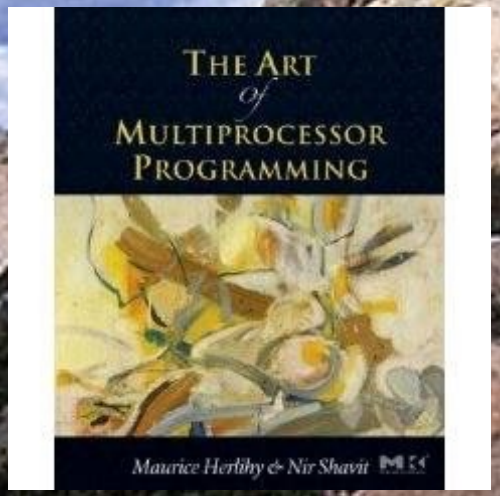
Data Parallelism from a Multicore Perspective

Hydra
Summer 2021



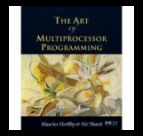
Maurice Herlihy
Brown University

Did You Ever Wonder …

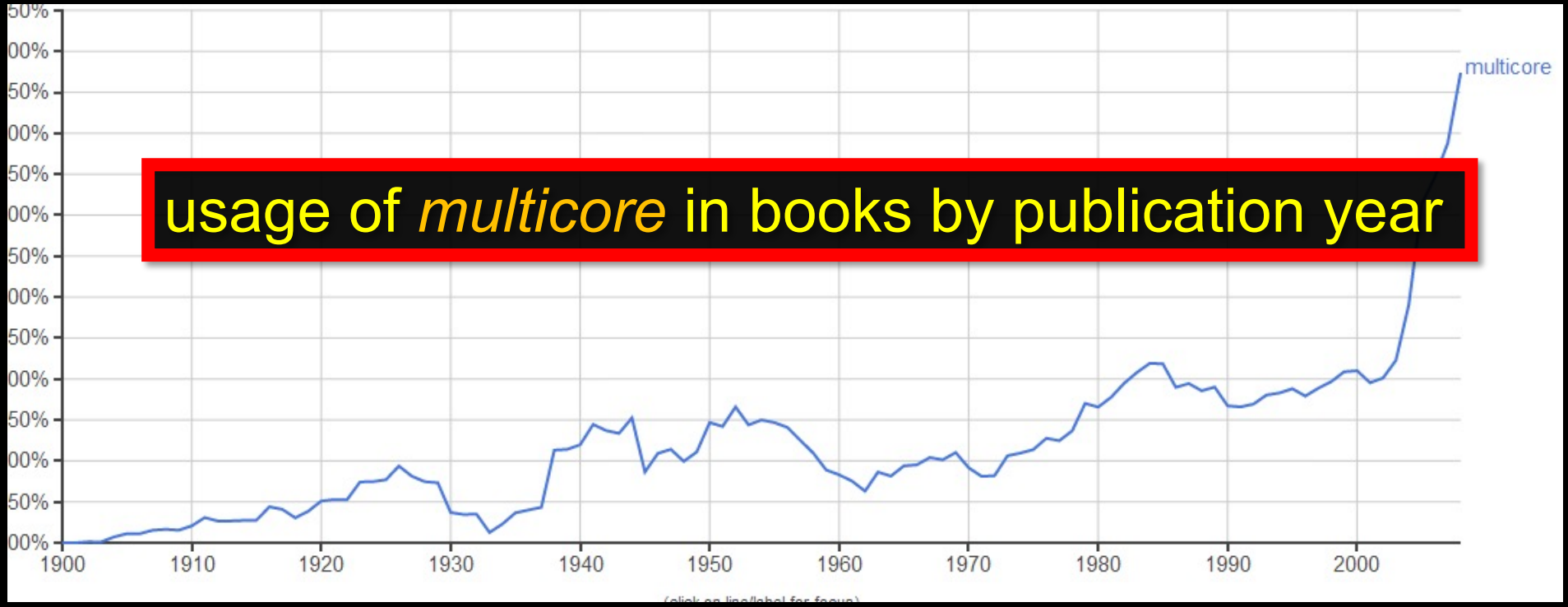
When did the term *multicore* become popular?

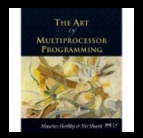
"A multi-core processor is a single computing component with two or more independent actual central processing units, which are the units that read and execute program instructions."

wikipedia



Let's Ask Google Ngram!





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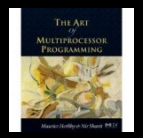

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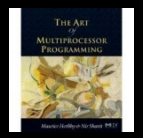

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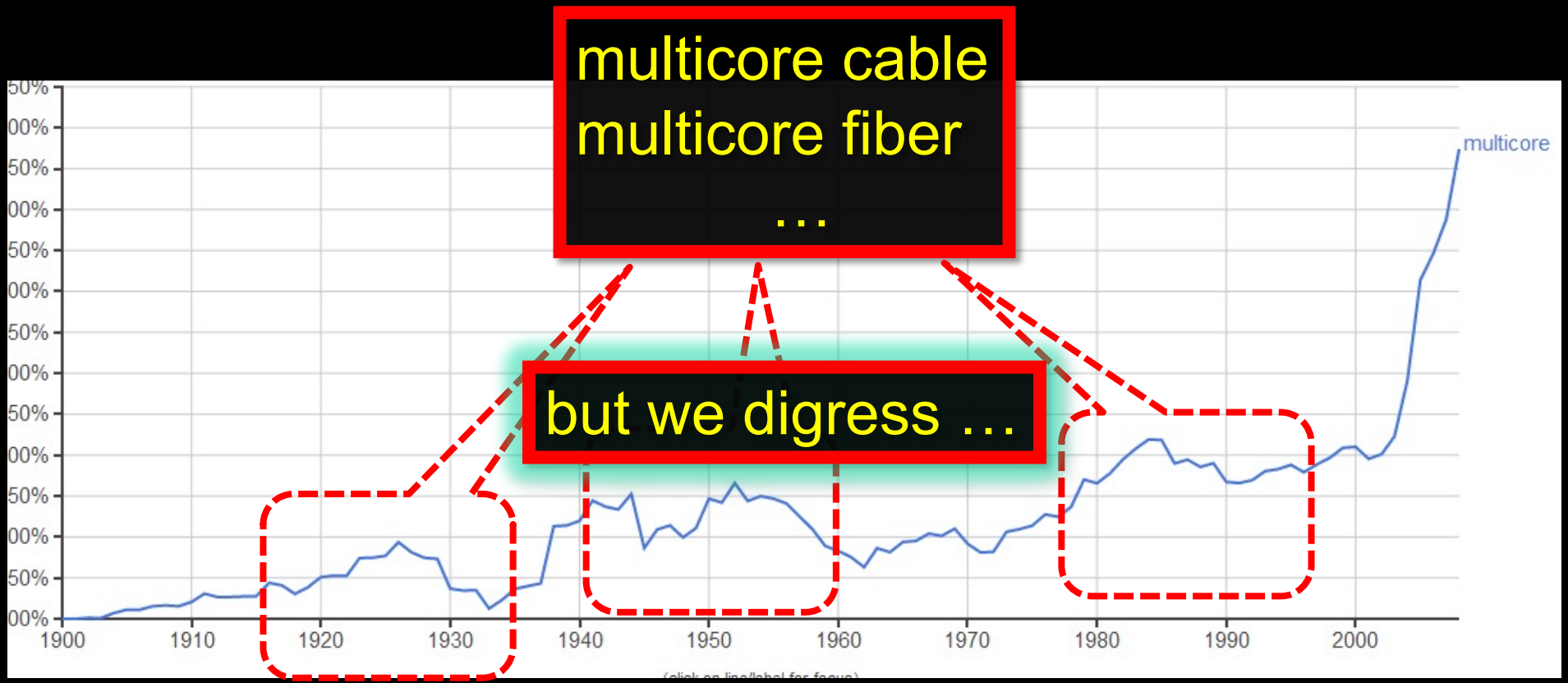
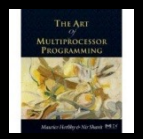
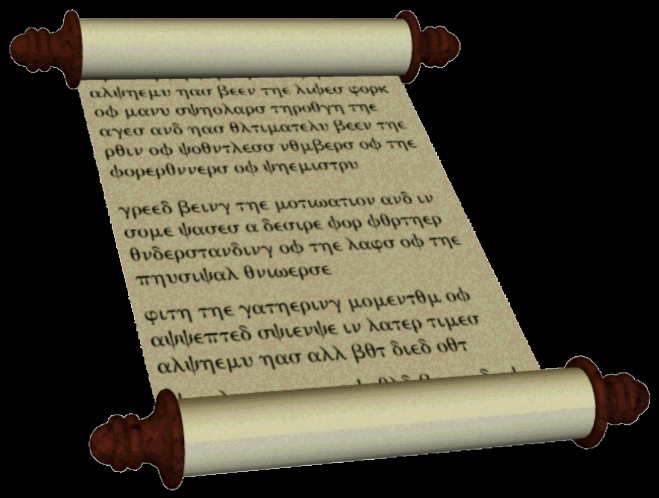
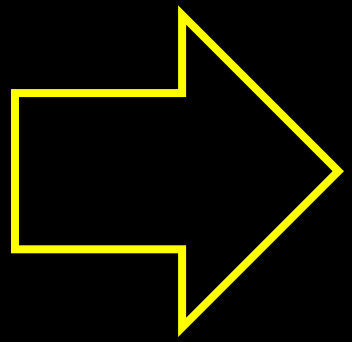




WordCount





alpha → 8

bravo → 3

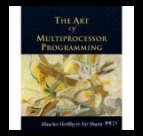
charlie → 9

…

zulu → 1

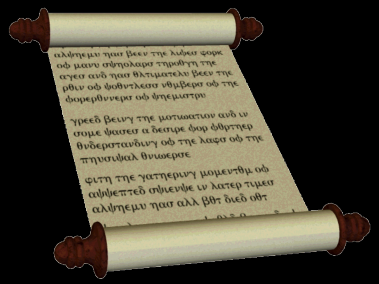
easy to do sequentially …

what about in parallel?

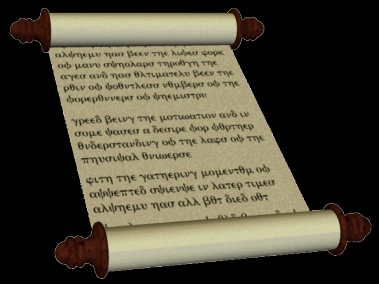


MapReduce

split text among *mapping* threads

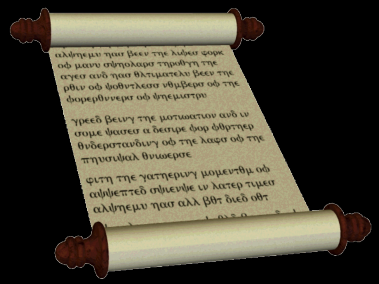


chapter 1

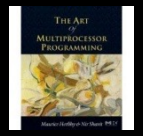


chapter 2

...



chapter *k*

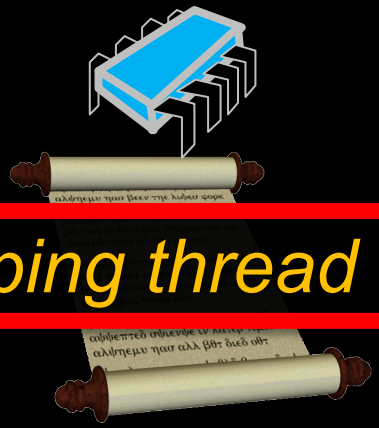


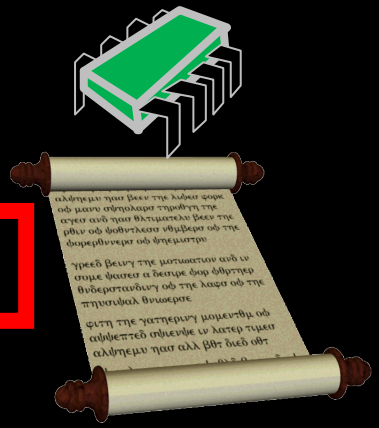
Map Phase

must count words!

must count words!

must count words!





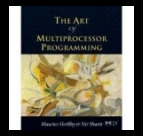
a *mapping thread* per chapter

…

chapter 1

chapter 2

chapter *k*



Map Phase

alpha → 9
juliet → 2,
alpha → 1
tango → 4

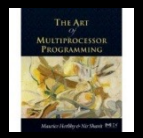
each mapper thread produces a *stream* …

of *key-value* pairs …

key: word

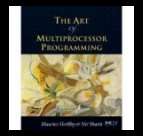
value: local count

chapter 1



Mapper Class

```
abstract class Mapper<IN, K, V>
    extends RecursiveTask<Map<K, V>> {
  IN input;
  public void setInput(IN anInput) {
    input = anInput;
  }
}
```



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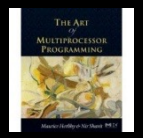
input: document fragment



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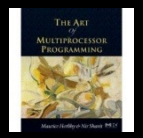
key: individual word



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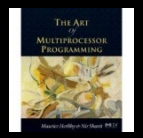
value: local count



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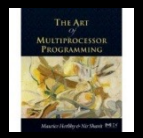
```

a task that runs in parallel with other tasks



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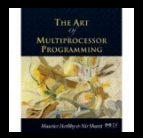
```

produces a map: word → count



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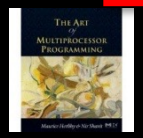
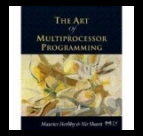
```

initialize input: which document fragment?



WordCount Mapper

```
class WordCountMapper extends
  mapreduce.Mapper<
      List<String>, String, Long
    > {
  …
  }
```



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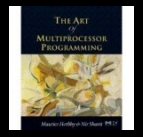
document fragment is list of words



WordCount Mapper

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class WordCountMapper extends
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        List<String>, String, Long
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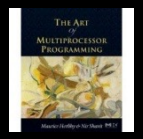
```

document fragment is list of words

map each word …



WordCount Mapper

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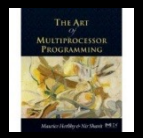
```

document fragment is list of words

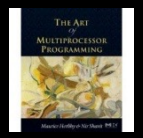
map each word …

to its count in the fragment



WordCount Mapper

```
Map<String,Long> compute() {
  Map<String,Long> map = new HashMap<>();
      for (String word : input) {
        map.merge(word,
                  1L,
                  (x, y) -> x + y);
      }
      return map;
    }
  }
```



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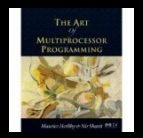
```

the `compute()` method constructs the local word count



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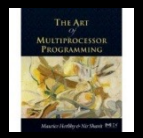
```

create a map to hold the output



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    }
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  }
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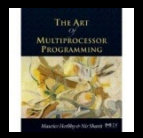
```

examine each word in the document fragment



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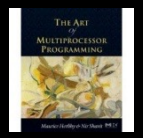
      }
      return map;
    }
  }
```

increment that word's count in the map



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      for (String word : input) {
        map.merge(word,
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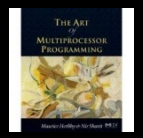
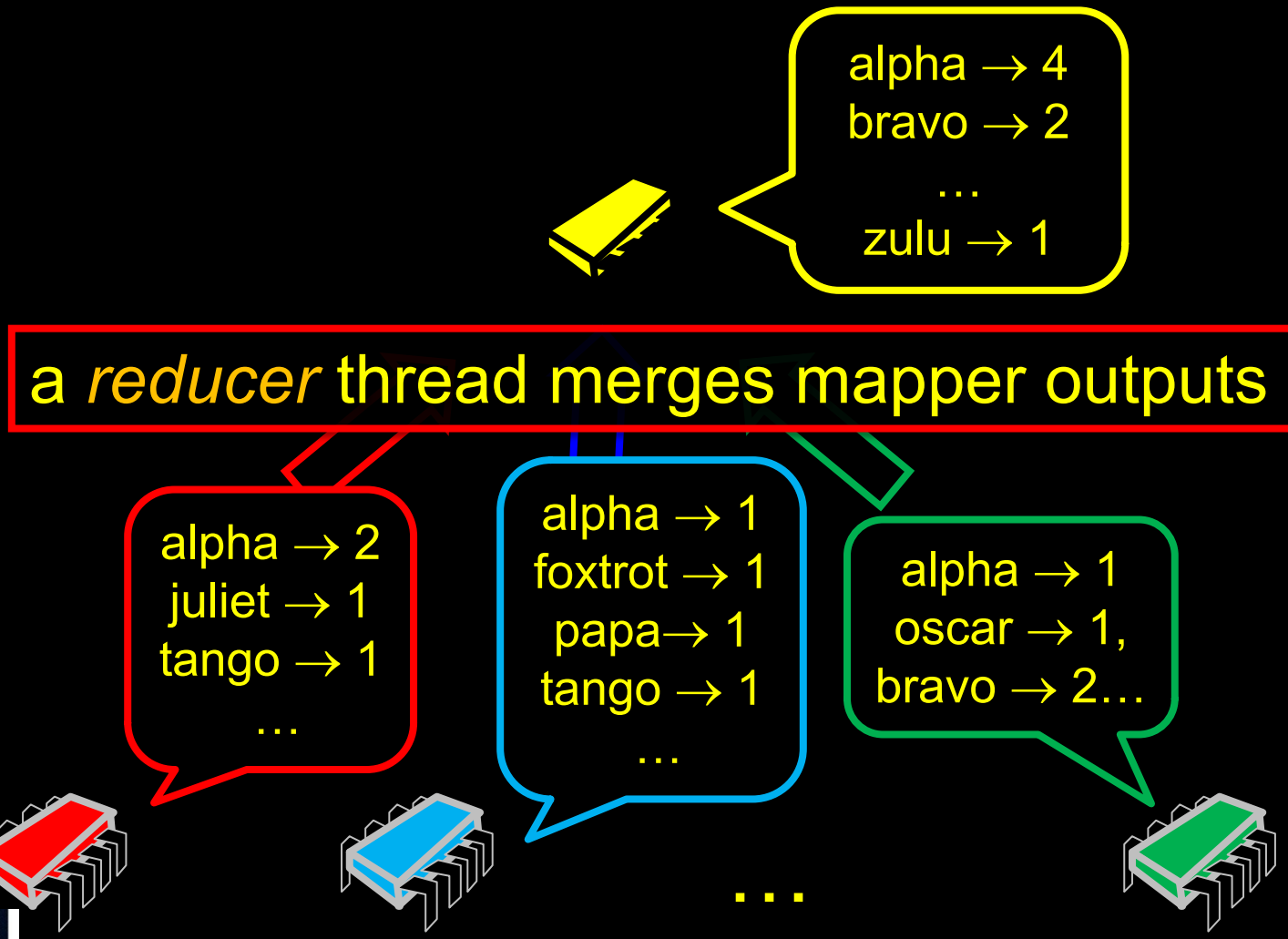
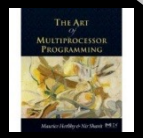
      }
      return map;
    }
  }
```

when the local count is complete, return the map



Reduce Phase





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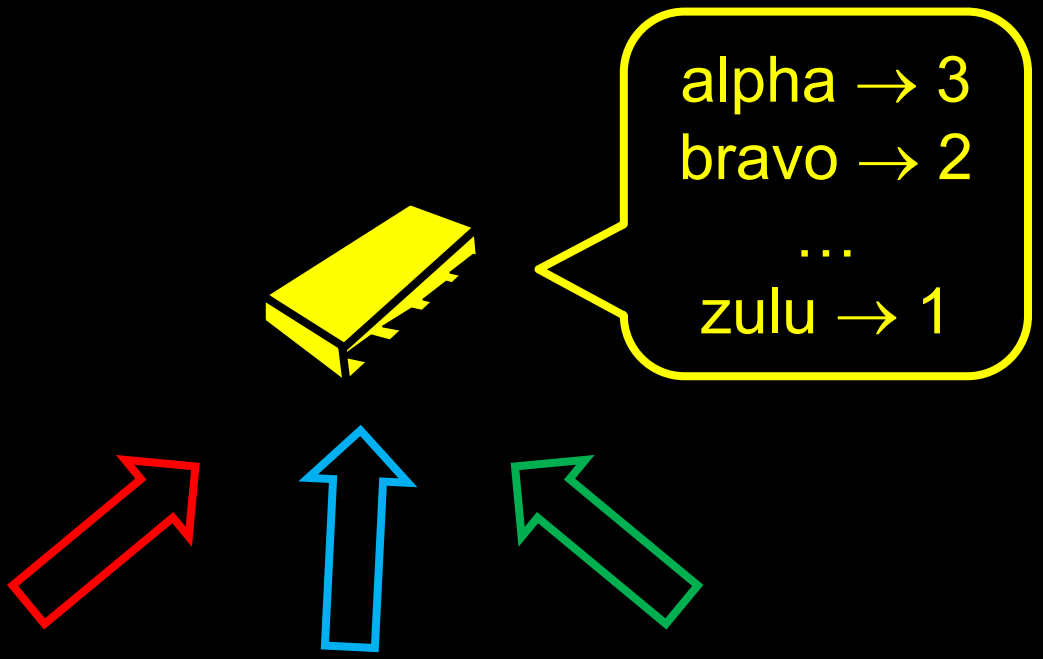
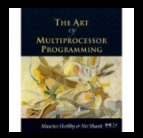


the reducer task produces a *stream* …

of *key-value* pairs …

key: word

value: word count



Reducer Class

```
abstract class Reducer<K, V, OUT>
    extends RecursiveTask<OUT> {
  K key;
  List<V> valueList;
  public void setInput(
    K aKey,
    List<V> aList) {
    key = aKey;
    valueList = aList;
  }
}
```

Reducer Class

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  public void setInput(
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    key = aKey;
    valueList = aList;
  }
}
```

each reducer is given a single key (word)

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    valueLis
  }
}
```

and a list of associated values
(word count per fragment)

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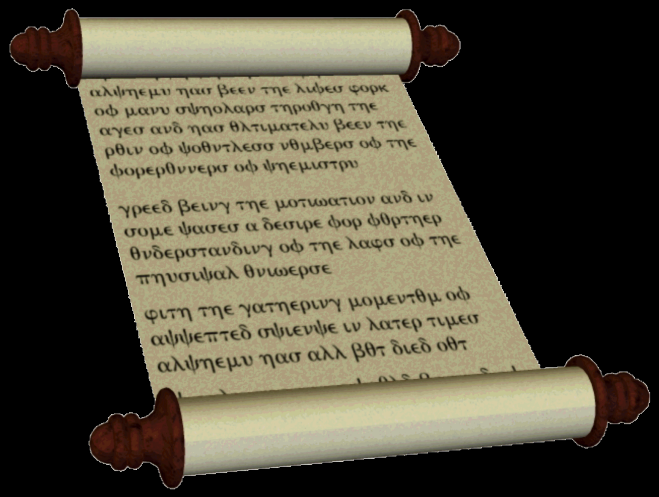
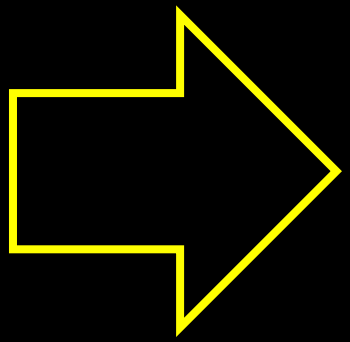
    valu
  }
}
```

It produces a single summary value (the total count for that word)

WordCount

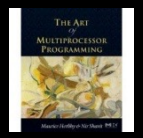




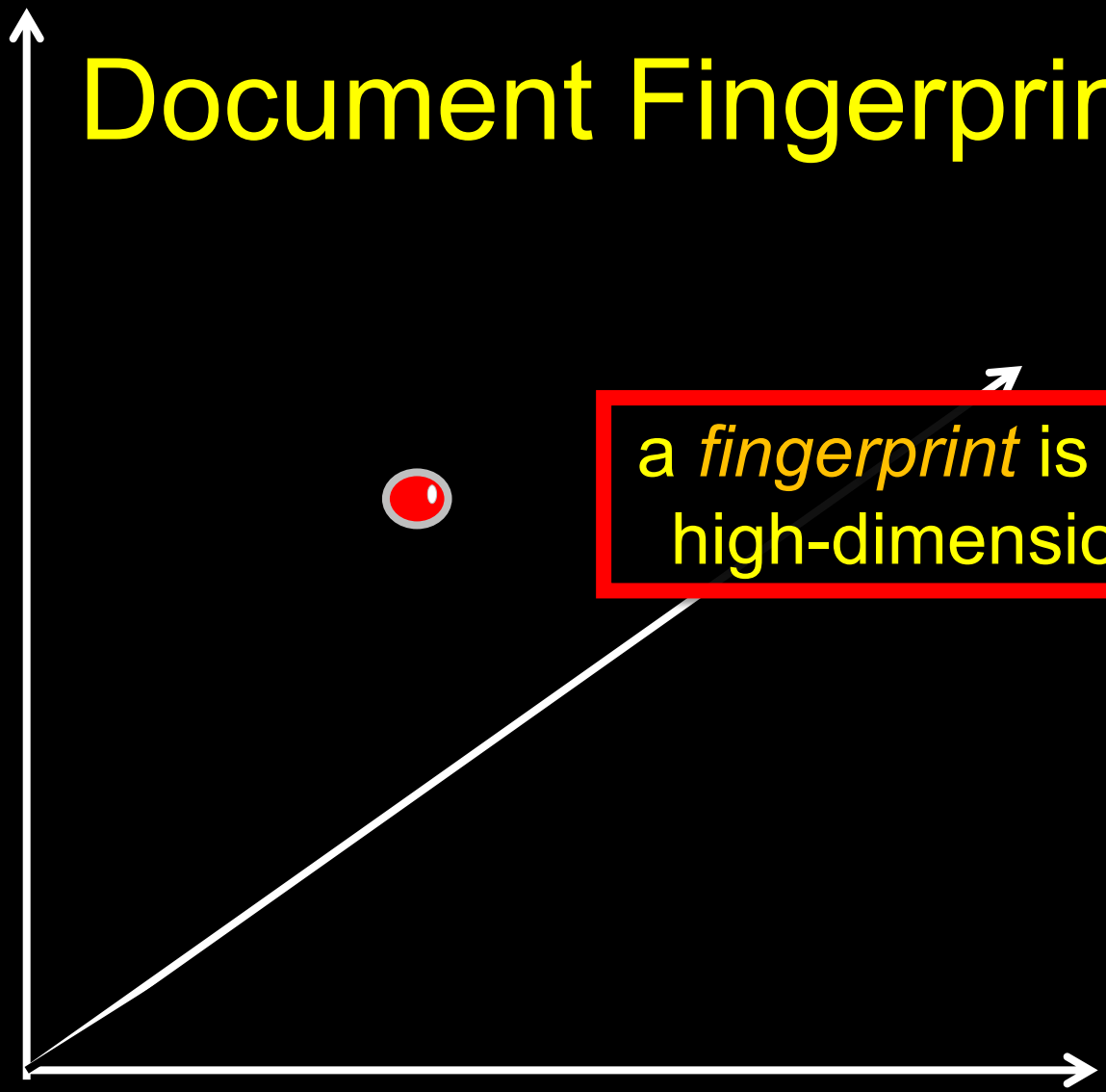
0.037
0.002
0.045
…
0.000

normalizing document wordcount

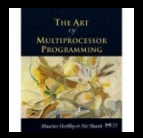
gives a *fingerprint* vector



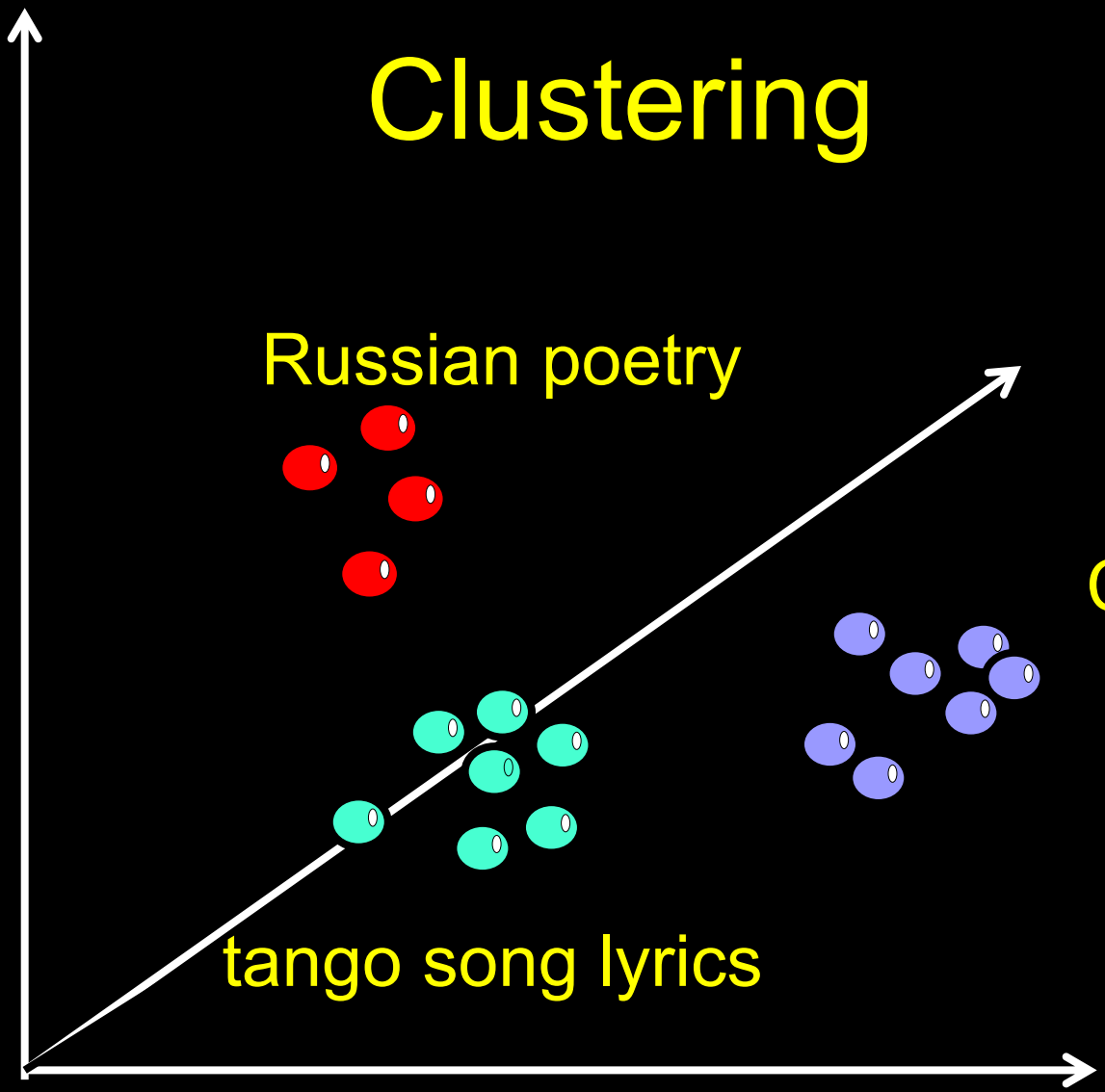
Document Fingerprint

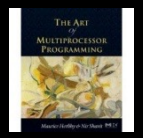


a *fingerprint* is a point in a high-dimensional space



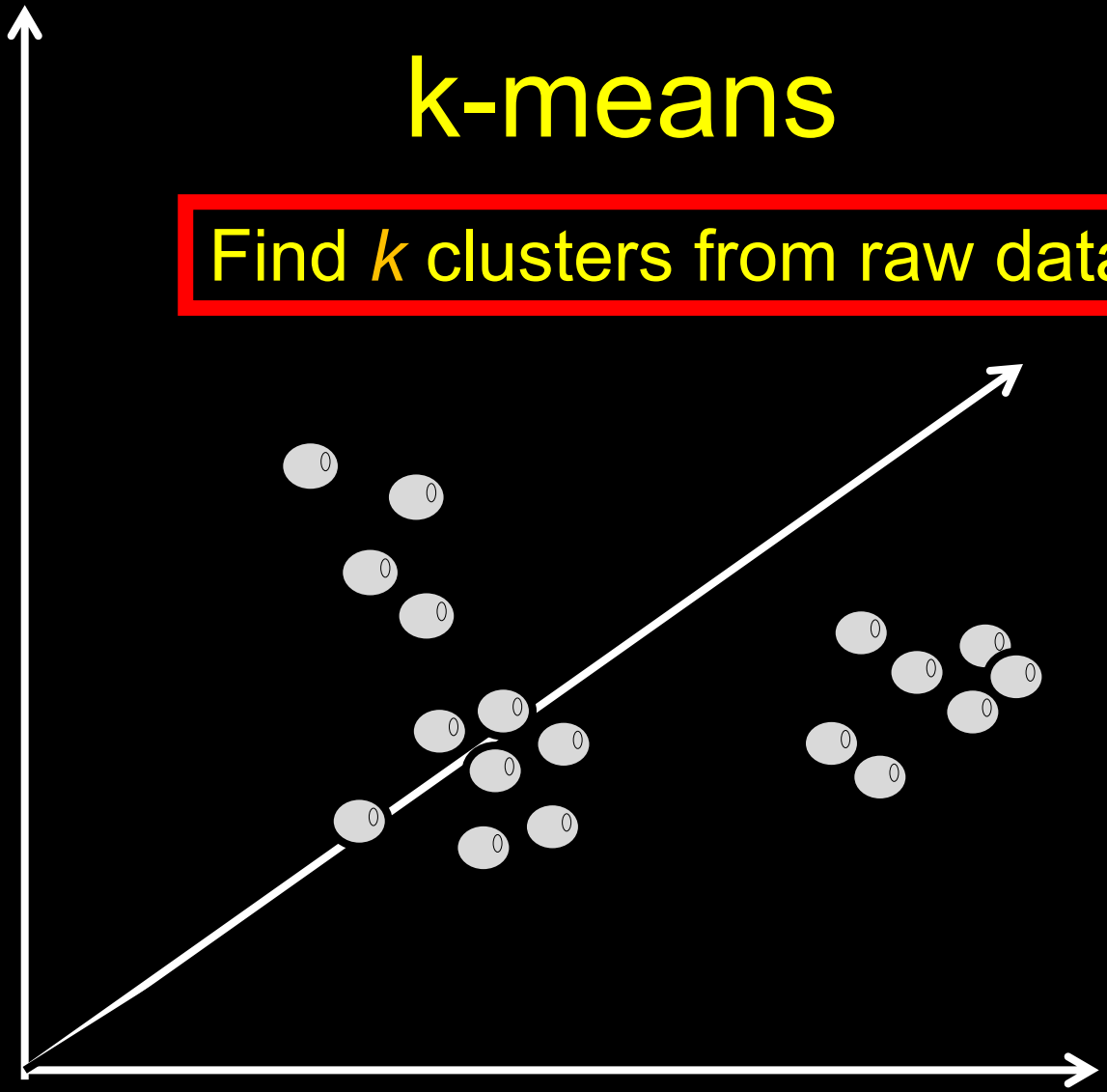
Clustering

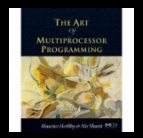

Russian poetry
Computer Science papers
tango song lyrics


The Art of Multiprocessor Programming

k-means

Find *k* clusters from raw data



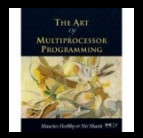


k-means

Find *k* clusters from raw data

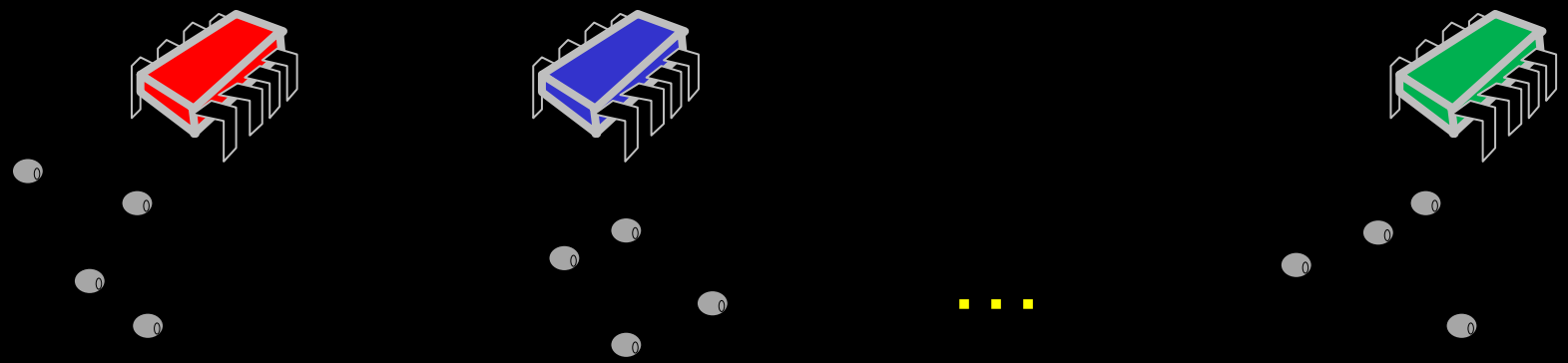
each vector closer to those in same cluster …

than in different clusters.

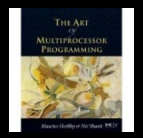


MapReduce

split points among *mapping* threads

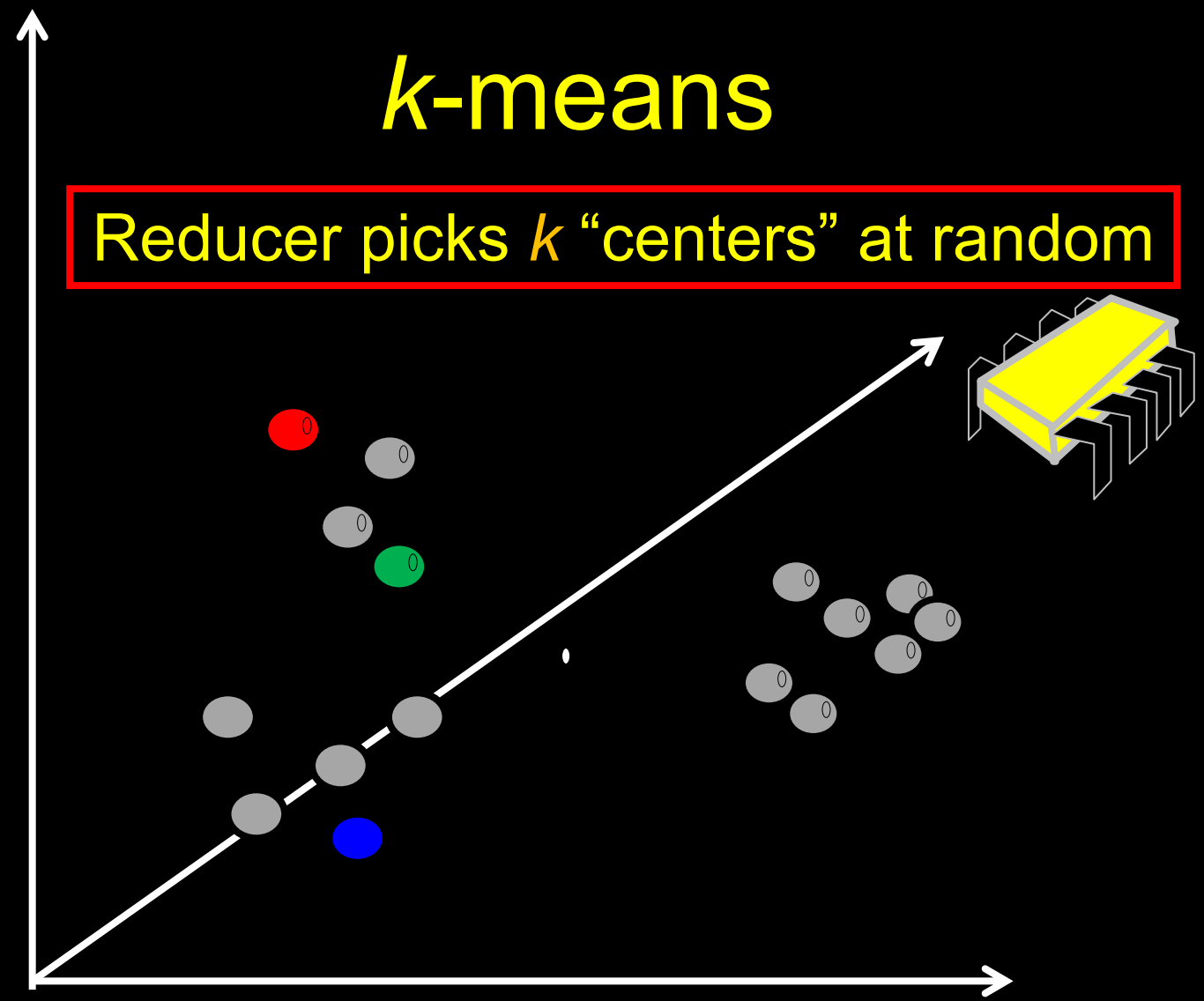


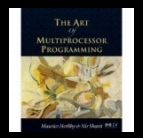
thread 1 thread 2 … thread *k*



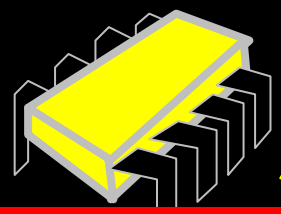
k-means

Reducer picks *k* “centers” at random





Reduce Phase

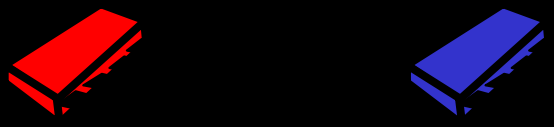


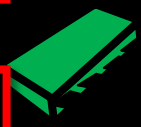
$0 \rightarrow c_0$
$1 \rightarrow c_1$
$2 \rightarrow c_2$

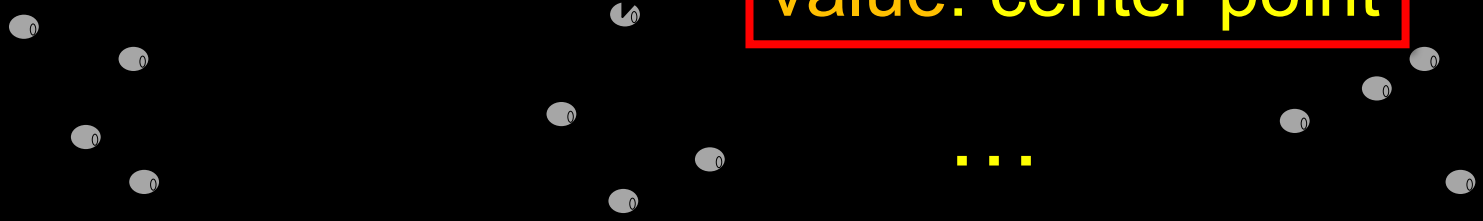
reducer sends *key-value* pair to mappers

key: cluster number

value: center point



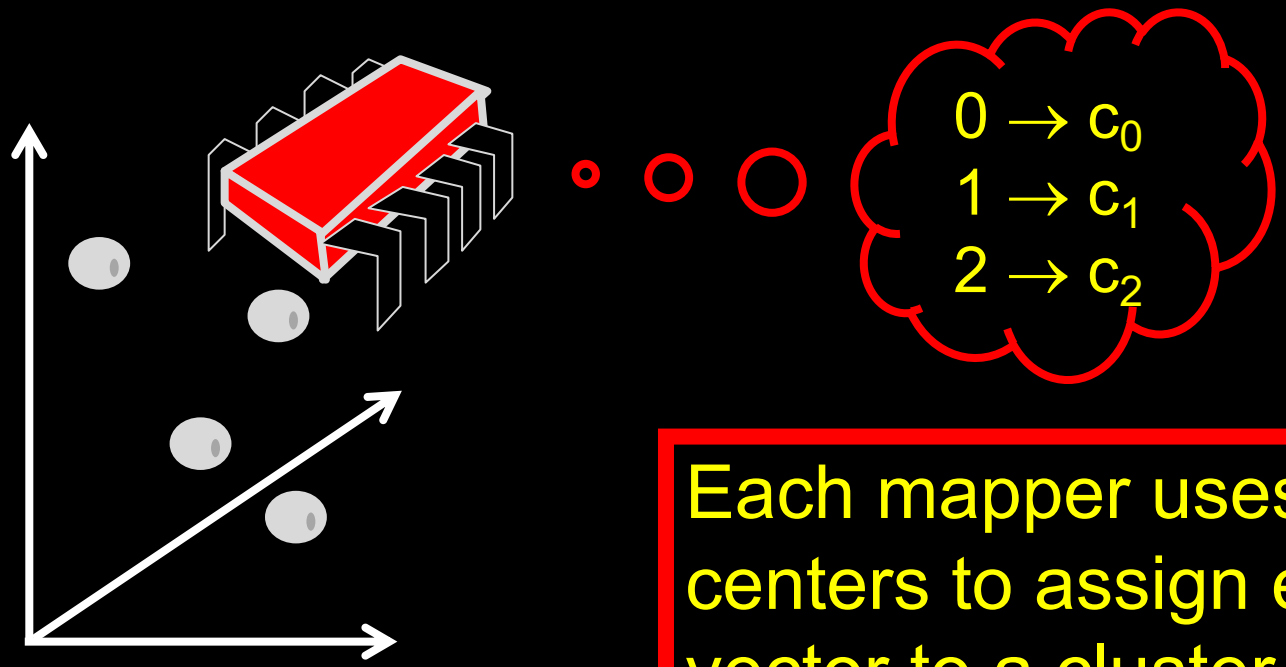




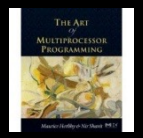
…

thread 1 thread 2 thread *k*

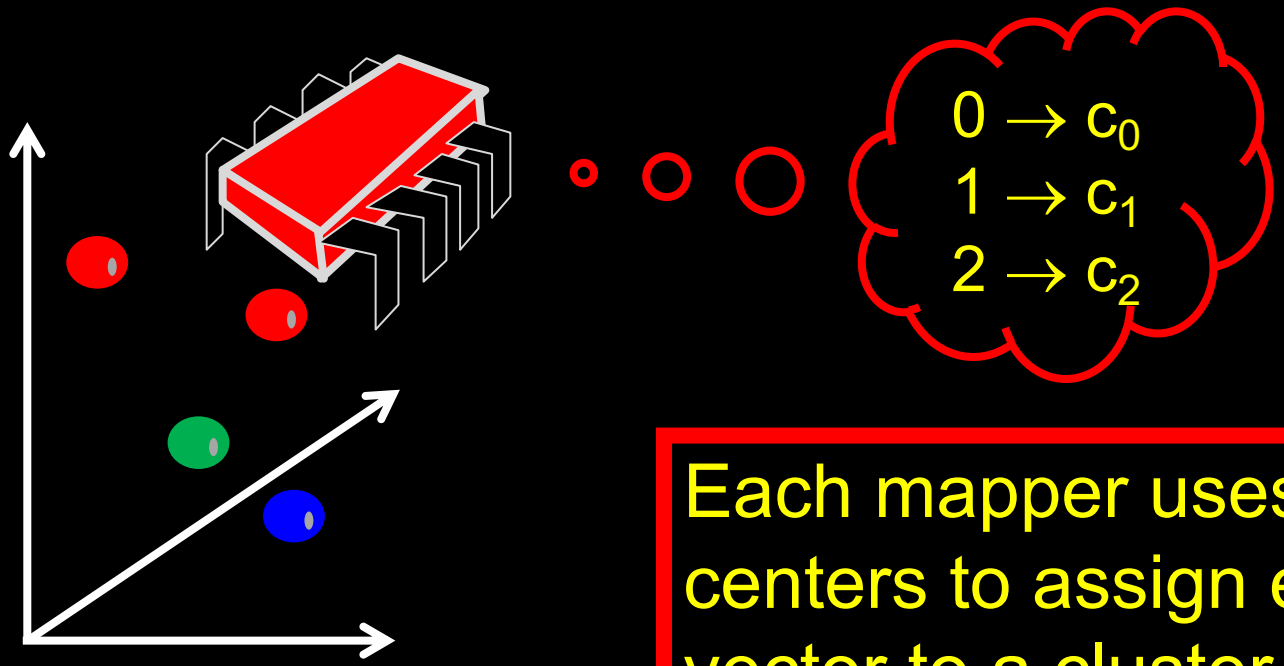
Mappers



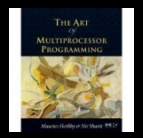
Each mapper uses centers to assign each vector to a cluster



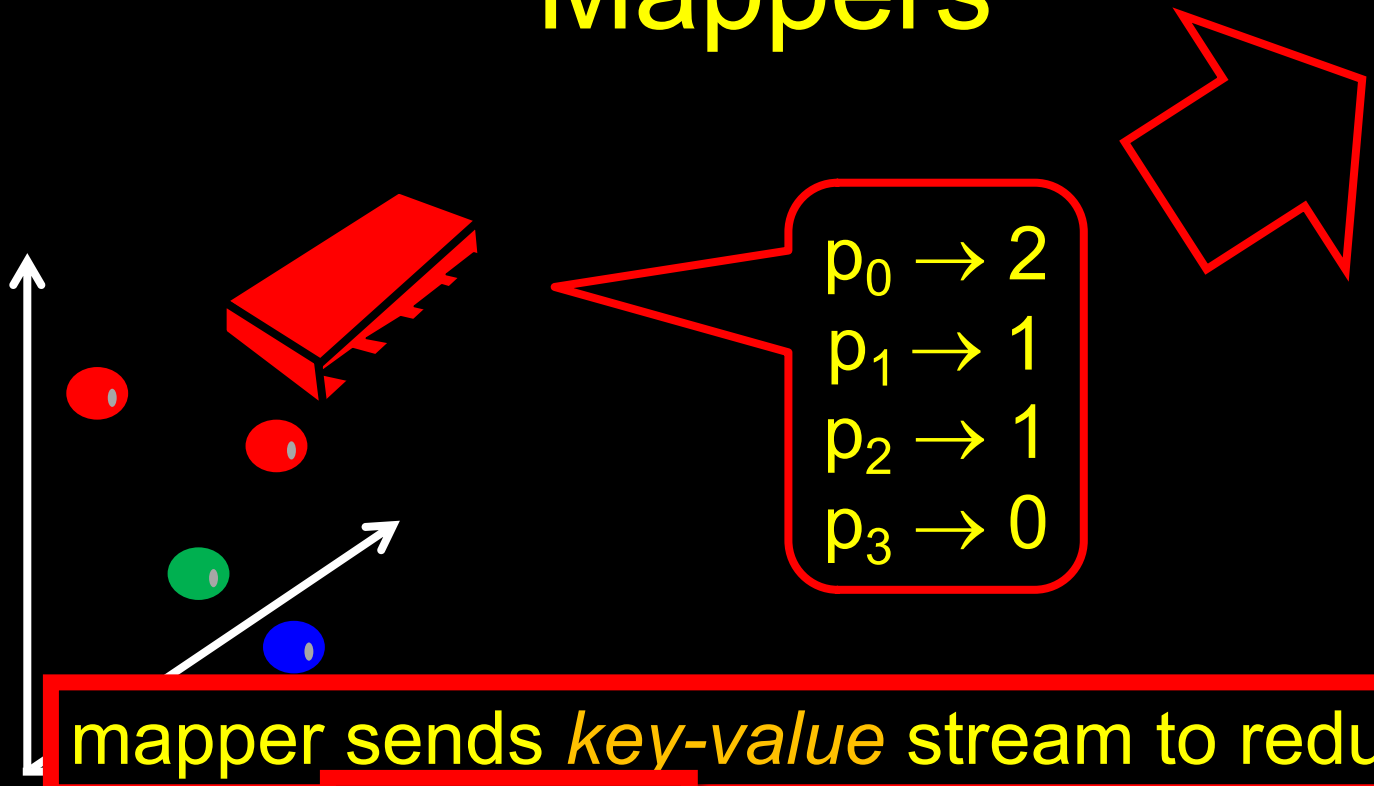
Mappers



Each mapper uses centers to assign each vector to a cluster



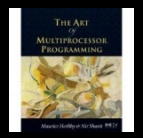
Mappers



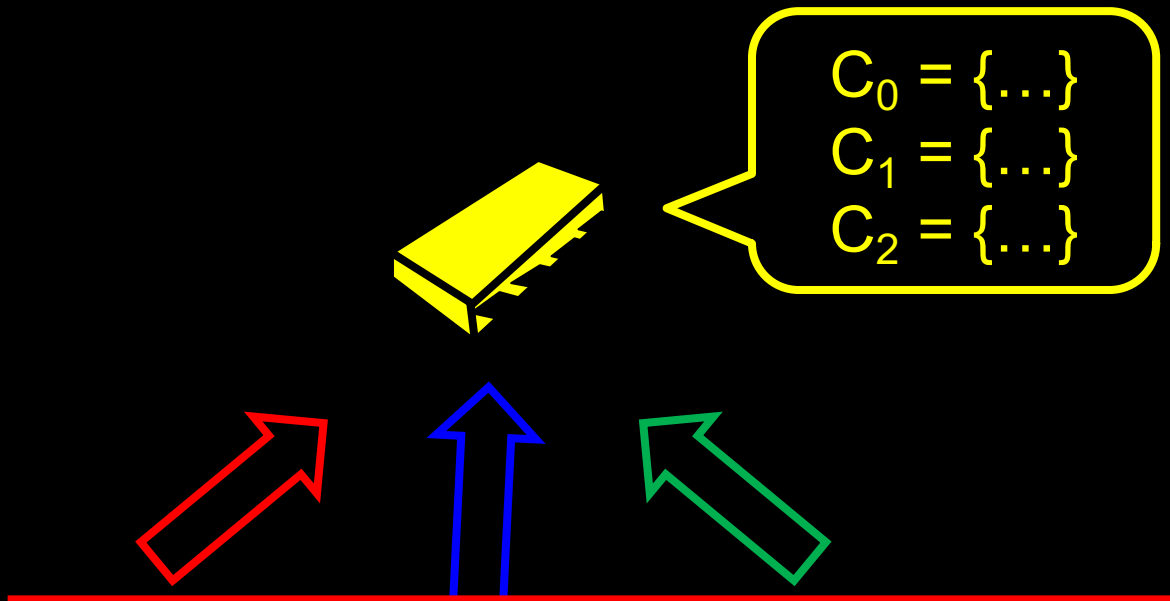
mapper sends *key-value* stream to reducer

key: point

value: cluster ID

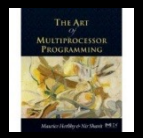


Back at the Reducer

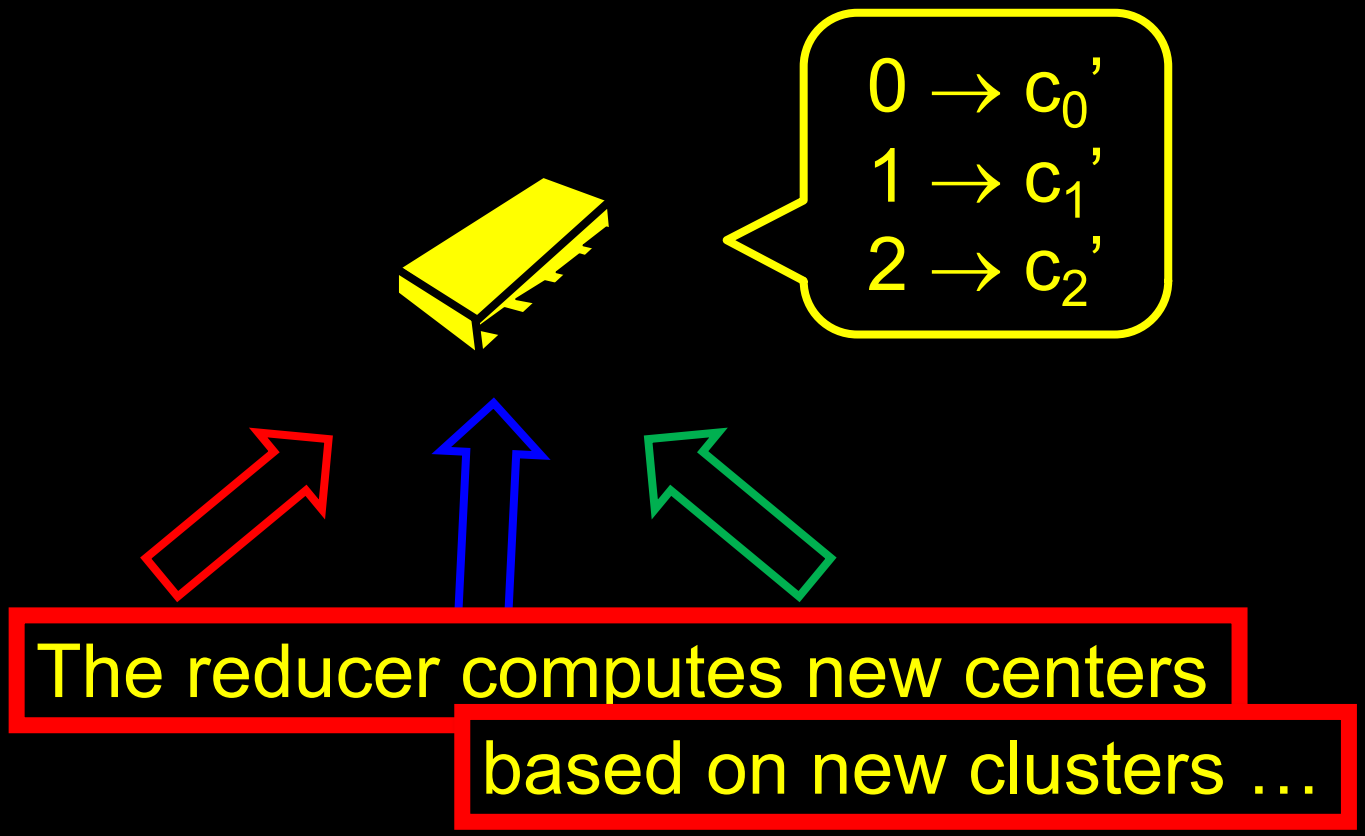


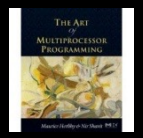
The reducer merges the streams ….

and assembles clusters …

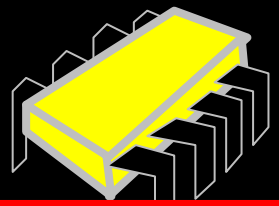


Back at the Reducer





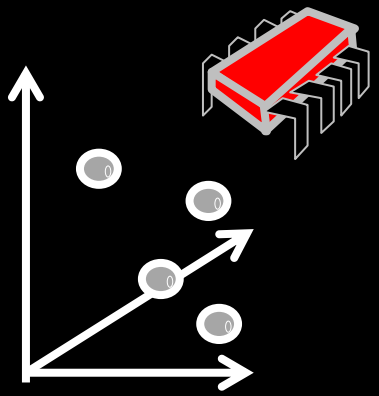
Once is Not Enough



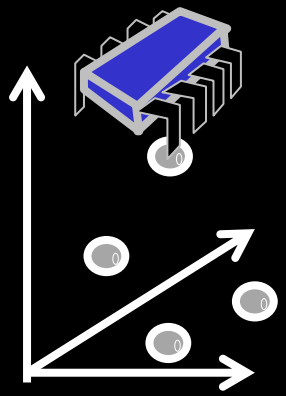
$0 \rightarrow c_0'$
$1 \rightarrow c_1'$
$2 \rightarrow c_2'$

reducer sends *new centers* to mappers

process ends when centers become stable

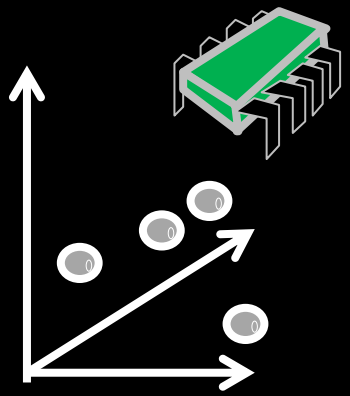


thread 1



thread 2

…



thread *k*

To Recapitulate

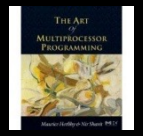
We saw two problems …

wordcount & *k-means* …

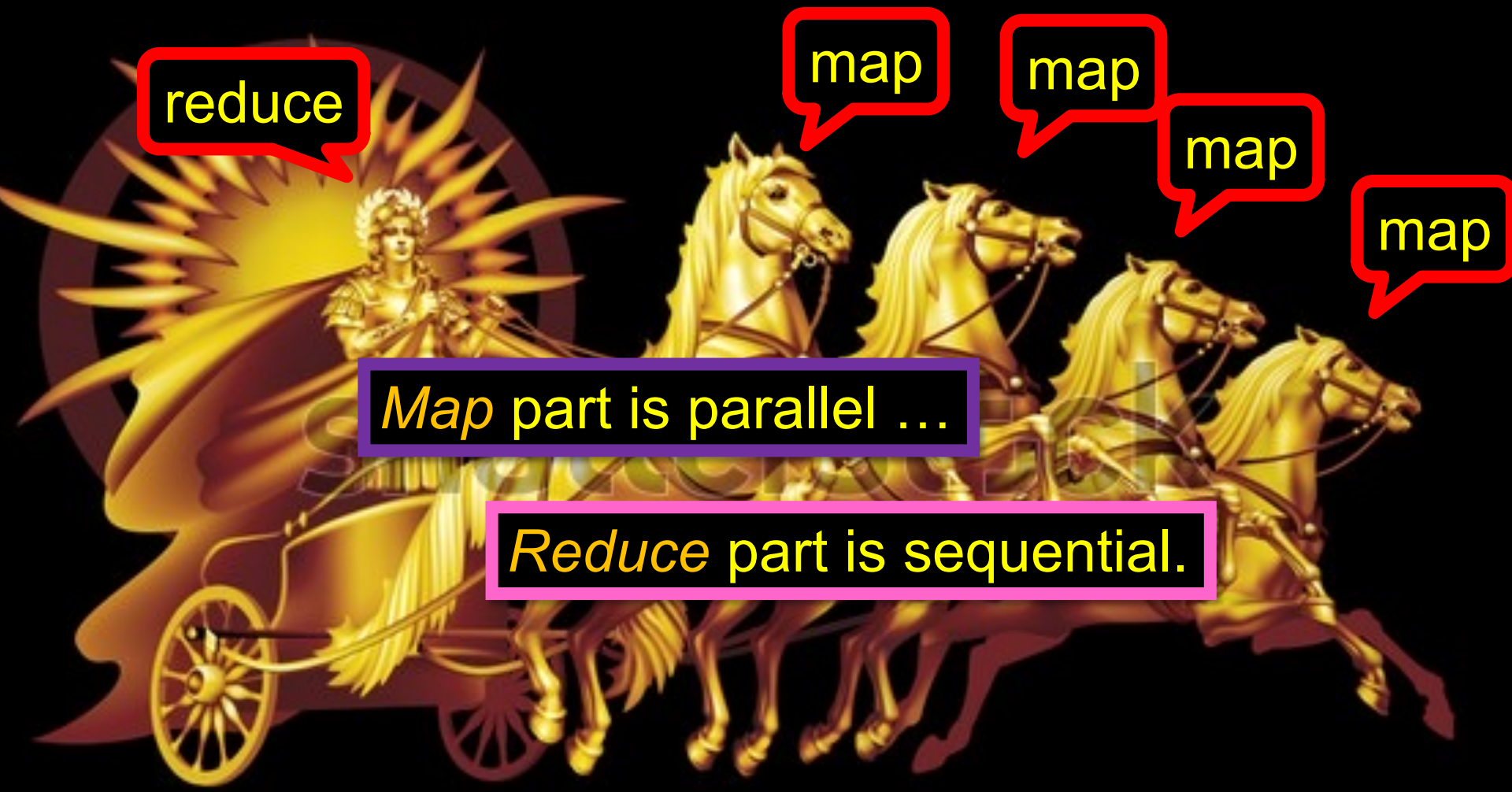
with similar parallel solutions

Map part is parallel …

Reduce part is sequential.



Big Picture

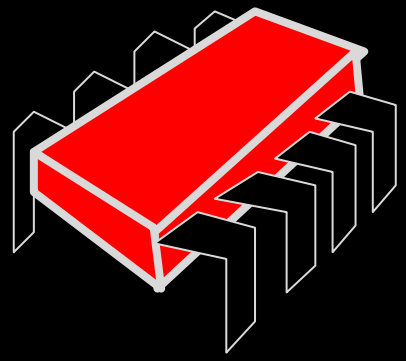


Map part is parallel …

Reduce part is sequential.

Map Function

(k_1, v_1)



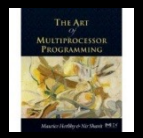
$list(k_2, v_2)$

doc, contents

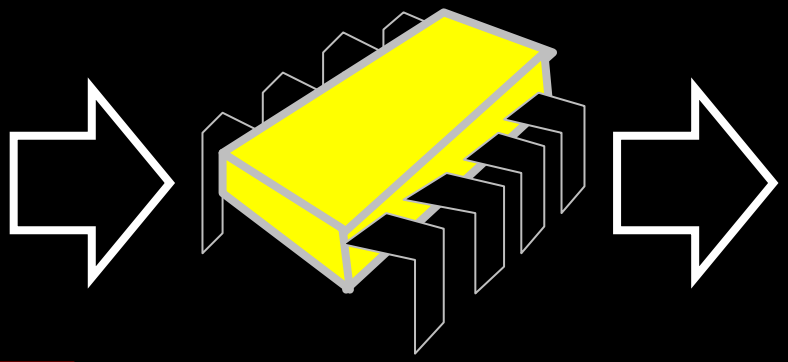
word, count

cluster ID, center

point, cluster ID



Reduce Function

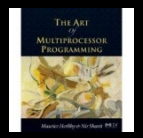
$(k_2, \text{list}(v_2))$  $\text{list}(v_2)$

word, list of counts

count

cluster ID, list of points

new cluster center



Example

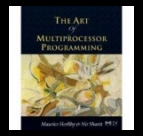
Distributed Grep

Map:

line of document

Reduce:

copy line to display



Example

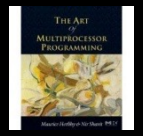
URL Access Frequency

Map:

(URL, local count)

Reduce:

(URL, total count)



Example

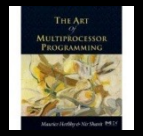
Reverse web link graph

Map:

(target link, source page)

Reduce:

(target link, list of source pages)



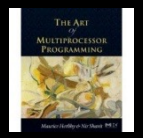
Other Examples

histogram

matrix multiplication

PageRank

Betweenness centrality



Distributed MapReduce

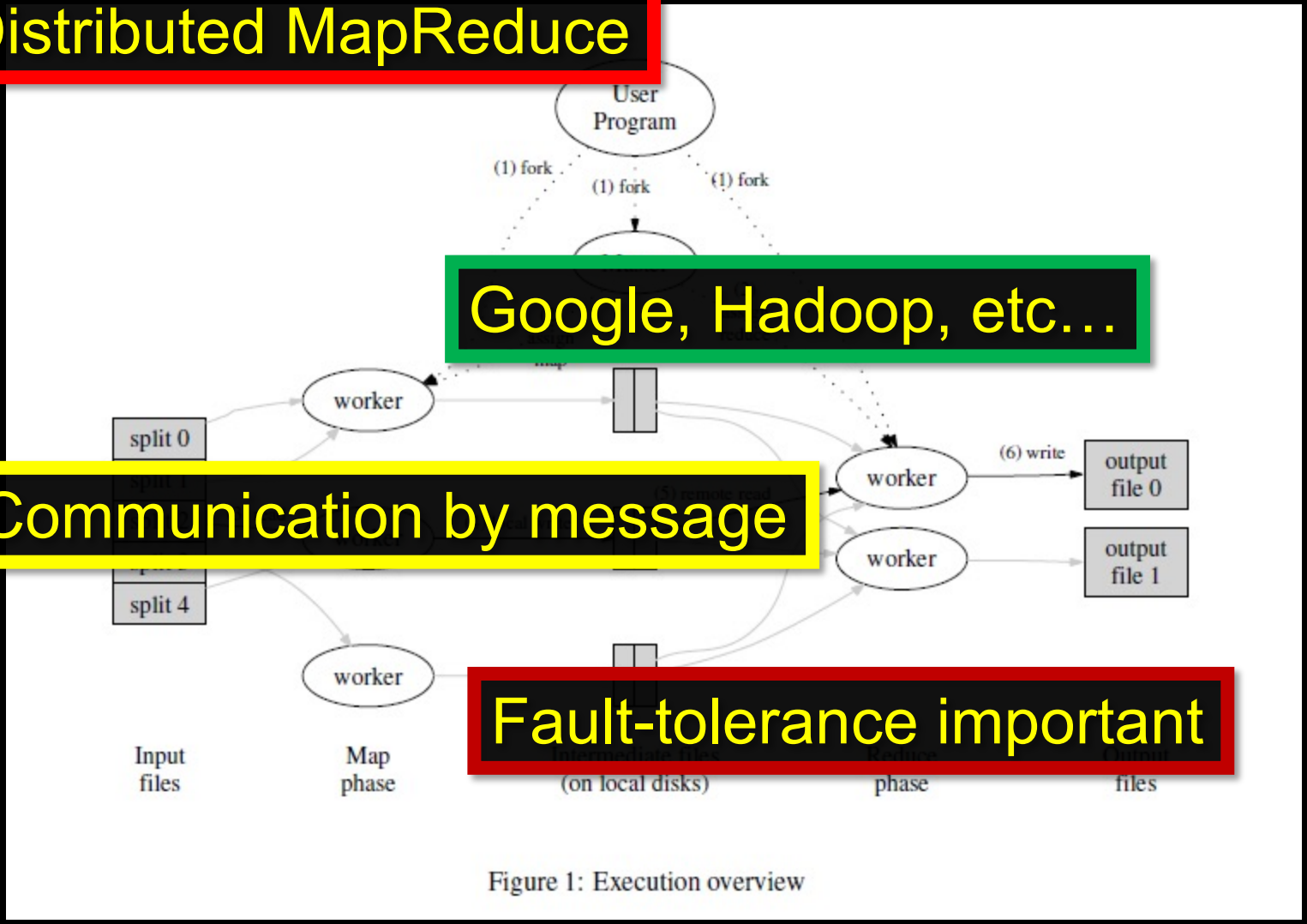
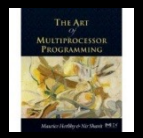


Figure 1: Execution overview

Google, Hadoop, etc…

Communication by message

Fault-tolerance important

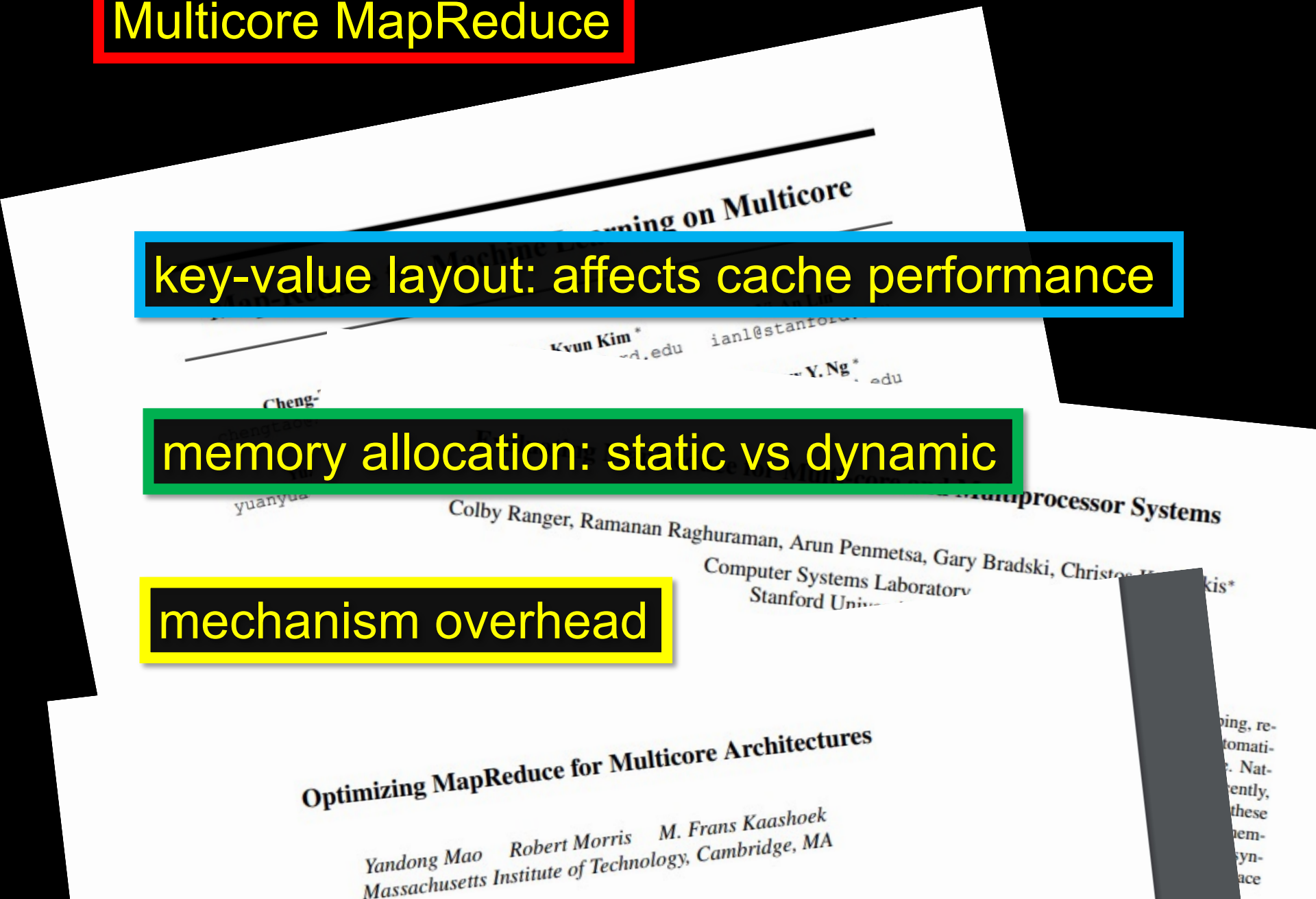


Multicore MapReduce

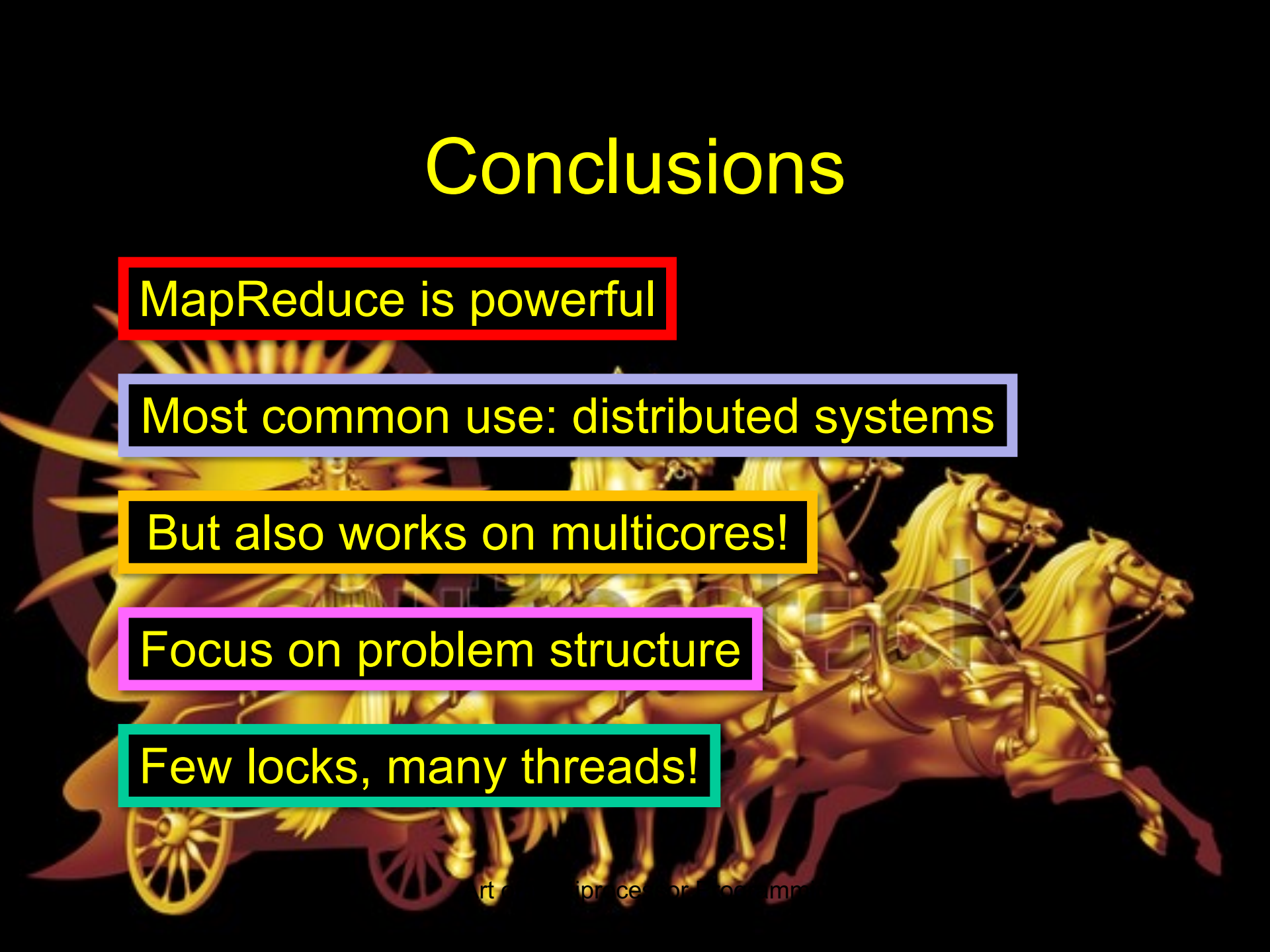
key-value layout: affects cache performance

memory allocation: static vs dynamic

mechanism overhead



Conclusions



MapReduce is powerful

Most common use: distributed systems

But also works on multicores!

Focus on problem structure

Few locks, many threads!