CSE 444: Database Internals

Lectures 21
MapReduce

References

- MapReduce: Simplified Data Processing on Large Clusters. Jeffrey Dean and Sanjay Ghemawat. OSDI'04.

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

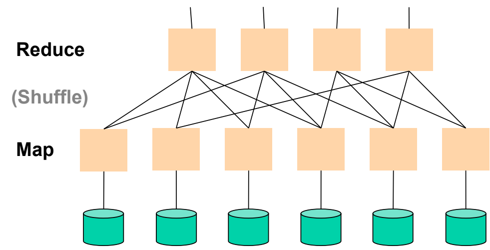
Data Processing at Massive Scale

- 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 blocks (64MB or more)
  - Blocks are stored on random machines & replicated
  - 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

slide source: Jeff Dean

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)`
- Ouput: **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)`

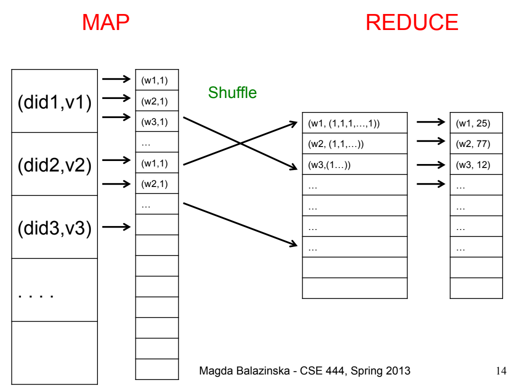
System groups all pairs with the same intermediate key, and passes the bag of values to the REDUCE function

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));
```

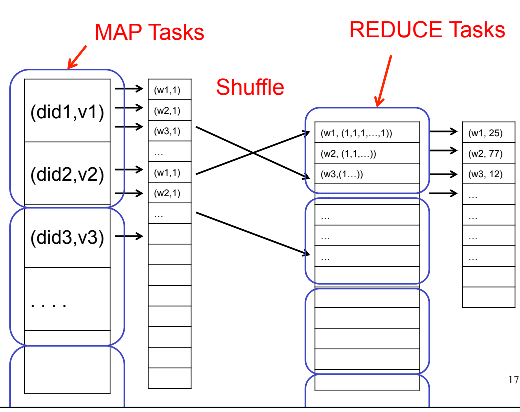



Jobs v.s. Tasks

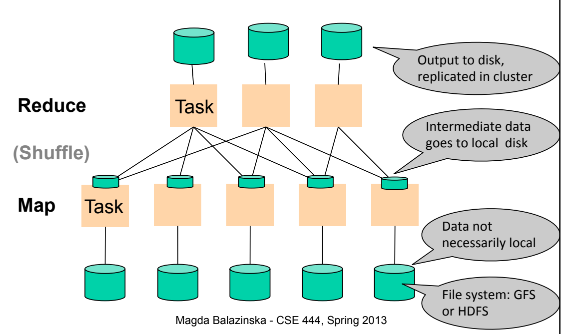
- A MapReduce Job
  - One single "query", e.g. count the words in all docs
  - More complex queries may consists of multiple jobs
- A Map Task, or a Reduce Task
  - A group of instantiations of the map-, or reduce-function, which are scheduled on a single worker

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



Parallel MapReduce Details

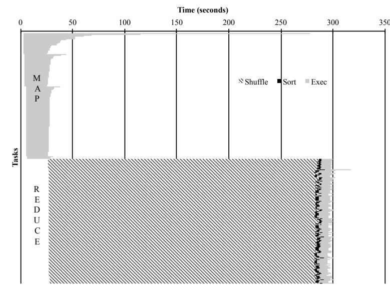


MapReduce Implementation

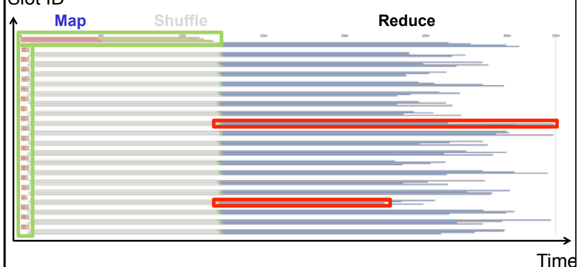
- There is one master node
- Input file gets partitioned further into *M' splits*
  - Each split is a contiguous piece of the input file
- Master assigns *workers* (=servers) to the *M' map tasks*, keeps track of their progress
- Workers write their output to local disk
- Output of each map task is partitioned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

Example MapReduce Execution

PageRank Application

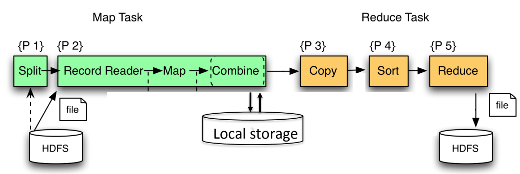


Example: CloudBurst



CloudBurst. Lake Washington Dataset (1.1GB). 80 Mappers 80 Reducers.

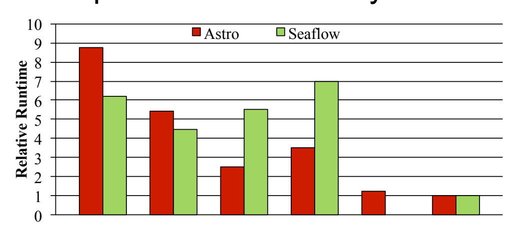
MapReduce Phases



Interesting Implementation Details

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

MapReduce Granularity Illustration



Coarse	Fine	Finer	Finest	Manual	SkewReduce	
14.1	8.8	4.1	5.7	2.0	1.6	Hours
87.2	63.1	77.7	98.7	-	14.1	Minutes

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*

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.

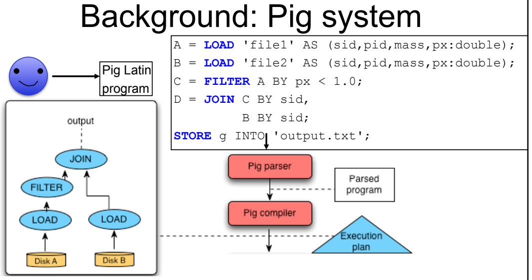
Parallel DBMS vs MapReduce

- 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!

Declarative Languages on MR

- PIG Latin (Yahoo!)
  - New language, like Relational Algebra
  - Open source
- HiveQL (Facebook)
  - SQL-like language
  - Open source
- SQL / Tenzing (Google)
  - SQL on MR
  - Proprietary

Background: Pig system



MapReduce State

- Lots of extensions to address limitations
  - Capabilities to write DAGs of MapReduce jobs
  - Declarative languages (see 344)
  - Ability to read from structured storage (e.g., indexes)
  - Etc.
- Most companies use both types of engines
- Increased integration of both engines