JavaScriptCore, Many Compilers Make this Engine Perform

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https://svn.webkit.org/repository/webkit/trunk

Agenda

- High Level Overview
- Tiers
- Optimization Techniques
  - Counting Triggers
  - OSR (On Stack Replacement)
  - Profiling
  - Speculation
  - Inline Caching
  - Other Compiler Optimizations

JavaScriptCore Uses

- JS engine for Safari.
- Used by many apps, Apple and 3rd party including React Native.
- Other WebKit contributors use it for set top boxes, video game consoles, in vehicle systems and other custom JS environments.

JavaScriptCore

- Fork from KDE JS engine 17 years ago (~37K lines / 94 files).
- Written mostly in C++
  some Objective-C, Ruby, Python and Perl.
- >600K lines of code in >2500 source files.
- >4.5M lines of test code in >50,000 tests.

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{
    o.sum += v;
}
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addTo:
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[  11] add        loc6, loc6, arg2
[  17] put_by_id  arg1, “sum”, loc6
[  23] ret        Undefined
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Fast Path / Slow Path

Fast Path / Slow Path

```
op_add(a, b)
{
    if (isInt32(a) && isInt32(b))
        return a + b;
    return slowAdd(a, b);
}
```

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~9 JIT Compilers

JavaScript execution engines:

- LLInt *interpreter*
- Baseline *template JIT*
- DFG *less optimizing JIT*
- FTL *full optimizing JIT*
- Polymorphic Access *template JIT*
- Snippet *template JIT*

WebAssembly execution engines:

- Wasm *interpreter*
- Wasm BBQ *less optimizing JIT*
- Wasm OMG *full optimizing JIT*

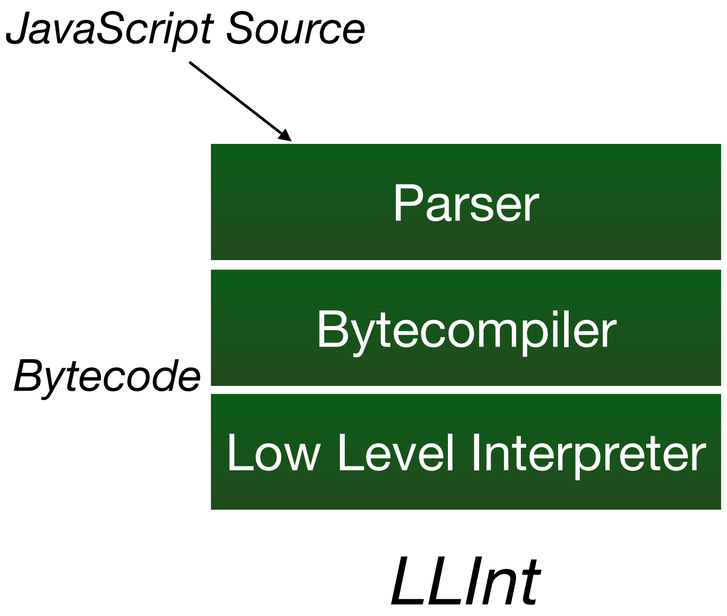
Other engines:

- YARR *regexp interpreter*
- YARR *regexp template JIT*
- CSS *template JIT*

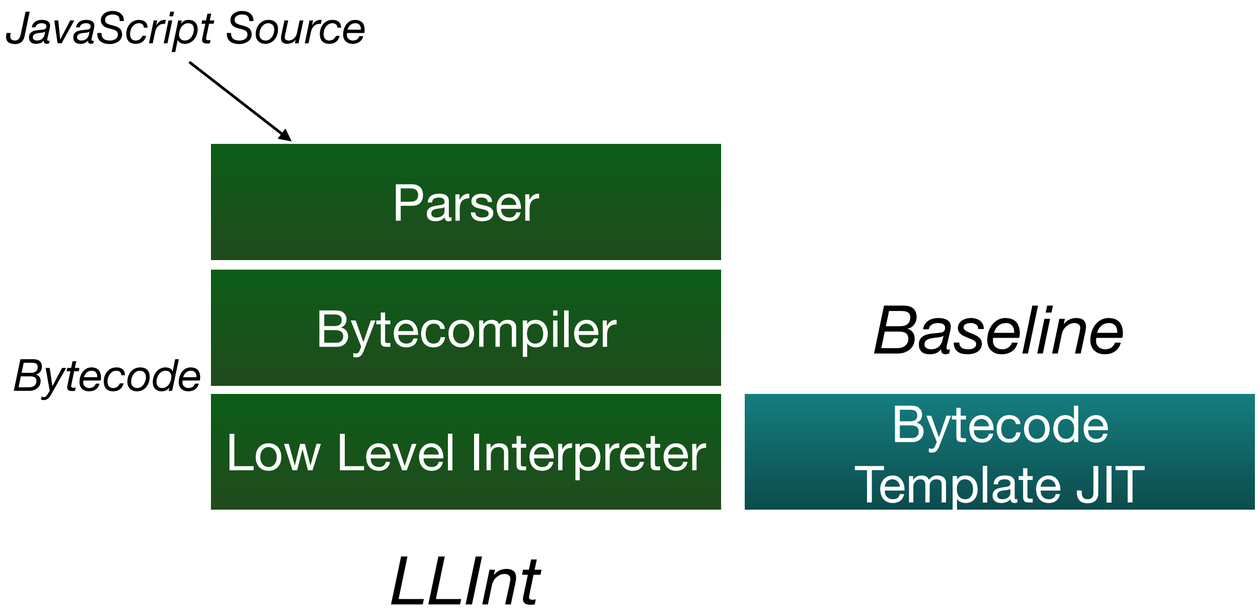
Four JS Tiers

Four JS Tiers

JavaScript Source


JavaScript Source
Parser
Bytecompiler
Bytecode
Low Level Interpreter

LLInt


JavaScript Source
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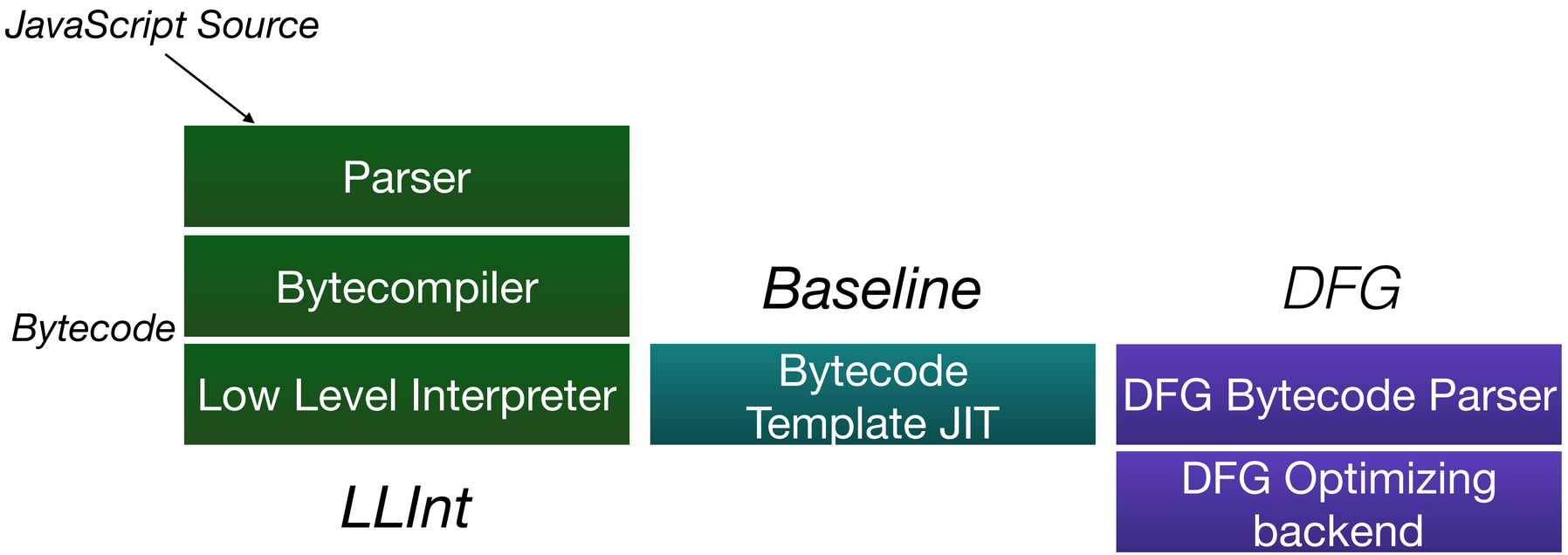
Template JIT


JavaScript Source
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DFG
DFG Bytecode Parser
DFG Optimizing
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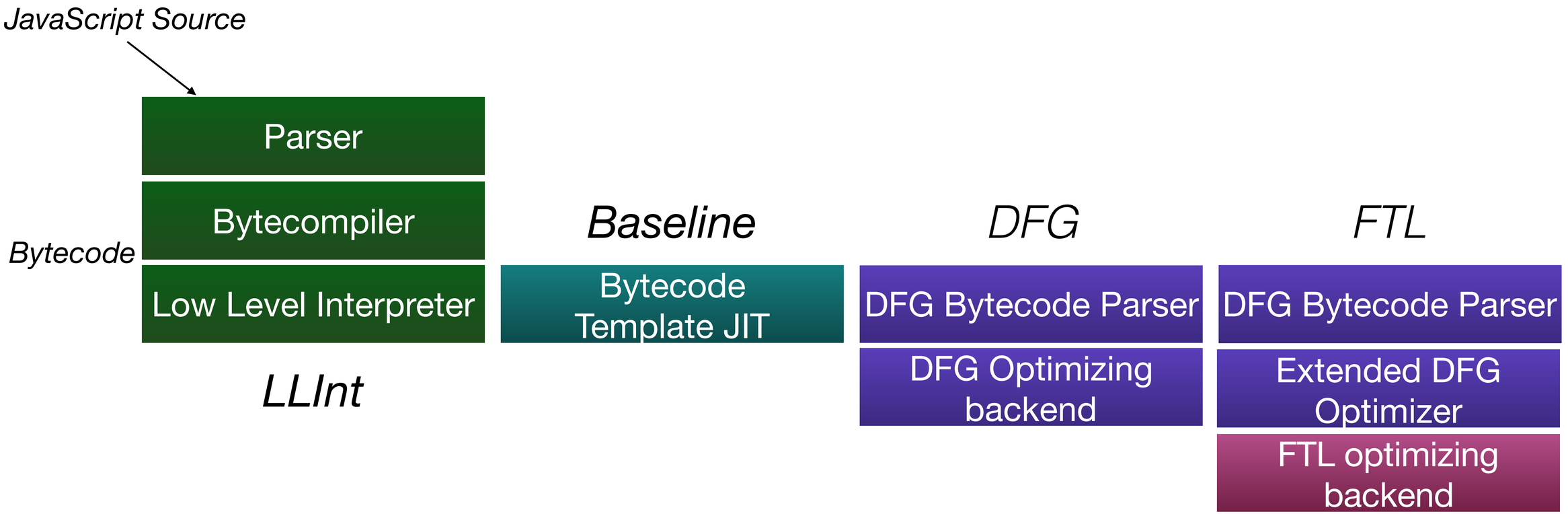
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Execution Count Thresholds for Tier-up

Tier-up Case	Required Count for Tier-up
LLInt → Baseline	500
Baseline → DFG	1000
DFG → FTL	100000

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[  17] put_by_id  arg1, “sum”, loc6
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```

```
"use strict";

let accumulator = { sum: 0 };

for (let i = 0; i < 10000000; ++i)
    accumulator.sum += i;

print(accumulator.sum);
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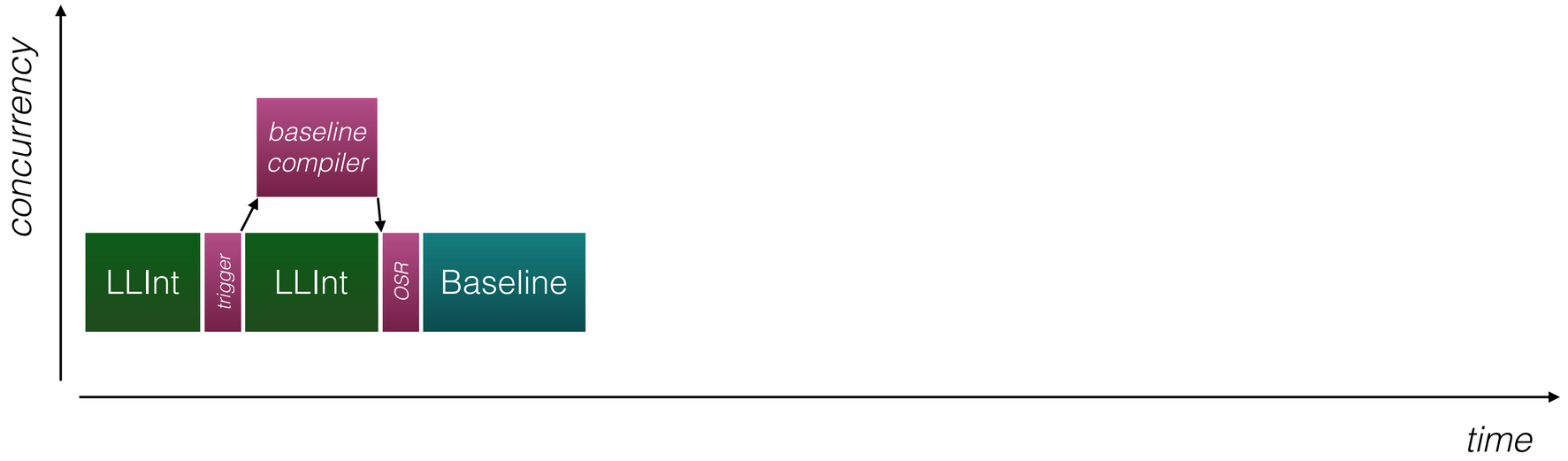

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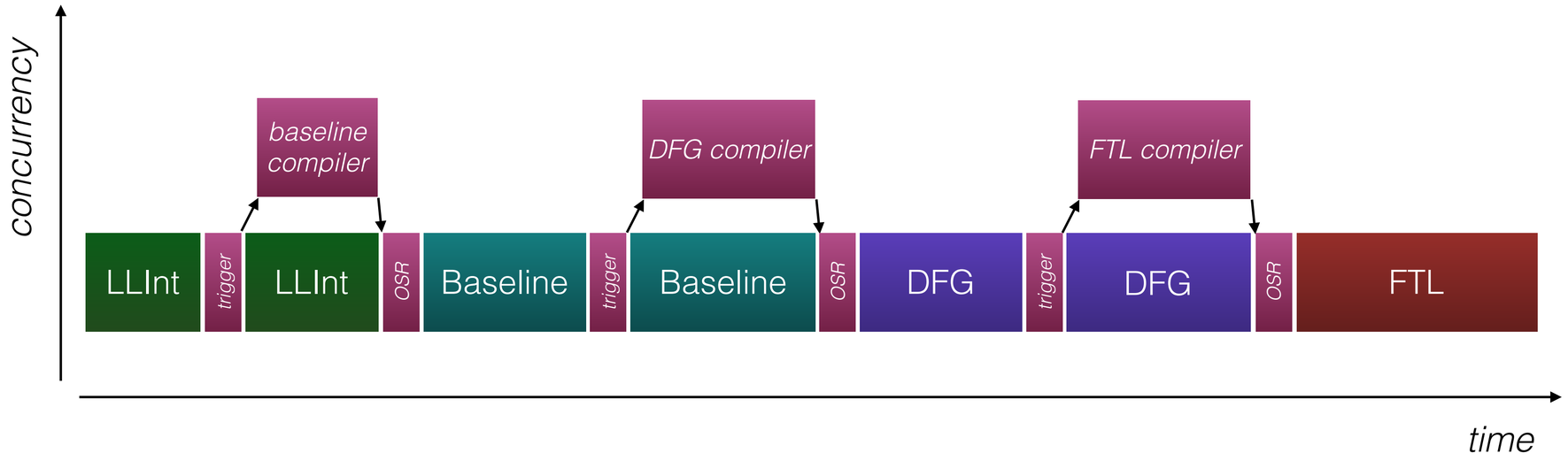

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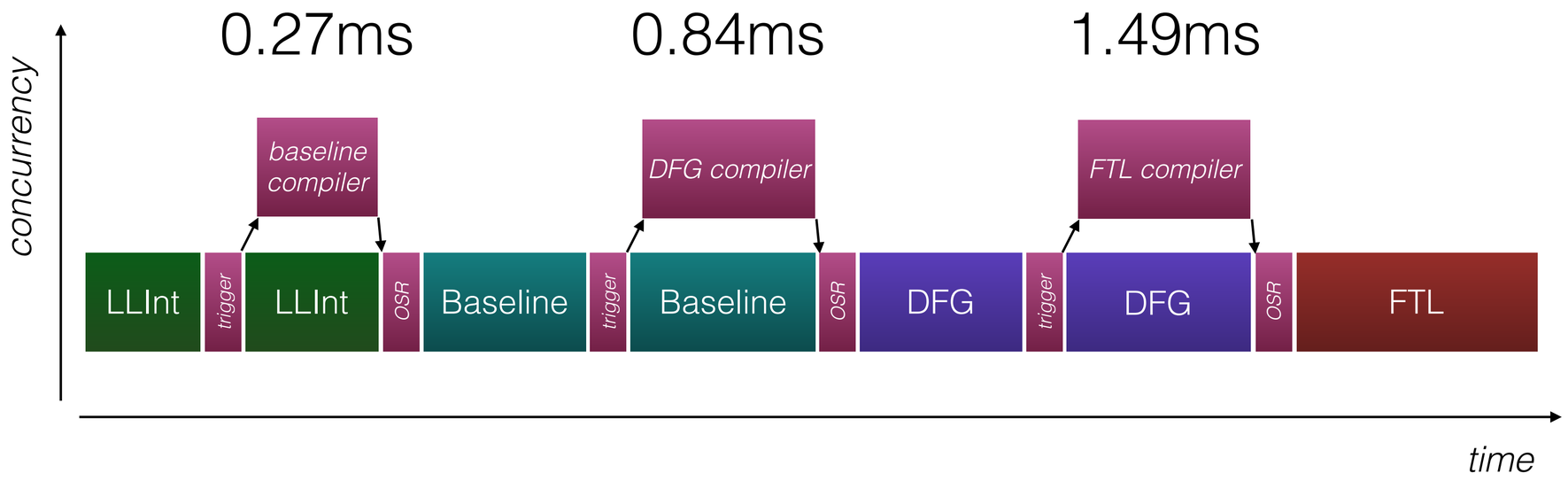

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OSR

On Stack Replacement

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}
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```
[  0] enter
```

```
[  0] enter
```

frame layout
matches bytecode

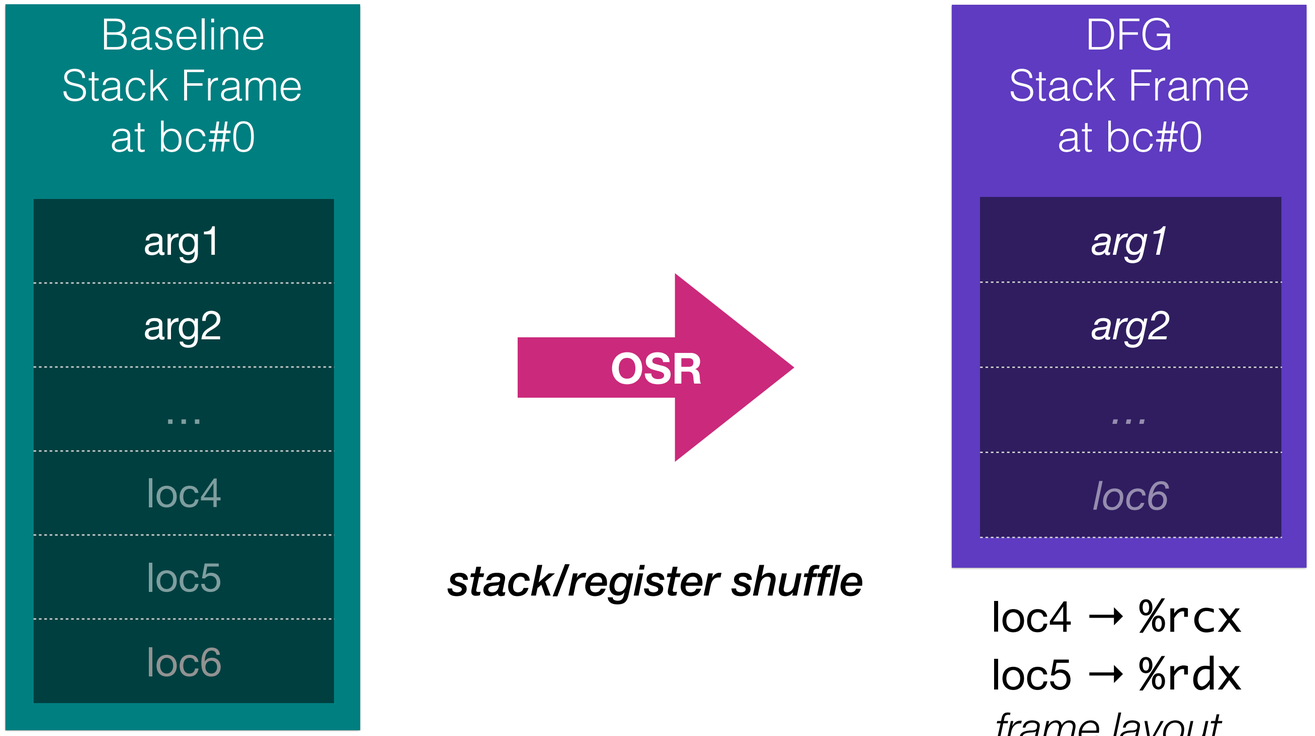
```
[  0] enter
```

frame layout matches bytecode

loc4 → %rcx
loc5 → %rdx

frame layout selected by complex process

```
[  0] enter
```



frame layout matches bytecode

frame layout selected by complex process

Fast Path / Slow Path

```
op_add(a, b)
{
    if (isInt32(a) && isInt32(b))
        return a + b;
    return slowAdd(a, b);
}
```

Fast Only

```
op_add(a, b)
{
    if (!isInt32(a) || !isInt32(b))
        exitToUnoptimizedTier();
    // Code below only needs int32 path
    return a + b;
}
```

Fast Only

```
op_addFast(a, b)
{
    return a + b;
}

if (!isInt32(a))
    exitToUnoptimizedTier();
if (!isInt32(b))
    exitToUnoptimizedTier();
…
result = op_addFast(x, 12);
…
```

```
[  11] add loc6, loc6, arg2
```

```
[  11] add loc6, loc6, arg2
```

frame layout
matches bytecode

```
[  11] add loc6, loc6, arg2
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frame layout matches bytecode

loc4 → %rcx
loc5 → %rdx

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```
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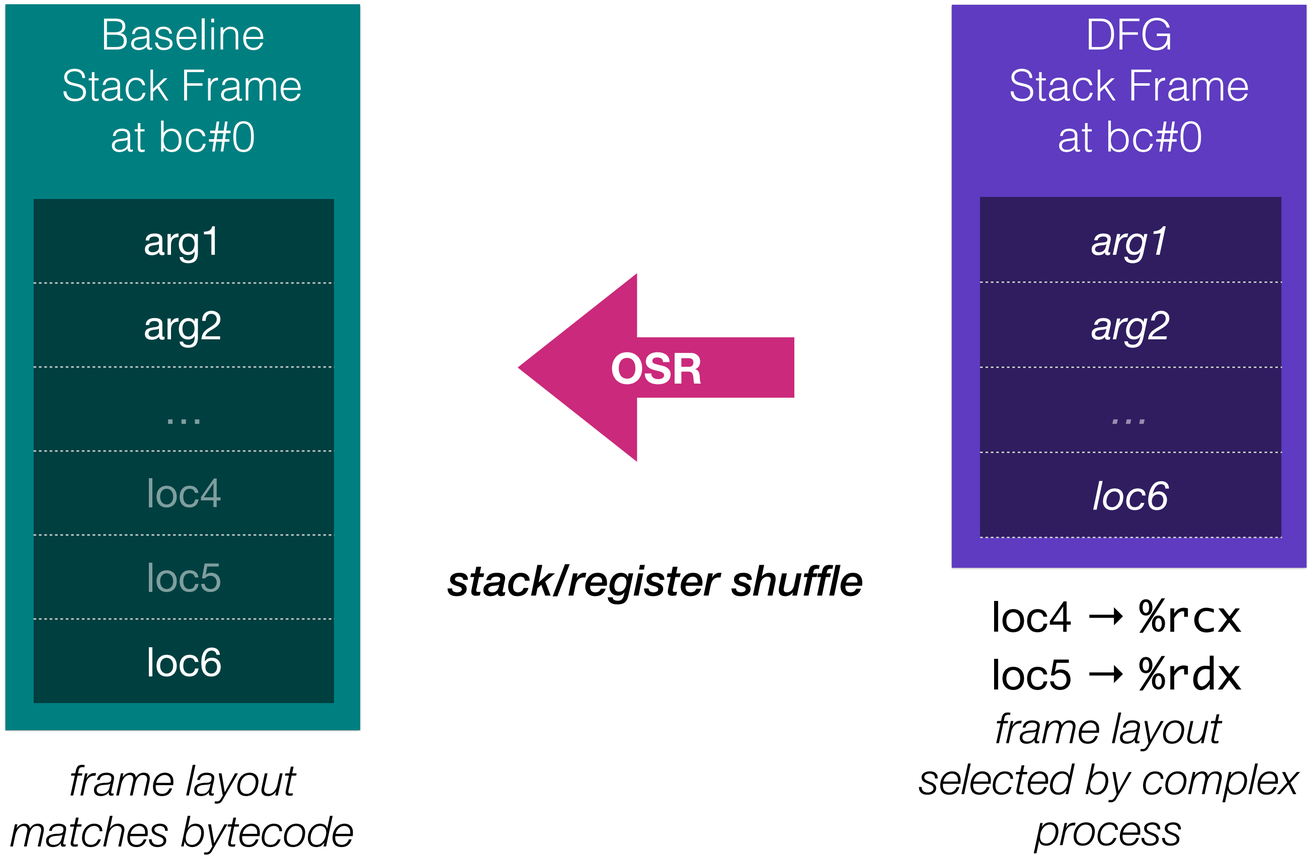
```



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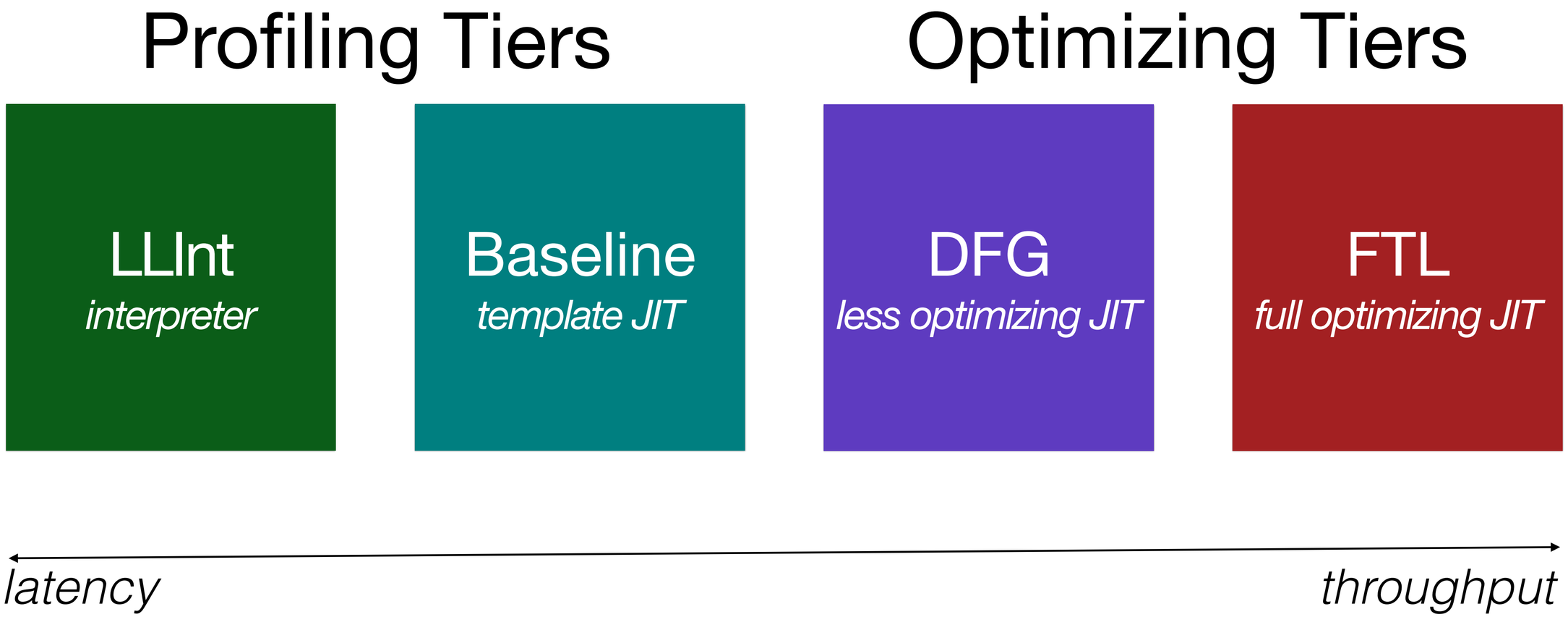

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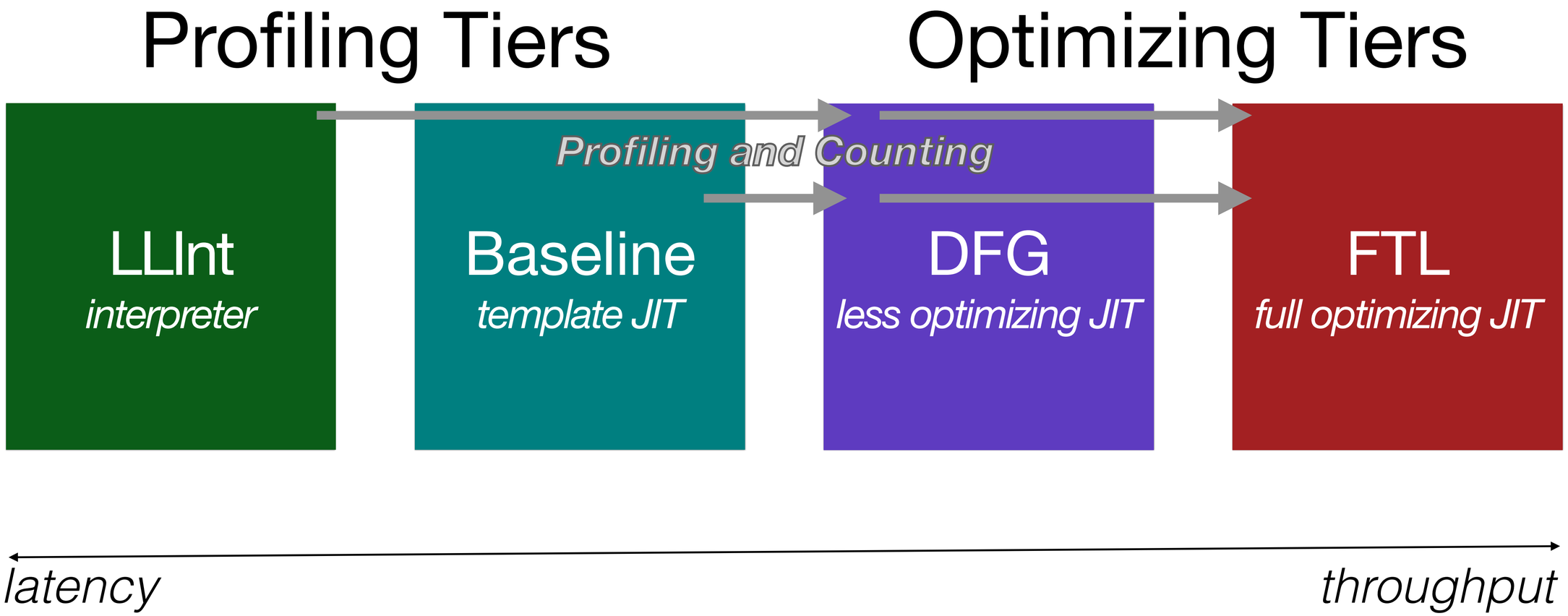

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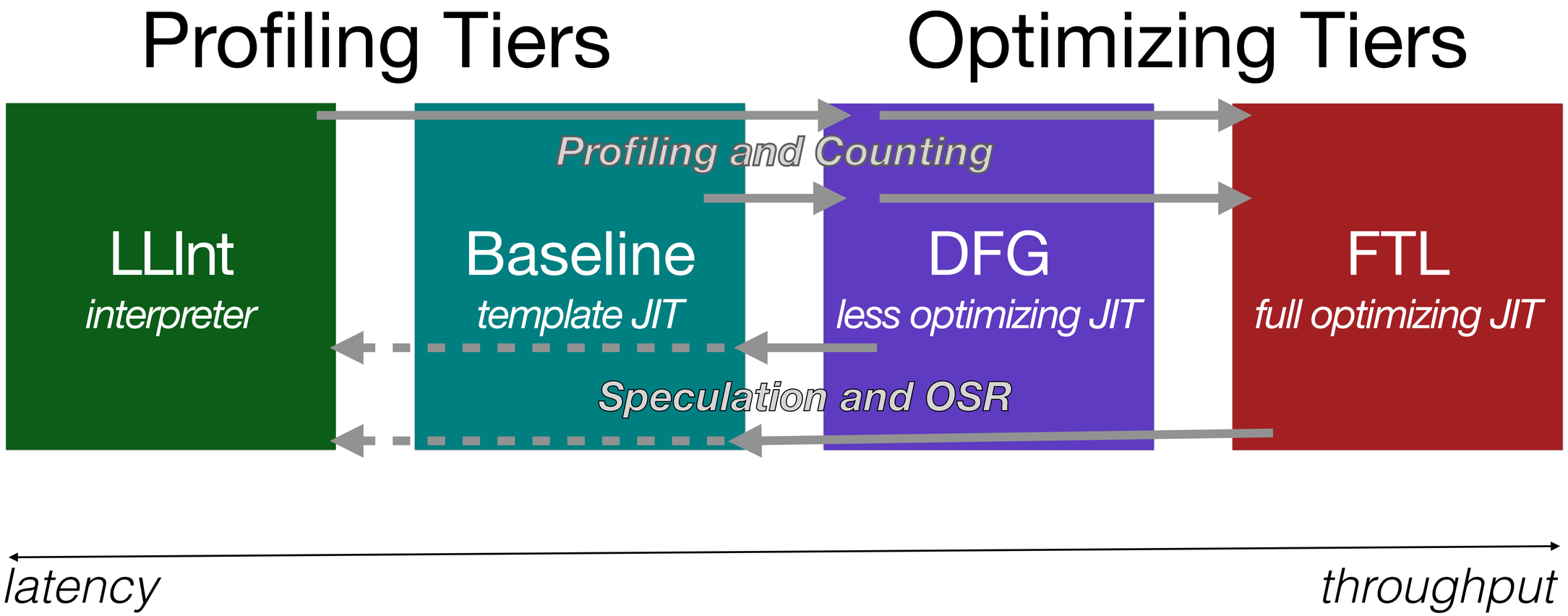

Simple Profiling

- Record values, types, counts and flags
  - ✦ Low overhead
  - ✦ Provides enough detail
  - ✦ Occasionally we aggregate values and types into sets
  - ✦ Sets kept as a bit masks

Profiling Sources in JSC

- Value Profiling
- Inline Caches
- Case Flags
- Case Counts
- Watchpoints
- Exit Flags

Some Profiling Sources in JSC

- Value Profiling — *type inference of values*
- Inline Caches — *type inference of object structure*
- Case Flags — *branch speculation*
- Case Counts — *branch speculation*

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Speculation Check

Speculation Check

```
speculateIsInt32(v)
{
    if (!isInt32(v))
        exitToUnoptimizedTier();
}
```

Speculation

- Speculation is making a bet
- Profiling helps us win that bet

Winning at Speculation

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- Only speculate if we believe that we will win every time.

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Winning at Speculation

- Only speculate if we believe that we will win every time.
- Profiling should record counterexamples to useful speculations.
- Profiling should run for a long time.
- Don’t stress when speculation fails, unless it fails in the average.

```
function addTo(o, v)
{
    o.sum += v;
}
```

Optimized JS function

```
function addTo(o, v)
{
    speculateIsInt32(o.sum);
    speculateIsInt32(v);
    o.sum += v;
}
```

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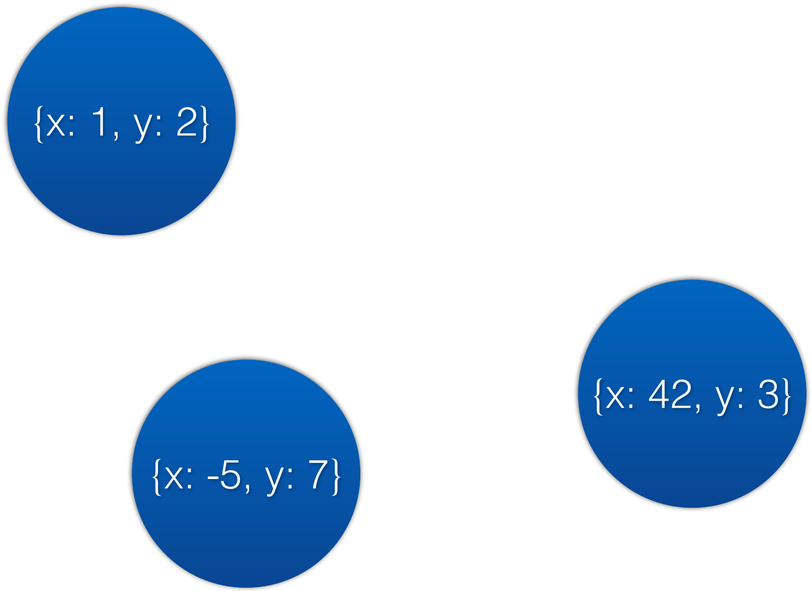
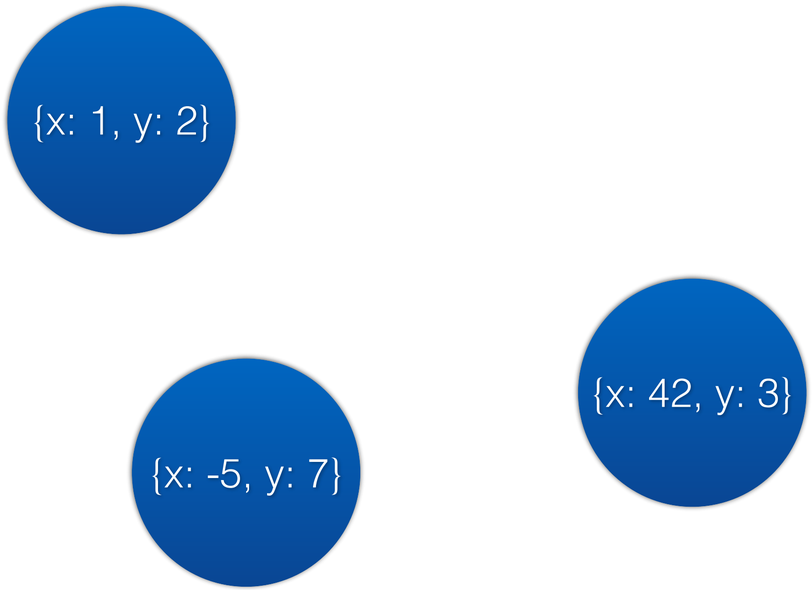
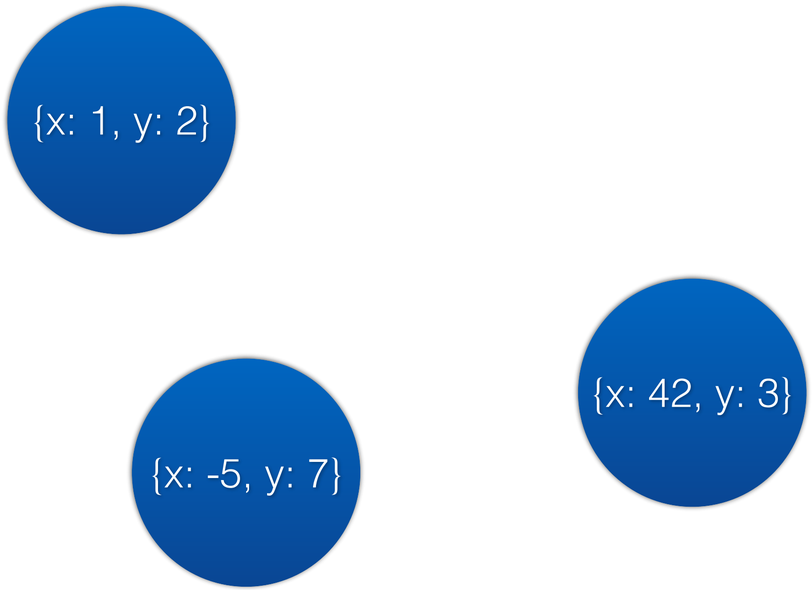

{x: 1, y: 2}
{x: -5, y: 7}
{x: 42, y: 3}

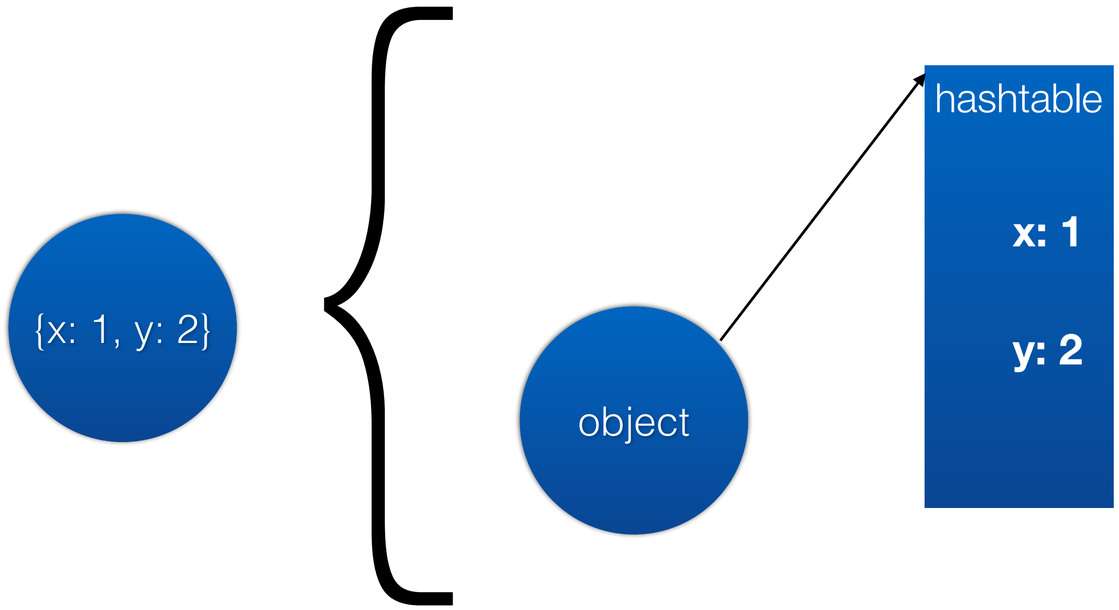
```
var x = o.x;
```



```
o.x = x;
```



Hashtable



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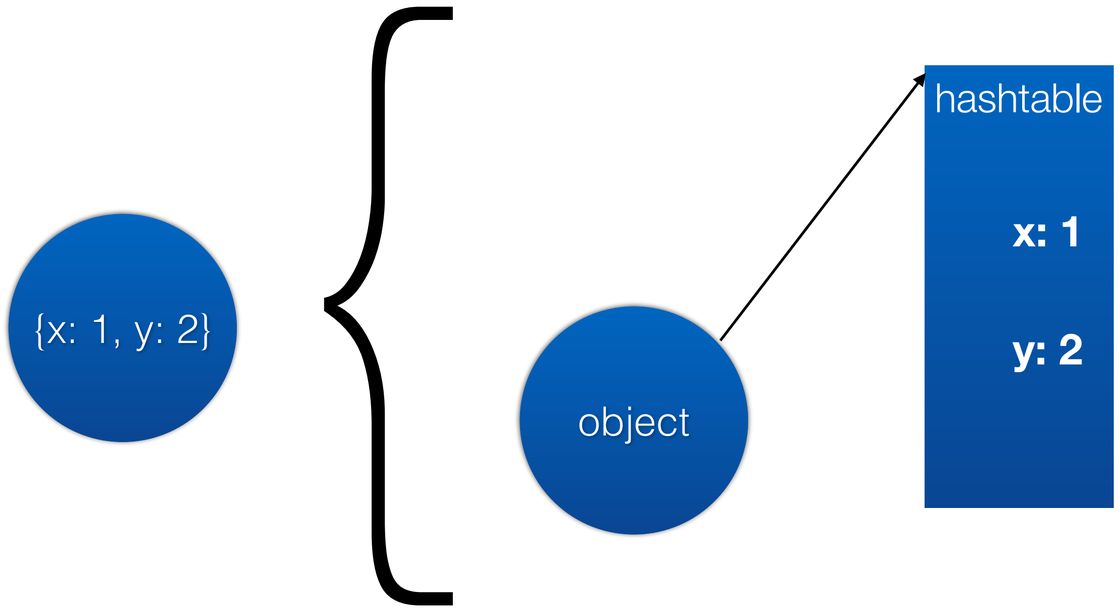

- Pointer chasing is slow

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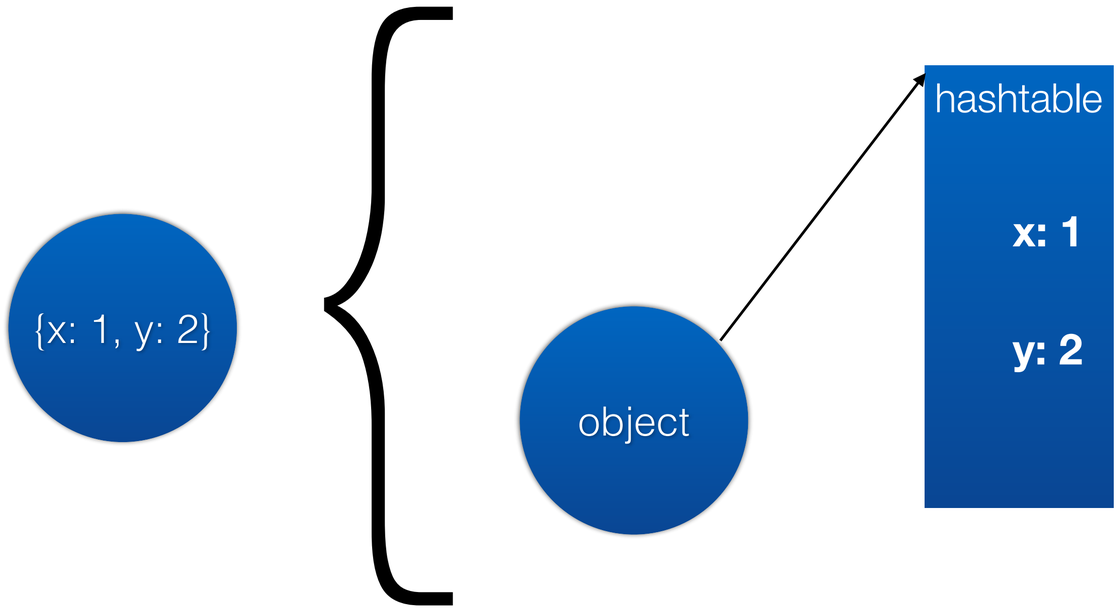

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- Hash codes take time to compute

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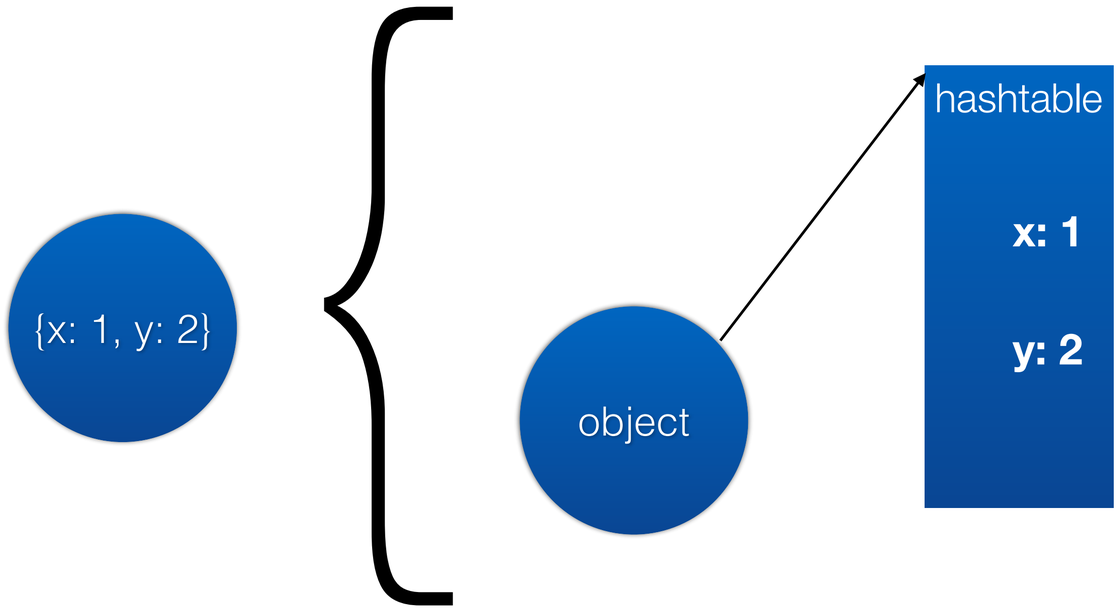

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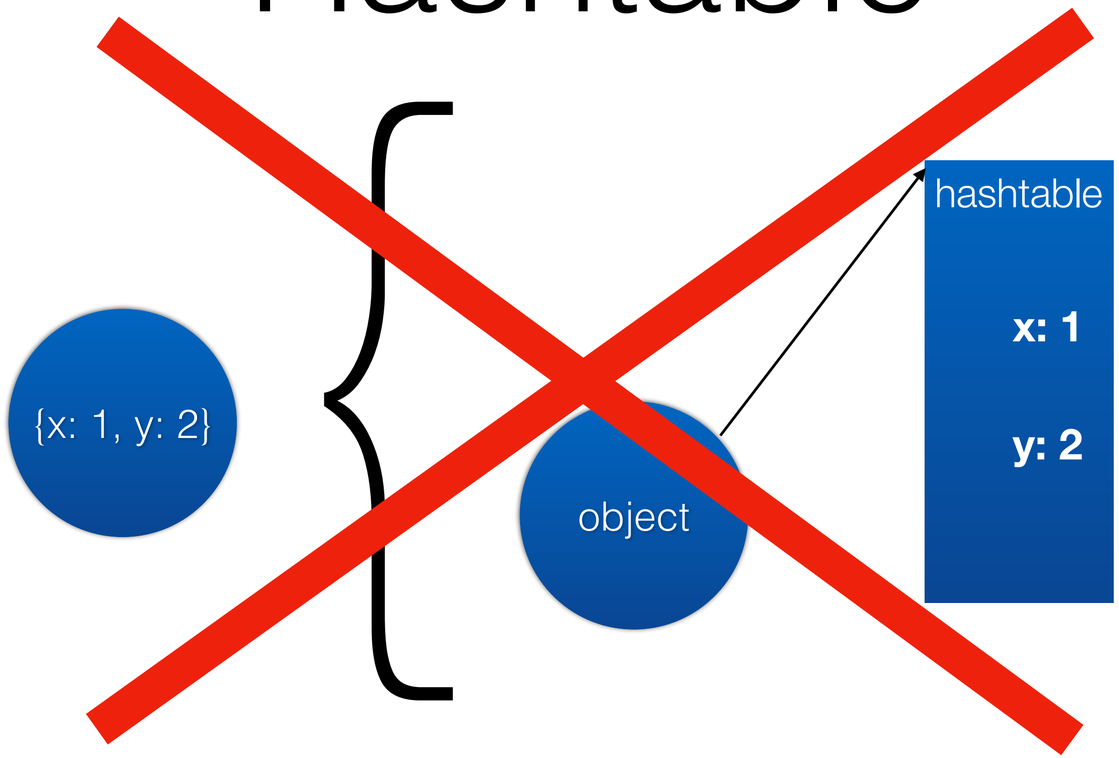

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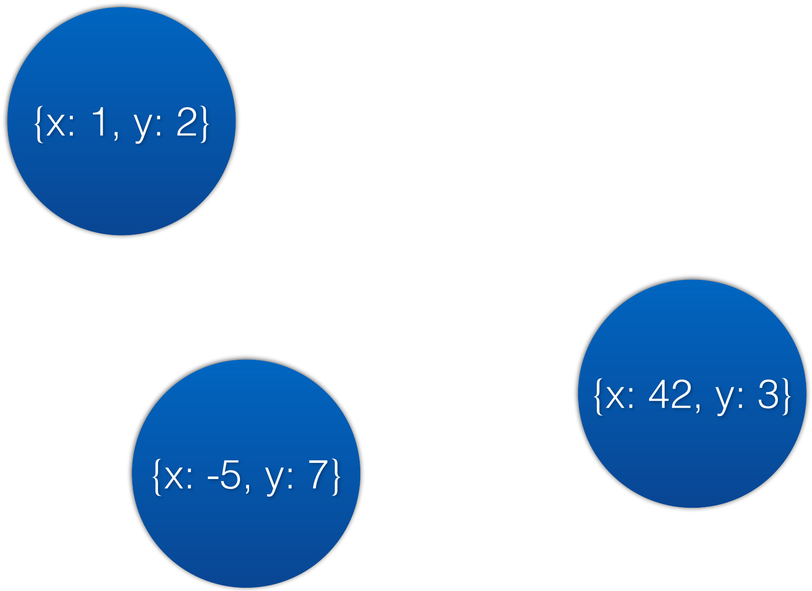
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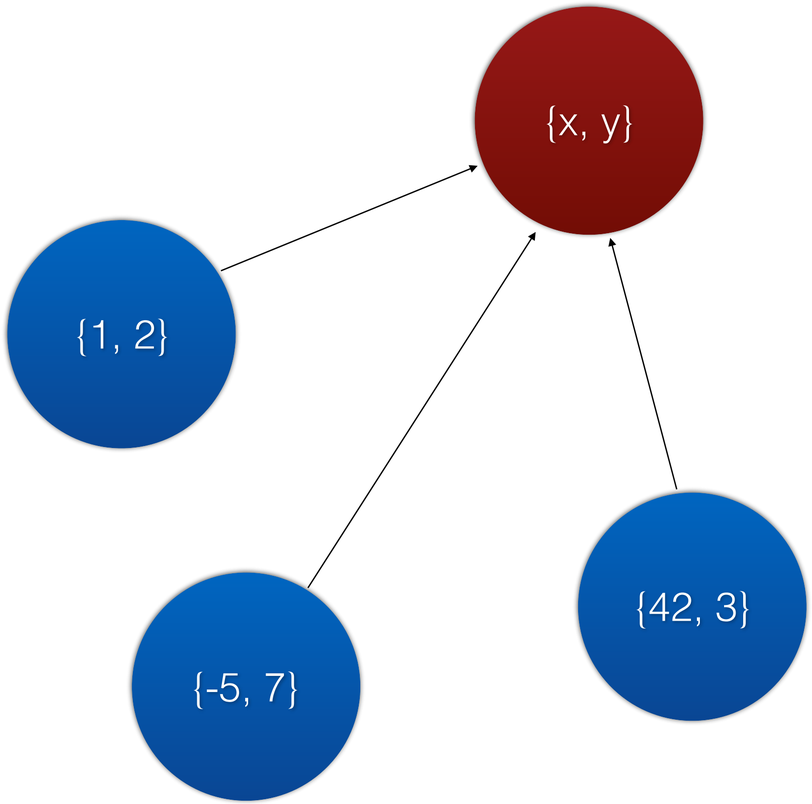
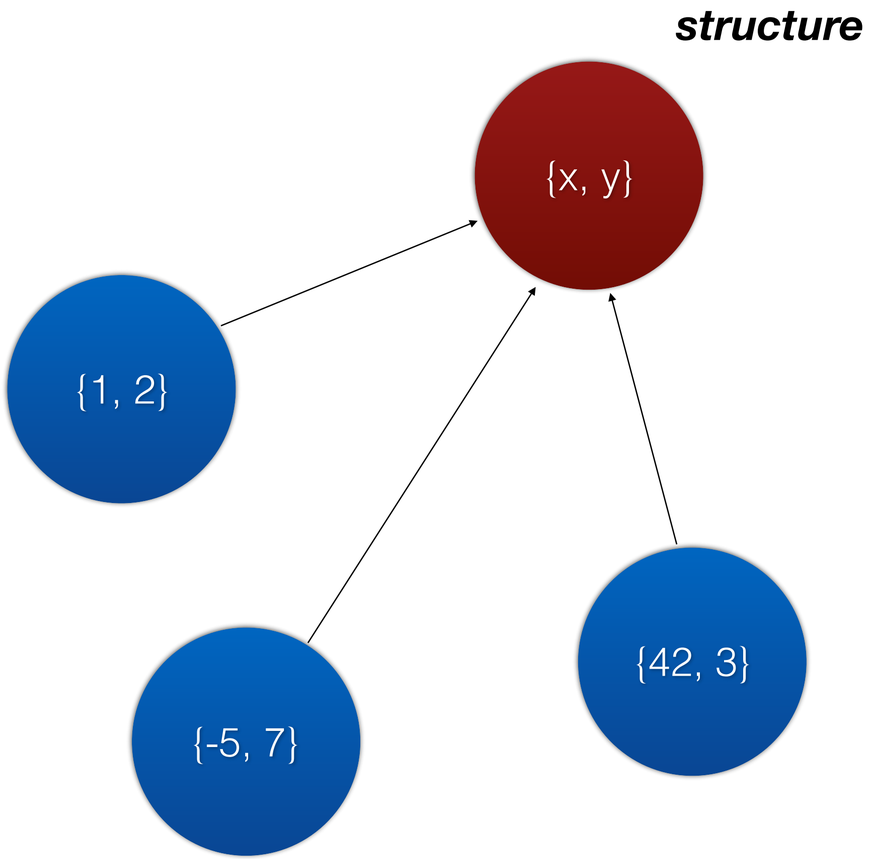
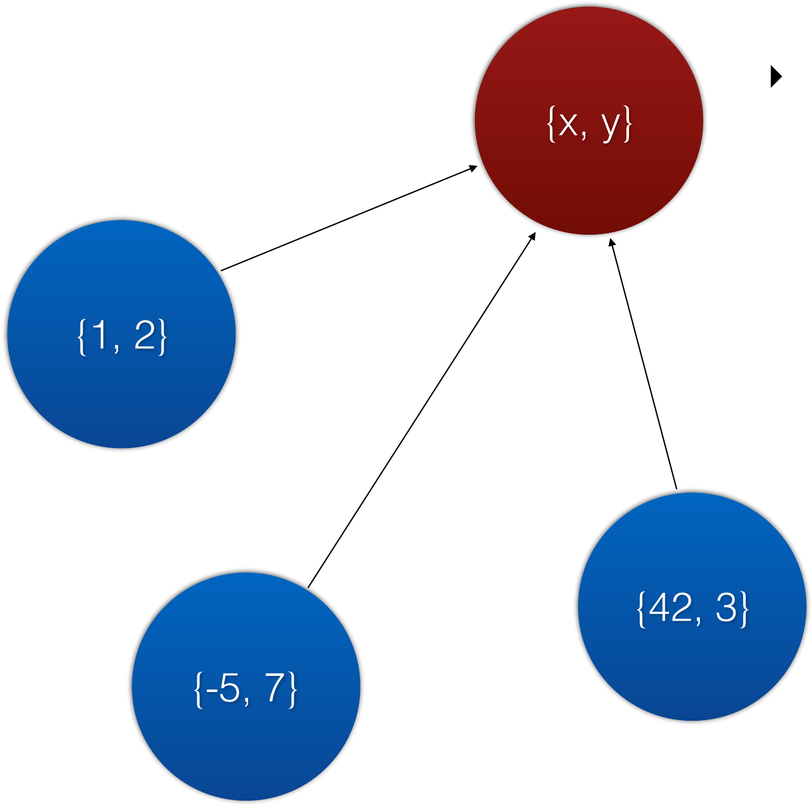
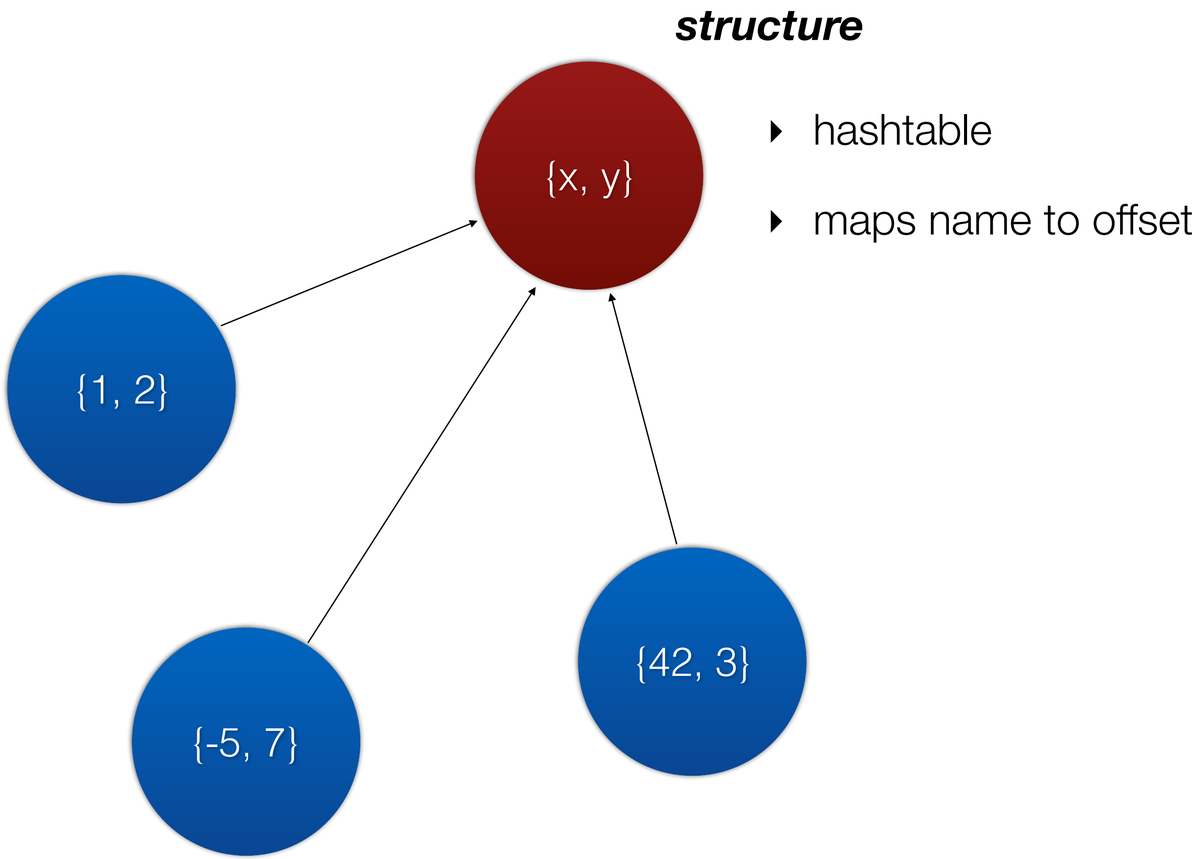

{x, y}
{1, 2}
{-5, 7}
{42, 3}


structure
{x, y}
{1, 2}
{-5, 7}
{42, 3}

structure

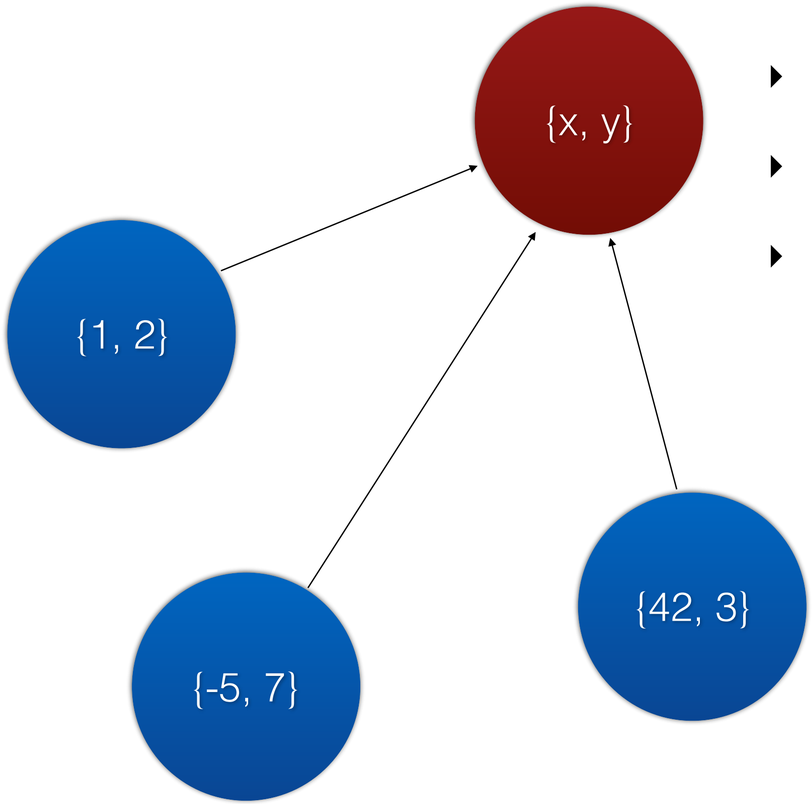
- hashtable





- hashtable
- maps name to offset

structure



- hashtable
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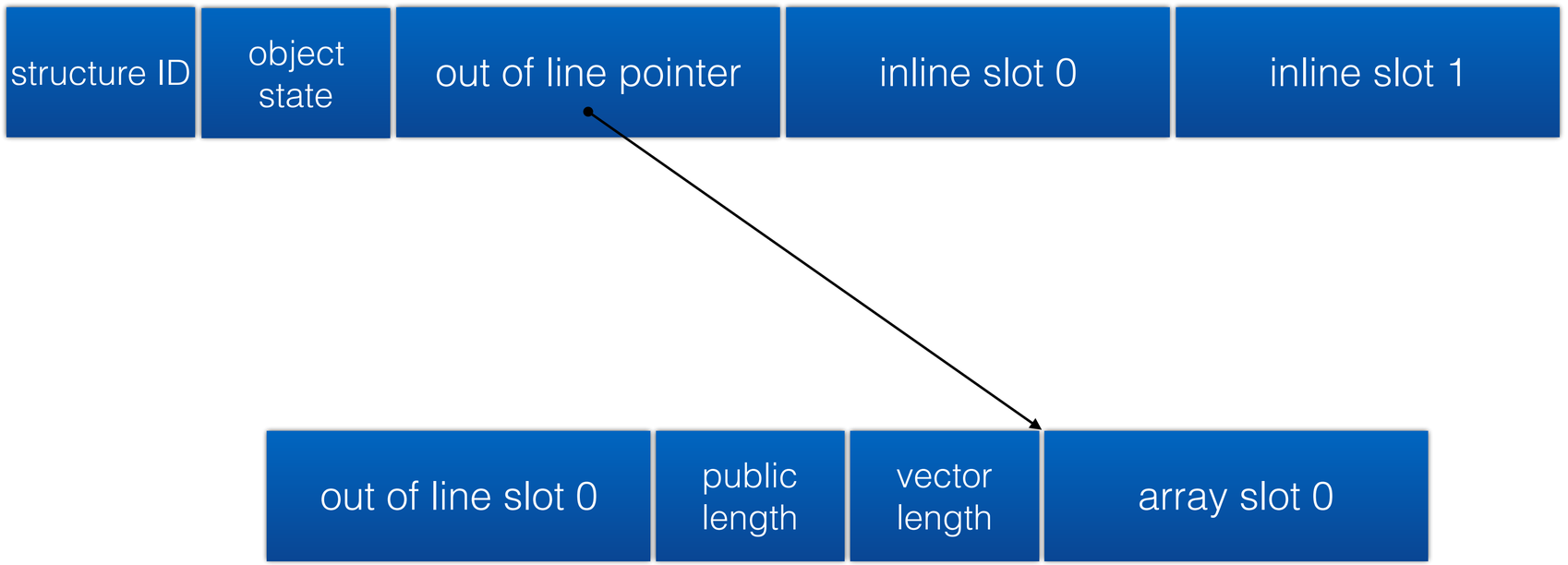
- hash-consed

JSC Object Model



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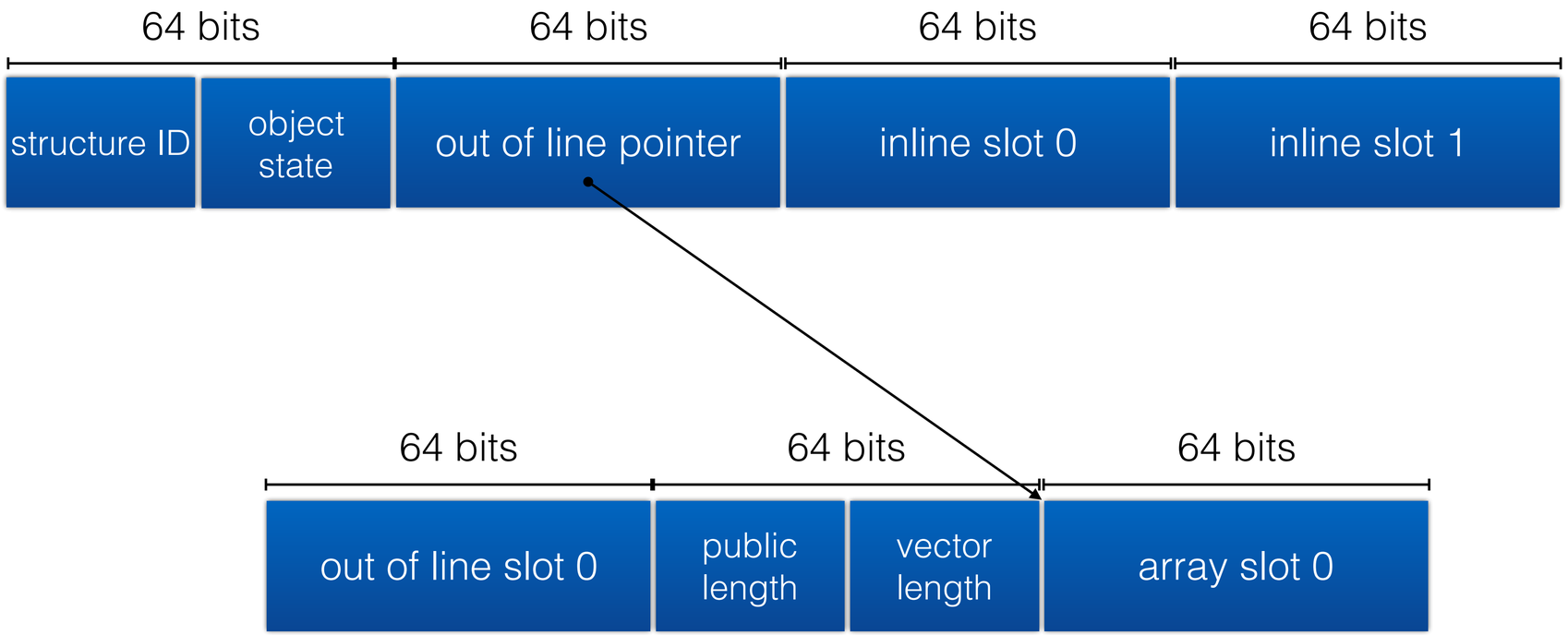

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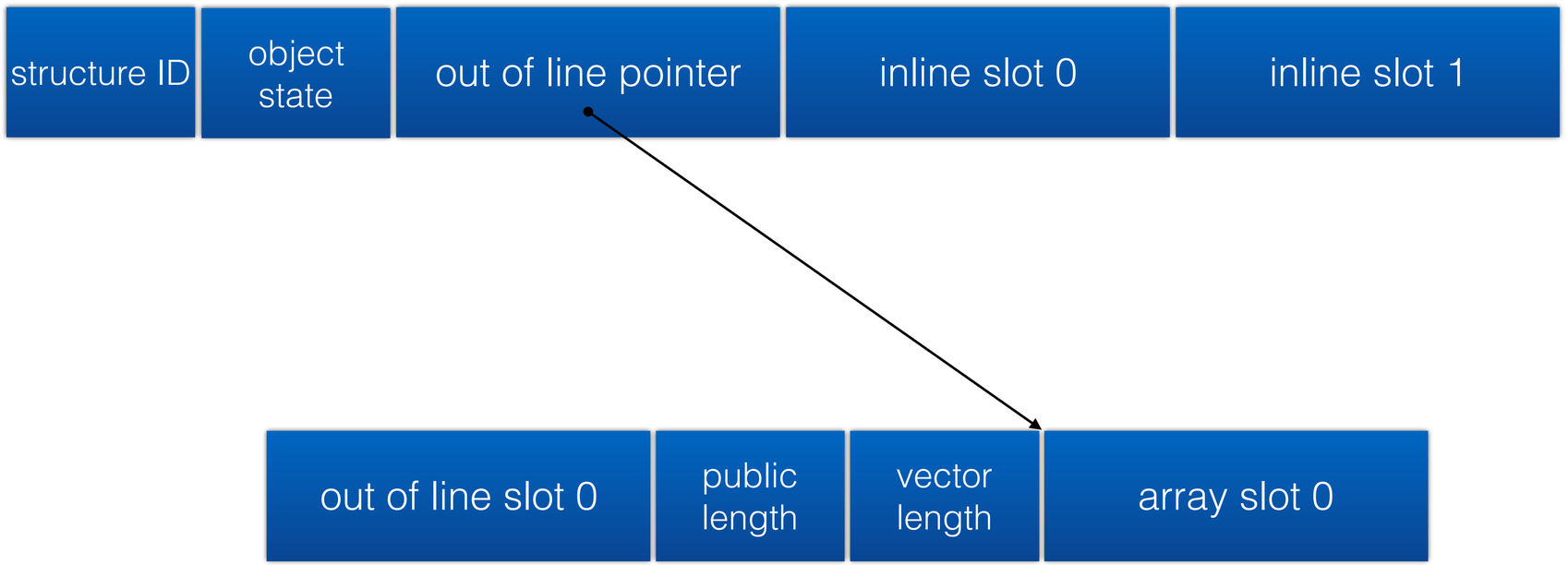

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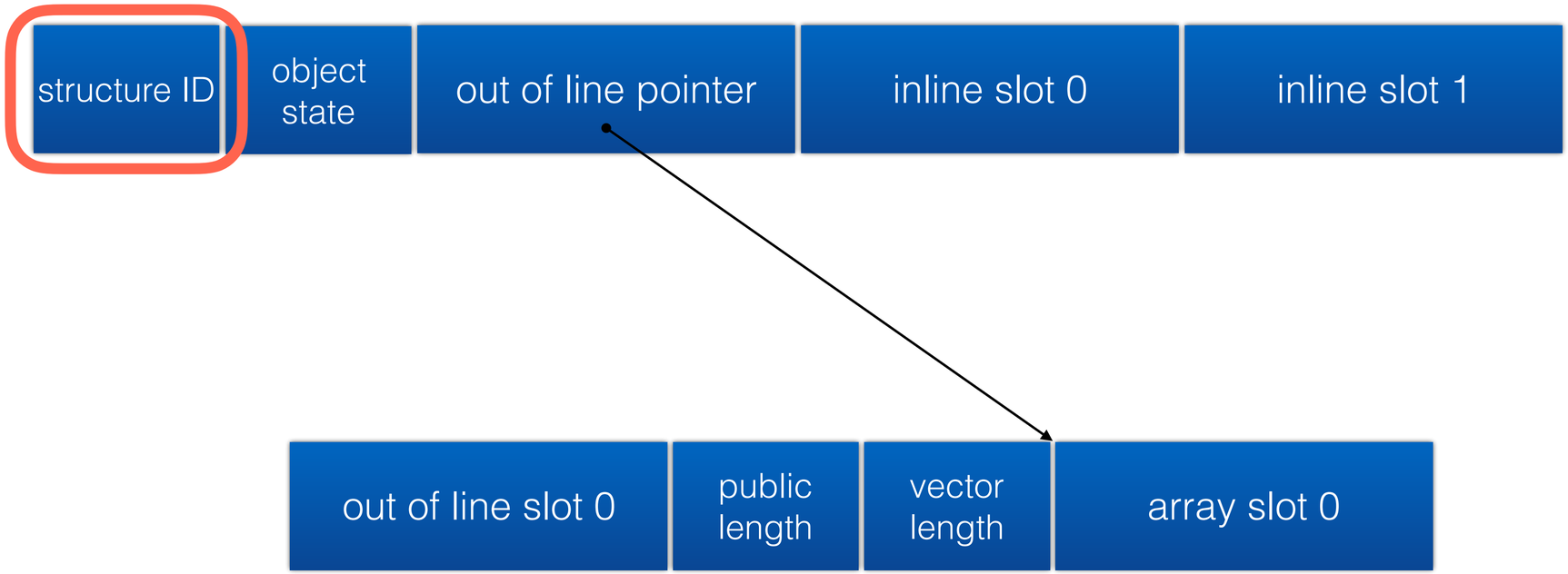

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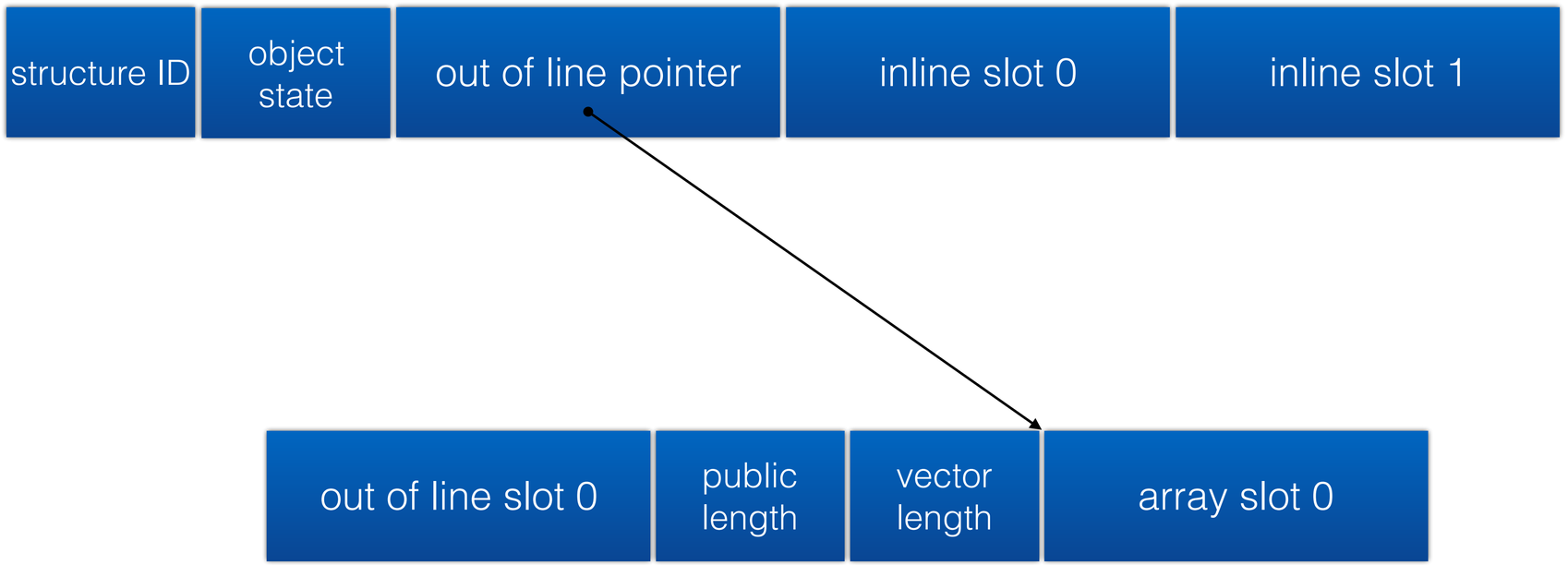

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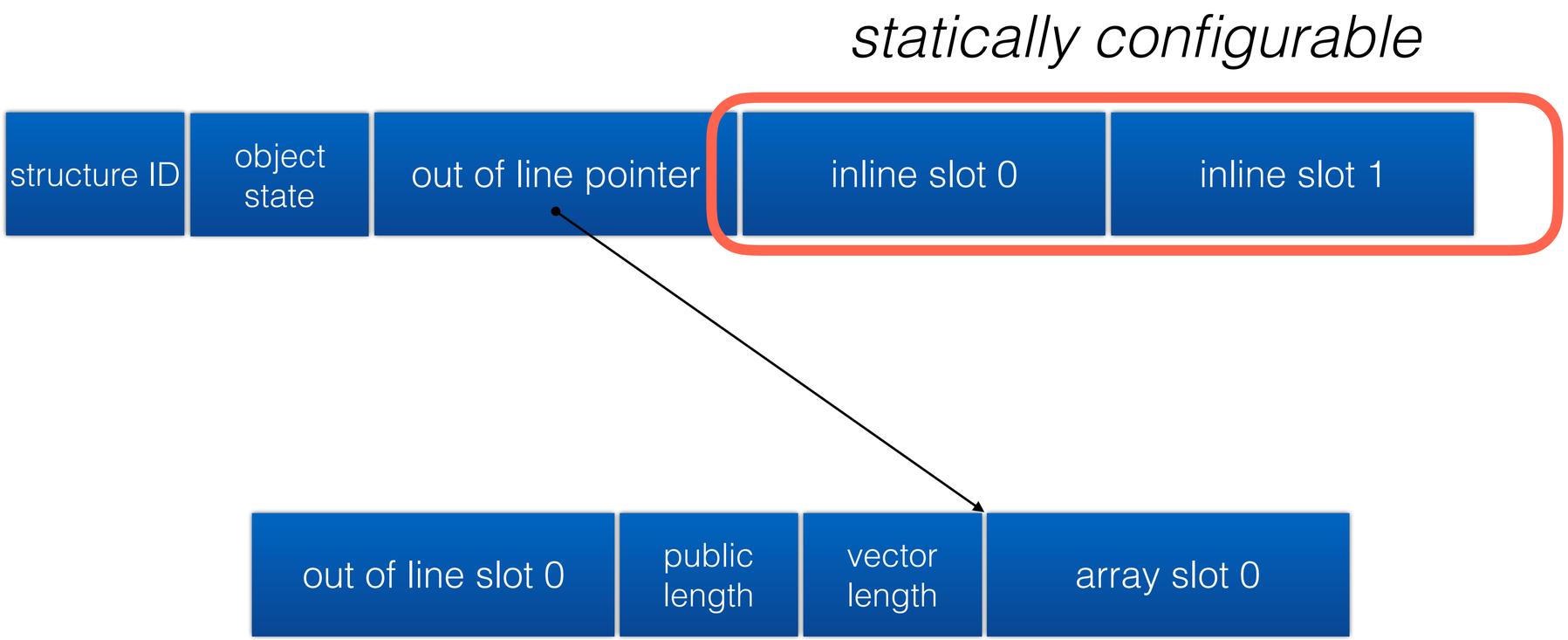
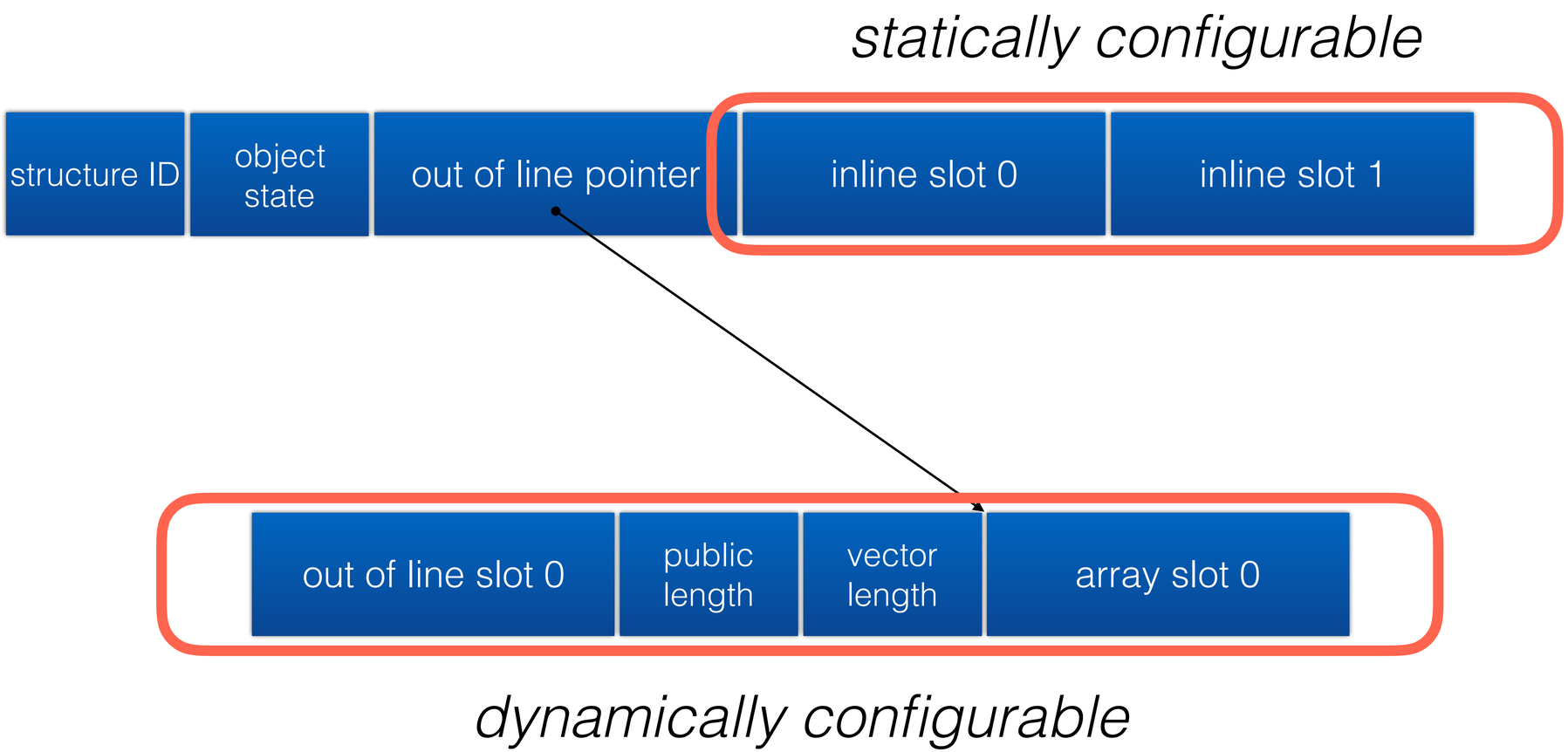


JSC Object Model



Fast JSObject

var o = {x: 5, y: 6};

Fast JSObject

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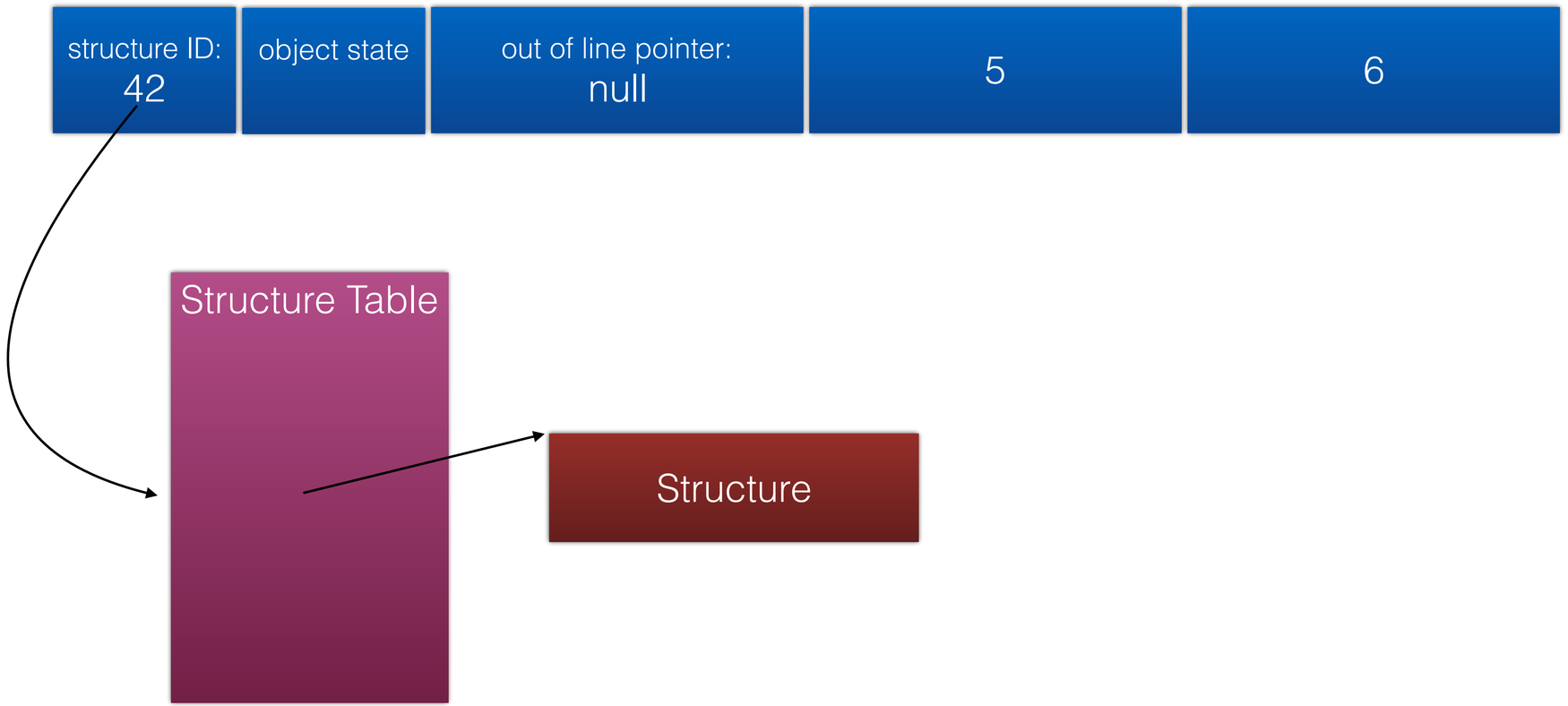
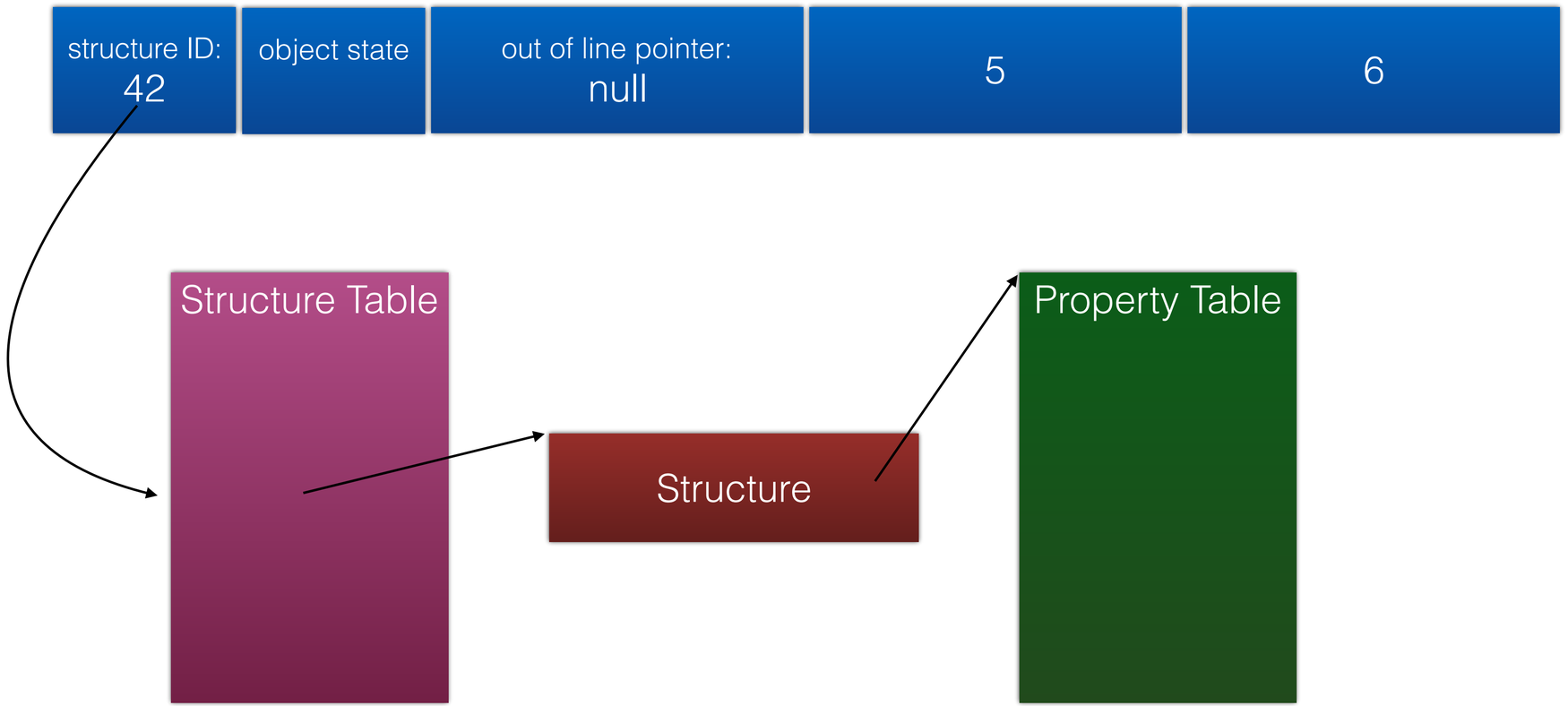


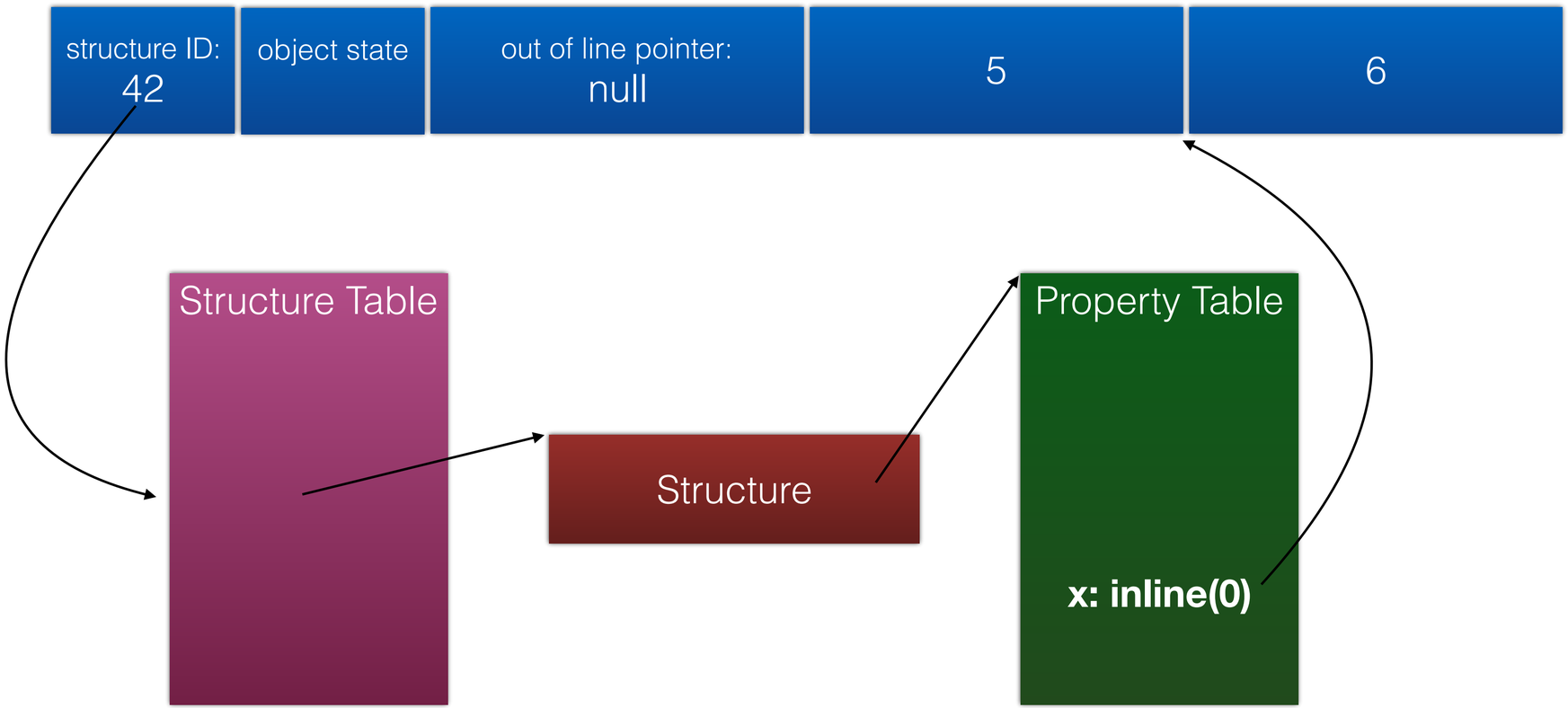
Fast JSObject

var o = {x: 5, y: 6};



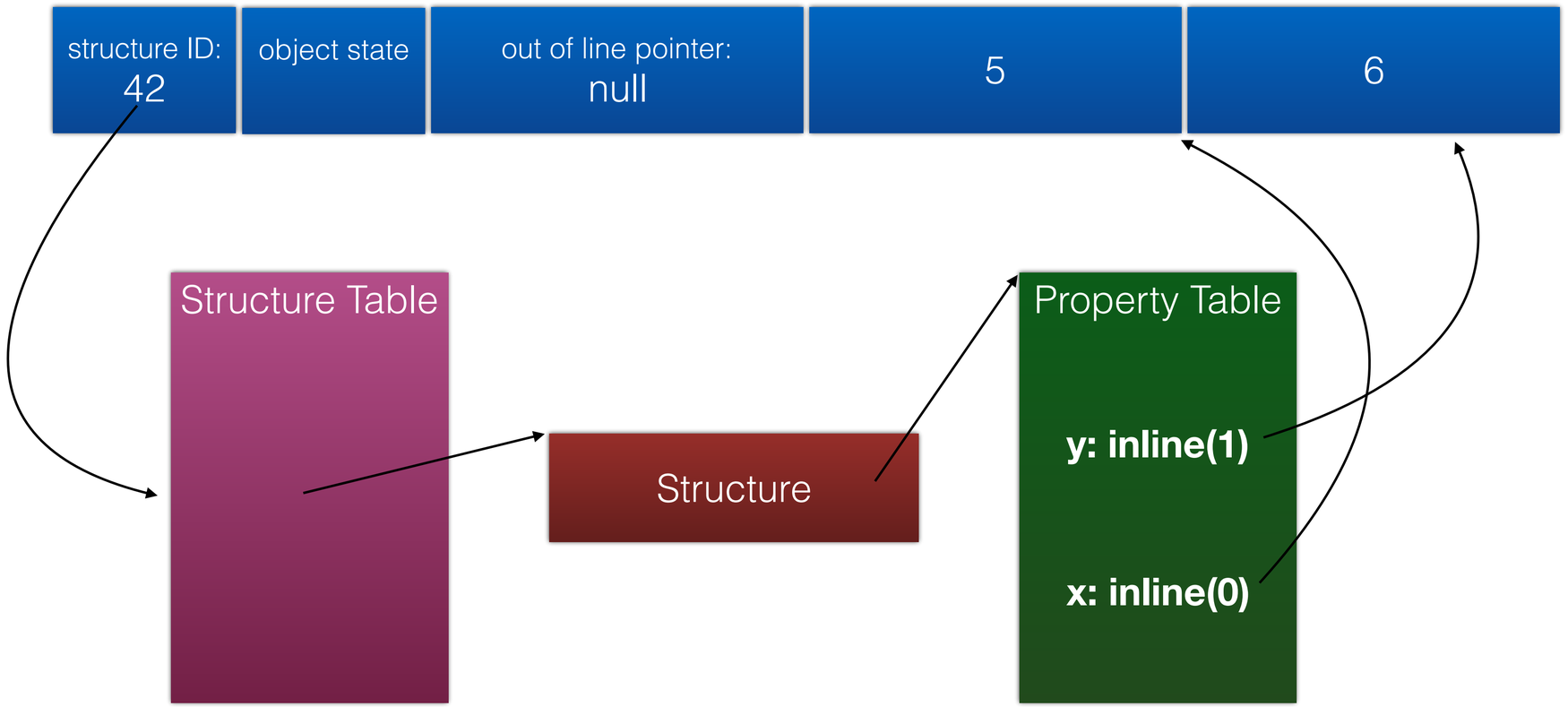
Fast JSObject

var o = {x: 5, y: 6};

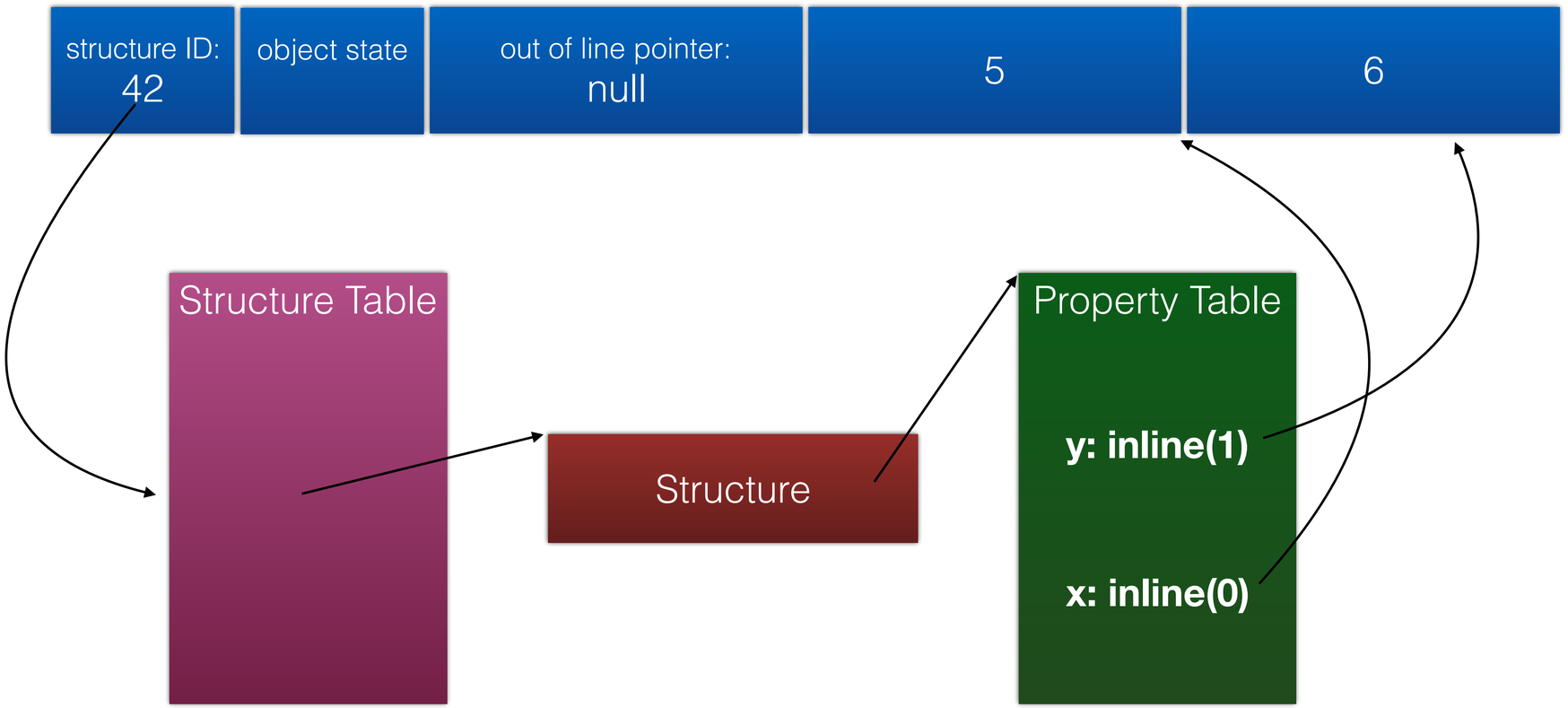


Fast JSObject

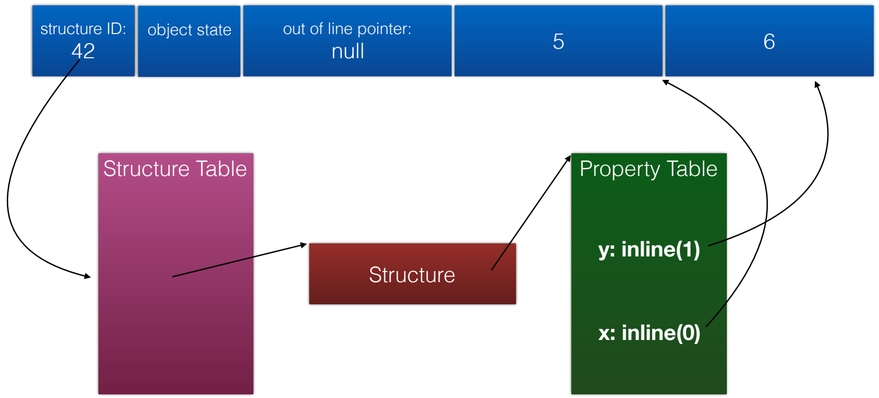
var o = {x: 5, y: 6};



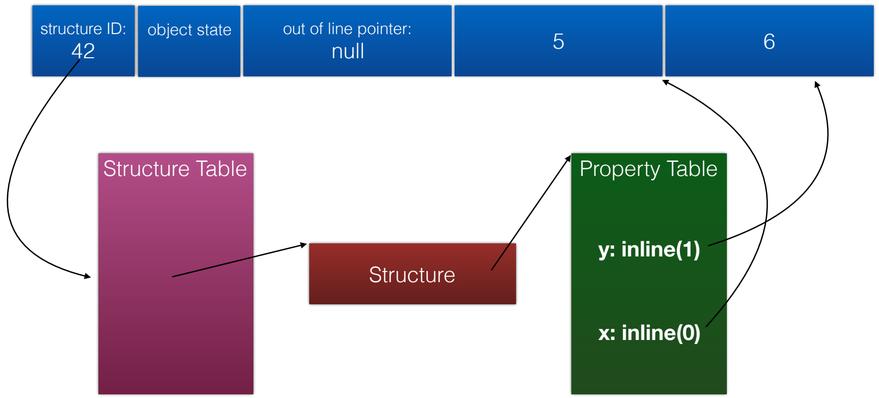
var o = {x: 5, y: 6};


structure ID:
42
object state
out of line pointer:
null
5
6
Structure Table
Structure
Property Table
y: inline(1)
x: inline(0)

var o = {x: 5, y: 6};

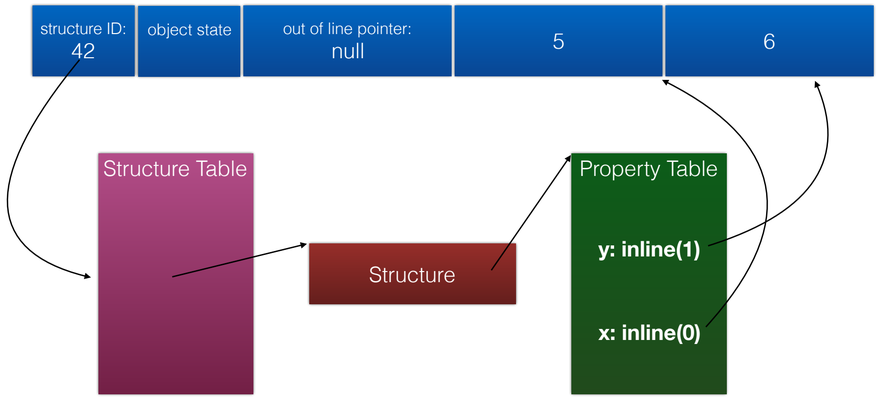

structure ID:
42
object state
out of line pointer:
null
5
6
Structure Table
Structure
Property Table
y: inline(1)
x: inline(0)

var o = {x: 5, y: 6};




```
var v = o.x;
```

var o = {x: 5, y: 6};

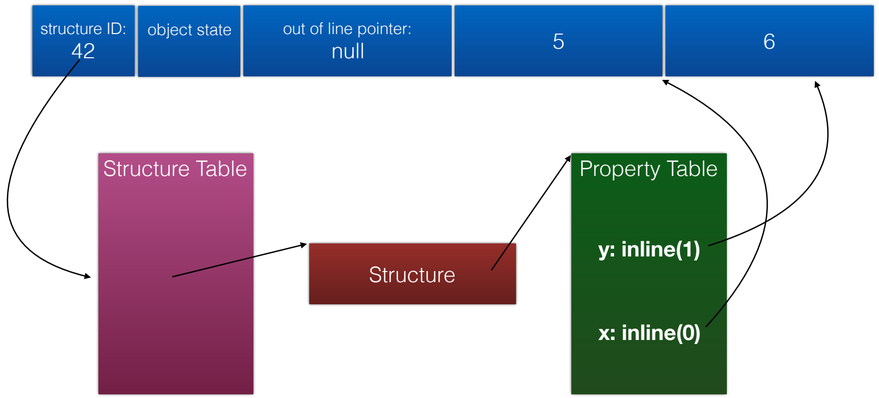



```
var v = o.x;
```

```
if (o->structureID == 42)
    v = o->inlineStorage[0]
else
    v = slowGet(o, “x”)
```

“Inline Cache”

var o = {x: 5, y: 6};




```
var v = o.x;
```

```
if (o->structureID == 42)
    v = o->inlineStorage[0]
else
    v = slowGet(o, “x”)
```

Interpreter Inline Cache

```
get_by_id <result>, <base>, <properyName>
```

Interpreter Inline Cache

```
get_by_id <result>, <base>, <properyName>,
          <cachedStructureID>, <cachedOffset>
```

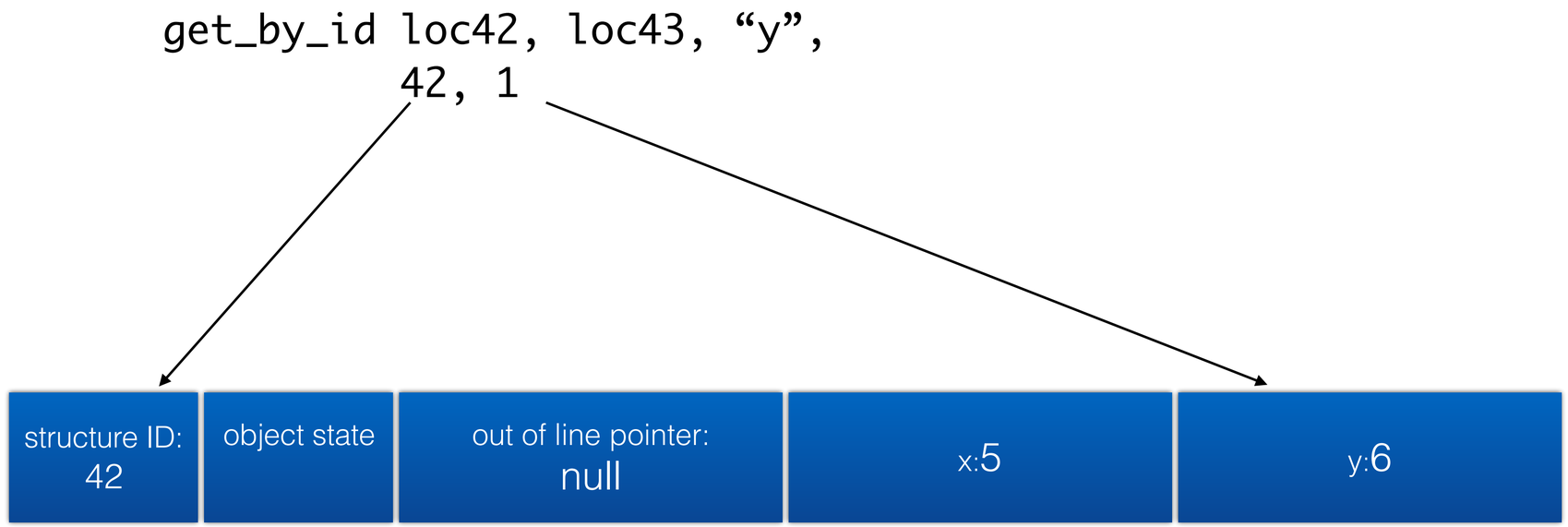
Interpreter Inline Cache

```
get_by_id loc42, loc43, “y”,
          0, 0
```

Interpreter Inline Cache

```
get_by_id loc42, loc43, “y”,
          0, 0
```

Interpreter Inline Cache



JIT Inline Cache

```
0x46f8c30b9b0: mov 0x30(%rbp), %rax
0x46f8c30b9b4: test %rax, %r15
0x46f8c30b9b7: jnz 0x46f8c30ba2c
0x46f8c30b9bd: jmp 0x46f8c30ba2c
0x46f8c30b9c2: o16 nop %cs:0x200(%rax,%rax)
0x46f8c30b9d1: nop (%rax)
0x46f8c30b9d4: mov %rax, -0x38(%rbp)
```

JIT Inline Cache

```
0x46f8c30b9b0: mov 0x30(%rbp), %rax
0x46f8c30b9b4: test %rax, %r15
0x46f8c30b9b7: jnz 0x46f8c30ba2c
0x46f8c30b9bd: jmp 0x46f8c30ba2c
0x46f8c30b9c2: o16 nop %cs:0x200(%rax,%rax)
0x46f8c30b9d1: nop (%rax)
0x46f8c30b9d4: mov %rax, -0x38(%rbp)
```

JIT Inline Cache

```
0x46f8c30b9b0: mov 0x30(%rbp), %rax
0x46f8c30b9b4: test %rax, %r15
0x46f8c30b9b7: jnz 0x46f8c30ba2c
0x46f8c30b9bd: jmp 0x46f8c30ba2c
0x46f8c30b9c2: o16 nop %cs:0x200(%rax,%rax)
0x46f8c30b9d1: nop (%rax)
0x46f8c30b9d4: mov %rax, -0x38(%rbp)
```

JIT Inline Cache

```
0x46f8c30b9b0: mov 0x30(%rbp), %rax
0x46f8c30b9b4: test %rax, %r15
0x46f8c30b9b7: jnz 0x46f8c30ba2c
0x46f8c30b9bd: cmp $0x2a, (%rax)
0x46f8c30b9c3: jnz 0x46f8c30ba2c
0x46f8c30b9c9: mov 0x18(%rax), %rax
0x46f8c30b9cd: nop 0x200(%rax)
0x46f8c30b9d4: mov %rax, -0x38(%rbp)
```

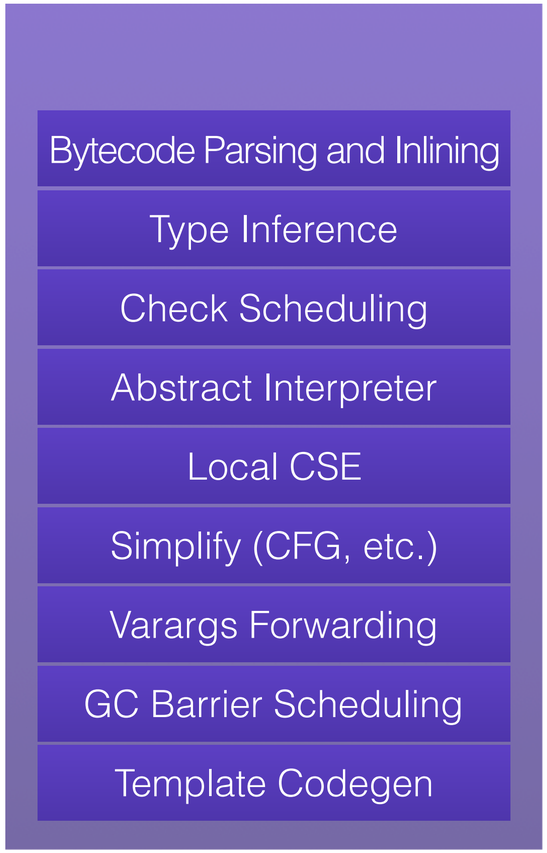
Agenda

- High Level Overview
- Tiers
- Optimization Techniques
  - Counting Triggers
  - OSR (On Stack Replacement)
  - Profiling
  - Speculation
  - Inline Caching
  - Other Compiler Optimizations

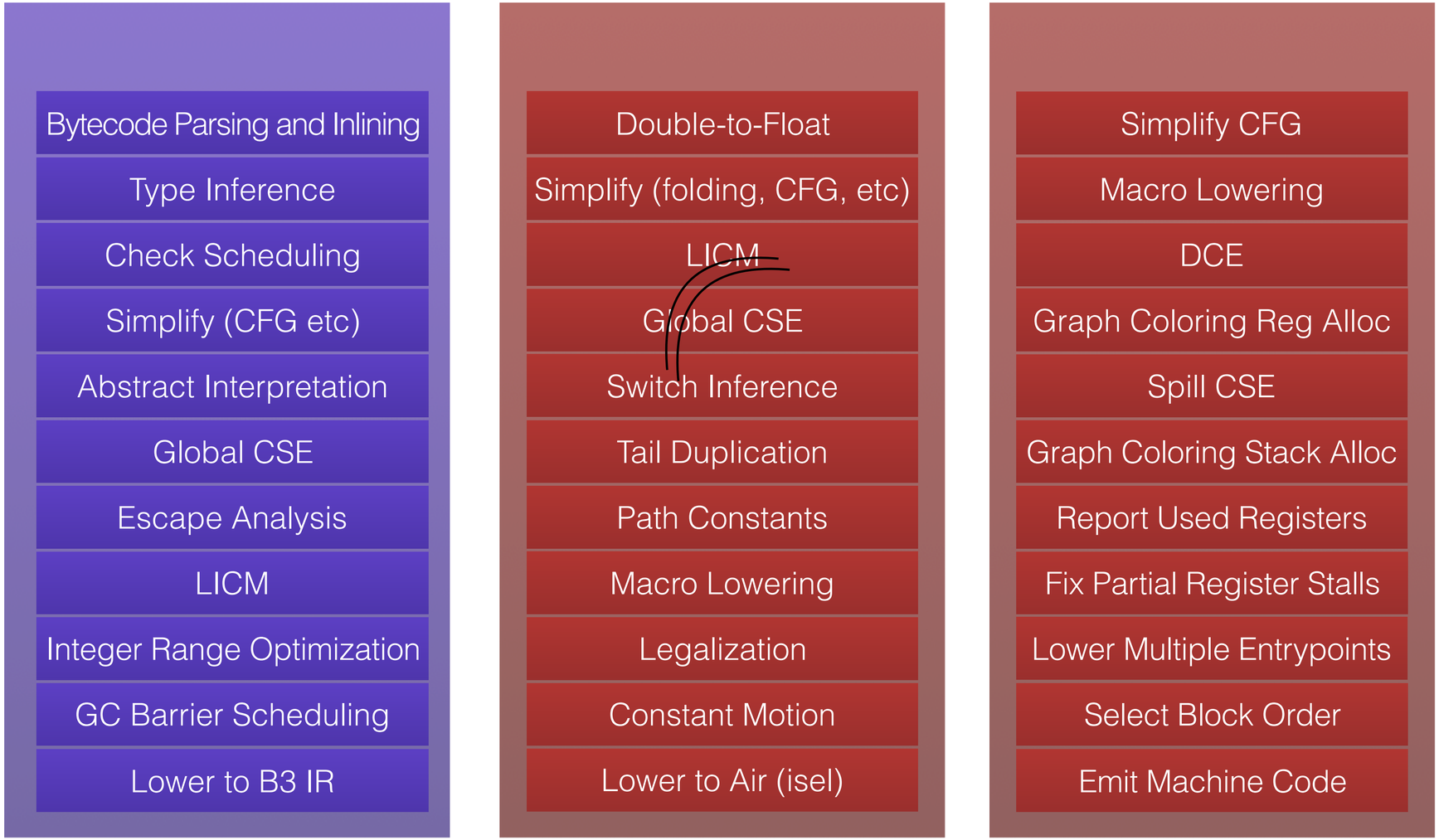
Optimizations

- Generatorification
- Inlining
- Strength Reduction
- CSE (local and global)
- LICM
- Type/Bounds/Overflow Check Removal
- Object Allocation Sinking
- Arguments/Varargs Elimination
- Sparse Conditional Constant Propagation
- Barrier Placement
- Strength Reduction
- Tail Duplication
- Switch Inference
- Float Inference
- DCE
- Register Allocation
  - Linear Scan
  - Briggs
  - Iterated Register Coalescing
- Stack Allocation

DFG optimization pipeline



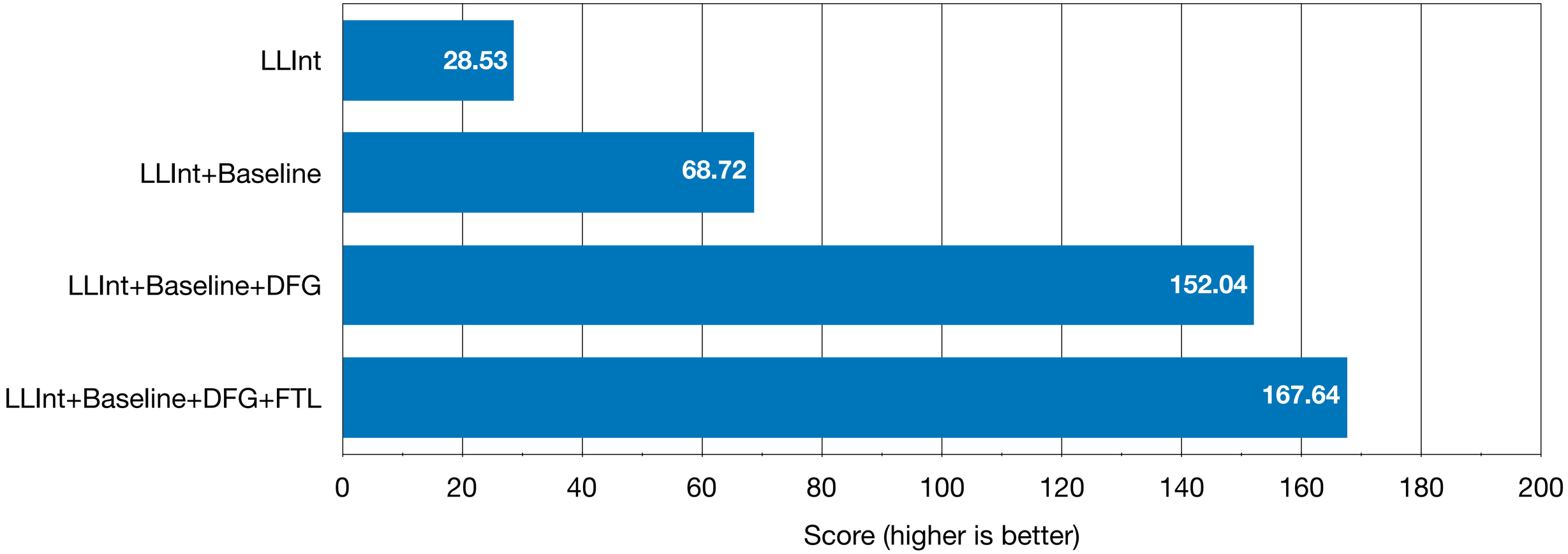
FTL optimization pipeline



Results

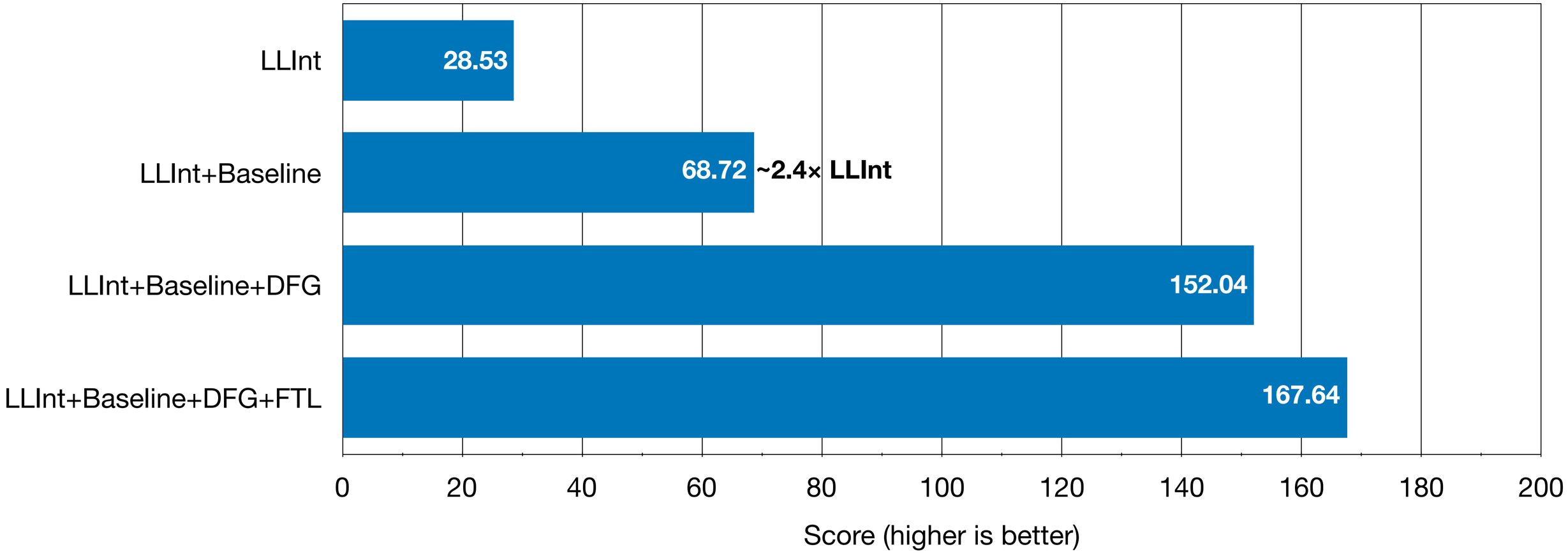
JetStream 2 Score

on my computer one day



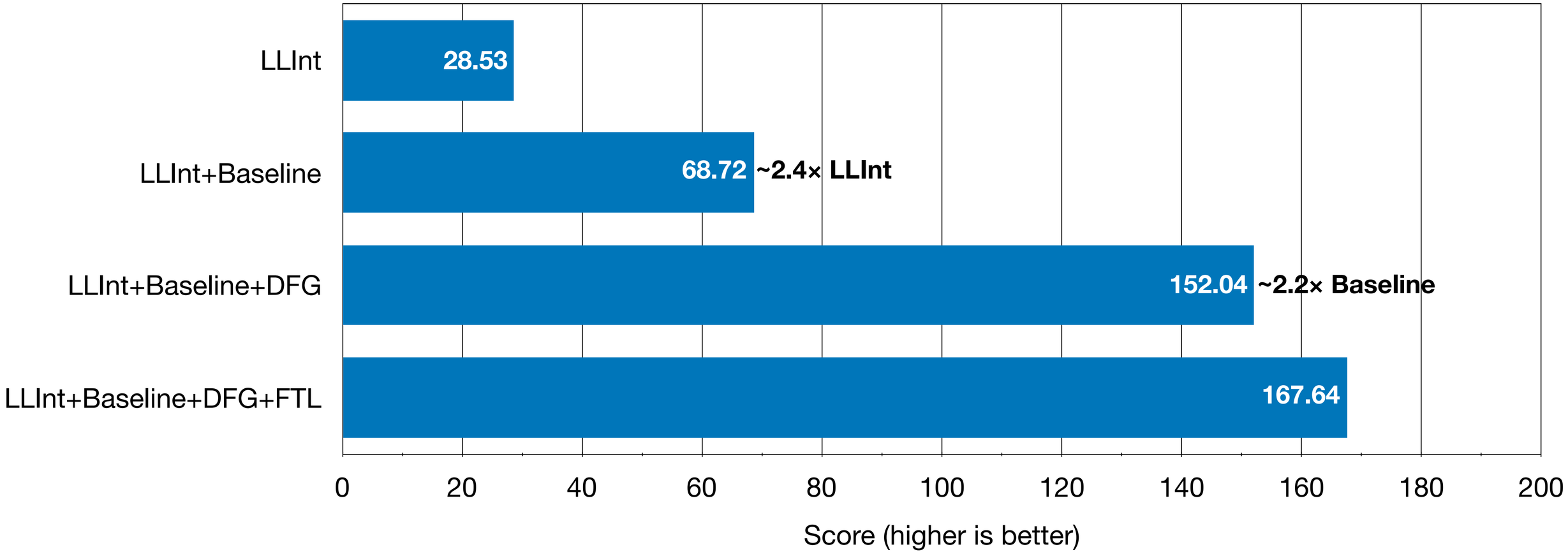
JetStream 2 Score

on my computer one day



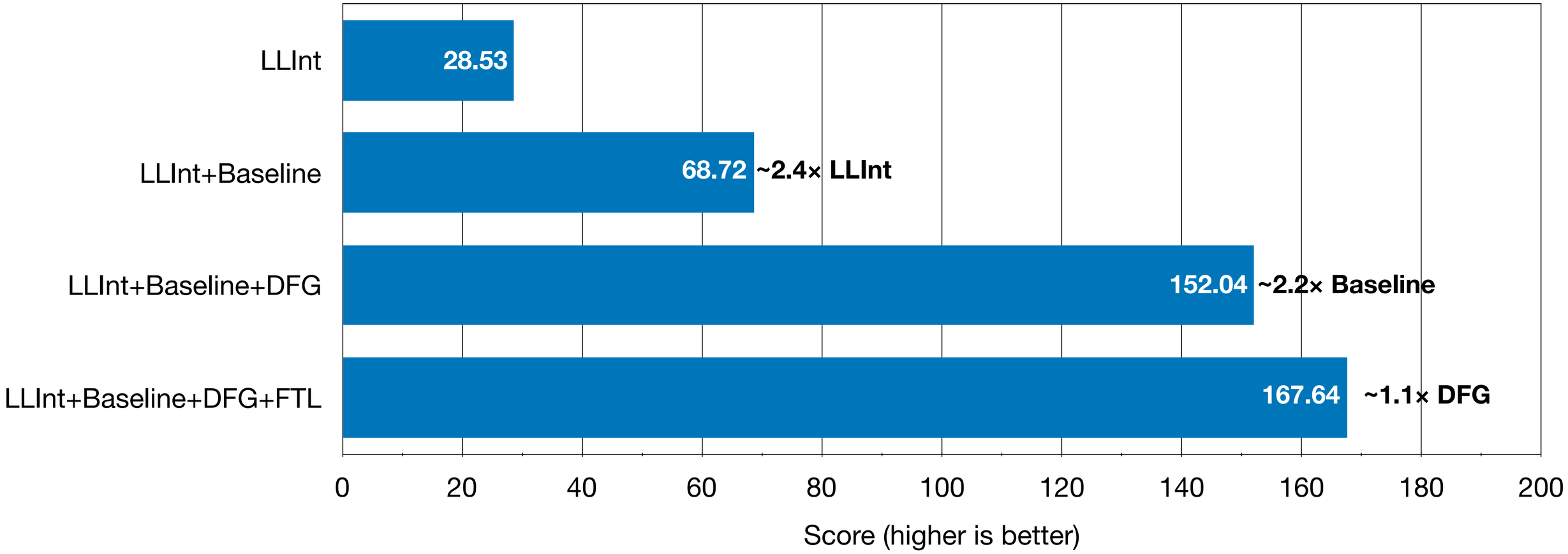
JetStream 2 Score

on my computer one day



JetStream 2 Score

on my computer one day



Questions?

JavaScriptCore, Many Compilers Make this Engine Perform

Michael Saboff
Apple Inc.