

Database System Internals

MapReduce

Paul G. Allen School of Computer Science and Engineering
University of Washington, Seattle

This lecture

Data model?

Relational

Scaleup goal?

OLAP

Architecture?

Shared-Nothing

This lecture

Data model?

Relational



text/kv-pairs

Scaleup goal?

OLAP

Architecture?

Shared-Nothing

References

- **MapReduce: Simplified Data Processing on Large Clusters.** Jeffrey Dean and Sanjay Ghemawat. OSDI'04
- Mining of Massive Datasets, by Rajaraman and Ullman, <http://i.stanford.edu/~ullman/mmds.html>
 - Map-reduce (Section 20.2);
 - Chapter 2 (Sections 1,2,3 only)

Outline

- Review high-level MR ideas from 344
- Discuss implementation in greater detail

Map Reduce Review

- Google: [Dean 2004]
- Open source implementation: Hadoop
- MapReduce = high-level programming model and implementation for large-scale parallel data processing

MapReduce Motivation

- Not designed to be a DBMS
- Designed to simplify task of writing parallel programs
 - A simple programming model that applies to many large-scale computing problems
- Hides messy details in MapReduce runtime library:
 - Automatic parallelization
 - Load balancing
 - Network and disk transfer optimizations
 - Handling of machine failures
 - Robustness
 - **Improvements to core library benefit all users of library!**

content in part from: Jeff Dean

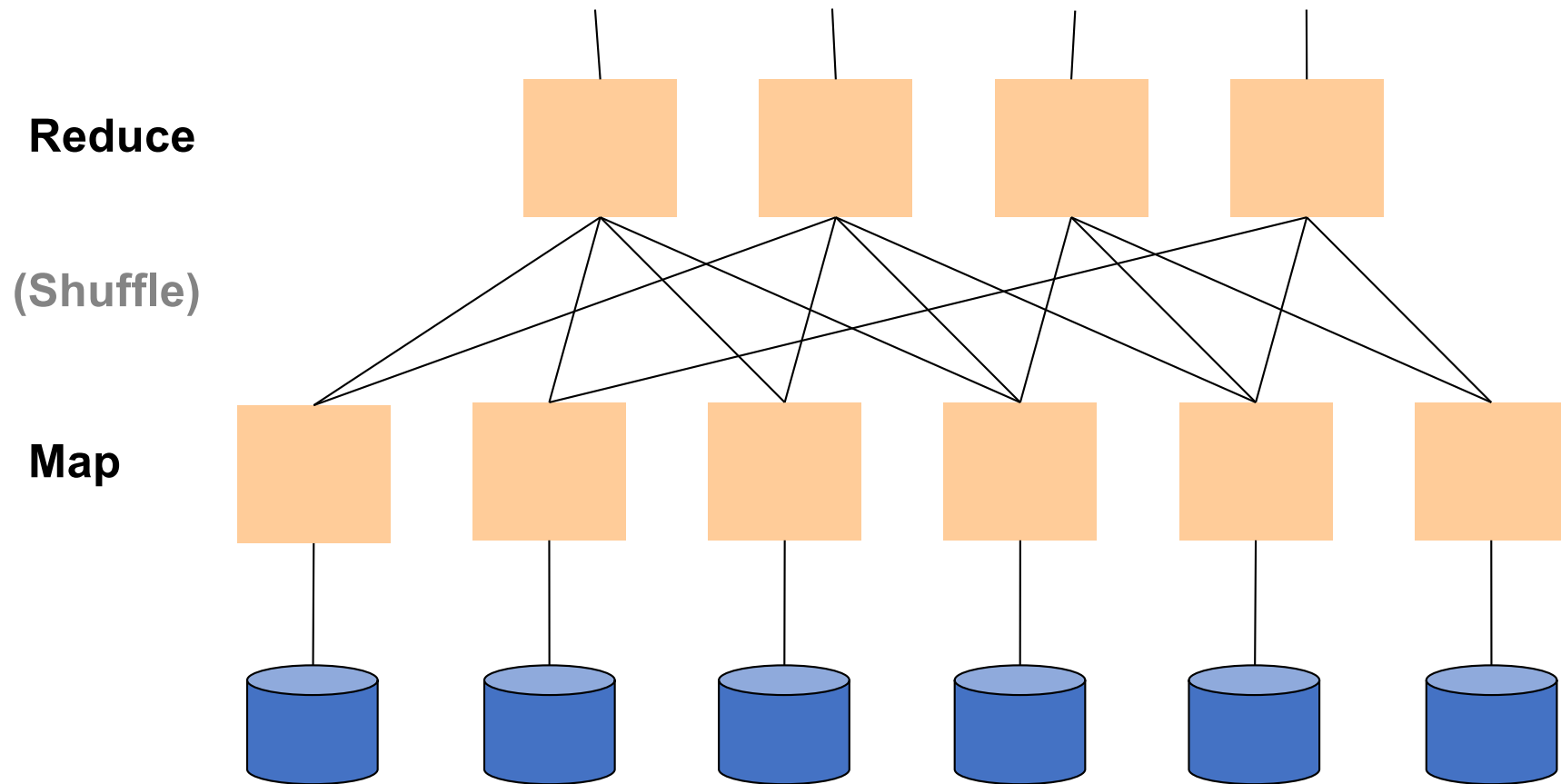
Data Processing at Massive Scale

- Want to process petabytes of data and more
- Massive parallelism:
 - 100s, or 1000s, or 10000s servers (think data center)
 - Many hours
- Failure:
 - If medium-time-between-failure is 1 year
 - Then 10000 servers have one failure / hour

Data Storage: GFS/HDFS

- MapReduce job input is a file
- Common implementation is to store files in a highly scalable file system such as **GFS/HDFS**
 - GFS: Google File System
 - HDFS: Hadoop File System
 - Each data file is split into M partitions (64MB or more)
 - Blocks are replicated & stored on random machines
 - Files are append only

Observation: Your favorite parallel algorithm...



Typical Problems Solved by MR

- Read a lot of data
- **Map**: extract something you care about from each record
- Shuffle and Sort
- **Reduce**: aggregate, summarize, filter, transform
- Write the results

Outline stays the same,
map and reduce change to fit the problem

Data Model

Files !

A file = a bag of **(key, value)** pairs

A MapReduce program:

- Input: a bag of **(inputkey, value)** pairs
- Output: a bag of **(outputkey, value)** pairs

Step 1: the MAP Phase

User provides the **MAP**-function:

- Input: `(input key, value)`
- Output: **bag** of `(intermediate key, value)`

System applies map function in parallel to all `(input key, value)` pairs in the input file

Step 2: the REDUCE Phase

User provides the **REDUCE** function:

- Input:
(intermediate key, bag of values)
- Output (original MR paper): bag of output (values)
- Output (Hadoop): bag of (output key, values)

System groups all pairs with the same intermediate key, and passes the bag of values to the REDUCE function

Example

- Counting the number of occurrences of each word in a large collection of documents
- Each Document
 - The **key** = document id (**did**)
 - The **value** = set of words (**word**)

```
map(String key, String value):  
// key: document name  
// value: document contents  
for each word w in value:  
    EmitIntermediate(w, "1");
```

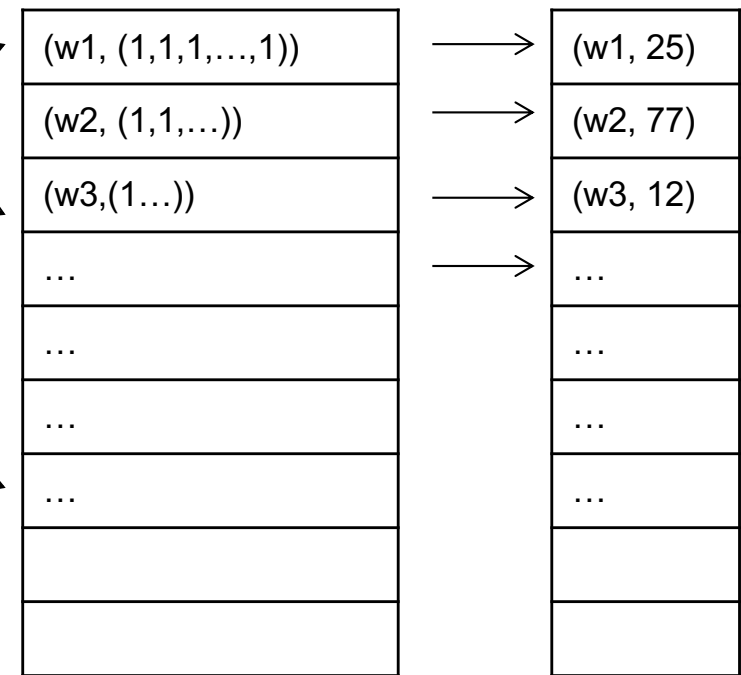
```
reduce(String key, Iterator values):  
// key: a word  
// values: a list of counts  
int result = 0;  
for each v in values:  
    result += ParseInt(v);  
Emit(AsString(result));
```

MAP



Shuffle

REDUCE



Jobs vs. Tasks

- A **MapReduce Job**
 - One single “query”, e.g. count the words in all docs
 - More complex queries may consists of multiple jobs
- A **Map Task**, or a **Reduce Task**
 - A group of instantiations of the map-, or reduce-function, which are scheduled on a single worker

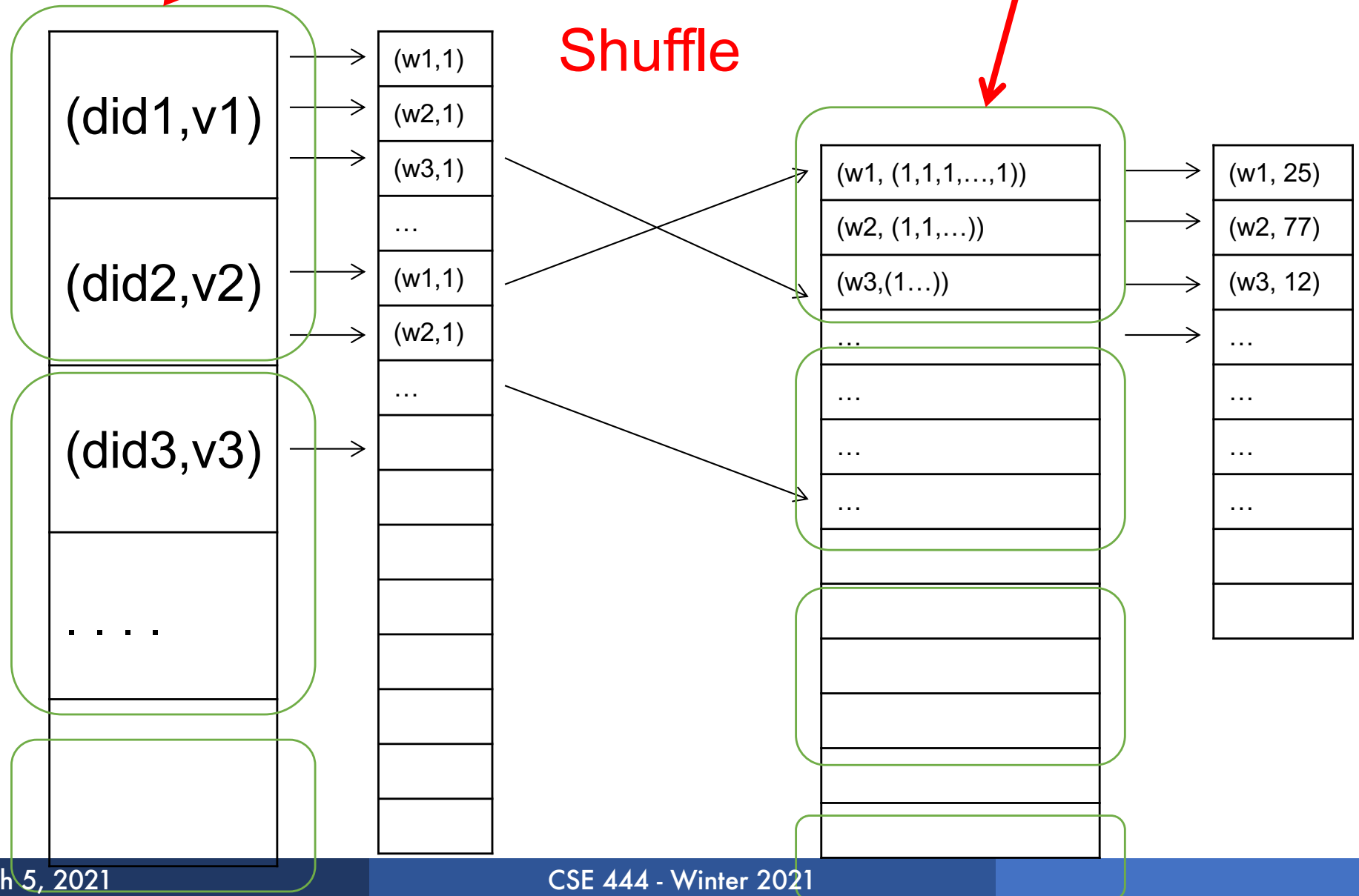
Workers

- A **worker** is a process that executes one task at a time
- Typically there is one worker per processor, hence 4 or 8 per node
- Often talk about “slots”
 - E.g., Each server has 2 map slots and 2 reduce slots

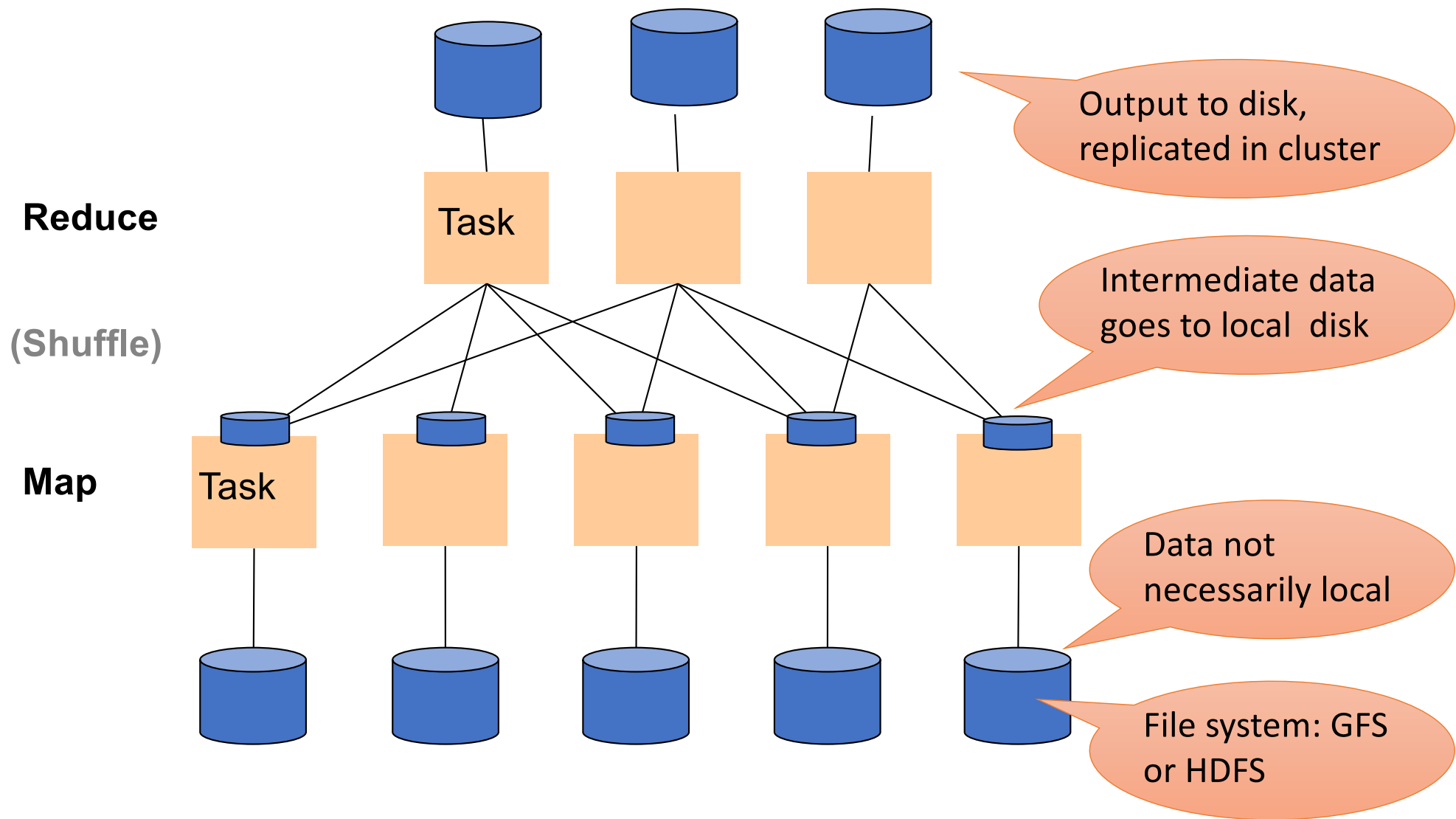
MAP Tasks

REDUCE Tasks

Shuffle



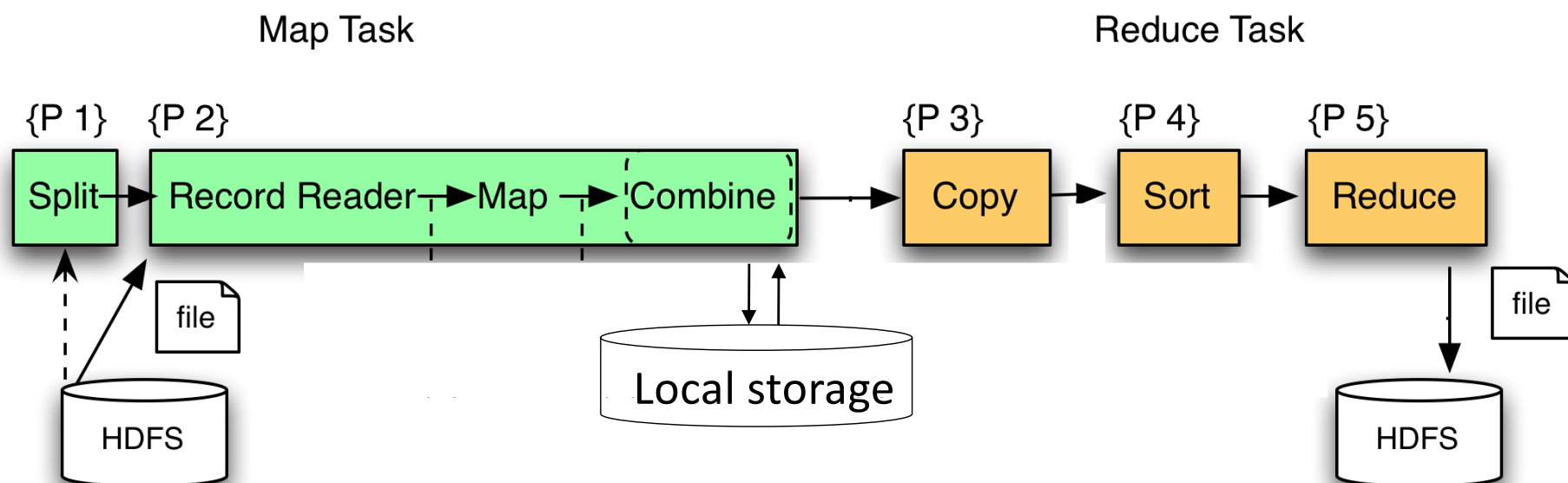
Parallel MapReduce Details



MapReduce Implementation

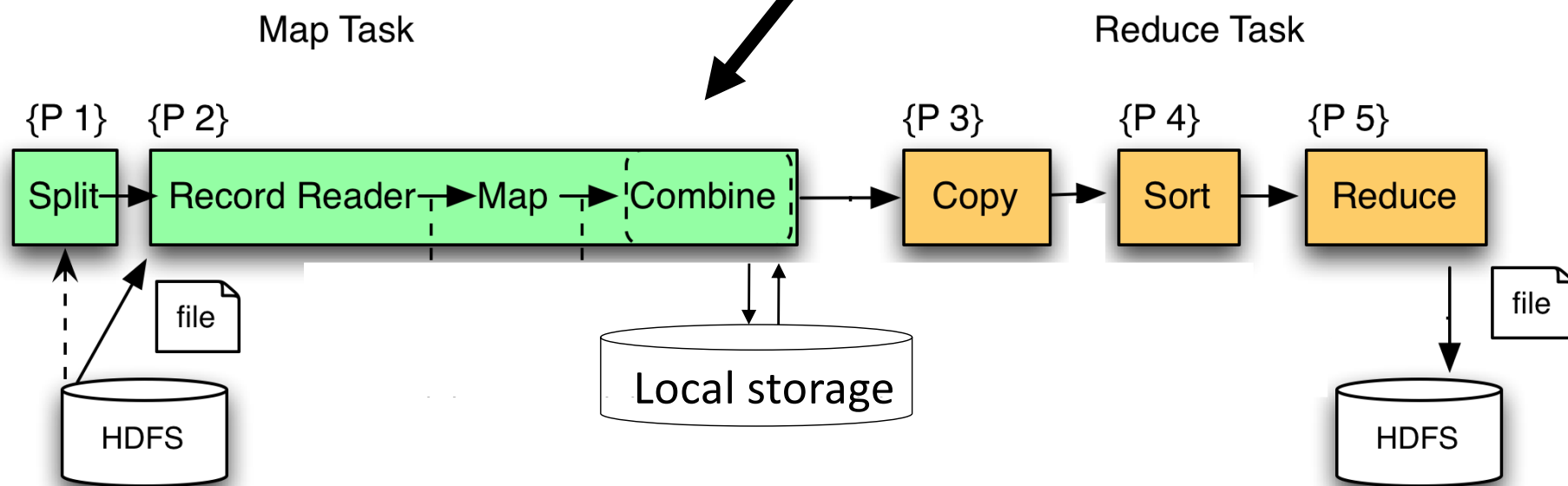
- There is one master node
- Input file gets partitioned further into M' splits
 - Each split is a contiguous piece of the input file
 - By default splits correspond to blocks
- Master assigns *workers* (=servers) to the M' map tasks, keeps track of their progress
- Workers write their output to local disk
- Output of each map task is partitioned into R regions
- Master assigns workers to the R reduce tasks
- Reduce workers read regions from the map workers' local disks

MapReduce Phases



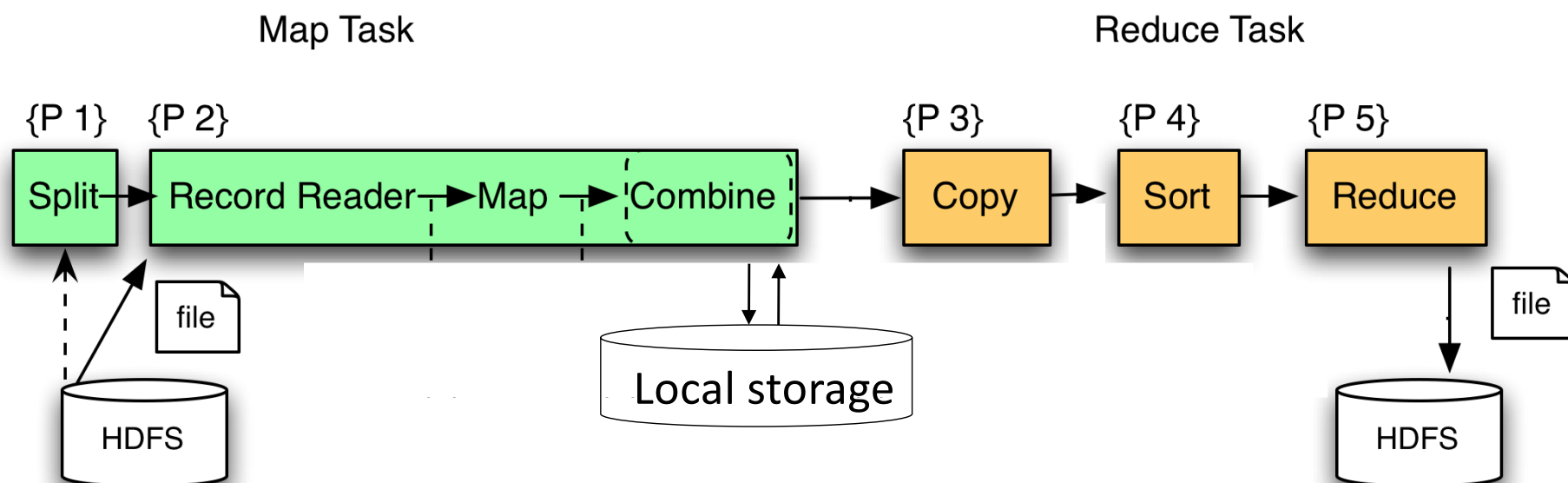
MapReduce Phases

Q: If we compute an aggregate, when can we use a combiner?



MapReduce Phases

Combine runs same code as reduce



Interesting Implementation Details

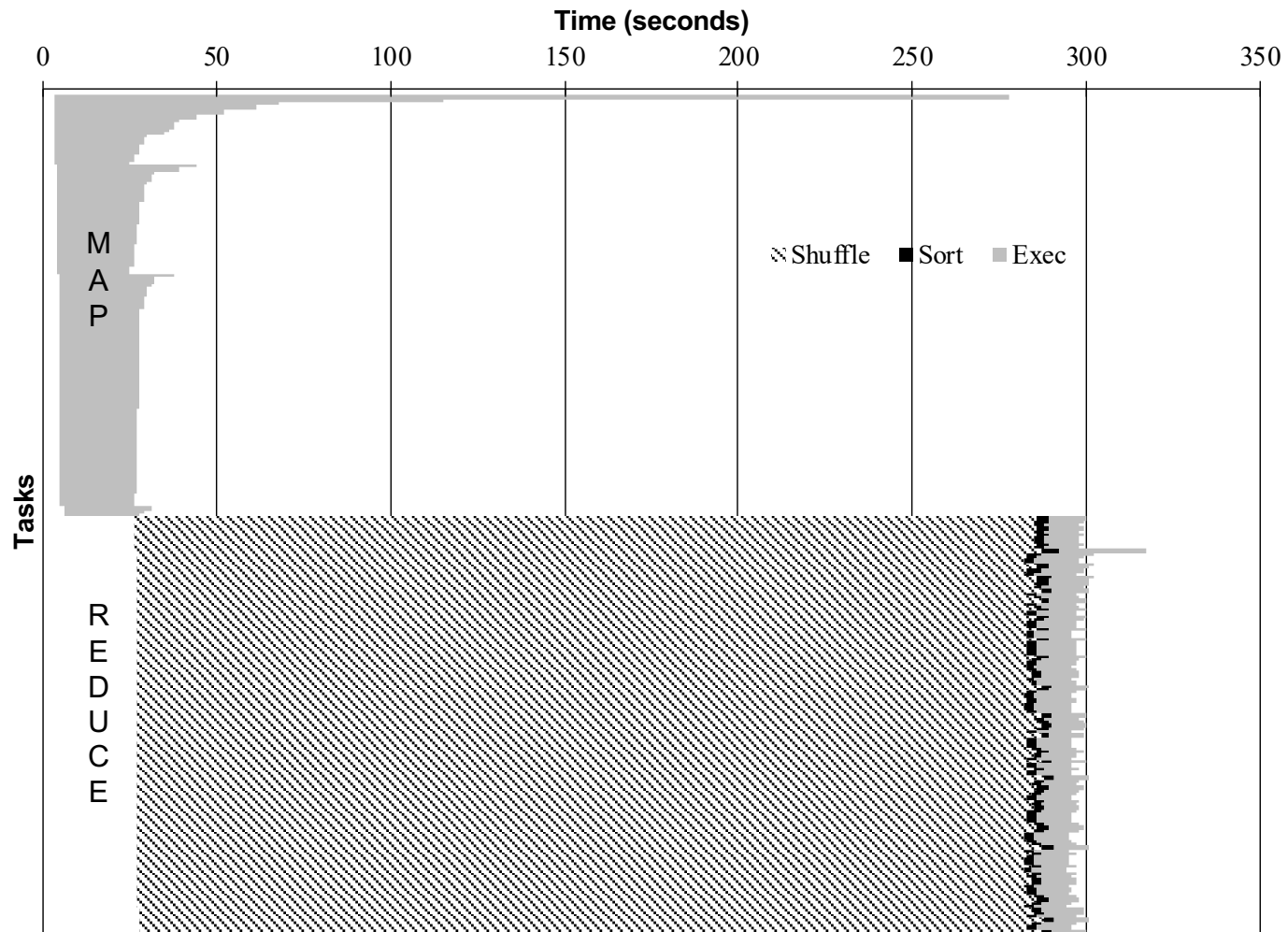
- Worker failure:
 - Master pings workers periodically,
 - If down then reassigns its task to **another worker**
 - (\neq a parallel DBMS restarts whole query)
- How many map and reduce tasks:
 - Larger is better for load balancing
 - But more tasks also add overheads
 - (\neq parallel DBMS spreads ops across all nodes)

Interesting Implementation Details

Backup tasks:

- **Straggler** = a machine that takes unusually long time to complete one of the last tasks. Eg:
 - Bad disk forces frequent correctable errors (30MB/s → 1MB/s)
 - The cluster scheduler has scheduled other tasks on that machine
- Stragglers are a main reason for slowdown
- Solution: *pre-emptive backup execution of the last few remaining in-progress tasks*

PageRank Application



The State of MapReduce Systems

- Lots of extensions to address limitations
 - Capabilities to write DAGs of MapReduce jobs
 - Declarative languages
 - Ability to read from structured storage (e.g., indexes)
 - Etc.
- Most companies use both types of engines (MR and DBMS), with increased integration
- New systems emerged which improve over MapReduce: e.g. Spark

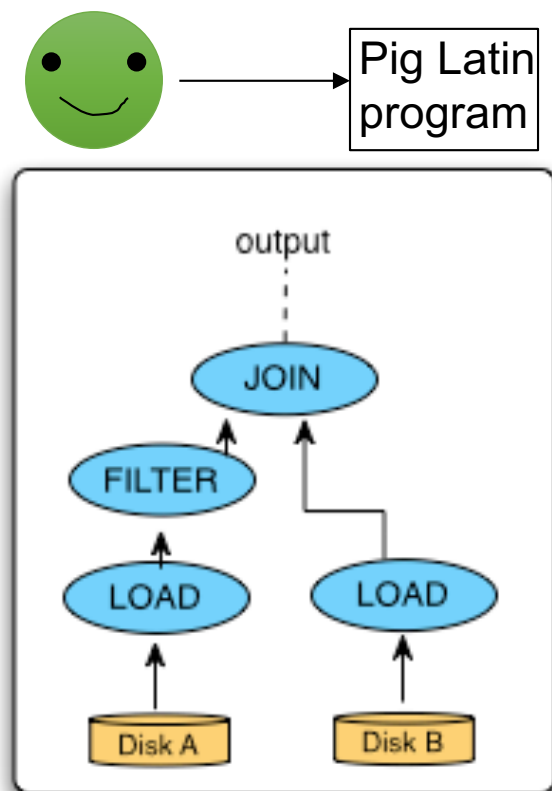
Declarative Languages on MR

- PIG Latin (Yahoo!)
 - Domain specific language, like Relational Algebra
 - Open source
- HiveQL (Facebook)
 - SQL-like language
 - Open source
- SQL / Tenzing (Google)
 - SQL on MR
 - Proprietary
 - Morphed into BigQuery

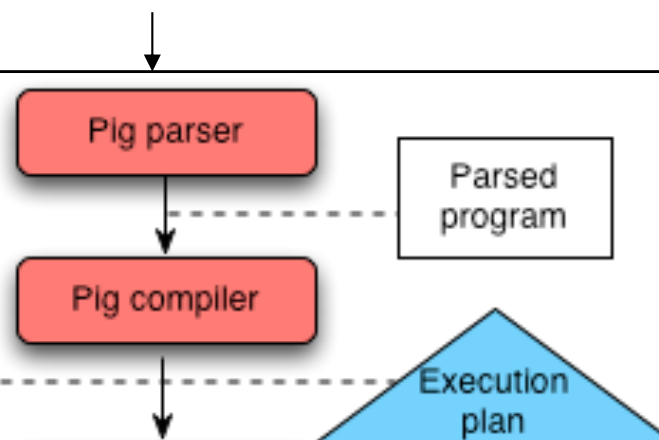
Relational Queries over MR

- Query → query plan
- Each operator → one MapReduce job
- Example: the Pig system

Background: Pig system



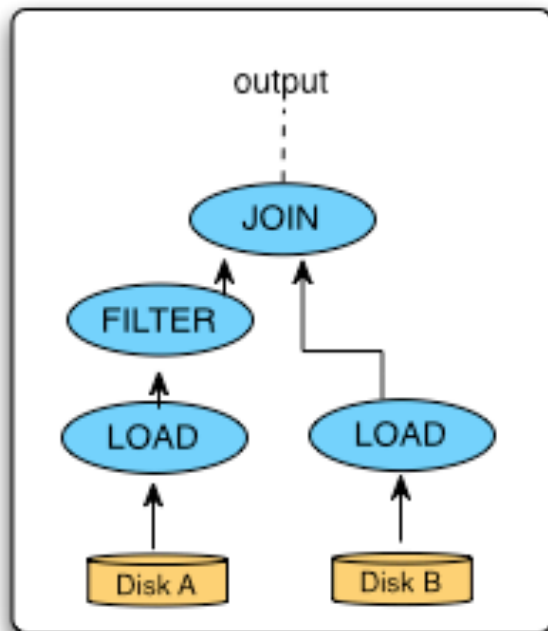
```
A = LOAD 'file1' AS (sid,pid,mass,px:double);  
B = LOAD 'file2' AS (sid,pid,mass,px:double);  
C = FILTER A BY px < 1.0;  
D = JOIN C BY sid,  
      B BY sid;  
STORE g INTO 'output.txt';
```



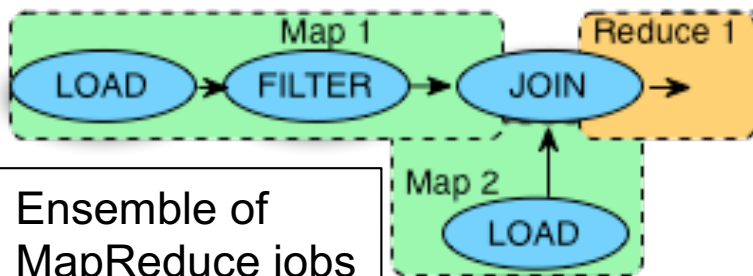
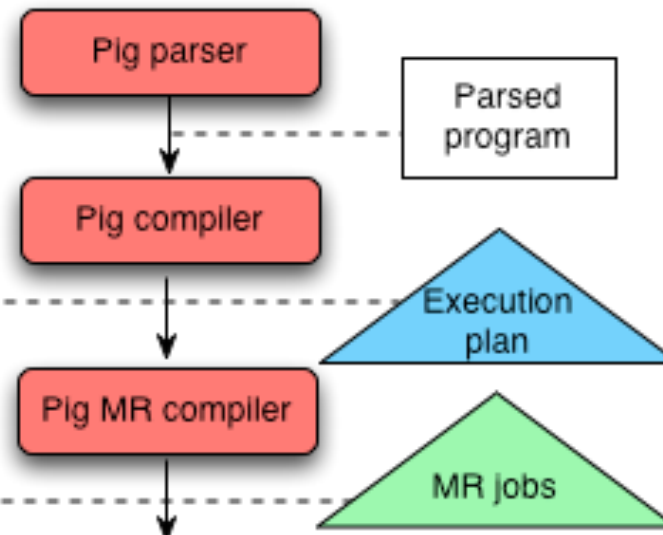
Background: Pig system



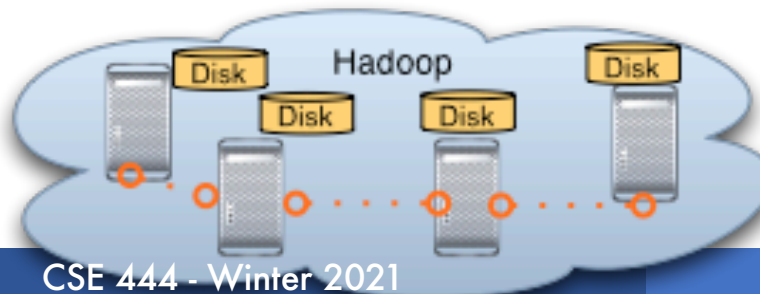
Pig Latin program



```
A = LOAD 'file1' AS (sid,pid,mass,px:double);  
B = LOAD 'file2' AS (sid,pid,mass,px:double);  
C = FILTER A BY px < 1.0;  
D = JOIN C BY sid,  
      B BY sid;  
STORE g INTO 'output.txt';
```



Ensemble of MapReduce jobs



GroupBy in MapReduce

Doc(key, word)

MapReduce IS A GroupBy!

MAP=GROUP BY, **REDUCE**=Aggregate

```
SELECT word, sum(1)
FROM Doc
GROUP BY word
```

Joins in MapReduce

- If MR is GROUP-BY plus AGGREGATE, then how do we compute $R(A,B) \bowtie S(B,C)$ using MR?

Joins in MapReduce

- If MR is GROUP-BY plus AGGREGATE, then how do we compute $R(A,B) \bowtie S(B,C)$ using MR?
- Answer:
 - Map: group R by R.B, group S by S.B
 - Input = either a tuple $R(a,b)$ or a tuple $S(b,c)$
 - Output = $(b,R(a,b))$ or $(b,S(b,c))$ respectively
 - Reduce:
 - Input = $(b,\{R(a_1,b),R(a_2,b),\dots,S(b,c_1),S(b,c_2),\dots\})$
 - Output = $\{R(a_1,b),R(a_2,b),\dots\} \times \{S(b,c_1),S(b,c_2),\dots\}$
 - In practice: improve the reduce function (next...)

Join in MR

Users(name, age)
Pages(userName, url)

```
Users = load `users` as (name, age);  
Pages = load `pages` as (userName, url);  
Jnd = join Users by name, Pages by userName;
```

```
map([String key], String value):  
    // value.relation is either 'Users' or 'Pages'  
    if value.relation='Users':  
        EmitIntermediate(value.name, (1, value));  
    else // value.relation='Pages':  
        EmitIntermediate(value.userName, (2, value));
```

```
reduce(String user, Iterator values):  
    Users = empty; Pages = empty;  
    for each v in values:  
        if v.type = 1: Users.insert(v)  
        else Pages.insert(v);  
    for v1 in Users, for v2 in Pages  
        Emit(v1,v2);
```

Join in MR

Users(name, age)
Pages(userName, url)

```
Users = load 'users' as (name, age);  
Pages = load 'pages' as (userName, url);  
Jnd = join Users by name, Pages by userName;
```

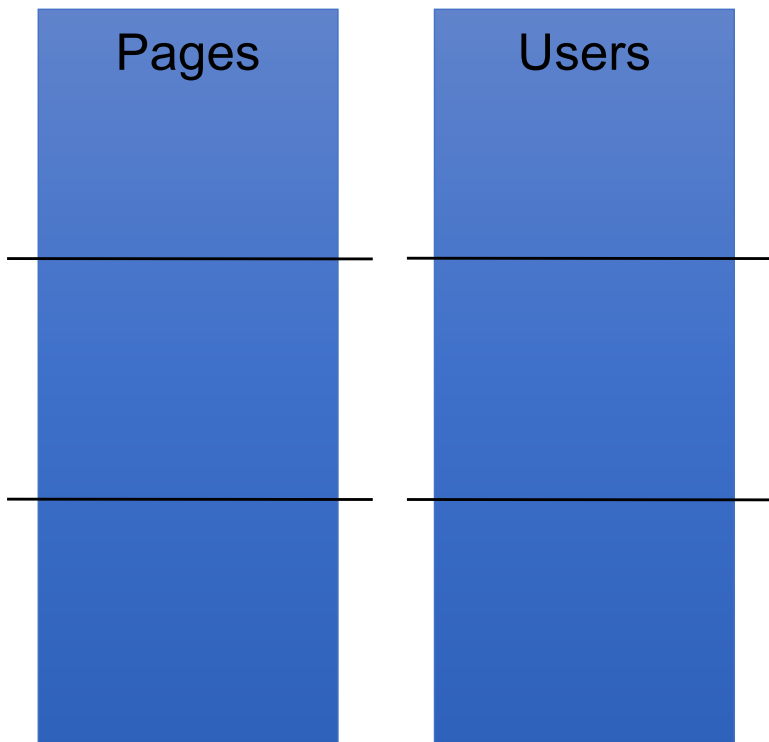
Pages

Users

Join in MR

Users(name, age)
Pages(userName, url)

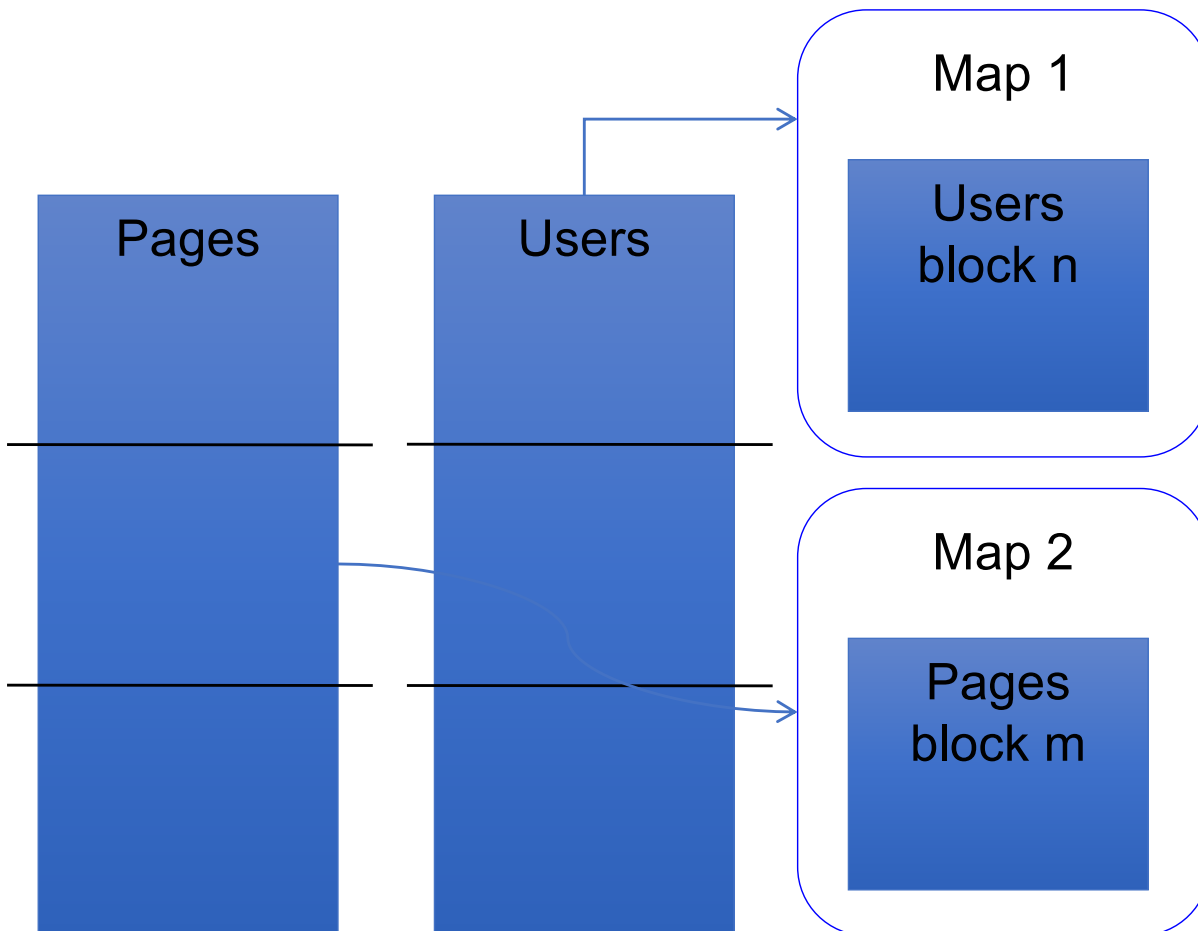
```
Users = load 'users' as (name, age);  
Pages = load 'pages' as (userName, url);  
Jnd = join Users by name, Pages by userName;
```



Join in MR

Users(name, age)
Pages(userName, url)

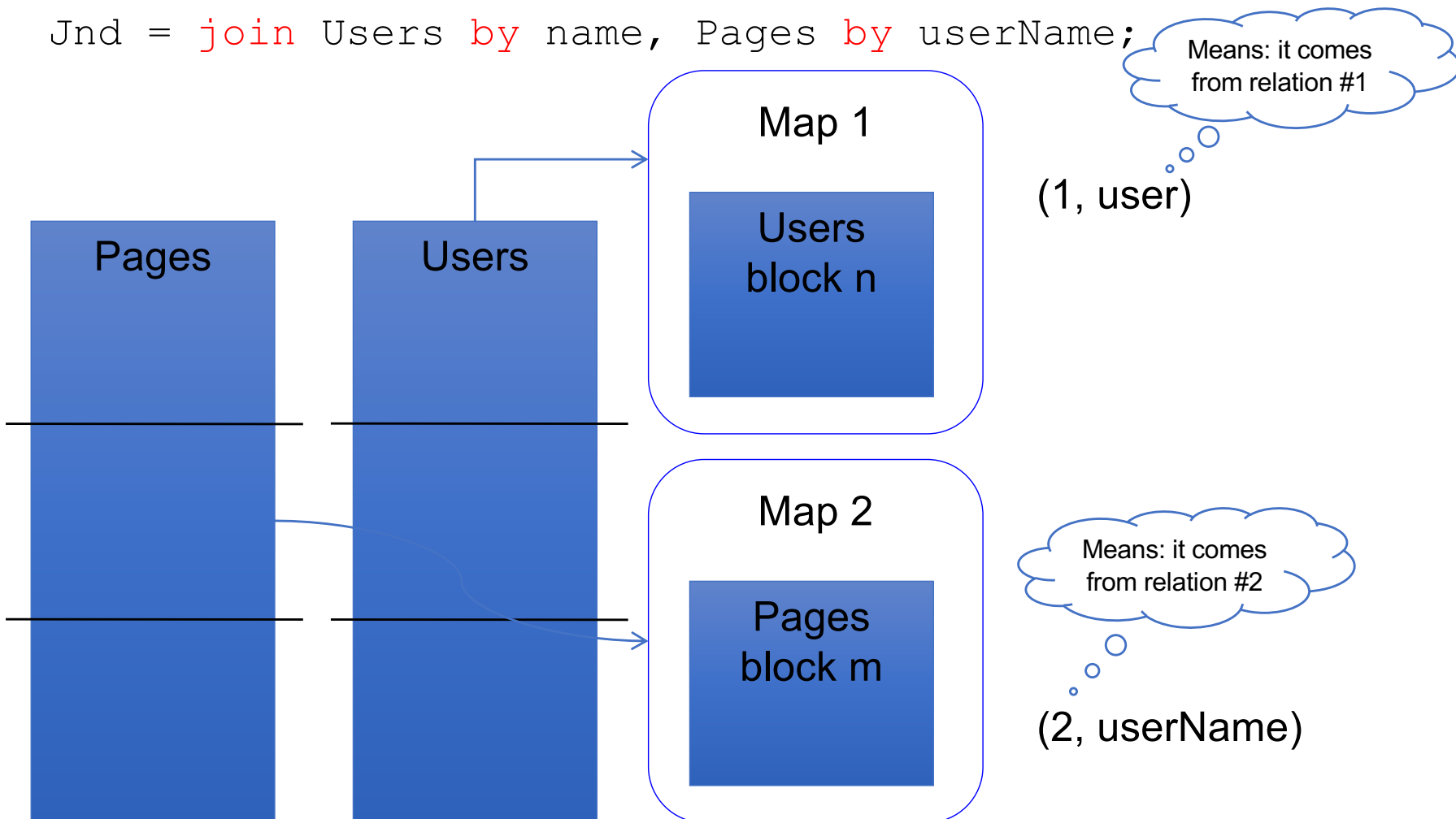
```
Users = load 'users' as (name, age);  
Pages = load 'pages' as (userName, url);  
Jnd = join Users by name, Pages by userName;
```



Join in MR

Users(name, age)
Pages(userName, url)

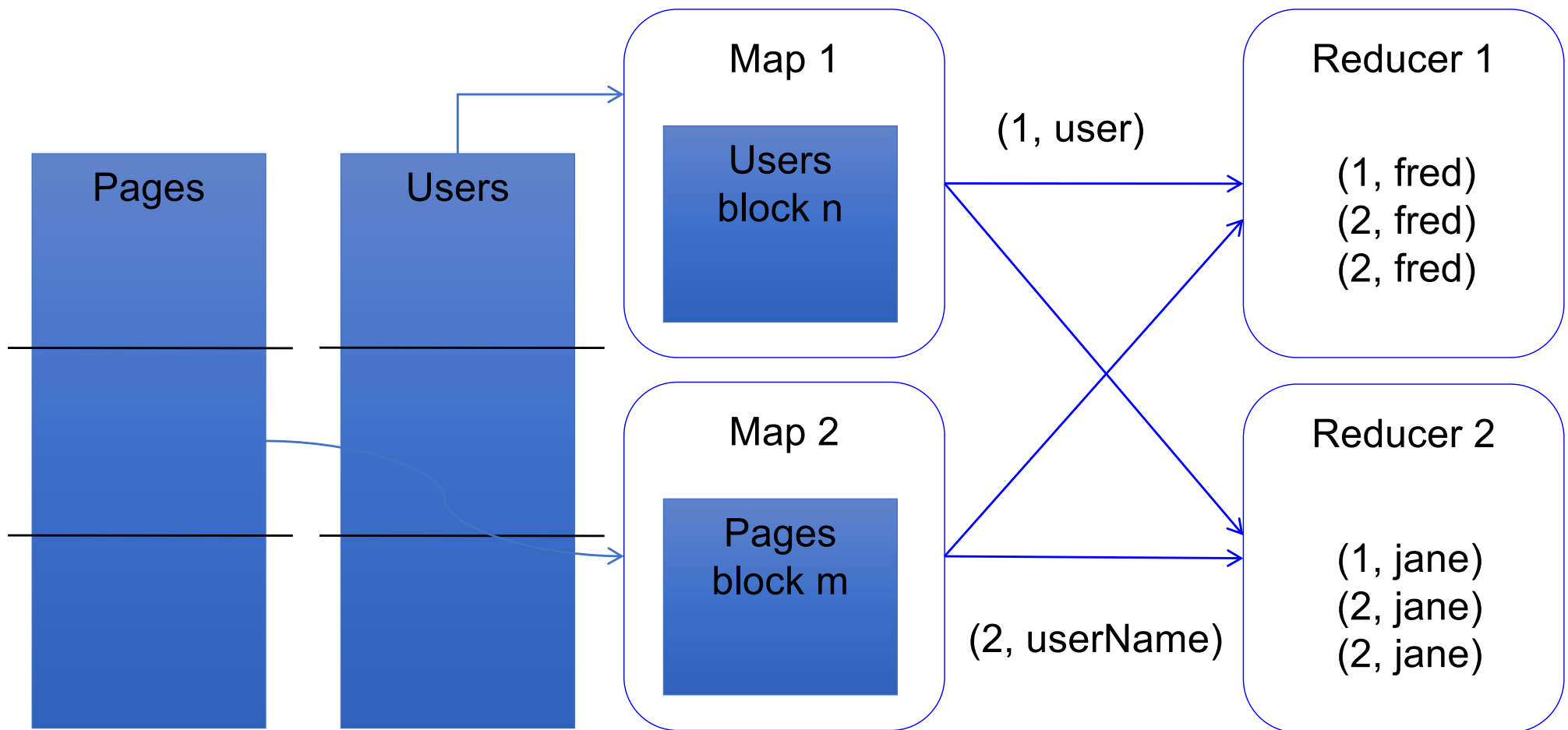
```
Users = load 'users' as (name, age);  
Pages = load 'pages' as (userName, url);  
Jnd = join Users by name, Pages by userName;
```



Join in MR

Users(name, age)
Pages(userName, url)

```
Users = load 'users' as (name, age);  
Pages = load 'pages' as (userName, url);  
Jnd = join Users by name, Pages by userName;
```



Parallel DBMS vs MapReduce

■ Parallel DBMS

- Relational data model and schema
- Declarative query language: SQL
- Many pre-defined operators: relational algebra
- Can easily combine operators into complex queries
- Query optimization, indexing, and physical tuning
- Streams data from one operator to the next without blocking
- **Can do more than just run queries: Data management**
 - Updates and transactions, constraints, security, etc.

Parallel DBMS vs MapReduce

■ Parallel DBMS

- Relational data model and schema
- Declarative query language: SQL
- Many pre-defined operators: relational algebra
- Can easily combine operators into complex queries
- Query optimization, indexing, and physical tuning
- Streams data from one operator to the next without blocking
- **Can do more than just run queries: Data management**

Interesting historical reading:

MapReduce: A major step backwards by David DeWitt

Parallel DBMS vs MapReduce

■ MapReduce

- Data model is a file with key-value pairs!
- No need to “load data” before processing it
- Easy to write user-defined operators
- Can easily add nodes to the cluster (no need to even restart)
- Uses less memory since processes one key-group at a time
- Intra-query fault-tolerance thanks to results on disk
- Intermediate results on disk also facilitate scheduling
- Handles adverse conditions: e.g., stragglers
- **Arguably more scalable... but also needs more nodes!**