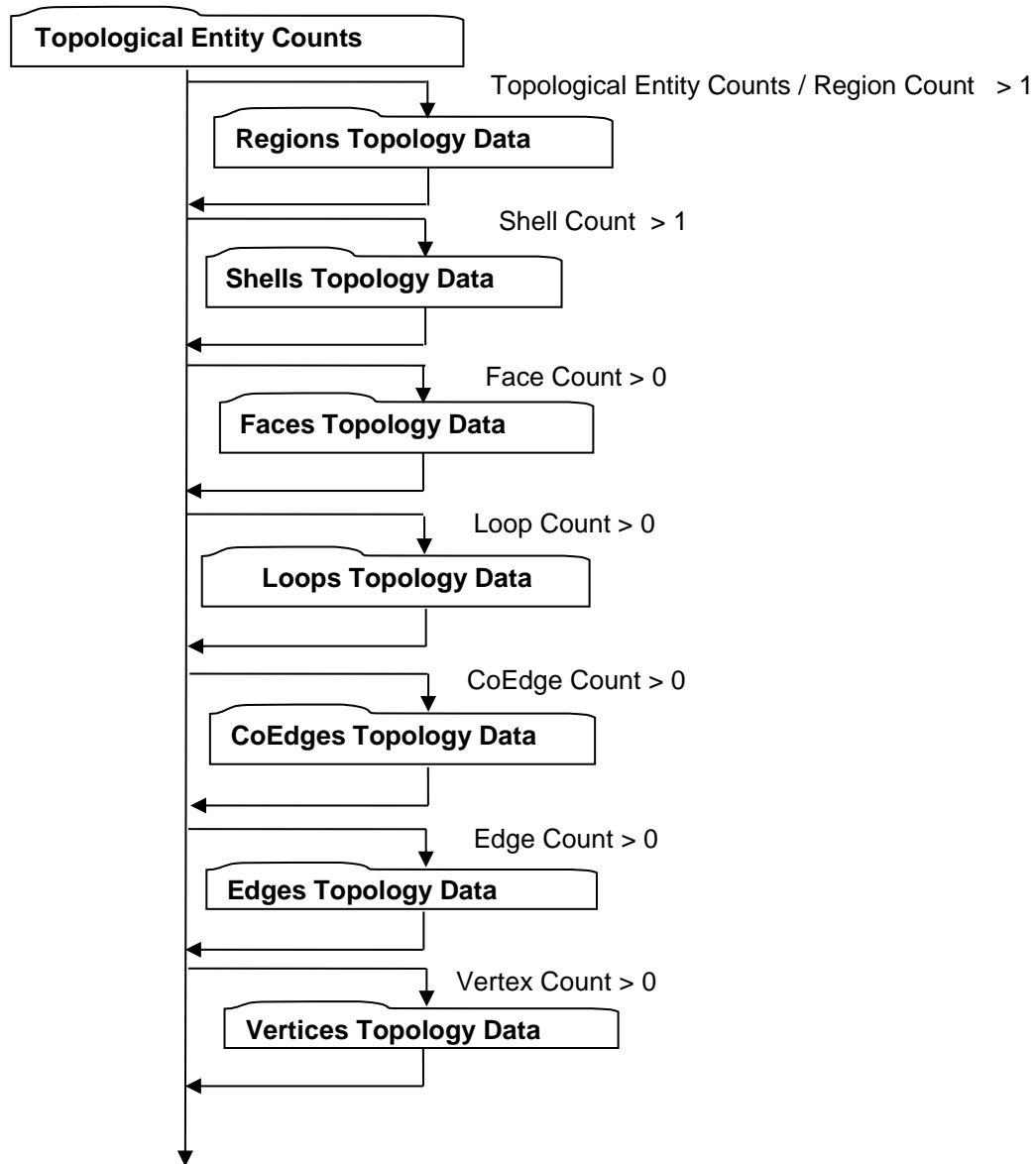
Version Number is the version identifier for this JT ULP Element. Information on local version numbers can be found in the Base Format Description under Common Data Conventions and Constructs Local version numbers.

I32: Material Attribute Element Count

Material Attribute Element Count, as shown in Figure G.3, is the number of material attribute elements.

Complete description for Material Attribute Element can be found in Material Attribute Element.

Figure G.3 — Topology Data collection



G.1.1 Topology Data

Topological Entity Counts

Topological Entity Counts data collection, as shown in Figure G.4, defines the counts for each of the various topological entities within a ULP.

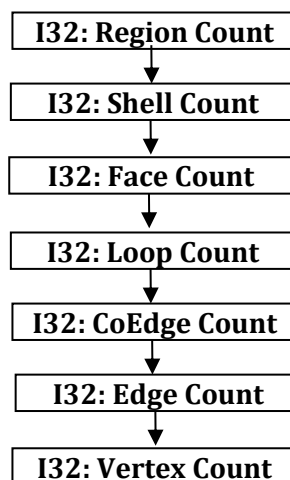


Figure G.4 — Topological Entity Counts data collection

I32: Region Count

Region Count indicates the number of topological region entities in the ULP.

I32: Shell Count

Shell Count indicates the number of topological shell entities in the ULP.

I32: Face Count

Face Count indicates the number of topological face entities in the ULP.

I32: Loop Count

Loop Count indicates the number of topological loop entities in the ULP.

I32: CoEdge Count

CoEdge Count indicates the number of topological coedge entities in the ULP.

I32: Edge Count

Edge Count indicates the number of topological edge entities in the ULP.

I32: Vertex Count

Vertex Count indicates the number of topological vertex entities in the ULP.

Combined Predictor Type

A predictor type may be combined with additional processing. When Combined Predictor Type is used, the additional processing step is encoded. For example, combined predictor type Combined:NULL means that the data collection follows the logical diagram in the Figure G.5 titled “Combined Predictor Type data collection” with ePredictorType set to be NULL.

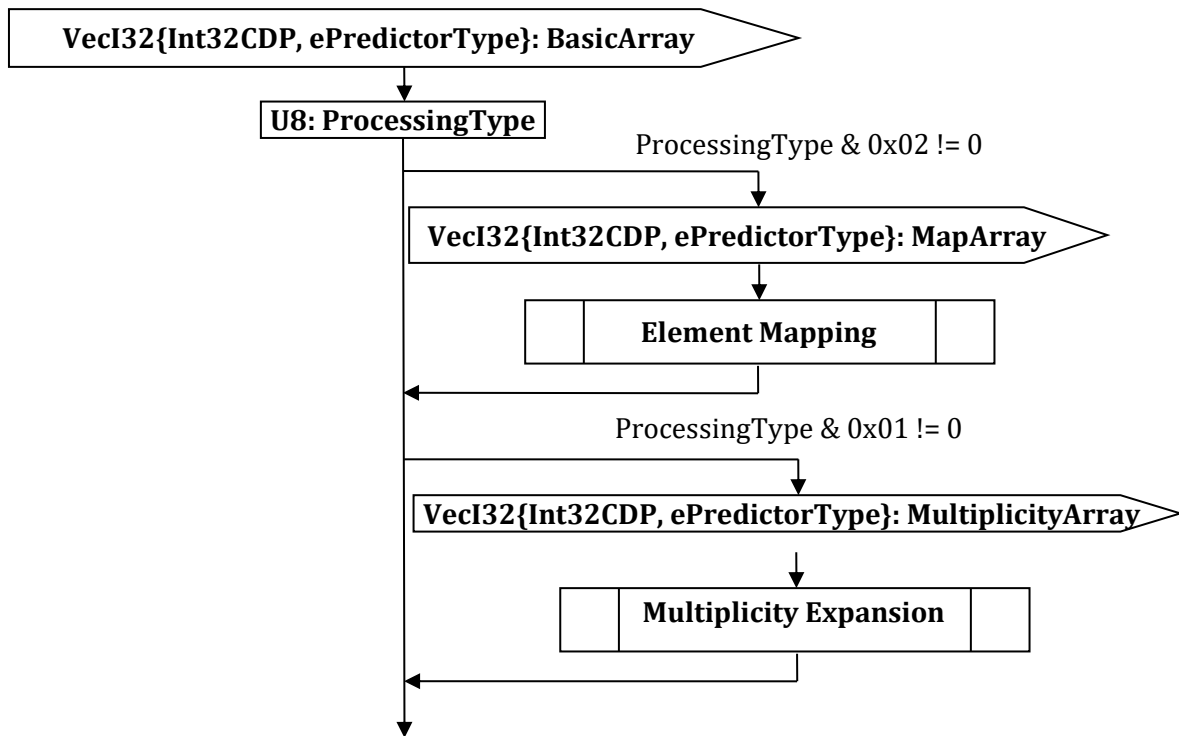


Figure G.5 — Combined Predictor Type data collection

VecI32{Int32CDP, ePredictorType}: BasicArray

BasicArray is an integer array, compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U8: ProcessingType

Two bits of this value are currently used. If bit 0x02 is set, then the integer array is a list of elements with unique values and Element Mapping step is needed to recover the original values. If bit 0x01 is set, then the some elements in the integer array may be repeated, and Multiplicity Expansion is used to recover the original values.

VecI32{Int32CDP, ePredictorType}: MapArray

MapArray is an integer array, where each element represents the index mapping information. MapArray is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Element Mapping

Element Mapping recovers the original array from BasicArray and MapArray, using relationship $\text{OriginalArray}[i] = \text{BasicArray}[\text{MapArray}[i]]$. After Element Mapping, the value of BasicArray is updated with OriginalArray.

VecI32{Int32CDP, ePredictorType}: MultiplicityArray

MultiplicityArray is an integer array, where each element represents the multiplicity of each element in BasicArray. MultiplicityArray is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Multiplicity Expansion

Multiplicity Expansion recovers the original array from BasicArray and MultiplicityArray. The original array is an expansion of the BasicArray. If the corresponding multiplicity value is greater than 1, the element in BasicArray is contiguously repeated in the original array according to multiplicity value.

Regions Topology Data

Regions Topology Data, as shown in Figure G.6, defines the disjoint set of non-overlapping Shells making up each Region. Each Region is defined by one or more non-overlapping Shells. The volume of a Region is that volume lying inside each “anti-hole Shell” and outside each simply-contained “hole Shell” belonging to the particular Region. A Region is analogous to a dimensionally elevated face where Region corresponds to Face and Shell corresponds to Trim Loop.

Each Region’s defining Shells are identified in a list of Shells by an index for both the first Shell and the last Shell in each Region (therefore all Shells inclusive between the specified first and last Shell list index define the particular Region). In addition, the indices of all the shells in a single Region are contiguous. The first shell index of the first region is 0, and the first shell index of other regions is one greater than the last shell index of the previous region. Therefore only the number of shells of each region is stored. In the special case when the number of regions is 1, no information needs be stored since its last Shell index is known to be Shell Count-1.

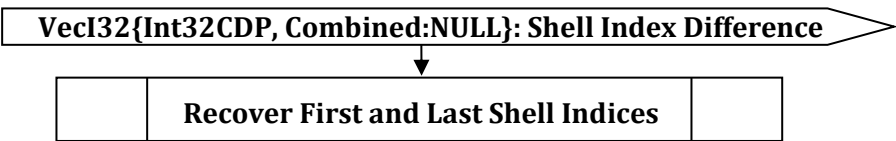


Figure G.6 — Regions Topology Data collection

VecI32{Int32CDP, Combined:NULL}: Shell Index Difference

Shell Index Difference is a vector of indices representing the integer value by subtracting first shell index from last shell index in each region, encoded using Combined Predictor Type. Shell Index Difference is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover First and Last Shell Indices

The first shell index of the first region is 0, and the last shell index of the first region is element 0 of Shell Index Difference. The first shell index of region $k, k \geq 1$ equals to the last shell index of region $k - 1$ plus 1. The last shell index of region $k, k \geq 1$ equals to the first shell index of region k plus element k of Shell Index Difference array.

Shells Topology Data

Shells Topology Data, as shown in Figure G.7, defines the set of topological adjacent Faces making up each Shell. A Shell’s set of topological adjacent Faces define a single (usually closed) two manifold solid that in turn defines the boundary between the finite volume of space enclosed within the Shell and the infinite volume of space outside the Shell. In addition, each Shell has a flag that denotes whether the Shell refers to the finite interior volume (therefore a “hole Shell”) or the infinite exterior volume (therefore an “anti-hole Shell”).

Each Shell’s defining Faces are identified in a list of Faces by an index for both the first Face and the last Face in each Shell (therefore all Faces inclusive between the specified first and last Face list index define the particular Shell). In addition, the indices of all the faces in a single Shell are contiguous. The first face index of the first shell is 0, and the first face index of other shells is one greater than the last face index of the previous shell. Therefore only the number of faces of each shell is stored. In the special case when the number of shells is 1, no information needs be stored since its last face index is known to be Face Count-1.

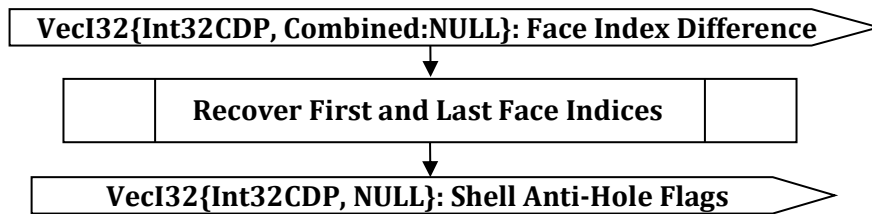


Figure G.7 — Shells Topology Data collection

VecI32{Int32CDP, Combined:NULL}: Face Index Difference

Face Index Difference is a vector of indices representing the integer value by subtracting first face index from last face index in each shell, encoded using Combined Predictor Type. Face Index Difference is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover First and Last Face Indices

The first face index of the first shell is 0, and the last face index of the first shell is element 0 of Face Index Difference. The first face index of shell k , $k \geq 1$ equals to the last face index of shell $k - 1$ plus 1. The last face index of shell k , $k \geq 1$ equals to the first face index of shell k plus element k of Face Index Difference array.

VecI32{Int32CDP, NULL}: Shell Anti-Hole Flags

Each Shell has a flag identifying whether the Shell is an anti-hole Shell. Shell Anti-Hole Flags is a vector of anti-hole flags for a set of Shells.

In an uncompressed/decoded form the flag values have the following meaning, as shown in Table G.1:

Table G.1 — JT ULP Shell Anti-Hole Flag values

| | |
|-----|---------------------------------|
| = 0 | Shell is not an anti-hole Shell |
| = 1 | Shell is an anti-hole Shell |

Shell Anti-Hole Flags uses the Int32 version of the CODEC to compress and encode data.

Faces Topology Data

A Face shall be trimmed with at least one “anti-hole” Trim Loop and may be trimmed with one or more “hole” Trim Loops. The complete description of face and its relation to the trim loops can be found in Faces Topology Data.

Each Face’s defining Trim Loops are identified in a list of trim Loops by an index for both the first Trim Loop and the last Trim Loop in each Face (therefore all Trim Loops inclusive between the specified first and last Trim Loop list index define the particular Face). In addition, the indices of all the loops in a single Face are contiguous. The first loop index of the first face is 0, and the first loop index of other faces is one greater than the last loop index of the previous face. Therefore only the number of loops of each face is stored. In the special case when the number of faces is 1, no information needs be stored since its last loop index is known to be Loop Count-1.

Each Face’s underlying Geometric Surface is identified by an index into a list of Geometric Surfaces. Each face’s material is identified by an index into the list of f Material Attribute Elements, as shown in Figure G.8.

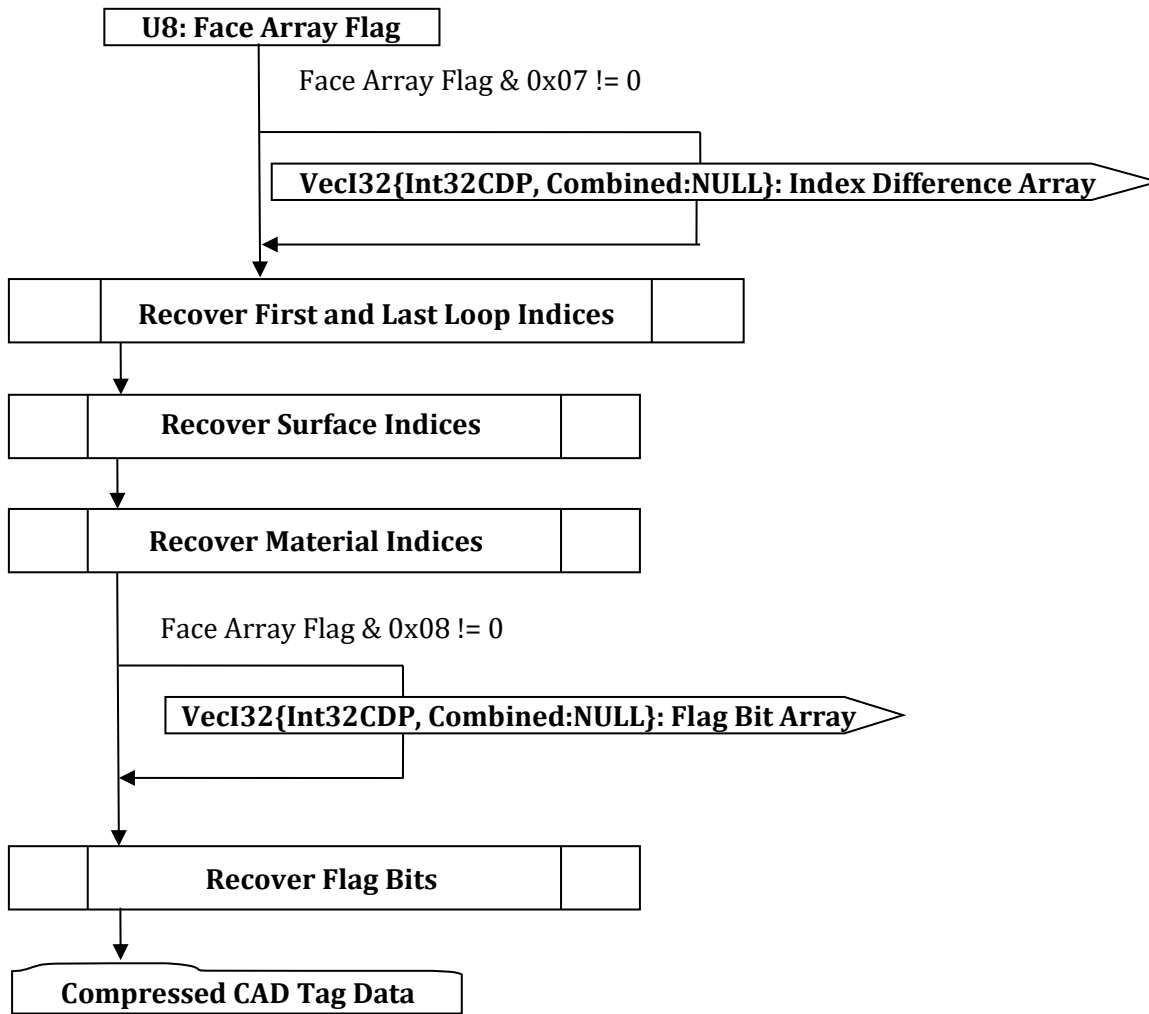


Figure G.8 — Faces Topology Data collection

U8: Face Array Flag

Face Array Flag indicates which arrays of face topology data are not trivial and therefore encoded.

VecI32{Int32CDP, Combined:NULL}: Index Difference Array

Index Difference Array is a combined vector of indices encoded using Int32 version of CODEC and Combined Predictor Type, with its content decided by the value of Face Array Flag. If Face Array Flag has bit 0x01 set, then the vector of integer values obtained by subtracting first loop index from last loop index in each face is appended to the end of Index Difference Array. If Face Array Flag has bit 0x02 set, then the vector of integer values obtained by subtracting surface index from face index in each face is appended to the end of Index Difference Array. If Face Array Flag has bit 0x04 set, then the vector of integer values representing the material index of each face is appended to the end of Index Difference Array.

Recover First and Last Loop Indices

The first loop index of the first face is 0, and the last loop index of the first face is element 0 of Index Difference Array if the array is encoded, or 0 if bit 0x01 of Face Array Flag is not set. The first loop index of face k , $k \geq 1$ equals to the last loop index of face $k - 1$ plus 1. The last loop index of face k , $k \geq 1$ equals to the first loop index of face k plus element k of Index Difference Array, or 0 if bit 0x01 of Face Array Flag is not set.

Recover Surface Indices

The surface index of each face equals to the face index if bit 0x02 of Face Array Flag is not set. Otherwise the surface index of face k is obtained by subtracting element k + offset of Index Difference Array from face index k, where offset is equal to Face Count if bit 0x01 of Face Array Flag is set and 0 if the bit is not set.

Recover Material Indices

The material index of each face equals to 0 if bit 0x04 of Face Array Flag is not set. Otherwise the material index of face k equals to the element k + offset of Index Difference Array, where offset is equal to twice of Face Count if both bit 0x01 and bit 0x02 of Face Array Flag are set, is equal to Face Count if either bit 0x01 or bit 0x02 of Face Array Flag is set, and is equal to 0 if neither bit is set.

VecI32{Int32CDP, Combined:NULL}: Flag Bit Array

Only the lower 24 bits of the four integer indices, namely first loop index, last loop index, surface index, and material index, are used as integer identifiers, as shown in Table G.2. The other bits of these integers are documented as reserved for future use.

Table G.2 — JT ULP Flag Bit Array Look Index values

| | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|------------------|--------------|----------|----|-------------|----|-------------|----|------------------|
| First Loop Index | Surface Type | | | U Knot Type | | V Knot Type | | isNormalReversed |
| Last Loop Index | isIsolated | Reserved | | | | | | |
| Surface Index | Reserved | | | | | | | |
| Material Index | Reserved | | | | | | | |

Each element of Flag Bit Array is a 32 bit integer obtained by combining all 32 flag bits from four different integers. More specifically:

- Bits 0~7 of Flag Bit Array are equal to bits 24~31 of First Loop Index.
- Bits 8~15 of Flag Bit Array are equal to bits 24~31 of Last Loop Index.
- Bits 16~23 of Flag Bit Array are equal to bits 24~31 of Surface Index.
- Bits 24~31 of Flag Bit Array are equal to bits 24~31 of Material Index.

Supported Surface Type

In an uncompressed/decoded form, the supported surface types are listed below in Table G.3.

Table G.3 — JT ULP Supported Surface Type values

| | |
|---|----------|
| 0 | Nurbs |
| 1 | Plane |
| 2 | Cylinder |
| 3 | Cone |
| 4 | Sphere |
| 5 | Torus |
| 6 | Reserved |
| 7 | Reserved |

Supported Knot Type

In an uncompressed/decoded form, the supported knot types are listed below. The knot type of the underlying surface along both U and V parameter directions are encoded, as shown in Table G.4.

Table G.4 — JT ULP Supported Knot Type Values

| | |
|---|--|
| 0 | No Pattern |
| 1 | No knot value in between the clamped end knots |
| 2 | All knot values in between the end knots increase with an even interval |
| 3 | All knot values in between the end knots repeat exactly once, and the distinct values increase with an even interval |

In an uncompressed/decoded form, the Face Reverse Normal Flag has the following meaning, as shown in Table G.5:

Table G.5 — JT ULP Face Reverse Normal Flag values

| | |
|-----|-----------------------------|
| = 0 | Face normal is not reversed |
| = 1 | Face normal is reversed. |

Recover Flag Bits

If Face Array Flag & 0x08 is equal to 0, then each element in Flag Bit Array is set to have value 0. The flag bits are recovered by assigning bits 0~7 of Flag Bit Array to bits 24~31 of First Loop Index, bits 8~15 of Flag Bit Array to bits 24~31 of Last Loop Index, bits 16~23 of Flag Bit Array to bits 24~31 of Surface Index, and bits 24~31 of Flag Bit Array to bits 24~31 of Material Index

Loops Topology Data

A Loop (often called Trimming Loop) defines in parameter space a 1D boundary around which geometric surfaces are trimmed to form a Face. Loops Topology Data specifies the CoEdges making up each Loop along with an anti-hole flag and identifier tag for each Loop. The complete description of loop and its relation to the CoEdges can be found in Loops Topology Data, as shown in Figure G.9.

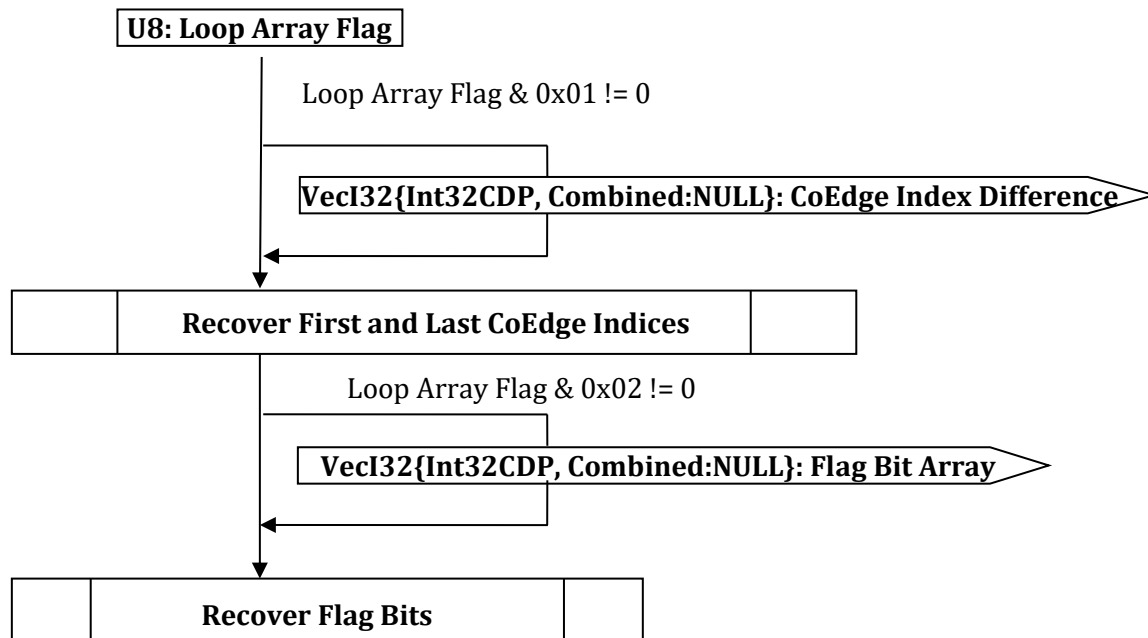


Figure G.9 — Loops Topology Data collection

U8: Loop Array Flag

Loop Array Flag indicates which arrays of loop topology data are not trivial and therefore encoded.

VecI32{Int32CDP, Combined:NULL}: CoEdge Index Difference

CoEdge Index Difference is a vector of indices representing the integer value by subtracting first CoEdge index from last CoEdge index in each loop, encoded using Combined Predictor Type. CoEdge Index Difference is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover First and Last CoEdge Indices

The first CoEdge index of the first loop is 0, and the last CoEdge index of the first loop is element 0 of CoEdge Index Difference. The first CoEdge index of loop k , $k \geq 1$ equals to the last CoEdge index of loop $k - 1$ plus 1. The last CoEdge index of loop k , $k \geq 1$ equals to the first CoEdge index of loop k plus element k of CoEdge Index Difference array.

VecI32{Int32CDP, Combined:NULL}: Flag Bit Array

Only the lower 24 bits of the two integer indices, namely first CoEdge index and last CoEdge index are used as integer identifiers. The other bits of these integers documented as reserved for future use, as shown in Table G.6.

Table G.6 —JT ULP Loops Topology Flag Bit Array values

| | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|--------------------|----------|----|----|----|----|----|----|----------------|
| First CoEdge Index | Reserved | | | | | | | isAntiHoleLoop |
| Last CoEdge Index | Reserved | | | | | | | |

Bits 0~7 of Flag Bit Array are equal to bits 24~31 of First CoEdge Index

Bits 8~15 of Flag Bit Array are equal to bits 24~31 of Last CoEdge Index

Bits 16~31 of Flag Bit Array are set to be 0

In an uncompressed/decoded form, the AntiHole Loop Flag has the following meaning, as shown in Table G.7:

Table G.7 — JT ULP Loops Topology Reverse Normal Flag values

| | |
|-----|-------------------------------|
| = 0 | Loop is not an anti-hole Loop |
| = 1 | Loop is an anti-hole Loop |

Recover Flag Bits

The flag bits are recovered by assigning bits 0~7 of Flag Bit Array to bits 24~31 of First CoEdge Index, and bits 8~15 of Flag Bit Array to bits 24~31 of Last CoEdge Index

CoEdges Topology Data

A CoEdge defines a parameter space edge trim Loop segment (therefore the projection of an Edge into the parameter space of the Face). CoEdges Topology Data specifies the underlying Edge and PCS Curve making up each CoEdge along with a MCS curve reversed flag and tag for each CoEdge. The complete description of CoEdge and its relation to the Edge can be found in CoEdges Topology Data, as shown in Figure G.10.

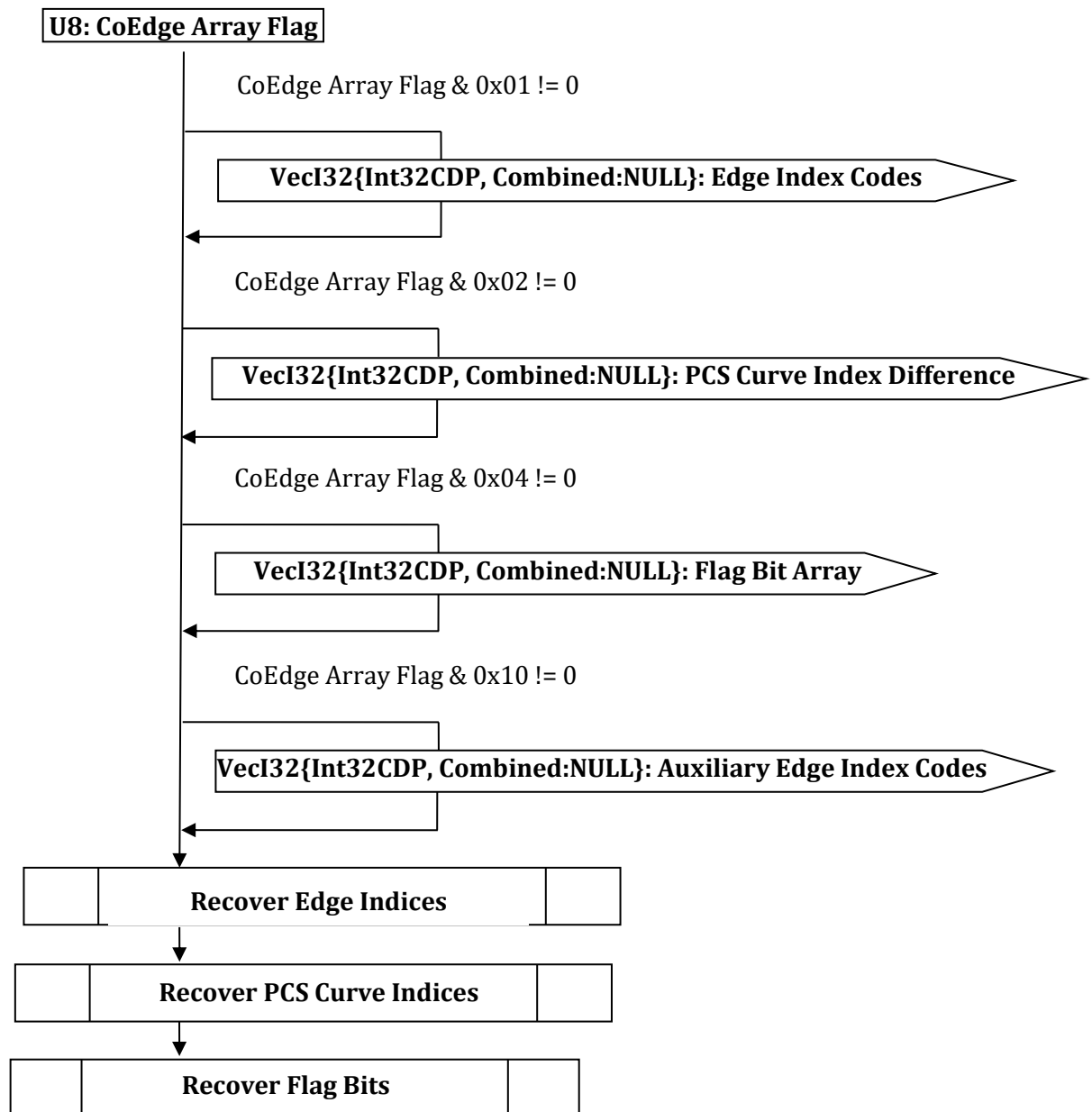


Figure G.10 — CoEdges Topology Data collection

U8: CoEdge Array Flag

CoEdge Array Flag indicates which arrays of coedge topology data are not trivial and therefore encoded.

VecI32{Int32CDP, Combined:NULL}: Edge Index Codes

Edge Index Codes is a vector of integer indices representing the Edge index for each CoEdge, encoded using Combined Predictor Type. Edge Index Codes is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Depending on how the edge indices are assigned, and indicated by bit 0x08 in CoEdge Array Flag, the Edge Index Codes may represent the Edge Index information in two different ways. If the edge indices are randomly assigned, for example as shown in the Figure below, then each element in Edge Index Codes represents the integer value by subtracting the Edge index from the CoEdge index for each CoEdge. For the example shown in the Figure below, the integer values in Edge Index Codes are -7, -4, -4, 3, 3, -1, -2, 5, 5, 1, 5, 7 and bit 0x08 is turned off in CoEdge Array Flag. If the edge indices are chosen to be based on the sequence of the reference from the parent coedges when the coedges are visited sequentially, as shown in the Figure below, then each element in Edge Index Codes has value 0 if the

edge is visited the first time, and value 1 if the edge is visited the second time. For the example shown in the Figure below, the integer values in Edge Index Codes are 0, 0, 0, 0, 0, 1, 0, 0, 0, 1, 1, 0, and bit 0x08 is turned on in CoEdge Array Flag. Note that the edge index for all CoEdges with 0 entry can be figured out by counting number of zeros in Edge Index Codes preceding (not including) this entry. Take CoEdge 6 that has entry 0 in Edge Index Codes for example. The number of zeros before this entry is 5, which is equal to the edge index of CoEdge 6. Therefore only the edge indices of those CoEdges with entry value 1 in Edge Index Codes need be stored. These edge indices are stored in Auxiliary Edge Index Codes. See the examples shown in Figure G.11 and G.12.

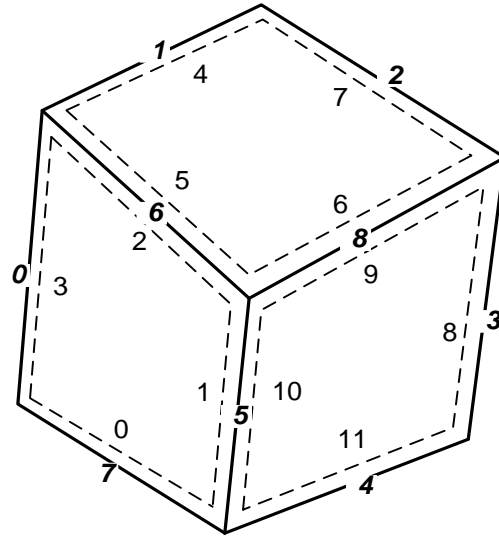


Figure G.11 — Sample Model with Randomly Assigned Edge Indices

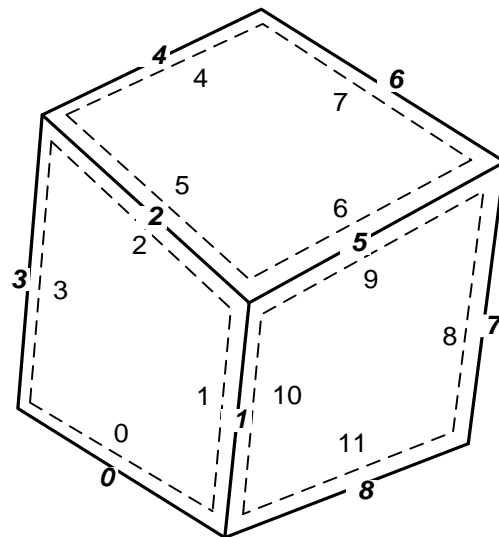


Figure G.12 — Sample Model with Sequentially Assigned Edge Indices

VecI32{Int32CDP, Combined:NULL}: Auxiliary Edge Index Codes

Auxiliary Edge Index Codes is an optional field and only exists if CoEdge Array Flag & 0x08 is not equal to 0. It contains the Edge indices that appear again during sequential traversal of the CoEdges. For the example shown in the Figure above, the entries in Auxiliary Edge Index Codes are 2, 5, 1. More detailed explanation of what these entries mean can be found in Edge Index Codes.

Recover Edge Indices

If CoEdge Array Flag & 0x08 is equal to 0, then the Edge index of each CoEdge is equal to the CoEdge index if CoEdge Array Flag & 0x01 is equal to 0. Otherwise, the Edge index of CoEdge with index k can be computed by subtracting element k of Edge Index Codes array from k, the CoEdge index.

If CoEdge Array Flag & 0x08 is equal to 1, then the Edge index of all CoEdges having 0 entry in Edge Index Codes is set to be the number of zeros in Edge Index Codes preceding (not including) this entry. For all CoEdges that have 1 in Edge Index Codes, their edge indices are sequentially assigned as the corresponding value in Auxiliary Edge Index Codes.

VecI32{Int32CDP, Combined:NULL}: PCS Curve Index Difference

PCS Curve Index Difference is a vector of indices representing the integer value by subtracting the PCS Curve index from the CoEdge index for each CoEdge, encoded using Combined Predictor Type. PCS Curve Index Difference is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover PCS Curve Indices

If CoEdge Array Flag & 0x02 is equal to 0, then the PCS Curve index of each CoEdge is equal to the CoEdge index. Otherwise, the PCS Curve index of CoEdge with index k can be computed by subtracting element k of PCS Curve Index Difference array from k, the CoEdge index.

VecI32{Int32CDP, Combined:NULL}: Flag Bit Array

Only the lower 24 bits of the two integer indices, namely Edge index and PCS Curve index, are used as integer identifiers. The other bits of these integers are documented as reserved for future use, as shown in Table G.8.

Table G.8 — JT ULP Recover Edge Indices Flag Bit Array values

| | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|-----------------|-----------|----------|-------------|----|----|----------------|----|---------------|
| Edge Index | Knot Type | | Domain Type | | | PCS Curve Type | | isXYZReversed |
| PCS Curve Index | isUvInc | Reserved | | | | | | |

Bits 0~7 of Flag Bit Array are equal to bits 24~31 of Edge Index

Bits 8~15 of Flag Bit Array are equal to bits 24~31 of PCS Curve Index

Bits 16~31 of Flag Bit Array are set to be 0

The Knot Type, defined in Supported Knot Type, is an integer with its value between 0 and 3.

Domain Type

An example of Surface Domain Classification is shown in Figure G.13

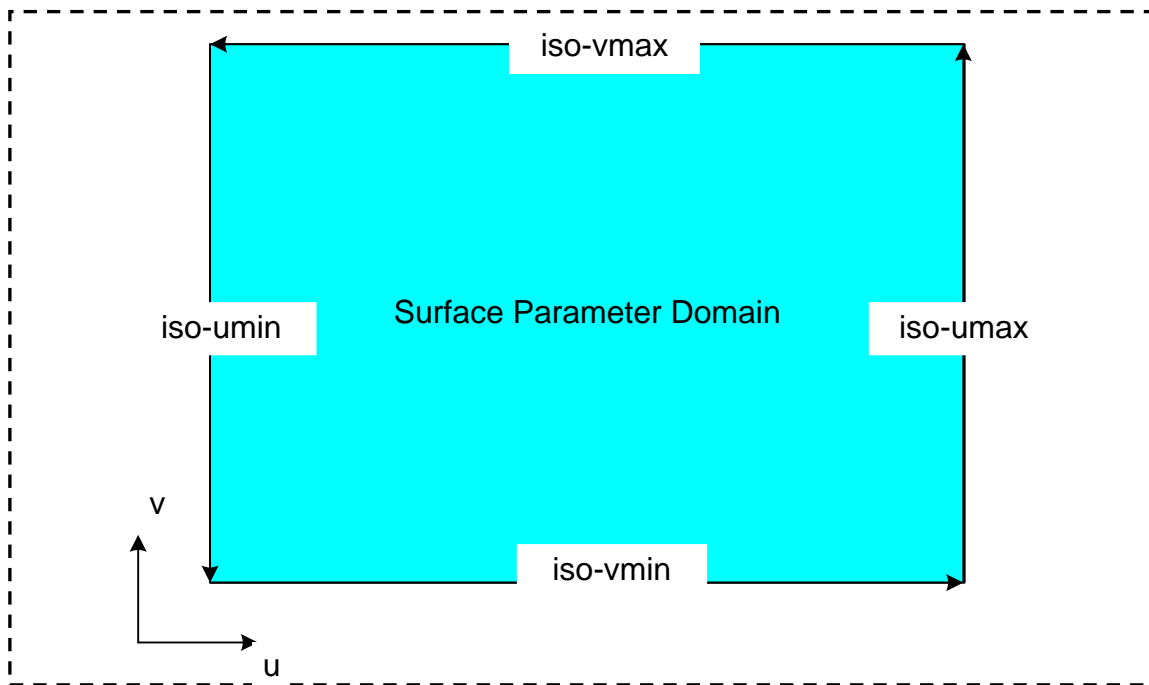


Figure G.13 — Surface Domain Classification

In an uncompressed/decoded form, the supported PCS Curve types are listed below in Table G.9.

Table G.9 — JT ULP Recover Edge Indices PCS curve type values

| | |
|---|---|
| 0 | General |
| 1 | PCS curve is coincident with iso-umin curve in the surface parameter domain |
| 2 | PCS curve is coincident with iso-umax curve in the surface parameter domain |
| 3 | PCS curve is coincident with iso-vmin curve in the surface parameter domain |
| 4 | PCS curve is coincident with iso-vmax curve in the surface parameter domain |
| 5 | Reserved |
| 6 | Reserved |
| 7 | PCS curve is to be derived from MCS curve and surface geometry |

PCS Curve Type

In an uncompressed/decoded form, the supported PCS Curve types are listed below in Table G.10.

Table G.10 — JT ULP PCS Curve Type values

| | |
|---|----------|
| 0 | Nurbs |
| 1 | Line |
| 2 | Circle |
| 3 | Reserved |

In an uncompressed/decoded form, the XYZReversed Flag has the following meaning, as shown in Table G.11:

Table G.11 — JT ULP PCS Curve Type XYZ Reversed Flag values

| | |
|-----|---|
| = 0 | Directional sense of associated edges MCS curve should not be interpreted as opposite the direction its parameterization implies. |
| = 1 | Directional sense of associated edges MCS curve should be interpreted as opposite the direction its parameterization implies. |

In an uncompressed/decoded form, the isUVInc Flag has the following meaning, as shown in Table G.12:

Table G.12 — JT ULP PCS Curve Type isUVInc Flag values

| | |
|-----|---|
| = 0 | PCS Curve is iso-parametric in surface parameter domain in one direction and the parameter increases in the other direction |
| = 1 | PCS Curve is iso-parametric in surface parameter domain in one direction and the parameter decreases in the other direction |

The isUVInc flag is set only if the Domain Type of this CoEdge has value between 1 and 4 inclusive.

Recover Flag Bits

If CoEdge Array Flag & 0x04 is equal to 0, then each element in Flag Bit Array is set to have value 0. The flag bits are recovered by assigning bits 0~7 of Flag Bit Array to bits 24~31 of Edge Index, and bits 8~15 of Flag Bit Array to bits 24~31 of PCS Curve Index.

Edges Topology Data

An Edge defines a model space trim Loop segment. Edges Topology Data specifies the underlying MCS Curve along with an identification tag for each Edge. The complete description of Edge can be found in Edges Topology Data, as shown in Figure G.14. Note that the start and end vertex index information is not stored. Instead it is recovered (Information Recovery).

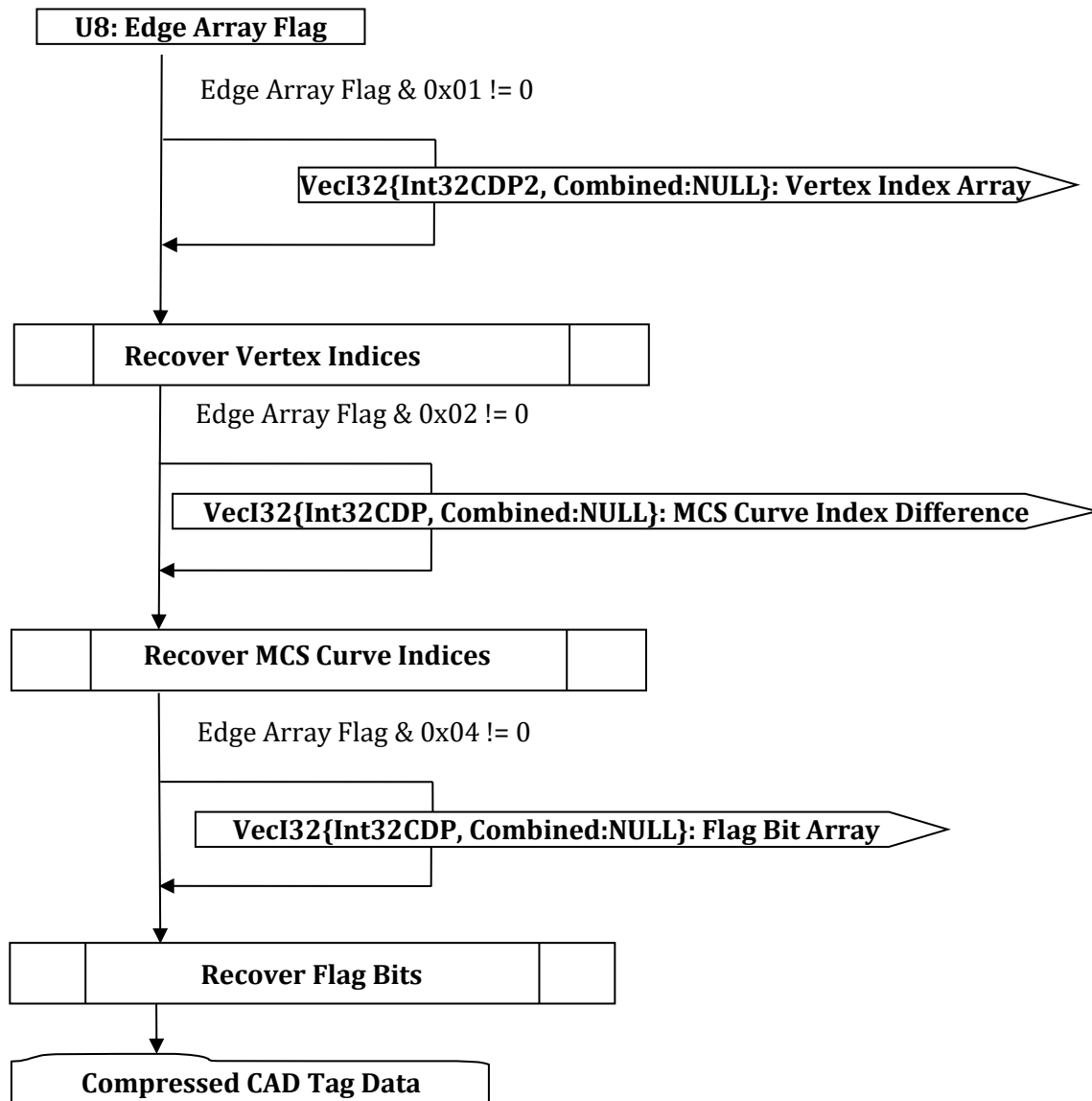


Figure G.14 — Edges Topology Data collection

U8: Edge Array Flag

Edge Array Flag indicates which arrays of edge topology data are not trivial and therefore encoded.

VecI32{Int32CDP, Combined:NULL}: MCS Curve Index Difference

MCS Curve Index Difference is a vector of indices representing the integer value by subtracting the MCS Curve index from the Edge index for each Edge, encoded using Combined Predictor Type. MCS Curve Index Difference is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover MCS Curve Indices

If Edge Array Flag & 0x02 is equal to 0, then the MCS Curve index of each Edge is equal to the Edge index. Otherwise, the MCS Curve index of Edge with index k can be computed by subtracting element k of MCS Curve Index Difference array from k , the Edge index.

VecI32{Int32CDP, Combined:NULL}: Flag Bit Array

Only the lower 24 bits of the three integer indices, namely MCS Curve index, Start Vertex index, and End Vertex index, are used as integer identifiers. The other bits of these integers documented as reserved for future use, as shown in Table G.13.

Table G.13 — JT ULP Edges Topology Recover MCS Curve Indices Flag Bit Array values

| | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|--------------------|-----------|----|----------------|----|----------|----|----|----|
| MCS Curve Index | Knot Type | | MCS Curve Type | | Reserved | | | |
| Start Vertex Index | Reserved | | | | | | | |
| End Vertex Index | Reserved | | | | | | | |

The Knot Type, defined in Supported Knot Type, is an integer with its value between 0 and 3.

MCS Curve Type

In an uncompressed/decoded form, the supported MCS Curve types are listed below in Table G.14.

Table G.14 — JT ULP Edges Topology Recover MCS Curve Type values

| | |
|---|--|
| 0 | Nurbs |
| 1 | Line |
| 2 | Circle |
| 3 | Projection: MCS curve geometry is to be computed from surface geometry and/or PCS curve geometry |

Recover Flag Bits

If Edge Array Flag & 0x04 is equal to 0, then each element in Flag Bit Array is set to have value 0. The flag bits are recovered by assigning bits 0~7 of Flag Bit Array to bits 24~31 of MCS Curve Index.

Vertices Topology Data

Vertices Topology Data is not stored on disk. Instead it is constructed (Information Recovery).

G.1.2 Geometric Data

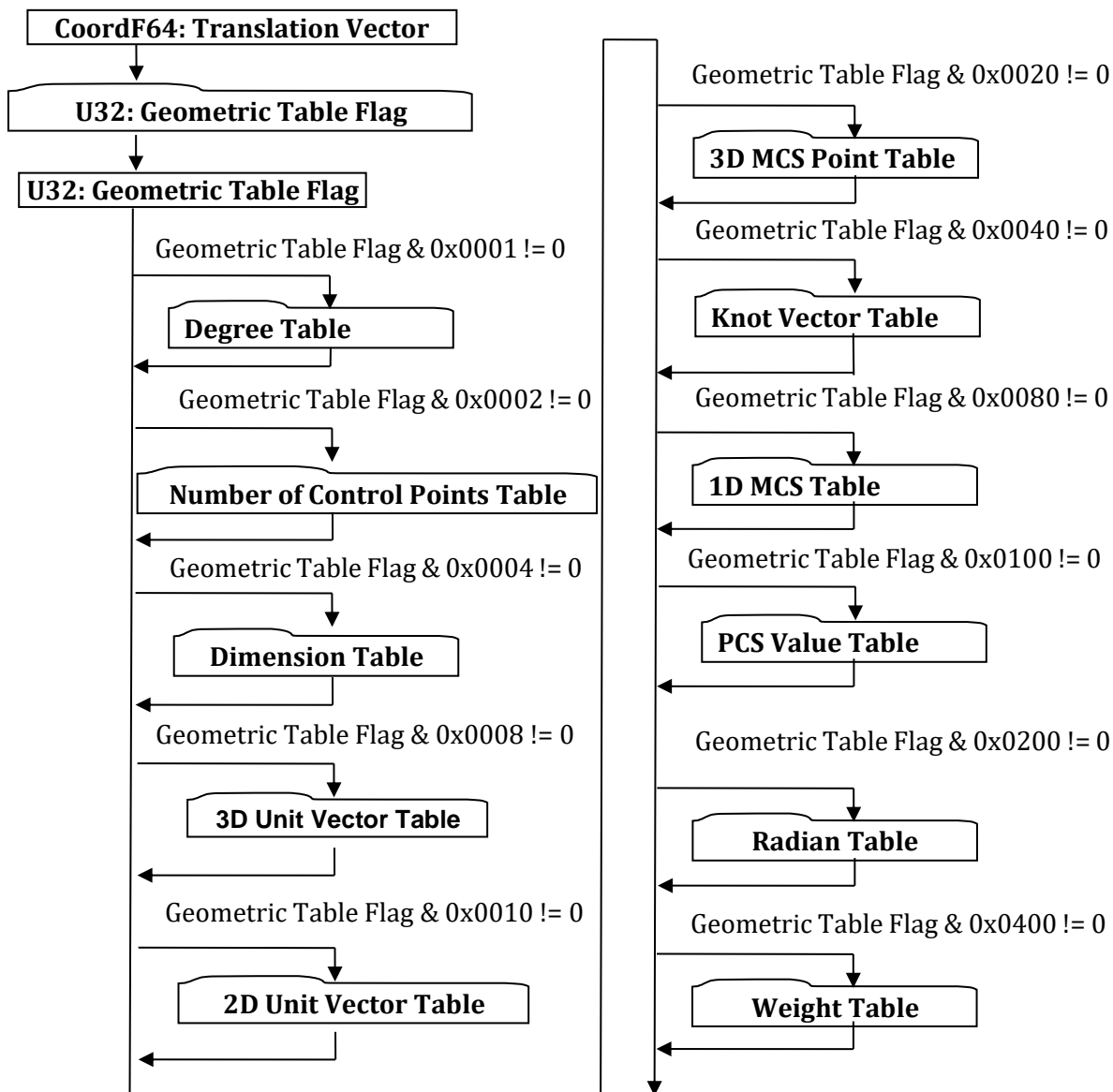


Figure G.15 — Geometric Data collection

CoordF64: Translation Vector

Translation Vector, as shown in Figure G.15, is a 3-dimensional vector that represents how the ULP geometry is defined w.r.t. the original B-Rep definition from which ULP geometry is derived. If the Translation Vector is not zero vector, then the ULP geometry read from disk is translated from original B-Rep definition by the amount of Translation Vector. This is usually done by the JT writer implementation to improve numerical accuracy of floating point numbers in the ULP geometry. It is important for all the JT readers to take this Translation Vector into consideration when consuming ULP geometry. For example if a LOD is generated from ULP geometry, for example by tessellation, then the LOD geometry shall be translated to undo the effect of Translation Vector for it be consistent with the original B-Rep definition. In other words, if we denote the Translation Vector as v , then the LOD geometry from ULP shall be translated by $-v$.

U32: Geometric Table Flag

Geometric Table Flag indicates which geometric tables are not trivial and therefore encoded.

Geometric Entity Counts

Geometric Entity Counts data collection, as shown in Figure G.16, defines the counts for each of the various geometric entities within a ULP.

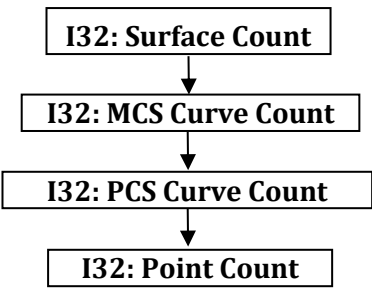


Figure G.16 — Geometric Entity Counts

I32: Surface Count

Surface Count indicates the number of distinct geometric surface entities in the ULP.

I32: MCS Curve Count

MCS Curve Count indicates the number of distinct geometric (Model Coordinate Space) curves (therefore XYZ curve) entities in the ULP.

I32: PCS Curve Count

PCS Curve Count indicates the number of distinct geometric Parameter Coordinate Space curves (therefore UV curve) entities in the ULP.

I32: Point Count

Point Count indicates the number of distinct geometric point entities in the ULP.

Degree Table

Degree Table, as shown in Figure G.17, stores a vector of integers that represent the degree information of Nurbs surfaces and/or curves. If the ULP does not contain any Nurbs entity, then the Tables empty and bit 0x0001 in Geometric Table Flag is set to be 0.

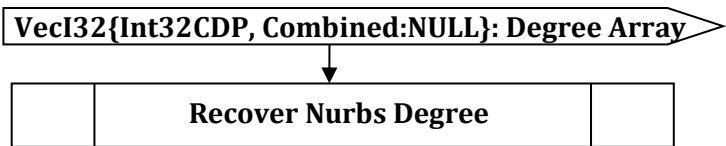


Figure G.17 — Degree Table data collection

VecI32{Int32CDP, Combined:NULL}: Degree Array

Degree Array is a vector of integers that stores the degree information for all the Nurbs entities in the ULP, encoded using Combined Predictor Type. Degree Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover Nurbs Degree

The logic diagram to recover degree information for all the Nurbs entities in the ULP from the Degree Array is shown below in Figure G.18.

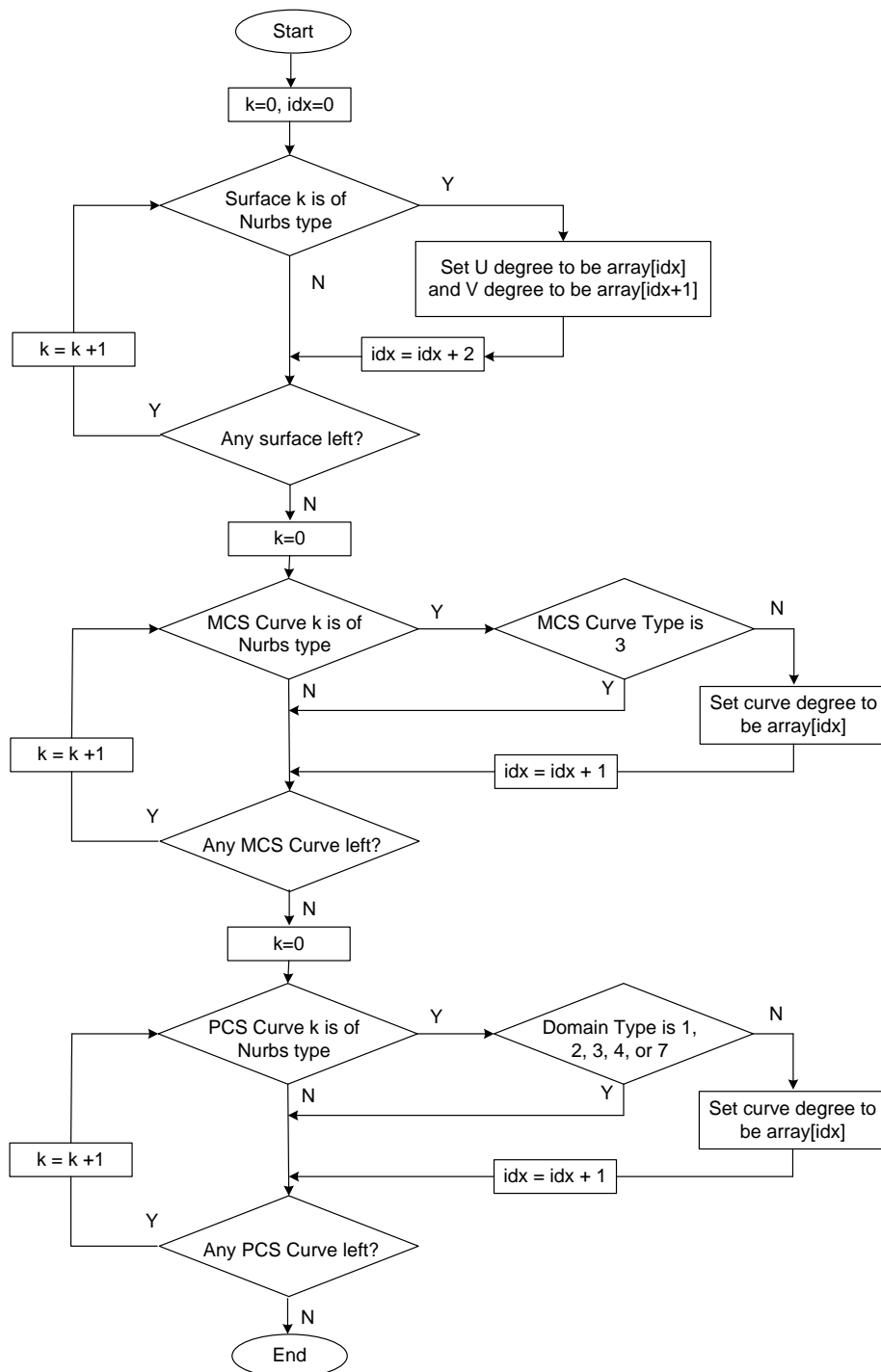


Figure G.18 — Recover Nurbs Degree

Number of Control Points Table

Number of Control Points Table, as shown in Figure G.19, stores a vector of integers that represent the number of control points information of Nurbs surfaces and/or curves. If the ULP does not contain any Nurbs entity, then the table is empty and bit 0x0002 in Geometric Table Flag is set to be 0.

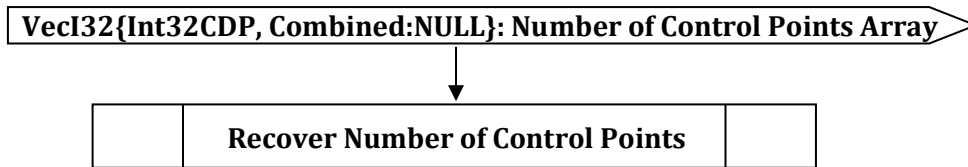


Figure G.19 — Number of Control Points Table data collection

VecI32{Int32CDP, Combined:NULL}: Number of Control Points Array

Number of Control Points Array is a vector of integers that stores the number of control points information for all the Nurbs entities in the ULP, encoded using Combined Predictor Type. Number of Control Points Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet

Recover Number of Control Points

The logic diagram to recover number of control points information for all the Nurbs entities in the ULP from the Number of Control Points Array is shown in Figure G.20.

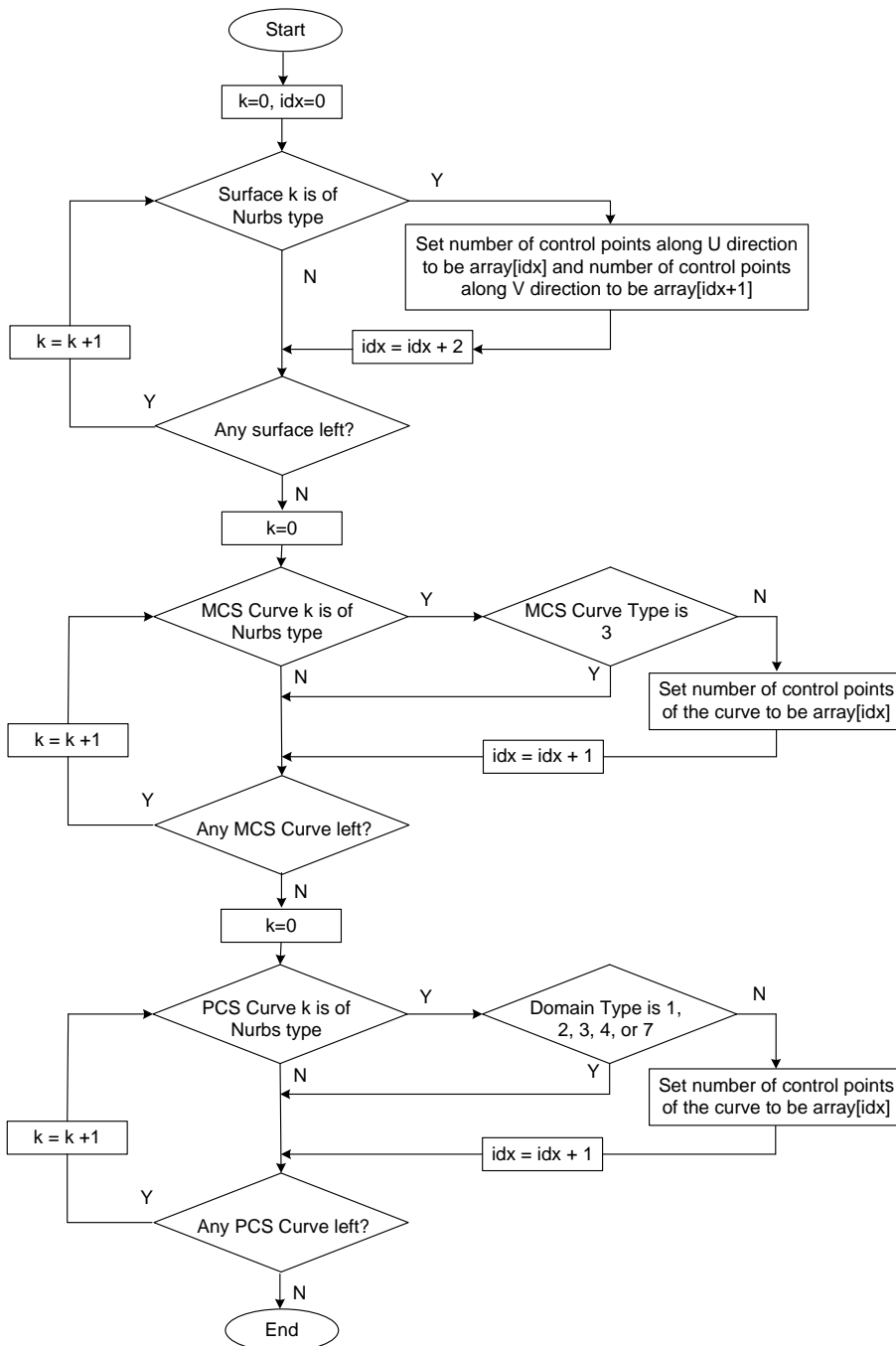


Figure G.20 — Recover Number of Control Points

Dimension Table

Dimension Table, as shown in Figure G.21, stores a vector of integers that represent the dimension information of Nurbs surfaces and/or curves. If the ULP does not contain any Nurbs entity, then the table is empty and bit 0x0004 in Geometric Table Flag is set to be 0.

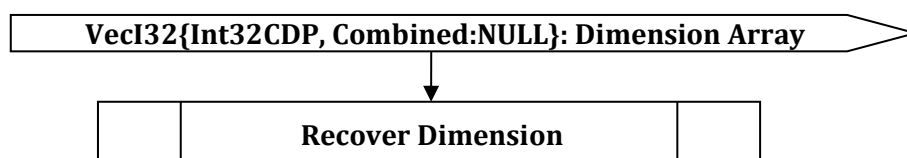


Figure G.21 — Dimension Table data collection

VecI32{Int32CDP, Combined:NULL}: Dimension Array

Dimension Array is a vector of integers that stores the dimension information for all the Nurbs entities in the ULP, encoded using Combined Predictor Type. Dimension Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover Dimension

The logic diagram to recover dimension information for all the Nurbs entities in the ULP from the Dimension Array is shown in Figure G.22.

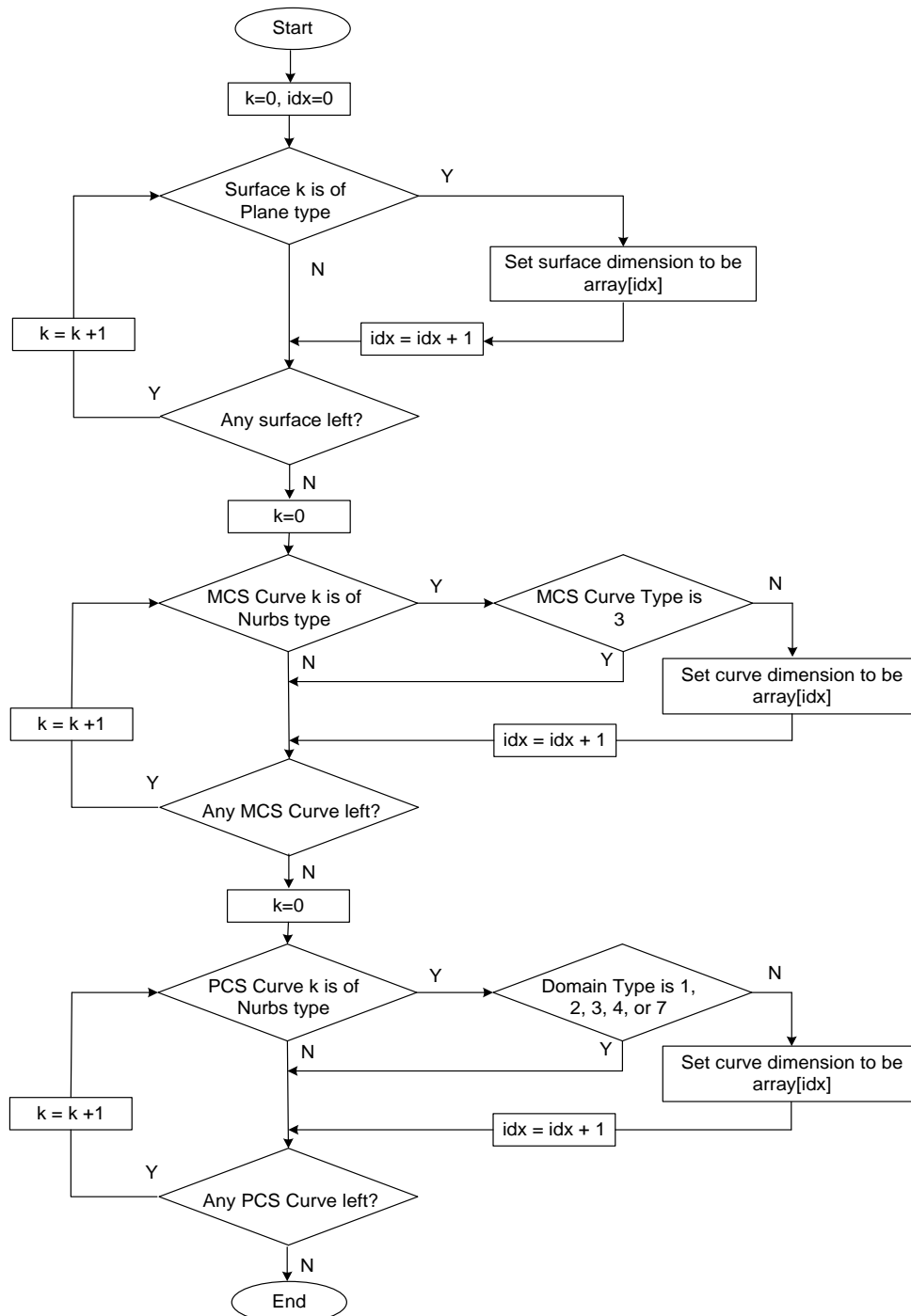


Figure G.22 — Recover Dimension

3D Unit Vector Table

3D Unit Vector Table, as shown in Figure G.23, stores an array of unit vectors in 3D that form part of the analytic surface or curve representation in ULP. If the ULP does not contain any analytic entity, then the table is empty and bit 0x0008 in Geometric Table Flag is set to be 0. The supported analytic surface types include plane, cylinder, cone, sphere, and torus, and the supported analytic curve types include line and circle for both parameter space and model space curves. The analytic representation of ULP follows XT convention as detailed in the XT Annex description.

Similar to the coding of Compressed Vertex Normal Array, each 3D unit vector is encoded as a single 32 bit integer using Deering Normal CODEC.

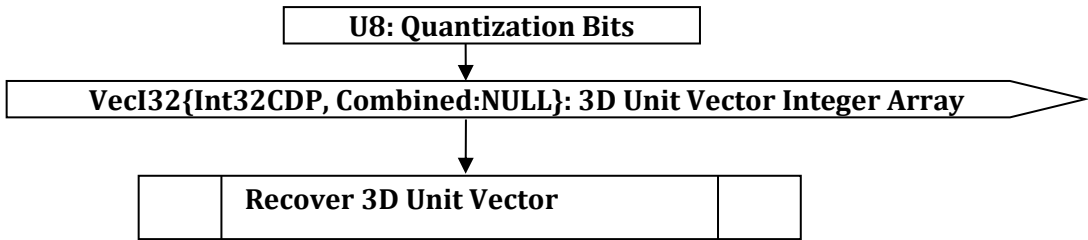


Figure G.23 — 3D Unit Vector Table data collection

U8: Quantization Bits

The number of bits used for the Deering Normal CODEC if quantization is enabled. A value of 0 denotes that quantization is disabled.

VecI32{Int32CDP, Combined:NULL}: 3D Unit Vector Integer Array

3D Unit Vector Integer Array is a vector of integers that stores the encoded 3D unit vector from all analytic entities in the ULP, encoded using Combined Predictor Type. 3D Unit Vector Integer Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Recover 3D Unit Vector

The logic diagram to recover 3D unit vector information for all the analytic entities in the ULP from the 3D Unit Vector Integer Array is shown in Figure G.24.

The recovery of a unit vector from an element in the 3D Unit Vector Integer Array is done as part of Deering Normal CODEC.

As described in the XT B-Rep Annex, the representation of an analytic surface of types plane, cylinder, cone, sphere, or torus, includes two 3D unit vectors. One is called “axis” and the other is called “x_axis”. These two unit vectors of each analytic surface are recovered for each analytic surface. In addition, the “normal” vector to the plane containing a 3D circle is also recovered

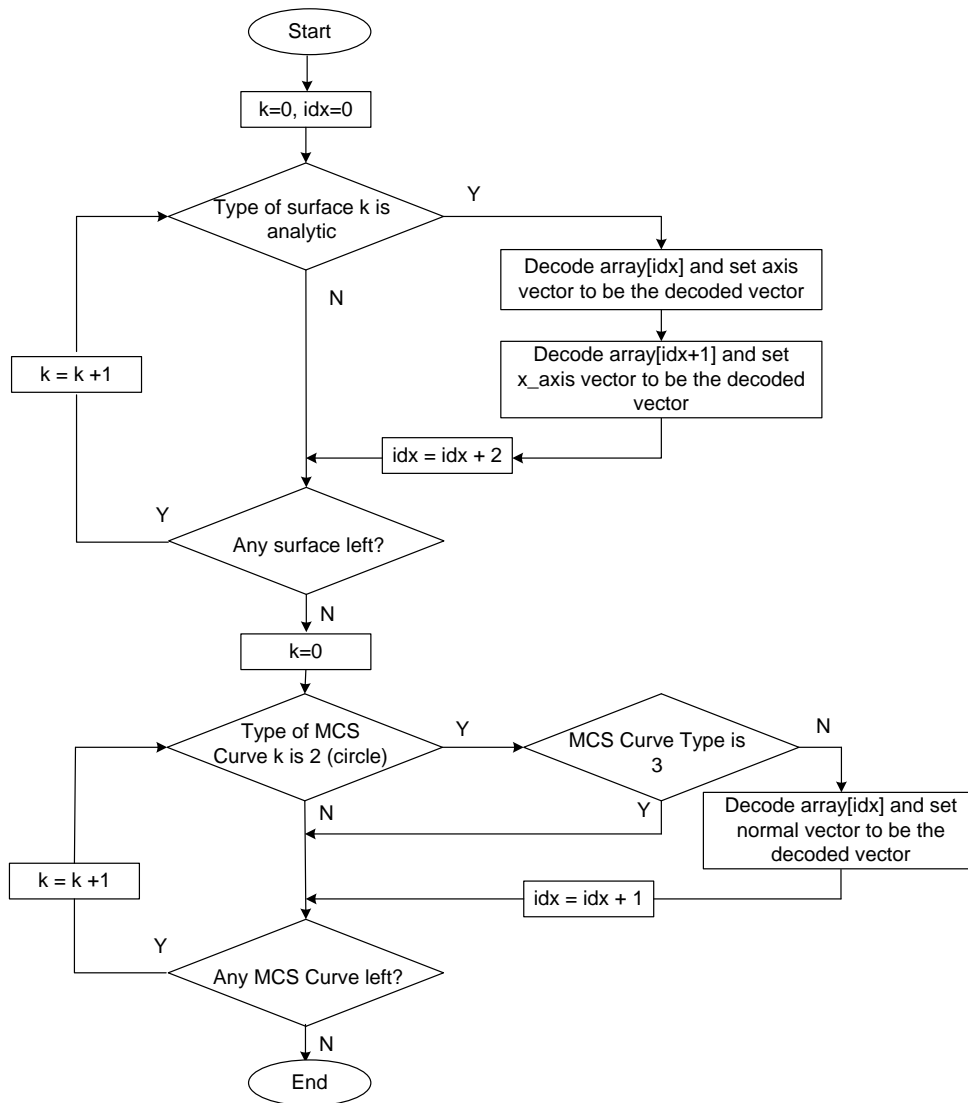


Figure G.24 — Recover Dimension

2D Unit Vector Table

2D Unit Vector Table, as shown in Figure G.25, stores an array of unit vectors in 2D that form part of PCS analytic circle representation in ULP. If the ULP does not contain any analytic circle in the PCS, then the table is empty and bit 0x0010 in Geometric Table Flag is set to be 0. The analytic curve representation of ULP follows XT convention as detailed in the XT B-Rep Annex.

Similar to the coding of Compressed Vertex Normal Array, each 2D unit vector is treated as a 3D unit vector with z component set to be 0.0, and encoded as a single 32 bit integer using Deering Normal CODEC. In addition, the Quantization Bits information of Deering Normal CODEC used to encode 2D Unit Vector Table is always the same as the one used for 3D Unit Vector Table.

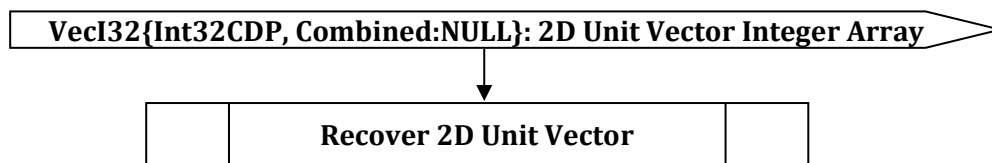


Figure G.25 — 2D Unit Vector Table data collection

VecI32{Int32CDP, Combined:NULL}: 2D Unit Vector Integer Array

2D Unit Vector Integer Array is a vector of integers that stores the encoded 2D unit vector from all analytic entities in the ULP.

Recover 2D Unit Vector

The logic diagram, shown in Figure G.26, to recover 2D unit vector information for all the analytic entities in the ULP from the 2D Unit Vector Integer Array is shown below.

The recovery of a unit vector from an element in the 2D Unit Vector Integer Array is done as part of Deering Normal CODEC. The Quantization Bits read from 3D Unit Vector Table should be used for Deering Normal CODEC to decode the vector information from each element in 2D Unit Vector Integer Array.

The “x_axis” vector to the circle in the PCS, as described in the XT B-Rep Annex, is recovered.

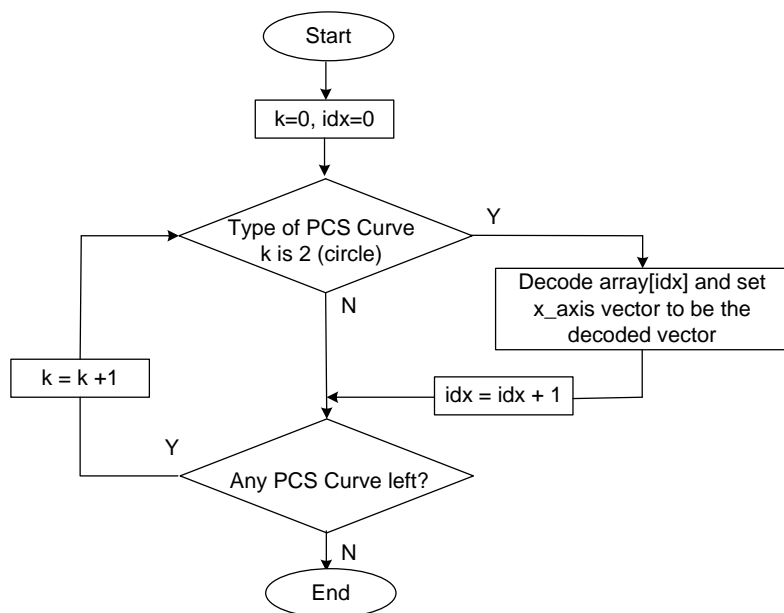


Figure G.26 — Recover 2D Unit Vector

3D MCS Point Table

3D MCS Point Table, as shown in Figure G.27, stores the quantization representation of an array of 3D MCS points in ULP. If the ULP does not contain 3D MCS points, then the table is empty and bit 0x0020 in Geometric Table Flag is set to be 0.

Each point coordinate is first encoded into an integer with uniform quantizer (see Uniform Quantizer Data) and then all the integers from each coordinate are grouped into an integer array, which is then encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type.

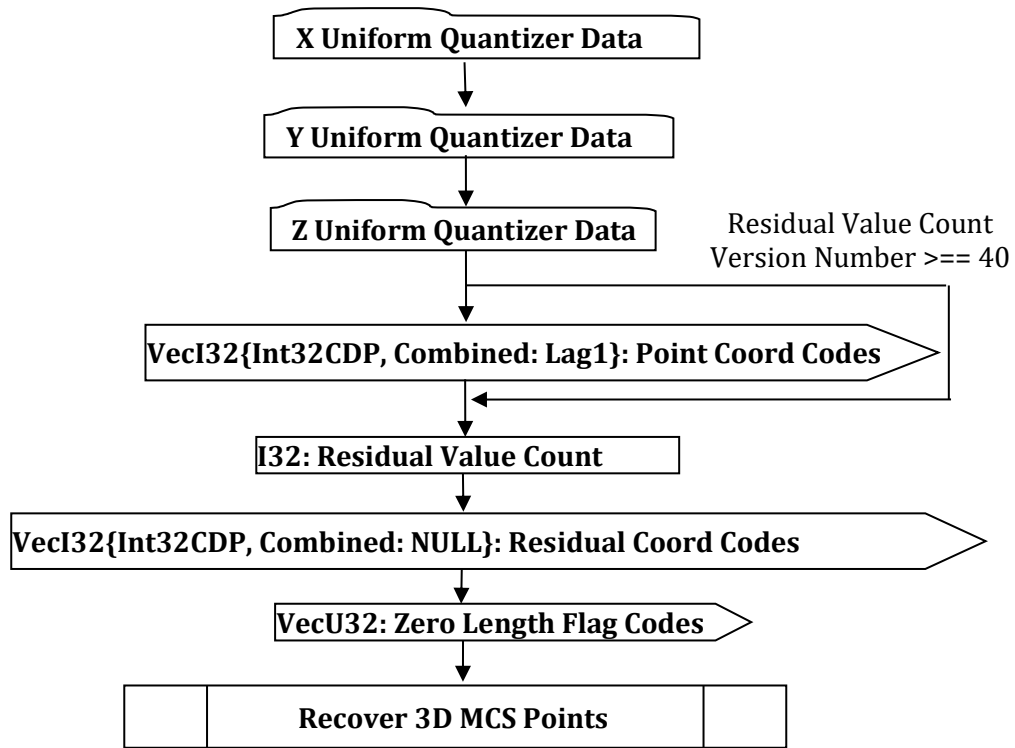


Figure G.27 — 3D MCS Point Table data collection

VecI32{Int32CDP, Combined: Lag1}: Point Coord Codes

Point Coord Codes is a vector of quantizer “codes” for all the coordinate components of an array of three dimensional points, arranged in the order of X-component of point 1, Y-component of point1, Z-component of point1, X-component of point2, etc.. Point Coord Codes uses the Int32CDP CODEC described in Int32 Compressed Data Packet to compress and encode data.

I32: Residual Value Count

Residual Value Count indicates the number of residual values.

VecI32{Int32CDP, Combined: NULL}: Residual Coord Codes

Residual Coord Codes is a vector of quantizer “codes” for all the coordinate components of an array of 3-dimensional residual points, arranged in the order of X-component of residual point 1, Y-component of residual point1, Z-component of residual point1, X-component of residual point2, etc.. The residual points are computed based on Parallelogram rule for the control points of Nurbs surfaces.

Denote $P_{i,i}, P_{i+1,i}, P_{i,i+1}, P_{i+1,i+1}$ as four control points of a Nurbs surface, and $Q_{i,i}, Q_{i+1,i}, Q_{i,i+1}$ as quantized points of $P_{i,i}, P_{i+1,i}, P_{i,i+1}$ respectively, the residual point of $P_{i+1,i+1}$ is defined as $R_{i+1,i+1} = P_{i+1,i+1} + Q_{i,i} - Q_{i,i+1} - Q_{i+1,i}$.

Residual Coord Codes uses the Int32CDP CODEC described in Int32 Compressed Data Packet to compress and encode data.

VecU32: Zero Length Flag Codes

Zero Length Flag Codes is a vector of 32 bit unsigned integers, with each bit indicating whether or not a MCS curve with line geometry has zero length. The bits are arranged the same sequence as the MCS curve array. After decoding, the first N bits, where N is the total number of MCS line curves in the ULP,

can be assigned to an integer array of length N with its element assigned with value 0 or 1. Each element in the decoded integer array describes whether or not the corresponding MCS line curve has zero length.

Recover 3D MCS Points

The logic diagram, shown in Figure G.28, to recover 3D MCS points information in the ULP from the three decoded arrays, point coordinate array P_{cc} (with index ip) decoded from Zero Length Flag Codes, residual coordinate array R_{cc} (with index ir) decoded from Residual Coord Codes, and zero length flag array Z_{lf} (with index iz) decoded from Zero Length Flag Codes, is shown below. Note that the point coordinates are decoded from the integer elements with Uniform Quantizer (see Uniform Quantizer Data).

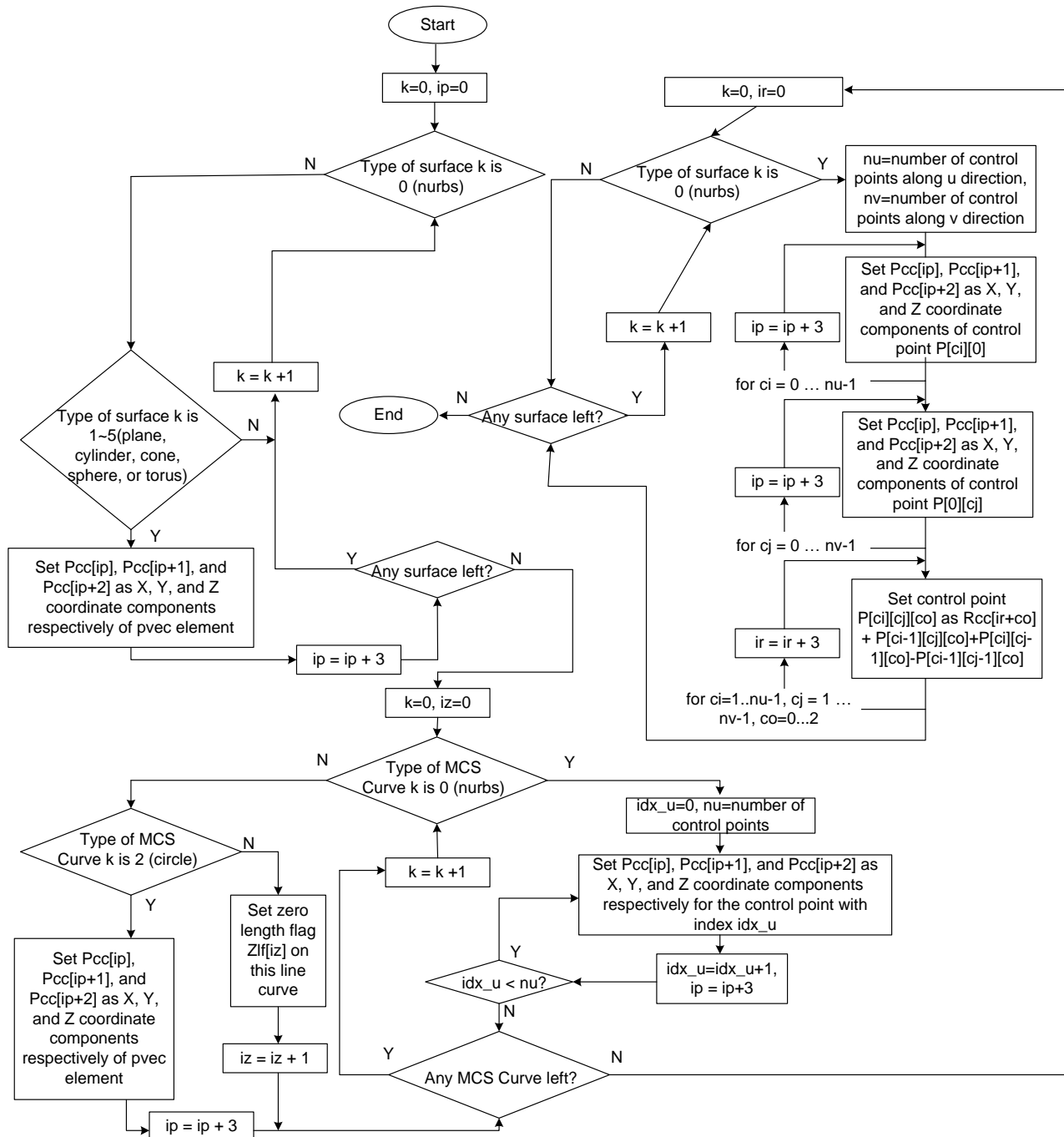


Figure G.28 — Recover 3D MCS Points

Knot Vector Table

Knot Vector Table, as shown in Figure G.29, stores the quantization representation of knot vectors in ULP. If the ULP does not contain any knot vector that needs be stored, then the table is empty and bit 0x0040 in Geometric Table Flag is set to be 0.

In ULP every knot vector starts with 0.0 and ends with 1.0 and is always clamped at both ends. The encoding of knot vector depends on its classified knot type. The knot values in the middle of a knot vector need be written only if the knot type is 0 (see Supported Knot Type). For all the knot values that need be written, each of them is encoded into an integer with uniform quantizer (see Uniform Quantizer Data) and then all the integers are grouped into an integer array. The integer array is then encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type.

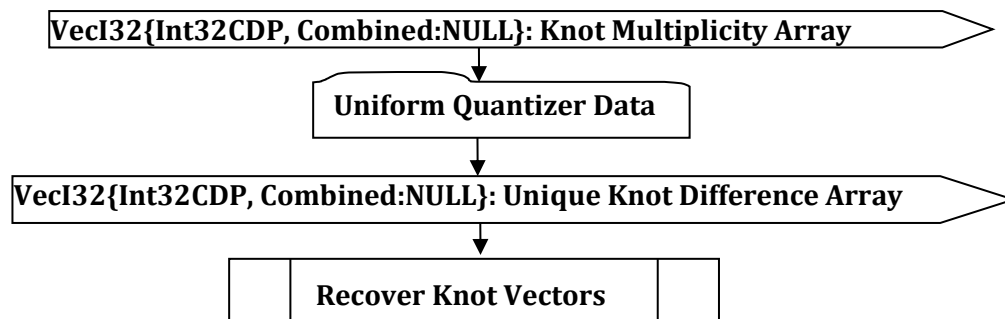


Figure G.29 — Knot Vector Table data collection

VecI32{Int32CDP, Combined:NULL}: Knot Multiplicity Array

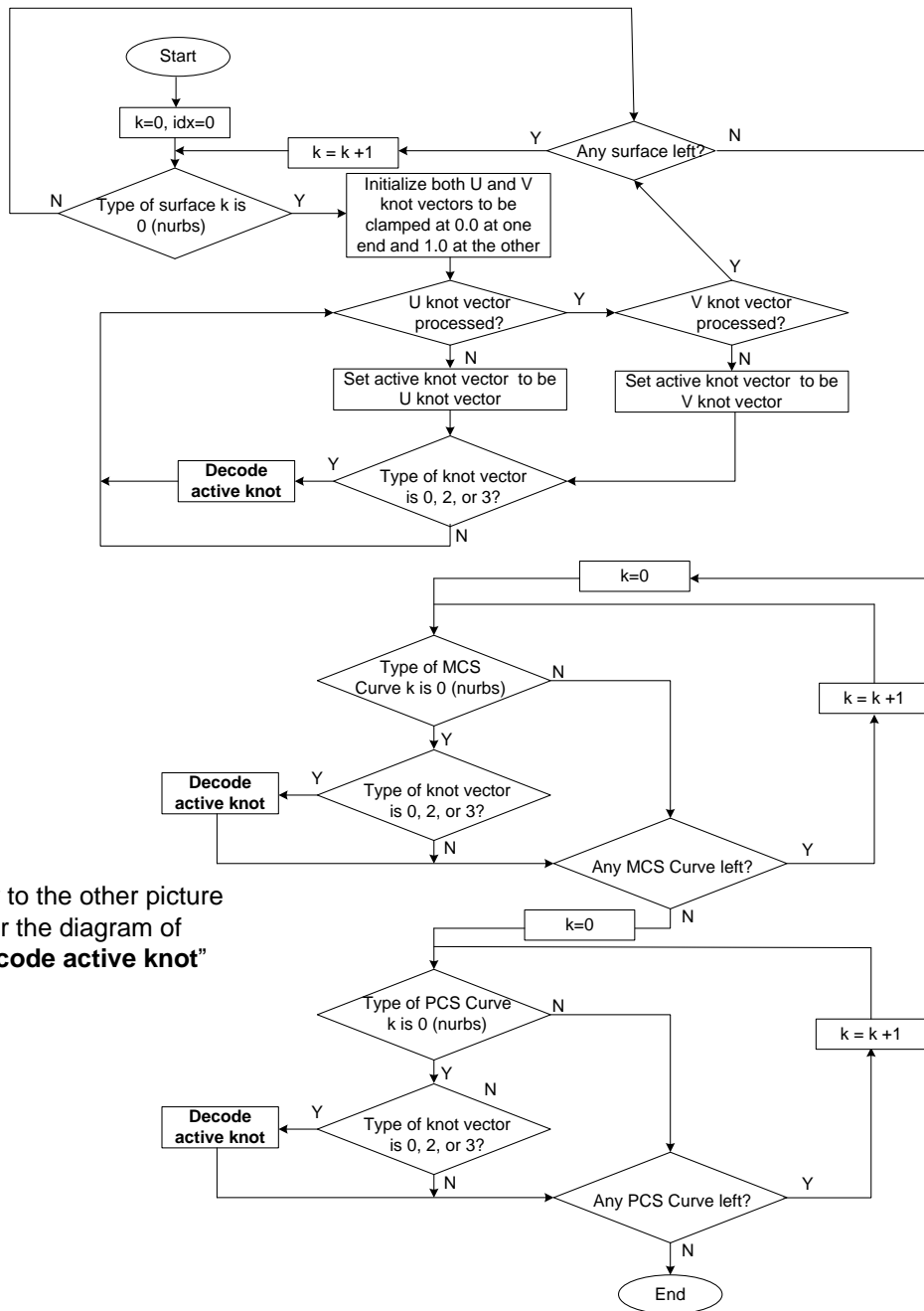
Knot Multiplicity Array is a vector of integers that describes knot multiplicity for all the knot vectors. The value of knot multiplicity is set to be 0 if the knot value does not repeat itself. Knot Multiplicity Array is parallel to Knot Multiplicity Array with the same length, and uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

VecI32{Int32CDP, Combined:NULL}: Unique Knot Difference Array

Unique Knot Difference Array is a vector that represents the unique knot values. The first element has the value of the first unique knot value. Each subsequent element k represents the value difference between unique knot value k and the quantized value of unique knot value $k-1$. Unique Knot Difference Array is first quantized (Uniform Data Quantization) and then the quantized value uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

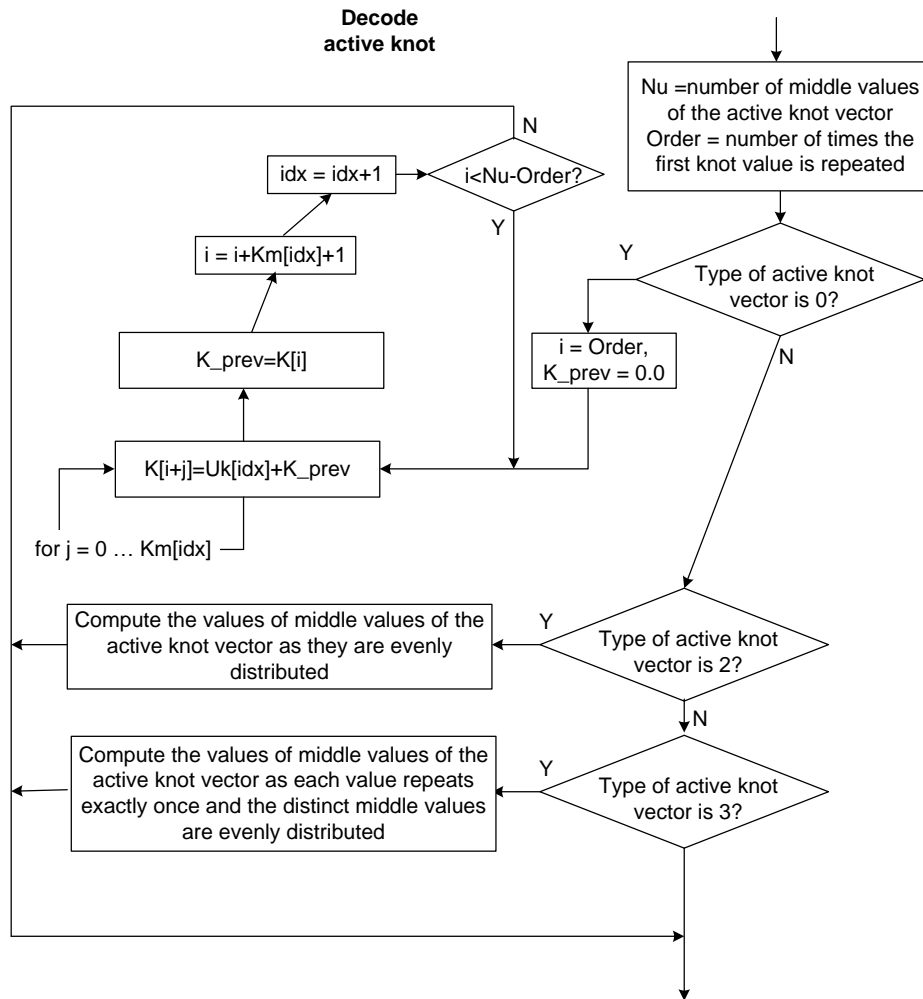
Recover Knot Vectors

The logic diagram, shown in Figure G.30, to recover knot vector information in the ULP from the Knot Multiplicity Array (array K_m) and Unique Knot Difference Array (array U_k) is shown below. Note that each integer element in the Unique Knot Difference Array is decoded with Uniform Quantizer.



Refer to the other picture
for the diagram of
“Decode active knot”

Figure G.30 — Recover Knot Vectors



Recover Knot Vectors (continued)

1D MCS Table

1D MCS Table, as shown in Figure G.31, stores the quantization representation of floating point values in MCS. If the ULP does not contain any such value, then the table is empty and bit 0x0080 in Geometric Table Flag is set to be 0. Each floating point value is encoded into an integer with uniform quantizer (see Uniform Quantizer Data) and then all the integers are grouped into an integer array. The integer array is then encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type.

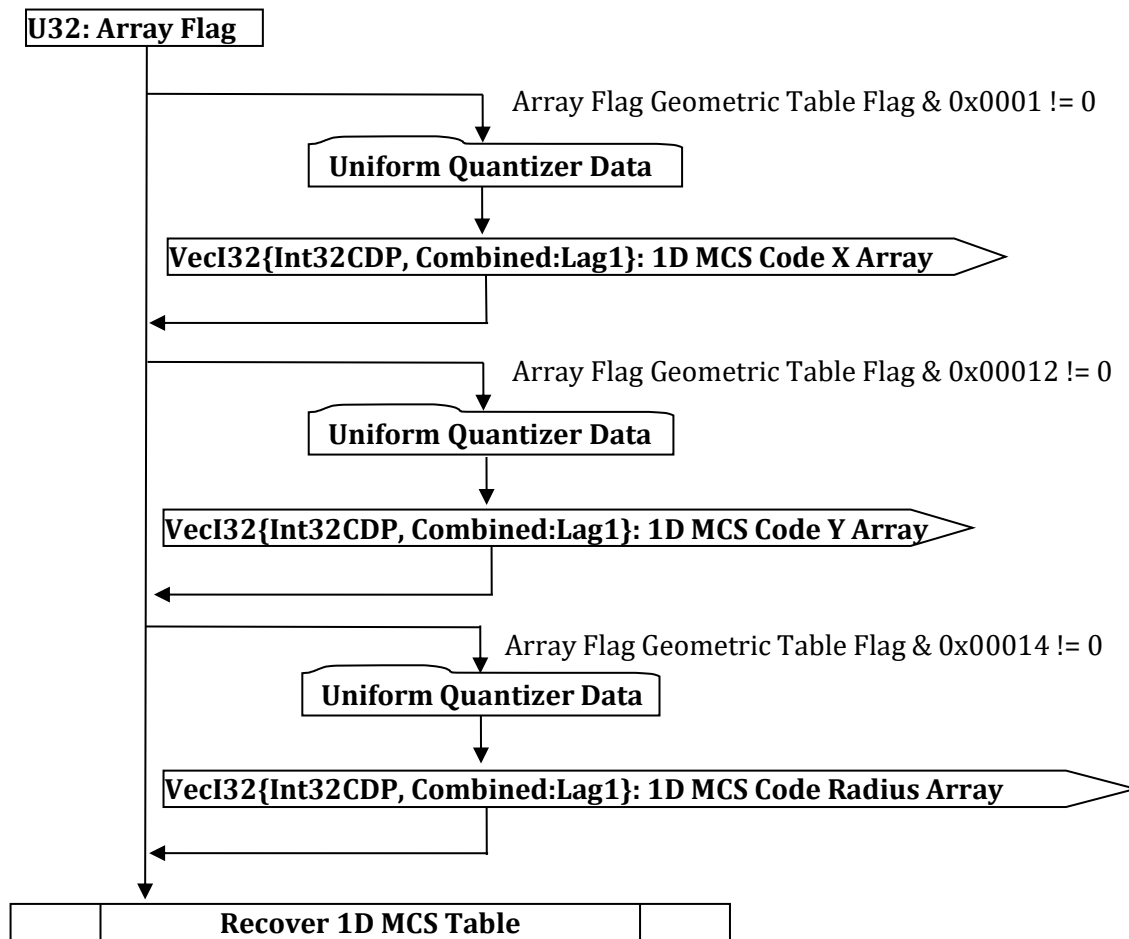


Figure G.31 — 1D MCS Table data collection

U32: Array Flag

Array Flag indicates which arrays are not trivial and therefore encoded.

VecI32{Int32CDP, Combined:Lag1}: 1D MCS Code X Array

1D MCS Code X Array is a vector of quantizer “codes” for one group of 1D floating point values in MCS that represent X coordinates. 1D MCS Code X Array uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

VecI32{Int32CDP, Combined:Lag1}: 1D MCS Code Y Array

1D MCS Code Y Array is a vector of quantizer “codes” for one group of 1D floating point values in MCS that represent Y coordinates. 1D MCS Code Y Array uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

VecI32{Int32CDP, Combined:Lag1}: 1D MCS Code Radius Array

1D MCS Code Radius Array is a vector of quantizer “codes” for one group of 1D floating point values in MCS that represent radius or other MCS metric values. 1D MCS Code Radius Array uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

Recover 1D MCS Table

The representation of each surface or curve in ULP includes information that describes the extent of the surface or curve in the parameter domain. For curves the extent information is represented by two

numbers, *umin* and *umax*, while for surfaces it is represented by two additional numbers for the other parametric direction, *vmin* and *vmax*. For surfaces or curves of Nurbs type such extent information is implied by the knot vector information. For surfaces or curves of other types the extent information needs be read from 1D MCS Table if the parameter value represents value in MCS, or Radian Table if the parameter value represents angle information. The detailed information about how the parameter domain information of different entities should be read is listed in Table G.15.

Table G.15 — Parameter Domain

| Entity Type | <i>umin</i> | <i>umax</i> | <i>vmin</i> | <i>vmax</i> |
|-----------------|-----------------|----------------------------|-----------------|-----------------|
| NURBS Surface | n/a (from knot) | n/a (from knot)) | n/a (from knot) | n/a (from knot) |
| Plane | n/a (always 0) | 1D MCS Table | n/a (always 0) | 1D MCS Table |
| Cylinder | n/a (always 0) | Radian Table | n/a (always 0) | 1D MCS Table |
| Cone | n/a (always 0) | Radian Table | n/a (always 0) | 1D MCS Table |
| Sphere | n/a (always 0) | Radian Table | Radian Table | Radian Table |
| Torus | n/a (always 0) | Radian Table | Radian Table | Radian Table |
| XYZ NURBS Curve | n/a (from knot) | n/a (from knot) | n/a | n/a |
| XYZ Line | n/a (always 0) | n/a (from vertex geometry) | n/a | n/a |
| XYZ Circle | n/a (always 0) | Radian Table | n/a | n/a |
| UV NURBS Curve | n/a (from knot) | n/a (from knot) | n/a | n/a |
| UV Line | n/a (always 0) | n/a (from next uv curve) | n/a | n/a |
| UV Circle | Radian Table | Radian Table | n/a | n/a |

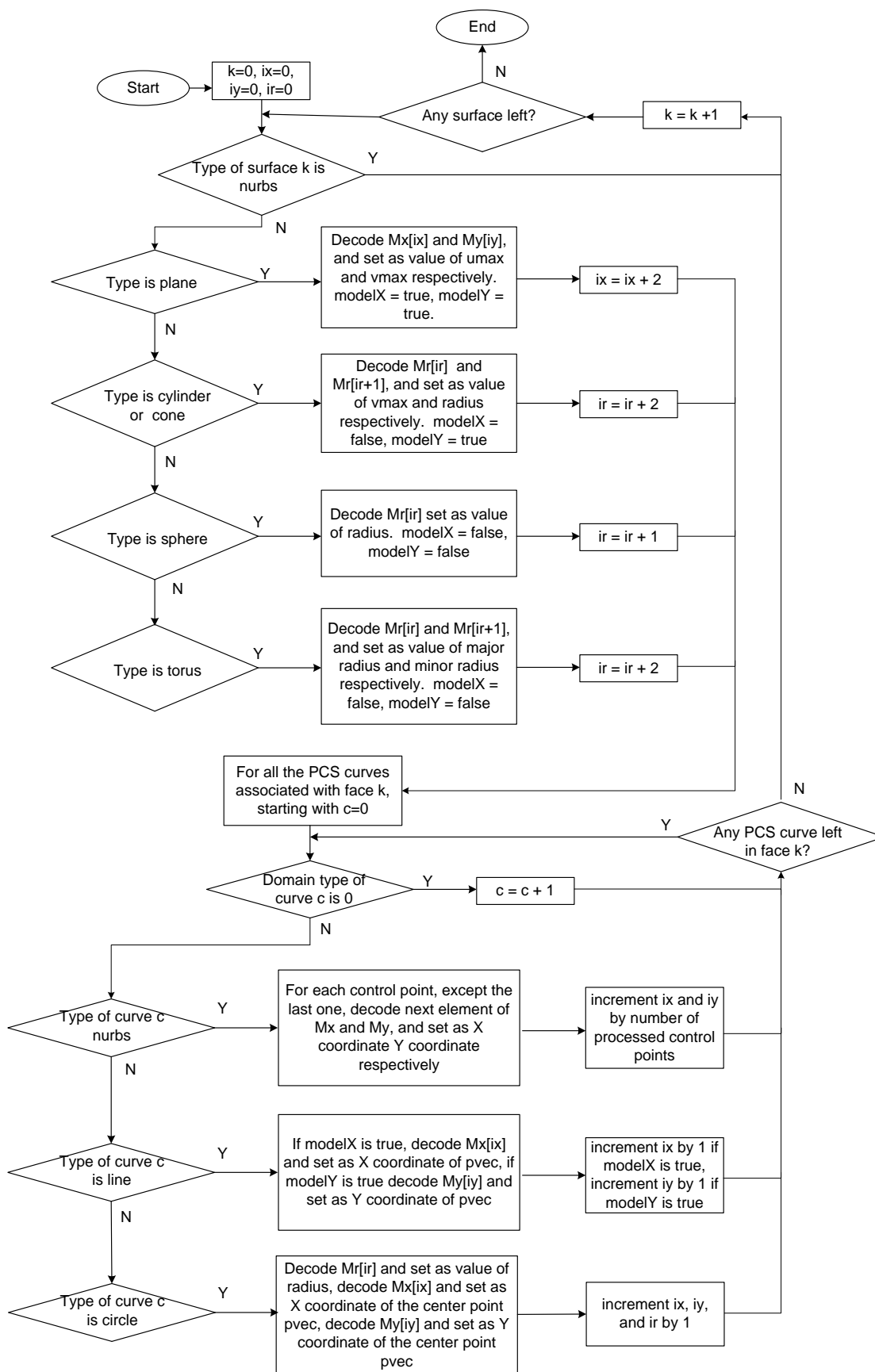


Figure G.32 — Recover 1D MCS Table

The logic diagram to recover 1D MCS table information in the ULP from the 1D MCS Code X Array is shown in the Figure G.32, titled Recover 1D MCS Table. 1D MCS Code X Array is denoted as M_x (with index ix), 1D MCS Code Y Array is denoted as M_y (with index iy), and 1D MCS Code Radius Array is

denoted as Mr (with index ir). Note that each integer element in the arrays is decoded with Uniform Quantizer.

PCS Value Table

PCS Value Table, as shown in Figure G.33, stores the quantization representation of floating point values in PCS. If the ULP does not contain any such value, then the table is empty and bit 0x0100 in Geometric Table Flag is set to be 0. Each floating point value is encoded into an integer with uniform quantizer (see Uniform Quantizer Data) and then all the integers are grouped into an integer array. The integer array is then encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type.

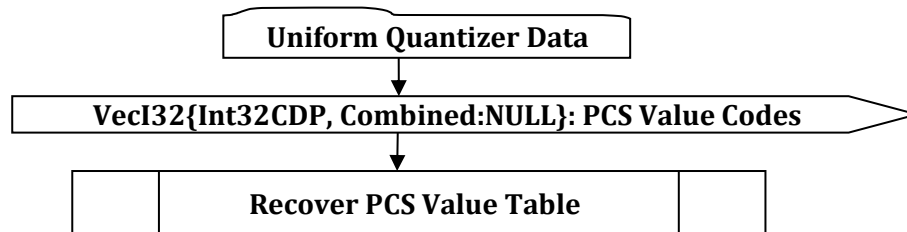


Figure G.33 — PCS Value Table data collection

VecI32{Int32CDP, Combined:NULL}: PCS Value Codes

PCS Value Codes is a vector of quantizer “codes” for all the floating point values in PCS. PCS Value Codes uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

Recover PCS Value Table

The logic diagram, shown in Figure G.34, to recover PCS Value Table information in the ULP from the PCS Value Codes is shown in the Figure below. Note that each integer element in the PCS Value Codes array is decoded with Uniform Quantizer.

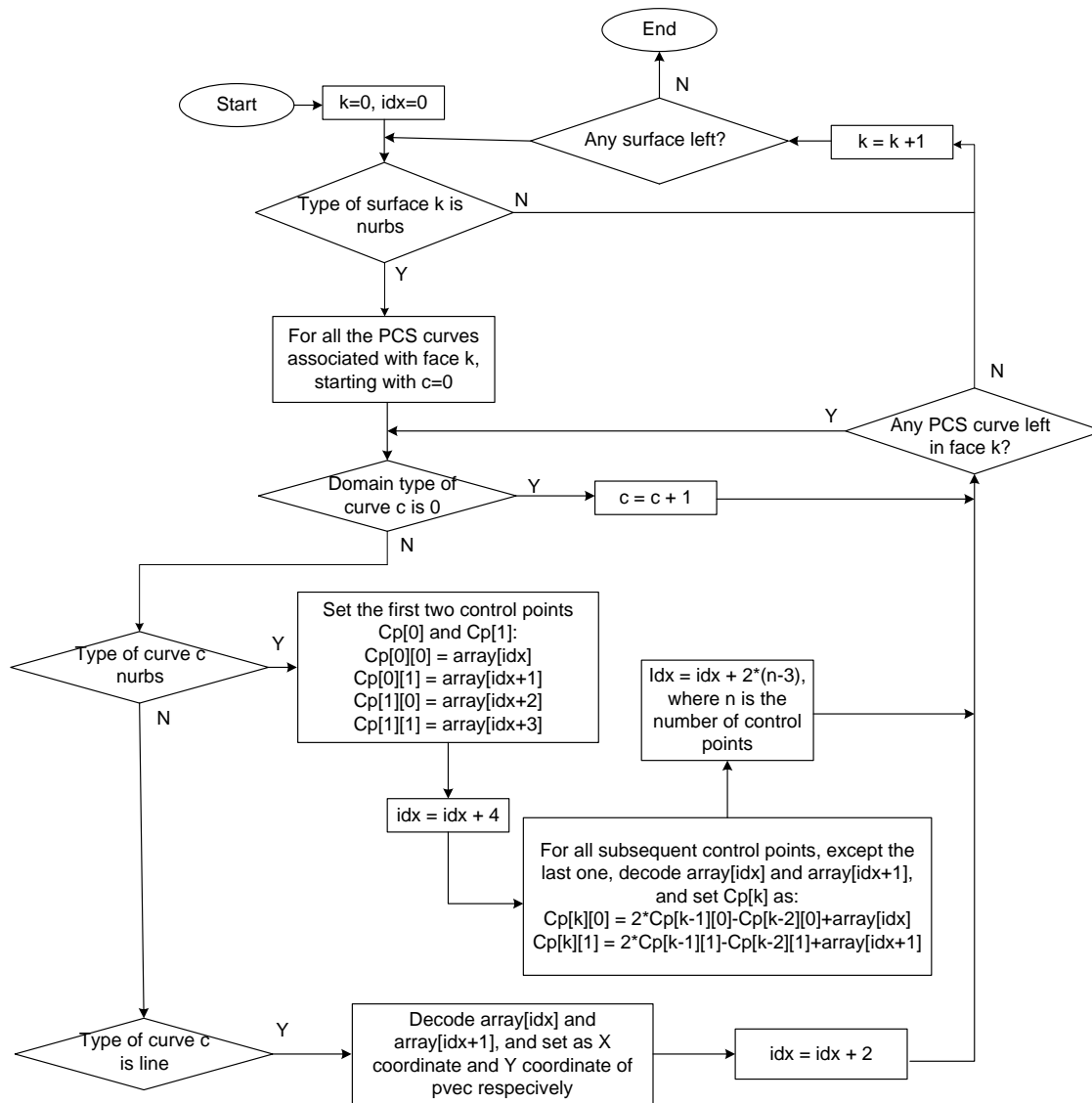


Figure G.34 — Recover PCS Value Table

Radian Table

Radian Table, shown in Figure G.35, stores the quantization representation of angular values. If the ULP does not contain any such angular value, then the table is empty and bit 0x0200 in Geometric Table Flag is set to be 0. Each angular value is encoded into an integer with uniform quantizer (see Uniform Quantizer Data) and then all the integers are grouped into an integer array. The integer array is then encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type.

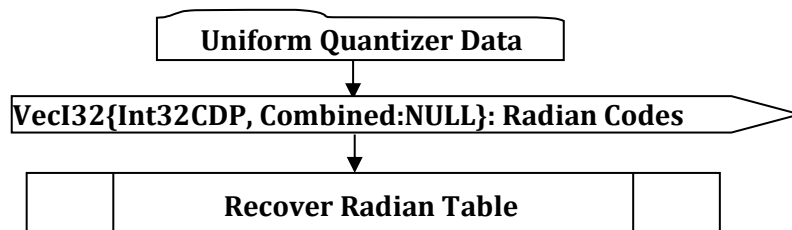


Figure G.35 — Radian Table data collection

VecI32{Int32CDP, Combined:NULL}: Radian Codes

Radian Codes is a vector of quantizer “codes” for all the angular values. Radian Codes uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

Recover Radian Table

The logic diagram, shown in Figure G.36, to recover Radian Table information in the ULP from the Radian Codes is shown in the Figure- Recover Radian Table. Note that each integer element in the Radian Codes array is decoded with Uniform Quantizer.

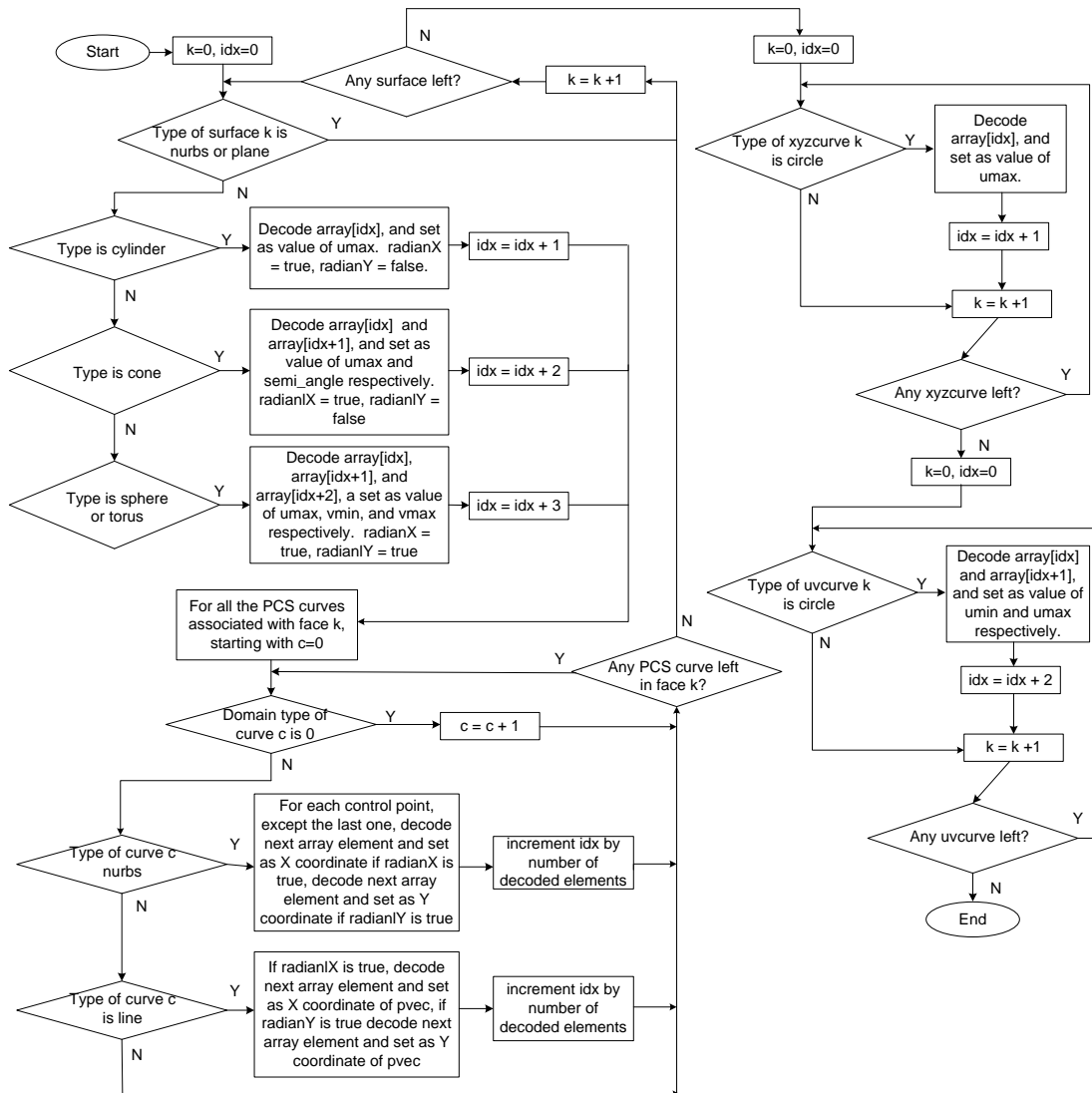


Figure G.36 — Recover Radian Table

Weight Table

Weight Table, as shown in Figure G.37, stores the quantization representation of weight values. If the ULP does not contain any such weight value, then the table is empty and bit 0x0400 in Geometric Table Flag is set to be 0. Each weight value is encoded into an integer with uniform quantizer (see Uniform Quantizer Data) and then all the integers are grouped into an integer array. The integer array is then encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type

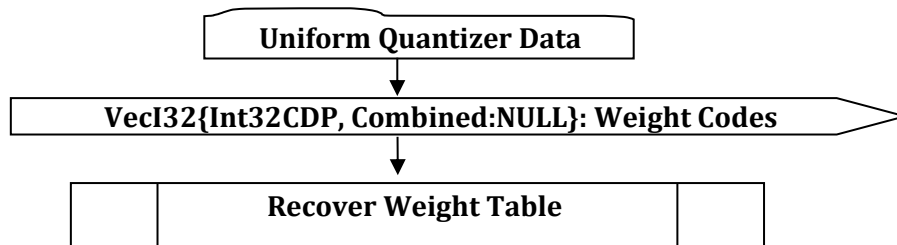


Figure G.37 — Weight Table data collection

VecI32{Int32CDP, Combined:NULL}: Weight Codes

Weight Codes is a vector of quantizer “codes” for all the weight values. Weight Codes uses the Int32CDP CODEC described in Int32 Compressed Data Packet with Combined Predictor Type to compress and encode data.

Recover Weight Table

The logic diagram, shown in Figure G.38, to recover Weight Table information in the ULP from the Weight Codes is shown in Figure - Recover Weight Table. Note that each integer element in the Weight Codes array is decoded with Uniform Quantizer.

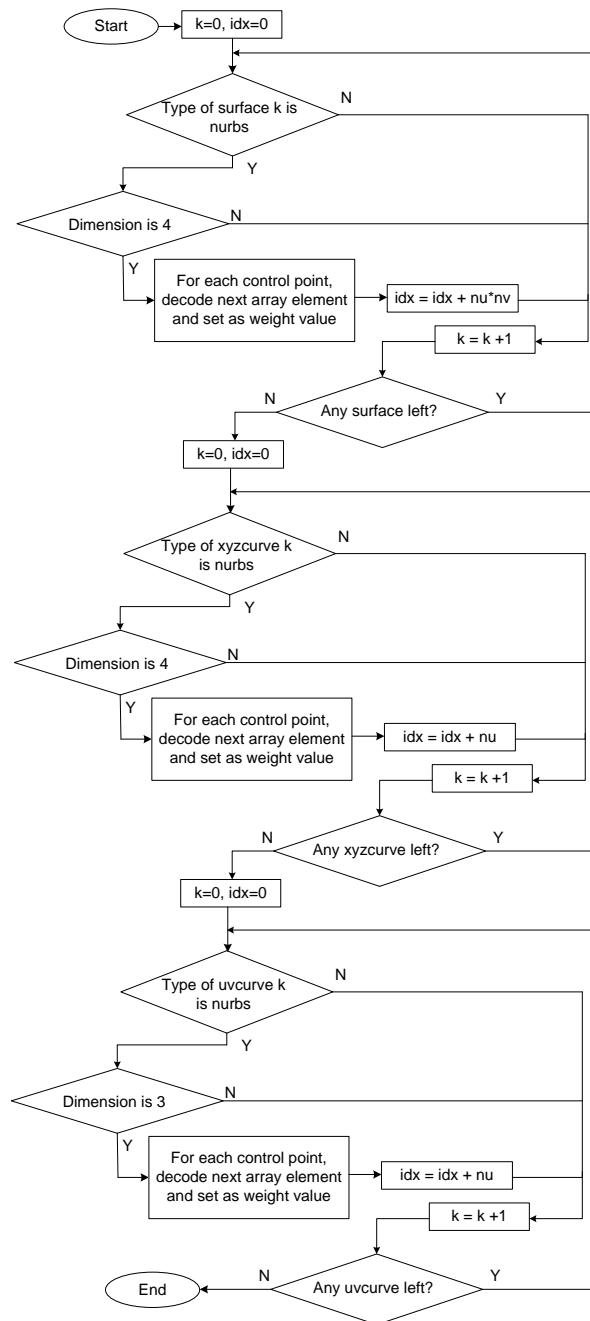


Figure G.38 — Recover Weight Table

G.1.3 Material Attribute Element Properties

The properties attached to material attribute are standard JT properties, and the logic diagram to read the properties attached to a material attribute is shown in Figure G.39, titled Material Attribute Element Properties.

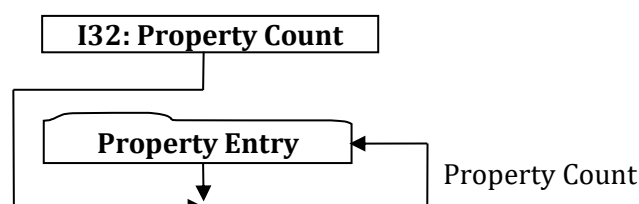


Figure G.39 — Material Attribute Element Properties

I32: Property Count

Property count is the number of properties attached.

Property Entry

Standard JT property entry, consisting of key and value pair.

G.1.4 Information Recovery

The information in ULP is classified as “essential information” that is explicitly written on disk, and “derivative information” that can be computed from the “essential information”. How “essential information” of ULP can be read from disk was covered in previous sections, and this section focuses on the logic to recover “derivative information” from “essential information”. The logic diagram is shown in Figure G.40.

The derivative information consists of curve information either in the parameter or model space. For example, the PCS curves associated with an untrimmed face can be inferred from the parameter domain of the surface, or an MCS curve may be computed from vertex information and/or the combination of corresponding PCS curve geometry and surface geometry, etc.. Shown in Figure Information Recovery is the high level diagram to recover “derivative information”. First, all the PCS line geometry are recovered from the associated surface domain information if the domain type of those PCS curves, stored in its associated coedge, are of value 1, 2, 3, 4 meaning that the PCS curve is identical to one of the parameter boundaries of the surface. The PCS curve geometry is then finalized by leveraging the knowledge that all the PCS curves in the same loop are joined in a head to tail fashion. The geometry of two end points of every MCS curve can then be computed from the corresponding PCS curve and surface geometry. Second, the MCS curve geometry is recovered depending on its type. If the MCS curve type is 0, 1, or 2, then the geometry of its two end points is used to compute the curve geometry. If the MCS curve type is 3, then its geometry is computed by projecting PCS curve onto the surface geometry. The logical steps that are displayed with dark colour indicate steps that will be elaborated in more detail later.

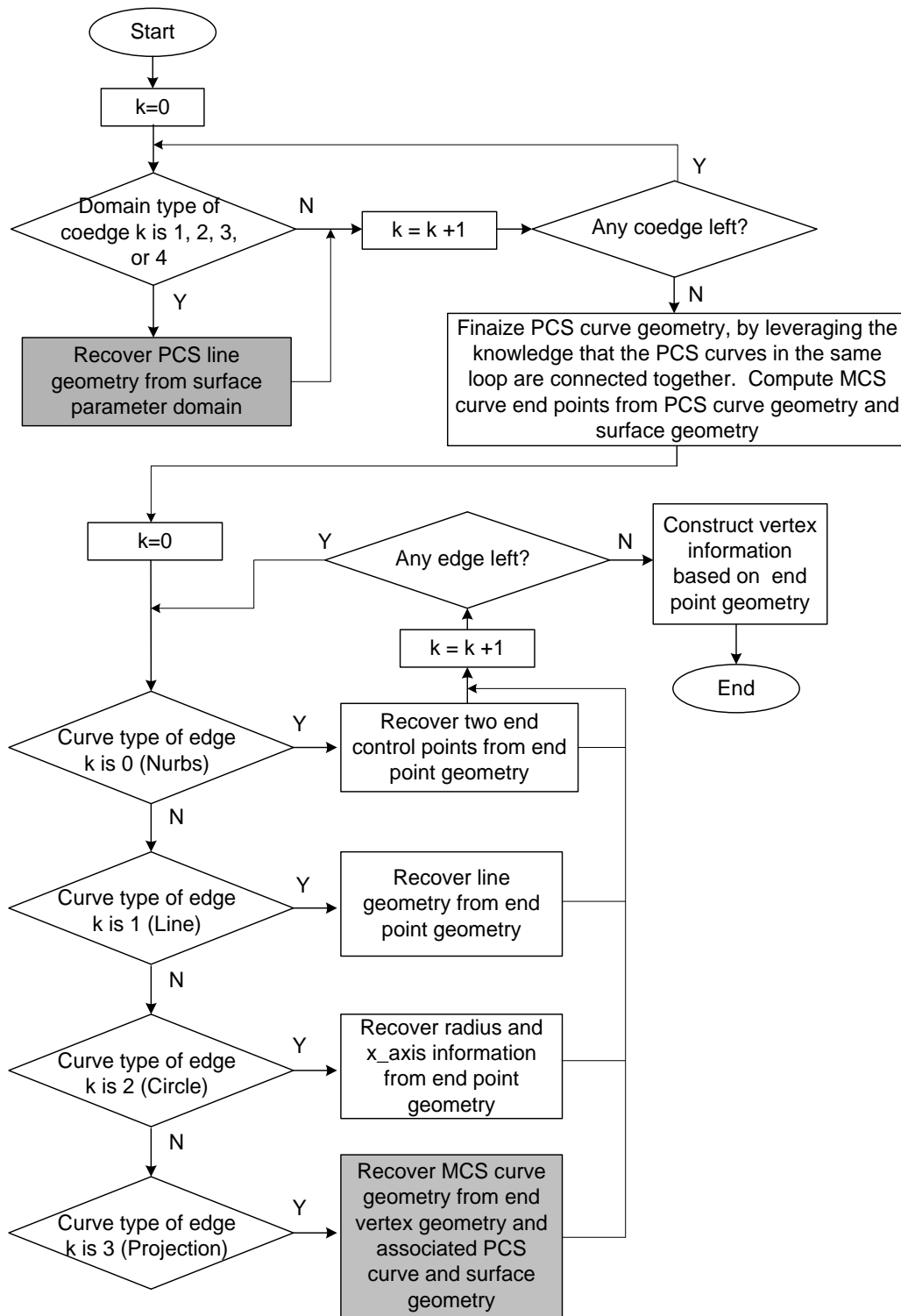


Figure G.40 — Information Recovery

PCS Curve Recovery from Surface Domain

Shown in Figure G.41, titled PCS Curve Recovery from Surface Domain, is the diagram illustrating how the PCS curve geometry is recovered from surface parameter domain information.

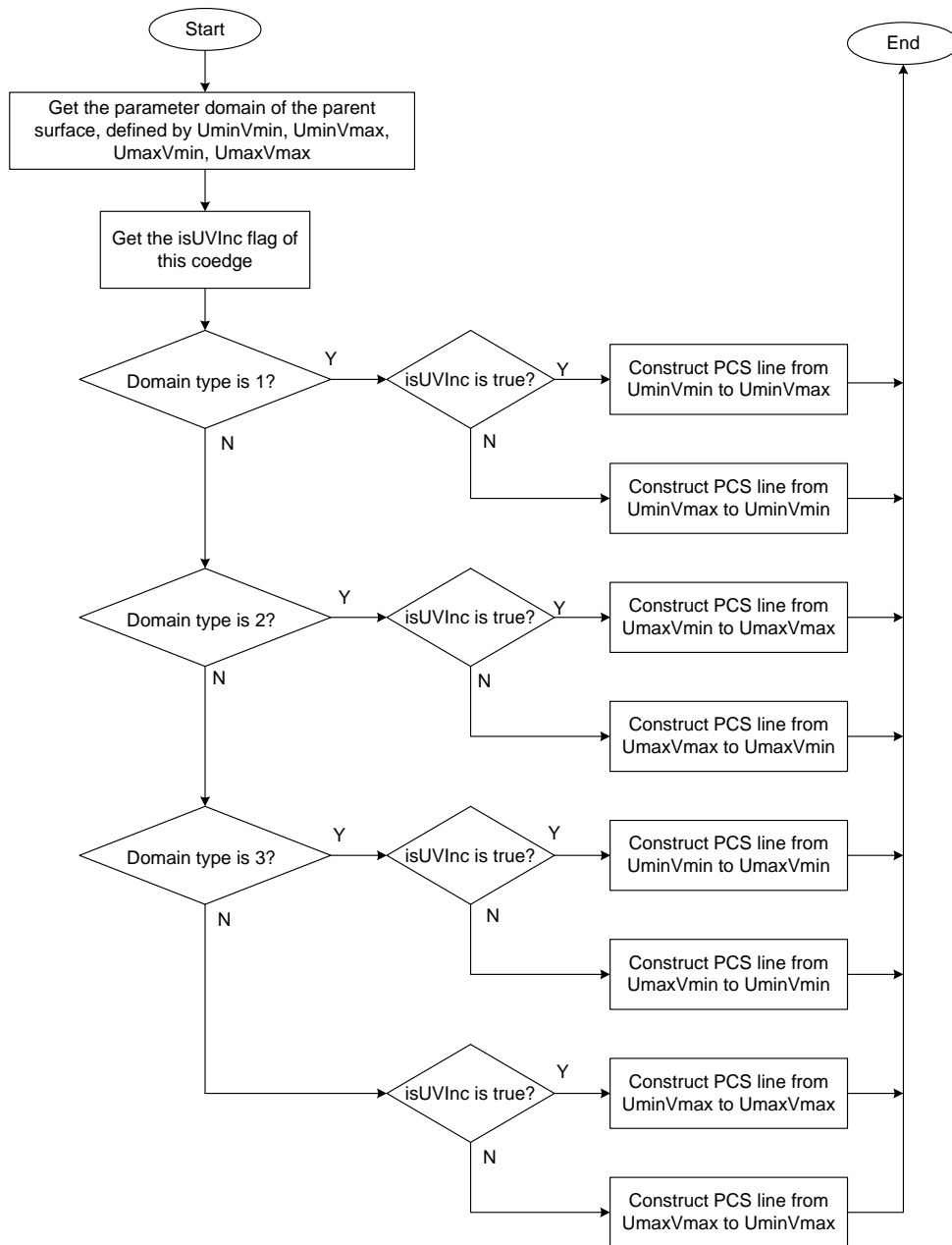


Figure G.41 — PCS Curve Recovery from Surface Domain

MCS Curve Recovery

Shown in Figure G.42, titled MCS Curve Recovery, is the diagram illustrating how MCS curve geometry is recovered from its end point geometry, and/or its associated PCS curve geometry and surface geometry. If the associated PCS curve is coincident with one of the parameter boundaries of the parent surface, then the MCS curve can be recovered from parent surface geometry. Otherwise, if the surface type is planar and PCS curve is of type Nurbs or circle, then the MCS curve geometry can be recovered by projecting the PCS curve from parameter domain to model space onto the planar surface.

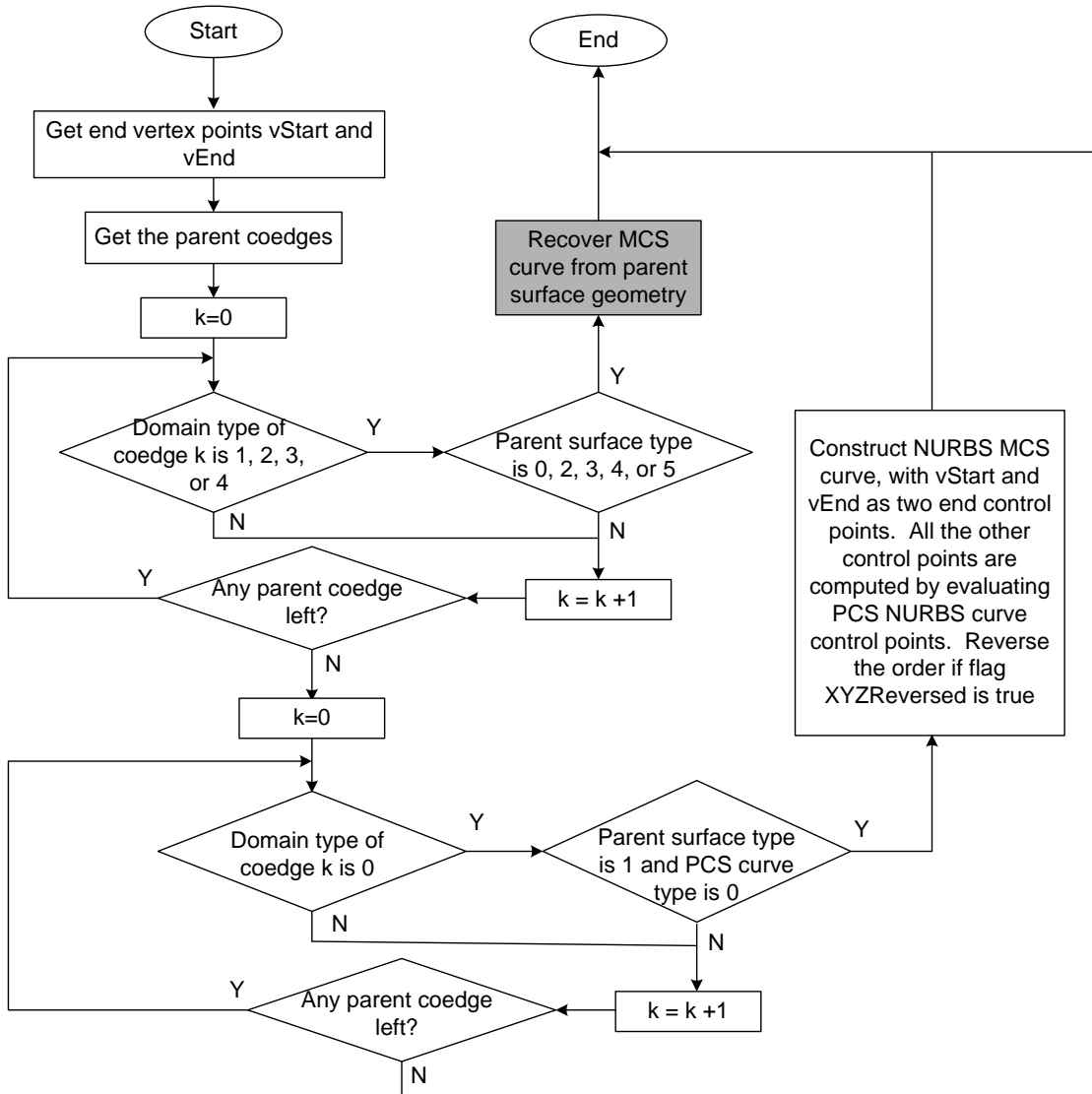


Figure G.42 — MCS Curve Recovery

Shown in Figure G.43, titled MCS Curve Recovery from Surface Geometry, is the detailed description of how MCS curve can be recovered from surface geometry.

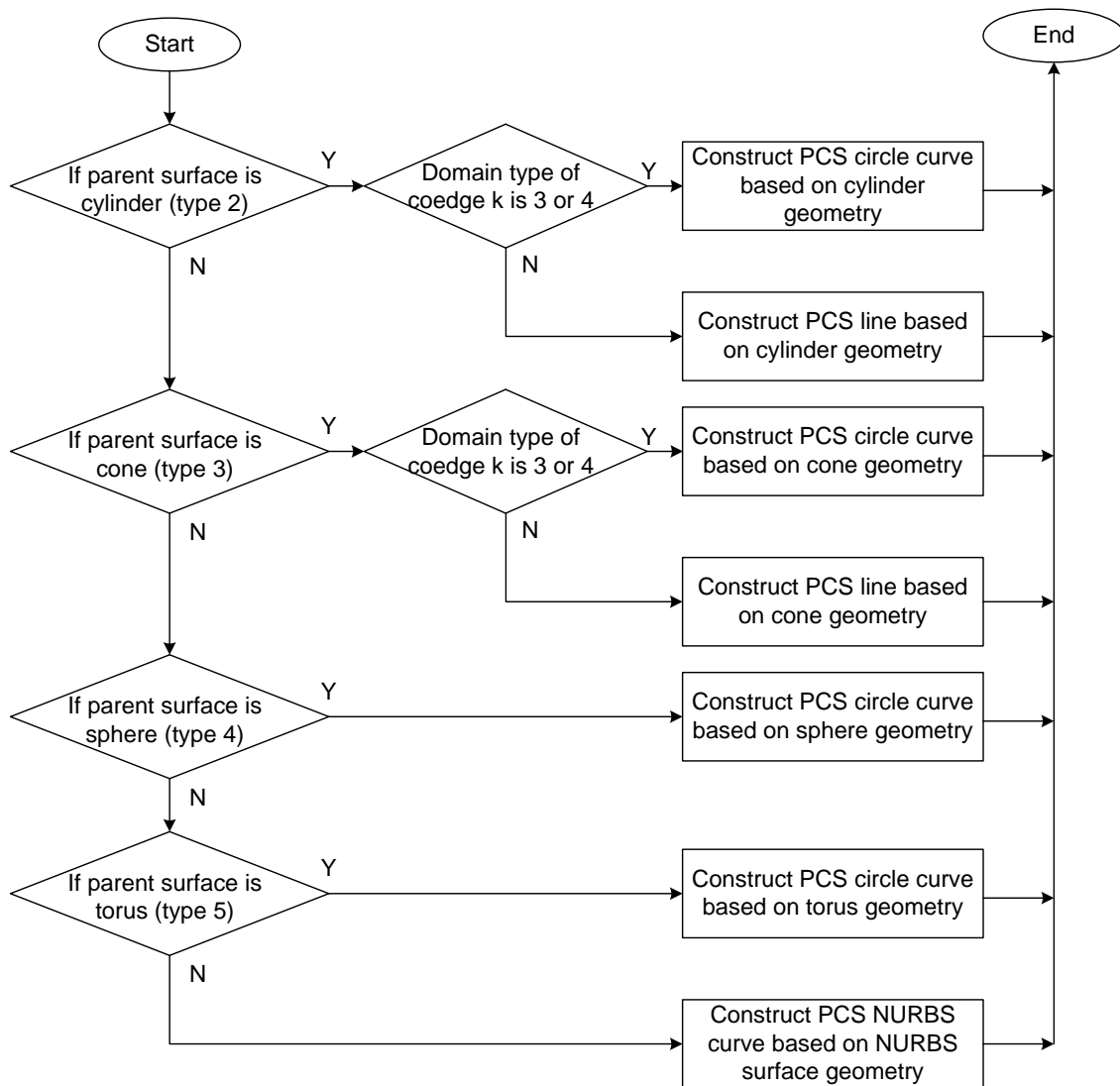


Figure G.43 — MCS Curve Recovery from Surface Geometry

Annex H

JT Smart Topology Table (STT) Segment

JT Smart Topology Table (hereafter referred to as STT) Segment, shown in Figure H.1, contains an Element that defines the lightweight B-Rep description for a particular Part.

JT STT Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The JT STT Segment type supports compression on all element data, so all elements in JT STT Segment use the Logical Element Header Compressed form of element header data.

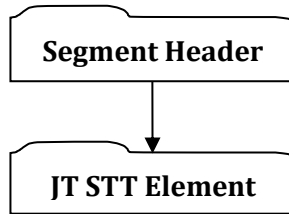


Figure H.1 — JT STT Segment data collection

Complete description for Segment Header can be found in the File Header section of Base Format Description under Data Segment.

H.1 JT STT Element

Object Type ID: 0xca7e6f89, 0x97c8, 0x47f0, 0x9f, 0xca, 0x16, 0x99, 0xc, 0xfb, 0xe2, 0x17

JT STT Element represents a lightweight B-Rep data. It contains complete B-Rep topology information, analytic geometry information, and attribute information, as shown in Figure H.2.

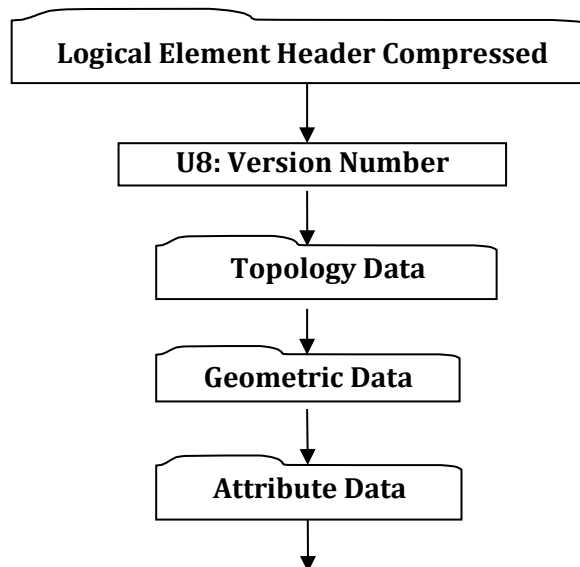


Figure H.2 — JT STT Element data collection

Complete description for Logical Element Header Compressed can be found in the File Header section of Base Format Description under Data Segment, Data.

U8: Version Number

Version Number is the version identifier for this JT STT Element. Information on local version numbers can be found in the Base Format Description under Common Data Conventions and Constructs Local version numbers.

H.1.1 Topology Data

A diagrammatic representation of the Topology Data Collection is shown in Figure H.3.

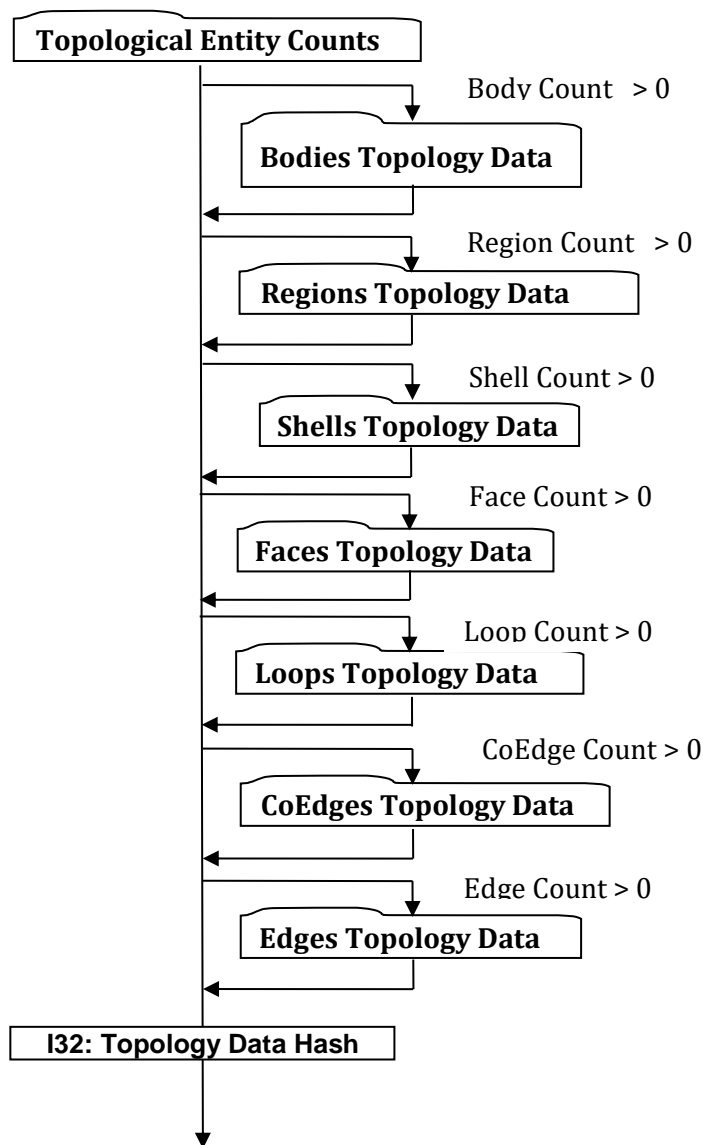


Figure H.3 — Topology Data collection

Topological Entity Counts

Topological Entity Counts data collection, as shown in Figure H.4, defines the counts for each of the various topological entities within a STT.

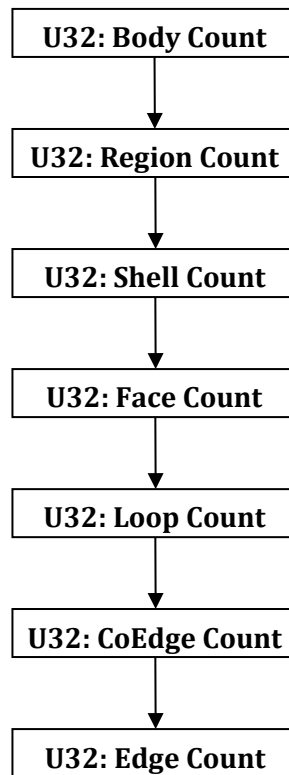


Figure H.4 — Topological Entity Counts data collection

U32: Body Count

Body Count indicates the number of topological body entities.

U32: Region Count

Region Count indicates the number of topological region entities.

U32: Shell Count

Shell Count indicates the number of topological shell entities.

U32: Face Count

Face Count indicates the number of topological face entities.

U32: Loop Count

Loop Count indicates the number of topological loop entities.

U32: CoEdge Count

CoEdge Count indicates the number of topological coedge entities.

U32: Edge Count

Edge Count indicates the number of topological edge entities.

Body Topology Data

Body Topology Data, as shown in Figure H.5, defines the disjoint set of non-overlapping Regions making up each Body. Each Body is defined by one or more non-overlapping Regions. A Body is the sum of all regions of this Body.

Each Body's defining Regions are identified in the Start Region Index. The indices of all the Regions in a single Body are contiguous. The first Region index of the first Body is 0. The first Region index of Body k , $k \geq 0$ is the value of the k th element in Start Region Index. The last Region index of Body k , $k \geq 0$ equals to the first Region index of Body $k+1$ minus 1.

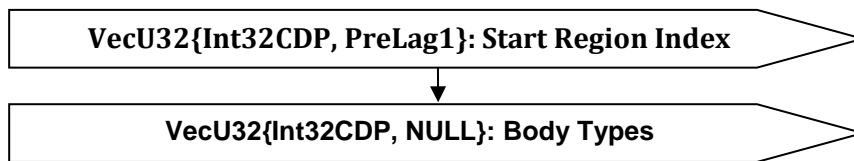


Figure H.5 — Body Topology Data collection

VecU32{Int32CDP, PreLag1}: Start Region Index

Start Region Index is a vector of indices representing the integer index value of start region for this body, which is equal to the last region index from last body plus 1. Start Region Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Body Types

Each Body has a type identifying the type of the Body. Body Types indexed by Body Index contains the body type enum values for corresponding Bodies.

In an uncompressed/decoded form the type values can be one of the following values as shown in Table H.1:

Table H.1 — Body Type Values

| | |
|---|--|
| 0 | A body consisting solely of an unbounded void region. |
| 1 | A topologically zero dimensional manifold body containing a single isolated vertex. |
| 2 | A topologically zero dimensional manifold body containing two or more isolated vertices. |
| 3 | A topologically one dimensional manifold body containing one or more connected sets of edges, where any vertex is at the junction of no more than two edges. |
| 4 | A topologically two dimensional manifold body containing one or more connected sets of faces, where any edge is at the junction of no more than two faces. |
| 5 | A topologically three dimensional manifold body containing one or more disjoint and separate solid regions. All faces form a boundary between a solid and a void region. |
| 6 | A body which is non-manifold and/or of mixed topological dimensionality. |
| 7 | The body type is not specified. |

Body types uses the Int32 version of the CODEC to compress and encode data.

Region Topology Data

Region Topology Data, as shown in Figure H.6, defines the disjoint set of non-overlapping Shells making up each Region. Each Region is defined by one or more non-overlapping Shells. The volume of a Region is that volume lying inside each “anti-hole Shell” and outside each simply-contained “hole Shell” belonging to the particular Region. A Region is analogous to a dimensionally elevated face where Region corresponds to Face and Shell corresponds to Trim Loop.

Each Region’s defining Shells are identified in the Start Shell Index. The indices of all the Shells in a single Region are contiguous. The first Shell index of the first Region is 0. The first Shell index of Region $k, k \geq 0$ is the value of the k th element in Start Shell Index. The last Shell index of Region $k, k \geq 0$ equals to the first Shell index of Region $k+1$ minus 1.

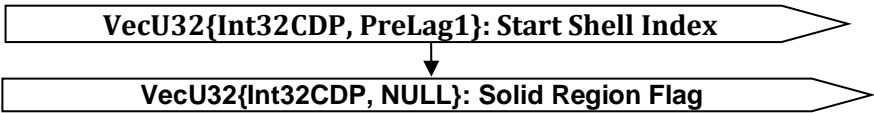


Figure H.6 — Region Topology Data collection

VecU32{Int32CDP, PreLag1}: Start Shell Index

Start Shell Index is a vector of indices representing the integer index value of start shell for this region, which is equal to the last shell index from last region plus 1. Start Shell Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Solid Region Flag

Solid Region Flag, as shown in Table H.2, is a vector of flags representing the solid property of the Regions. The flag value is set according to the table below . Solid Region Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Table H.2 — Solid Region Flag Values

| | |
|-----|---------------------|
| = 0 | Region is not solid |
| = 1 | Region is solid |

Shell Topology Data

Shell Topology Data, as shown in Figure H.7, defines the set of topological adjacent faces making up each shell. A shell’s set of topological adjacent faces define a single (usually closed) two manifold solid that in turn defines the boundary between the finite volume of space enclosed within the shell and the infinite volume of space outside the shell. In addition, each shell has a flag that denotes whether the shell refers to the finite interior volume (therefore a “inner shell”), the infinite exterior volume (therefore an “outer shell”), or an open shell. Because an inner shell and its counterpart outer shell share the same set of faces, face information is only represented for outer shells and open shells. An outer or open shells for which face information is represented is called “a represented shell”.

Each represented shell’s defining faces are identified in the Start Face Index. The indices of all the faces in a single shell are contiguous. The first face index of the first shell is 0. The first face index of represented shell $k, k \geq 0$ is the value of the k th element in Start Face Index. The last face index of shell $k, k \geq 0$ equals to the first face index of shell $k+1$ minus 1.

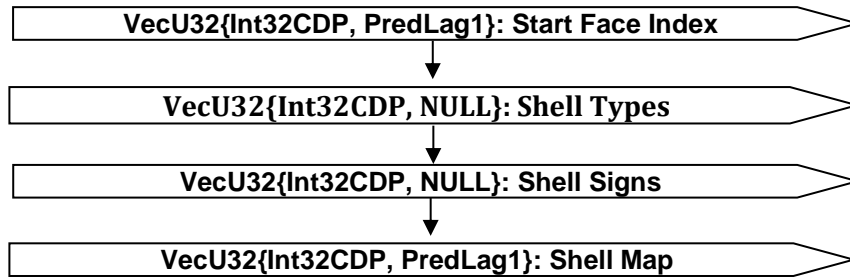


Figure H.7 — Shell Topology Data collection

VecU32{Int32CDP, PredLag1}: Start Face Index

Start Face Index is a vector of indices representing the integer index value of start face for this shell, which is equal to the last face index from last shell plus 1. The length of this array is equal to the number of represented shells that are either open or positive. Start Face Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Shell Types

Each shell has a type identifying the type of the Shell. Shell Types indexed by the Shell index contains enum type values of corresponding Shells.

In an uncompressed/decoded form the type values is from the following enumeration, as shown in Table H.3:

Table H.3 — Shell Types

| | |
|---|---|
| 0 | Shell has a single acorn vertex |
| 1 | Shell has one or more wireframe edges |
| 2 | Shell has no wireframe edges, but one or more faces |
| 3 | Shell has both wireframe edges and faces |
| 4 | The shell type is not specified. |

Shell types uses the Int32 version of the CODEC to compress and encode data.

VecU32{Int32CDP, NULL}: Shell Signs

Each shell has a sign. The Shell Signs array indexed by shell index contains the sign values of all the shells.

In an uncompressed/decoded form the type values is from the following enumeration as shown in Table H.4:

Table H.4 — JT STT Shell Signs

| | | |
|---|--------------------------|---|
| 0 | JT_SHELL_sign_positive_c | There is a subset of the faces of the shell which divides space into two volumes, the volume inside the shell being finite; for example, the outermost shell of a solid region. |
| 1 | JT_SHELL_sign_negative_c | There is a subset of the faces of the shell which divides space into two volumes, the volume inside the shell being infinite; for example, an inner shell of a solid region. |
| 2 | JT_SHELL_sign_open_c | There is no subset of faces of the shell which divides space into two volumes, in other words, all points are |

| | | |
|---|---------------------|---|
| | | either in or on the shell; for example, any shell consisting only of wireframe edges. |
| 3 | JT_SHELL_sign_unset | The shell sign is not specified |

Shell signs uses the Int32 version of the CODEC to compress and encode data.

VecU32{Int32CDP, PredLag1}: Shell Map

Shell Map is a vector that indicates the index of represented shell for every shell. Shell Map is compressed and encoded using the Int32CDP CODEC described in 12.1.1 Int32 Compressed Data Packet.

Face Topology Data

A Face, as represented in Figure H.8, shall be trimmed with at least one “anti-hole” Trim Loop and may be trimmed with one or more “hole” Trim Loops.

Each face’s defining loops are identified in the Start Loop Index. The indices of all the loops in a single face are contiguous. The first loop index of the first face is 0. The first loop index of face k , $k \geq 0$ is the value of the k th element in Start Loop Index. The last loop index of face k , $k \geq 0$ equals to the first loop index of face $k+1$ minus 1.

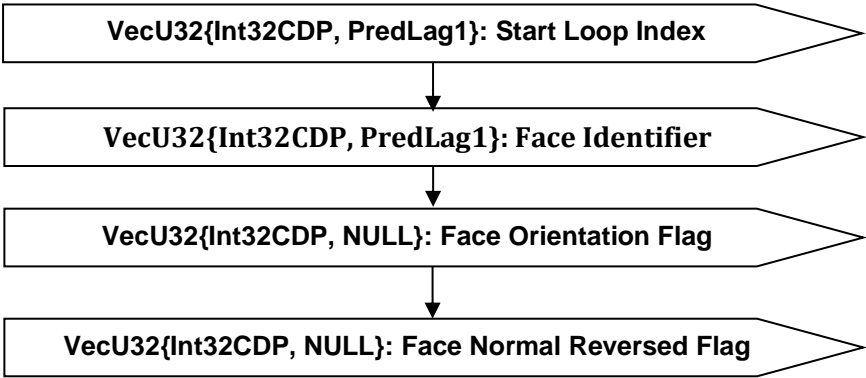


Figure H.8 — Face Topology Data collection

VecU32{Int32CDP, PredLag1}: Start Loop Index

Start Loop Index is a vector of indices representing the integer index value of start loop for each face, which is equal to the last loop index of previous face plus 1. Start Loop Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, PredLag1}: Face Identifier

Assigned identifiers of each face. Face Identifier is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Face Orientation Flag

Face Orientation Flag, as shown in Table H.5, is a vector of flags, indexed by Face Identifier, representing the orientation of the face with respect to the volume bounded by its owner shell. The flag is set to 1 if face’s normal points into its owner shell, and 0 otherwise. Face Orientation Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Table H.5 — Face Orientation Flag Values

| | |
|-----|---|
| = 0 | The face’s normal points into its owner shell |
|-----|---|

| | |
|-----|--|
| = 1 | The face's normal points away from its owner shell |
|-----|--|

VecU32{Int32CDP, NULL}: Face Normal Reversed Flag

Face Normal Reversed Flag, as shown in Table H.6, is a vector of flags, indexed by face identifier, representing the normal direction of the face with respect to the underlying surface normal. The flag is set to be 1 if the face normal is anti-parallel to the surface normal, and 0 otherwise. Face Orientation Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

TableH.6 — Face Normal Reversed Flag values

| | |
|-----|---|
| = 1 | the face normal is opposite to the surface normal |
| = 0 | the face normal is parallel to the surface normal |

Loop Topology Data

A loop, as represented in Figure H.9, defines in parameter space a 1D boundary around which geometric surfaces are trimmed to form a face. Loops Topology Data specifies the CoEdges making up each loop along with an anti-hole flag and identifier tag for each loop. Each Loop's defining CoEdges are identified in the Start CoEdge Index. The indices of all the CoEdges in a single Loop are contiguous. The first CoEdge index of the first Loop is 0. The first CoEdge index of Loop k , $k \geq 0$ is the value of the k th element in Start CoEdge Index. The last CoEdge index of Loop k , $k \geq 0$ equals to the first CoEdge index of Loop $k+1$ minus 1.

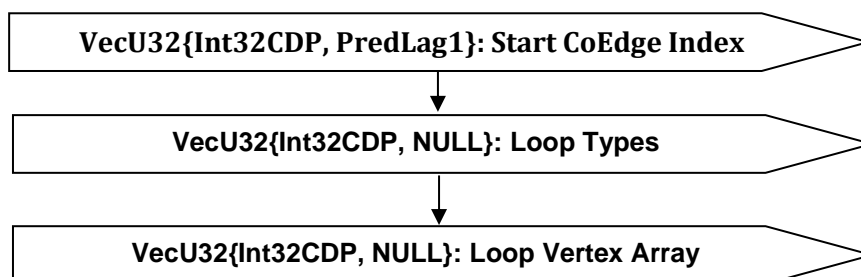


Figure H.9 — Loop Topology Data collection

VecU32{Int32CDP, PredLag1}: Start CoEdge Index

Start CoEdge Index is a vector of indices representing the integer index value of start CoEdge for this Loop, which is equal to the last coedge index from previous loop plus 1. Start CoEdge Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Loop Types

Each Loop has a type identifying the type of the Loop.

In an uncompressed/decoded form the type values is from the following enumeration, as shown in Table H.7:

Table H.7 — Loop Types

| | |
|----|---|
| 0 | Loop is just a vertex without any edges |
| 1 | Loop has no interior, for example from a wire body |
| 2 | Simple peripheral loop |
| 3 | Loop is a simple hole |
| 4 | Winding loop on a periodic surface for example a circle on a cylinder or doughnut |
| 5 | Loop is a hole around the surface singularity for example chopping the top off a cone |
| 6 | An apparently peripheral loop on a doubly closed surface |
| 7 | An apparent hole in a doubly closed surface |
| 8 | A loop dividing a periodic degenerate surface in two (contains just one pole) |
| 9 | Invalid loop or algorithm failure |
| 10 | The loop type is not specified |

Loop types uses the Int32 version of the CODEC to compress and encode data.

Loop Vertex Array

The element of Loop Vertex Array is the associated vertex identifier if it exists, -1 if the loop does not have associated vertex. Loop Vertex Array uses the Int32 version of the CODEC to compress and encode data.

CoEdges Topology Data

A CoEdge, as represented in Figure H.10, defines a parameter space edge trim Loop segment (therefore the projection of an Edge into the parameter space of the Face). A CoEdge represents the oriented use of an Edge by a Loop.

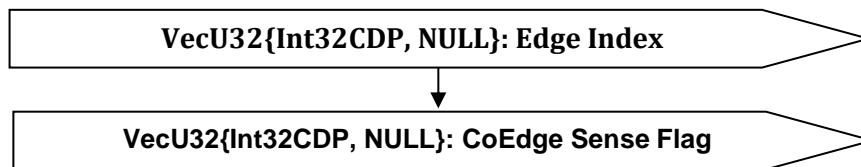


Figure H.10 — CoEdge Topology Data collection

VecU32{Int32CDP, NULL}: Edge Index

Edge Index indicates which Edge each CoEdge belongs to. Edge Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: CoEdge Sense

CoEdge Sense Flag, as shown in Table H.8, is a vector of flags representing the direction of the CoEdge with respect to the corresponding Edge. The flag is set to 1 if the CoEdge direction conforms to its corresponding Edge or 0 otherwise. CoEdge Sense Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

TableH.8 — CoEdge Sense Flag Values

| | |
|-----|--|
| = 0 | The CoEdge direction is the opposite to its corresponding Edge |
| = 1 | The CoEdge direction is the same as its corresponding Edge |

Edge Topology Data

An Edge, as represented in Figure H.11, defines a model space trim Loop segment. Its boundary is a collection of zero, one or two vertices.

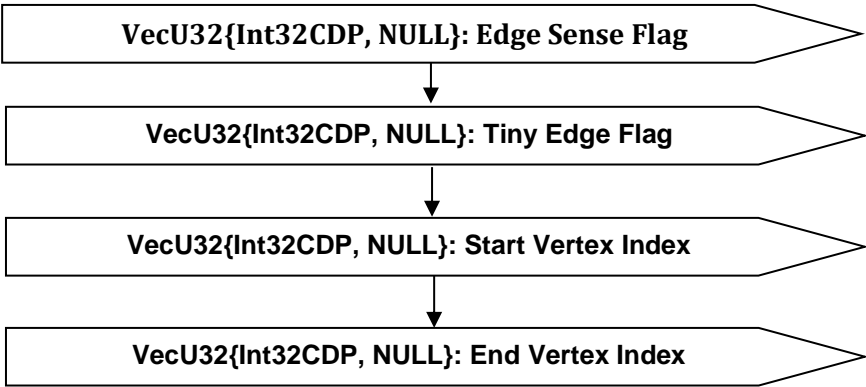


Figure H.11 — Edge Topology Data collection

VecU32{Int32CDP, NULL}: Edge Sense Flag

Edge Sense Flag, as shown in Table H.9, is a vector of flags representing the direction of the edge with respect to the corresponding curve. The flag is set to 1 if the edge direction conforms to its corresponding curve and 0 otherwise. Edge Sense Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Table H.9 — Edge Sense Flag Values

| | |
|-----|---|
| = 0 | The Edge direction is the opposite to its corresponding curve |
| = 1 | The Edge direction is the same as its corresponding curve |

VecU32{Int32CDP, NULL}: Tiny Edge Flag

Tiny Edge Flag is a vector of flags representing whether the edge is tiny (e. g. shorter than 1*10⁻⁵ meters). The flag is set to 1 if the edge is tiny and 0. Tiny Edge Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Start Vertex Index

Start Vertex Index contains start vertex index of each edge. Start Vertex Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: End Vertex Index

End Vertex Index contains end vertex index of each edge. End Vertex Index is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

I32: Topology Data Hash

The Topology Data Hash is the combined hash of all the topology data. Refer to the Hashing Annex for a more detailed description of hashing.

H.1.2 Geometric Data

A diagrammatic representation of the Geometric Data collection is shown in Figure H.12.

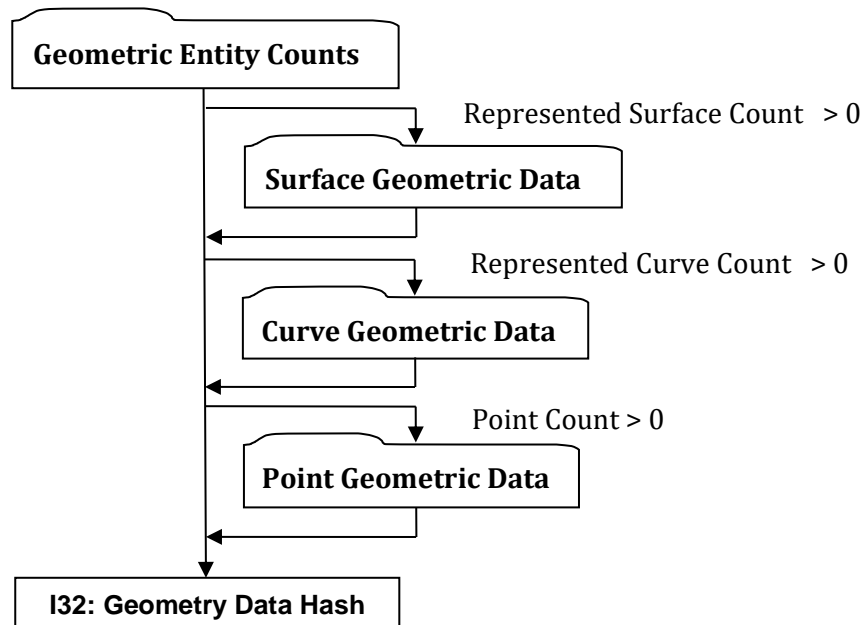


Figure H.12 — Geometric Data collection

Geometric Entity Counts

Geometric Entity Counts data collection, as shown in Figure H.13, defines the counts for each of the various geometric entities within a STT.

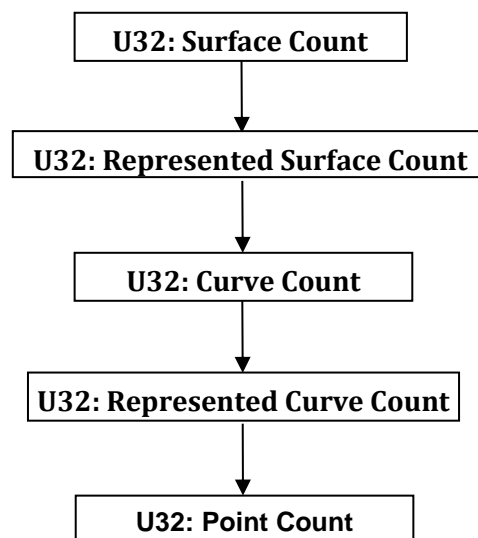


Figure H.13 — Geometric Entity Counts

U32: Surface Count

Surface Count indicates the number of distinct geometric surface entities in the STT.

U32: Represented Surface Count

Represented Surface Count indicates the number of geometric surfaces that are represented in the STT.

U32: Curve Count

Curve Count indicates the number of distinct geometric curve entities in the STT.

U32: Represented Curve Count

Represented Curve Count indicates the number of geometric curves that are represented in the STT.

U32: Point Count

Point Count indicates the number of distinct geometric point entities in the STT.

Surface Geometric Data

Surface Geometric Data, as shown in Figure H.14, defines a collection of surfaces and their mapping to the original B-Rep surfaces. Only surfaces of type Plane, Cylinder, Cone, Sphere, and Torus are represented.

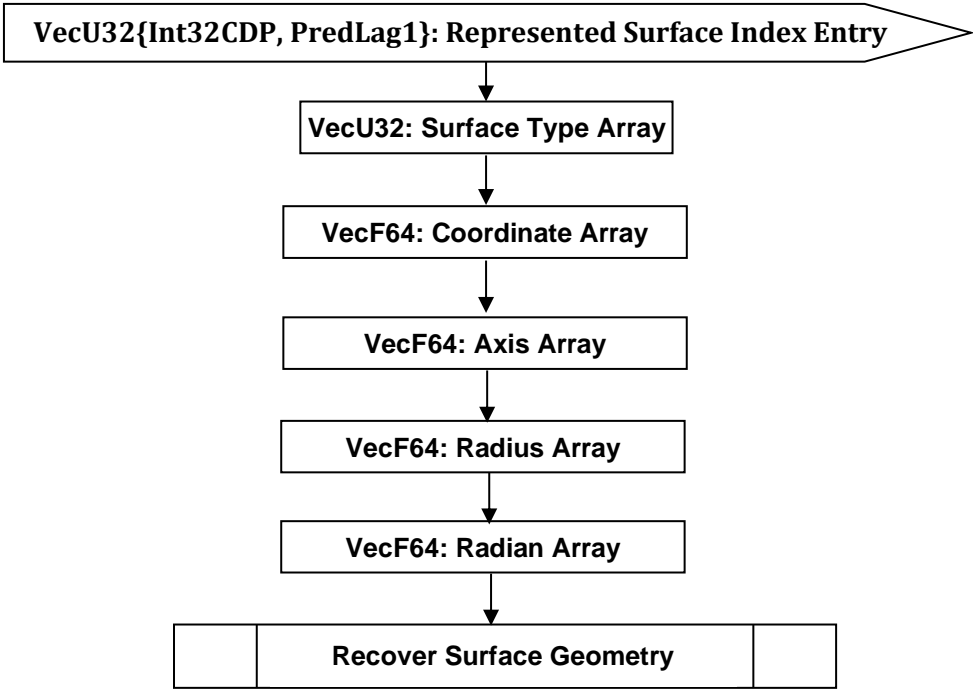


Figure H.14 — Surface Geometric Data collection

VecU32{Int32CDP, PredLag1}: Represented Surface Index Entry

Represented Surface Index Entry is a vector of integers that stores the index of the represented surfaces. Represented Surface Index Entry is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32: Surface Type Array

Surface Type Array, shown in Table H.10, is a vector of integers that stores the enumeration values of the analytical surface type. Surface Type Array is encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Table H.10 — Represented Surface Types

| | |
|---|---------------|
| 0 | PLANE |
| 1 | CYLINDER |
| 2 | CONE |
| 3 | SPHERE |
| 4 | JT_SURF_TORUS |

The detailed definitions of the Surface Types can be found: F.2.4.3.1 PLANE; F.2.4.3.2 CYLINDER; F.2.4.3.3 CONE; F.2.4.3.4 SPHERE; F.2.4.3.5 TORUS.

VecF64: Coordinate Array

Coordinate Array contains an array of double precision floating point numbers that represent the collection of point coordinate information in the definition of the analytic surface entities. The composite type VecF64 is defined in the Symbols table of Notational Conventions.

VecF64: Axis Array

Axis Array contains an array of double precision floating point numbers that represent the collection of unit vector information in the definition of the analytic surface entities. The composite type VecF64 is defined in the Symbols table found in Notational Conventions.

VecF64: Radius Array

Radius Array contains an array of double precision floating point numbers that represent the collection of radius information in the definition of the analytic surface entities. The composite type VecF64 is defined in in the Symbols table found in Notational Conventions.

VecF64: Radian Array

Radian Array contains an array of double precision floating point numbers that represent the collection of radian information in the definition of the analytic surface entities. The composite type VecF64 is defined in in the Symbols table found in Notational Conventions.

Recover Surface Geometry

The logic diagram to recover surface geometry from the arrays is shown in Figure H.15. All the represented surfaces are processed one by one sequentially, with its definition recovered from relevant arrays. In the diagram, vCoord represents “coordinate array”, vAxis represents “axis array”, vRadius represents “radius array”, and vRadian represents “radian array”

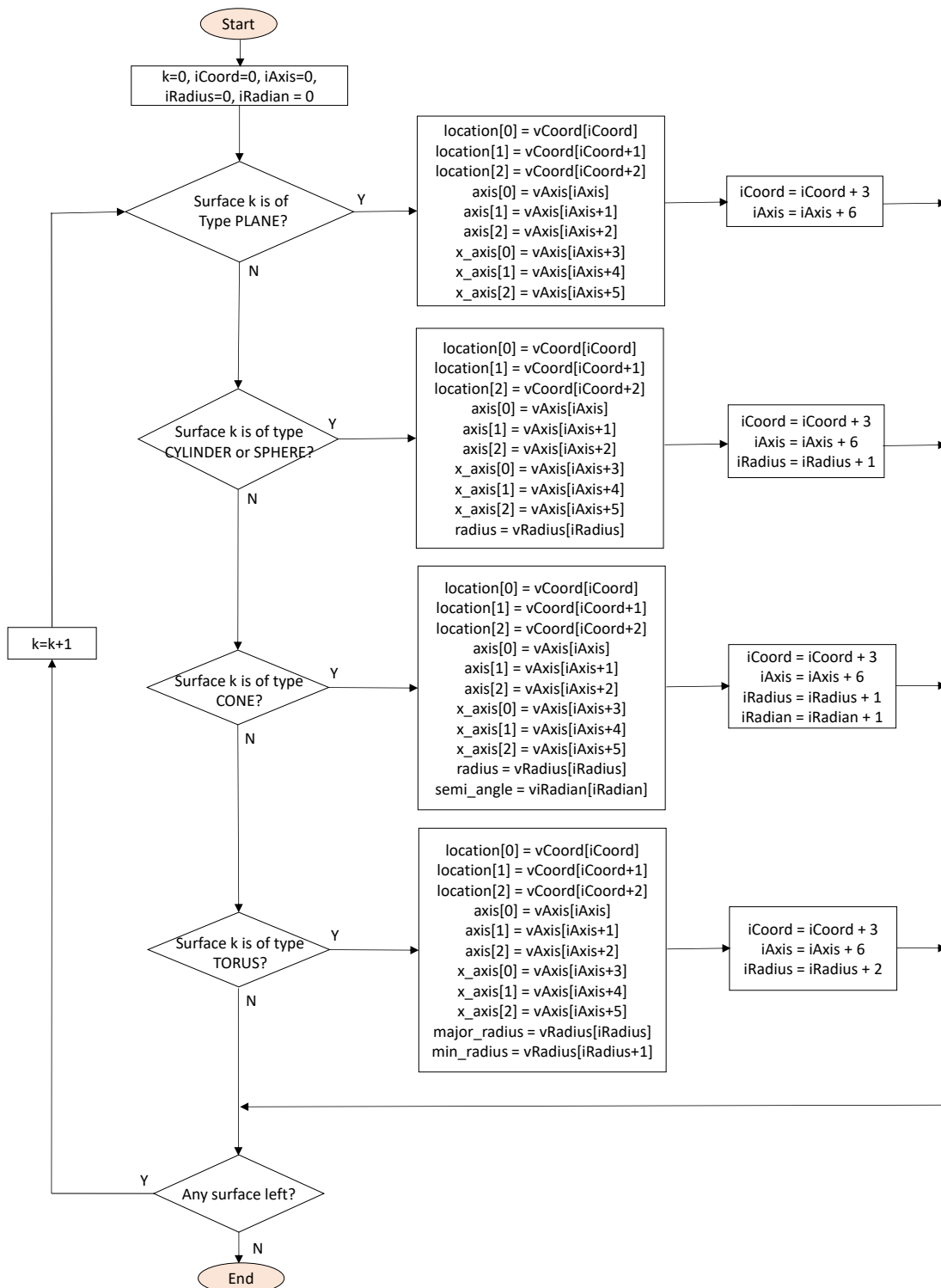


Figure H.15— Surface Geometry Recovery

Curve Geometric Data

Curve Geometric Data, shown in Figure H.16, defines a collection of analytic curves and their mapping to the original B-Rep curves.

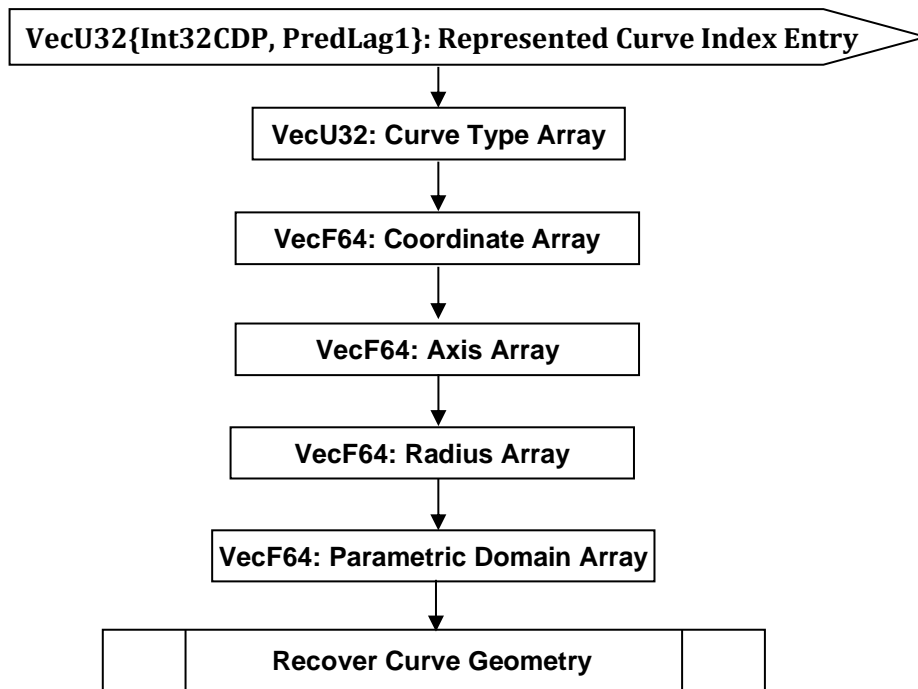


Figure H.16— Curve Geometric Data collection

VecU32{Int32CDP, PredLag1}: Represented Curve Index Entry

Represented Curve Index Entry is a vector of integers that stores the indices of curves represented in STT. Represented Curve Index Entry is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32: Curve Type Array

Curve Type Array, shown in Table H.11, is a vector of integers that stores the enumeration values of curve types. Curve Type Array is encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Table H.11 — JT STT Analytical Curve Types

| | |
|---|---------|
| 0 | LINE |
| 1 | CIRCLE |
| 2 | ELLIPSE |

The detailed definitions of the Curve Types can be found: F.2.4.2.2 Line; F.2.4.2.3 CIRCLE and F.2.4.2.4 ELLIPSE.

VecF64: Coordinate Array

Coordinate Array contains an array of double precision floating point numbers that represent the collection of point coordinate information in the definition of the curve entities. The composite type VecF64 is defined in the Symbols table of Notational Conventions.

VecF64: Axis Array

Axis Array contains an array of double precision floating point numbers that represent the collection of unit vector information in the definition of the curve entities. The composite type VecF64 is defined in the Symbols table found in Notational Conventions.

VecF64: Radius Array

Radius Array contains an array of double precision floating point numbers that represent the collection of radius information in the definition of the curve surface. The composite type VecF64 is defined in in the Symbols table found in Notational Conventions.

VecF64: Parametric Domain Array

Parametric Domain Array contains an array of double precision floating point numbers that represent the collection of parametric domain information in the definition of the curve entities. The composite type VecF64 is defined in in the Symbols table found in Notational Conventions.

Recover Curve Geometry

The logic diagram to recover curve geometry from the arrays is shown in Figure H.17. All the represented curves are processed one by one sequentially, with its definition recovered from relevant arrays. In the diagram, vCoord represents “coordinate array”, vAxis represents “axis array”, vRadius represents “radius array”, and vDomain represents “parameter domain array”.

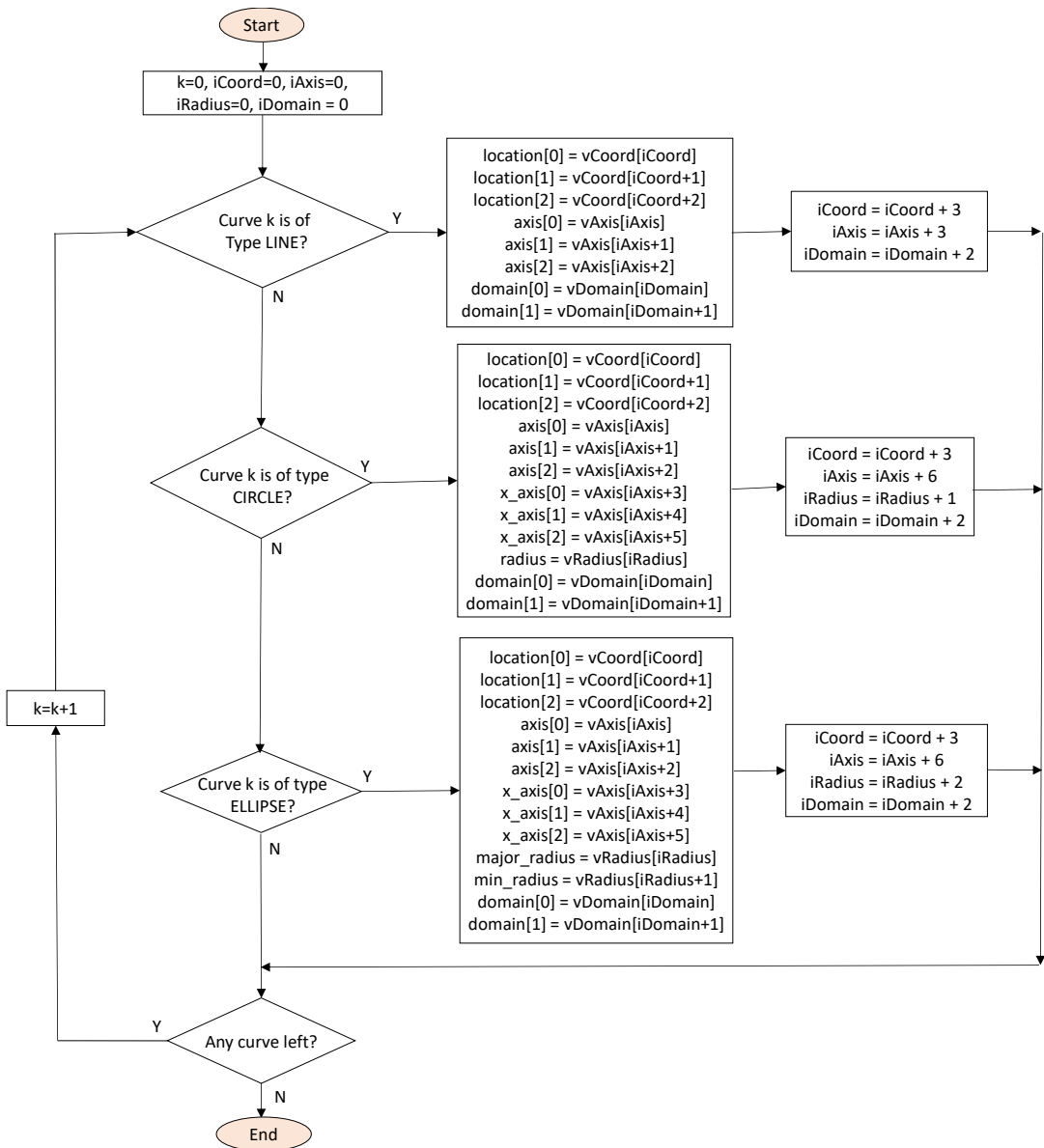


Figure H.17 — Curve Geometry Recovery

Point Geometric Data

Point Geometric Data, shown in Figure H.18, defines a collection of vertex points.

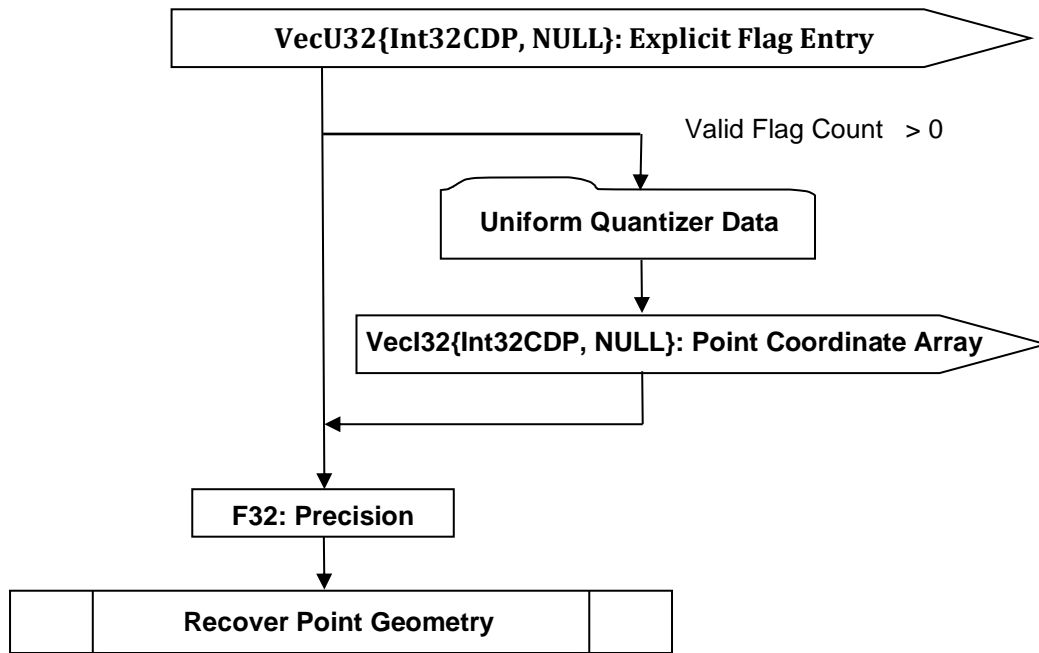


Figure H.18 — Point Geometric Data collection

VecU32{Int32CDP, NULL}: Explicit Flag Entry

Explicit Flag Entry is a vector of flags that indicates if a particular point is explicitly written. A point may not be explicitly written if that point can be inferred from curve geometry, for example, coincident with one of the end points of a represented curve. The flag value is 1 if the point geometry is explicitly written, and 0 otherwise. Explicit Flag Entry is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecF32{Int32CDP, NULL}: Point Coordinate Array

Point Coordinate Array contains explicit point geometry to write. Point Coordinate Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

F32: Precision

Precision of Point Coordinate Array.

Recover Point Geometry

The logic diagram to recover point geometry by evaluating represented curves is shown in Figure H.19.

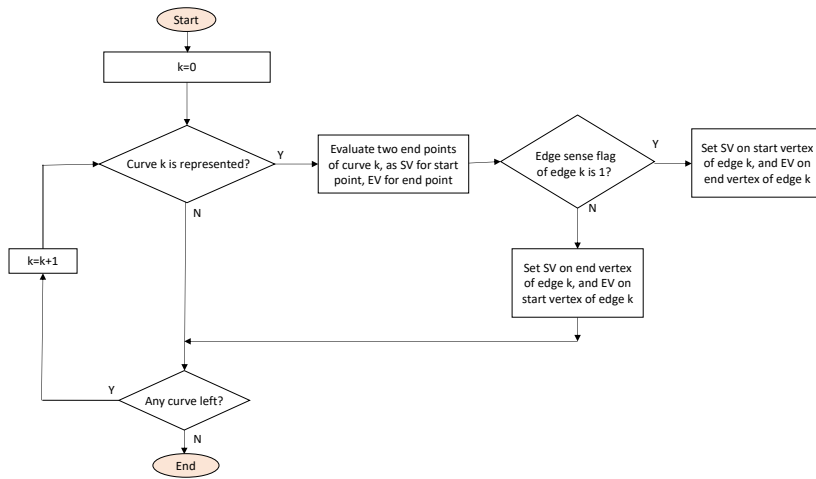


Figure H.19 — Point Geometry Recovery

I32: Geometry Data Hash

The Geometry Data Hash is the combined hash of all the elements in Geometry Data. Refer to the Hashing Annex for a more detailed description on hashing

H.1.3 Attribute Data

The Attribute Data, shown in Figure H.20, is B-Rep attributes from XTbRep. Attributes contain Body Attribute, Face Attribute and Edge Attribute.

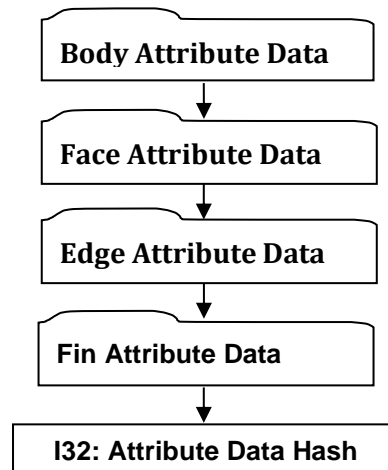


Figure H.20 — Attribute Data Collection

Body Attribute Data

The Body Attribute Data, shown in Figure H.21, includes Body Identifiers, Body Checksums,

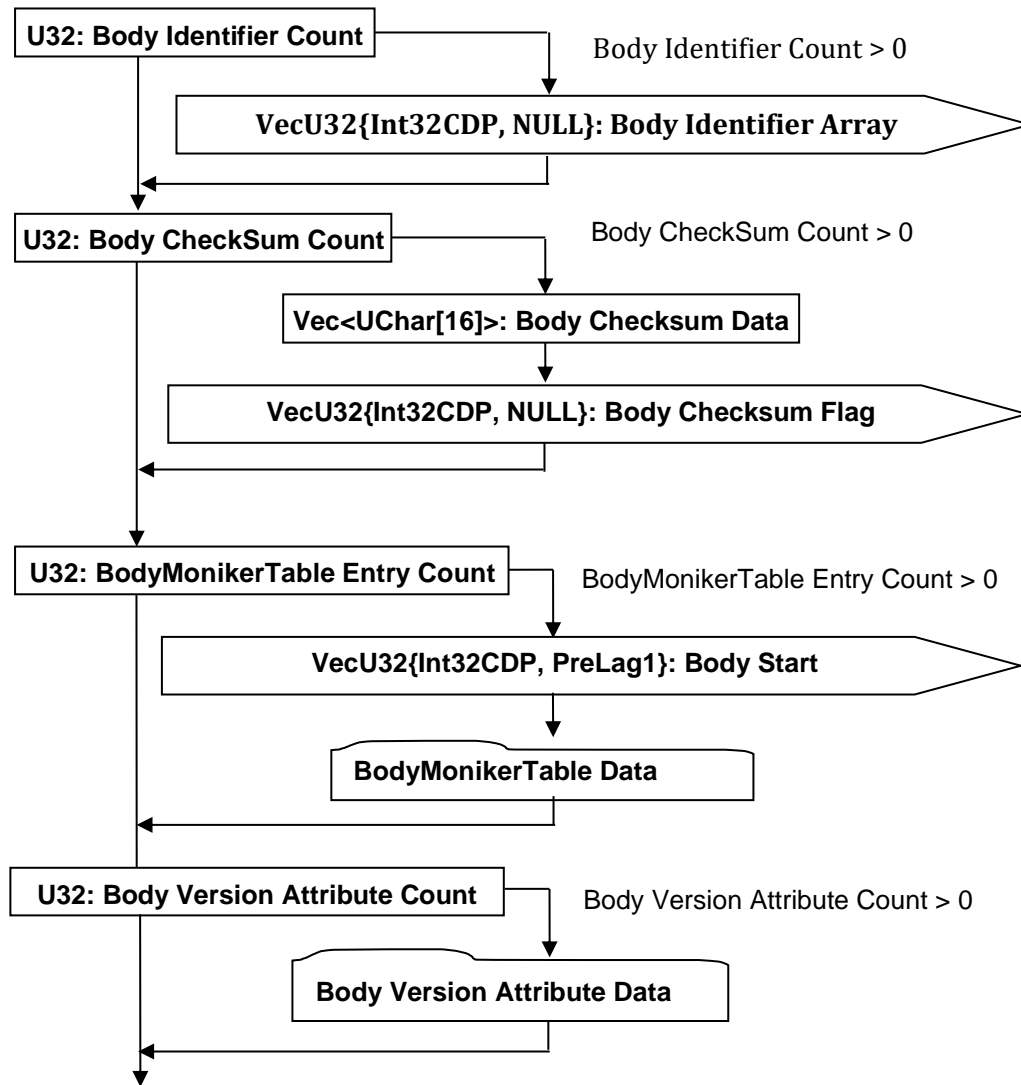


Figure H.21 — Bodies Attribute Data collection

U32: Body Identifier Count

Body Identifier Count indicates the number of body identifiers. Its value is either the number of bodies or 0.

VecU32{Int32CDP, NULL}: Body Identifier Array

Body Identifier Array is a vector of integer attributes, with its length indicated by Body Identifier Count. When Body Identifier Array exists, therefore, Body Identifier Count is greater than 0, it is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U32: Body Checksum Count

Body Checksum Count indicates the number of body checksums. Its value is either the number of bodies or 0.

Vec<UChar[16]>: Body Checksum Data

Body Checksum Data is a vector of checksums, where each checksum, composed of 16 UChar values, represents the checksum of corresponding body in STT. The length of Body Checksum Data is indicated by Body Checksum Count.

VecU32{Int32CDP, NULL}: Body CheckSum Flag

Body CheckSum Flag is a vector of flags representing additional information about the Checksum value. It has the same length as Body Checksum Data, so that each checksum has an associated flag. The flag value can be either 0 or 1. Body Checksum Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, PreLag1}: Body Start Array

Body Start Array is a vector of indices representing the integer index value of start MonikerGuidTable entry for each body. Body Start Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U32: BodyMonikerTable Entry Count

BodyMonikerTable Entry Count indicates the number of entries in BodyMonikerTable. Its value is either the number of bodies or 0.

BodyMonikerTable Data

BodyMonikerTable Data, shown in Figure H.22, contains all the moniker entries for all the bodies in STT. The association between bodies and these entries are represented in Body Start Array. Each entry includes three pieces of information: an integer that identifies the GUID, the GUID representation, and a string that describes the source of the GUID.

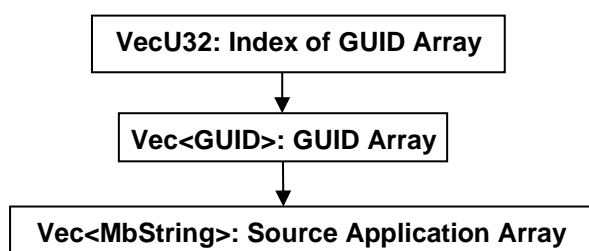


Figure H.22 — MonikerGuidTable Data collection

VecU32: Index of GUID Array

Index of GUID Array is a vector of integers that collects all the identifier fields from all MonikerGuidTable entries.

Vec<GUID>: GUID Array

GUID Array is a vector of GUIDs that collects all the GUIDs from all MonikerGuidTable entries.

Vec<MbString>: Source Application Array

Source Application Array is a vector of strings that collects all the source strings from all MonikerGuidTable entries.

U32: Body Version Attribute Count

Body Version Attribute Count indicates the number of body Version attributes. Its value is either the number of bodies or 0.

Body Version Attribute Data

Body Version Attribute Data, shown in Figure H.23, consists of Body Version ID and Source Application descriptions.

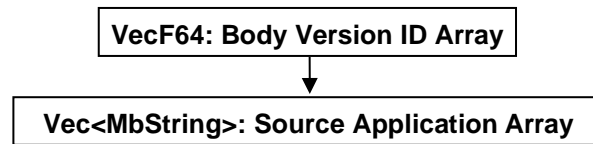


Figure H.23 — Body ID Attribute Data

VecF64: Body Version ID

Body Version ID Array is a vector of Float64 numbers, each of which describes version information for a body in STT.

Vec<MbString>: Source Application Array

Source Application Array is a vector of strings, each of which describes the source application that is associated with the version information.

Face Attribute Data

The Face Attribute Data, shown in Figure H.24, describes attribute information for all the Faces in STT.

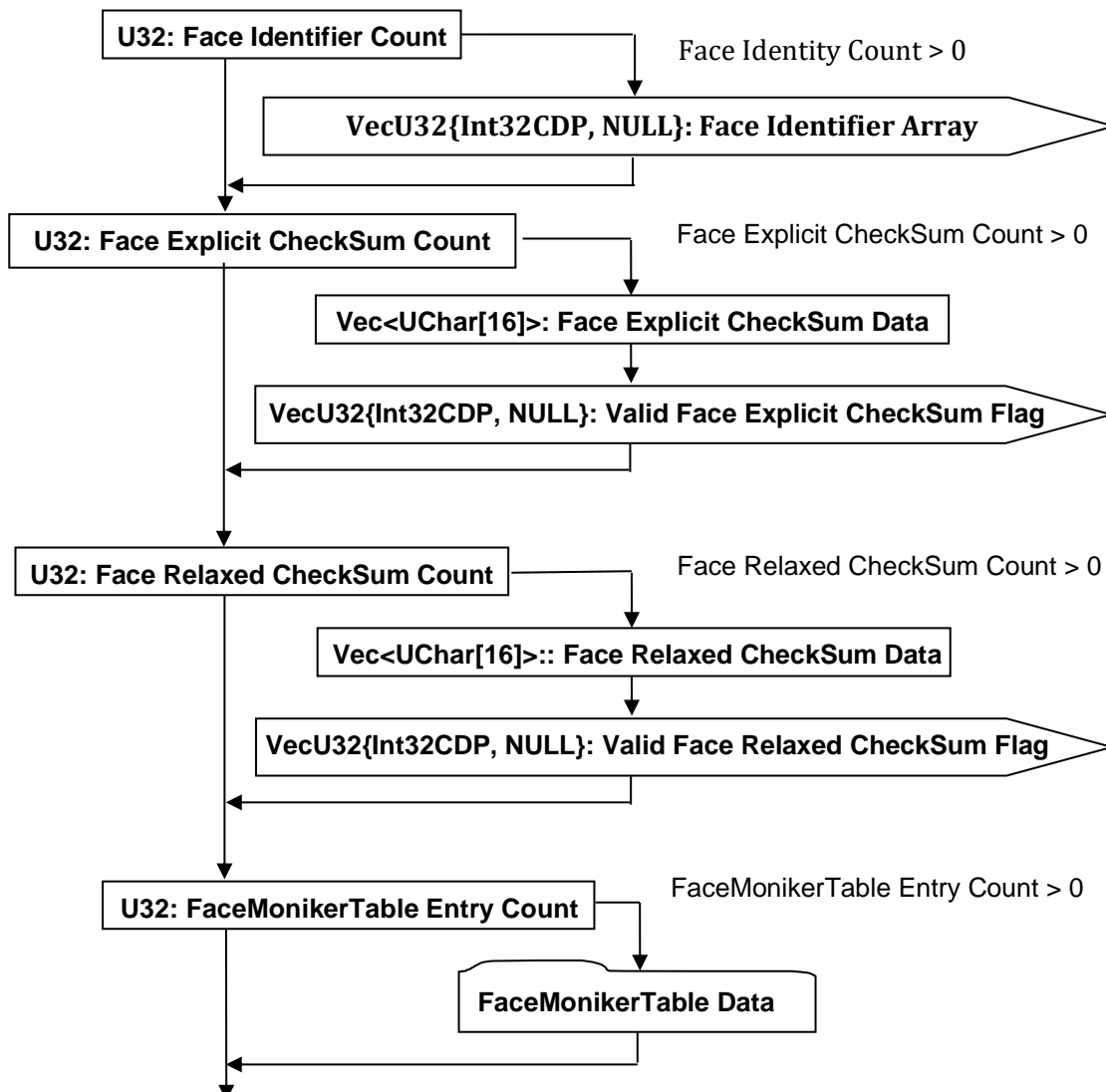


Figure H.24 — Face Attribute Data collection

U32: Face Identifier Count

Face Identifier Count indicates the number of face identifiers. Its value is either the number of faces or 0.

VecU32{Int32CDP, NULL}: Face Identifier Array

Face Identifier Array is a vector of integers that provides face identification. Face Identifier Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U32: Face Explicit CheckSum Count

Face Explicit CheckSum Count indicates the number of Face Explicit CheckSums. Its value is either the number of faces or 0.

Vec<UChar[16]>: Face Explicit CheckSum Data

Face Explicit CheckSum Data describes Explicit CheckSum for all the faces, where each CheckSum is composed of 16 UChar values.

VecU32{Int32CDP, NULL}: Valid Face Explicit CheckSum Flag

Valid Face Explicit CheckSum Flag is a vector of flags representing if the corresponding CheckSum in Face Explicit CheckSum Data is valid. Valid Face Explicit CheckSum Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U32: Face Relaxed CheckSum Count

Face Relaxed CheckSum Count indicates the number of face Relaxed CheckSums. Its value is either the number of faces or 0.

UChar: Face Relaxed CheckSum Data

Face Relaxed CheckSum Data describes Relaxed CheckSum for all the faces, where each CheckSum is composed of 16 UChar values.

VecU32{Int32CDP, NULL}: Valid Face Relaxed CheckSum Flag

Valid Face Relaxed CheckSum Flag is a vector of flags representing if the corresponding CheckSum is valid. Valid Face Relaxed CheckSum Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U32: FaceMonikerTable Entry Count

FaceMonikerTable Entry Count indicates the number of entries in FaceMonikerTable. Its value is either the number of faces in STT or 0.

Face Moniker Table Data

FaceMonikerTable Data, shown in Figure H.25, includes a vector of entries, each of which describes moniker attribute for a face in STT. The description of each face includes three fields: a string label, an integer describing the index of GUID, and an integer that provides identification. Each field is grouped into a separate array for serialization.

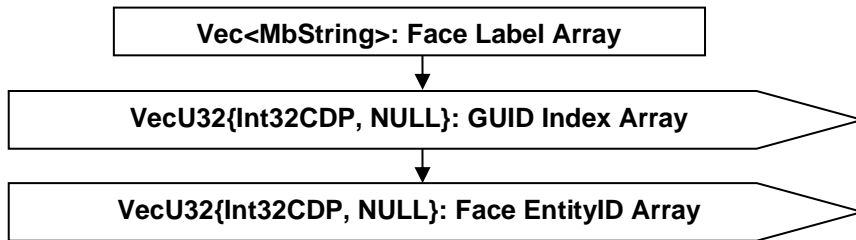


Figure H.25 — MONIKER/MONIKER_DATA_ATTRIB Data collection

Vec<MbString>: Face Label Array

Face Label Array is a vector of strings that provides label description for each Face.

VecU32{Int32CDP, NULL}: GUID Index Array

GUID Index Array is a vector of integers that provides GUID index into the GUID table associated with the body in which the face is part of. GUID Index Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Face Identity Array

Face Identity Array is a vector of integers that provides face identification. Face Identity Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Edge Attribute Data

The Edge Attribute Data, shown in Figure H.26, contains attribute information for edges in STT.

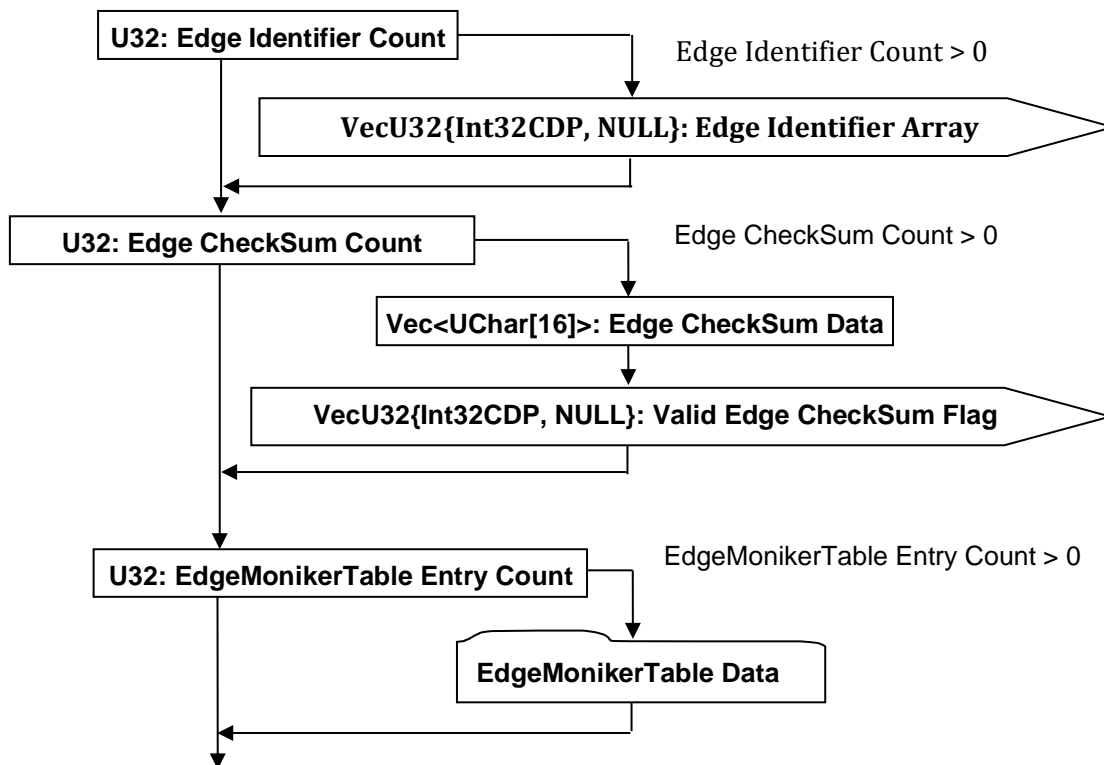


Figure H.26 — Edge Attribute Data collection

U32: Edge Identifier Count

Edge Identifier Count indicates the number of Edge identifiers. Its value is either the number of Edges in STT or 0.

VecU32{Int32CDP, NULL}: Edge Identifier Array

Edge Identifier Array is a vector of integer Edge identifiers. Edge Identifier Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U32: Edge CheckSum Count

Edge CheckSum Count indicates the number of Edge CheckSums. Its value is either the number of Edges or 0.

Vec<UChar[16]>: Edge CheckSum Data

Edge CheckSum Data is a vector of checksum values for all the edges, where each checksum is composed of a 16 UChar values.

VecU32{Int32CDP, NULL}: Valid Edge CheckSum Flag

Valid Edge CheckSum Flag is a vector of integer flags representing whether the corresponding edge CheckSum is valid. Valid Edge CheckSum Flag is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

U32: EdgeMonikerTable Entry Count

EdgeMonikerTable Entry Count indicates the number of edge moniker entries. Its value is either the number of edges or 0.

Edge Moniker Table Data

Edge MonikerTable Data, shown in Figure H.27, describes moniker attribute information for all the edges. The moniker attribute information includes three fields: Edge Label string, GUID index, and integer identifier. Each field is grouped into separate arrays.

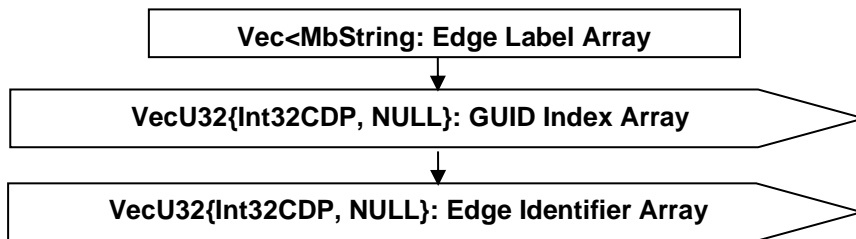


Figure H.27 — EdgeMonikerTable Data collection

Vec<MbString>: Edge Label Array

Edge Label Array is a vector of strings describing the Edge Label for all the edges. **VecU32{Int32CDP, NULL}: GUID Index Array**

GUID Index Array is a vector of integers that provides GUID index into the GUID table associated with the body in which the Edge is part of. GUID Index Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

VecU32{Int32CDP, NULL}: Edge Identifier Array

Edge Identifier Array is a vector of integers that provides Edge identification. Edge Identity Array is compressed and encoded using the Int32CDP CODEC described in Int32 Compressed Data Packet.

Fin Attribute Data

The Fin Attribute Data, shown in Figure H.28, describes information associated with the fins in STT.

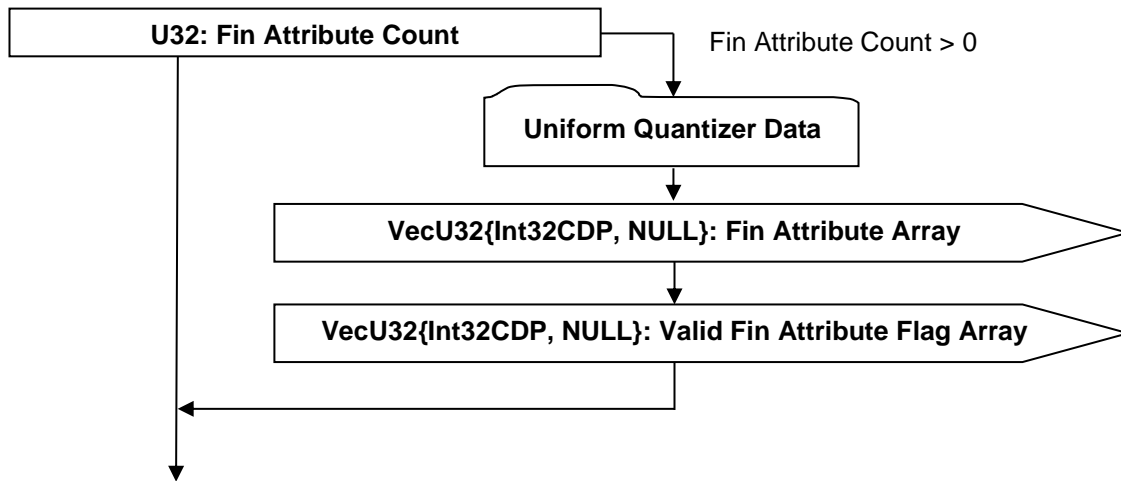


Figure H.28 — Fin Attribute Data collection

U32: Fin Attribute Count

Fin Attribute Count indicates the number of Fin Attributes. Its value is either the number of Fins or 0.

VecU32{Int32CDP, NULL}: Fin Attribute Array

Fin Attribute Data is a vector of integers for all the fins, where each integer represents a quantized value. There are two integers for each fin, with the first integer describing the normalized *u* parameter of the middle point on the Fin and second integer describing the normalized *v* parameter of the middle point on the Fin. These two integers of the same fin are continuous in the vector, and therefore the length of Fin Attribute Array is twice the number of fins in STT. Fin Attribute Array uses the Int32CDP CODEC Int32 Compressed Data Packet to compress and encode data.

VecU32{Int32CDP, NULL}: Valid Fin Attribute Flag Array

Valid Fin Attribute Flag is a vector of integer flags representing whether each corresponding Fin attribute, composed of two integer numbers in Fin Attribute Array, is valid. The corresponding Fin attribute is invalid if the flag has value 0 and valid otherwise.

Version Data

Version data, as shown in Figure H.29, is informative. It describes additional version information related to STT.

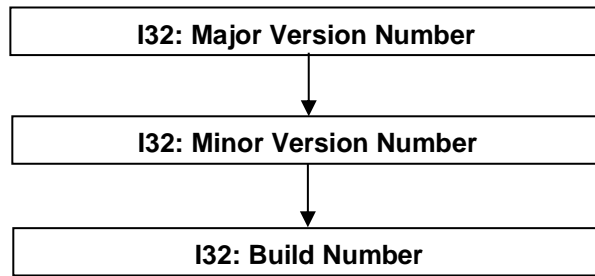


Figure H.29 — Version Data

I32: Major Version Number

Major Version Number specifies the major version number for the STT data in the JT File. Major version number is an informative field which can be set to 0 without negative impact to implementation.

I32: Minor Version Number

Minor Version Number specifies the minor version number for the STT data in the JT File. Minor version number is an informative field which can be set to 0 without negative impact to implementation.

I32: Build Number

Build Number specifies the build number for the STT data in the JT File. Build number is an informative field which can be set to 0 without negative impact to implementation.

I32: Attribute Data Hash

The Attribute Data Hash is the combined hash of all the data in Attribute Data. Refer to the Hashing Annex for a more detailed description on hashing.

Annex I

JT LWPA Segment

JT LWPA Segment, shown in Figure I.1, contains an Element that defines light weight precise analytic data for a particular part. More specifically LWPA contains the collection of analytic surfaces in the B-Rep definition of the part.

JT LWPA Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The JT LWPA Segment type supports LZMA compression on all element data, so all elements in JT LWPA Segment use the Logical Element Header Compressed form of element header data.

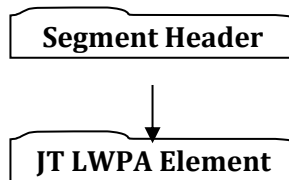


Figure I.1 — JT LWPA data collection

Complete description for Segment Header can be found in the File Header section of Base Format Description under Data Segment.

I.1.1 JT LWPA Element

Object Type ID: 0xd67f8ea8, 0xf524, 0x4879, 0x92, 0x8c, 0x4c, 0x3a, 0x56, 0x1f, 0xb9, 0x3a

JT LWPA Segment, shown in Figure I.2, represents a particular Part's precise analytic surfaces. It can be viewed as a subset of B-Rep representation where the subset refers to the complete collection of all the surfaces that are of one of the analytic types shown in the Supported Surface Type table, therefore, plane, cylinder, cone, sphere, or torus. Unlike JT B-Rep Element or XT B-Rep Element, JT LWPA Element does not contain any B-Rep topology information, nor does it contain geometric curve or point information. LWPA is designed to represent most essential part geometry information with much lighter weight on disk and much faster to load than B-Rep. Typically LWPA is less than 2 percent of B-Rep size on disk, and takes less than 5 percent time to load into memory. The analytic representation of LWPA follows XT convention as detailed in the XT B-Rep geometry Annex.

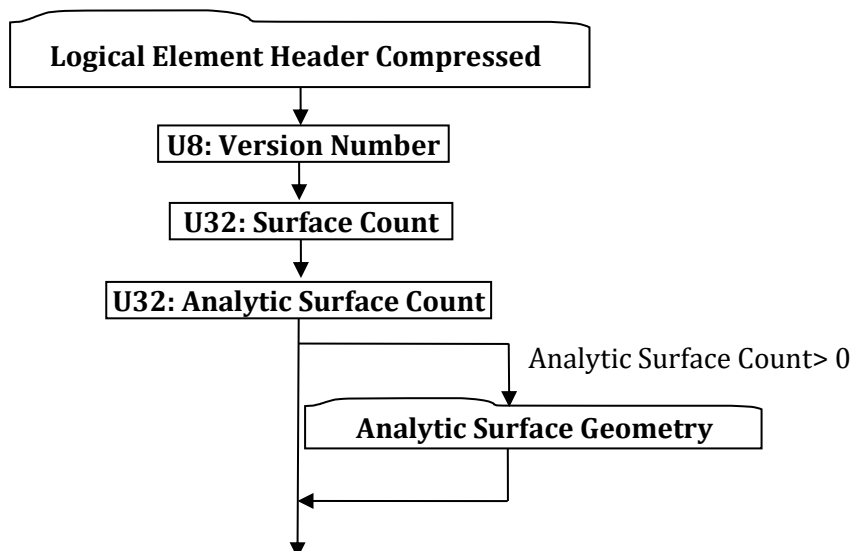


Figure I.2 — JT LWPA Element data collection

U8: Version Number

Version Number is the version identifier for this JT LWPA Element. Information on local version numbers can be found in the Base Format Description under Common Data Conventions and Constructs Local version numbers.

U32: Surface Count

Surface Count indicates the number of surface entries in LWPA. The number of surface entries is equal to the number of surfaces in the B-Rep representation. The surface entry does not contain any information if the corresponding B-Rep surface is not of analytic type.

U32: Analytic Surface Count

Analytic Surface Count indicates the number of analytic surface entries in LWPA.

Analytic Surface Geometry

Analytic Surface Geometry, shown in Figure I.3, defines a collection of analytic surfaces and their mapping to the original B-Rep surfaces.

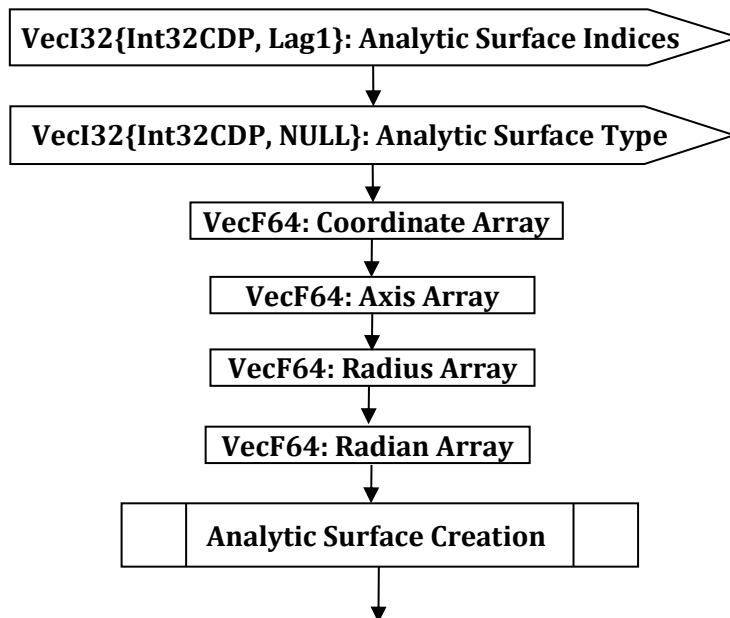


Figure I.3 — Analytic Surface Geometry data collection

VecI32{Int32CDP, Lag1}: Analytic Surface Indices

Analytic Surface Indices is an integer array with its length equal to the number of analytic surfaces in the LWPA. The value of each element in this array represents the index of this analytic surface in the original B-Rep representation.

VecI32{Int32CDP, NULL}: Analytic Surface Type

Analytic Surface Type is an integer array with its length equal to the number of analytic surfaces in the LWPA. The value of each element in this array represents the type of each analytic surface, as defined in table Supported Surface Type.

VecF64: Coordinate Array

Coordinate Array contains an array of double precision floating point numbers that represent the collection of point coordinate information in the definition of the analytic surface entities. The composite type VecF64 is defined in the Symbols table of Notational Conventions. Each floating point number in the array is written in binary form.

VecF64: Axis Array

Axis Array contains an array of double precision floating point numbers that represent the collection of unit vector information in the definition of the analytic surface entities. The composite type VecF64 is defined in the Symbols table found in Notational Conventions. Each floating point number in the array is written in binary form.

VecF64: Radius Array

Radius Array contains an array of double precision floating point numbers that represent the collection of radius information in the definition of the analytic surface entities. The composite type VecF64 is defined in in the Symbols table found in Notational Conventions. Each floating point number in the array is written in binary form.

VecF64: Radian Array

Radian Array contains an array of double precision floating point numbers that represent the collection of radian information in the definition of the analytic surface entities. The composite type VecF64 is defined in in the Symbols table found in Notational Conventions. Each floating point number in the array is written in binary form.

Analytic Surface Creation

Analytic surfaces in LWPA are constructed based on the information of the above arrays, as illustrated by logical diagram in Figure I.4, titled Analytic Surface Creation.

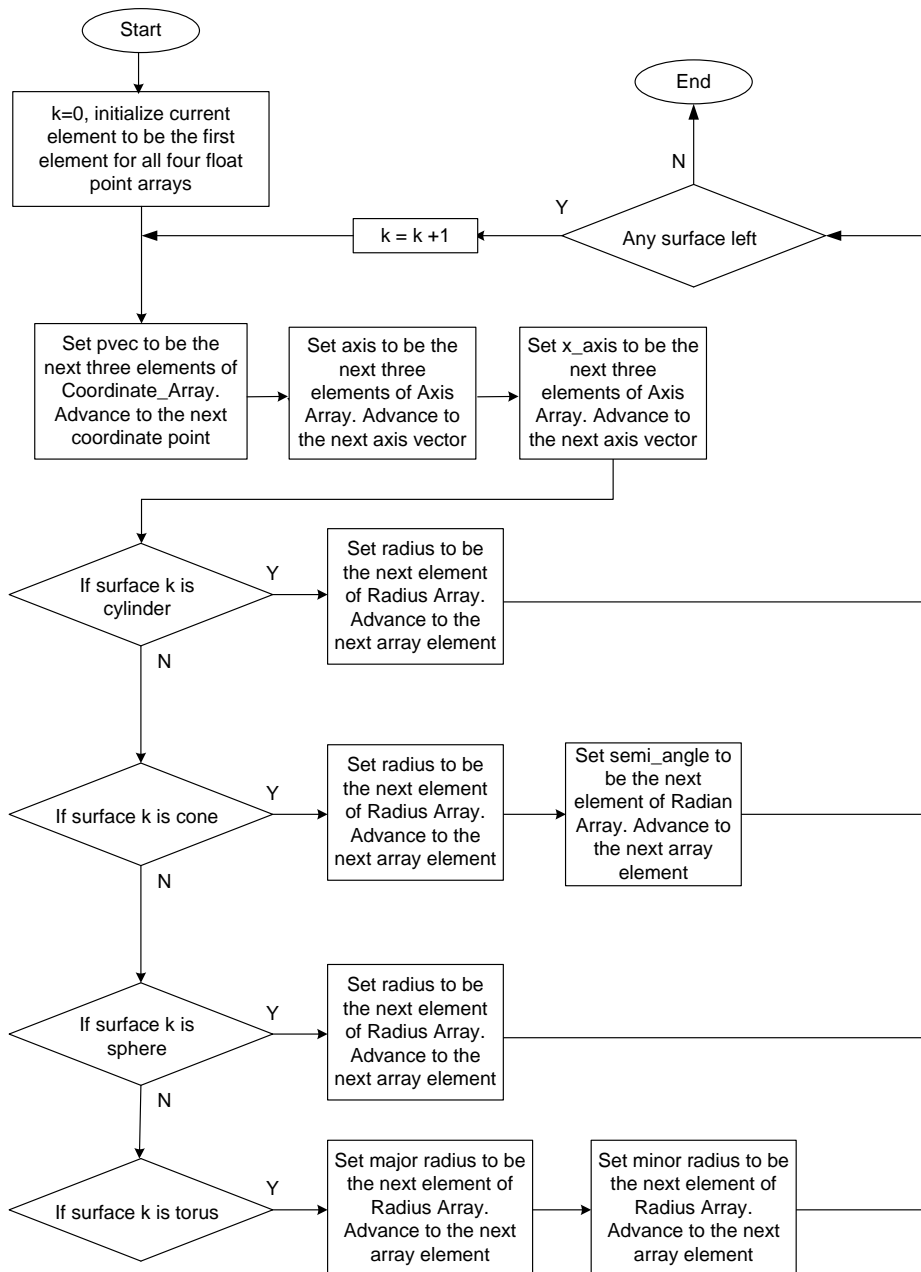


Figure I.4 — Analytic Surface Creation

Annex J

Wireframe Segment

Wireframe Segment, as shown in Figure J.1, contains an Element that defines the precise 3D wireframe data for a particular Part. A Wireframe Segment is typically referenced by a Part Node Element (see 6.1.1.5 Part Node Element) using a Second specifies the date Second value. Valid values are [0, 59] inclusive.

Late Loaded Property Atom Element (see Late Loaded Property Atom Element). The Wireframe Segment type supports LZMA compression on all element data, so all elements in Wireframe Segment use the Logical Element Header Compressed form of element header data.

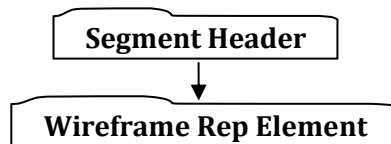


Figure J.1 — Wireframe Segment data collection

Complete description for Segment Header can be found in the File Header section of Base Format Description under Data Segment

J.1.1 Wireframe Rep Element

Object Type ID: 0x873a70d0, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

A Wireframe Rep Element, as shown in Figure J.2, represents a particular Part's precise 3D wireframe data (for example reference curves, section curves). Much of the "heavyweight" data contained within a Wireframe Rep Element is compressed and/or encoded. The compression and/or encoding state is indicated through other data stored in each Wireframe Rep Element.

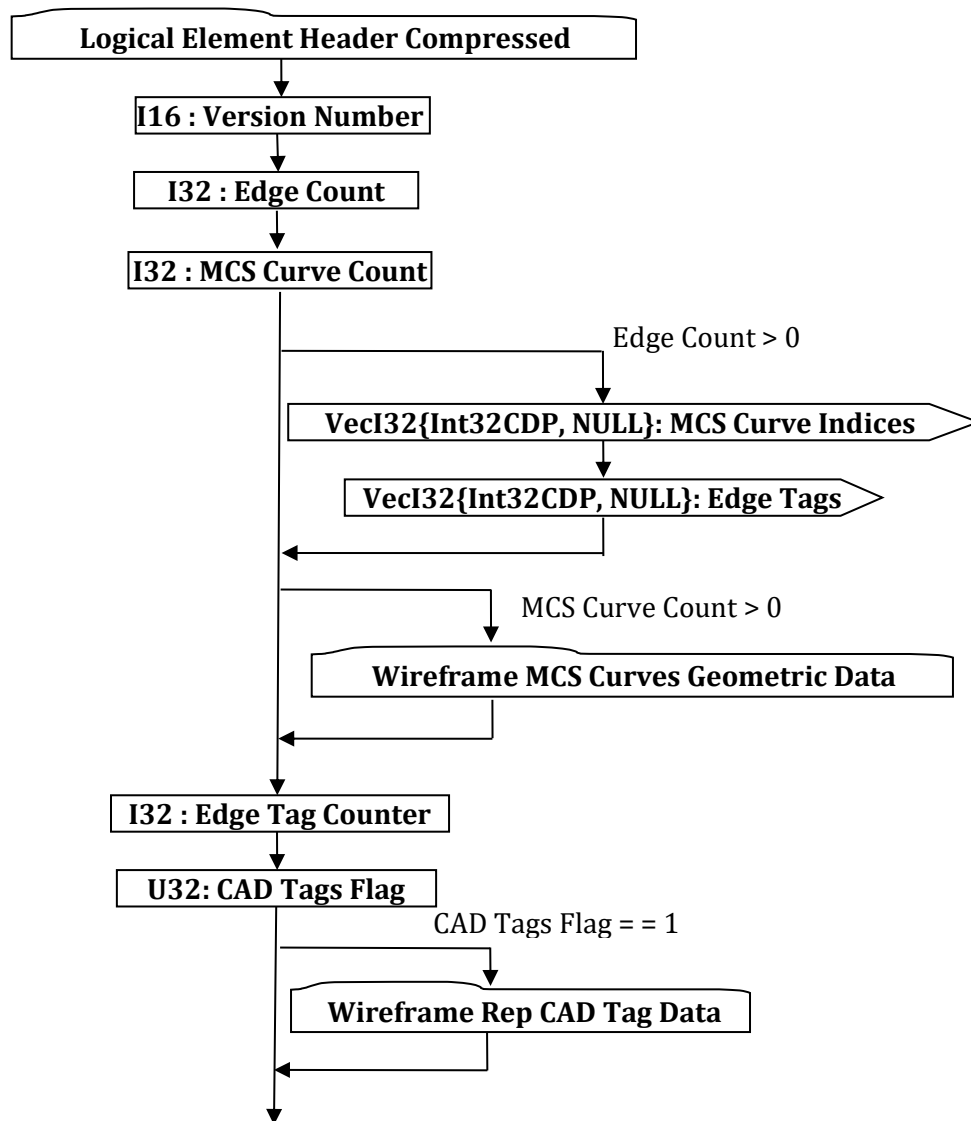


Figure J.2— Wireframe Rep Element data collection

Complete description for Logical Element Header Compressed can be found in the File Header section of Base Format Description under Data Segment, Data.

I16: Version Number

Version Number is the version identifier for this JT Wireframe Rep Element. Information on local version numbers can be found in the Base Format Description under Common Data Conventions and Constructs Local version numbers.

I32: Edge Count

Edge Count indicates the number of topological Edge entities in the Wireframe Rep.

I32: MCS Curve Count

MCS Curve Count indicates the number of distinct geometric (Model Coordinate Space) curves (therefore XYZ curve) entities in the Wireframe Rep.

VecI32{Int32CDP, NULL}: MCS Curve Indices

MCS Curve Indices is a vector of indices representing the index of the MCS Curve (Model Space curve) for each Edge. MCS Curve Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: Edge Tags

Each Edge has an identifier Tag. Edge Tags is a vector of identifier Tags for a set of Edges. Edge Tags uses the Int32 version of the CODEC to compress and encode data.

I32: Edge Tag Counter

Edge Tag Counter specifies the next available “unique” tag value for Edge entity.

U32: CAD Tags Flag

CAD Tags Flag is a flag indicating whether CAD Tag data exist for the Wireframe Rep.

Wireframe MCS Curves Geometric Data

Wireframe MCS Curves Geometric Data collection, as shown in Figure J.3, contains the Wireframe Rep’s Model Coordinate System geometric Curve data (therefore XYZ Curve data). Currently only NURBS Curve types are supported within a Wireframe Rep. The count/number of MCS Curves within a Wireframe Rep is indicated by data field MCS Curve Count documented in Wireframe Rep Element.



Compressed Curve Data

Figure J.3— Wireframe MCS Curves Geometric Data collection

Complete description for Compressed Curve Data can be found in Compressed Curve Data.

Wireframe Rep CAD Tag Data

The Wireframe Rep CAD Tag Data collection, as shown in Figure J.4, contains the list of persistent IDs, as defined in the CAD System, to uniquely identify individual Edges in the Wireframe Rep. The existence of this Wireframe Rep CAD Tag Data collection is dependent upon the value of previously read data field CAD Tags Flag as documented in Wireframe Rep Element.

If Wireframe Rep CAD Tag Data collection is present, there will be a CAD Tag for every Edge in the Wireframe Rep. Therefore the total number of CAD Tags in the list should be equal to “Edge Count” as documented in Wireframe Rep Element.



Compressed CAD Tag Data

Figure J.4— Wireframe Rep CAD Tag Data collection

Complete description for Compressed CAD Tag Data can be found in Compressed CAD Tag Data.

Annex K (deprecated) JT B-Rep Segment

JT B-Rep Segment, as shown in Figure K.1, contains an Element that defines the precise geometric Boundary Representation data for a particular Part in JT B-Rep format. The JT B-Rep segment specification is deprecated with JT IAP V2. The description is provided here to support legacy JT content.

JT B-Rep Segments are typically referenced by Part Node Elements (see Part Node Element) using Late Loaded Property Atom Elements (see Late Loaded Property Atom Element). The JT B-Rep Segment type supports compression on all element data, so all elements in JT B-Rep Segment use the Logical Element Header Compressed form of element header data.

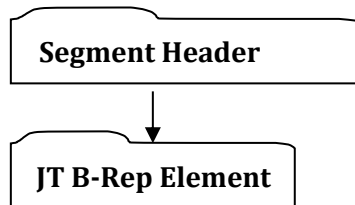


Figure K.1— JT B-Rep Segment data collection

A Complete description for Segment Header can be found in the File Header section of Base Format Description under Data Segment.

K.1.1 JT B-Rep Element

Object Type ID: 0x873a70c0, 0x2ac8, 0x11d1, 0x9b, 0x6b, 0x00, 0x80, 0xc7, 0xbb, 0x59, 0x97

JT B-Rep Element, as shown in Figure K.2, represents a particular Part's precise data in JT boundary representation format. Much of the "heavyweight" data contained within a JT B-Rep Element is compressed and/or encoded. The compression and/or encoding state is indicated through other data stored in each JT B-Rep Element.

Two important aspects of a Part are its geometry and its topology. The geometry describes the shape of a Part: this Surface is a plane, that Surface is a cylinder, this Curve is an arc, etc. The topology describes the connectivity of the Part: this Point is inside the Part, these Surfaces are next to each other, etc. The 0, 1, and 2 dimensional building blocks of geometry are Points, Curves, and Surfaces. The corresponding topological building blocks are Vertices, Edges, and Faces. Topology also uses Shells and Regions to conceptually divide up the three dimensional space.

Parts may have the same topology, but wildly different geometry. Imagine the Surfaces of a Part being composed of rubber. The topology of the Part does not change as we deform the Part by bending or stretching the surfaces, as long as we do not cut or glue them (we call this a "nice" deformation). A Part's topology can be classified as being "manifold" or "non-manifold"; where "manifold" implies that the Part has the property that each Edge, excluding seams and poles, has exactly two faces using it.

Similarly, Parts may have nearly identical geometry but different topology. The topology of a Part depends on how the geometry is put together. A Part may be manifold or non-manifold simply depending on how the geometry is put together. In addition to describing connectivity in space, topology is used to describe areas of interest (active areas) on Surfaces. These active Surface areas are used in defining a complex Part. The areas are specified by oriented Loops and often referred to as trimmed Surfaces which are exactly the 2-dimensional topological building block called a Face.

Readers desiring/needing a more in-depth exploration of boundary representation theory in order to understand the significance/meaning of some of the JT B-Rep data fields are referred to references [22] and [23] listed in the bibliography section of this specification.

Since the topology is a convenient way to describe or organize the Part, it is also convenient to store the geometry of the Part in the topological structures. The following sub-sections document the JT B-Rep format for storing the topology and geometry of a Part in a JT file.

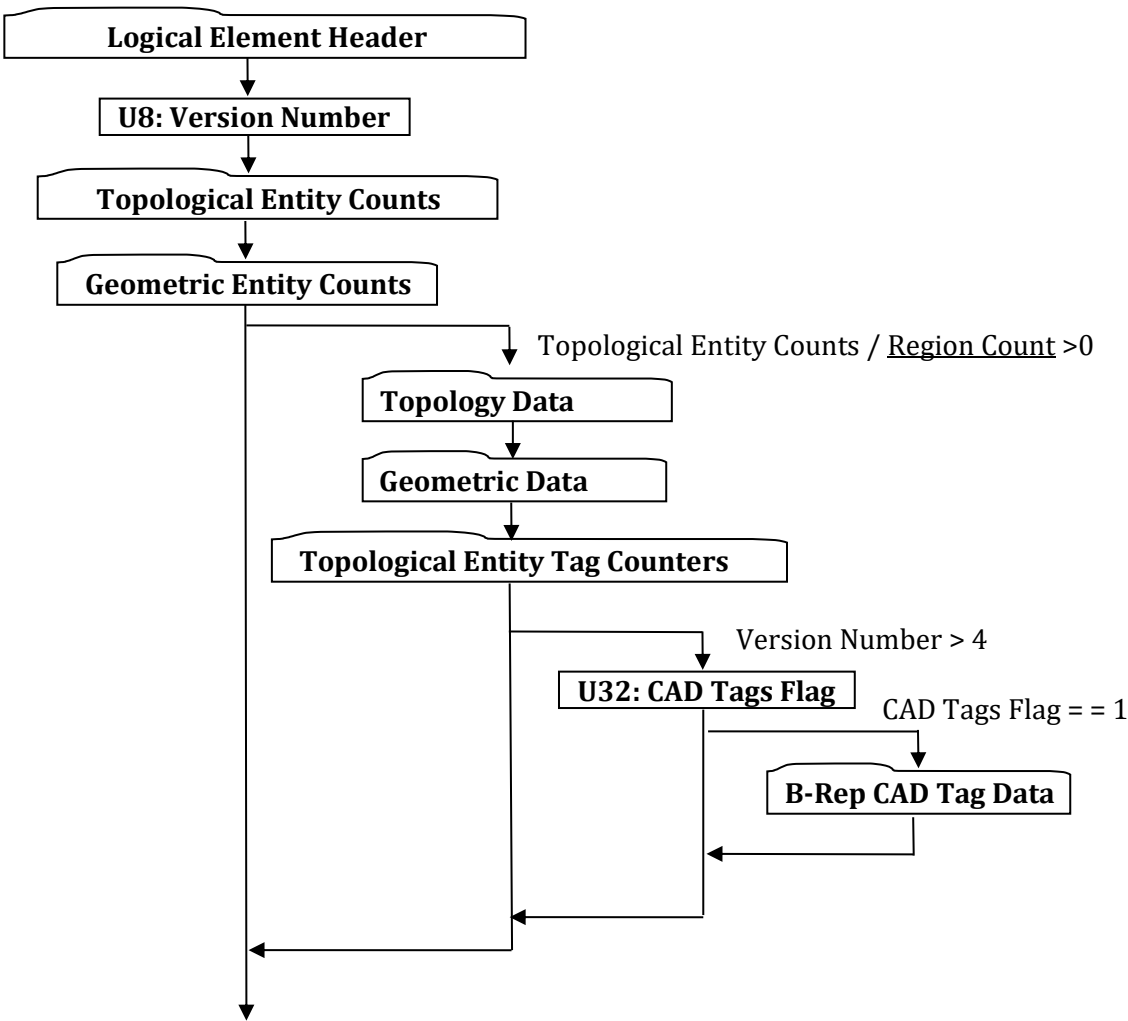


Figure K.2— JT B-Rep Element data collection

Complete description for Logical Element Header Compressed can be found in the File Header section of Base Format Description under Data Segment, Data.

U8: Version Number

Version Number is the version identifier for this JT B-Rep Element. Information on local version numbers can be found in the Base Format Description under Common Data Conventions and Constructs Local version numbers.

U32: CAD Tags Flag

CAD Tags Flag is a flag indicating whether CAD Tag data exist for the JT B-Rep.

Topological Entity Counts

Topological Entity Counts data collection, shown in Figure K.3, defines the counts for each of the various topological entities within a B-Rep.

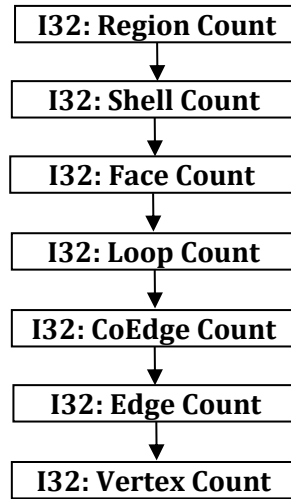


Figure K.3— Topological Entity Counts data collection

I32: Region Count

Region Count indicates the number of topological region entities in the B-Rep.

I32: Shell Count

Shell Count indicates the number of topological shell entities in the B-Rep.

I32: Face Count

Face Count indicates the number of topological face entities in the B-Rep.

I32: Loop Count

Loop Count indicates the number of topological loop entities in the B-Rep.

I32: CoEdge Count

CoEdge Count indicates the number of topological coedge entities in the B-Rep.

I32: Edge Count

Edge Count indicates the number of topological edge entities in the B-Rep.

I32: Vertex Count

Vertex Count indicates the number of topological vertex entities in the B-Rep.

Geometric Entity Counts

Geometric Entity Counts data collection, shown in Figure K.4, defines the counts for each of the various geometric entities within a B-Rep.

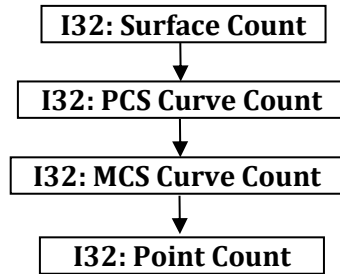


Figure K.4— Geometric Entity Counts data collection

I32: Surface Count

Surface Count indicates the number of distinct geometric surface entities in the B-Rep.

I32: PCS Curve Count

PCS Curve Count indicates the number of distinct geometric Parameter Coordinate Space curves (therefore UV curve) entities in the B-Rep.

I32: MCS Curve Count

MCS Curve Count indicates the number of distinct geometric (Model Coordinate Space) curves (therefore XYZ curve) entities in the B-Rep.

I32: Point Count

Point Count indicates the number of distinct geometric point entities in the B-Rep.

Topology Data

A diagrammatic representation of Topology Data collection is shown in Figure K.5.

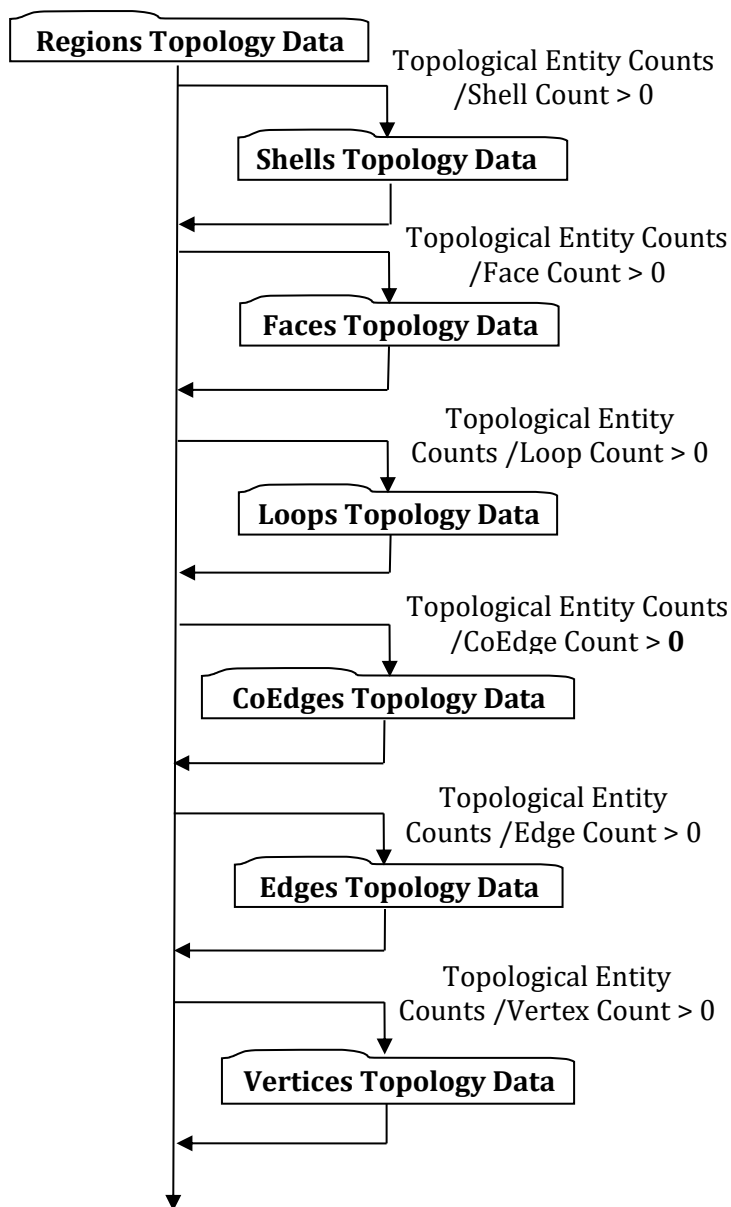


Figure K.5 — Topology Data collection

Regions Topology Data

Regions Topology Data, shown in Figure K.6, defines the set of non-overlapping Shells comprising each Region. The volume of a Region is that volume lying inside each “anti-hole Shell” and outside each simply-contained “hole Shell” belonging to the particular Region. A Region is analogous to a dimensionally elevated face where Region corresponds to Face and Shell corresponds to Trim Loop.

Each Region’s defining Shells are identified in a list of Shells by an index for both the first Shell and the last Shell in each Region (therefore all Shells inclusive between the specified first and last Shell list index define the particular Region).

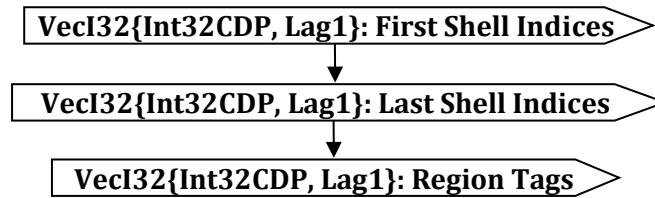


Figure K.6— Regions Topology Data collection

VecI32{Int32CDP, Lag1}: First Shell Indices

First Shell Indices is a vector of indices representing the index of the first Shell in each Region. First Shell Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Last Shell Indices

Last Shell Indices is a vector of indices representing the index of the last Shell in each Region. Last Shell Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Region Tags

Each Region has an identifier tag. Region Tags is a vector of identifier tags for a set of Regions. Region Tags uses the Int32 version of the CODEC to compress and encode data.

Shells Topology Data

Shells Topology Data, shown in Figure K.7, defines the set of topological adjacent Faces making up each Shell. A Shell's set of topological adjacent Faces define a single (usually closed) two manifold solid that in turn defines the boundary between the finite volume of space enclosed within the Shell and the infinite volume of space outside the Shell. Additionally, each Shell has a flag that denotes whether the Shell refers to the finite interior volume (therefore a "hole Shell") or the infinite exterior volume (therefore an "anti-hole Shell").

Each Shell's defining Faces are identified in a list of Faces by an index for both the first Face and the last Face in each Shell (therefore all Faces inclusive between the specified first and last Face list index define the particular Shell).

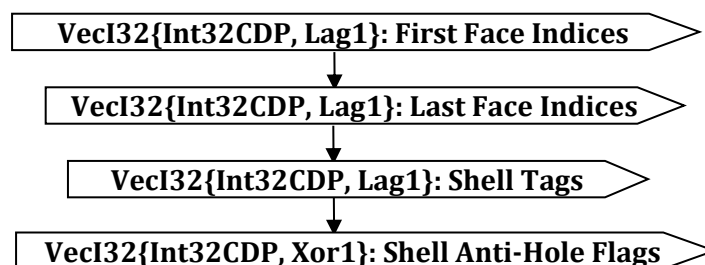


Figure K.7— Shells Topology Data collection

VecI32{Int32CDP, Lag1}: First Face Indices

First Face Indices is a vector of indices representing the index of the first Face in each Shell. First Face Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Last Face Indices

Last Face Indices is a vector of indices representing the index of the last Face in each Shell. Last Face Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Shell Tags

Each Shell has an identifier tag. Shell Tags is a vector of identifier tags for a set of Shells. Shell Tags uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Xor1}: Shell Anti-Hole Flags

Each Shell has a flag identifying whether the Shell is an anti-hole Shell. Shell Anti-Hole Flags is a vector of anti-hole flags for a set of Shells.

In an uncompressed/decoded form the flag values have the following meaning, shown in Table K.1:

Table K.1 — JT B-Rep Shell Topology Anti-Hole Flag values

| | |
|-----|---------------------------------|
| = 0 | Shell is not an anti-hole Shell |
| = 1 | Shell is an anti-hole Shell |

Shell Anti-Hole Flags uses the Int32 version of the CODEC to compress and encode data.

Faces Topology Data

A Face is a two-dimensional topological building block defined as the active (that portion to be used in the model) regions/areas of a Geometric Surface; where active regions/areas of a Geometric Surface are indicated using oriented Trim Loops. Faces Topology Data specifies the underlying Geometric Surface and Trim Loops making up each Face along with a “reverse normal” flag and identifier tag for each Face.

A Face shall be trimmed with at least one “anti-hole” Trim Loop and zero or more “hole” Trim Loops. Thus the area of the Geometric Surface defined as the Face, is the area inside the “anti-hole” Trim Loops and outside each “hole” Trim Loop. No Trim Loops (“hole” or “anti-hole”) may intersect/cross or be tangent at any point. “Anti-Hole” Trim Loops shall be defined with a counter-clockwise orientation in the underlying surface's parameter space whereas “hole” Trim Loops shall be defined with a clockwise orientation. With this Trim Loop orientation definition, as one traverses a Trim Loop of a Face, the material or “active region” is always to one’s left. The figure below gives an example in parameter space of proper trim loop definition and orientation (as indicated by the arrows on the loop’s CoEdges) for a face with two holes. “L1” represents the face “anti-hole” Trim Loop while “L2” and L3” represent the two “hole” Trim Loops. Note that each hole is always represented by a separate distinct “hole” Trim Loop.

A diagrammatic representation is shown in Figure K.8.

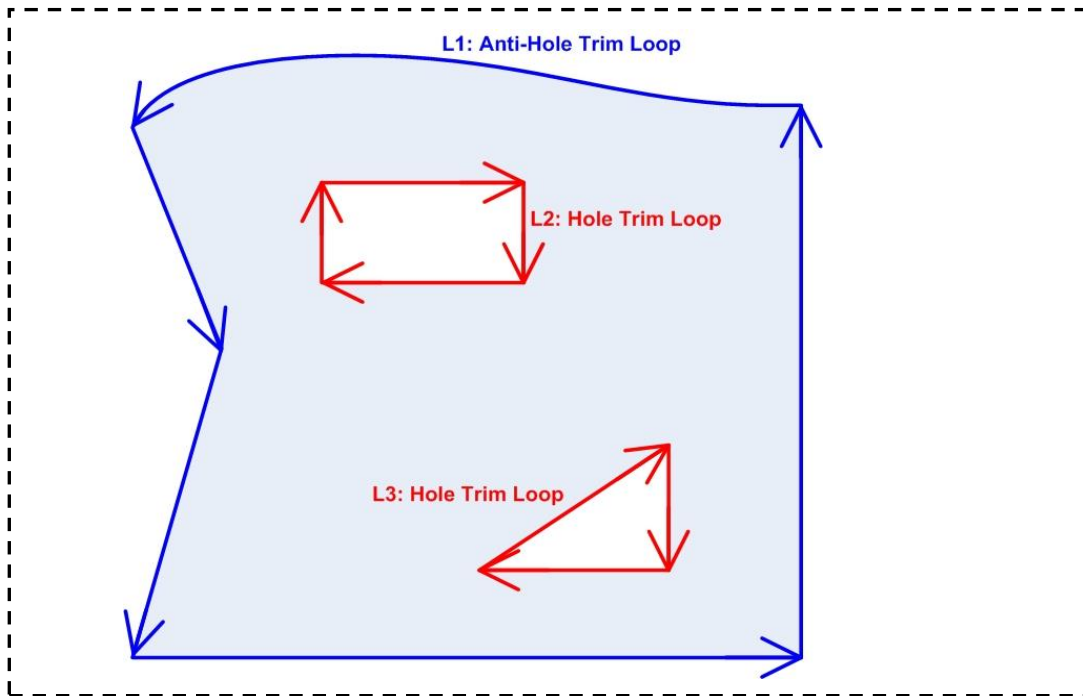


Figure K.8— Trim Loop example in parameter Space - One Face with 2 Holes

Each Face's underlying Geometric Surface is identified by an index into a list of Geometric Surfaces. Each Face's defining Trim Loops are identified in a list of trim Loops by an index for both the first Trim Loop and the last Trim Loop in each Face (therefore all Trim Loops inclusive between the specified first and last Trim Loop list index define the particular Face). This is shown in Figure K.9.

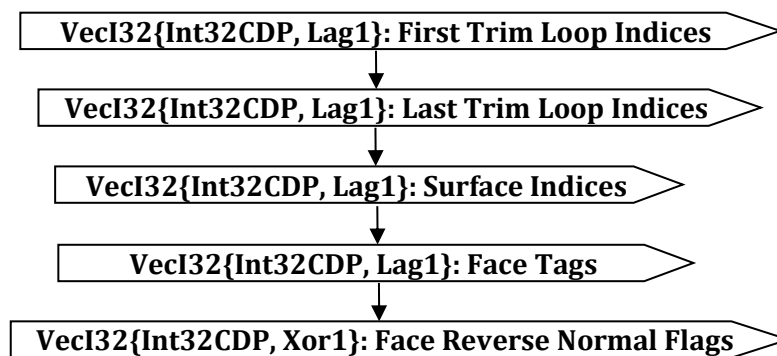


Figure K.9 — Faces Topology Data collection

VecI32{Int32CDP, Lag1}: First Trim Loop Indices

First Trim Loop Indices is a vector of indices representing the index of the first Trim Loop in each Face. First Trim Loop Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Last Trim Loop Indices

Last Trim Loop Indices is a vector of indices representing the index of the last Trim Loop in each Face. Last Trim Loop Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Surface Indices

Surface Indices is a vector of indices representing the index of the underlying Geometric Surface for each Face. Surface Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Face Tags

Each Face has an identifier tag. Face Tags is a vector of identifier tags for a set of Faces. Face Tags uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Xor1}: Face Reverse Normal Flags

Each Face has a flag identifying whether the Face's normal(s) should be interpreted to point in the direction opposite of the usual U cross V normal (note that these flags do not imply any sort of parameter reversal, the flag only implies that the material is on the other side of the surface).

Face Reverse Normal Flags is a vector of reverse-normal flags for a set of Faces.

In an uncompressed/decoded form the flag values have the following meaning, shown in Table K.2:

Table K.2 — JT B-Rep Face Reverse Normal Flag values

| | |
|-----|-----------------------------|
| = 0 | Face normal is not reversed |
| = 1 | Face normal is reversed. |

Face Reverse Normal Flags uses the Int32 version of the CODEC to compress and encode data.

Loops Topology Data

A Loop (often called Trimming Loop), as shown in Figure K.10, defines in parameter space a 1D boundary around which geometric surfaces are trimmed to form a Face. Loops Topology Data specifies the CoEdges making up each Loop along with an anti-hole flag and identifier tag for each Loop.

A Loop is composed of one or more CoEdges and the Loop shall be closed and non-self-intersecting.

Each Loop's defining CoEdges are identified in a list of CoEdges by an index for both the first CoEdge and the last CoEdge in each Loop (therefore all CoEdges inclusive between the specified first and last CoEdge list index define the particular Loop).

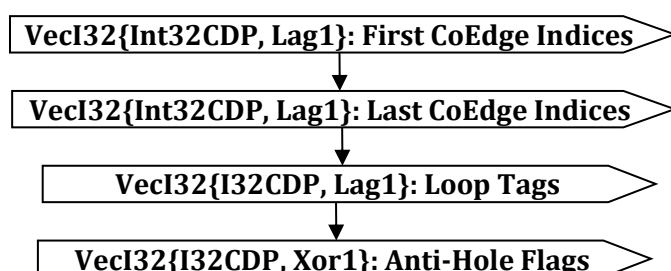


Figure K.10 — Loops Topology Data collection

VecI32{Int32CDP, Lag1}: First CoEdge Indices

First CoEdge Indices is a vector of indices representing the index of the first CoEdge in each Loop. First CoEdge Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Last CoEdge Indices

Last CoEdge Indices is a vector of indices representing the index of the last CoEdge in each Loop. Last CoEdge Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{I32CDP, Lag1}: Loop Tags

Each Loop has an identifier tag. Loop Tags is a vector of identifier tags for a set of Loops. Loop Tags uses the Int32 version of the CODEC to compress and encode data.

VecI32{I32CDP, Xor1}: Anti-Hole Flags

Each Loop has a flag identifying whether the Loop is an anti-hole Loop. Anti-Hole Flags is a vector of anti-hole flags for a set of Loops.

In an uncompressed/decoded form the flag values have the following meaning, shown in Table K.3:

Table K.3 — JT B-Rep Loops Topology Data Anti-Hole Flag values

| | |
|-----|-------------------------------|
| = 0 | Loop is not an anti-hole Loop |
| = 1 | Loop is an anti-hole Loop |

Anti-Hole Flags uses the Int32 version of the CODEC to compress and encode data.

CoEdges Topology Data

A CoEdge defines a parameter space edge trim Loop segment (therefore the projection of an Edge into the parameter space of the Face). CoEdges Topology Data specifies the underlying Edge and PCS Curve making up each CoEdge along with a MCS curve reversed flag and tag for each CoEdge.

The “Co” portion of the CoEdge name derives from the manifold topology definition that each Edge has exactly two Faces containing it; thus a CoEdge defines one Face’s “use” of an Edge and the adjoining Face also has a CoEdge (“edge use” in some other terminologies) for the same underlying Edge. This sharing of the same underlying Edge by two adjoining Faces requires an “MCS Curve Reversed Flag” on each CoEdge to indicate the edge traversal direction (therefore for a proper manifold topology definition each CoEdge shall traverse the Edge in opposite directions). This is shown in Figure K.11.

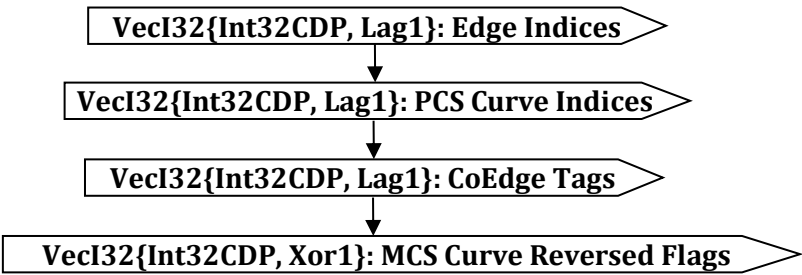


Figure K.11 — CoEdges Topology Data collection

VecI32{Int32CDP, Lag1}: Edge Indices

Edge Indices is a vector of indices representing the index of the underlying Edge for each CoEdge. Edge Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: PCS Curve Indices

PCS Curve Indices is a vector of indices representing the index of the PCS Curve (UV Curve) for each CoEdge. PCS Curve Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: CoEdge Tags

Each CoEdge has an identifier tag. CoEdge Tags is a vector of identifier tags for a set of CoEdges. CoEdge Tags uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Xor1}: MCS Curve Reversed Flags

Each CoEdge has a flag indicating whether the directional sense of the associated Edge’s MCS curve should be interpreted as opposite the direction its parameterization implies. MCS Curve Reversed Flags is a vector of reverse flags for a set of CoEdges.

In an uncompressed/decoded form the flag values have the following meaning, shown in Table K.4:

Table K.4 — JT B-Rep MCS Curve Reversed Flag values

| | |
|-----|---|
| = 0 | Directional sense of associated edges MCS curve should not be interpreted as opposite the direction its parameterization implies. |
| = 1 | Directional sense of associated edges MCS curve should be interpreted as opposite the direction its parameterization implies. |

MCS Curve Reversed Flags uses the Int32 version of the CODEC to compress and encode data.

Edges Topology Data

An Edge defines a model space trim Loop segment. Edges Topology Data specifies the underlying MCS Curve and start and end Vertex making up each Edge along with an identification tag for each Edge.

If manifold topology, then two faces join at a single model Edge and thus an edge is shared/referenced by two CoEdges (one per Face). This is shown in Figure K.12.

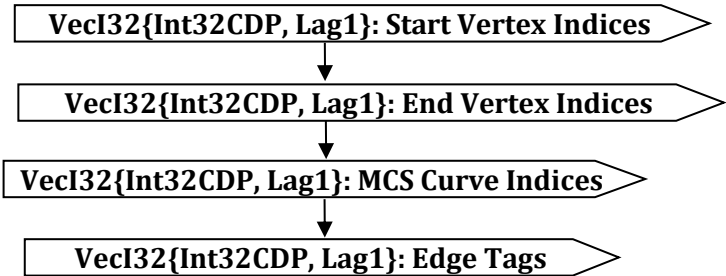


Figure K.12 — Edges Topology Data collection

VecI32{Int32CDP, Lag1}: Start Vertex Indices

Start Vertex Indices is a vector of indices representing the index of the start Vertex in each Edge. Start Vertex Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: End Vertex Indices

End Vertex Indices is a vector of indices representing the index of the end Vertex in each Edge. End Vertex Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: MCS Curve Indices

MCS Curve Indices is a vector of indices representing the index of the MCS Curve (Model Space curve) for each Edge. MCS Curve Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Edge Tags

Each Edge has an identifier Tag. Edge Tags is a vector of identifier Tags for a set of Edges. Edge Tags uses the Int32 version of the CODEC to compress and encode data.

Vertices Topology Data

A Vertex is the simplest topological entity and is basically made up of a geometric Point. Vertices Topology Data, as shown in Figure K.13, specifies the underlying geometric Point making up each Vertex along with an identification tag for each Vertex.

The presence of Vertices Topology Data in a JT B-Rep topology definition is optional. Vertex data is optional because unlike most topological entities, no connectivity information is contained in a Vertex structure and Vertex data is also not necessary for performing operations such as tessellation or mass properties calculations.

A Vertex is usually shared/referenced by two or more Edges (for example if the corners of four rectangular Faces touches at a common point, this point is represented by a Vertex and is shared by four Edges).

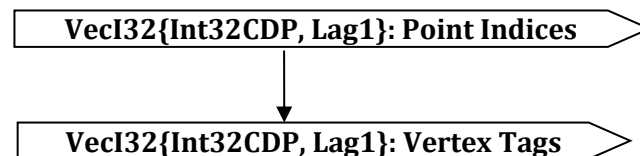


Figure K.13 — Vertices Topology Data collection

VecI32{Int32CDP, Lag1}: Point Indices

Point Indices is a vector of indices representing the index of the geometric point for each Vertex. Point Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Vertex Tags

Each Vertex has an identifier Tag. Vertex Tags is a vector of identifier Tags for a set of Vertices. Vertex Tags uses the Int32 version of the CODEC to compress and encode data.

Geometric Data

A diagrammatic representation of Geometric Data collection is shown in Figure K.14.

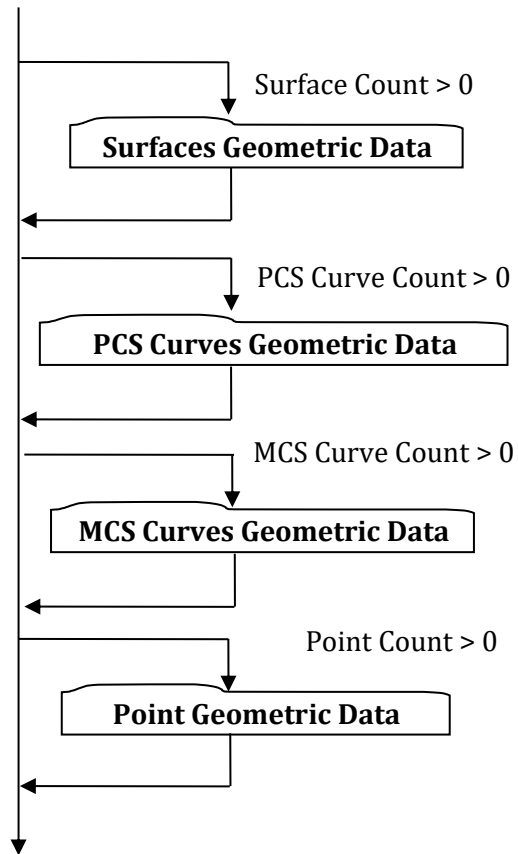


Figure K.14 — Geometric Data collection

Surfaces Geometric Data

Surfaces Geometric Data collection, as shown in Figure K.15, contains the JT B-Rep's geometric Surface data. Currently only NURBS Surface types are supported within a JT B-Rep. The count/number of Surfaces within a JT B-Rep is indicated by data field Surface Count documented in Geometric Entity Counts.

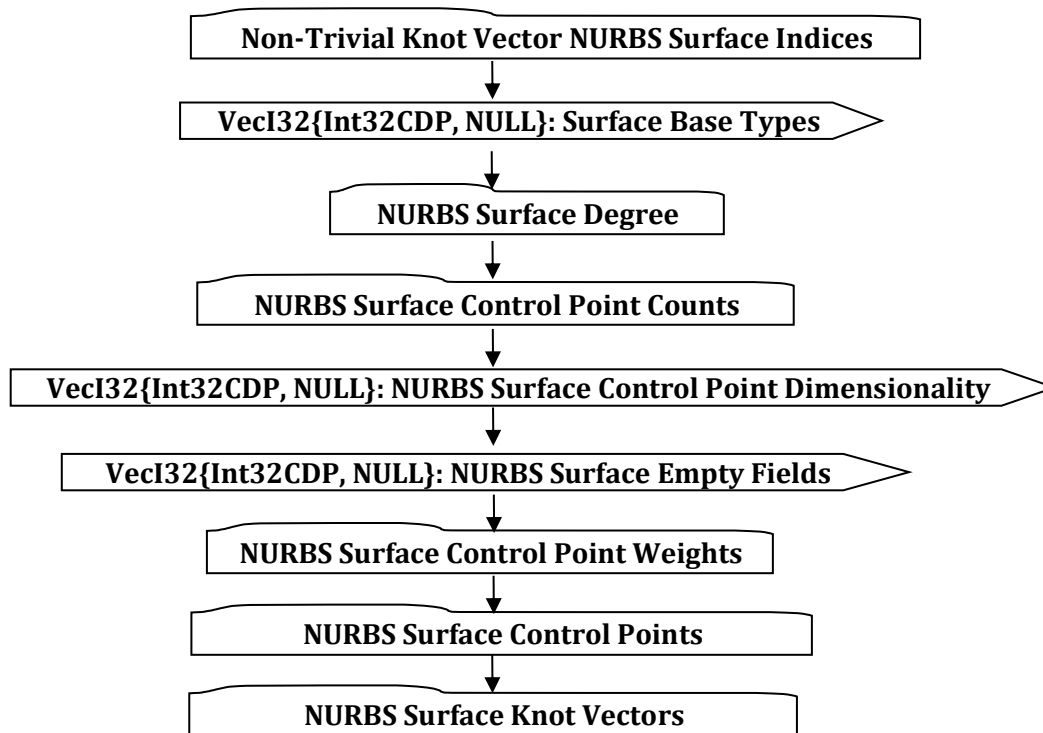


Figure K.15 — Surfaces Geometric Data collection

VecI32{Int32CDP, NULL}: Surface Base Types

Each Surface is assigned a base type identifier. Surface Base Types is a vector of base type identifiers for each Surface in a list of Surfaces. Currently only NURBS Surface Base Type is supported, but a type identifier is still included in the specification to allow for future expansion of the JT Format to support other surface types within a JT B-Rep.

In an uncompressed/decoded form the Surface base type identifier values have the following meaning, shown in Table K.5:

Table K.5 — JT B-Rep Surface Base Type value

| | |
|-----|----------------------------|
| = 1 | Surface is a NURBS surface |
|-----|----------------------------|

Surface Base Types uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: NURBS Surface Control Point Dimensionality

NURBS Surface Control Point Dimensionality is a vector of control point dimensionality values for each NURBS Surface in a list of Surfaces (therefore there is a stored values for each NURBS Surface in the list).

In an uncompressed/decoded form dimensionality values have the following meaning, shown in Table K.6:

Table K.6 — JT B-Rep NURBS Surface Control Point Dimensionality values

| | |
|-----|---|
| = 3 | Non-Rational (each control point has 3 coordinates) |
| = 4 | Rational (each control point has 4 coordinates) |

NURBS Surface Control Point Dimensionality uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: NURBS Surface Empty Fields

NURBS Surface Empty Fields is a vector of data. Each NURBS Surface in a list of Surfaces has one empty data field entry in this NURBS Surface Empty Fields vector. NURBS Surface Empty Fields uses the Int32 version of the CODEC to compress and encode data. Refer to Common Data Conventions and Construct, Empty Field.

Non-Trivial Knot Vector NURBS Surface Indices

Non-Trivial Knot Vector NURBS Surface Indices data collection, as shown in Figure K.16, specifies for both U and V directions the Surface index identifiers (therefore indices to particular NURBS Surfaces within a list of Surfaces) for all NURBS Surfaces containing non-trivial knot vectors. A description/definition for “non-trivial knot vector” can be found in Compressed Entity List for Non-Trivial Knot Vector.

This Surface index data is stored in a compressed format.

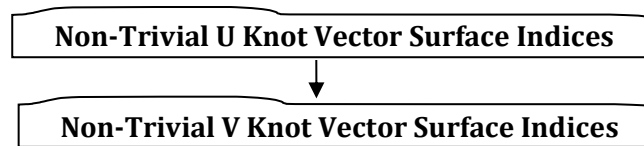


Figure K.16 — Non-Trivial Knot Vector NURBS Surface Indices data collection

Both Non-Trivial U Knot Vector Surface Indices and Non-Trivial V Knot Vector Surface Indices have the same data format as that documented for data collection Compressed Entity List for Non-Trivial Knot Vector.

NURBS Surface Degree

NURBS Surface Degree data collection, as shown in Figure K.17, defines the Surface degree in both U and V directions for each NURBS Surface in a list of Surfaces (therefore there are stored values for each NURBS Surface in the list). This degree data for the list of Surfaces is stored in a compressed format.

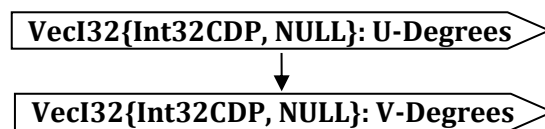


Figure K.17 — NURBS Surface Degree data collection

VecI32{Int32CDP, NULL}: U-Degrees

U-Degrees is a vector of Surface degree values in U direction for each NURBS Surface in a list of Surfaces. U-Degrees uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: V-Degrees

V -Degrees is a vector of Surface degree values in V direction for each NURBS Surface in a list of Surfaces. V-Degrees uses the Int32 version of the CODEC to compress and encode data.

NURBS Surface Control Point Counts

NURBS Surface Control Point Counts, as shown in Figure K.18, defines the number of NURBS Surface control points for both U and V directions for each NURBS Surface in a list of Surfaces (therefore there are stored values for each NURBS Surface in the list). The control point count data for the list of Surfaces is stored in a compressed format.

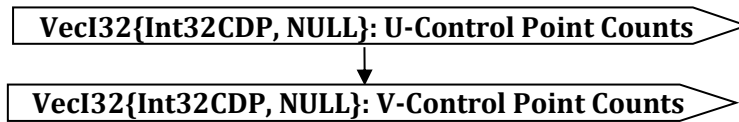


Figure K.18 — NURBS Surface Control Point Counts data collection

VecI32{Int32CDP, NULL}: U-Control Point Counts

U-Control Point Counts is a vector of control point counts in U direction for each NURBS Surface in a list of Surfaces. U-Control Point Counts uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, NULL}: V-Control Point Counts

V-Control Point Counts is a vector of control point counts in V direction for each NURBS Surface in a list of Surfaces. V-Control Point Counts uses the Int32 version of the CODEC to compress and encode data.

NURBS Surface Control Point Weights

NURBS Surface Control Point Weights data collection, as shown in Figure K.19, defines the Weight values for a conditional set of Control Points for a list of NURBS Surfaces. The storing of the Weight value for a particular Control Point is conditional, because if NURBS Surface Control Point Dimension is “non-rational” or the actual Control Point’s Weight value is “1”, then no Weight value is stored for the Control Point (therefore Weight value can be inferred to be “1”).

The NURBS Surface Control Point Weights data is stored in a compressed format.



Figure K.19 — NURBS Surface Control Point Weights data collection

Complete description for Compressed Control Point Weights Data can be found in Compressed Control Point Weights Data.

NURBS Surface Control Points

NURBS Surface Control Points, as shown in Figure K.20, is the compressed and/or encoded representation of the Control Point coordinates for each NURBS Surface in a list of Surfaces (therefore there are stored values for each NURBS Surface in the list). Note that these are non-homogeneous coordinates (therefore Control Point coordinates have been divided by the corresponding Control Point Weight values).



Figure K.20 — NURBS Surface Control Points data collection

VecF64{Int64CDP, NULL}: Control Points

Control Points is a vector of Control Point coordinates for all the NURBS Surfaces in a list of Surfaces. All the NURBS Surfaces Control Point coordinates are cumulated into this single vector in the same order as the Surface appears in the Surface list (therefore Surface-1 U Control Points, Surface-1 V Control Points, Surface-2 U Control Points, Surface-2 V Control Points, etc.). Control Points uses the Int64 version of the CODEC to compress and encode data in a “lossless” manner. Each deserialized 64 bit integer number should be converted to bit wise equivalent 64 bit floating number.

NURBS Surface Knot Vectors

NURBS Surface Knot Vectors, as shown in Figure K.21, defines the knot vectors for both U and V directions for each NURBS Surface having non-trivial knot vectors in a list of Surfaces (therefore there are stored values for each non-trivial knot vector NURBS Surface in the list). The NURBS Surfaces for which knot vectors are stored (therefore those containing non-trivial knot vectors) are identified in data collection Non-Trivial Knot Vector NURBS Surface Indices documented in Non-Trivial Knot Vector NURBS Surface Indices.

The knot vector data for the list of Surfaces is stored in a compressed format.

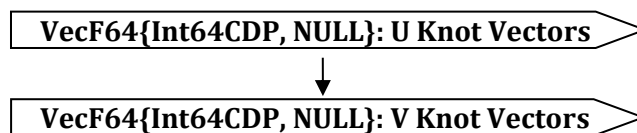


Figure K.21 — NURBS Surface Knot Vectors data collection

VecF64{Int64CDP, NULL}: U Knot Vectors

U Knot Vectors is a list of knot vector values in U direction for each NURBS Surface having non-trivial knot vectors in a list of Surfaces. All these NURBS Surface U direction non-trivial knot vectors are cumulated into this single list in the same order as the Surface appears in the Surface list (therefore Surface-N Non-Trivial U Knot Vector, Surface-M Non-Trivial U Knot Vector, etc.). U Knot Vectors uses the Int64 version of the CODEC to compress and encode data. Each deserialized 64 bit integer number should be converted to bit wise equivalent 64 bit floating number.

VecF64{Int64CDP, NULL}: V Knot Vectors

V Knot Vectors is a list of knot vector values in V direction for each NURBS Surface having non-trivial knot vectors in a list of Surfaces. All these NURBS Surface V direction non-trivial knot vectors are cumulated into this single list in the same order as the Surface appears in the Surface list (therefore Surface-N Non-Trivial V Knot Vector, Surface-M Non-Trivial V Knot Vector, etc.). V Knot Vectors uses the Int64 version of the CODEC to compress and encode data. Each deserialized 64 bit integer number should be converted to bit wise equivalent 64 bit floating number.

PCS Curves Geometric Data

PCS Curves Geometric Data collection, as shown in Figure K.22, contains the JT B-Rep’s Parameter Coordinate Space geometric Curve data (therefore UV Curve data). This geometric PCS Curve data is divided up into two collection types; one data collection for what are considered “Trivial” PCS curves and one data collection for compressed/encoded PCS NURBS Curve data.

“Trivial” PCS Curves are those UV Curves whose definition is such that the actual UV Curve definition can be derived from the parametric domain definition by storing a limited amount of descriptive data for each UV curve (therefore do not have to store the complete NURBS UV Curve definition).

The count/number of PCS Curves within a JT B-Rep is indicated by data field PCS Curve Count documented in Geometric Entity Counts.

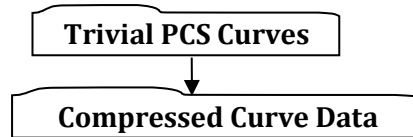


Figure K.22 — PCS Curves Geometric Data collection

Trivial PCS Curves

Trivial PCS Curves data collection, as shown in Figure K.23, represents those UV curves whose definition is such (therefore “trivial” enough) that the actual UV curve definition can be derived from the parametric domain definition by storing a limited amount of descriptive data for each UV curve (therefore do not have to store the complete UV curve definition). These Trivial PCS Curves are grouped into three classifications (Trivial Domain Loop, Trivial Box Loop, or Trivial Domain UV Curve) and stored as described in the following sub-sections.

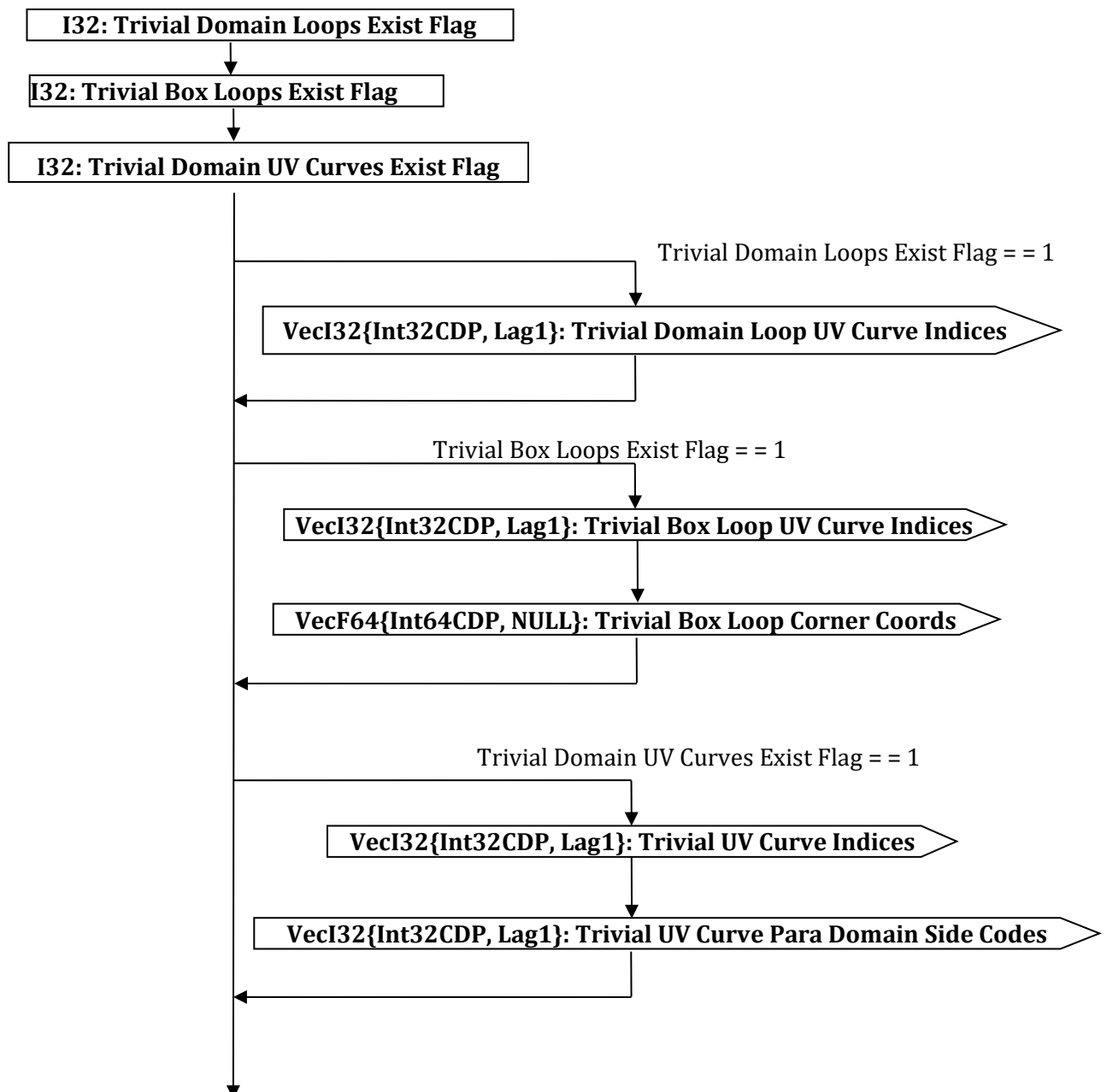


Figure K.23 — Trivial PCS Curves data collection

I32: Trivial Domain Loops Exist Flag

Trivial Domain Loops Exist Flag is a flag indicating whether “trivial” domain loops exist/follow. A Trivial Domain Loop is a Loop that encloses the entire parametric domain (therefore all UV Curves of the Loop span the entire length of the Surface parametric domain). Given this criteria a Trivial Domain Loop shall always be made up of four Trivial Domain UV curves. This is shown in Table K.7.

Table K.7 — Trivial Domain Loops Exist Flag values

| | |
|-----|------------------------------------|
| = 0 | Trivial Domain Loops do not exist. |
| = 1 | Trivial Domain Loops exist. |

I32: Trivial Box Loops Exist Flag

Trivial Box Loops Exist Flag is a flag indicating whether “trivial” box loops exist/follow. A trivial Box Loop is a Loop that forms a rectangle (therefore corresponding curve end coordinates of opposite sides of the box are equal). Given this criteria a Trivial Box Loop shall always be made up of four UV curves. This is shown in Table K.8

Table K.8 — Trivial Box Loops Exist Flag values

| | |
|-----|---------------------------------|
| = 0 | Trivial Box Loops do not exist. |
| = 1 | Trivial Box Loops exist. |

“Equality of corresponding curve end coordinates of opposite sides of the box” is represented graphically in Figure K.24.

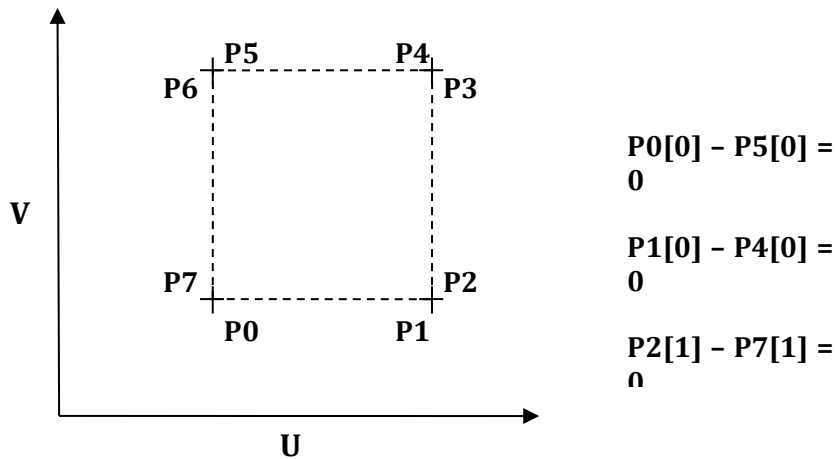


Figure K.24 — Equality of corresponding curve end coordinates of opposite sides of the box

I32: Trivial Domain UV Curves Exist Flag

Trivial Domain UV Curves Exist Flag is a flag indicating whether “trivial” domain UV curves (Loop CoEdges) exist/follow that are not part of a Trivial Domain Loop or Trivial Box Loop (therefore a Loop contains some UV curves that span the entire length of the Surface parametric domain but not all the Loop UV curves meet this criteria and thus not captured as part of the Trivial Domain Loop data). This is shown in Table K.9

Table K.9 — Trivial Domain UV Curves Exist Flag values

| | |
|-----|--|
| = 0 | Trivial Domain UV Curves do not exist. |
|-----|--|

| | |
|-----|---------------------------------|
| = 1 | Trivial Domain UV Curves exist. |
|-----|---------------------------------|

VecI32{Int32CDP, Lag1}: Trivial Domain Loop UV Curve Indices

Trivial Domain Loop UV Curve Indices is a vector of all UV curve indices that are part of a Trivial Domain Loop. Note that each Trivial Domain Loop is always made up of four UV curves (thus four UV curve indices per Loop). Trivial Domain Loop UV Curve Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Trivial Box Loop UV Curve Indices

Trivial Box Loop UV Curve Indices is a vector of all UV Curve indices that are part of a Trivial Box Loop. Note that each Trivial Box Loop is always made up of four UV Curves (thus four UV Curve indices per Loop). Trivial Box Loop UV Curve Indices uses the Int32 version of the CODEC to compress and encode data.

VecF64{Int64CDP, NULL}: Trivial Box Loop Corner Coords

Trivial Box Loop Corner Coords is a vector of box corner coordinates for all Trivial Box Loops (therefore each Box Loop will store two box corner coordinates). A Box Loop's set of "box corner coordinates" are the coordinates of the two min/max diagonally opposite corners of the box. Note that if the Box Loop is a "hole", then the max and min corners are the other ends of the respective box sides that contain the max and min corners. Trivial Box Loop Corner Coords uses the Int64 version of the CODEC to compress and encode data. Each deserialized 64 bit integer number should be converted to bit wise equivalent 64 bit floating number.

VecI32{Int32CDP, Lag1}: Trivial UV Curve Indices

Trivial UV Curve Indices is a vector of all Loop UV Curve indices that are not part of a Trivial Domain Loop or Trivial Box Loop. Trivial UV Curve Indices uses the Int32 version of the CODEC to compress and encode data.

VecI32{Int32CDP, Lag1}: Trivial UV Curve Para Domain Side Codes

Trivial UV Curve Para Domain Side Codes is a vector containing a "side code" for each Trivial UV Curve indicating which parametric domain side the UV Curve lies on.

In an uncompressed/decoded form the parametric domain side values have the following meaning, as shown in Table K.10:

Table K.10 — Trivial UV Curve Para Domain Side Codes values

| | |
|-----|----------------------------------|
| = 0 | Bottom side of parametric domain |
| = 1 | Right side of parametric domain |
| = 2 | Top side of parametric domain |
| = 3 | Left side of parametric domain |

Trivial UV Curve Para Domain Side Codes uses the Int32 version of the CODEC to compress and encode data.

MCS Curves Geometric Data

MCS Curves Geometric Data collection, as shown in Figure K.25, contains the JT B-Rep's Model Coordinate System geometric Curve data (therefore XYZ Curve data). Currently only NURBS Curve types are supported within a JT B-Rep. The count/number of MCS Curves within a JT B-Rep is indicated by data field MCS Curve Count documented in Geometric Entity Counts.

Compressed Curve Data

Figure K.25 — MCS Curves Geometric Data collection

Complete description for Compressed Curve Data can be found in Compressed Curve Data.

Point Geometric Data

Point Geometric Data collection, as shown in Figure K.26, contains the JT B-Rep's geometric Point data. Each Point is simply represented by a CoordF32 for the Point's coordinate components. The count/number of Points within a JT B-Rep is indicated by data field Point Count documented in Geometric Entity Counts.

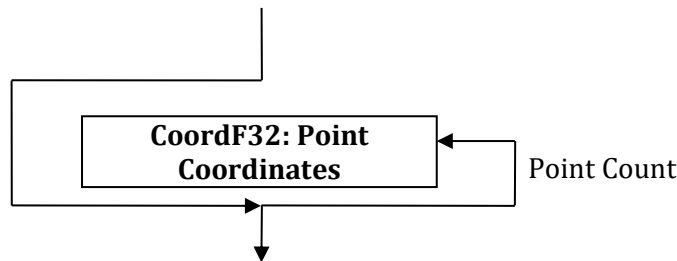


Figure K.26 — Point Geometric Data collection

CoordF32: Point Coordinates

Point Coordinates specifies the XYZ coordinate components for a Point.

Topological Entity Tag Counters

Topological Entity Tag Counters data collection, as shown in Figure K.27, specifies the next available "unique" tag value for each entity type in a JT B-Rep. These are rolling tag counters that are meant to be used for assigning a unique tag when a new entity is added to a JT B-Rep.

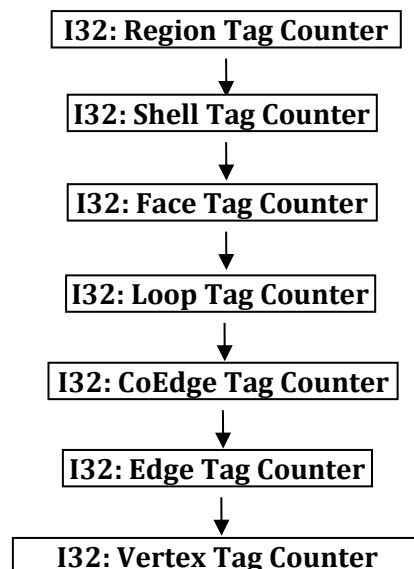


Figure K.27 — Topological Entity Tag Counters data collection

I32: Region Tag Counter

Region tag Counter specifies the next available “unique” tag value for Region entity.

I32: Shell Tag Counter

Shell Tag Counter specifies the next available “unique” tag value for Shell entity.

I32: Face Tag Counter

Face Tag Counter specifies the next available “unique” tag value for Face entity.

I32: Loop Tag Counter

Loop Tag Counter specifies the next available “unique” tag value for Loop entity.

I32: CoEdge Tag Counter

CoEdge Tag Counter specifies the next available “unique” tag value for CoEdge entity.

I32: Edge Tag Counter

Edge Tag Counter specifies the next available “unique” tag value for Edge entity.

I32: Vertex Tag Counter

Vertex Tag Counter specifies the next available “unique” tag value for Vertex entity.

B-Rep CAD Tag Data

The B-Rep CAD Tag Data collection, shown in Figure K.28, contains the list of persistent IDs, as defined in the CAD System, to uniquely identify individual Faces and Edges in the JT B-Rep. The existence of this B-Rep CAD Tag Data collection is dependent upon the value of previously read data field CAD Tags Flag as documented in JT B-Rep Element.

If B-Rep CAD Tag Data collection is present, there will be a CAD Tag for every Face and every Edge in the JT B-Rep and the list order will be Face CAD Tags followed by Edge CAD Tags. Therefore the total number of CAD Tags in the list should be equal to “Face Count + Edge Count” as documented in Topological Entity Counts.



Compressed CAD Tag Data

Figure K.28 — B-Rep CAD Tag Data collection

Complete description for Compressed CAD Tag Data can be found in Compressed CAD Tag Data.

Annex L (deprecated) PMI Data Segment

JT files that have been migrated to JT v10.6 format description from a JT Version 8 format description may have PMI information represented in a PMI Data Segment. From a parsing point of view, a PMI Data Segment should be treated exactly the same as a PMI Manager Meta Data Element.

PMI Data Segments are deprecated and should not be written to JT file

Annex M

Procedural Geometry – Evaluation and Approximation

The following section describes in detail algorithms used for evaluation of procedural geometry elements of type Intersection Curve and Blend Edge Surface.

M.1 Introduction & Scope

These notes are intended to help people understand the procedural geometry that is used in JT/XT data. Specifically, we discuss procedural intersection curves (“icurves” for short), and rolling-ball blend surfaces. The chapter includes mathematical background and pseudocode that can be used to evaluate a point at a given parametric location on either an icurve or a blend surface; this evaluation procedure provides a clear and completely unambiguous definition of the geometry.

Once the evaluation functions are available, it is quite straightforward to approximate an icurve or a blend surface with b-spline geometry of some sort. This is just general-purpose approximation technology, but we explain how to do it, anyway. Internally, Parasolid makes very little use of spline approximations, so this is not an area where we invest heavily, and the algorithms given below could probably be improved. The spline geometry is easier to import into other CAD systems, and might possibly deliver better performance in some types of computations. The disadvantage, of course, is that the b-spline geometry will occupy more space, and it will only replicate the true procedural geometry within some tolerance.

M.2 Notation

Upright bold upper-case letters like **A**, **B**, **C**, **P**, **X** denote 3D points and vectors. Points and vectors are not the same thing, of course, but the context should make things clear. Italic lower-case letters like *s*, *t*, *u*, *v*, *w* denote real numbers, which are often parameter values on curves and surfaces.

M.3 Pseudocode

The pseudocode is written in a language that is roughly C#. We assume that we have Point and Vector classes that represent 3D points and vectors respectively. These classes have obvious functions, like Vector.Norm (computes the length of the given vector), and so on. We also assume that the usual arithmetic operators (+, -, *) have been overloaded in these classes, so that $P - Q$ is the difference of two points (which is a vector), $U + V$ is the sum of two vectors, $U * V$ is their dot product, and so on.

The procedural geometry algorithms used inside Parasolid are extremely complex. Parasolid has a zero-regression policy. So, if we develop a new algorithm that improves 99% of all data cases, we sometimes retain the old algorithm to avoid regressions in the other 1%. There are many different paths through the code, and the descriptions below represent only the primary ones (therefore the ones that are most often followed, and the ones that we regard as the best).

M.4 Intersection Curve

Intersection Curve Basics

Suppose we have two surfaces **A** and **B** with parameterizations $(s, t) \mapsto \mathbf{A}(s, t)$ and $(u, v) \mapsto \mathbf{B}(u, v)$, and we are interested in their curve of intersection, **C**. Specifically, suppose we are given a parameter value *w*, and we want to calculate the corresponding point $\mathbf{C}(w)$ on the icurve. If we can do this for any given *w*, then we have a clear and unambiguous definition of the icurve, and approximating it by an explicit spline curve should be straightforward.

In a JT file, the representation of an icurve is a sequence of “chart points” $\mathbf{P}_0, \dots, \mathbf{P}_n$. To each chart point \mathbf{P}_i we assign a parameter value $w = w_i$; detailed procedures for doing this are explained later, but, for now, assume that this has already been done, and that the w_i values are strictly increasing. We assume that the given parameter value w lies in the range $w_0 \leq w \leq w_n$. Therefore, we can find an index i such that $w_i \leq w \leq w_{i+1}$.

We first find a point $\mathbf{L}(w)$ on the chord $\mathbf{P}_i\mathbf{P}_{i+1}$. We let r denote the ratio

$$r = \frac{w - w_i}{w_{i+1} - w_i}$$

and then

$$\mathbf{L}(w) = (1 - r)\mathbf{P}_i + r\mathbf{P}_{i+1} = \frac{w_{i+1} - w}{w_{i+1} - w_i}\mathbf{P}_i + \frac{w - w_i}{w_{i+1} - w_i}\mathbf{P}_{i+1}$$

We see that $\mathbf{L}(w)$ divides the chord in the ratio r to $1 - r$, as shown in Figure M.1

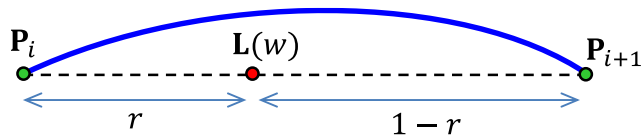


Figure M.1 — Dividing a chord

Next, we construct the plane $\pi(w)$ that passes through the point $\mathbf{L}(w)$ and is perpendicular to the chord $\mathbf{P}_i\mathbf{P}_{i+1}$. The point $\mathbf{C}(w)$ of the intersection curve is the intersection of the two surfaces **A** and **B** and the plane $\pi(w)$, as shown Figure M.2

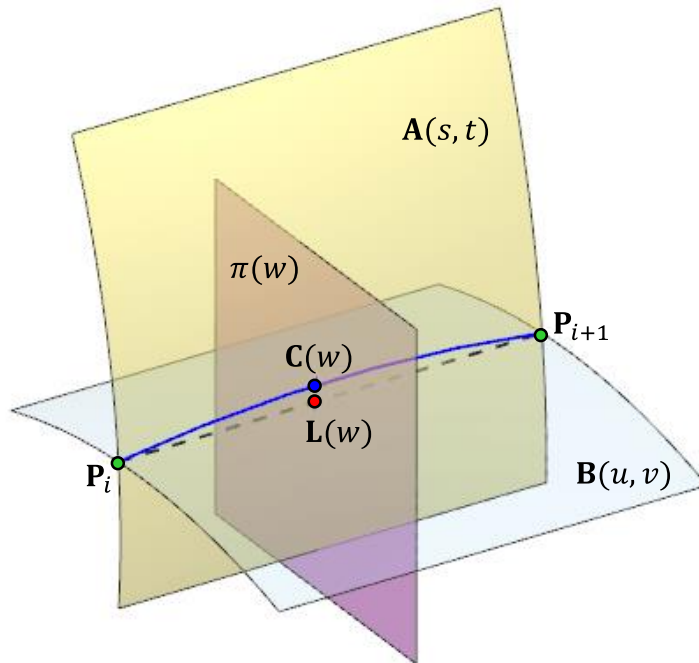


Figure M.2 — Constructing a perpendicular plane

The construction is clearer if we omit the two surfaces and look at the plane $\pi(w)$ edge-on as shown in Figure M.3

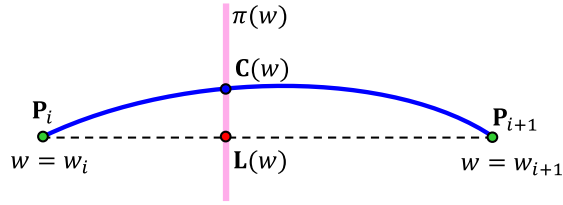


Figure M.3 — Perpendicular plane view with out surfaces

Populating Chart Points

An icurve consists primarily of a sequence of “chart points”. Each chart point is represented by a structure called an hvec. The name “hvec” is an abbreviation for “heptavector”, so-called because the structure originally had 7 members. The members are described in the following declaration:

```
struct hvec {
    Point      CurvePoint;          // Point on curve
    double[]   st;                  // Parameter value pair (s,t) on first surface
    double[]   uv;                  // Parameter value pair (u,v) on second surface
    Vector      CurveTangent;        // Curve tangent vector (a unit vector)
    double     w;                   // Curve parameter value }
```

In the hvecs structures of an icurve in a JT file, only the CurvePoint fields are populated. The remaining elements of the hvec structures can all be derived from these as explained below

Getting Surface Parameter Values

First, we need to calculate the surface parameter values at each chart point P_i . In other words, we need to find two parameter pairs (s, t) and (u, v) such that $A(s, t) = P_i$ and $B(u, v) = P_i$. The computations for the two surfaces are similar, and independent of each other, so we just illustrate with the surface **B**.

If the surface **B** is simple and analytic, the calculations are easy, so we omit them.

If the surface **B** is complex, we need to use an iterative numerical method. The major problem with the numerical approach is that the iteration needs a good starting point. To obtain one, we use a construction based on the (parameterized) tangent plane π at the previous chart point, P_{i-1} , as shown in Figure M.4

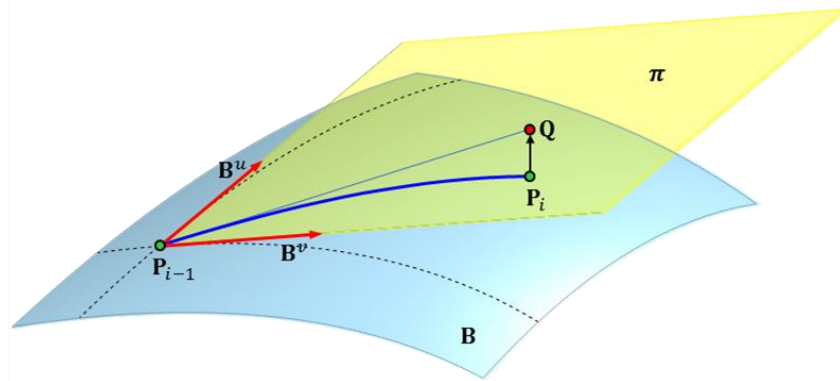


Figure M.4 — Surface B illustration

Let B^u and B^v denote the partial derivatives of the surface **B** at the previous point P_{i-1} . Then the equation of the tangent plane at P_{i-1} can be written as

$$\pi(\delta u, \delta v) = P_{i-1} + \delta u B^u + \delta v B^v$$

We want to find values of u and v such that the point $\pi(u, v)$ on the tangent plane is as close as possible to the point P_i .

This means that $\pi(u, v)$ must be the orthogonal projection of \mathbf{P}_i onto the plane π , so

$$(\pi(\delta u, \delta v) - \mathbf{P}_i) \cdot \mathbf{B}^u = 0$$

$$(\pi(\delta u, \delta v) - \mathbf{P}_i) \cdot \mathbf{B}^v = 0$$

Substituting for $\pi(\delta u, \delta v)$, and rearranging, this gives

$$\delta u(\mathbf{B}^u \cdot \mathbf{B}^u) + \delta v(\mathbf{B}^u \cdot \mathbf{B}^v) = (\mathbf{P}_i - \mathbf{P}_{i-1}) \cdot \mathbf{B}^u$$

$$\delta u(\mathbf{B}^u \cdot \mathbf{B}^v) + \delta v(\mathbf{B}^v \cdot \mathbf{B}^v) = (\mathbf{P}_i - \mathbf{P}_{i-1}) \cdot \mathbf{B}^v$$

This is a system of two linear equations in the unknowns δu and δv , which we can easily solve (by Cramer's rule, for example). So, if (u_0, v_0) denote the surface parameter values at \mathbf{P}_{i-1} , then it is reasonable to assume that $\mathbf{B}(u_0 + \delta u, v_0 + \delta v) \approx \mathbf{P}_i$, so $(u, v) = (u_0 + \delta u, v_0 + \delta v)$ will be suitable starting values in an iterative algorithm that finds (u, v) such that $\mathbf{B}(u, v) = \mathbf{P}_i$.

Finding (u, v) such that $\mathbf{B}(u, v) = \mathbf{P}_i$ will be impossible, in floating point arithmetic, of course, so a more practical approach is to try to find (u, v) that minimizes $\|\mathbf{B}(u, v) - \mathbf{P}_i\|^2$. Since the point \mathbf{P}_i lies very close to the surface \mathbf{B} , this minimum will be very small, and this may be helpful in locating it. The pseudocode for this process is as follows:

```
// Finds parameter values at a given point on a surface
// Input:
//   B      -- the surface
//   P      -- a point on the surface
//   nearUV -- (u,v) values such that B(u,v) is close to P. Same as (u0,v0) in notes
//           above.
// Returns:
//   The (u,v) values such that B(u,v) = P

double[] SurfaceParametersAtPoint(Surface B, Point P, double[] nearUV)
{
    // Calculate position and partial derivatives at previous chart point
    Point    Q = B.Position(nearUV);      // Position at nearUV = (u0,v0)
    Vector    Bu = B.DerivDu (nearUV);    // Partial deriv wrt u at nearUV
    Vector    Bv = B.DerivDv (nearUV);    // Partial deriv wrt v nearUV

    // Construct linear equations for finding uv delta values, and solve
    double a = Bu * Bu;  double b = Bu * Bv;  double h = (P - Q) * Bu;
    double c = Bu * Bv;  double d = Bv * Bv;  double k = (P - Q) * Bv;
    double[] deltaUV = LinearSystemSolve(a, b, c, d, h, k);

    // Add on delta values: startUV = nearUV + deltaUV
    double[] startUV = { nearUV[0] + deltaUV[0], nearUV[1] + deltaUV[1] };

    // Minimize to find closest point on surface, where B(u,v) = P,
    double outUV = FindMinimum(SurfaceDistance2, double[] startUV);
    return outUV;
}
```

Here we have assumed the existence of three other standard functions.

First, a simple linear system solver:

```
// Computes (x,y) that are solutions to the system:
//      a*x + b*y = h
//      c*x + d*y = k
// Input:
//   a,b,c,d -- coefficients
//   h,k     -- right-hand sides
// Returns:
//   Solution (x,y) of the linear system

double[] LinearSystemSolve(double a, double b, double c, double d, double h, double k)
```

Next, a function that calculates (squared) distance from a point to the surface B:

```
// Calculates squared distance from a given point to a point on a surface
// Input:
//   surf -- the surface
//   P     -- the point
// Returns:
// Squared distance from point P to point surf(u,v)
```

```
double SurfaceDistance2(Surface surf, Point P, double[] uv)
{
    Position Q = surf.Point(uv);
    double dist2 = (P - Q) * (P - Q);
    return dist2;
}
```

and, finally, an iterative numerical minimization function

```
// Minimizes a real-valued function of two variables
// Input:
//   f      -- the real-valued function to be minimized
//   start  -- the starting values of the variables, from which to start iteration
// Returns:
//   Arguments for which the function f is a local minimum

double[] FindMinimum(RealFunction2 f, double[] start)
```

There is nothing very special about the minimization function that is required here. Parasolid uses a home-grown function, but it is unremarkable. It uses a maximum of 20 iterations, and it terminates when either the function value or the step size is less than a small tolerance `epsilonDistance`, whose value is 10^{-8} . Examples of suitable functions can be found in the Numerical Recipes book [7], in the GNU Scientific Library [8], in MINPACK[9], or in numerous other places. Specifically, the functions `frpmin` or `dfpmin` from the Numerical Recipes book have the necessary functionality.

We do exactly the same computation to find parameter values (s, t) on the first surface, **A**, such that $\mathbf{A}(s, t) = \mathbf{P}_i$. We write the (s, t) and (u, v) values into the `hvec`.

Special Case: the First Point

In the previous section, we calculated surface parameter values at the current chart point by “stepping” from the previous point to get to a place where we could start an iterative algorithm. Of course, if there is no previous point, this doesn’t work, so we need some other way to start our iteration. Unfortunately, a brute-force global search is the only option. One possible way to do this is outlined below. Again, we use the surface **B** as an example.

The objective is to find parameter values (u, v) such that $\mathbf{B}(u, v)$ is close to the current point **P**; these (u, v) values can then be used to start an iterative minimization, as described in the previous section. The basic idea is to test the value of $\mathbf{B}(u, v)$ at some $m \times n$ locations $(u, v) = (u_i, v_j)$, and simply choose the location that’s closest to **P**. The question is: what values should be used for m and n . Some suggestions are outlined in Table M.1

Table M.1 — Suggested values for m and n parameters

| Surface Type | Description |
|------------------|--|
| Bezier patch | If the patch has degrees $p \times q$, use an array size somewhere between $p \times q$ and $2p \times 2q$. |
| NURBs surface | Treat each constituent Bézier patch as described above |
| Offset surface | Use the same array of locations as on the base surface |
| Extruded surface | Do a 2D calculation in a plane that’s perpendicular to the extrusion direction. If the generator curve is a spline of degree p , use somewhere between p and $2p$ points on each of its Bézier segments. |
| Revolved surface | Again, do the computation in 2D, in a plane containing the surface’s axis of rotation. If the generator curve is a spline, handle as above. |

If the global searching method is implemented in a function `GlobalSearch`, then the pseudocode for this approach is as follows:

```
// Do global search to get a near point
double[] nearUV = GlobalSearch(B, P);

// Use this near point as input to SurfaceParametersAtPoint
double outUV = SurfaceParametersAtPoint(B, P, nearUV)
```

This basic calculation should work adequately, but there are many ways to improve it. Firstly, convex hull or boxing algorithms can be used to eliminate large portions of the surface that are clearly further from \mathbf{P} than the current minimum. This will not produce better results, but it will certainly improve performance. Also, a tessellation could be used instead of an array of points — this would require point-to-triangle distance calculations rather than point-to-point calculations, but it will yield better starting values. The tessellation can be a simple one constructed from the $m \times n$ array of points described above, or more sophisticated tessellation algorithms could be used.

If stepping from the previous chart point (as described in section) fails, then the global search method described in this section can be used as a backup. In fact, the global search could be used at every point, in principle, though this is likely to result in poor performance.

Getting the Tangent Vector

The next thing that's needed in the `hvec` is the `CurveTangent` vector. This is just the unitized cross product of the two surface normals at the point, so it's easy to compute:

```
Vector normA = A.Normal(st);
Vector normB = B.Normal(uv);
Vector curveTangent = Vector.UnitCross(normA, normB);
```

Obviously this calculation won't work if the two surface normal are parallel (because the surfaces are tangent), but this should not happen at a chart point.

Getting Chart Point Parameters

Finally, we need to assign a parameter value w_i to each chart point \mathbf{P}_i . These parameter values do not have any influence on the shape of the icurve — they are used only to identify an interval $[w_i, w_{i+1}]$ containing the given value w , and to compute a local parameter r (a ratio) within this interval. The computation of points on the icurve will work no matter what sequence of values w_0, \dots, w_n we use (as long as they are increasing). The w_i values do not affect the shape of the icurve, they only affect the mapping $w \mapsto \mathbf{C}(w)$. So, if we only care about the shape of the icurve, and not about its parameterization, it doesn't much matter what w_i values we assign to the chart points.

The simplest option would be to make the w_i values evenly spaced — we would just set $w_i = i$ or $w_i = i/n$ for $i = 0, 1, \dots, n$. Saying this another way, this scheme makes the parameter increments $h_i = w_{i+1} - w_i$ constant. Another simple option would be to space the w_i according to chord-lengths, so

$$h_i = w_{i+1} - w_i = \|\mathbf{P}_i - \mathbf{P}_{i-1}\| \quad \text{for } i = 0, 1, \dots, n-1$$

However, both of these simple schemes have a drawback: the icurve constructed this way will be G1 (it will have continuous unit tangent) but it will not necessarily be C1 (it will not have a continuous first derivative). In many situations, the lack of C1 continuity is not a problem — a jump in the length of the first derivative vector as the curve passes through a chart point is not likely to cause much trouble. In other situations, C1 continuity is desirable, and it turns out that this can be achieved by a careful choice of the parameter values w_i (or, more precisely, by the right choice of the parameter increments h_i). There is no special mathematics here: it is well-known that **any** piecewise G1 curve can be made C1 simply by adjusting parameter increments in this way. The details are given below

Let \mathbf{T}_i be the unit tangent of the icurve at the chart point \mathbf{P}_i , let $\mathbf{V}_i = \mathbf{P}_{i+1} - \mathbf{P}_i$ be the i -th chord vector, let $d_i = \|\mathbf{V}_i\|$ be its length, and let $\mathbf{U}_i = \mathbf{V}_i/d_i$ be the unit vector along the i -th chord. Also, let α_i and β_i be the angles between the tangent \mathbf{T}_i and the unit chord vectors \mathbf{U}_i and \mathbf{U}_{i-1} respectively, as shown in the Figure M.5 below:

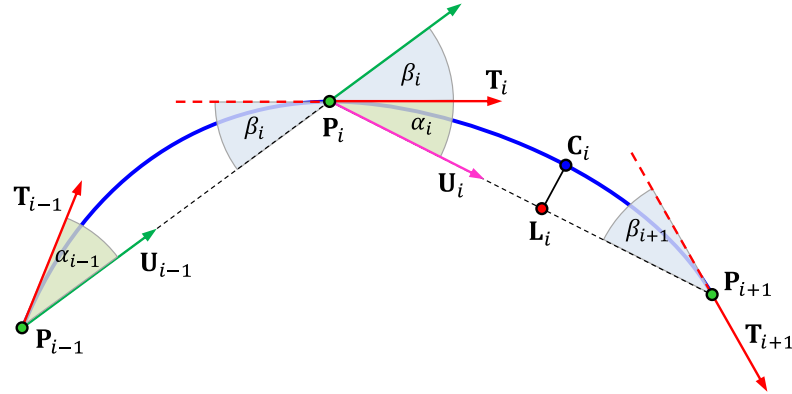


Figure M.5 — Piecewise parameter increments

Our goal is to compute suitable values for the parameter increments $h_i = w_{i+1} - w_i$.

On the segment where $w_i \leq w \leq w_{i+1}$, the equation of the chord is

$$\mathbf{L}_i(w) = \frac{w_{i+1} - w}{w_{i+1} - w_i} \mathbf{P}_i + \frac{w - w_i}{w_{i+1} - w_i} \mathbf{P}_{i+1} = \mathbf{P}_i + \frac{w - w_i}{h_i} \mathbf{V}_i$$

and so

$$\mathbf{L}'_i(w) = \frac{\mathbf{V}_i}{h_i} = \frac{d_i \mathbf{U}_i}{h_i}$$

Since the vector $\mathbf{C}_i(w) - \mathbf{L}_i(w)$ is perpendicular to the chord $\mathbf{P}_i\mathbf{P}_{i+1}$, we have

$$[\mathbf{C}_i(w) - \mathbf{L}_i(w)] \cdot \mathbf{U}_i = 0$$

Differentiating with respect to w and substituting the expression for $\mathbf{L}'_i(w)$ from above gives

$$\left[\mathbf{C}'_i(w) - \frac{d_i \mathbf{U}_i}{h_i} \right] \cdot \mathbf{U}_i = 0$$

Then, since $\mathbf{U}_i \cdot \mathbf{U}_i = 1$, we get

$$\mathbf{C}'_i(w) \cdot \mathbf{U}_i = \frac{d_i}{h_i}$$

When $w = w_i$, we have $\mathbf{C}'_i(w_i) \cdot \mathbf{U}_i = \|\mathbf{C}'_i(w_i)\| \cos \alpha_i$, so

$$\|\mathbf{C}'_i(w_i)\| = \frac{d_i}{h_i \cos \alpha_i}$$

Doing the same sort of calculations on the icurve segment \mathbf{C}_{i-1} where $w_{i-1} \leq w \leq w_i$, we get

$$\mathbf{C}'_{i-1}(w) \cdot \mathbf{U}_{i-1} = \frac{d_{i-1}}{h_{i-1}}$$

and setting $w = w_i$ in this equation, we get

$$\|\mathbf{C}'_{i-1}(w_i)\| = \frac{d_{i-1}}{h_{i-1} \cos \beta_i}$$

To get C1 continuity at $w = w_i$, we need to have $\|\mathbf{C}'_{i-1}(w_i)\| = \|\mathbf{C}'_i(w_i)\|$, which implies that

$$\frac{d_{i-1}}{h_{i-1} \cos \beta_i} = \frac{d_i}{h_i \cos \alpha_i}$$

and hence

$$h_i = \frac{d_i \cos \beta_i}{d_{i-1} \cos \alpha_i} h_{i-1}$$

This is the form that's actually used in the Parasolid code. But $\cos \beta_i = (\mathbf{T}_i \cdot \mathbf{V}_{i-1})/d_{i-1}$ and $\cos \alpha_i = (\mathbf{T}_i \cdot \mathbf{V}_i)/d_i$, so this can also be written

$$h_i = \frac{d_i^2 (\mathbf{T}_i \cdot \mathbf{V}_{i-1})}{d_{i-1}^2 (\mathbf{T}_i \cdot \mathbf{V}_i)} h_{i-1} = \frac{(\mathbf{V}_i \cdot \mathbf{V}_i)(\mathbf{T}_i \cdot \mathbf{V}_{i-1})}{(\mathbf{V}_{i-1} \cdot \mathbf{V}_{i-1})(\mathbf{T}_i \cdot \mathbf{V}_i)} h_{i-1}$$

This is a very efficient computation since it involves no square roots or trigonometric functions.

The first parameter value w_0 and the first increment $h_0 = w_1 - w_0$ are arbitrary, but, for definiteness, their values are set using the `base_parameter` and `base_scale` properties of the chart, respectively. Once these are established, all other h_i and w_i values can be calculated recursively from the formula above.

The pseudocode to implement this is as follows:

```
// Calculates parameter values at chart points
// Input:
//   P -- array of chart points
//   T -- array of (unit) tangents at chart points
// Returns
//   Array of parameter values to be assigned to chart points
double[] ChartParameters(Position[] P, Vector[] T)
{
    int n = P.Length;

    double[] w = new double[n];      // parameter values at chart points
    double[] h = new double[n-1];    // parameter increments between chart points
    Vector[] V = new Vector[n-1];    // chord vectors
    double[] c2 = new double[n-1];   // chord lengths (squared)

    w[0] = base_parameter;
    V[0] = P[1] - P[0];
    d2[0] = V[0] * V[0];
    h[0] = base_scale;
    w[1] = w[0] + h[0];

    for (int i = 1 ; i < n-1 ; i++)
    {
        V[i] = P[i+1] - P[i];          // chord vector
        d2[i] = V[i] * V[i];           // squared length of chord V[i]
        double numer = d2[i]*(T[i] * V[i-1]);
        double denom = d2[i-1]*(T[i] * V[i]);
        h[i] = (numer/denom) * h[i-1];
        w[i+1] = w[i] + h[i];
    }

    return w;
}
```

This code is obviously very inefficient — several of the arrays we used are not really necessary. It is written to correspond closely with the mathematical description above, so the goal is clarity rather than efficiency.

Computing a Point & Tangent on an Intersection Curve

Now that the chart points are fully populated, we can describe the procedure for calculating a point and tangent at a given parameter value on our icurve.

Equations for the Point on the Intersection Curve

So, assume we have chart points $\mathbf{P}_0, \dots, \mathbf{P}_n$ where the point \mathbf{P}_i has curve parameter w_i and surface parameters (s_i, t_i) and (u_i, v_i) . We want to calculate a point on the curve at a given parameter value w which we assume to lie in the range $w_0 \leq w \leq w_n$. Therefore, we can find an index i such that $w_i \leq w \leq w_{i+1}$.

From section on Intersection Curve Basics we recall that the chord $\mathbf{P}_i\mathbf{P}_{i+1}$ has the equation

$$\mathbf{L}(w) = \frac{w_{i+1} - w}{w_{i+1} - w_i} \mathbf{P}_i + \frac{w - w_i}{w_{i+1} - w_i} \mathbf{P}_{i+1}$$

We construct the plane $\pi(w)$ that passes through the point $\mathbf{L}(w)$ and is perpendicular to the chord $\mathbf{P}_i\mathbf{P}_{i+1}$. A 3D point \mathbf{X} lies on this plane iff $(\mathbf{X} - \mathbf{L}(w)) \cdot (\mathbf{P}_{i+1} - \mathbf{P}_i) = 0$.

The point $\mathbf{C}(w)$ of the intersection curve is the intersection of the two surfaces \mathbf{A} and \mathbf{B} and the plane $\pi(w)$, as shown in Figure M.6

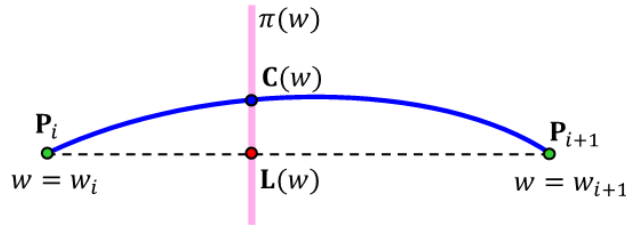


Figure M.6 — Intersection curve point

To compute the point $\mathbf{C}(w)$, we have to find parameter values s, t, u, v that satisfy the equations

$$\mathbf{A}(s, t) = \mathbf{B}(u, v)$$

$$(\mathbf{A}(s, t) - \mathbf{L}(w)) \cdot (\mathbf{P}_{i+1} - \mathbf{P}_i) = 0$$

The first equation says that we have two points (one on each surface) that are identical, and the second equation says that one (and hence both) of these points lies on the plane $\pi(w)$. If we write

$$f_1(s, t, u, v) = \mathbf{A}_x(s, t) - \mathbf{B}_x(u, v)$$

$$f_2(s, t, u, v) = \mathbf{A}_y(s, t) - \mathbf{B}_y(u, v)$$

$$f_3(s, t, u, v) = \mathbf{A}_z(s, t) - \mathbf{B}_z(u, v)$$

$$f_4(s, t, u, v) = (\mathbf{A}(s, t) - \mathbf{L}(w)) \cdot (\mathbf{P}_{i+1} - \mathbf{P}_i)$$

then our problem reduces to finding the common roots s, t, u, v of the four equations $f_i(u, v, s, t) = 0$ ($i = 1, 2, 3, 4$). Once we have done this, we can also obtain the icurve tangent at the parameter value w : it will be in the direction of the cross product of the two surface normals:

$$\left(\frac{\partial \mathbf{A}}{\partial s} \times \frac{\partial \mathbf{A}}{\partial t} \right) \times \left(\frac{\partial \mathbf{B}}{\partial u} \times \frac{\partial \mathbf{B}}{\partial v} \right)$$

The four equations above are non-linear, of course, so they will have to be solved by an iterative numerical method. Again, there is nothing special about the root finder used in Parasolid. Suitable functions can be

found in the Numerical Recipes book [7], in the GNU Scientific Library [8], or in numerous other places. Specifically, the function `newt` from the Numerical Recipes book has the required functionality.

There is no reason to fear that an iterative numerical procedure will deliver answers that are less accurate than a closed form formula. In fact, common closed-form formulas will deliver inaccurate answers if implemented poorly [10]. Accuracy depends on careful coding (avoiding loss of precision) rather than on the choice between numerical or analytical methods.

However, as in all numerical root-finding, the key is to find a good starting point. The recommended technique for doing this is described in the next section.

Estimating a Starting Point

To simplify notation, let's define $\mathbf{P} = \mathbf{P}_i$, $\mathbf{Q} = \mathbf{P}_{i+1}$, $\mathbf{U} = \mathbf{T}_i$, $\mathbf{V} = \mathbf{T}_{i+1}$, $\mathbf{K} = \mathbf{Q} - \mathbf{P}$ as displayed in Figure M.7

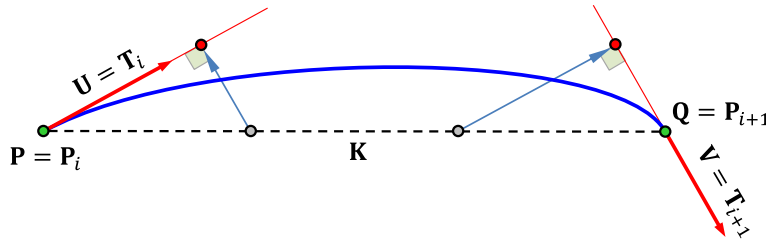


Figure M.7 — Estimating a starting point

We are going to construct a cubic Bezier curve that approximates the icurve and can be used to generate starting points for our iteration. The first and fourth poles of the Bezier curve will obviously be \mathbf{P} and \mathbf{Q} respectively. To get the second pole, we project the grey point $\mathbf{P} + \frac{1}{3}\mathbf{K}$ onto the tangent line at \mathbf{P} , as shown in the diagram. The result is the red point, which is $\mathbf{P} + \frac{1}{3}(\mathbf{K} \cdot \mathbf{U})\mathbf{U}$. Similarly, for the third pole, we use the point $\mathbf{Q} - \frac{1}{3}(\mathbf{K} \cdot \mathbf{V})\mathbf{V}$. So, in summary, our Bezier curve has poles, \mathbf{P} , $\mathbf{P} + \frac{1}{3}(\mathbf{K} \cdot \mathbf{U})\mathbf{U}$, $\mathbf{Q} - \frac{1}{3}(\mathbf{K} \cdot \mathbf{V})\mathbf{V}$, and \mathbf{Q} , so its equation is:

$$\mathbf{C}(r) = (1-r)^3 \mathbf{P} + 3r(1-r)^2 \left(\mathbf{P} + \frac{1}{3} (\mathbf{K} \cdot \mathbf{U})\mathbf{U} \right) + 3r^2 (1-r) \left(\mathbf{Q} - \frac{1}{3} (\mathbf{K} \cdot \mathbf{V})\mathbf{V} \right) + r^3 \mathbf{Q}$$

where, as before, r is the ratio

$$r = \frac{w - w_i}{w_{i+1} - w_i}$$

In fact, it is more convenient to express this cubic in Hermite form. If we define so-called blending functions h_0, h_1, k_0, k_1 by

$$h_0(t) = 1 - 3t^2 + 2t^3$$

$$h_1(t) = 3t^2 - 2t^3$$

$$k_0(t) = t - 2t^2 + t^3$$

$$k_1(t) = t^3 - t^2$$

Then the cubic curve can be written in the somewhat tidier form

$$\mathbf{C}(r) = h_0(r)\mathbf{P} + h_1(r)\mathbf{Q} + k_0(r)(\mathbf{K} \cdot \mathbf{U})\mathbf{U} + k_1(r)(\mathbf{K} \cdot \mathbf{V})\mathbf{V}$$

With either formula, it is easy to check that $\mathbf{C}(0) = \mathbf{P}$, $\mathbf{C}(1) = \mathbf{Q}$, and

$$\frac{d\mathbf{C}}{dr}(0) = (\mathbf{K} \cdot \mathbf{U})\mathbf{U} \quad ; \quad \frac{d\mathbf{C}}{dr}(1) = (\mathbf{K} \cdot \mathbf{V})\mathbf{V}$$

The basic function for performing this cubic interpolation is as follows:

```
// Calculate a point on a Hermite cubic curve
// Input:
//   P0 -- start point of curve
//   P1 -- end point of curve
//   V0 -- first derivative vector at start point
//   V1 -- first derivative vector at end point
//   t -- parameter value at which to evaluate (0 <= t <= 1)
// Returns
//   Point on cubic curve that interpolates P, Q, U, V

static Position HermiteCubic(Point P0, Point P1, Vector V0, Vector V1, double t)
{
    double t2 = t*t;
    double t3 = t*t2;

    double h0 = 1 - 3*t2 + 2*t3;
    double h1 = 3*t2 - 2*t3;
    double k0 = t - 2*t2 + t3;
    double k1 = t3 - t2;

    return h0*P0 + h1*P1 + k0*V0 + k1*V1;
}
```

This function is used to compute an estimated point on an icurve as follows:

```
// Define variable names as in math notes above
Point P = chart[i].CurvePoint;    Vector U = chart[i+1].CurveTangent;
Point Q = chart[i].CurvePoint;    Vector V = chart[i+1].CurveTangent;

//Get parameter values. We assume that wi < w < wip1
double wi = chart[i].w;
double wip1 = chart[i+1].w;

// Compute the ratio r
double r = (w - wi)/(wip1 - wi);

// Chord and derivative vectors
Vector K = Q - P;
Vector KUU = (K*U)*U;
Vector KVV = (K*V)*V;

// Calculate point Cr =C(r) on cubic approximation
Position Cr = HermiteCubic(P, Q, KUU, KVV, r);
```

From this point $\mathbf{C}(r)$, we can obtain surface parameter values (s, t) and (u, v) using the techniques described in section Getting Surface Parameter Values. We step along tangent planes to get rough estimates, and then refine these estimates by iterative numerical methods. If $r < 0.5$, we use the tangent plane at \mathbf{P}_i , and if $r \geq 0.5$, we use the tangent plane at \mathbf{P}_{i+1} .

Then we use these (s, t) and (u, v) values as the starting point in an iterative numerical root finder, as described in section L.4.3.1.

M.4.1 Approximating an Intersection Curve

The approximation process described here is completely generic — it can be applied to any curve for which points and first derivative vectors can be computed. The procedure has no relationship to JT/XT icurves, specifically.

The basic idea is to start with cubic segments constructed from set of points on the curve (the chart points, in the case of an icurve), and then add intermediate points to split these cubic segments as needed. The splitting is continued until the cubic segments are close enough to the original icurve. An implementation of this idea is provided in the section on Approximation Code.

Fitting Hermite Cubics

At the i -th chart point, we know the location \mathbf{P}_i , the unit tangent vector \mathbf{T}_i , and the parameter value w_i . As in section L.4.2.4, let $\mathbf{V}_i = \mathbf{P}_{i+1} - \mathbf{P}_i$ denote the chord vector, and let $h_i = w_{i+1} - w_i$. Then, from the discussion in section L.4.3, we know that the icurve's first derivative vector at \mathbf{P}_i is given by

$$\frac{d\mathbf{C}}{dw}(w = w_i) = \frac{\|\mathbf{V}_i\|}{h_i \cos \alpha_i} \mathbf{T}_i = \frac{(\mathbf{V}_i \cdot \mathbf{V}_i)}{h_i(\mathbf{V}_i \cdot \mathbf{T}_i)} \mathbf{T}_i$$

Similarly, at the other end of the segment,

$$\frac{d\mathbf{C}}{dw}(w = w_{i+1}) = \frac{(\mathbf{V}_i \cdot \mathbf{V}_i)}{h_{i+1}(\mathbf{V}_i \cdot \mathbf{T}_{i+1})} \mathbf{T}_{i+1}$$

Note that this last equation holds true even if we have not made the special choices for the w_i values described in to make the icurve C1 continuous.

We can now use this data to construct a Hermite cubic approximation \mathbf{H} of the icurve on the interval $w_i \leq w \leq w_{i+1}$. The relevant Hermite cubic construction is given in the function HermiteCubic.

Next we check to see if the Hermite cubic segment \mathbf{H} is sufficiently close to the icurve \mathbf{C} throughout the interval $w_i \leq w \leq w_{i+1}$; details of the method for doing this are described in the next section. If \mathbf{H} and \mathbf{C} are sufficiently close, then we're done; if not, we compute a point and tangent at some interior location in the interval $\bar{w} \in [w_i, w_{i+1}]$, and we treat the two intervals $[w_i, \bar{w}]$ and $[\bar{w}, w_{i+1}]$ as described above.

Continuing this testing and splitting process recursively, we eventually obtain a sequence of cubic segments that form an adequate approximation of the icurve (to within the caller-specified tolerance). Then we use well-known techniques to join these cubic segments together to get a cubic b-spline, as explained in the section on Constructing a Cubic B-spline found below.

Estimating Approximation Error

The key to the process described in the previous section is the ability to measure the error between the original icurve \mathbf{C} and a cubic approximation \mathbf{H} on some interval $[w_i, w_{i+1}]$. If the approximation error is larger than some caller-specified value ε , then we have to split the segment into two and approximate each of the two pieces separately. There are many ways to measure the approximation error, and the choice we make will be a trade-off between certainty and performance.

If we were being rigorous, we would calculate either the "parametric" error

$$\text{error} = \max_{w_i \leq w \leq w_{i+1}} \|\mathbf{C}(w) - \mathbf{H}(w)\|$$

or perhaps even the "geometric" (Hausdorff) error

$$\text{error} = \max_{w_i \leq s \leq w_{i+1}} \min_{w_i \leq t \leq w_{i+1}} \|\mathbf{C}(s) - \mathbf{H}(t)\|$$

However, both of these are very difficult to calculate, especially the geometric error, so a simpler estimate is needed. If our estimate is overly pessimistic, we may generate more cubic segments than we really need, but this is not a great disaster. A more realistic approach is to choose some n sample locations $\bar{w}_1, \dots, \bar{w}_n$ in $[w_i, w_{i+1}]$ and check the error only at these points. In other words, our error estimate is:

$$\text{error} = \max_{1 \leq i \leq n} \|\mathbf{C}(\bar{w}_i) - \mathbf{H}(\bar{w}_i)\|$$

Using larger values of n will reduce performance but will provide a more reliable approximation, of course. The simplest approach is to choose $n = 1$, which means that we simply use one sample location at $\bar{w} = \frac{1}{2}(w_i + w_{i+1})$. This is especially fast because the value of $\mathbf{C}(w)$ used in measuring the error can be re-used if we find that we need to split the segment into two. Our prior experiences (and perhaps some

theorems in approximation theory) tell us that the error when approximating by a Hermite cubic typically looks like Figure M.8

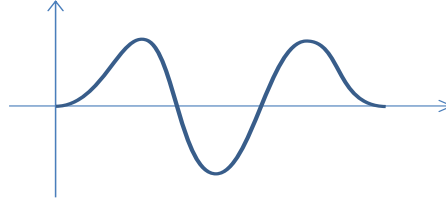


Figure M.8 — Hermite cubic curve error approximation

and this suggests checking the error at the values $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$. This test is implemented in the function MeasureError in the section on Approximation Code.

Constructing a Cubic B-spline

Suppose that for $i = 0, 1, \dots, n$ we have a point \mathbf{P}_i , a derivative vector \mathbf{V}_i , and a parameter value w_i , and we wish to interpolate this data with a cubic b-spline. In other words, we want to construct a cubic b-spline \mathbf{S} such that $\mathbf{S}(w_i) = \mathbf{P}_i$ and $\mathbf{S}'(w_i) = \mathbf{V}_i$ for $i = 0, 1, \dots, n$.

Geometrically, the construction is very simple, as shown Figure M.9

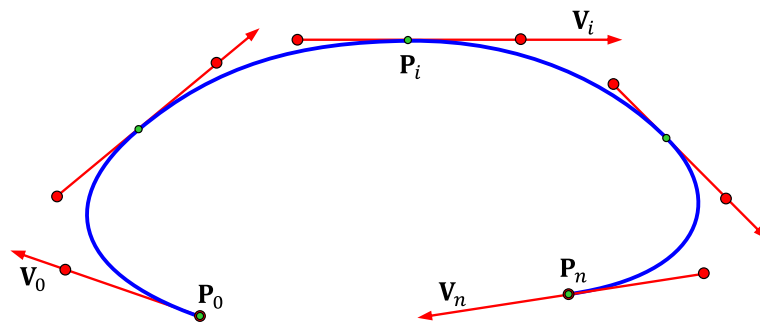


Figure M.9 — Cubic B-spline construction

The small green points are the original points \mathbf{P}_i , and the red points are the poles (control points) of the cubic b-spline. The construction algorithm is as follows:

- I. The first pole is \mathbf{P}_0
- II. The second pole is at $\mathbf{P}_0 + \frac{1}{3}(w_1 - w_0)\mathbf{V}_0$
- III. Near the i -th point \mathbf{P}_i , there are two poles at $\mathbf{P}_i - \frac{1}{3}(w_i - w_{i-1})\mathbf{V}_i$ and $\mathbf{P}_i + \frac{1}{3}(w_{i+1} - w_i)\mathbf{V}_i$
- IV. The last-but-one pole is at $\mathbf{P}_n - \frac{1}{3}(w_n - w_{n-1})\mathbf{V}_n$
- V. The last pole is at \mathbf{P}_n

The spline's knot sequence is also easy to construct. It is

$$w_0, w_0, w_0, w_0, w_1, w_1, w_2, w_2, \dots, w_i, w_i, \dots, w_{n-1}, w_{n-1}, w_n, w_n, w_n, w_n$$

As we can see, each interior knot has multiplicity =2, and the end knots have multiplicity =4. This technique for creating a spline is implemented in a Spline constructor in the Approximating an Intersection Curve description of this document.

M.4.1.1 Approximation Code

This section provides a complete implementation of the type of approximation function described in section above. The function is completely generic and can be applied to any curve on which we can calculate points and first-derivative vectors.

As before, the code emphasizes clarity rather than efficiency.

The approximation function is `CubicApproximation.Approximate`. The `Main` function calls this function to construct an approximation of a curve described by an evaluator function `IntEval`. This is just a “fake” evaluator function to illustrate the process. In the usage that is of immediate interest to us here, the real evaluator function would actually return points and derivatives of an `icurve`, using the methods described in section L.4.2.3. The approximation process is begun from a sequence of `Point/Derivative` quantities, which would be read from the chart of the `icurve`.

The code uses *Vector* and *Position* classes with obvious properties, as described in section L.3. You have to provide these classes in order for the code to work.

The code is as follows:

```
using System.Collections.Generic;          // For List class

public class MyProgram
{
    static void Main()
    {
        // Data to be passed to the curve evaluator function (cylinder radii, in this case)
        double a = 150;
        double b = 200;
        double[] data = { a, b };

        // Evaluator function for a cylinder/cylinder intersection curve.
        CurveEvaluator eval = IntEval;

        // Get initial points to start approximation process
        double pi = System.Math.PI;
        double t0 = 0;           CurvePoint pv0 = eval(data, t0);
        double t1 = pi/4;        CurvePoint pv1 = eval(data, t1);
        double t2 = pi/2;        CurvePoint pv2 = eval(data, t2);
        CurvePoint[] initPoints = { pv0, pv1, pv2 };

        // Define the desired approximation tolerance
        double tol = 0.0015;

        // Calculate a cubic spline approximation
        Spline approx = CubicApproximation.Approximate(eval, data, initPoints, tol);

        // Write out spline data to console
        approx.Write();
    }

    /// <summary>Sample evaluator function -- for an intersection curve</summary>
    private static CurvePoint IntEval(object data, double t)
    {
        double[] ab = (double[])data;
        double a = ab[0];      // Smaller radius; cylinder  $x^2 + y^2 = a^2$ 
        double b = ab[1];      // Larger radius; cylinder  $y^2 + z^2 = b^2$ 

        double cost = System.Math.Cos(t);
        double sint = System.Math.Sin(t);

        double x = a*cost;
        double y = a*sint;
        double z = System.Math.Sqrt(b*b - y*y);
        Position pt = new Position(x, y, z);

        double dx = -a*sint;
        double dy = a*cost;
```

```

        double dz = -(a*a*cost*sint) / System.Math.Sqrt(b*b - a*a*sint*sint);
        Vector deriv = new Vector(dx, dy, dz);

        return new CurvePoint(pt, deriv, t);
    }
}

/// <summary>Provides functions for approximating a given curve by a cubic
spline</summary>
public class CubicApproximation
{
    /// <summary>
    /// Constructs a cubic b-spline approximation of a curve, starting from initial
    CurvePoint data
    /// </summary>
    /// <param name="eval">Evaluator function to calculate point/derivative on curve to be
    approximated</param>
    /// <param name="data">Data to be passed to the evaluator function</param>
    /// <param name="initPoints">Initial list of CurvePoint objects to start
    approximation</param>
    /// <param name="tol">The tolerance for the approximation process</param>
    /// <returns>A cubic b-spline approximating the given curve to within the given
    tolerance</returns>
    /// <remarks>
    /// This function is suitable for approximating a JT/XT icurve. The chart points of the
    icurve
    /// provide the initial list of CurvePoint items that this function receives.
    /// </remarks>
    public static Spline Approximate(CurveEvaluator eval, object data, CurvePoint[]
    initPoints, double tol)
    {
        // The list of points that will be used to construct the spline approximation
        List<CurvePoint> outPoints = new List<CurvePoint>();

        // Add the first point to the list
        outPoints.Add(initPoints[0]);

        // Cycle through inter-point intervals, adding split points
        for (int i = 0 ; i <= initPoints.Length - 2 ; i++)
        {
            CurvePoint[] splitPoints = TestAndSplit(eval, data, tol, initPoints[i],
            initPoints[i+1]);
            outPoints.AddRange(splitPoints);
        }

        // Create a cubic spline from the CurvePoint data
        return new Spline(outPoints.ToArray());
    }

    /// <summary>Recursively tests/splits a Hermite cubic segment until approximation
    tolerance is met</summary>
    /// <param name="eval">Evaluator function to calculate point/derivative on curve to be
    approximated</param>
    /// <param name="data">Data to be passed to the evaluator function</param>
    /// <param name="tol">Tolerance to be used to test whether approximation is good
    enough</param>
    /// <param name="ends">The two ends of the Hermite segment to be tested</param>
    /// <returns>Array of CurvePoint items that give a good piecewise cubic
    approximation</returns>
    private static CurvePoint[] TestAndSplit(CurveEvaluator eval, object data, double tol,
    params CurvePoint[] ends)
    {
        // The list of CurvePoints that we will eventually output
        List<CurvePoint> outPoints = new List<CurvePoint>();

        CurvePoint pv0 = ends[0];    double t0 = pv0.T;
        CurvePoint pv1 = ends[1];    double t1 = pv1.T;

        double error = MeasureError(eval, data, ends);

        if (error < tol) // Success, so just add end-point to pointList
        {
            outPoints.Add(pv1);

```

```

    }
    else // Split segment and proceeds two halves recursively
    {
        double tmid = (t0 + t1) / 2;
        CurvePoint splitPoint = eval(data, tmid);
        CurvePoint[] newPoints1 = TestAndSplit(eval, data, tol, pv0, splitPoint);
        outPoints.AddRange(newPoints1);
        CurvePoint[] newPoints2 = TestAndSplit(eval, data, tol, splitPoint, pv1);
        outPoints.AddRange(newPoints2);
    }

    return outPoints.ToArray();
}

/// <summary>Measures the error between a curve and a Hermite cubic
approximation</summary>
/// <param name="eval">Evaluator function to calculate point/derivative on curve to be
approximated</param>
/// <param name="data">Data to be passed to the evaluator function</param>
/// <param name="ends">The two ends of the Hermite segment to be tested</param>
/// <returns>An estimate of the error (deviation) between the curve and the
cubic</returns>
/// <remarks>
/// The error estimate is quite simplistic. Much more accurate estimates could be
computed,
/// but this would also be much slower.
/// </remarks>
private static double MeasureError(CurveEvaluator eval, object data, params
CurvePoint[] ends)
{
    Position P0 = ends[0].Point;    Vector V0 = ends[0].Derivative;    double t0 =
ends[0].T;
    Position P1 = ends[1].Point;    Vector V1 = ends[1].Derivative;    double t1 =
ends[1].T;

    double c = t1 - t0;
    double t;
    Position curvePoint;
    Position cubicPoint;
    double error, error1, error2;

    t = t0 + c/3;
    curvePoint = eval(data, t).Point;
    cubicPoint = HermiteCubic(P0, P1, V0, V1, t0, t1, t);
    error = Position.Distance(curvePoint, cubicPoint);

    t = t0 + c/2;
    curvePoint = eval(data, t).Point;
    cubicPoint = HermiteCubic(P0, P1, V0, V1, t0, t1, t);
    error1 = Position.Distance(curvePoint, cubicPoint);
    error = System.Math.Max(error, error1);

    t = t0 + 2*c/3;
    curvePoint = eval(data, t).Point;
    cubicPoint = HermiteCubic(P0, P1, V0, V1, t0, t1, t);
    error2 = Position.Distance(curvePoint, cubicPoint);
    error = System.Math.Max(error, error2);

    return error;
}

/// <summary>Calculate a point on a Hermite cubic curve</summary>
/// <param name="P0">Start point</param>
/// <param name="P1">End point</param>
/// <param name="V0">Start first derivative</param>
/// <param name="V1">End first derivative</param>
/// <param name="t0">Start parameter</param>
/// <param name="t1">End parameter</param>
/// <param name="t">Parameter value at which to evaluate</param>
/// <returns>Point on curve</returns>
private static Position HermiteCubic(Position P0, Position P1, Vector V0, Vector V1, double
t0, double t1, double t)
{

```

```

        double c = t1 - t0;
        double u = (t - t0)/c;
        double u2 = u*u;
        double u3 = u*u2;

        double h0 = 1 - 3*u2 + 2*u3;
        double h1 = 1 - h0;
        double k0 = u - 2*u2 + u3;
        double k1 = u3 - u2;

        return h0*P0 + h1*P1 + (k0*c)*V0 + (k1*c)*V1;
    }
}

/// <summary>Represents a location on a curve</summary>
public class CurvePoint
{
    /// <summary>Point location</summary>
    public Position Point { get; set; }

    /// <summary>Derivative vector</summary>
    public Vector Derivative { get; set; }

    /// <summary>Parameter value</summary>
    public double T { get; set; }

    /// <summary>Constructor</summary>
    /// <param name="point">Point</param>
    /// <param name="deriv">Derivative vector</param>
    /// <param name="t">Parameter value</param>
    public CurvePoint(Position point, Vector deriv, double t)
    {
        this.Point = point;
        this.Derivative = deriv;
        this.T = t;
    }
}

/// <summary>Represents a polynomial b-spline</summary>
public class Spline
{
    /// <summary>The poles (control points) of the spline</summary>
    public Position[] Poles { get; set; }

    /// <summary>The knots of the spline</summary>
    public double[] Knots { get; set; }

    /// <summary>Constructs a cubic spline from an array of CurvePoint objects</summary>
    /// <param name="points">The Hermite points</param>
    /// <remarks>
    /// The cubic spline interpolates the point and derivative values stored in the
    CurvePoint array.
    /// </remarks>
    public Spline(CurvePoint[] points)
    {
        int npts = points.Length;

        List<double> knotList = new List<double>();
        List<Position> poleList = new List<Position>();

        Position P;
        Vector V;
        double h, k;

        // Initial knot has multiplicity = 4
        for (int i = 1; i <= 4; i++) knotList.Add(points[0].T);

        // Construct first two poles
        P = points[0].Point;
        V = points[0].Derivative;
        k = points[1].T - points[0].T;
        poleList.Add(P);
        poleList.Add(P + k*V/3);
    }
}

```

```

//Cycle through interior knots
for (int i = 1; i < npts - 1; i++)
{
    P = points[i].Point;
    V = points[i].Derivative;
    h = points[i].T - points[i - 1].T;
    k = points[i + 1].T - points[i].T;
    poleList.Add(P - h*V/3);
    poleList.Add(P + k*V/3);
    knotList.Add(points[i].T);
    knotList.Add(points[i].T);
}

// Construct last two poles
P = points[npts - 1].Point;
V = points[npts - 1].Derivative;
h = points[npts - 1].T - points[npts - 2].T;
poleList.Add(P - h*V/3);
poleList.Add(P);

//Last knot has multiplicity = 4
for (int i = 1; i <= 4; i++) knotList.Add(points[npts - 1].T);

this.Knots = knotList.ToArray();
this.Poles = poleList.ToArray();
}

/// <summary>Write out spline knots and poles to the console</summary>
public void Write()
{
    System.Console.WriteLine("Knot values");
    System.Console.WriteLine("=====");

    for (int i = 0; i < this.Knots.Length; i++)
    {
        System.Console.WriteLine("t[{0}] = {1}", i, this.Knots[i].ToString("F8"));
    }

    System.Console.WriteLine("");
    System.Console.WriteLine("Poles (Control Points)");
    System.Console.WriteLine("=====");

    for (int i = 0; i < this.Poles.Length; i++)
    {
        System.Console.Write("p[{0}] = ( ", i);
        System.Console.Write(this.Poles[i].X.ToString("F8") + " , ");
        System.Console.Write(this.Poles[i].Y.ToString("F8") + " , ");
        System.Console.Write(this.Poles[i].Z.ToString("F8") + " )\n");
    }

    System.Console.ReadLine();
}

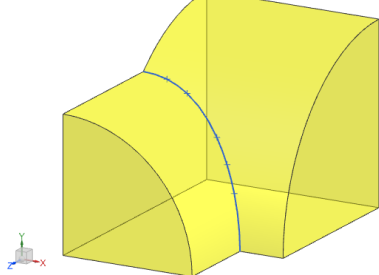
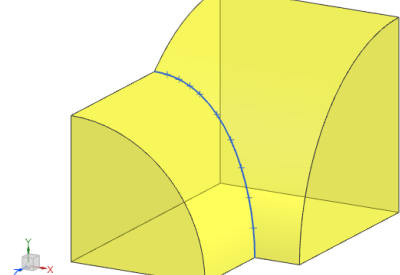
}

/// <summary>
/// An evaluator function that calculates position and first derivative at a parameter
value on a curve
/// </summary>
/// <param name="data">Data to be used in evaluation</param>
/// <param name="t">Parameter value at which to evaluate</param>
/// <returns>PointVector containing the calculated point and first derivative</returns>
/// <remarks>
/// You write a CurveEvaluator function to provide information
/// about a curve that you're approximating with a spline.
/// </remarks>
public delegate CurvePoint CurveEvaluator(object data, double t);

```


Running the code with tolerance values of 0.02 and 0.0015 produces the results in Table M.2

Table M.2 — Sample code results for tolerance values of 0.02 and 0.0015

| Tolerance = 0.02 | Tolerance = 0.0015 |
|---|--|
|  |  |
| <p>Knot values =====</p> <pre> t[0] = 0.00000000 t[1] = 0.00000000 t[2] = 0.00000000 t[3] = 0.00000000 t[4] = 0.39269908 t[5] = 0.39269908 t[6] = 0.58904862 t[7] = 0.58904862 t[8] = 0.78539816 t[9] = 0.78539816 t[10] = 1.17809725 t[11] = 1.17809725 t[12] = 1.37444679 t[13] = 1.37444679 t[14] = 1.57079633 t[15] = 1.57079633 t[16] = 1.57079633 t[17] = 1.57079633 </pre> <p>Poles (Control Points) =====</p> <pre> p[0] = (150.00000000 , 0.00000000 , 200.00000000) p[1] = (150.00000000 , 19.63495408 , 200.00000000) p[2] = (146.09590150 , 39.26218265 , 197.02054165) p[3] = (134.82494406 , 66.47268096 , 188.86777357) p[4] = (130.17473985 , 75.17260112 , 185.55245365) p[5] = (119.26614384 , 91.49846878 , 178.06926525) p[6] = (113.00802177 , 99.12401259 , 173.90077364) p[7] = (92.18200800 , 119.95002636 , 160.87320146) p[8] = (75.54284706 , 131.06795825 , 151.42586520) p[9] = (48.33234875 , 142.33891569 , 140.59439414) p[10] = (38.89238528 , 145.20249730 , 137.56536054) p[11] = (19.63471133 , 149.03308682 , 133.40589446) p[12] = (9.81747704 , 150.00000000 , 132.28756555) p[13] = (0.00000000 , 150.00000000 , 132.28756555) </pre> | <p>Knot values =====</p> <pre> t[0] = 0.00000000 t[1] = 0.00000000 t[2] = 0.00000000 t[3] = 0.00000000 t[4] = 0.19634954 t[5] = 0.19634954 t[6] = 0.39269908 t[7] = 0.39269908 t[8] = 0.58904862 t[9] = 0.58904862 t[10] = 0.78539816 t[11] = 0.78539816 t[12] = 0.98174770 t[13] = 0.98174770 t[14] = 1.17809725 t[15] = 1.17809725 t[16] = 1.27627202 t[17] = 1.27627202 t[18] = 1.37444679 t[19] = 1.37444679 t[20] = 1.47262156 t[21] = 1.47262156 t[22] = 1.57079633 t[23] = 1.57079633 t[24] = 1.57079633 t[25] = 1.57079633 </pre> <p>Poles (Control Points) =====</p> <pre> p[0] = (150.00000000 , 0.00000000 , 200.00000000) p[1] = (150.00000000 , 9.81747704 , 200.00000000) p[2] = (149.03308682 , 19.63471133 , 199.27172642) p[3] = (145.20249730 , 38.89238528 , 196.42333163) p[4] = (142.33891569 , 48.33234875 , 194.30295229) p[5] = (134.82494406 , 66.47268096 , 188.86777357) p[6] = (130.17473985 , 75.17260112 , 185.55245365) p[7] = (119.26614384 , 91.49846878 , 178.06926525) p[8] = (113.00802177 , 99.12401259 , 173.90077364) p[9] = (99.12401259 , 113.00802177 , 165.21572552) </pre> |

```

p[10] = ( 91.49846878 , 119.26614384 ,
160.69930611 )
p[11] = ( 75.17260112 , 130.17473985 ,
151.99742483 )
p[12] = ( 66.47268096 , 134.82494406 ,
147.81537485 )
p[13] = ( 52.86743180 , 140.46042278 ,
142.39963932 )
p[14] = ( 48.24007148 , 142.11611878 ,
140.73804072 )
p[15] = ( 38.84533170 , 144.96598194 ,
137.80076707 )
p[16] = ( 34.07796679 , 146.16014468 ,
136.52549402 )
p[17] = ( 24.44912982 , 148.07543944 ,
134.44576098 )
p[18] = ( 19.58767265 , 148.79656849 ,
133.64169964 )
p[19] = ( 9.81746945 , 149.75884951 ,
132.56247459 )
p[20] = ( 4.90873852 , 150.00000000 ,
132.28756555 )
p[21] = ( 0.00000000 , 150.00000000 ,
132.28756555 )

```

In some systems (like NX), a b-spline knot sequence is expected to start with a value of 0, and end with a value of 1. To obtain a knot sequence of this form, you can just divide each of the above knots by 1.57079633. This will not change the shape of the curve.

M.5 Rolling-Ball Blend Surface

Computing a Point on a Blend Surface

Conceptually, a blend surface is the envelope of a spherical ball that is rolling across two base surfaces, staying in contact with both of them, as shown in Figure M.10

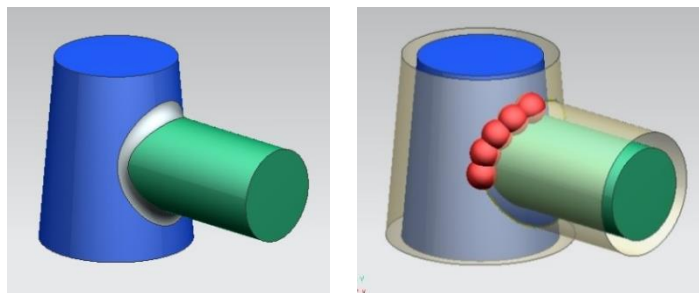


Figure M.10 — Blend surface as a spherical ball

A more detailed depiction of the construction is shown in the Figure M.11

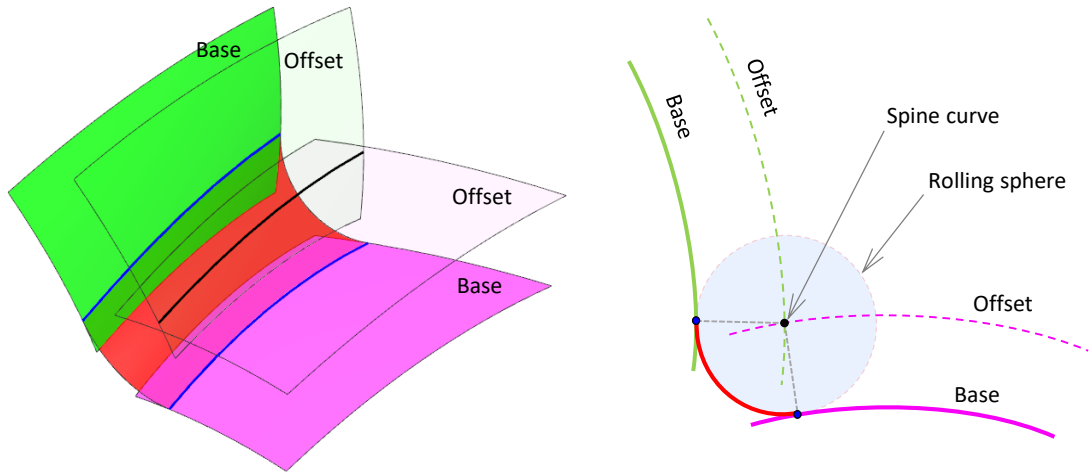


Figure M.11 — Detailed view of a blend surface

The curves shown in blue are the contact curves, where the rolling ball touches the base surfaces. Equivalently, we can think of the ball moving so that its center lies on a “spine” curve that is the intersection of two offset surfaces.

Whenever possible, simple analytic surfaces are used to perform blending operations, rather than using blend surfaces. So, many blends are modeled using cylindrical, toroidal or spherical surfaces. At the other extreme, very complex blends (for example varying radius ones, or ones with non-circular cross sections) are modeled using b-spline surfaces.

Stored Data

The stored data for a blend surface provided in Table M.3

Table M.3 — Blend surface data

| Field name | Data type | Description |
|--------------|-------------|--|
| type | char | Type of blend: ‘R’ or ‘E’ (see below) |
| surface | pointer[2] | Base surfaces (adjacent to original edge) |
| spine | pointer | Spine curve of the blend (locus of center of rolling ball) |
| range | double[2] | Offset distances to be applied to the base surfaces |
| thumb_weight | double[2] | Always [1,1] |
| boundary | pointer0[2] | Always [0, 0] |
| start | pointer0 | Start LIMIT in certain degenerate cases |
| end | pointer0 | End LIMIT in certain degenerate cases |

The thumb-weight and boundary fields are obsolete, and can be ignored.

The two entries in the range array always have equal magnitudes, and this common magnitude is the radius of the blend surface.

Surface Equation

The equation of a rolling-ball blend surface is:

$$\mathbf{S}(u, v) = \mathbf{C}(u) + r \cos(v\alpha(u)) \mathbf{X}(u) + r \sin(v\alpha(u)) \mathbf{Y}(u)$$

where

- I. $\mathbf{C}(u)$ is the spine curve

- II. r is the blend radius
- III. $\mathbf{X}(u)$ and $\mathbf{Y}(u)$ are unit vectors that are perpendicular to the tangent vector $\mathbf{C}'(u)$, and to each other. $\mathbf{X}(u)$ is in the direction $\mathbf{S}(u, 0) - \mathbf{C}(u)$.
- IV. $\alpha(u)$ is the angle subtended by points on the boundary curves at the spine

\mathbf{X} , \mathbf{Y} and α are expressed as functions of u , since their values change with u .

We note the following basic facts that are apparent from the parametric equation:

- V. For all u and v , we have $\|\mathbf{S}(u, v) - \mathbf{C}(u)\| = r$
- VI. Setting $v = 0$, we get $\mathbf{S}(u, 0) = \mathbf{C}(u) + r\mathbf{X}(u)$, which is a curve lying on the first base surface
- VII. Setting $v = 1$, we get a curve $\mathbf{S}(u, 1)$ lying on the second base surface
- VIII. If we fix u , we get a circular arc of radius r , with center at the point $\mathbf{C}(u)$, lying in the plane of the two vectors $\mathbf{X}(u)$ and $\mathbf{Y}(u)$

Figure M.12 illustrates the situation:

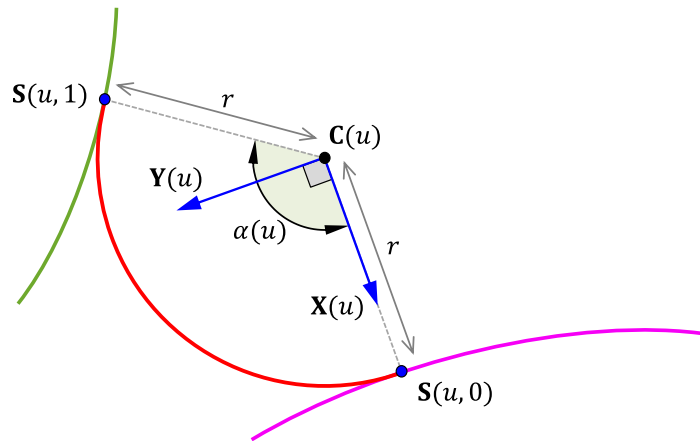


Figure M.12 — Rolling ball surface equation parameters

Transmit files can contain blends of the following types:

Type = 'R': a rolling ball blend

Type = 'E': a cliff edge blend

For rolling ball blends, the spine curve will be the intersection of the two surfaces obtained by offsetting the supporting surfaces by an amount given by the respective entry in `range[]`. Note that the offsets to be applied may be positive or negative, and that the sense of the surface is significant; therefore the offset vector is the natural unit surface normal, times the range, times -1 if the sense is negative.

For cliff edge blends, one of the surfaces will be a `blended_edge` with a range of $[0,0]$; its spine will be the cliff edge curve, and its supporting surfaces will be the surfaces of the faces adjacent to the cliff edge. Its type will be R.

The limit fields will only be non-null if the spine curve is periodic but the edge curve being blended has terminators – for example if the spine is elliptical but the blend degenerates. In this case the two LIMIT nodes, of type 'L', determine the extent of the spine.

Calculating a Point on a Blend Surface

The computation of a point on a blend surface is very similar to the computation of a point on an intersection curve, as described in section L.4.3 above.

Suppose we have two base surfaces **A** and **B** with parameterizations $(p, q) \mapsto \mathbf{A}(p, q)$ and $(s, t) \mapsto \mathbf{B}(s, t)$, and we want to calculate a point $\mathbf{S}(u, v)$ on the blend surface.

Let \mathbf{N}_A and \mathbf{N}_B denote the unit normal functions of the surfaces **A** and **B** respectively:

$$\mathbf{N}_A = \frac{\frac{\partial \mathbf{A}}{\partial p} \times \frac{\partial \mathbf{A}}{\partial q}}{\left\| \frac{\partial \mathbf{A}}{\partial p} \times \frac{\partial \mathbf{A}}{\partial q} \right\|} ; \quad \mathbf{N}_B = \frac{\frac{\partial \mathbf{B}}{\partial s} \times \frac{\partial \mathbf{B}}{\partial t}}{\left\| \frac{\partial \mathbf{B}}{\partial s} \times \frac{\partial \mathbf{B}}{\partial t} \right\|}$$

Then we can form the two offset surfaces:

$$\bar{\mathbf{A}}(p, q) = \mathbf{A}(p, q) + r\mathbf{N}_A(p, q)$$

$$\bar{\mathbf{B}}(s, t) = \mathbf{B}(s, t) + r\mathbf{N}_B(s, t)$$

Assume for the time being that the spine curve **C** is an icurve (this is usually the case). If we use the techniques described in section L.4.3 to calculate the point $\mathbf{C}(u)$, we will obtain surface parameter values p, q, s, t such that

$$\bar{\mathbf{A}}(p, q) = \bar{\mathbf{B}}(s, t) = \mathbf{C}(u)$$

Although the parameter values p, q, s, t came from a computation on offset surfaces, they can also be used to calculate points on the original surfaces **A** and **B**, too, which will define the vectors $\mathbf{X}(u)$ and $\mathbf{Y}(u)$. The equation immediately above tells us that

$$\mathbf{A}(p, q) + r\mathbf{N}_A(p, q) = \mathbf{C}(u)$$

$$\mathbf{B}(s, t) + r\mathbf{N}_B(s, t) = \mathbf{C}(u)$$

So the point $\mathbf{A}(p, q)$ is the foot of the normal from the point $\mathbf{C}(u)$ to the surface **A**. Similarly, $\mathbf{B}(s, t)$ is the foot of the normal from the point $\mathbf{C}(u)$ to the surface **B**. The vectors $\mathbf{A}(p, q) - \mathbf{C}(u)$ and $\mathbf{B}(s, t) - \mathbf{C}(u)$ are perpendicular to the curve **C**. Then we set

$$\mathbf{X}(u) = \frac{\mathbf{A}(p, q) - \mathbf{C}(u)}{\|\mathbf{A}(p, q) - \mathbf{C}(u)\|} ; \quad \mathbf{W}(u) = \frac{\mathbf{B}(s, t) - \mathbf{C}(u)}{\|\mathbf{B}(s, t) - \mathbf{C}(u)\|}$$

$$\mathbf{Y}(u) = \frac{\mathbf{X}(u) \times (\mathbf{X}(u) \times \mathbf{W}(u))}{\|\mathbf{X}(u) \times (\mathbf{X}(u) \times \mathbf{W}(u))\|}$$

so $\mathbf{X}(u)$ and $\mathbf{Y}(u)$ are orthogonal unit vectors that lie in a plane perpendicular to the curve $\mathbf{C}(u)$. A diagrammatic representation is shown in Figure M.13.

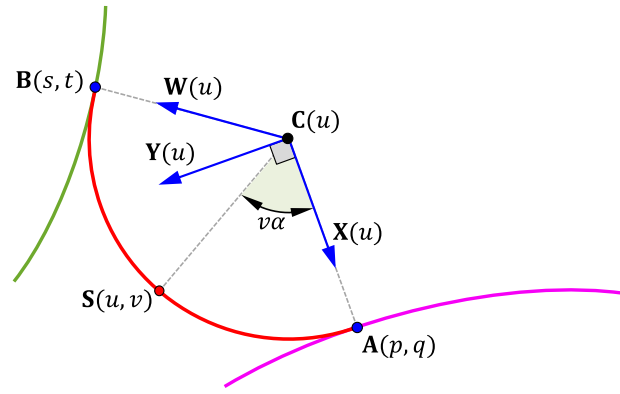


Figure M.13 — Additional rolling ball surface equation parameters

We let $\alpha(u)$ be the angle between $\mathbf{X}(u)$ and $\mathbf{W}(u)$. Then the point $\mathbf{S}(u, v)$ on the blend surface is:

$$\mathbf{S}(u, v) = \mathbf{C}(u) + r \cos(v\alpha(u)) \mathbf{X}(u) + r \sin(v\alpha(u)) \mathbf{Y}(u)$$

Alternatively, we know that $\mathbf{W}(u) = (\cos \alpha) \mathbf{X}(u) + (\sin \alpha) \mathbf{Y}(u)$. Dividing through by $\sin \alpha$, we get $\mathbf{Y}(u) = (\operatorname{cosec} \alpha) \mathbf{W}(u) - (\cot \alpha) \mathbf{X}(u)$. Substituting this into the formula above gives:

$$\mathbf{S}(u, v) = \mathbf{C}(u) + r(\cos v\alpha - \cot \alpha \sin v\alpha) \mathbf{X}(u) + r(\operatorname{cosec} \alpha \sin v\alpha) \mathbf{W}(u)$$

In fact, this is the formula that is actually used in the Parasolid code.

M.5.1 Blend Surface Pseudocode

We assume that we already have a function that computes surface parameter values corresponding to a given parameter value on an icurve, as described in the section Computing a Point & Tangent on an Intersection Curve

```
/// <summary>Calculates surface parameters at a location on an icurve</summary>
/// <param name="A">First surface evaluation function, (s,t) --> A(s,t)</param>
/// <param name="B">Second surface evaluation function (u,v) --> B(u,v)</param>
/// <param name="w">Parameter value on icurve, C</param>
/// <returns>Surface parameter values (s,t,u,v)</returns>
/// <remarks>
/// The surface parameter values (s,t,u,v) are such that
/// A(s,t) = B(u,v) = C(w)
/// </remarks>
static double[] ICurveParams(SurfaceFunction A, SurfaceFunction B, double w)
```

Also, we assume that we have functions to compute points on the offset surfaces

$\bar{\mathbf{A}}$ = offsetA and $\bar{\mathbf{B}}$ = offsetB. For example:

```
/// <summary>Compute point on offset surface OffsetA</summary>
/// <param name="u">Parameter value</param>
/// <param name="v">Parameter value</param>
/// <returns>Position on offset surface at parameter values (u,v)</returns>
public static Position OffsetA(double u, double v)
{
    Position P = surfaceA.Position(u, v);
    Vector N = surfaceA.UnitNormal(u, v);
    return P + d*N;
}
Then the code to compute a point on a blend surface is as follows:
/// <summary>Calculate a point on a blend surface at given parameter values
(u,v)</summary>
/// <param name="surfaceA">First surface</param>
/// <param name="surfaceB">Second surface</param>
/// <param name="r">Radius of blend surface</param>
/// <param name="u">Parameter value</param>
/// <param name="v">Parameter value</param>
/// <returns>Point S(u,v) on blend surface</returns>
```

```

public static Position Blend(Surface surfA, Surface surfB, double r, double u, double v)
{
    // Compute surface parameter values at point on blend spine,
    // which is the intersection curve of two offset surfaces
    double[] pqst = ICurveParams(OffsetA, OffsetB, u);
    double p = pqst[0];    double q = pqst[1];
    double s = pqst[2];    double t = pqst[3];

    // Compute point on icurve.
    Position Cu = OffsetA(r, p, q);

    // Compute radial vectors. Note that these are not unitized.
    Position Apq = surfA.Position(p,q);    Vector X = Apq - Cu;
    Position Bst = surfB.Position(s,t);    Vector W = Bst - Cu;

    // Angular calculations in v direction
    double denom = r*r;
    double cosA = (X*W) / denom;
    double sinA = Vector.Norm(Vector.Cross(X, W));
    double A = System.Math.Atan2(sinA, cosA);

    double cosvA = System.Math.Cos(v*A);
    double sinvA = System.Math.Sin(v*A);
    double cotA = cosA / sinA;
    double cosecA = 1 / sinA;

    // Final point on blend surface
    Position Suv = Cu + (cosvA - cotA*sinvA)*X + (cosecA*sinvA)*W;
    return Suv;
}

```

M.6 Approximating a Blend Surface

Approximation of a blend surface can be performed using an approach that's very similar to the spline approximation technique described in section L.4.4. The basic calculation is the construction of certain rational Bézier patches, as outlined in section L.5.2.1 below, which interpolate the circular cross-sections of the blend plus some derivatives. These Bézier patches can be assembled into a smooth NURBS surface.

The Basic Bézier Patch

The construction starts with the following data that can easily be obtained from a blend surface, as shown in Figure M.14:

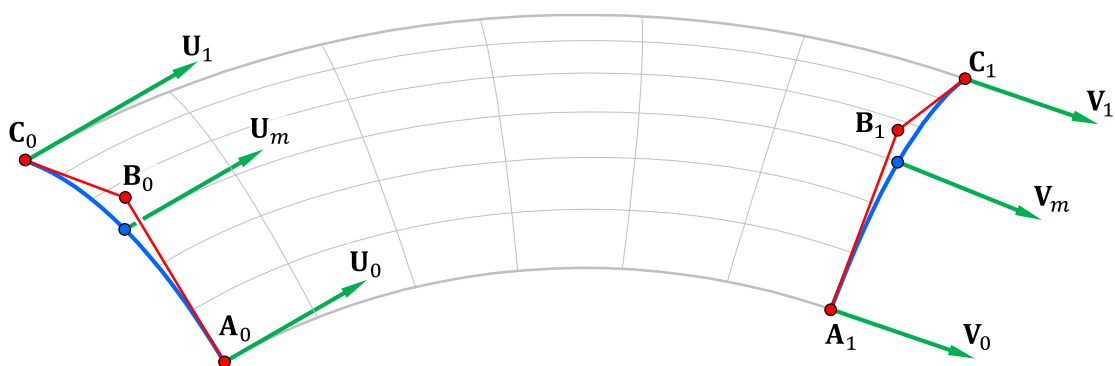


Figure M.14 — Blend surface data

We have:

- I. At one end, a circular arc, expressed as a rational quadratic Bézier curve with poles A_0 , B_0 , C_0 . The poles A_0 and C_0 have weights equal to one, and the pole B_0 has weight w_0 .

- II. Similarly, at the other end: a circular arc, expressed as a rational quadratic Bézier curve with poles $\mathbf{A}_1, \mathbf{B}_1, \mathbf{C}_1$. The poles \mathbf{A}_1 and \mathbf{C}_1 have weights of 1, and the pole \mathbf{B}_1 has weight w_1 .
- III. Three derivative vectors $\mathbf{U}_0, \mathbf{U}_m, \mathbf{U}_1$ at one end
- IV. Three derivative vectors $\mathbf{V}_0, \mathbf{V}_m, \mathbf{V}_1$ at the other end

From this data, we can construct a Bézier patch $\mathbf{S}(u, v)$, as shown in Figure M.15

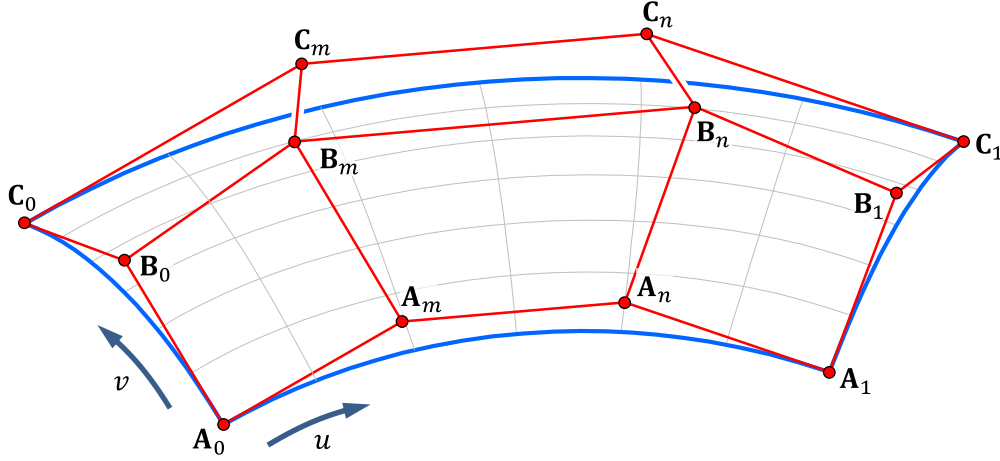


Figure M.15 — Bézier patch construction

The patch is rational, and has degree 3 in the u -direction, and degree 2 in the v -direction. Its poles are constructed as follows:

- V. The poles $\mathbf{A}_0, \mathbf{B}_0, \mathbf{C}_0$ and their weights are copied directly from the circular arc.
- VI. The poles $\mathbf{A}_1, \mathbf{B}_1, \mathbf{C}_1$ and their weights are copied directly from the other circular arc.
- VII. $\mathbf{A}_m = \mathbf{A}_0 + \frac{1}{3}\mathbf{U}_0$, and $\mathbf{C}_m = \mathbf{C}_0 + \frac{1}{3}\mathbf{U}_1$
- VIII. $\mathbf{B}_m = \mathbf{B}_0 + \frac{2}{3w_0}(\mathbf{U}_m - \frac{1}{4}\mathbf{U}_0 - \frac{1}{4}\mathbf{U}_1)$; weight = w_0
- IX. $\mathbf{A}_n = \mathbf{A}_1 - \frac{1}{3}\mathbf{V}_0$, and $\mathbf{C}_n = \mathbf{C}_1 - \frac{1}{3}\mathbf{V}_1$
- X. $\mathbf{B}_n = \mathbf{B}_1 - \frac{2}{3w_1}(\mathbf{V}_m - \frac{1}{4}\mathbf{V}_0 - \frac{1}{4}\mathbf{V}_1)$; weight = w_1

With this definition, it is straightforward to verify that

- XI. $v \mapsto \mathbf{S}(0, v)$ is a circular arc coinciding with the given one
- XII. $v \mapsto \mathbf{S}(1, v)$ is a circular arc coinciding with the other given one
- XIII. $\mathbf{S}^u(0, 0) = \mathbf{U}_0$, $\mathbf{S}^u(0, \frac{1}{2}) = \mathbf{U}_m$, and $\mathbf{S}^u(0, 1) = \mathbf{U}_1$
- XIV. $\mathbf{S}^u(1, 0) = \mathbf{V}_0$, $\mathbf{S}^u(1, \frac{1}{2}) = \mathbf{V}_m$, and $\mathbf{S}^u(1, 1) = \mathbf{V}_1$

So, the Bézier patch interpolates the two given circular arcs and the 6 given derivative vectors.

M.6.1 Approximation Code

Pseudocode for approximating a blend surface is as follows:

```
/// <summary>Create a b-surface approximation of a blend surface</summary>
```



```

/// <param name="blend">The blend surface to be aproximated</param>
/// <param name="nodesU">Parameter values (fractional) at which to interpolate</param>
/// <returns>The b-surface approximation</returns>
public static Bsurface ApproxBlend(BlendSurface blend, double[] nodesU)
{
    int n = nodesU.Length;

    Position[] A = new Position[2*n];    // Row of poles along edge v=0
    Position[] B = new Position[2*n];    // Middle row of poles
    Position[] C = new Position[2*n];    // Row of poles along edge v=1
    double[] wm = new double[2*n];       // Weights for middle row of poles

    double[] knotsU = new double[2*n + 4];    // Surface knots in u-direction
    double[] knotsV = { 0, 0, 0, 1, 1, 1 };    // Surface knots in v-direction

    knotsU[0] = 0;    knotsU[2*n + 2] = 1;
    knotsU[1] = 0;    knotsU[2*n + 3] = 1;

    double u0 = blend.MinU;    double u1 = blend.MaxU;
    double v0 = blend.MinV;    double v1 = blend.MaxV;
    double vm = (v0 + v1) / 2;

    double third = 1.0 / 3.0;

    double[] u = new double[n];
    for (int i = 0; i < n ; i++) u[i] = (1 - nodesU[i])*u0 + nodesU[i]*u1;

    for (int i = 0; i < n ; i++)
    {
        Spline bezierArc = blend.IsoCurveU(u[i]);    // Rational quadratic
        double w = bezierArc.Weights[1];    // Weight at its middle pole
        wm[2*i] = w;    wm[2*i + 1] = w;

        double h = (i > 0)    ?    u[i] - u[i-1]    :    0.0;
        double k = (i < n - 1)    ?    u[i+1] - u[i]    :    0.0;

        Vector U0 = blend.DerivDu(u[i], v0);    Position P0 = bezierArc.Poles[0];
        Vector Um = blend.DerivDu(u[i], vm);    Position Pm = bezierArc.Poles[1];
        Vector U1 = blend.DerivDu(u[i], v1);    Position P1 = bezierArc.Poles[2];
        Vector D = (2/w) * (Um - 0.25*U0 - 0.25*U1);

        A[2*i] = P0 - third*h*U0;    A[2*i + 1] = P0 + third*k*U0;
        B[2*i] = Pm - third*h*D;    B[2*i + 1] = Pm + third*k*D;
        C[2*i] = P1 - third*h*U1;    C[2*i + 1] = P1 + third*k*U1;

        knotsU[2*i + 2] = nodesU[i];
        knotsU[2*i + 3] = nodesU[i];
    }

    Position[,] poles = new Position[2*n, 3];
    double[,] weights = new double[2*n, 3];

    for (int i = 0; i < 2*n; i++)
    {
        poles[i, 0] = A[i]; poles[i, 1] = B[i];    poles[i, 2] = C[i];
        weights[i, 0] = 1;    weights[i, 1] = wm[i];    weights[i, 2] = 1;
    }

    return Bsurface(poles, weights, knotsU, knotsV);
}

```

As you can see, one of the inputs to this function is an array nodesU of parameter values at which circular cross-sections and partial derivatives are to be interpolated. The idea is that this code will be called as in section Constructing a Cubic B-spline, you construct an approximation, measure the error, and add new values into the nodesU array if necessary. This refinement process continues until the desired approximation error has been achieved.

Example

We use an example that's very similar to the one used in the section Approximating an Intersection Curve. We have two cylinders, $x^2 + y^2 = 150^2$, and $y^2 + z^2 = 200^2$, and their intersection is blended with a radius of 50. The ApproxBlend function shown above was called with $\text{nodesU} = \{ 0, 0.6, 1 \}$

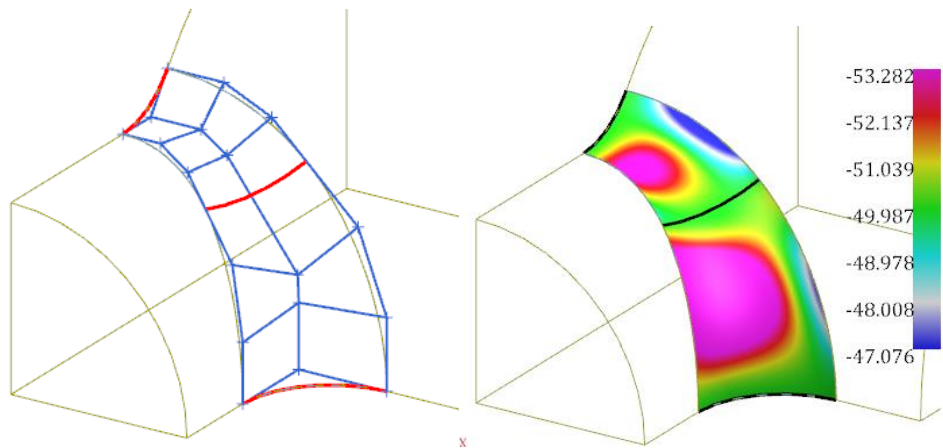


Figure M.16 — NURBS surface approximation and curvature values

The image on the left in Figure M.16 shows the control points of the NURBS surface approximation that was produced, and the one on the right shows its minimum curvature values. The correct minimum curvature value (-50) is preserved near the three interpolated arcs, but not elsewhere. Since this surface has only two patches, the approximation is rather poor. Using a larger number of arcs (therefore more entries in the nodesU array) would improve the accuracy, of course. The main approximation function should call ApproxBlend with a progressively more dense nodesU array until the desired accuracy is achieved.

For the simple surface shown above, the poles (control points) are

```
(100.00000000, 0.00000000, 250.00000000) (70.71067812, 0.00000000, 141.42135624) (150.00000000, 0.00000000, 200.00000000)
(100.00000000, 32.05918779, 250.00000000) (70.71067812, 24.64162626, 141.42135624) (150.00000000, 38.47102535, 200.00000000)
( 83.61937997, 62.80582420, 233.62398975) (82.28854357, 40.56677690, 165.79553058) (125.42906995, 75.36698904, 186.89919180)
( 42.38837901, 92.84163156, 208.63992245) (38.53818429, 76.94324822, 149.78734763) ( 63.58256851, 111.40995788, 166.91193796)
( 21.35441981, 100.00000000, 200.00000000) (25.43275108, 89.44271910, 156.52475842) ( 32.03162971, 120.00000000, 160.00000000)
( 0.00000000, 100.00000000, 200.00000000) ( 0.00000000, 89.44271910, 156.52475842) ( 0.00000000, 120.00000000, 160.00000000)
```

the corresponding weights are

```
1.00000000 ; 0.70710678 ; 1.00000000
1.00000000 ; 0.70710678 ; 1.00000000
1.00000000 ; 0.83426112 ; 1.00000000
1.00000000 ; 0.83426112 ; 1.00000000
1.00000000 ; 0.89442719 ; 1.00000000
1.00000000 ; 0.89442719 ; 1.00000000
```

and the knot vectors are

```
knotsU = { 0,0,0,0, 0.6, 0.6, 1,1,1,1 }
knotsV = { 0,0,0, ,1,1,1 }
```

M.6.2 Derivatives of Projected Curves

The algorithm given in section on The Basic Bezier Patch makes use of the partial derivatives with respect to u on the blend surface, so we need a way to calculate these.

As a first step, consider the general problem of finding the derivative of a curve that is a “normal projection” of a curve \mathbf{C} onto a surface \mathbf{S} . More specifically, suppose we have a curve $t \mapsto \mathbf{C}(t)$ that lies above a surface $(u, v) \mapsto \mathbf{S}(u, v)$. For each given t , we can find $u = u(t)$ and $v = v(t)$ such that the vector $\mathbf{R}(t) = \mathbf{S}(u(t), v(t)) - \mathbf{C}(t)$ is normal to the surface \mathbf{S} . In other words, the point $\mathbf{S}(u(t), v(t))$ is the “foot” of the normal from the point $\mathbf{C}(t)$ to the surface \mathbf{S} , and the curve $t \mapsto \mathbf{S}(u(t), v(t))$ is the normal projection of \mathbf{C} onto \mathbf{S} . The vector $\mathbf{R}(t)$ is normal to the surface \mathbf{S} , so we have

$$\mathbf{R}(t) \cdot \mathbf{S}^u = 0 \quad ; \quad \mathbf{R}(t) \cdot \mathbf{S}^v = 0$$

Here, as usual, \mathbf{S}^u and \mathbf{S}^v denote partial derivatives of \mathbf{S} with respect to u and v . Differentiating each of these equations with respect to t and rearranging, we get

$$[\mathbf{S}^u \cdot \mathbf{S}^u + \mathbf{R}(t) \cdot \mathbf{S}^{uu}] \frac{du}{dt} + [\mathbf{S}^u \cdot \mathbf{S}^v + \mathbf{R}(t) \cdot \mathbf{S}^{uv}] \frac{dv}{dt} = -\frac{d\mathbf{C}}{dt} \cdot \mathbf{S}^u$$

$$[\mathbf{S}^u \cdot \mathbf{S}^v + \mathbf{R}(t) \cdot \mathbf{S}^{uv}] \frac{du}{dt} + [\mathbf{S}^v \cdot \mathbf{S}^v + \mathbf{R}(t) \cdot \mathbf{S}^{vv}] \frac{dv}{dt} = -\frac{d\mathbf{C}}{dt} \cdot \mathbf{S}^v$$

This is a system of two linear equations that we can solve to get du/dt and dv/dt . Then the derivative of the projected curve $\mathbf{P}(t) = \mathbf{S}(u(t), v(t))$ is

$$\frac{d\mathbf{P}}{dt} = \frac{du}{dt} \mathbf{S}^u + \frac{dv}{dt} \mathbf{S}^v$$

and the derivative of the vector \mathbf{R} is

$$\frac{d\mathbf{R}}{dt} = \frac{du}{dt} \mathbf{S}^u + \frac{dv}{dt} \mathbf{S}^v - \frac{d\mathbf{C}}{dt}$$

Blend Surface Derivatives

The blend surface equation we obtained at the end of section L5.1.2 was:

$$\mathbf{S}(u, v) = \mathbf{C}(u) + r(\cos v\alpha - \cot \alpha \sin v\alpha)\mathbf{X}(u) + r(\csc \alpha \sin v\alpha)\mathbf{W}(u)$$

Differentiating this with respect to u , we get

$$\begin{aligned} \frac{d\mathbf{S}}{du} &= \frac{d\mathbf{C}}{du} + \frac{d\alpha}{du} \{ \sin v\alpha (\csc^2 \alpha - v) - v \cot \alpha \cos v\alpha \} r\mathbf{X} \\ &\quad + \frac{d\alpha}{du} \csc \alpha (v \cos v\alpha - \sin v\alpha \cos \alpha \csc \alpha) r\mathbf{W} \\ &\quad + (\cos v\alpha - \sin v\alpha \cot \alpha) r\mathbf{X}^u + (\sin v\alpha \csc \alpha) r\mathbf{W}^u \end{aligned}$$

We can obtain \mathbf{X}^u and \mathbf{W}^u using the techniques described in the previous section, so the only remaining unknown is $d\alpha/du$.

But we know that $\mathbf{X} \cdot \mathbf{W} = r^2 \cos \alpha$, and differentiating this with respect to u gives

$$\mathbf{X} \cdot \mathbf{W}^u + \mathbf{W} \cdot \mathbf{X}^u = -r^2 \sin \alpha \frac{d\alpha}{du}$$

and so

$$\frac{d\alpha}{du} = -\frac{\mathbf{X} \cdot \mathbf{W}^u + \mathbf{W} \cdot \mathbf{X}^u}{r^2 \sin \alpha}$$

While all of the above might be interesting mathematics, for some people, a more practical approach is to use divided difference approximations to obtain partial derivatives. The following function does this – the recommendation is to use this approach instead of the analytical one above:

```

/// <summary>Evaluates approximate first derivative on a blend surface</summary>
/// <param name="blend">The blend surface</param>
/// <param name="u">Parameter value u at which to compute</param>
/// <param name="v">Parameter value v at which to compute</param>
/// <returns>Partial derivative wrt u at parameter values (u,v)</returns>
public static Vector ApproxDerivDu(BlendSurface blend, double u, double v)
{
    Position p0, pm, p1;
    Vector deriv;

    // Step needs to be chosen carefully; not too big, and not too small
    double u0 = blend.MinU;    double u1 = blend.MaxU;
    double step = 0.000001;
    double du = (u1 - u0)*step;

    if (u < u0 + du)    // Near beginning, so use forward difference formula
    {
        p0 = blend.Position(u,v);
        pm = blend.Position(u + du, v);
        p1 = blend.Position(u + 2*du, v);
        deriv = (3 * (pm - p0) - (p1 - pm)) / (2 * du);
    }

    else if (u > u1 - du)    // Near the end, so use backward difference formula
    {
        p0 = blend.Position(u - 2*du, v);
        pm = blend.Position(u - du, v);
        p1 = blend.Position(u, v);
        deriv = (3*(p1 - pm) - (pm - p0)) / (2*du);
    }

    else    // Normal case in interior of interval [u0,u1], so use central difference formula
    {
        p0 = blend.Position(u - du, v);
        p1 = blend.Position(u + du, v);
        deriv = (p1 - p0) / (2.0 * du);
    }

    return deriv;
}

```

There are much more sophisticated algorithms for numerical estimation of derivatives; see section 5.7 of the Numerical Recipes book for details. In particular, the discussion of the choice of the variable step is well worth reading. If step is too large, the divided difference formula has a large truncation error, and if step is too small, the calculations will be ruined by subtractive cancellation. But our only use for partial derivatives is the construction of a blend surface approximation, so we do not need to know their values very accurately, and the simple function given above is more than adequate for our purpose. In fact, for the blend surface example given, the derivative estimates given by the ApproxDerivDu function are everywhere within 0.00000019 of the correct values, which is certainly good enough.

Approximating Blend Surface Edges

The “contact curve” edges of a blend surface are icurves formed by intersections with special “blend bound” surfaces. Blend bound surfaces are complicated and require special techniques, so it would be nice if we could avoid them; it turns out that we can. Suppose we have constructed a b-spline approximation **S** of a blend surface **B**. Then the edges of **S** can easily be constructed, and these will provide spline curve approximations of the edges of **B**.

M.6.3 Evaluating a NURBS curve outside the range defined by the knot vector

The recommended approach to evaluate a NURBS curve outside the range defined by the knot vector is to take the linear extension using the first derivative at the beginning or end of the range."

For a b-curve C parameterised over range $[t_0, t_1]$, evaluating at t and using the conventional notation where $C'(t)$ represents the first derivative d/dt of $C(t)$

set $t_eval = t$, $dt = 0$, $out_of_range = false$

if $t < t_0$, set $t_eval = t_0$, $dt = t - t_0$, $out_of_range = true$

if $t > t_1$, set $t_eval = t_1$, $dt = t - t_1$, $out_of_range = true$

evaluate $C(t_eval)$ using standard methods, giving P, P', P'', \dots i.e. the values at the boundary

set $C(t) = P + (dt * P')$

$C'(t) = P'$

$C''(t) = out_of_range ? (0,0,0) : P''$ – Second and higher order derivatives are treated as zero

...

The recommended approach to evaluate a surface beyond the range defined by the knot vector is to calculate the ruled surface that is obtained from linearly extending the isoparametric curves at the boundary.

For a b-surface S parameterised over ranges $[u_0, u_1], [v_0, v_1]$, evaluating at (u, v) and using the conventional notation where $S_u(u,v)$ represents the derivative d/du of $S(u,v)$ etc.:

set $u_eval = u$, $du = 0$, $u_out_of_range = false$

set $v_eval = v$, $dv = 0$, $v_out_of_range = false$

if $u < u_0$, set $u_eval = u_0$, $du = u - u_0$, $u_out_of_range = true$

if $u > u_1$, set $u_eval = u_1$, $du = u - u_1$, $u_out_of_range = true$

if $v < v_0$, set $v_eval = v_0$, $dv = v - v_0$, $v_out_of_range = true$

if $v > v_1$, set $v_eval = v_1$, $dv = v - v_1$, $v_out_of_range = true$

evaluate $S(u_eval, v_eval)$ using standard methods, giving $P, P_u, P_v, P_{uv}, \dots$ i.e. the values at the boundary.

set $S(u, v) = P + (du * P_u) + (dv * P_v) + (du * dv * P_{uv})$

$S_u(u, v) = P_u + (dv * P_{uv})$

$S_v(u, v) = P_v + (du * P_{uv})$

$S_{uv}(u, v) = P_{uv}$

Higher order derivatives may be treated as zero

M.6.4 Blend Surface Questions and Answers

This section reproduces some earlier questions and answers about blend surfaces, for easy reference.

How does the blend radius r , correspond to the data stored in the XT Data? And is the parametric representation correct – can't r be positive for one surface and negative for another?

The blend radius r is the magnitude of the offset distance of each underlying surface and directly relates to the range values stored in the rolling ball blend surface data. The range value for each surface can be $+r$ or $-r$. The $+$ or $-$ indicates the direction of the offset of the underlying surface taking into account the surface sense.

When interpreting the parametric representation quoted in the XT Data Description, the current formula is correct since the blend radius r itself is always a positive value (even though the offset value in the range field may be negative):

$$\mathbf{R}(u, v) = \mathbf{C}(u) + r \cos(v\alpha(u)) \mathbf{X}(u) + r \sin(v\alpha(u)) \mathbf{Y}(u)$$

However, to avoid confusion you may prefer to think of the formula as follows:

$$\mathbf{R}(u, v) = \mathbf{C}(u) + |r| \cos(v\alpha(u)) \mathbf{X}(u) + |r| \sin(v\alpha(u)) \mathbf{Y}(u)$$

What is the spine curve of a rolling ball blend surface?

Conceptually, for a rolling ball blend surface, the spine curve describes the path of the center of the ball as it moves along the two underlying surfaces, maintaining point contact with both surfaces at any one time as it does so.

This is explained in the XT Data Description as follows:

For rolling ball blends, the spine curve will be the intersection of the two surfaces obtained by offsetting the supporting surfaces by an amount given by the respective entry in range[]. Note that the offsets to be applied may be positive or negative, and that the sense of the surface is significant; therefore the offset vector is the natural unit surface normal, times the range, times -1 if the sense is negative.

What type of curves can be referenced as the spine of the rolling ball blend surface?

For a rolling ball blend surface that has been created using the Parasolid Kernel, the most common types of spine curves are ellipses, intersection curves, rational b-spline curves which exactly represent a portion of an ellipse.

Additionally, for cliff blends (type = E) created by the Parasolid Kernel, it is also common to see lines, b-curves and circles representing the spine of the supporting (zero radius rolling ball blend) surface.

The format does not preclude using any exact 3D curve as the spine curve within the blended_edge data structure.

How is the rolling ball blend surface parameterized?

The XT Data Description explains the parameterization as follows:

The u parameter is inherited from the spine, the constant u lines being circles perpendicular to the spine curve. The v parameter is zero [0] at the blend boundary on the first surface, and one [1] on the blend boundary on the second surface; unless the sense of the spine curve is negative, in which case it is the other way round. The v parameter is proportional to the angle around the circle.

Given an $[x, y, z]$ point on a blend surface, how do I determine the corresponding $[u, v]$?

A blend surface is such that the following is always true:

- I. Given a point \mathbf{P} on the blend surface, find the closest point \mathbf{P}_1 on the blend spine. The parameter of that point \mathbf{P}_1 on the curve, provides the u parameter of \mathbf{P} .

- II. Given the point, P_1 on the spine curve, find the closest points P_2 and P_3 on each of the underlying surfaces. These points P_2 and P_3 will both lie on the corresponding blend boundaries.
- III. One of the points P_2 and P_3 will have v parameter [0] and the other will have v parameter [1], dependent on the sense of the spine curve.
- IV. Points P , P_2 and P_3 will all lie on the same circular arc on the underlying blend surface. The v parameter of P will be proportional to its angular location along the arc between P_2 and P_3 .

Figure M.17 illustrates further

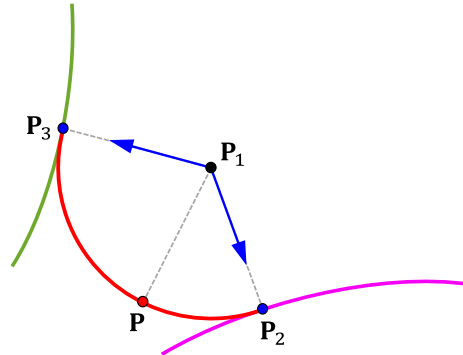


Figure M.17 — Cliff edge blend parameters

What is a 'cliff-edge blend'? How does it relate to the `blended_edge` structure?

The presence of a 'cliff-edge blend' (referred to in the following explanation as just 'cliff blend') is denoted when the **blend_type** field of the `blended_edge` structure is set to 'E' (rather than 'R'). This indicates that the `blended_edge` structure represents a cliff blend.

Conceptually, a cliff blend is one where a rolling ball blend surface would overflow a face boundary. In order to stay within the face boundary, the rolling ball moves along this 'cliff' edge whilst also maintaining contact with the other surface and such that the resultant cliff blend surface meets that other surface tangentially.

A simple example of a rolling ball blend surface (in yellow) and a cliff blend surface (in blue) are shown in Figure M.18 below. The cliff (edge/curve) is also shown (in red). Note that this is shown for representation purposes only; if such a part had been constructed using the Parasolid Kernel, the yellow surface would be simplified exactly to a torus as part of the blend construction.

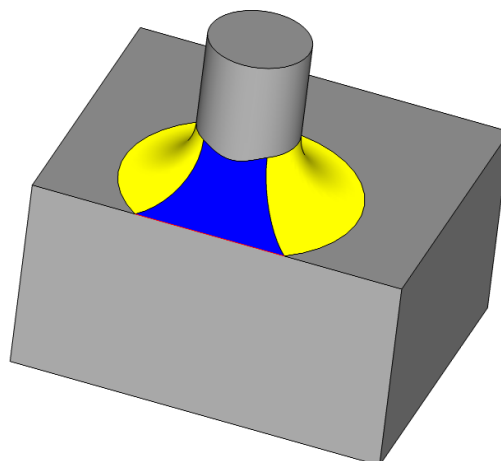


Figure M.18 — Rolling ball blend with a cliff edge

For a cliff blend, the spine curve is represented in a different way to the spine of a rolling ball blend surface. This is explained in the XT Data Description as follows:

For cliff edge blends, one of the surfaces will be a blended_edge with a range of [0,0]; its spine will be the cliff edge curve, and its supporting surfaces will be the surfaces of the faces adjacent to the cliff edge. Its type will be R.

For example in the case pictured above, the elements of the structure include the following:

For the rolling ball blend surface in yellow:

- One of the elements of the surface array is the cylinder
- The other element of the surface array is the planar surface of the top face
- The spine is a curve representing the intersection of the offsets of the two surfaces above
- The range is $[+/-r, +/-r]$ (the sign for each takes into account the surface normal and surface sense)
- The blend_type is R

For the cliff blend surface in blue:

- One of the elements of the surface array is the cylinder
- The other element of the surface array is a rolling ball blend surface with range = [0,0]
- Conceptually this is a representation of the cliff curve as a zero radius blend (see below for more details)
- The spine is derived in exactly the same way as for a rolling ball blend (based on the intersection of the offsets of the two surfaces)
- The range is $[+/-r, +/-r]$
- The blend_type is E

For the other element of the surface array above:

- One of the elements of its surface array is the front-facing planar surface adjacent to the edge
- The other element of its surface array is the top-facing planar surface adjacent to the edge in the original model
- Note that these two surfaces intersect to give the cliff curve
- The range is [0,0]
- The spine is the cliff curve (formed by intersecting the two surfaces), and can be conceptually thought of as the curve of the cliff edge
- The blend_type is R

M.7 Annex Reference Documents

The following documents are referenced in the Procedural Geometry – Evaluation and Approximation Annex:

1. JT Implementor Forum – Implementation Guidelines, Version 0.9 (May 27, 2014)
2. JT Content Harmonization (v3.0) – Progress Report and Proposal for JT and Accompanying Formats (2013-05-21)
3. Layer Filter Support in JT Files (v2.0; February, 2013) – provided by Siemens
4. JT-v10-file-format-reference-rev-A_tcm1023-224370.pdf – JT File Format Reference Version 10.0 Rev-A – provided by Siemens
5. JT OPEN ADVANCED MATERIALS (March, 2012) – provided by Siemens
6. Numerical Recipes, by Press, Teukolsky, Vetterling, Flannery.
7. GSL - GNU Scientific Library <https://www.gnu.org/software/gsl/>
8. MINPACK is a library of FORTRAN subroutines for the solving of systems of nonlinear equations, or the least squares minimization of the residual of a set of linear or nonlinear equations. <https://en.wikipedia.org/wiki/MINPACK>
9. Loss of significance is an undesirable effect in calculations using finite-precision arithmetic such as floating-point arithmetic. https://en.wikipedia.org/wiki/Loss_of_significance

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- [10] *JT Open Program* (<http://www.jtopen.com>) --- A program to help members leverage the benefits of open collaboration across the extended enterprise through the adoption of the JT format, a technology that makes it possible to view and share product information throughout the product lifecycle. Membership in the JT Open Program provides access to the JT Open Toolkit library, which among other things, provides read and write access to JT data and enforces certain JT conventions to ensure data compatibility with other JT-enabled applications.
- [11] *JT2Go download* (<http://www.jt2go.com>) --- JT2Go is the no-charge 3D JT viewer from Siemens. JT2Go puts 3D data at your fingertips by allowing anyone to download the no-charge viewer. JT2Go also allows anyone to embed 3D JT data directly into Microsoft Office documents. JT2Go offers full 3D interactivity on parts, assemblies, and even 2D drawings (CGM & TIF).
- [12] *Siemens: PLM Components: Parasolid: XT Pipeline* (<http://www.ugs.com/products/open/parasolid/pipeline.shtml>) --- This web page provides information on the Parasolid precise boundary representation format (XT) and how this XT format fits within the Siemens vision of seamless exchange of digital product models across enterprises, between different disciplines, using their PLM applications of choice.
- [13] *OpenGL Programming Guide : The official guide to learning OpenGL Version 2*, Fifth Edition, by OpenGL Architecture Review Board, Dave Shreiner, Mason Woo, Jackie Neider, and Tom Davis (Addison-Wesley 2005) --- This book gives in-depth explanation of the OpenGL Specification and will provide further insight into the significance of some of the data (for example Materials, Textures) that can exist in a JT file. Information in this book may also serve as a guide for how one could process the data contained in an JT file to produce/render an image on the screen.
- [14] Michael Deering, *Geometry Compression*, Computer Graphics, Proceedings SIGGRAPH '95, August 1995, pp. 13-20.
- [15] Michael Deering, Craig Gotsman, Stefan Gumhold, Jarek Rossignac, and Gabriel Taubin, *3D Geometry Compression*, Course Notes for SIGGRAPH 2000, July 25, 2000.

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- [20] *Planetmath.org - Huffman Coding* (<http://planetmath.org/encyclopedia/HuffmanCoding.html>) --- This web page provides a technical overview of Huffman coding which is one form of data encoding used within the JT format.
- [21] Michael Schindler, *Practical Huffman Coding* (<http://www.compressconsult.com/huffman/#encoding>) --- This web page provides some coding hints for implementing Huffman coding which is one form of data encoding used within the JT format.
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- [24] zlib.net (<http://www.zlib.net/>) --- This web page provides (either directly or through links) complete detailed information on ZLIB compression including frequently asked questions, technical documentation, source code downloads, etc.
- [25] Andrei Khodakovsky, Pierre Alliez, Mathieu Desbrun, and Peter Schröder, *Near-Optimal Connectivity Encoding of 2-Manifold Polygon Meshes*, Graphical Models, Vol. 64, No. 3-4, Pages: 147 - 168, 2002.
- [26] VDA Recommendation 231-300, Digital data exchange in material sampling taking into account 3D data