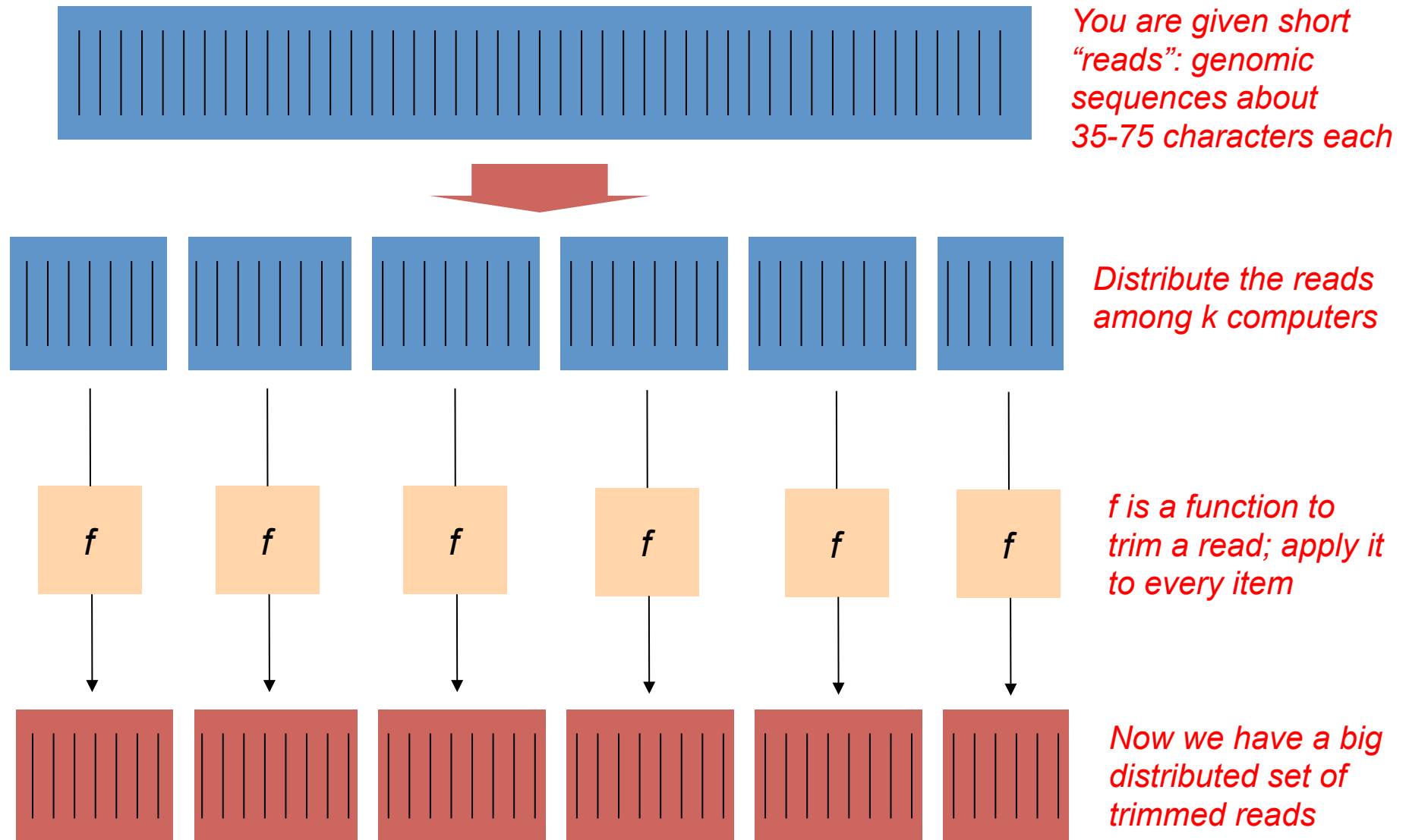


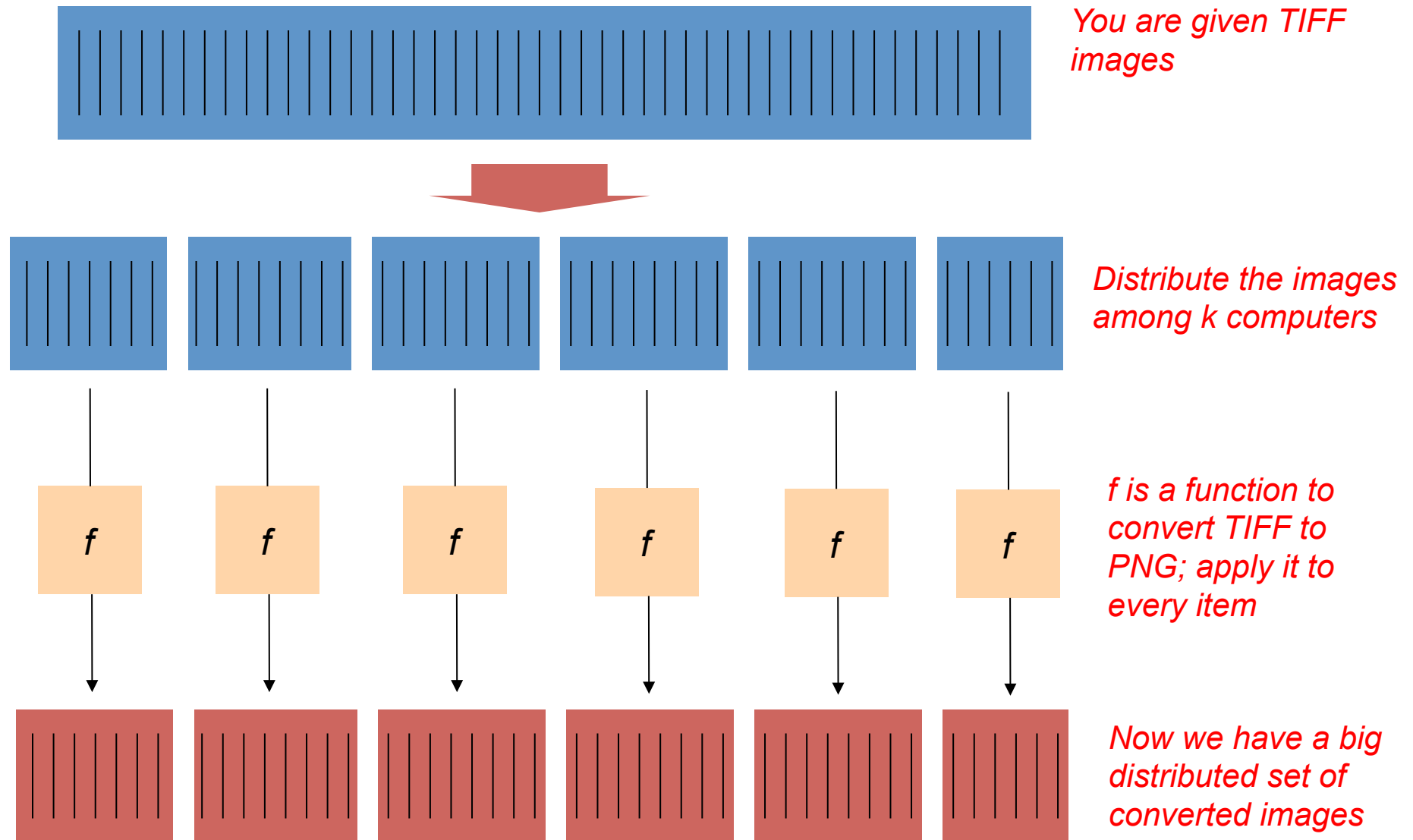
# W

## Schematic of a Parallel “Read Trimming” Task

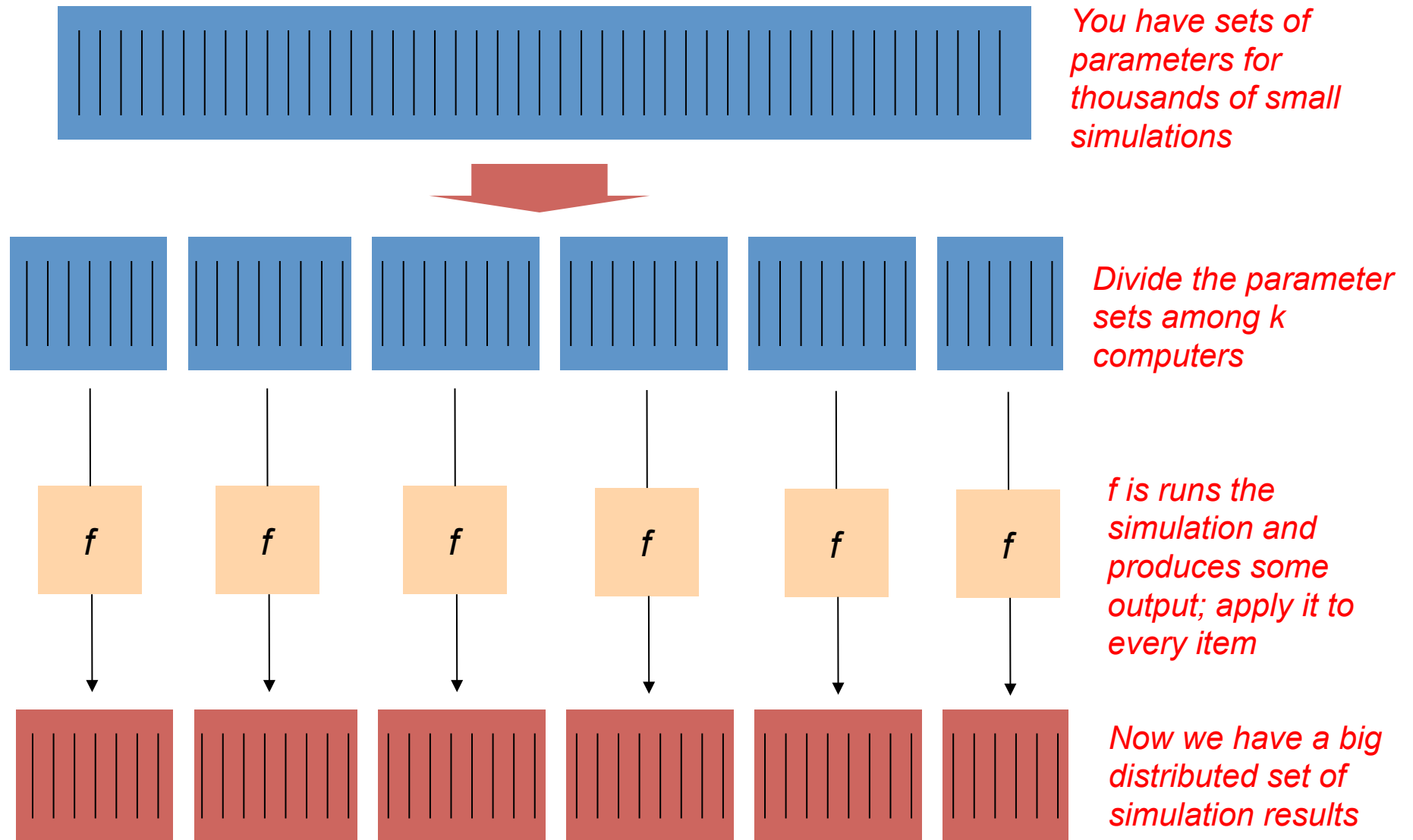


W

## New Task: Convert 405k TIFF images to PNG

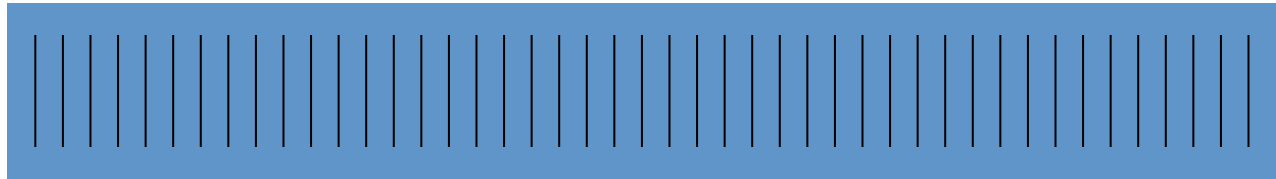


# New Task: Run thousands of simulations

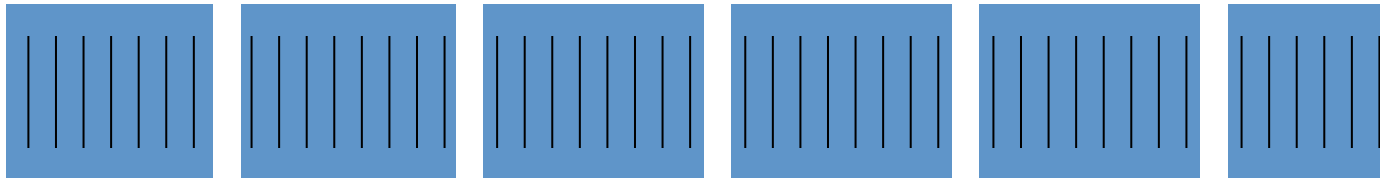


W

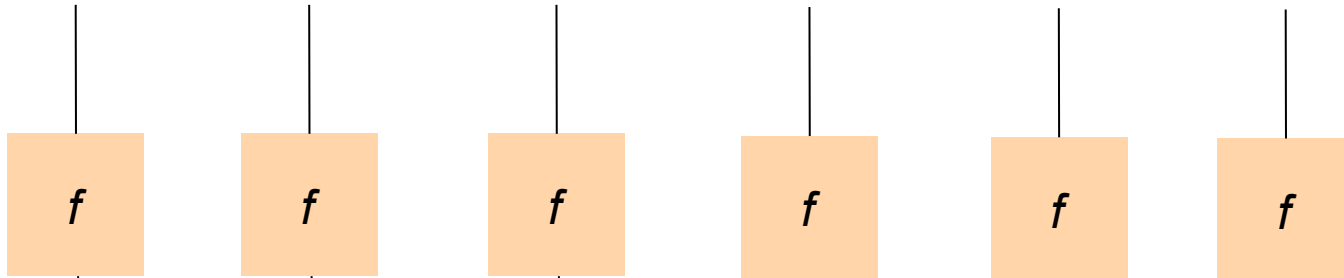
Find the most common word in each document



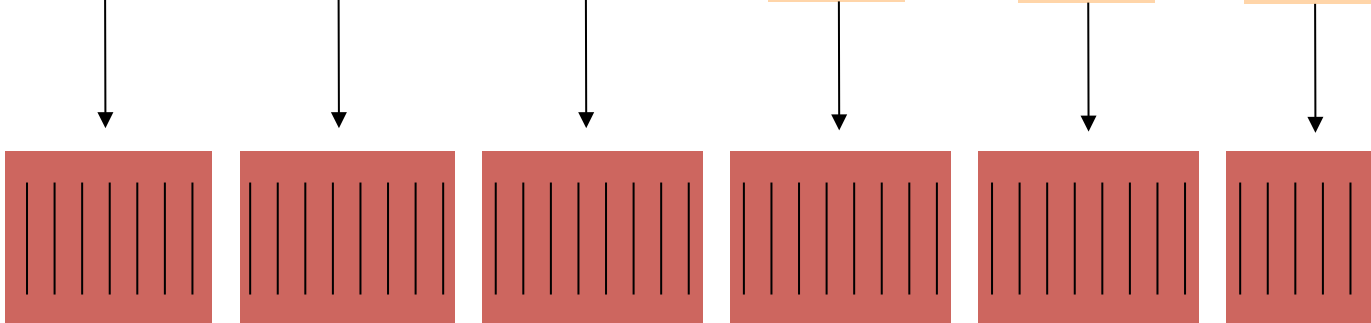
*You have millions of documents*



*Distribute the documents among  $k$  computers*



*$f$  finds the most common word in a single document*



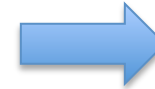
*Now we have a big distributed list of  $(doc\_id, word)$  pairs*

## Consider a slightly more general program to compute the word frequency of every word in a single document

### Abridged Declaration of Independence

A Declaration By the Representatives of the United States of America, in General Congress Assembled. When in the course of human events it becomes necessary for a people to advance from that subordination in which they have hitherto remained, and to assume among powers of the earth the equal and independent station to which the laws of nature and of nature's god entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the change.

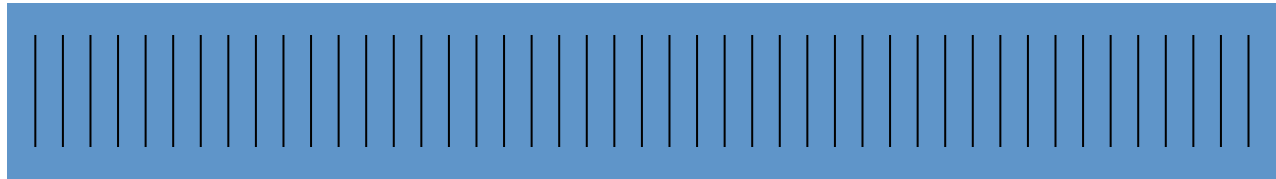
We hold these truths to be self-evident; that all men are created equal and independent; that from that equal creation they derive rights inherent and inalienable, among which are the preservation of life, and liberty, and the pursuit of happiness; that to secure these ends, governments are instituted among men, deriving their just power from the consent of the governed; that whenever any form of government shall become destructive of these ends, it is the right of the people to alter or to abolish it, and to institute new government, laying it's foundation on such principles and organizing it's power in such form, as to them shall seem most likely to effect their safety and happiness. Prudence indeed will dictate that governments long established should not be changed for light and transient causes: and accordingly all experience hath shewn that mankind are more disposed to suffer while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations, begun at a distinguished period, and pursuing invariably the same object, evinces a design to reduce them to arbitrary power, it is their right, it is their duty, to throw off such government and to provide new guards for future security. Such has been the patient sufferings of the colonies; and such is now the necessity which constrains them to expunge their former systems of government. the history of his present majesty is a history of unremitting injuries and usurpations, among which no one fact stands single or solitary to contradict the uniform tenor of the rest, all of which have in direct object the establishment of an absolute tyranny over these states. To prove this, let facts be submitted to a candid world, for the truth of which we pledge a faith yet unsullied by falsehood.



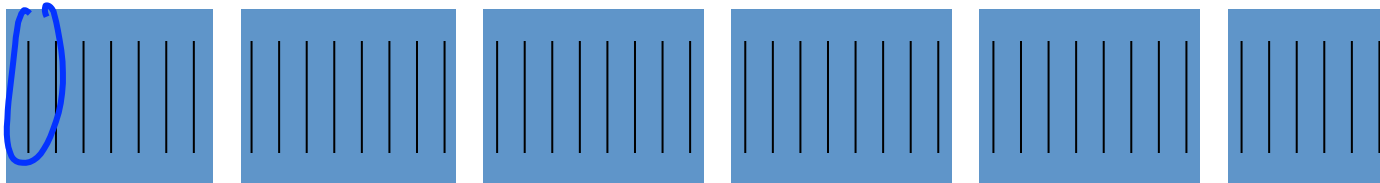
(people, 2)  
(government, 6)  
(assume, 1)  
(history, 2)  
...

W

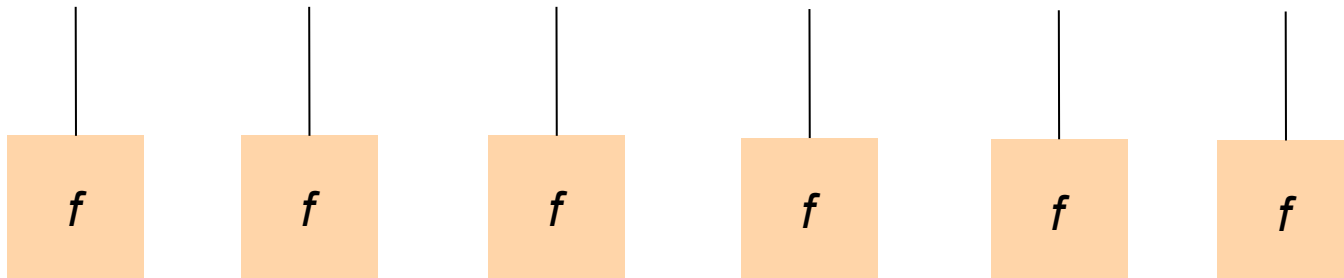
# Compute the word frequency of 5M documents



*You have millions of documents*



*Distribute the documents among  $k$  computers*



*For each document  $f$  returns a set of (word, freq) pairs*



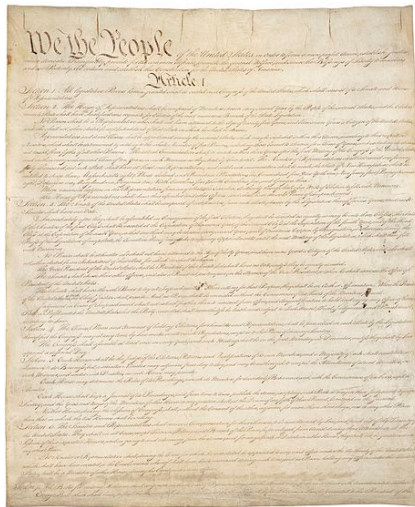
*Now we have a big distributed list of sets of word freqs.*

## There's a pattern here....

- A function that maps a read to a trimmed read
- A function that maps a TIFF image to a PNG image
- A function that maps a set of parameters to a simulation result
- A function that maps a document to its most common word
- A function that maps a document to a histogram of word frequencies

W

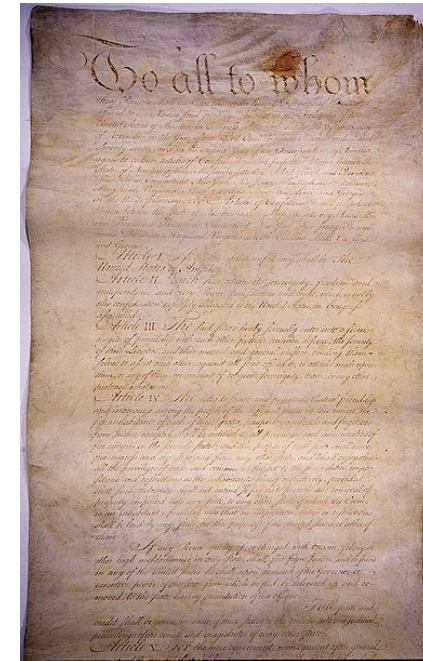
# What if we want to compute the word frequency across *all* documents?



US Constitution



Declaration of Independence

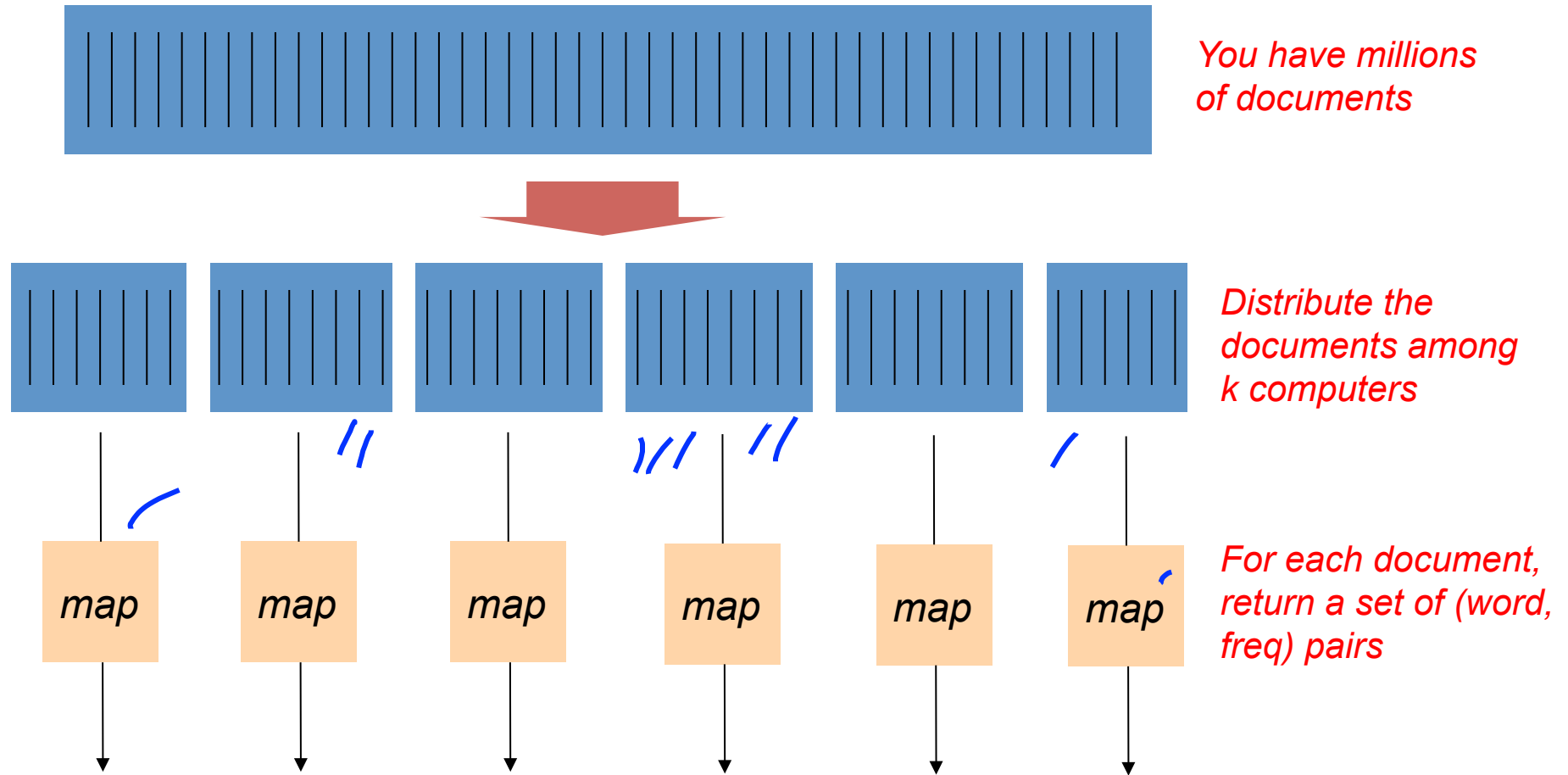


Articles of Confederation

(people, 78)  
(government, 123)  
(assume, 23)  
(history, 38)  
...



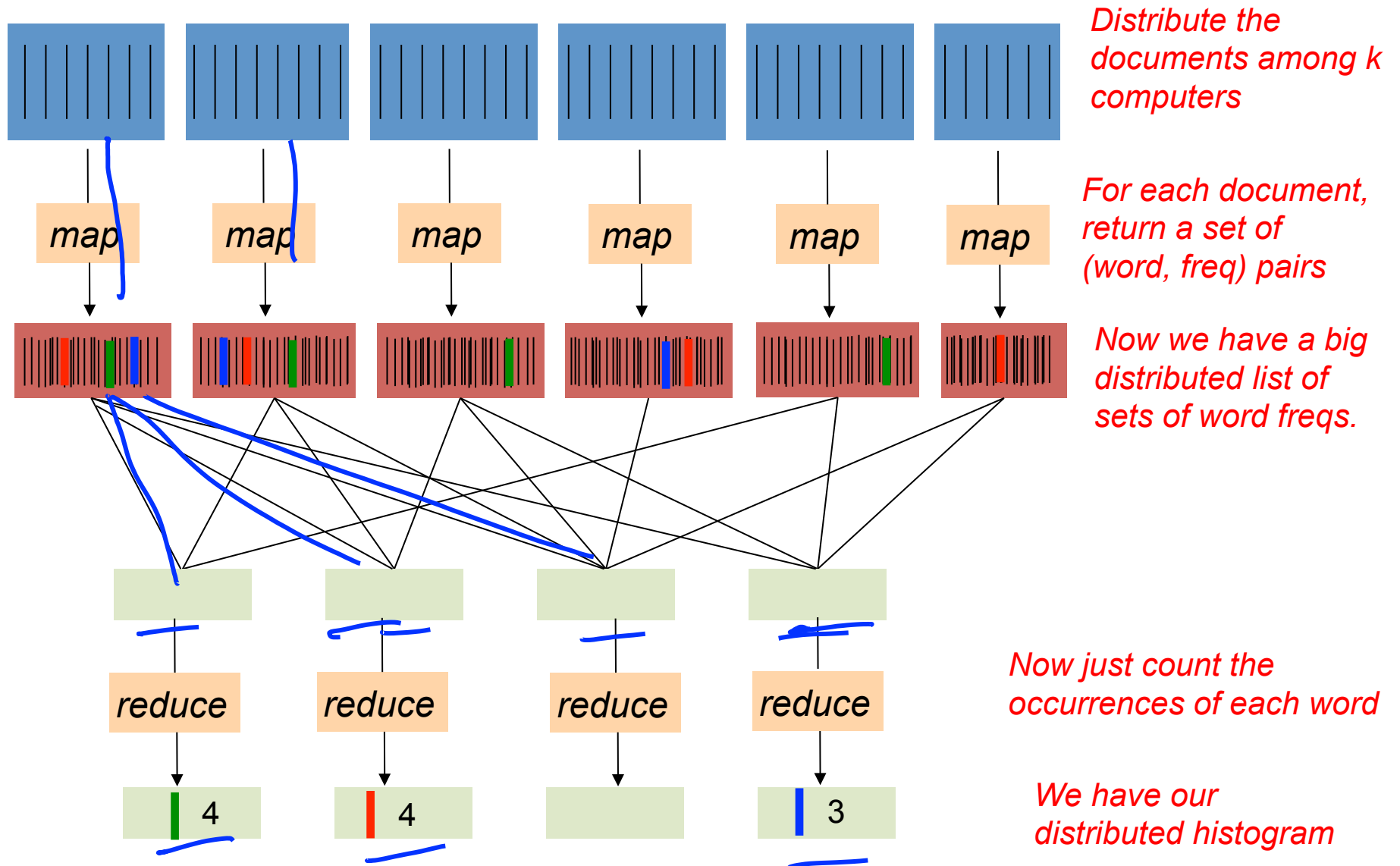
# W Compute the word frequency **across** 5M documents



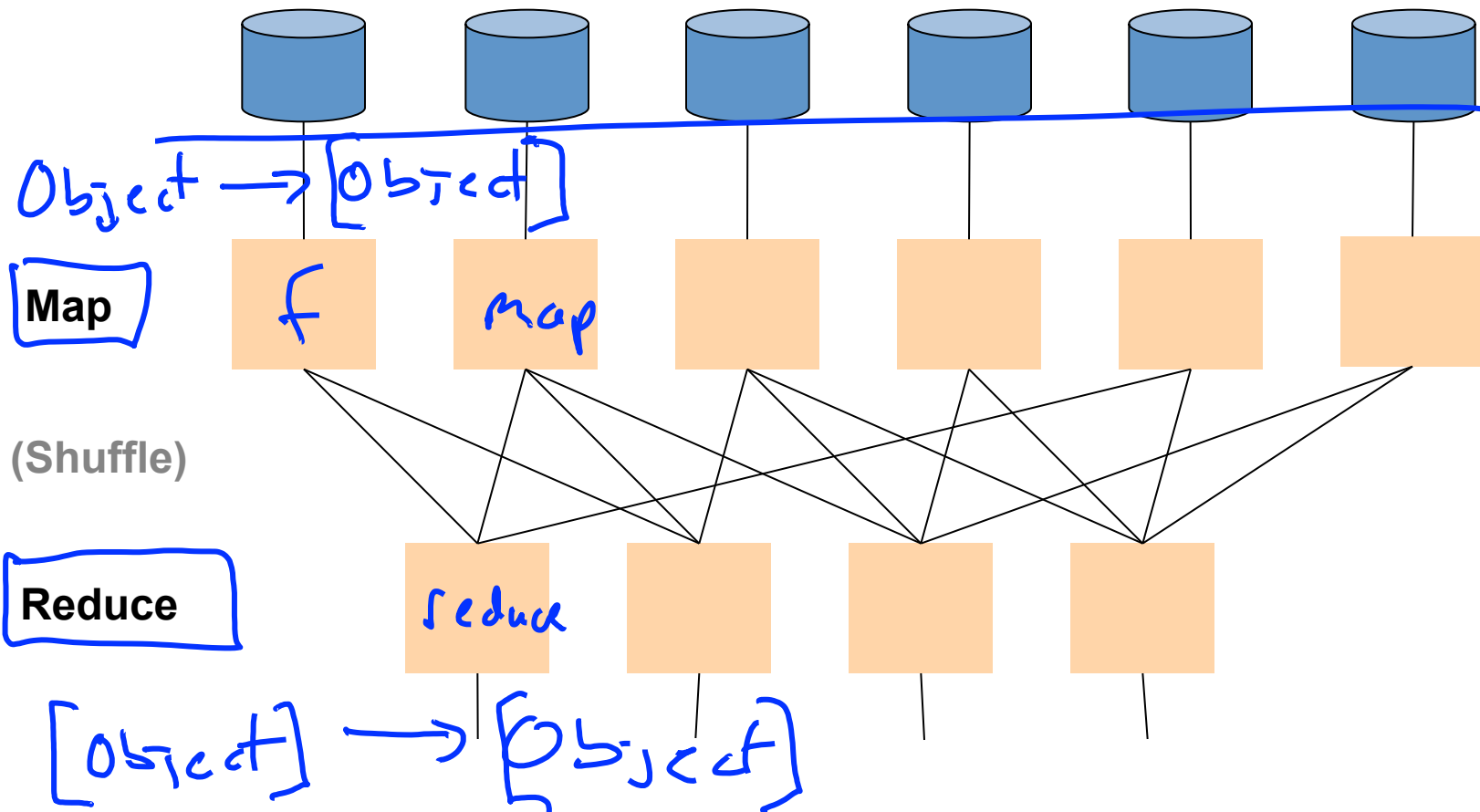
Now what?

- But we don't want a bunch of little histograms – we want one big histogram.
- How can we make sure that a single computer has access to every occurrence of a given word regardless of which document it appeared in?

# W Compute the word frequency **across** 5M documents



## Some distributed algorithm...



# MapReduce Programming Model

- Input & Output: each a set of key/value pairs
- Programmer specifies two functions:

**map (in\_key, in\_value) → list(out\_key, intermediate\_value)**

- Processes input key/value pair
- Produces set of intermediate pairs

**reduce (out\_key, list(intermediate\_value)) → list(out\_value)**

- Combines all intermediate values for a particular key
- Produces a set of merged output values (usually just one)

*Inspired by primitives from functional programming languages such as Lisp, Scheme, and Haskell*

## Example: What does this do?

```
map(String input_key, String input_value):
```

```
// input_key: document name
```

```
// input_value: document contents
```

```
for each word w in input_value:
```

```
    EmitIntermediate(w, 1);
```

```
reduce(String output_key, Iterator intermediate_values):
```

```
// output_key: word
```

```
// output_values: ????
```

```
int result = 0;
```

```
for each v in intermediate_values:
```

```
    result += v;
```

```
Emit(result);
```

# Example: Document Processing

## Abridged Declaration of Independence

A Declaration By the Representatives of the United States of America, in General Congress Assembled. When in the course of human events it becomes necessary for a people to advance from that subordination in which they have hitherto remained, and to assume among powers of the earth the equal and independent station to which the laws of nature and of nature's god entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the change.

We hold these truths to be self-evident; that all men are created equal and independent; that from that equal creation they derive rights inherent and inalienable, among which are the preservation of life, and liberty, and the pursuit of happiness; that to secure these ends, governments are instituted among men, deriving their just power from the consent of the governed; that whenever any form of government shall become destructive of these ends, it is the right of the people to alter or to abolish it, and to institute new government, laying it's foundation on such principles and organizing it's power in such form, as to them shall seem most likely to effect their safety and happiness. Prudence indeed will dictate that governments long established should not be changed for light and transient causes: and accordingly all experience hath shewn that mankind are more disposed to suffer while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations, begun at a distinguished period, and pursuing invariably the same object, evinces a design to reduce them to arbitrary power, it is their right, it is their duty, to throw off such government and to provide new guards for future security. Such has been the patient sufferings of the colonies; and such is now the necessity which constrains them to expunge their former systems of government. the history of his present majesty is a history of unremitting injuries and usurpations, among which no one fact stands single or solitary to contradict the uniform tenor of the rest, all of which have in direct object the establishment of an absolute tyranny over these states. To prove this, let facts be submitted to a candid world, for the truth of which we pledge a faith yet unsullied by falsehood.

# Example: Word length histogram

## Abridged Declaration of Independence

A Declaration By the Representatives of the United States of America, in General Congress Assembled. When in the course of human events it becomes necessary for a people to advance from that subordination in which they have hitherto remained, and to assume among powers of the earth the equal and independent station to which the laws of nature and of nature's god entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the change.

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How many “big”, “medium”, and “small” words are used?

# Example: Word length

Abridged Declaration of Independence

## histogram

Big = Yellow = 10+ letters

Medium = Red = 5..9 letters

Small = Blue = 2..4 letters

Tiny = Pink = 1 letter

A Declaration By the Representatives of the United States of America, in General Congress Assembled.

When in the course of human events it becomes necessary for a people to advance from that subordination in which they have hitherto remained, and to assume among powers of the earth the equal and independent station to which the laws of nature and of nature's god entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the change.

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# Example: Word length

## Abridged Declaration of Independence

Split the document into chunks and process each chunk on a different computer

Chunk 1

Chunk 2

A Declaration By the Representatives of the United States of America, in General Congress assembled.

When in the course of human events it becomes necessary for a people to advance from that subordination in which they have hitherto remained, and to assume among powers of the earth the equal and independent station to which the laws of nature and of nature's god entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the change.

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# Example: Word length histogram

## Abridged Declaration of Independence

Map Task 1  
(204 words)

A Declaration By the Representatives of the United States of America, in General Congress Assembled.  
When in the course of human events it becomes necessary for a people to advance from that subordination in which they have hitherto remained, and to assume among powers of the earth the equal and independent station to which the laws of nature and of nature's god entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the change.  
We hold these truths to be self-evident; that all men are created equal and independent; that from that equal creation they derive rights inherent and inalienable, among which are the preservation of life, and liberty, and the pursuit of happiness; that to secure these ends, governments are instituted among men, deriving their just power from the consent of the governed; that whenever any form of government shall become destructive of these ends, it is the right of the people to alter or to abolish it, and to institute new government, laying it's foundation on such principles and organizing it's power in such form, as to them shall seem most likely to effect their safety and happiness. Prudence indeed will

(key, value)

(yellow, 17)  
(red, 77)  
(blue, 107)  
(pink, 3)

Map Task 2  
(190 words)

dictate that governments long established should not be changed for light and transient causes: and accordingly all experience hath shewn that mankind are more disposed to suffer while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations, begun at a distinguished period, and pursuing invariably the same object, evinces a design to reduce them to arbitrary power, it is their right, it is their duty, to throw off such government and to provide new guards for future security. Such has been the patient sufferings of the colonies; and such is now the necessity which constrains them to expunge their former systems of government. the history of his present majesty is a history of unremitting injuries and usurpations, among which no one fact stands single or solitary to contradict the uniform tenor of the rest, all of which have in direct object the establishment of an absolute tyranny over these states. To prove this, let facts be submitted to a candid world, for the truth of which we pledge a faith yet unsullied by falsehood.

(yellow, 20)  
(red, 71)  
(blue, 93)  
(pink, 6)

# Example: Word length histogram

“Shuffle step”

## Map task 1

A Declaration By the Representatives of the United States of America, in General Congress Assembled.

When in the course of human events it becomes necessary for a people to advance from that subordination in which they have hitherto remained, and to assume among powers of the earth the equal and independent station to which the laws of nature and of nature's god entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the change.

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(yellow, 17)

(red, 77)

(blue, 107)

(pink, 3)

## Map task 2

dictate that governments long established should not be changed for light and transient causes: and accordingly all experience hath shewn that mankind are more disposed to suffer while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations, begun at a distinguished period, and pursuing invariably the same object, evinces a design to reduce them to arbitrary power, it is their right, it is their duty, to throw off such government and to provide new guards for future security. Such has been the patient sufferings of the colonies; and such is now the necessity which constrains them to expunge their former systems of government, the history of his present majesty is a history of unremitting injuries and usurpations, among which no one fact stands single or solitary to contradict the uniform tenor of the rest, all of which have in direct object the establishment of an absolute tyranny over these states. To prove this, let facts be submitted to a candid world, for the truth of which we pledge a faith yet unsullied by falsehood.

(yellow, 20)

(red, 71)

(blue, 93)

(pink, 6)

## Reduce tasks

(yellow, 17)

(yellow, 20)

(yellow, 37)

(red, 77)

(red, 71)

(red, 148)

(blue, 93)

(blue, 107)

(blue, 200)

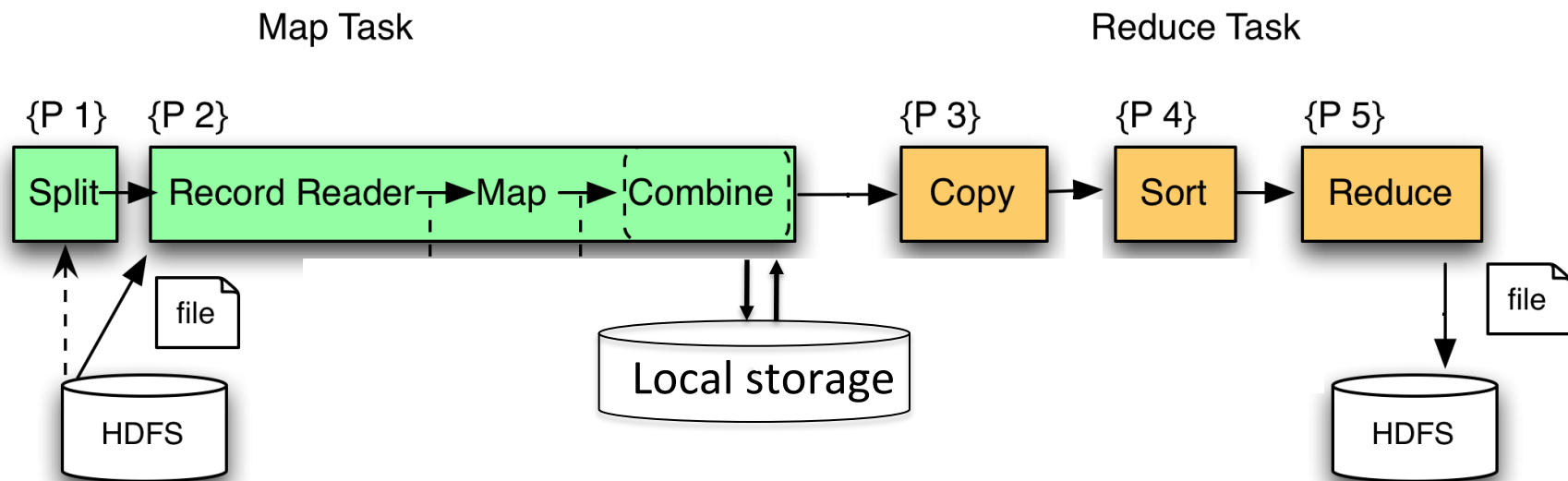
(pink, 6)

(pink, 3)

(pink, 9)

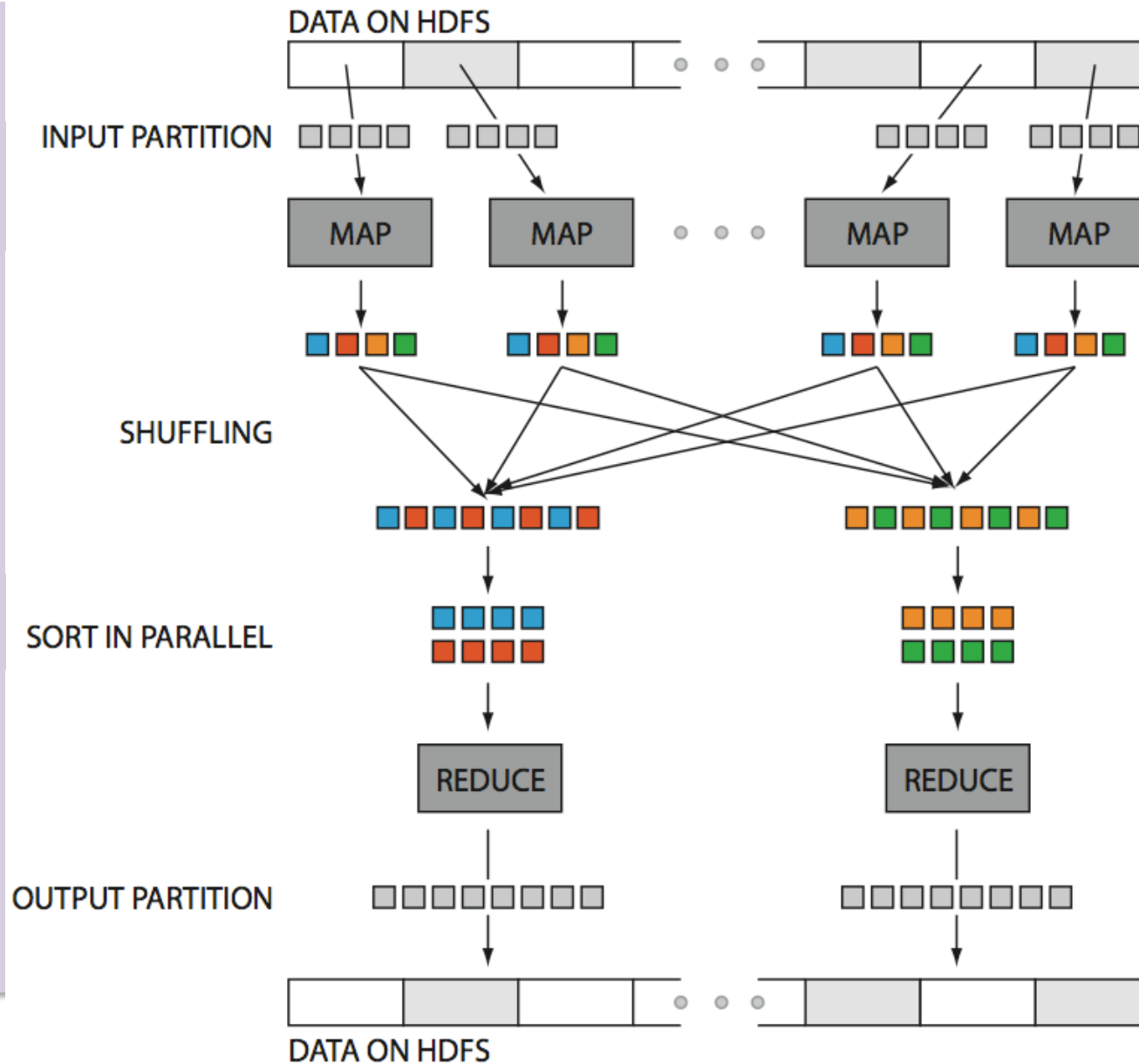
# MR Phases

- Each Map and Reduce task has multiple phases:



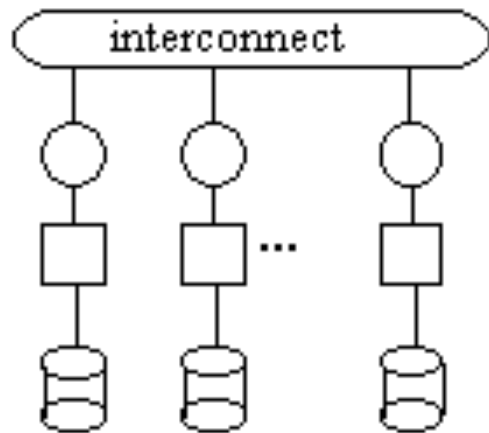
# Hadoop in One Slide

src: Huy Vo,  
NYU Poly

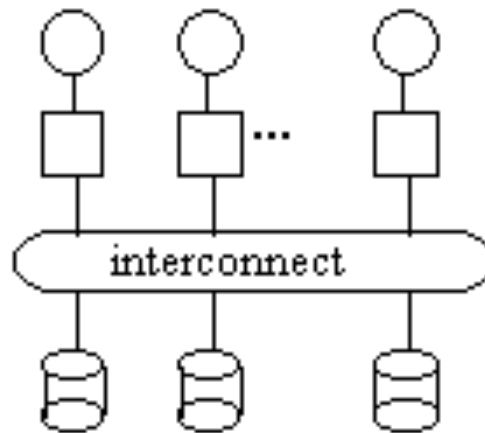


# Taxonomy of Parallel Architectures

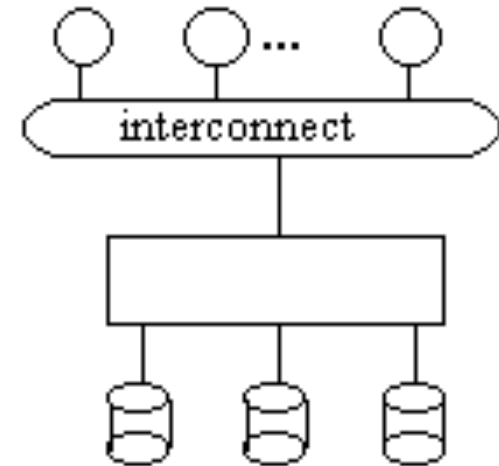
**Scales to 1000s of computers**






a) shared nothing



b) shared disc



c) shared memory

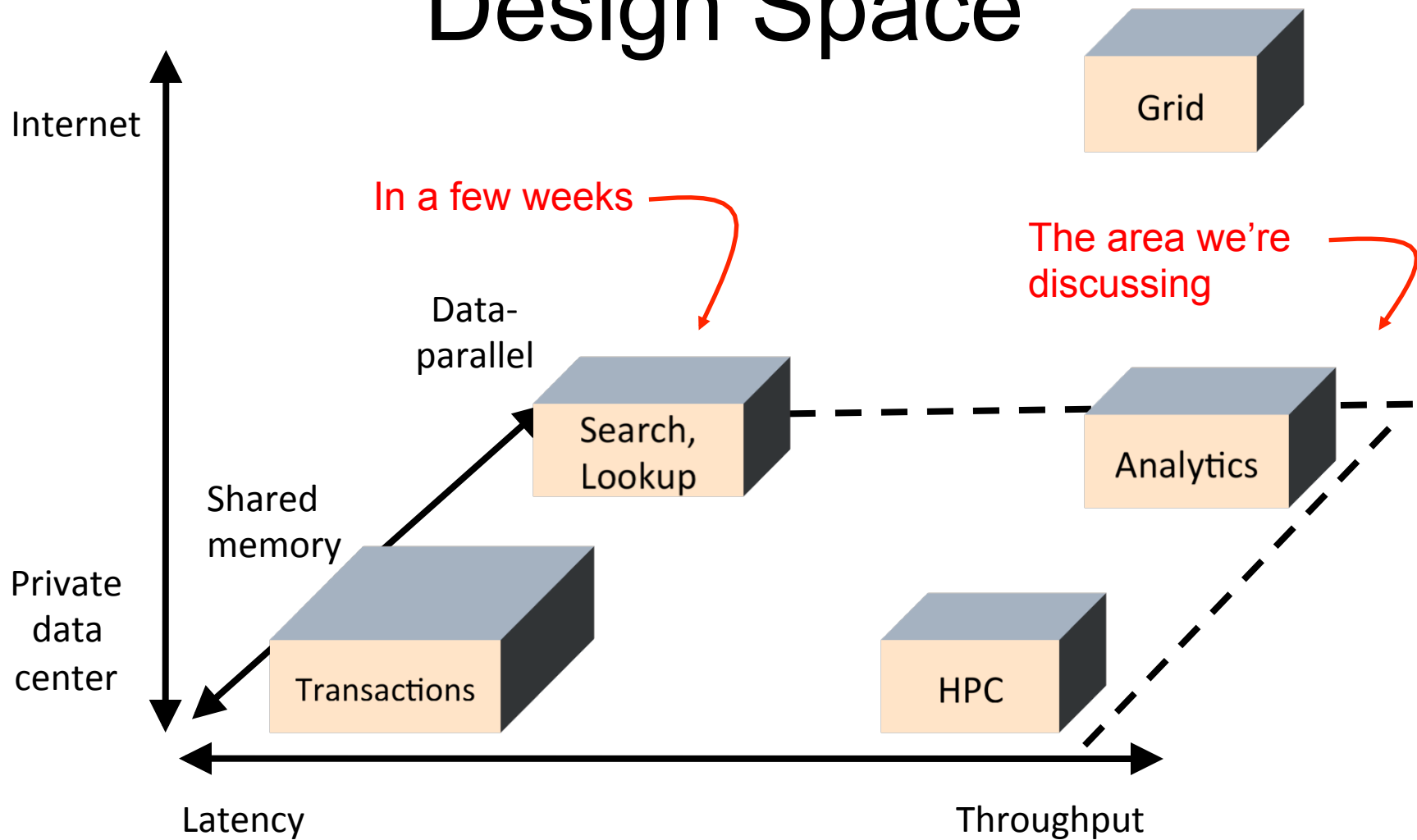
 = disc       = memory       = processor

**Easiest to program,**

**but \$\$\$\$**

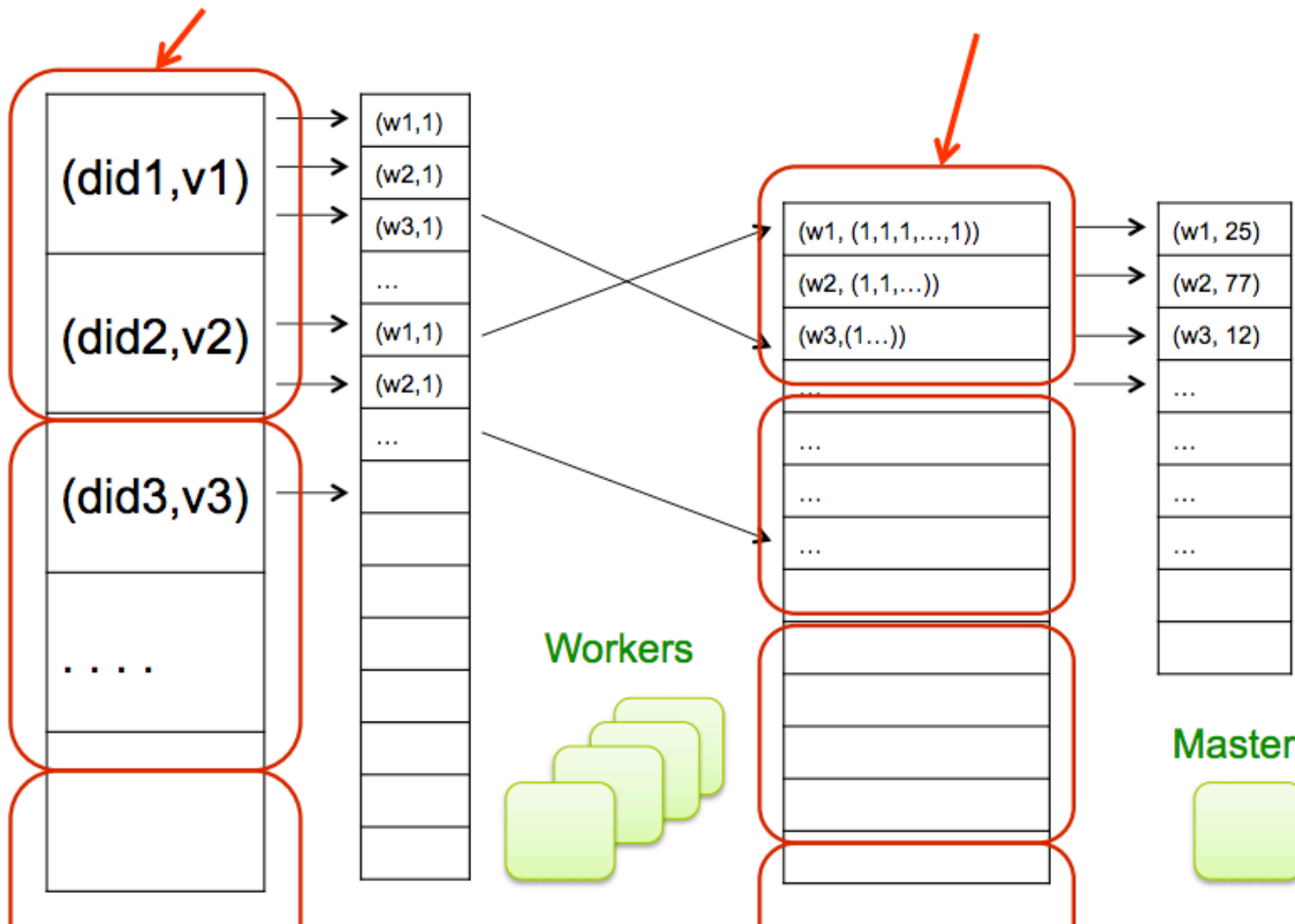
**Fig. 3.1 Logical multi-processor database designs (diagram after [DEWI92])**

# Design Space



## MAP Tasks

## REDUCE Tasks





# Implementation

- There is one master node
- Master partitions input file into *M splits*, by key
- Master assigns *workers* (=servers) to the *M map tasks*, keeps track of their progress
- Workers write their output to local disk, partition into *R regions*
- Master assigns workers to the *R reduce tasks*
- Reduce workers read regions from the map workers' local disks

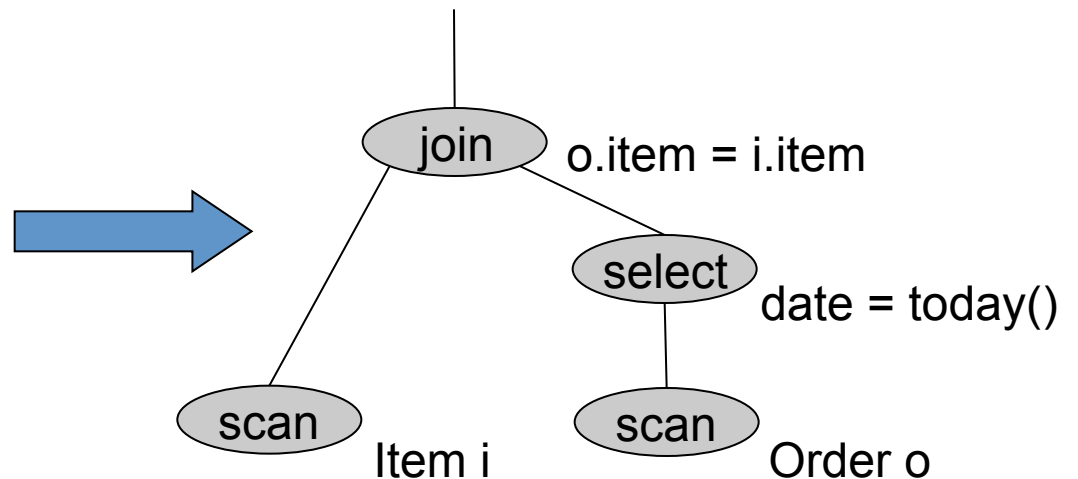
## Large-Scale Data Processing

- Many tasks process big data, produce big data
- Want to use hundreds or thousands of CPUs
  - ... but this needs to be easy
  - **Parallel databases** exist, but they are expensive, difficult to set up, and do not necessarily scale to hundreds of nodes.
- MapReduce is a *lightweight* framework, providing:
  - **Automatic parallelization and distribution**
  - **Fault-tolerance**
  - **I/O scheduling**
  - **Status and monitoring**

# Key Idea: Declarative Languages

*Find all orders from today, along with the items ordered*

```
SELECT *  
  FROM Order o, Item i  
 WHERE o.item = i.item  
    AND o.date = today()
```



## Two notions of parallel query processing

- “Distributed Query”
  - Rewrite the query as a union of subqueries
  - Workers communicate through standard interfaces, so compatible with federated, heterogeneous, or distributed databases
- “Parallel Query”
  - Each operator is implemented with a parallel algorithm

# Distributed Query Example

```
CREATE VIEW Sales AS
```

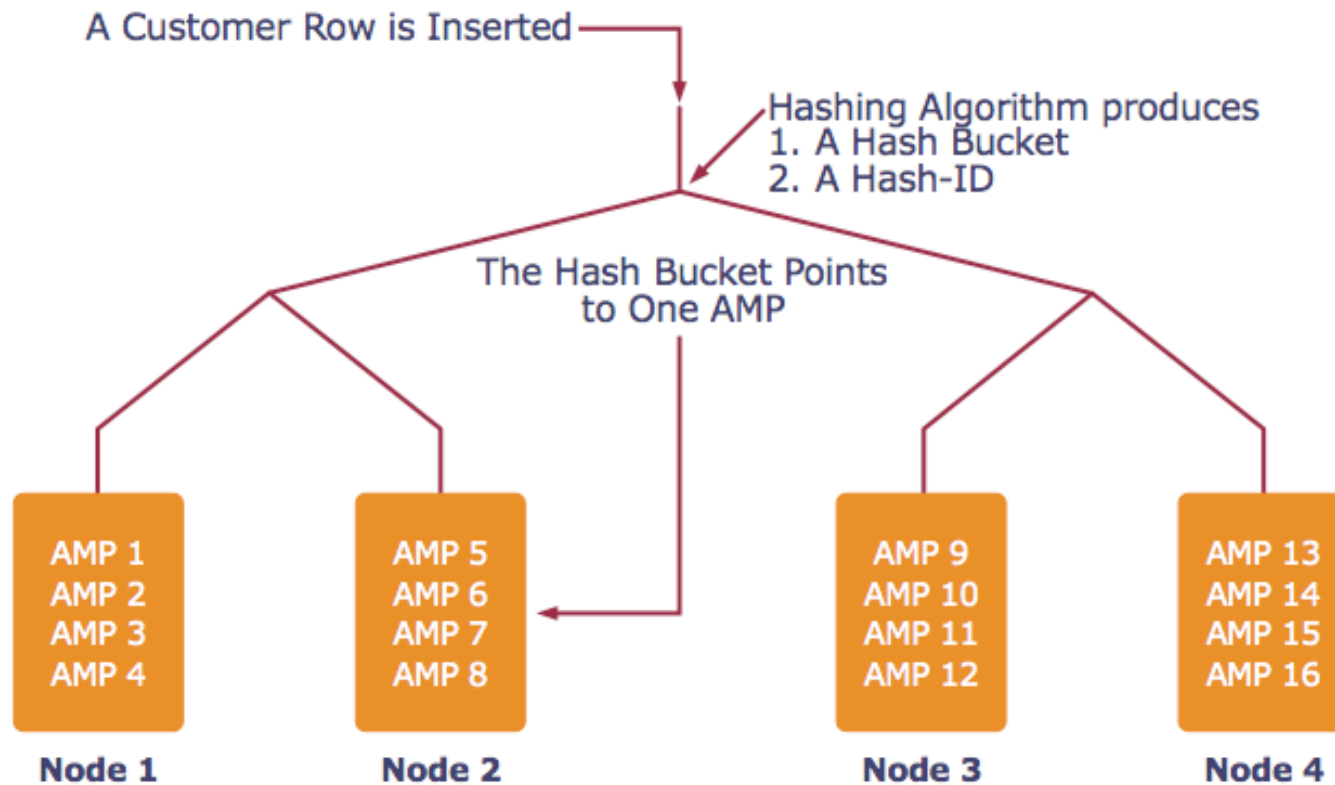
```
SELECT * FROM JanSales  
UNION ALL
```

```
SELECT * FROM FebSales  
UNION ALL
```

```
SELECT * FROM MarSales
```

```
CREATE TABLE MarSales(  
    OrderID      INT,  
    CustomerID   INT      NOT NULL,  
    OrderDate    DATETIME  NULL  
    CHECK (DATEPART(mm, OrderDate) = 3),  
    CONSTRAINT OrderIDMonth PRIMARY KEY(OrderID)  
)
```

# Parallel Query Example: Teradata

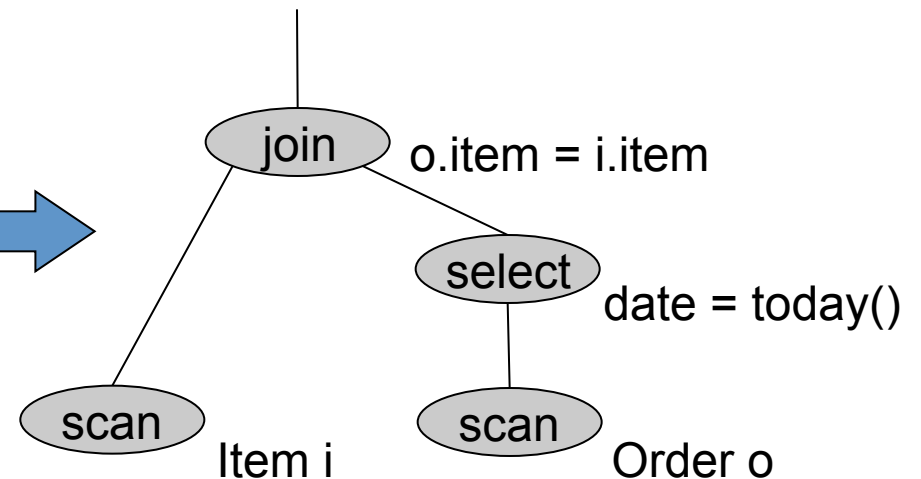


*AMP = unit of parallelism*

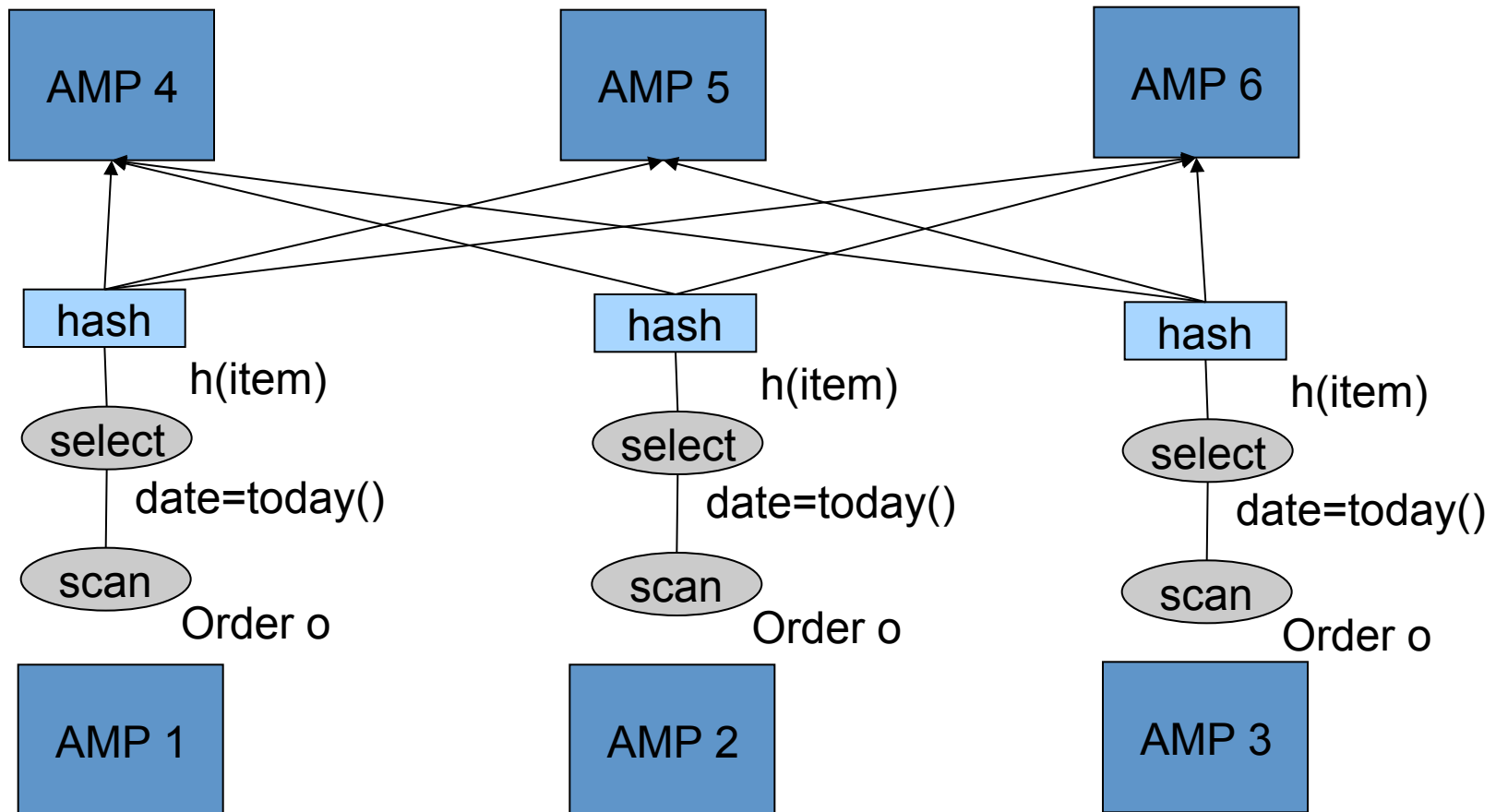
## Example System: Teradata

*Find all orders from today, along with the items ordered*

```
SELECT *  
  FROM Orders o, Lines i  
 WHERE o.item = i.item  
    AND o.date = today()
```

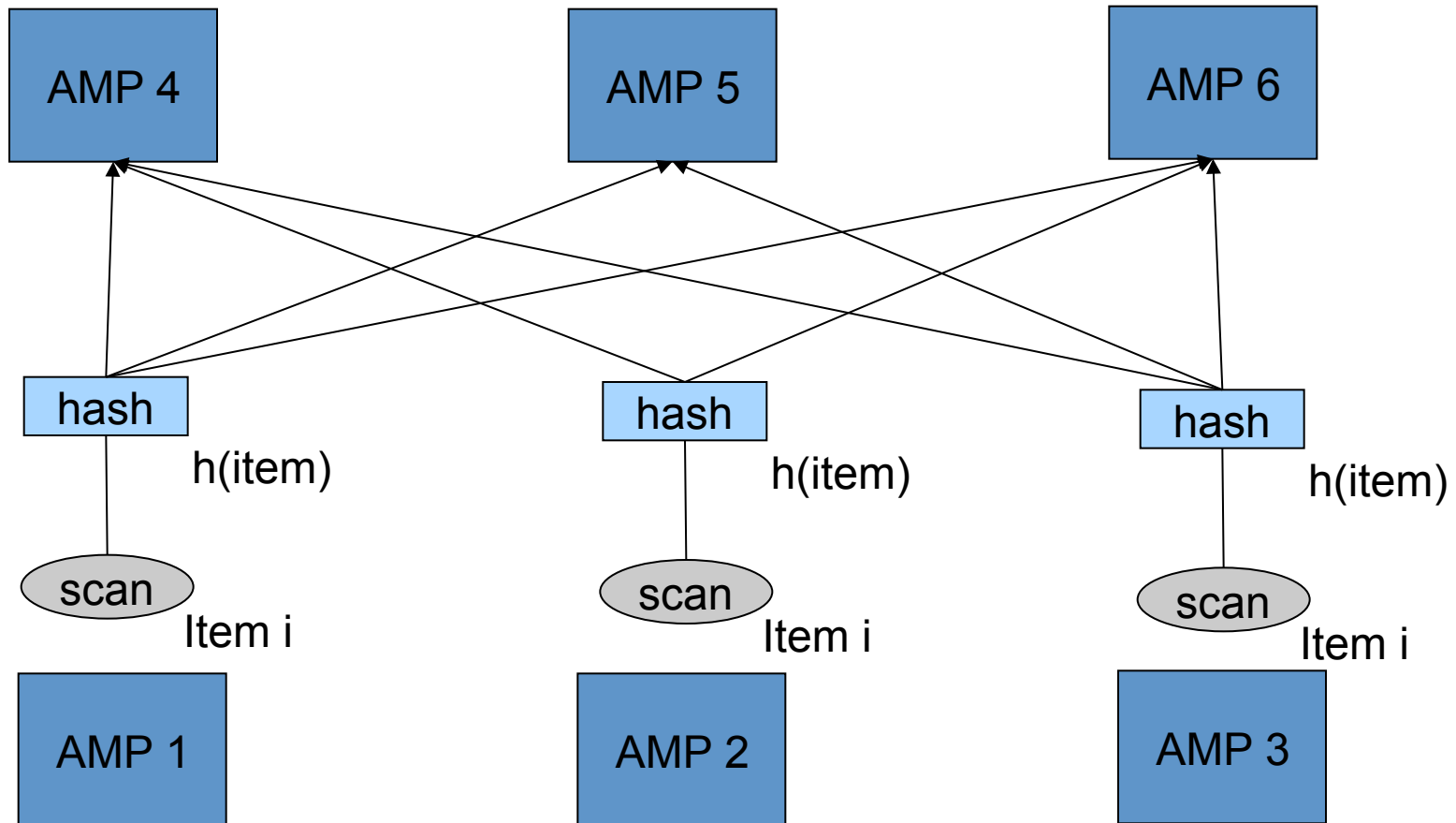


## Example System: Teradata

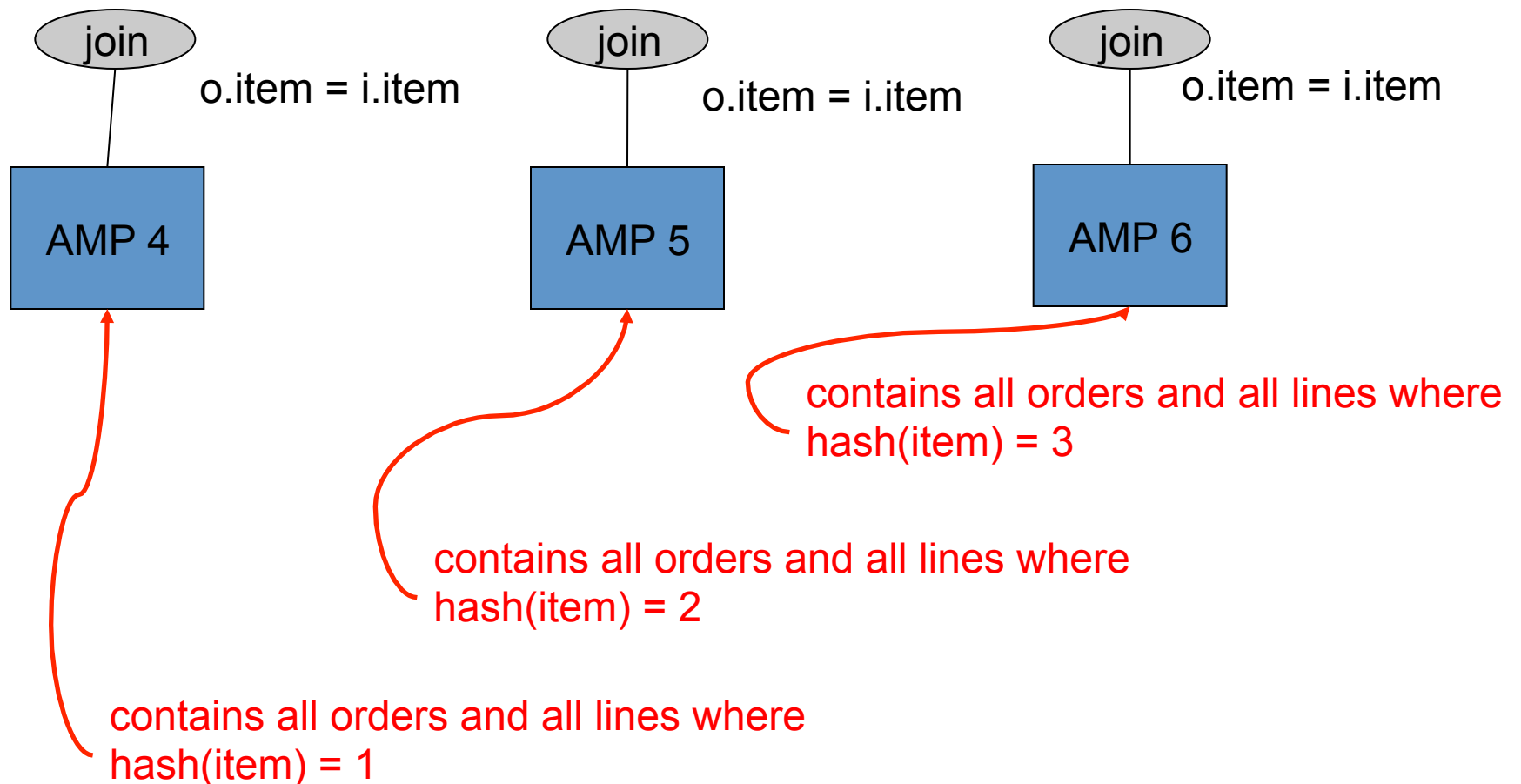




## Example System: Teradata



## Example System: Teradata



# MapReduce Contemporaries

- Dryad (Microsoft)
  - Relational Algebra
- Pig (Yahoo)
  - Near Relational Algebra over MapReduce
- HIVE (Facebook)
  - SQL over MapReduce
- Cascading
  - Relational Algebra
- Clustera
  - U of Wisconsin
- Hbase
  - Indexing on HDFS

## MapReduce vs RDBMS

- RDBMS
    - Declarative query languages
    - Schemas
    - Logical Data Independence
    - Indexing
    - Algebraic Optimization
    - Caching/Materialized Views
    - *ACID/Transactions*
  - MapReduce
    - High Scalability
    - Fault-tolerance
    - “One-person deployment”
- DryadLINQ, Pig, HIVE
- HIVE, Pig, DryadLINQ
- Hbase
- Pig, (Dryad, HIVE)

	<b>Data Model</b>	<b>Prog. Model</b>	<b>Services</b>
<b>GPL</b>	*	*	Typing (maybe)
<b>Workflow</b>	*	dataflow	typing, provenance, scheduling, caching, task parallelism, reuse
<b>Relational Algebra</b>	Relations	Select, Project, Join, Aggregate, ...	optimization, physical data independence, data parallelism
<b>MapReduce</b>	[(key,value)]	Map, Reduce	massive data parallelism, fault tolerance
<b>MS Dryad</b>	IQueryable, IEnumerable	RA + Apply + Partitioning	typing, massive data parallelism, fault tolerance
<b>MPI</b>	Arrays/ Matrices	70+ ops	data parallelism,      full control

Today's Reading, Pavlo 2009

# MR VS. DATABASES

# Hadoop vs. RDBMS

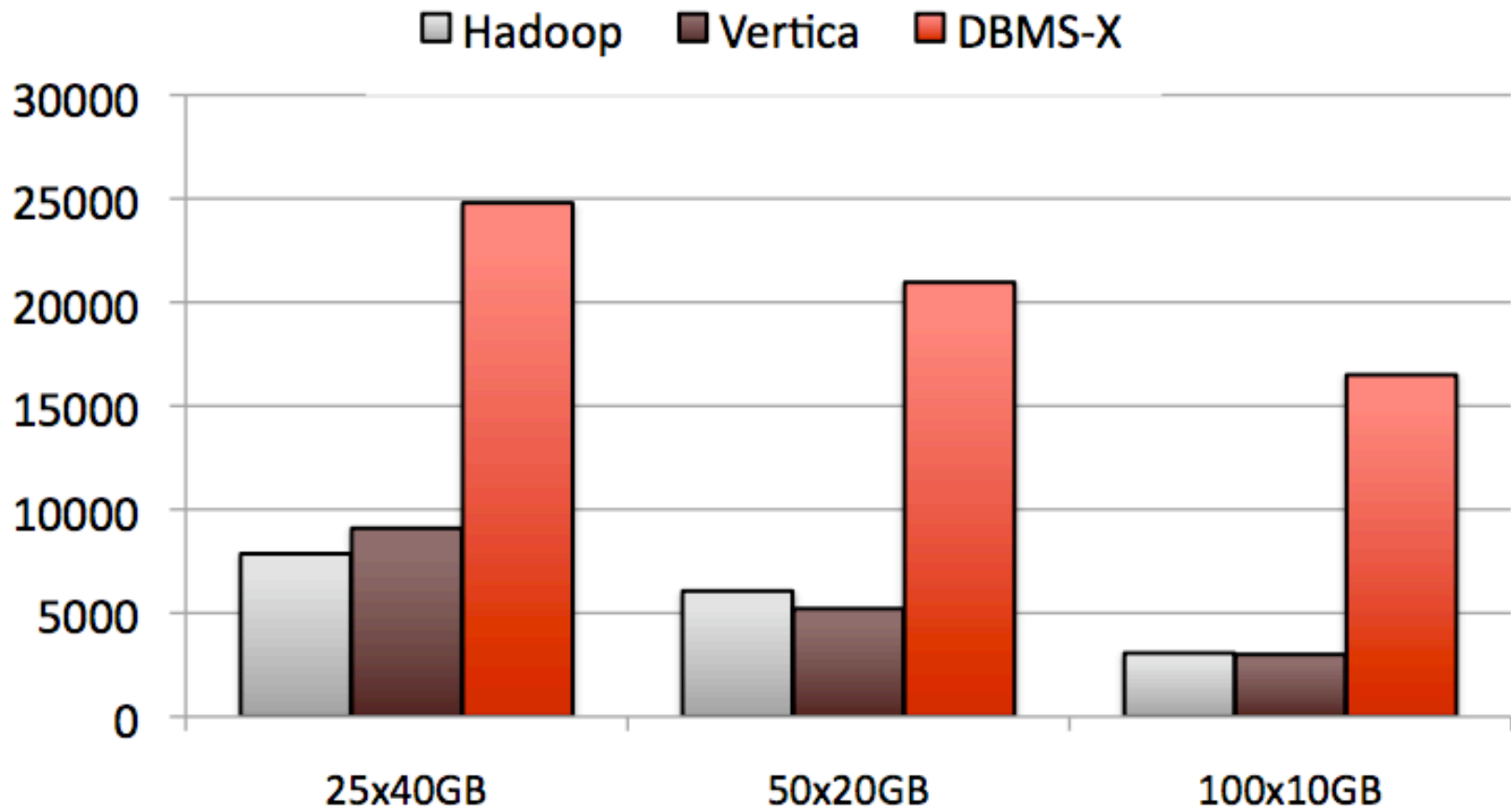
- Comparison of 3 systems
  - Hadoop
  - Vertica (a column-oriented database)
  - DBMS-X (a row-oriented database)
    - rhymes with “schmoracle”
- Qualitative
  - Programming model, ease of setup, features, etc.
- Quantitative
  - Data loading, different types of queries

# Grep Task

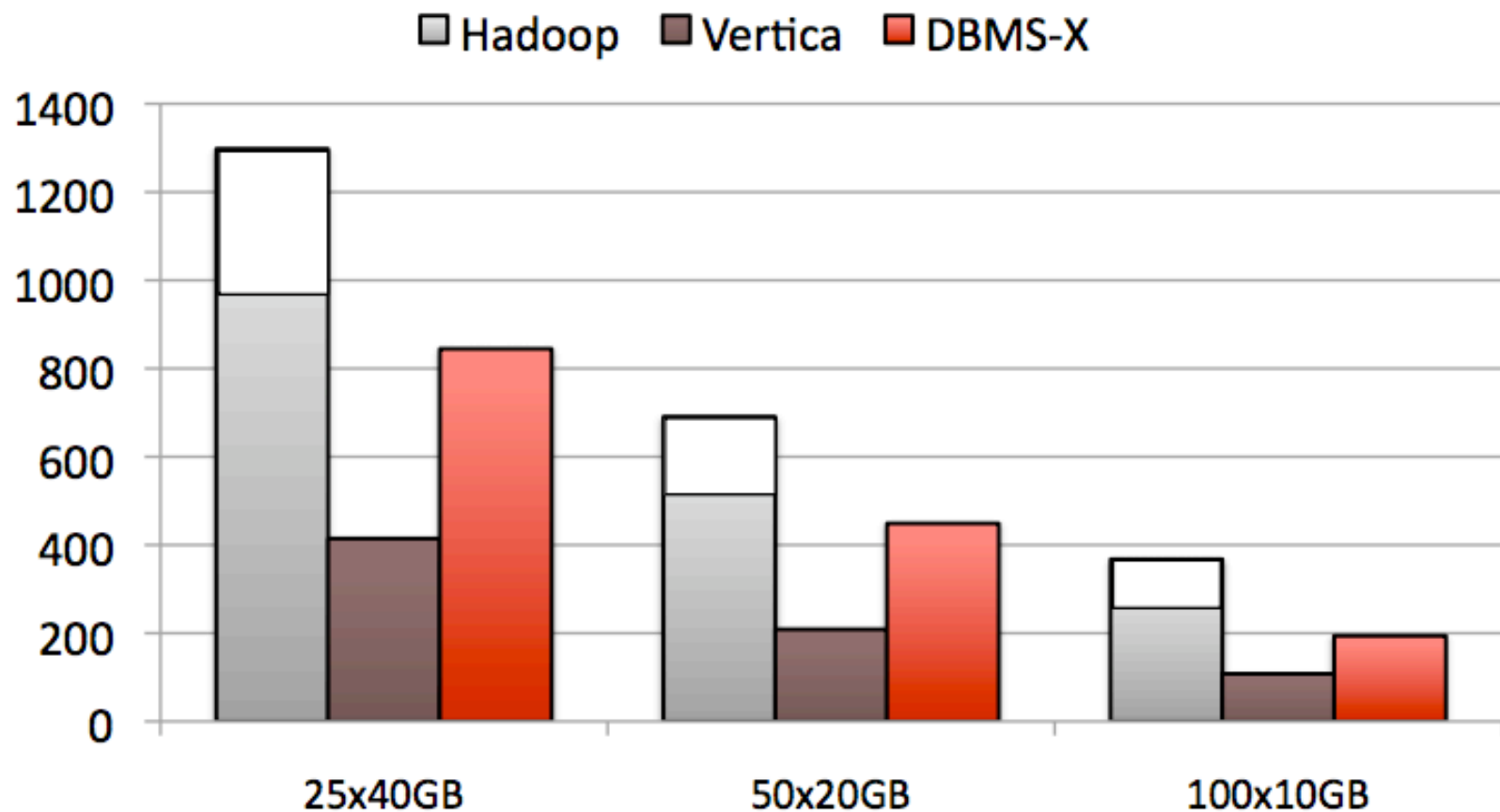
- Find 3-byte pattern in 100-byte record
  - *1 match per 10,000 records*
- Data set:
  - *10-byte unique key, 90-byte value*
  - *1TB spread across 25, 50, or 100 nodes*
  - *10 billion records*
- Original MR Paper (Dean et al. 2004)



# Grep Task Loading Results

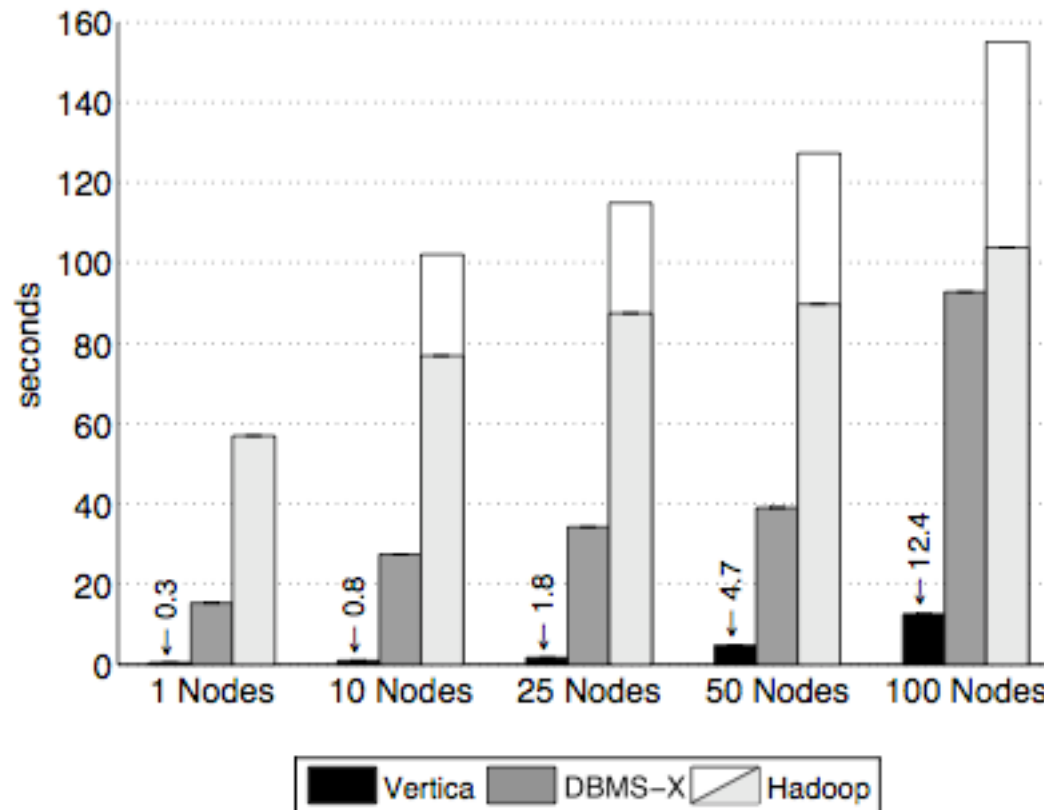


# Grep Task Execution Results



# Selection Task

```
SELECT pageURL, pageRank  
FROM Rankings WHERE pageRank > X
```



1 GB /  
node

# Analytical Tasks

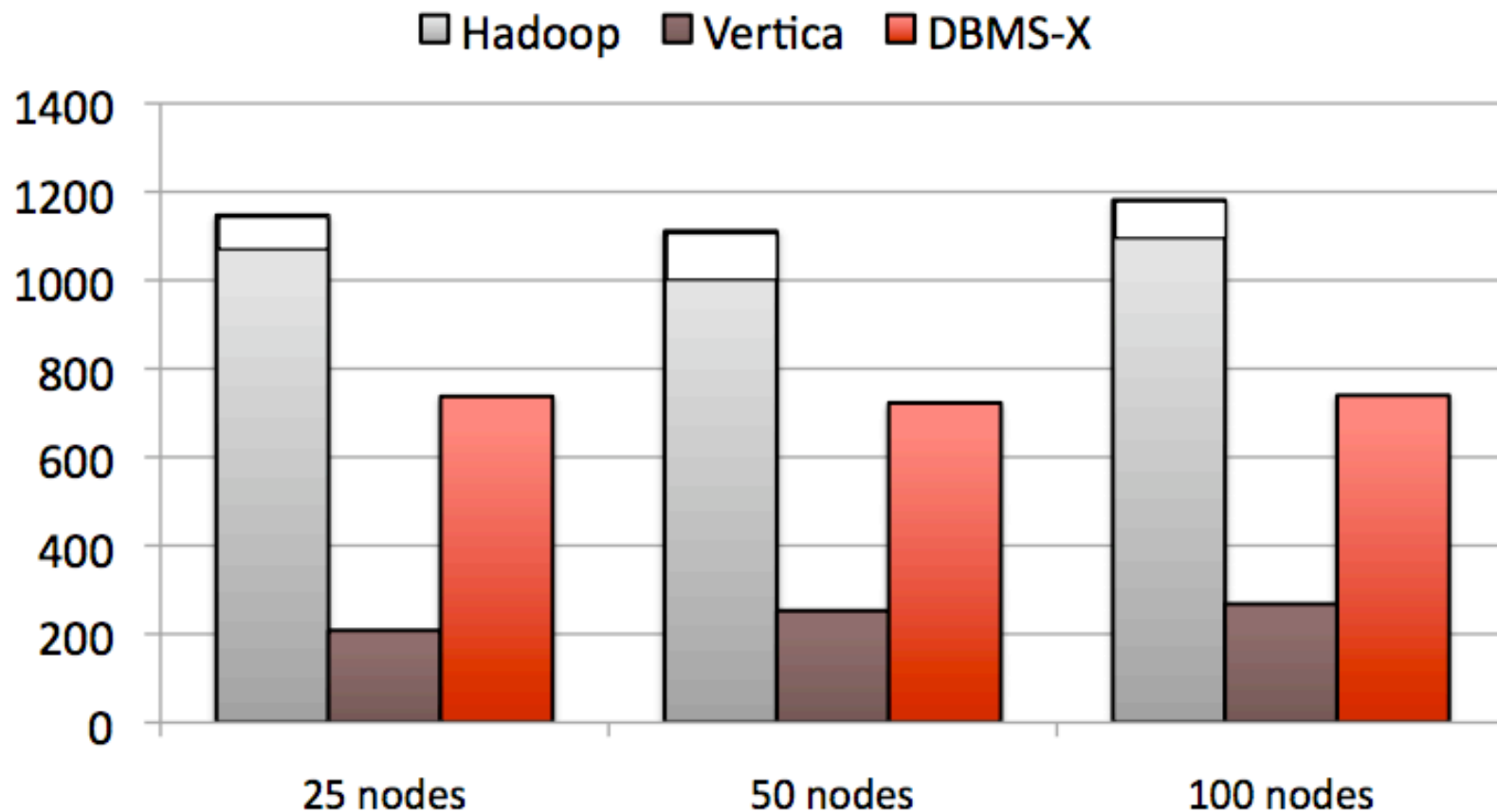
- Simple web processing schema
- Data set:
  - *600k HTML Documents (6GB/node)*
  - *155 million UserVisit records (20GB/node)*
  - *18 million Rankings records (1GB/node)*

# Aggregate Task

- Simple query to find adRevenue by IP prefix

```
SELECT SUBSTR(sourceIP, 1, 7),  
       SUM(adRevenue)  
FROM   userVistits  
GROUP BY SUBSTR(sourceIP, 1, 7)
```

# Aggregate Task Results



# Join Task

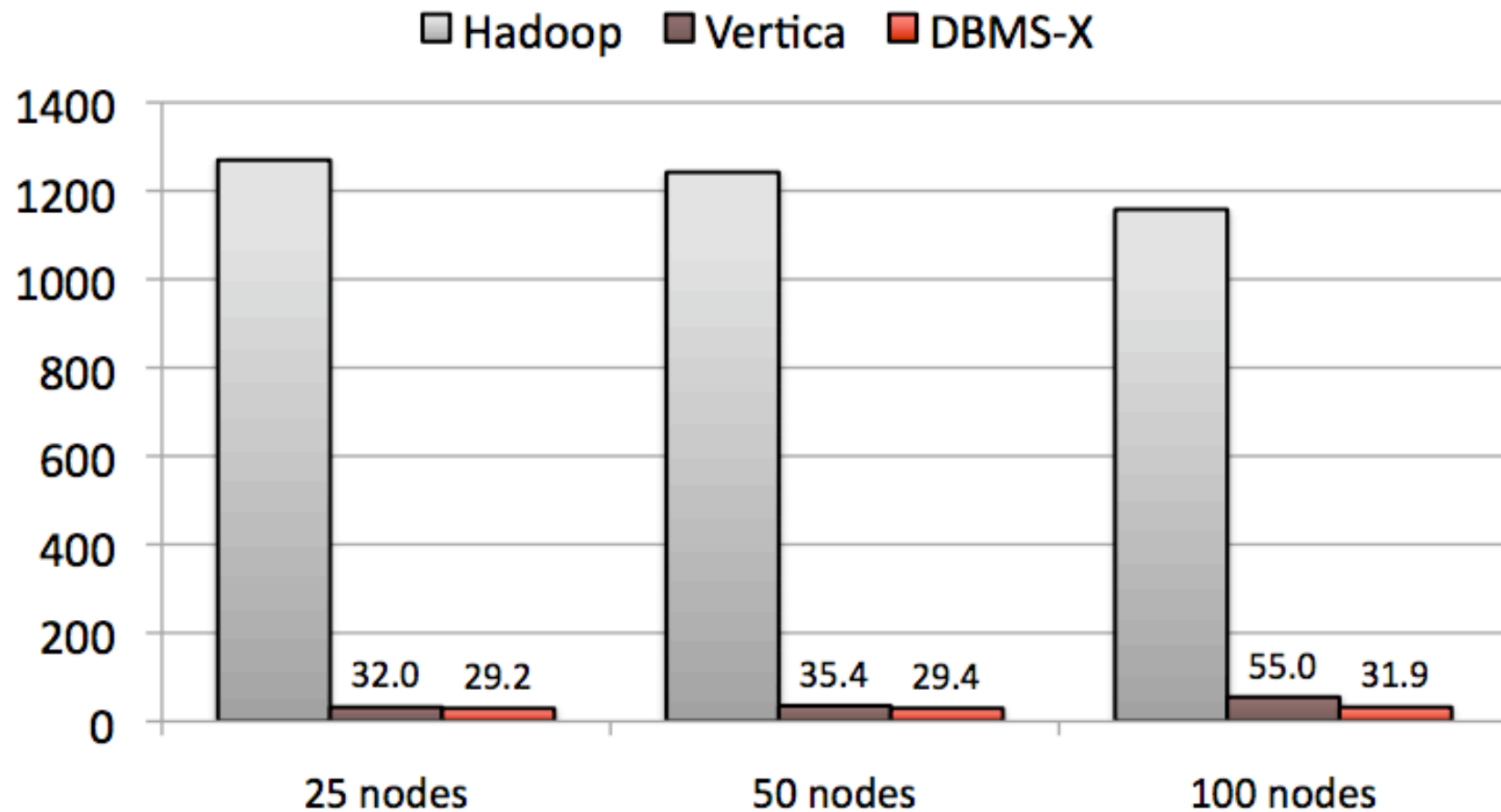
- Find the sourceIP that generated the most adRevenue along with its average pageRank.
- Implementations:
  - *DBMSs – Complex SQL using temporary table.*
  - *MapReduce – Three separate MR programs.*

# Join Task

```
SELECT INTO TempsourceIP,  
           AVG (pageRank) as avgPageRank,  
           SUM(adRevenue) as totalRevenue  
FROM RankingsAS R  
   , UserVisitsAS UV  
WHERE R.pageURL = UV.destURL  
AND UV.visitDate  
     BETWEEN '2000-01-15'  
     AND '2000-01-22'  
GROUP BY UV.sourceIP;  
  
SELECT sourceIP,  
       totalRevenue,  
       avgPageRank  
FROM Temp  
ORDER BY totalRevenueDESC  
LIMIT 1;
```



# Join Task Results



## Problems with this analysis?

- Other ways to avoid sequential scans?
- Fault-tolerance in large clusters?
- Tasks that cannot be expressed as queries?

# Google's Response: Cluster Size

- Largest known database installations:
  - *Greenplum – 96 nodes – 4.5 PB (eBay) [1]*
  - *Teradata – 72 nodes – 2+ PB (eBay) [1]*
- Largest known MR installations:
  - *Hadoop – 3658 nodes – 1 PB (Yahoo) [2]*
  - *Hive – 600+ nodes – 2.5 PB (Facebook) [3]*

[1] eBay's two enormous data warehouses – April 30<sup>th</sup>, 2009

<http://www.dbms2.com/2009/04/30/ebays-two-enormous-data-warehouses/>

[2] Hadoop Sorts a Petabyte in 16.25 Hours and a Terabyte in 62 Seconds – May 11<sup>th</sup>, 2009

[http://developer.yahoo.net/blogs/hadoop/2009/05/hadoop\\_sorts\\_a\\_petabyte\\_in\\_162.html](http://developer.yahoo.net/blogs/hadoop/2009/05/hadoop_sorts_a_petabyte_in_162.html)

[3] Hive - A Petabyte Scale Data Warehouse using Hadoop – June 10<sup>th</sup>, 2009

[http://www.facebook.com/note.php?note\\_id=89508453919](http://www.facebook.com/note.php?note_id=89508453919)

# Concluding Remarks

- What can *MapReduce* learn from *Databases*?
  - *Declarative languages are a good thing.*
  - *Schemas are important.*
- What can *Databases* learn from *MapReduce*?
  - *Query fault-tolerance.*
  - *Support for in situ data.*
  - *Embrace open-source.*

# Other Benchmarked Systems

- **HadoopDB (Abadi '09 - Yale)**
  - *Replaced Hadoop filesystem with Postgres.*
  - *Makes JDBC calls inside of MR functions.*
- **Hive (Thusoo '09 - Facebook)**
  - *Data warehouse interface on top of Hadoop.*
  - *Converts SQL-like language to MR programs.*