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CS 44800: Introduction To Relational Database Systems

Cloud: NoSQL Databases

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Indiana Center for Database Systems ™

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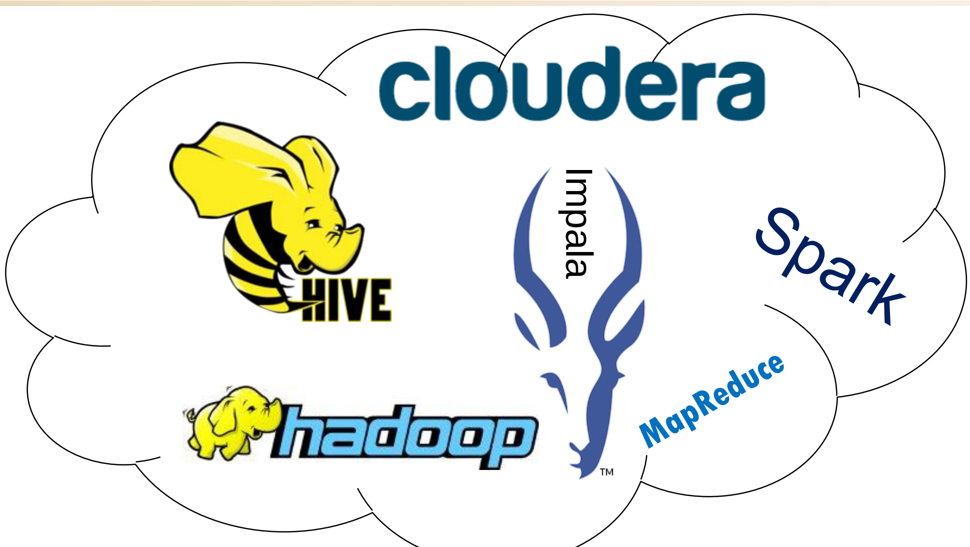
The Cloud: What's it all About?



Beyond RDBMS

The Relational Model is too limiting!

- Simple data model – doesn't capture semantics
  - Object-Oriented DBMS ('80s)
- Fixed schema – not flexible enough
  - XML databases ('90s)
- Too heavyweight/slow
  - NoSQL databases ('00s)

The Latest: Cloud Databases

- PERFORMANCE!
  - More speed, bigger data
- But this doesn't come for free
  - *Eventual* consistency (eventually all the updates will occur)
  - No isolation guarantees
  - Limited reliability guarantees

Cloud Databases: Why?

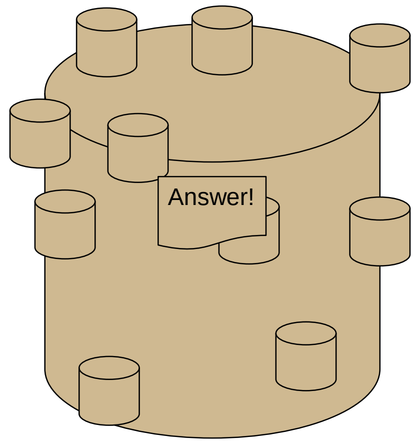
- Scaling
  - 1000's of nodes working simultaneously to analyze data
- Answer challenging queries on big data
  - If you can express the query in a limited query language
- Several examples
  - Hadoop, Spark, …

Are we Post-Relational?

- Object-oriented database → object-relational database
  - Today: Commercial RDBMS includes type extensibility and OO features
- XML database
  - XML storage tools for RDBMS
- Cloud Database
  - See Hive – will we see Map-Reduce engines as part of traditional RDBMS?

Cloud Data Processing Basic Idea: Divide and Conquer

- Divide data into units
- Compute on those units
- Combine results
- *Need algorithms where this works!*



Distributed Indexing

- Distributed processing driven by need to index and analyze huge amounts of data (i.e., the Web)
- Large numbers of inexpensive servers used rather than larger, more expensive machines
- *MapReduce* is a distributed programming tool designed for indexing and analysis tasks

Map/Reduce

- Map/Reduce is a programming model for efficient distributed computing
- Works like a Unix pipeline:
  - cat input | grep | sort | uniq -c | cat > output
  - **Input** | **Map** | Shuffle & Sort | **Reduce** | **Output**
- Efficiency from
  - Streaming through data, reducing seeks
  - Pipelining
- A good fit for a lot of applications
  - Log processing
  - Web index building

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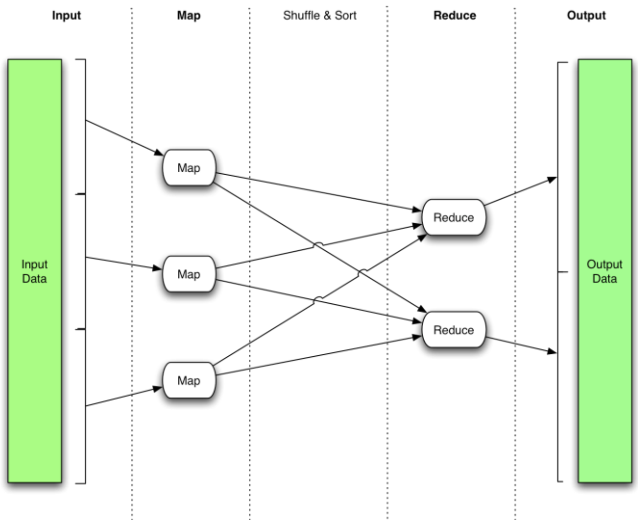
MapReduce

- Distributed programming framework that focuses on data placement and distribution
- *Mapper*
  - Generally, transforms a list of items into another list of items of the same length
- *Reducer*
  - Transforms a list of items into a single item
  - Definitions not so strict in terms of number of outputs
- Many mapper and reducer tasks on a cluster of machines

Map/Reduce Dataflow



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MapReduce

- Basic process
  - *Map* stage which transforms data records into pairs, each with a key and a value
  - *Shuffle* uses a hash function so that all pairs with the same key end up next to each other and on the same machine
  - *Reduce* stage processes records in batches, where all pairs with the same key are processed at the same time
- *Idempotence* of Mapper and Reducer provides fault tolerance
  - multiple operations on same input gives same output

Select word, count(*) from doc group by word;

```
public class WordCount {
public static class Map extends MapReduceBase implements Mapper<LongWritable, Text, Text, IntWritable> {
private final static IntWritable one = new IntWritable(1);
private Text word = new Text();
public void map(LongWritable key, Text value, OutputCollector<Text, IntWritable> output, Reporter reporter) throws IOException {
    String line = value.toString();
    StringTokenizer tokenizer = new StringTokenizer(line);
    while (tokenizer.hasMoreTokens()) {
        word.set(tokenizer.nextToken());
        output.collect(word, one);
        }
    }
}
```

```
public static class Reduce extends MapReduceBase implements Reducer<Text, IntWritable, Text, IntWritable> {
public void reduce(Text key, Iterator<IntWritable> values, OutputCollector<Text, IntWritable> output, Reporter reporter) throws IOException {
    int sum = 0;
    while (values.hasNext()) {
        sum += values.next().get();
    }
    output.collect(key, new IntWritable(sum));
}
}
```

Select word, count(*) from doc group by word;

```
public static void main(String[] args) throws Exception {
    JobConf conf = new JobConf(WordCount.class);
    conf.setJobName("wordcount");
    conf.setOutputKeyClass(Text.class);
    conf.setOutputValueClass(IntWritable.class);
    conf.setMapperClass(Map.class);
    conf.setCombinerClass(Reduce.class);
    conf.setReducerClass(Reduce.class);
    conf.setInputFormat(TextInputFormat.class);
    conf.setOutputFormat(TextOutputFormat.class);
    FileInputFormat.setInputPaths(conf, new Path(args[0]));
    FileOutputFormat.setOutputPath(conf, new Path(args[1]));
    JobClient.runJob(conf);
}
}
```

Introduction to Hadoop

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Problem

- How do you scale up applications?
  - Run jobs processing 100's of terabytes of data
  - Takes 11 days to read on 1 computer
- Need lots of cheap computers
  - Fixes speed problem (15 minutes on 1000 computers), but…
  - Reliability problems
    - In large clusters, computers fail every day
    - Cluster size is not fixed
- Need common infrastructure
  - Must be efficient and reliable

Solution

- Open Source Apache Project
- Hadoop Core includes:
  - Distributed File System - distributes data
  - Map/Reduce - distributes application
- Written in Java
- Runs on
  - Linux, Mac OS/X, Windows, and Solaris
  - Commodity hardware

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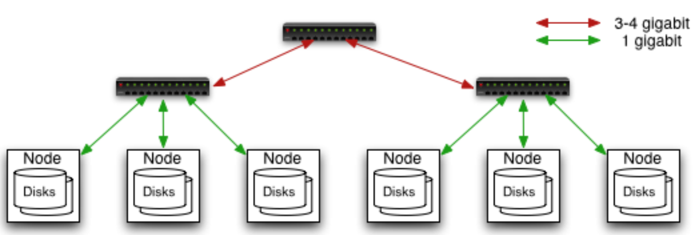
Commodity Hardware Cluster



- Typically in 2 level architecture
  - Nodes are commodity PCs
  - 40 nodes/rack
  - Uplink from rack is 8 gigabit
  - Rack-internal is 1 gigabit

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Distributed File System

- Single namespace for entire cluster
  - Managed by a single *namenode*.
  - Files are single-writer and append-only.
  - Optimized for streaming reads of large files.
- Files are broken in to large blocks.
  - Typically 128 MB
  - Replicated to several *datanodes*, for reliability
- Client talks to both namenode and datanodes
  - Data is not sent through the namenode.
  - Throughput of file system scales nearly linearly with the number of nodes.
- Access from Java, C, or command line.

Data Correctness

- Data is checked with CRC32
- File Creation
  - Client computes checksum per 512 byte
  - DataNode stores the checksum
- File access
  - Client retrieves the data and checksum from DataNode
  - If Validation fails, Client tries other replicas
- Periodic Validation

Map/Reduce features

- Java and C++ APIs
  - In Java use Objects, while in C++ bytes
- Each task can process data sets larger than RAM
- Automatic re-execution on failure
  - In a large cluster, some nodes are always slow or flaky
  - Framework re-executes failed tasks
- Locality optimizations
  - Map-Reduce queries HDFS for locations of input data
  - Map tasks are scheduled close to the inputs when possible

How is Yahoo using Hadoop?

- We started with building better applications
  - Scale up web scale batch applications (search, ads, …)
  - Factor out common code from existing systems, so new applications will be easier to write
  - Manage the many clusters we have more easily
- The mission now includes research support
  - Build a **huge** data warehouse with many Yahoo! data sets
  - Couple it with a huge compute cluster and programming models to make using the data easy
  - Provide this as a service to our researchers
  - We are seeing great results!
    - Experiments can be run much more quickly in this environment

Running Production WebMap

- Search needs a graph of the “known” web
  - Invert edges, compute link text, whole graph heuristics
- Periodic batch job using Map/Reduce
  - Uses a chain of ~100 map/reduce jobs
- Scale
  - 1 trillion edges in graph
  - Largest shuffle is 450 TB
  - Final output is 300 TB compressed
  - Runs on 10,000 cores
  - Raw disk used 5 PB
- Written mostly using Hadoop’s C++ interface

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Hadoop Community

- Apache is focused on project communities
  - Users
  - Contributors
    - write patches
  - Committers
    - can commit patches **too**
  - Project Management Committee
    - vote on new committers and releases **too**
- Apache is a meritocracy
- Use, contribution, and diversity is growing
  - But we need and want more!

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A ⋈ B

- A and B are Hadoop files
  - Produce new Hadoop file that is join of A and B
- Reduce-side join
  - Send different keys to different reducer
- Map-side join
  - Broadcast join

How to join efficiently?

- Sort-Merge join
  - Sort tables
  - Read both, outputting tuples that join
- Hash join
  - Hash function divides into groups
    - All keys that can match go into same group
  - Groups small enough to fit in memory
- *We'll use both ideas*

Hash Join Revisited

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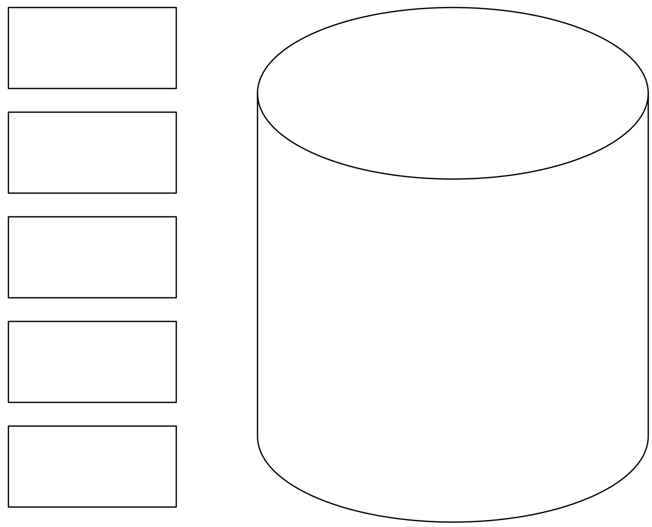
Aardvark
Caiman
Eagle
Deer
Alpaca
Alligator
Butterfly
Ferret
Bison
Bobcat
Bear
Bird
Bat



Aardvark
Caiman
Eagle
Deer
Albatross
Avocet
Butterfly
Ferret
Badger
Bobcat
Bear
Bird
Bat

Reduce-Side Join *(Chandar'10)*

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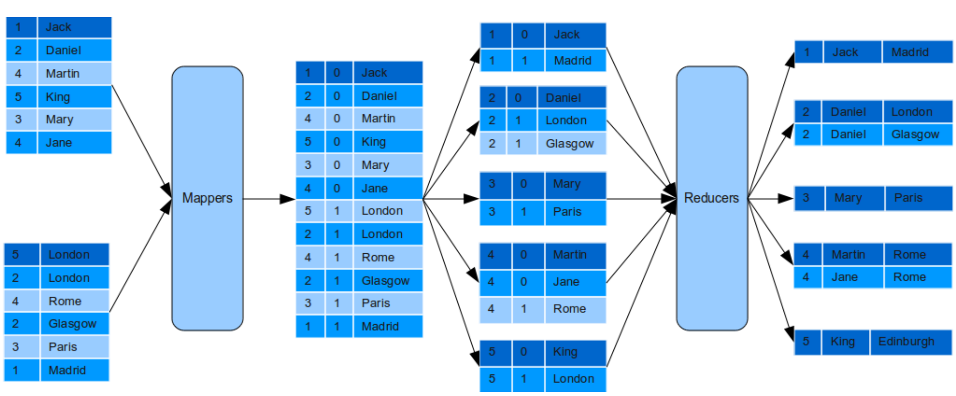

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Map function

- Read tuples
  - Write tuples with “tag”

```
void map(Text key , Text values ,
        OutputCollector <TextPair, TextPair> output ,
        Reporter reporter) throws IOException
{
        output.collect(new TextPair(key.toString (), tag),
                new TextPair(values.toString (), tag));
}
```

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Partition the Data

- Special partition function
  - Partition only on key (join attribute)

```
int getPartition (TextPair key ,
        TextPair value , int numPartitions ) {
        return (key.getFirst ().hashCode () &
                        Integer.MAX_VALUE)
                % numPartitions ;
}
```

Reduce

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- Read file
  - If first dataset, save
  - If second dataset, output matches
- Assumes data sorted
  - But Hadoop takes care of this

Reduce

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```
void reduce(TextPair key , Iterator <TextPair> values , OutputCollector <Text , Text > output , Reporter reporter)
        throws IOException {

        ArrayList <Text > T1 = new ArrayList <Text >();
        Text tag = key.getSecond ();
        TextPair value = null;
        while(values.hasNext ()) {
                value = values.next ();
                if(value.getSecond ().compareTo(tag)==0) {
                        T1.add(value.getFirst ());
                } else {
                        for(Text val : T1) {
                                output.collect(key.getFirst (),
                                new Text(val.toString () + "\t" +
                                        value.getFirst ().toString ()));
}       }       }       }
```

Broadcast Join *(Blanas et al. SIGMOD'10)*

- Map-only algorithm
  - Everything done in the "first phase"
  - Saves move/sort of data
- Limitation: One dataset must fit in memory
  - Copy kept at every mapper
  - Mapper(s) then run on large dataset "in place"
  - Outputs join

But what about…

- Schema
  - Need to know what the data is about
- Queries
  - Do you really want to write map-reduce programs?
  - Optimization?

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HIVE: RDBMS on Hadoop

- Limited schema
  - Tables
  - Primitive types
- Subset of SQL
  - Select-Project
  - (equi)join
  - Group by
- Operations implemented using Map-Reduce

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What is Hive?

- A system for managing and querying structured data built on top of Hadoop
- Three main components:
  - MapReduce for execution
  - Hadoop Distributed File System for storage
  - Metadata in an RDBMS
- Hive QL based on SQL
  - Easy for users familiar with SQL

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Hive Architecture

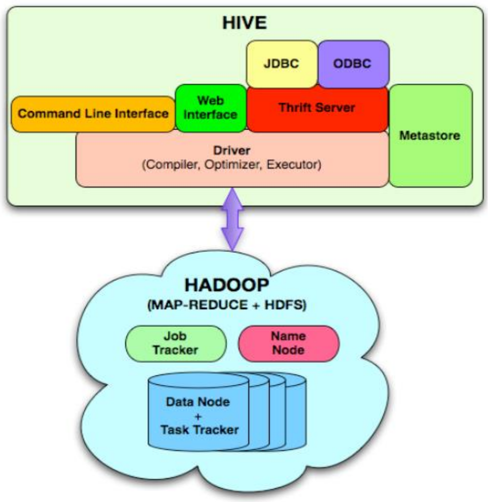

Fig. 1: Hive System Architecture

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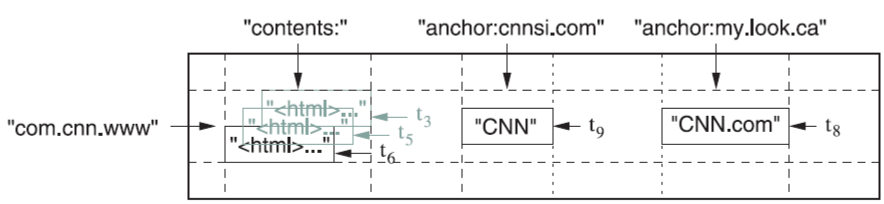
Google BigTable

- Simple data model



- Tables distributed
  - "row keys"
- Transactional consistency only on a per-row basis

Google Bigtable

- Multi-version
  - Each row timestamped
- Three-level location hierarchy
  - Claim: “B-tree like”