Data management in the cloud using Hadoop

Murat Kantarcioglu

Outline

- Hadoop - Basics
- HDFS
  - Goals
  - Architecture
  - Other functions
- MapReduce
  - Basics
  - Word Count Example
  - Handy tools
  - Finding shortest path example
- Related Apache sub-projects (Pig, Hbase,Hive)

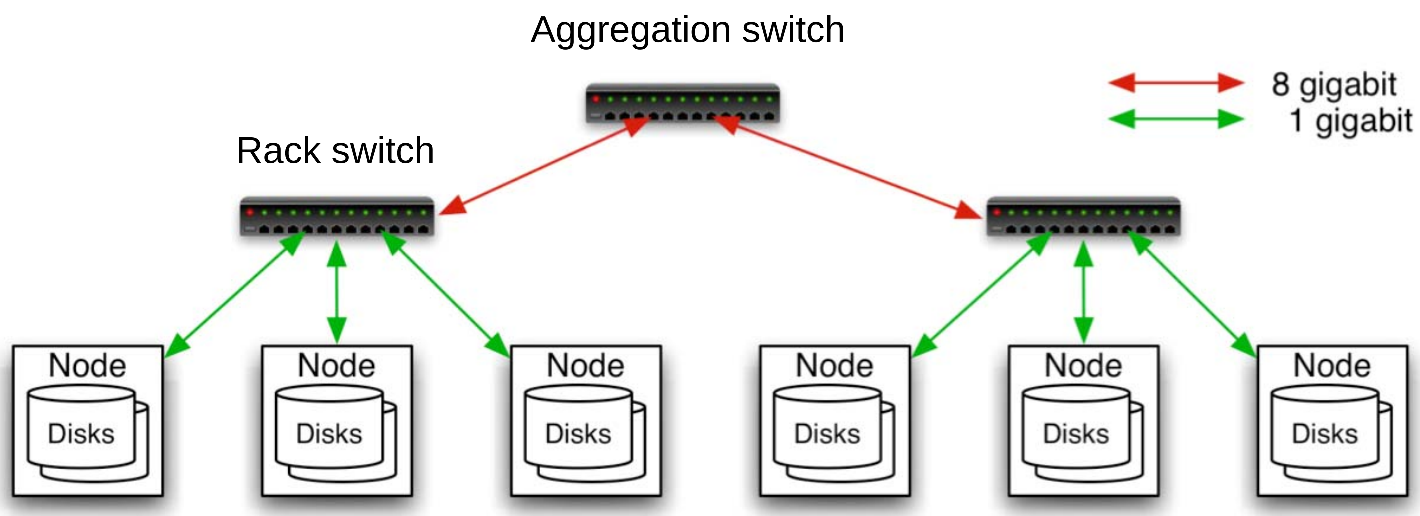
Hadoop - Why ?

- Need to process huge datasets on large clusters of computers
- Very expensive to build reliability into each application
- Nodes fail every day
  – Failure is expected, rather than exceptional
  – The number of nodes in a cluster is not constant
- Need a common infrastructure
  – Efficient, reliable, easy to use
  – Open Source, Apache Licence version of Google File System

Who uses Hadoop?

- Amazon/A9
- Facebook
- Google
  - It has GFS
- New York Times
- Veoh
- Yahoo!
- …. many more
- Cloudera
  - Similar to Redhat business model.
  - Added services on Hadoop

Commodity Hardware



- Typically in 2 level architecture
  - Nodes are commodity PCs
  - 30-40 nodes/rack
  - Uplink from rack is 3-4 gigabit
  - Rack-internal is 1 gigabit

Hadoop Distributed File System (HDFS)

Original Slides by

Dhruba Borthakur
Apache Hadoop Project Management Committee

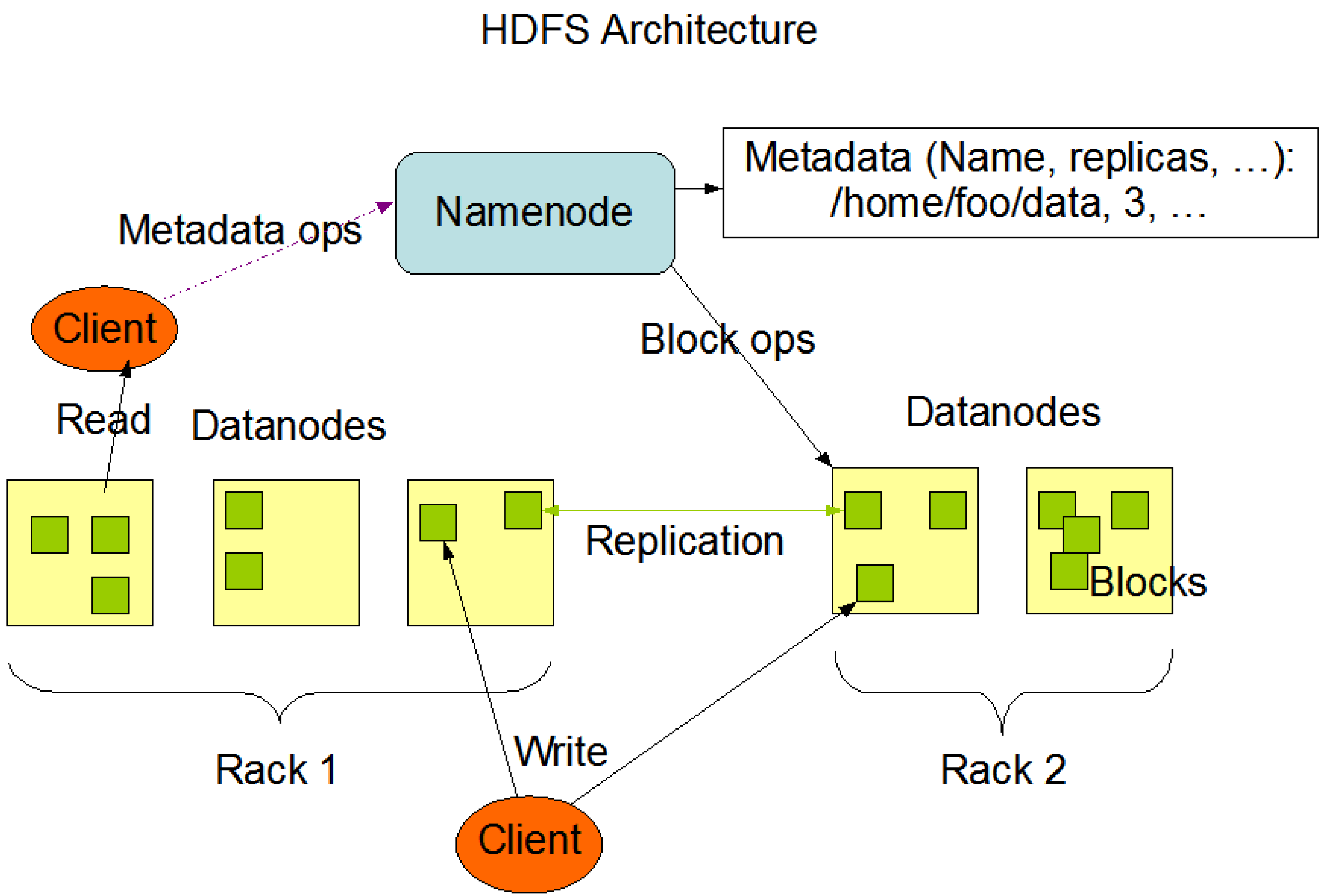
Goals of HDFS

- Very Large Distributed File System
  - 10K nodes, 100 million files, 10PB
  - Yahoo is working on a version that can scale to large amounts of data.
- Assumes Commodity Hardware
  - Files are replicated to handle hardware failure
  - Detect failures and recover from them
- Optimized for Batch Processing
  - Data locations exposed so that computations can move to where data resides
    - Remember moving large data is an important bottleneck.
  - Provides very high aggregate bandwidth

Distributed File System

- Single Namespace for entire cluster
  - Again this is changing soon!!!
- Data Coherency
  - Write-once-read-many access model
  - Client can only append to existing files
- Files are broken up into blocks
  - Typically 64MB block size
  - Each block replicated on multiple DataNodes
- Intelligent Client
  - Client can find location of blocks
  - Client accesses data directly from DataNode

HDFS Architecture



Functions of a NameNode

- Manages File System Namespace
  - Maps a file name to a set of blocks
  - Maps a block to the DataNodes where it resides
- Cluster Configuration Management
- Replication Engine for Blocks

NameNode Metadata

- Metadata in Memory
  - The entire metadata is in main memory
  - No demand paging of metadata
- Types of metadata
  - List of files
  - List of Blocks for each file
  - List of DataNodes for each block
  - File attributes, e.g. creation time, replication factor
- A Transaction Log
  - Records file creations, file deletions etc

DataNode

- A Block Server
  - Stores data in the local file system (e.g. ext3)
  - Stores metadata of a block (e.g. CRC)
  - Serves data and metadata to Clients
- Block Report
  - Periodically sends a report of all existing blocks to the NameNode
- Facilitates Pipelining of Data
  - Forwards data to other specified DataNodes

Block Placement

- Current Strategy
  - One replica on local node
  - Second replica on a remote rack
  - Third replica on same remote rack
  - Additional replicas are randomly placed
- Clients read from nearest replicas

Heartbeats

- DataNodes send hearbeat to the NameNode
  - Once every 3 seconds
- NameNode uses heartbeats to detect DataNode failure

Replication Engine

- NameNode detects DataNode failures
  - Chooses new DataNodes for new replicas
  - Balances disk usage
  - Balances communication traffic to DataNodes

Data Correctness

- Use Checksums to validate data
  - Use CRC32
- File Creation
  - Client computes checksum per 512 bytes
  - DataNode stores the checksum
- File access
  - Client retrieves the data and checksum from DataNode
  - If Validation fails, Client tries other replicas

NameNode Failure

- A single point of failure
- Transaction Log stored in multiple directories
  - A directory on the local file system
  - A directory on a remote file system (NFS/CIFS)
- Need to develop a real HA solution
  - Ongoing work to have multiple NameNodes

Data Pipelining

- Client retrieves a list of DataNodes on which to place replicas of a block
- Client writes block to the first DataNode
- The first DataNode forwards the data to the next node in the Pipeline
- When all replicas are written, the Client moves on to write the next block in file

Rebalancer

- Goal: % disk full on DataNodes should be similar
  - Usually run when new DataNodes are added
  - Cluster is online when Rebalancer is active
  - Rebalancer is throttled to avoid network congestion
  - Command line tool

Secondary NameNode

- Copies FsImage and Transaction Log from Namenode to a temporary directory
- Merges FSImage and Transaction Log into a new FSImage in temporary directory
- Uploads new FSImage to the NameNode
  - Transaction Log on NameNode is purged

User Interface

- Commands for HDFS User:
  - hadoop dfs -mkdir /foodir
  - hadoop dfs -cat /foodir/myfile.txt
  - hadoop dfs -rm /foodir/myfile.txt
- Commands for HDFS Administrator
  - hadoop dfsadmin -report
  - hadoop dfsadmin -decommision datanodename
- Web Interface
  - http://host:port/dfshealth.jsp

MapReduce

Original Slides by

Owen O'Malley (Yahoo!)

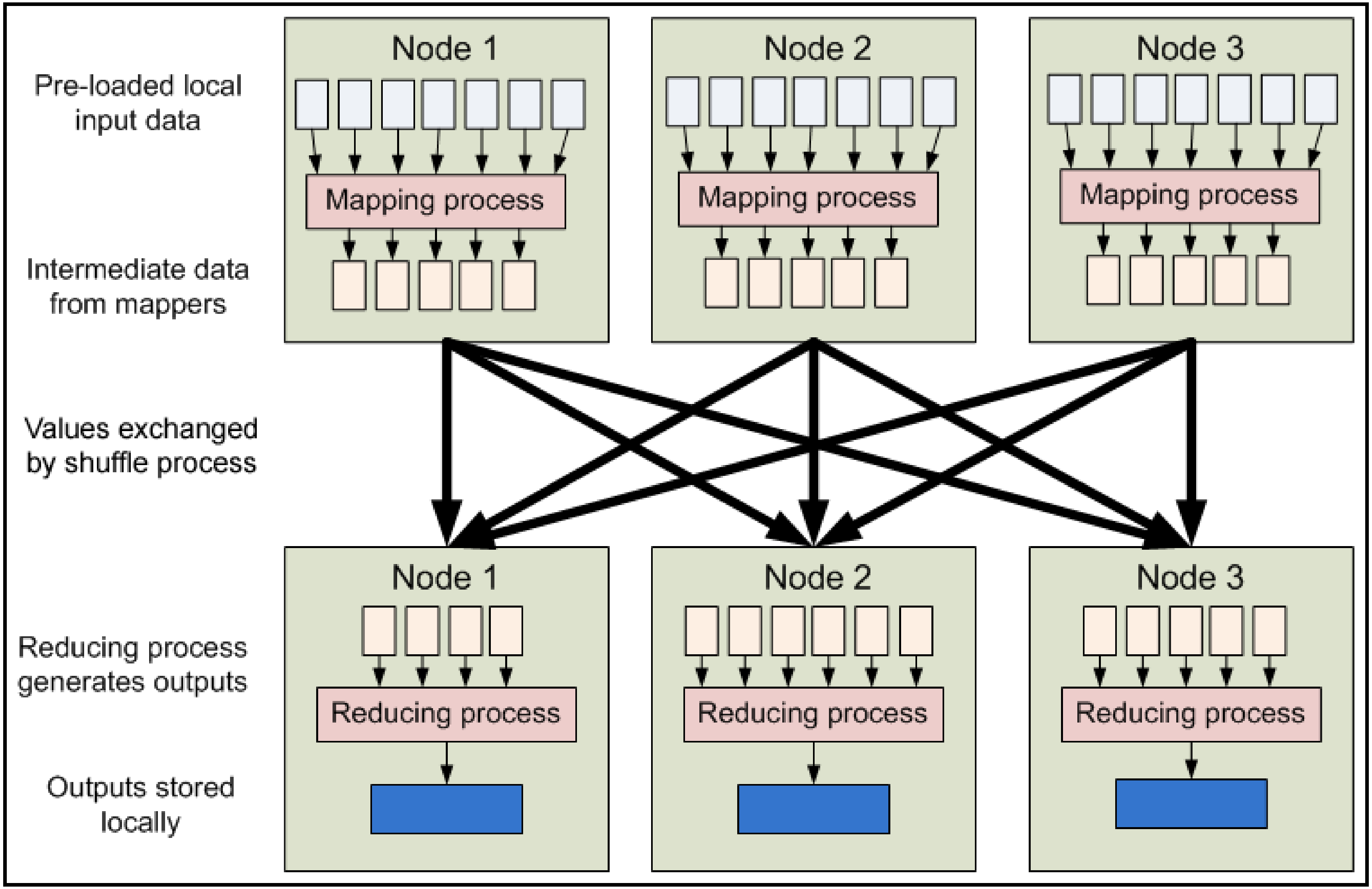
&

Christophe Bisciglia, Aaron Kimball & Sierra Michells-Slettvet

MapReduce - What?

- MapReduce is a programming model for efficient distributed computing
- It 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

MapReduce - Dataflow



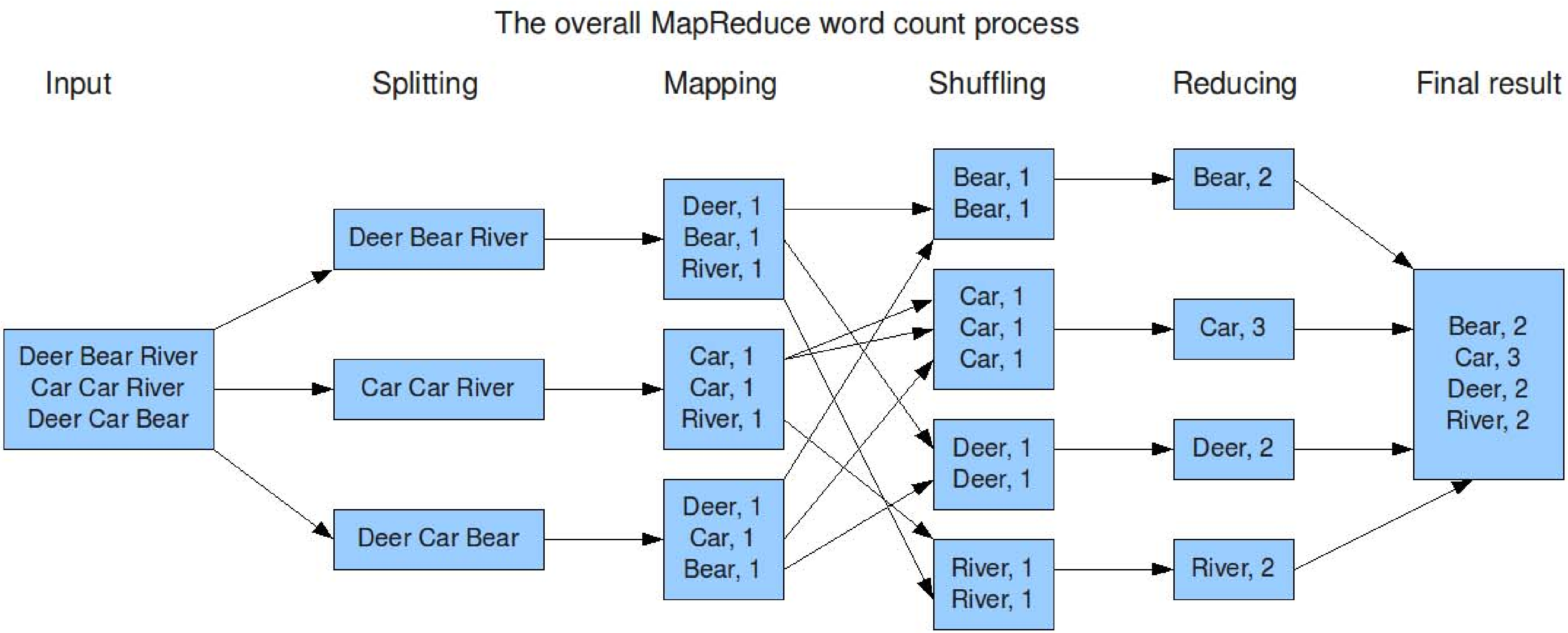
MapReduce - Features

- Fine grained Map and Reduce tasks
  - Improved load balancing
  - Faster recovery from failed tasks
- Automatic re-execution on failure
  - In a large cluster, some nodes are always slow or flaky
  - Framework re-executes failed tasks
- Locality optimizations
  - With large data, bandwidth to data is a problem
  - Map-Reduce + HDFS is a very effective solution
  - Map-Reduce queries HDFS for locations of input data
  - Map tasks are scheduled close to the inputs when possible

Word Count Example

- Mapper
  - Input: value: lines of text of input
  - Output: key: word, value: 1
- Reducer
  - Input: key: word, value: set of counts
  - Output: key: word, value: sum
- Launching program
  - Defines this job
  - Submits job to cluster

Word Count Dataflow



Word Count Mapper

```
public static class Map extends MapReduceBase implements
    Mapper<LongWritable,Text,Text,IntWritable> {
  private static final IntWritable one = new IntWritable(1);
  private Text word  = new Text();

  public static void map(LongWritable key, Text value,
    OutputCollector<Text,IntWritable> output, Reporter reporter) throws
    IOException {
     String line = value.toString();
     StringTokenizer = new StringTokenizer(line);
     while(tokenizer.hasNext()) {
        word.set(tokenizer.nextToken());
        output.collect(word,one);
        }
     }
 }
```

Word Count Reducer

```
public static class Reduce extends MapReduceBase implements
    Reducer<Text,IntWritable,Text,IntWritable> {
public static 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));
    }
}
```

Word Count Example

- Jobs are controlled by configuring *JobConfs*
- JobConfs are maps from attribute names to string values
- The framework defines attributes to control how the job is executed
  - `conf.set(“mapred.job.name”, “MyApp”);`
- Applications can add arbitrary values to the JobConf
  - `conf.set(“my.string”, “foo”);`
  - `conf.set(“my.integer”, 12);`
- JobConf is available to all tasks

Putting it all together

- Create a launching program for your application
- The launching program configures:
  - The *Mapper* and *Reducer* to use
  - The output key and value types (input types are inferred from the *InputFormat*)
  - The locations for your input and output
- The launching program then submits the job and typically waits for it to complete

Putting it all together

```
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.setReducer(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);
```

Input and Output Formats

- A Map/Reduce may specify how it's input is to be read by specifying an *InputFormat* to be used
- A Map/Reduce may specify how it's output is to be written by specifying an *OutputFormat* to be used
- These default to *TextInputFormat* and *TextOutputFormat*, which process line-based text data
- Another common choice is *SequenceFileInputFormat* and *SequenceFileOutputFormat* for binary data
- These are file-based, but they are not required to be

How many Maps and Reduces

- Maps
  - Usually as many as the number of HDFS blocks being processed, this is the default
  - Else the number of maps can be specified as a hint
  - The number of maps can also be controlled by specifying the *minimum split size*
  - The actual sizes of the map inputs are computed by:
    - *max(min(block_size,data/#maps), min_split_size)*
- Reduces
  - Unless the amount of data being processed is small
    - *0.95*num_nodes*mapred.tasktracker.tasks.maximum*

Some handy tools

- Partitioners
- Combiners
- Compression
- Counters
- Zero Reduces
- Distributed File Cache
- Tool

Partitioners

- Partitioners are application code that define how keys are assigned to reduces
- Default partitioning spreads keys evenly, but randomly
  - Uses `key.hashCode() % num_reduces`
- Custom partitioning is often required, for example, to produce a total order in the output
  - Should implement *Partitioner* interface
  - Set by calling `conf.setPartitionerClass(MyPart.class)`
  - To get a total order, sample the map output keys and pick values to divide the keys into roughly equal buckets and use that in your partitioner

Combiners

- When *maps* produce many repeated keys
  - It is often useful to do a local aggregation following the *map*
  - Done by specifying a *Combiner*
  - Goal is to decrease size of the transient data
  - Combiners have the same interface as Reduces, and often are the same class
  - Combiners must **not** side effects, because they run an intermdiate number of times
  - In *WordCount*, *`conf.setCombinerClass(Reduce.class);`*

Compression

- Compressing the outputs and intermediate data will often yield huge performance gains
  - Can be specified via a configuration file or set programmatically
  - Set *mapred.output.compress* to *true* to compress job output
  - Set *mapred.compress.map.output* to *true* to compress map outputs
- Compression Types (*mapred(.map)?.output.compression.type)*
  - "block" - Group of keys and values are compressed together
  - "record" - Each value is compressed individually
  - Block compression is almost always best
- Compression Codecs *(mapred(.map)?.output.compression.codec)*
  - Default (zlib) - slower, but more compression
  - LZO - faster, but less compression

Counters

- Often Map/Reduce applications have countable events
- For example, framework counts records in to and out of Mapper and Reducer
- To define user counters:

```
static enum Counter {EVENT1, EVENT2};
reporter.incrCounter(Counter.EVENT1, 1);
```

- Define nice names in a MyClass_Counter.properties file

```
CounterGroupName=MyCounters
EVENT1.name=Event 1
EVENT2.name=Event 2
```

Zero Reduces

- Frequently, we only need to run a filter on the input data
  - No sorting or shuffling required by the job
  - Set the number of reduces to 0
  - Output from maps will go directly to OutputFormat and disk

Distributed File Cache

- Sometimes need read-only copies of data on the local computer
  - Downloading 1GB of data for each Mapper is expensive
- Define list of files you need to download in JobConf
- Files are downloaded once per computer
- Add to launching program:

```
DistributedCache.addCacheFile(new
  URI(“hdfs://nn:8020/foo”), conf);
```

- Add to task:

```
Path[] files =
  DistributedCache.getLocalCacheFiles(conf);
```

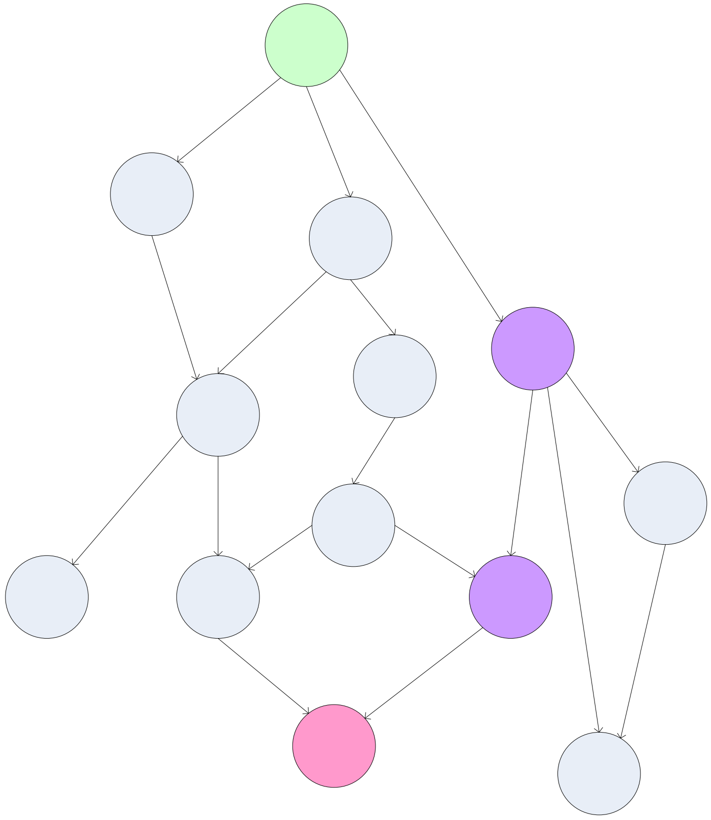
Tool

- Handle “standard” Hadoop command line options
  - `-conf file` - load a configuration file named file
  - `-D prop=value` - define a single configuration property prop
- Class looks like:

```
public class MyApp extends Configured implements Tool
  {
 public static void main(String[] args) throws
  Exception {
  System.exit(ToolRunner.run(new Configuration(),
          new MyApp(), args));
}
public int run(String[] args) throws Exception {
  …. getConf() ….
  }
}
```

Example: Finding the Shortest Path

- A common graph search application is finding the shortest path from a start node to one or more target nodes
- Commonly done on a single machine with *Dijkstra's Algorithm*
- Can we use BFS to find the shortest path via MapReduce?



Finding the Shortest Path: Intuition

- We can define the solution to this problem inductively
  - DistanceTo(startNode) = 0
  - For all nodes *n* directly reachable from startNode, DistanceTo(*n*) = 1
  - For all nodes *n* reachable from some other set of nodes *S*,

    DistanceTo(n) = 1 + min(DistanceTo(m), $m \in S$)

From Intuition to Algorithm

- A map task receives a node *n* as a key, and (*D*, *points-to*) as its value
  - *D* is the distance to the node from the start
  - *points-to* is a list of nodes reachable from *n*
- $\forall p \in$ points-to, emit (p, D+1)
- Reduces task gathers possible distances to a given *p* and selects the minimum one

What This Gives Us

- This MapReduce task can advance the known frontier by one hop
- To perform the whole BFS, a non-MapReduce component then feeds the output of this step back into the MapReduce task for another iteration
  - Problem: Where'd the *points-to* list go?
  - Solution: Mapper emits (*n*, *points-to*) as well

Blow-up and Termination

- This algorithm starts from one node
- Subsequent iterations include many more nodes of the graph as the frontier advances
- Does this ever terminate?
  - Yes! Eventually, routes between nodes will stop being discovered and no better distances will be found. When distance is the same, we stop
  - Mapper should emit (n,D) to ensure that "current distance" is carried into the reducer

Extensions to Map-Reduce

- There are other systems that
  - Use Distributed file systems
  - Manage large number of tasks that are instantiations of user-written functions.
  - Deal with failures gracefully.
  - Example from Ullman’s book:

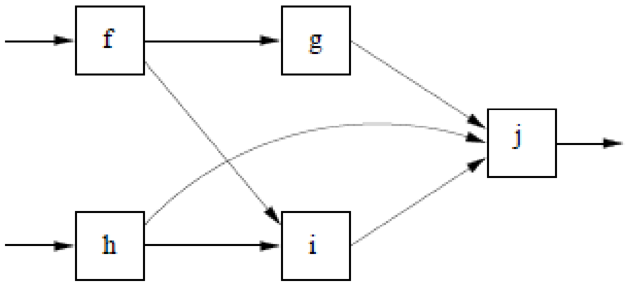


Figure 2.6: An example of a workflow that is more complex than Map feeding Reduce

Extensions to Map-Reduce

- Main applications for Workflow systems
  - Representing a cascade of multiple-map reduce jobs
  - Complex distributed tasks
- Generally more efficient than running multiple map-reduce sequentially.
  - Writing results to hard disks could be problematic.
  - Potential pipelining optimizations.

Hadoop Subprojects

Hadoop Related Subprojects

- Pig
  - High-level language for data analysis
- Hbase
  - Table storage for semi-structured data
- Zookeeper
  - Coordinating distributed applications
- Hive
  - SQL-like Query language and Metastore
- Mahout
  - Machine learning

Pig

Original Slides by

Matei Zaharia

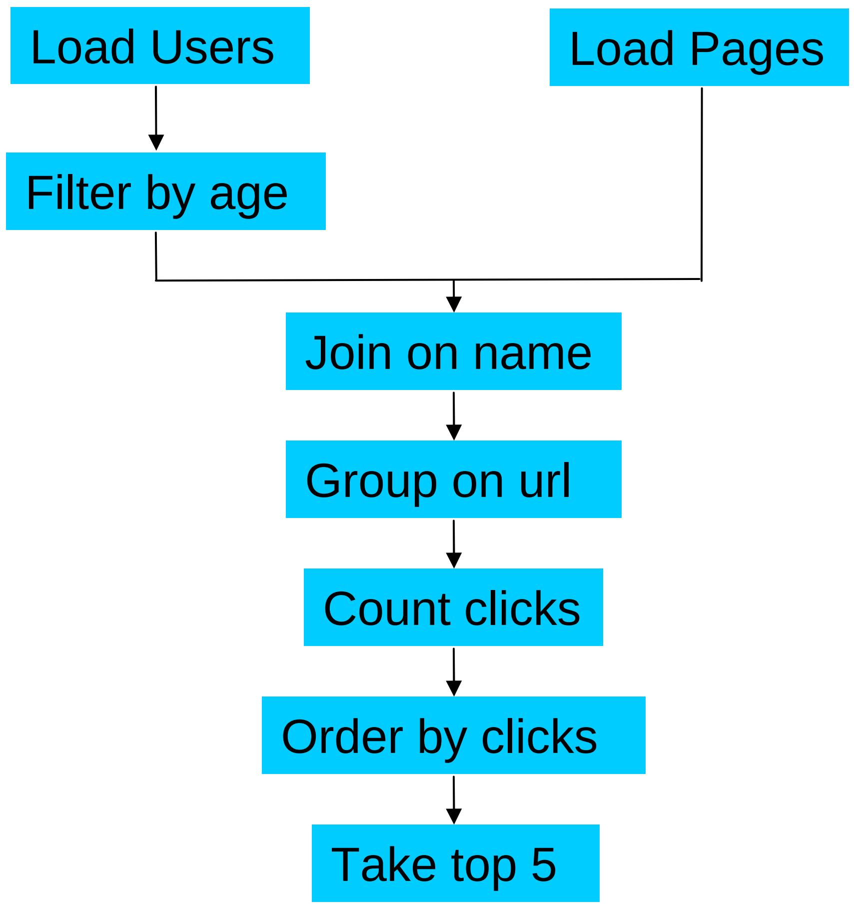
UC Berkeley RAD Lab

Pig

- Started at Yahoo! Research
- Now runs about 30% of Yahoo!'s jobs
- Features
  - Expresses sequences of MapReduce jobs
  - Data model: nested "bags" of items
  - Provides relational (SQL) operators (JOIN, GROUP BY, etc.)
  - Easy to plug in Java functions

An Example Problem

- Suppose you have user data in a file, website data in another, and you need to find the top 5 most visited pages by users aged 18-25



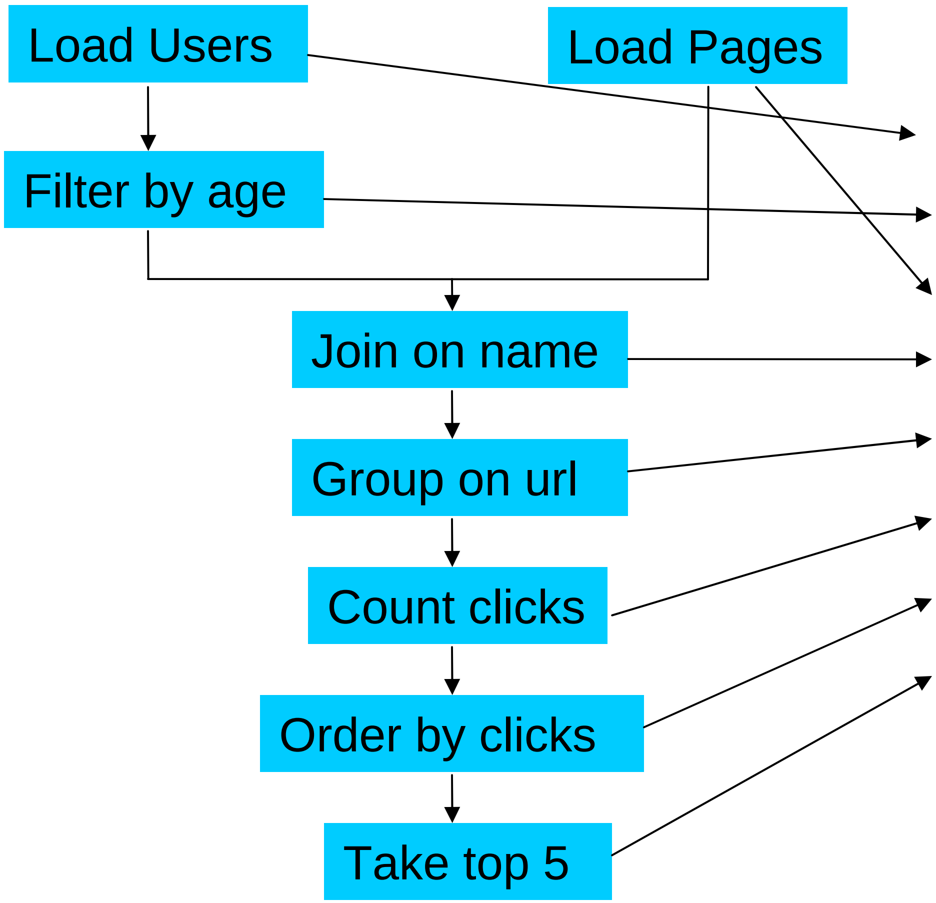
In MapReduce

```java
import java.io.IOException;
import java.util.ArrayList;
import java.util.Iterator;
import java.util.List;

import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.io.Writable;
import org.apache.hadoop.io.WritableComparable;
import org.apache.hadoop.mapred.FileInputFormat;
import org.apache.hadoop.mapred.FileOutputFormat;
import org.apache.hadoop.mapred.JobConf;
import org.apache.hadoop.mapred.KeyValueTextInputFormat;
import org.apache.hadoop.mapred.Mapper;
import org.apache.hadoop.mapred.MapReduceBase;
import org.apache.hadoop.mapred.OutputCollector;
import org.apache.hadoop.mapred.RecordReader;
import org.apache.hadoop.mapred.Reducer;
import org.apache.hadoop.mapred.Reporter;
import org.apache.hadoop.mapred.SequenceFileInputFormat;
import org.apache.hadoop.mapred.SequenceFileOutputFormat;
import org.apache.hadoop.mapred.TextInputFormat;
import org.apache.hadoop.mapred.jobcontrol.Job;
import org.apache.hadoop.mapred.jobcontrol.JobControl;
import org.apache.hadoop.mapred.lib.IdentityMapper;

public class MRExample {
    public static class LoadPages extends MapReduceBase
        implements Mapper<LongWritable, Text, Text, Text> {

        public void map(LongWritable k, Text val,
                OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // Pull the key out
            String line = val.toString();
            int firstComma = line.indexOf(',');
            String key = line.substring(0, firstComma);
            String value = line.substring(firstComma + 1);
            Text outKey = new Text(key);
            // Prepend an index to the value so we know which file
            // it came from.
            Text outVal = new Text("1" + value);
            oc.collect(outKey, outVal);
        }
    }
    public static class LoadAndFilterUsers extends MapReduceBase
        implements Mapper<LongWritable, Text, Text, Text> {

        public void map(LongWritable k, Text val,
                OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // Pull the key out
            String line = val.toString();
            int firstComma = line.indexOf(',');
            String value = line.substring(firstComma + 1);
            int age = Integer.parseInt(value);
            if (age < 18 || age > 25) return;
            String key = line.substring(0, firstComma);
            Text outKey = new Text(key);
            // Prepend an index to the value so we know which file
            // it came from.
            Text outVal = new Text("2" + value);
            oc.collect(outKey, outVal);
        }
    }
    public static class Join extends MapReduceBase
        implements Reducer<Text, Text, Text, Text> {

        public void reduce(Text key,
                Iterator<Text> iter,
                OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // For each value, figure out which file it's from and
store it
            // accordingly.
            List<String> first = new ArrayList<String>();
            List<String> second = new ArrayList<String>();

            while (iter.hasNext()) {
                Text t = iter.next();
                String value = t.toString();
                if (value.charAt(0) == '1')
first.add(value.substring(1));
                else second.add(value.substring(1));
                reporter.setStatus("OK");
            }

            // Do the cross product and collect the values
            for (String s1 : first) {
                for (String s2 : second) {
                    String outval = key + "," + s1 + "," + s2;
                    oc.collect(null, new Text(outval));
                    reporter.setStatus("OK");
                }
            }
        }
    }
    public static class LoadJoined extends MapReduceBase
        implements Mapper<Text, Text, Text, LongWritable> {

        public void map(
                Text k,
                Text val,
                OutputCollector<Text, LongWritable> oc,
                Reporter reporter) throws IOException {
            // Find the url
            String line = val.toString();
            int firstComma = line.indexOf(',');
            int secondComma = line.indexOf(',', firstComma);
            String key = line.substring(firstComma, secondComma);
            // drop the rest of the record, I don't need it anymore,
            // just pass a 1 for the combiner/reducer to sum instead.
            Text outKey = new Text(key);
            oc.collect(outKey, new LongWritable(1L));
        }
    }
    public static class ReduceUrls extends MapReduceBase
        implements Reducer<Text, LongWritable, WritableComparable,
Writable> {

        public void reduce(
                Text key,
                Iterator<LongWritable> iter,
                OutputCollector<WritableComparable, Writable> oc,
                Reporter reporter) throws IOException {
            // Add up all the values we see

            long sum = 0;
            while (iter.hasNext()) {
                sum += iter.next().get();
                reporter.setStatus("OK");
            }

            oc.collect(key, new LongWritable(sum));
        }
    }
    public static class LoadClicks extends MapReduceBase
        implements Mapper<WritableComparable, Writable, LongWritable,
Text> {

        public void map(
                WritableComparable key,
                Writable val,
                OutputCollector<LongWritable, Text> oc,
                Reporter reporter) throws IOException {
            oc.collect((LongWritable)val, (Text)key);
        }
    }
    public static class LimitClicks extends MapReduceBase
        implements Reducer<LongWritable, Text, LongWritable, Text> {

        int count = 0;
        public void reduce(
            LongWritable key,
            Iterator<Text> iter,
            OutputCollector<LongWritable, Text> oc,
            Reporter reporter) throws IOException {

            // Only output the first 100 records
            while (count < 100 && iter.hasNext()) {
                oc.collect(key, iter.next());
                count++;
            }
        }
    }
    public static void main(String[] args) throws IOException {
        JobConf lp = new JobConf(MRExample.class);
        lp.setJobName("Load Pages");
        lp.setInputFormat(TextInputFormat.class);
        lp.setOutputKeyClass(Text.class);
        lp.setOutputValueClass(Text.class);
        lp.setMapperClass(LoadPages.class);
        FileInputFormat.addInputPath(lp, new
Path("/user/gates/pages"));
        FileOutputFormat.setOutputPath(lp,
            new Path("/user/gates/tmp/indexed_pages"));
        lp.setNumReduceTasks(0);
        Job loadPages = new Job(lp);

        JobConf lfu = new JobConf(MRExample.class);
        lfu.setJobName("Load and Filter Users");
        lfu.setInputFormat(TextInputFormat.class);
        lfu.setOutputKeyClass(Text.class);
        lfu.setOutputValueClass(Text.class);
        lfu.setMapperClass(LoadAndFilterUsers.class);
        FileInputFormat.addInputPath(lfu, new
Path("/user/gates/users"));
        FileOutputFormat.setOutputPath(lfu,
            new Path("/user/gates/tmp/filtered_users"));
        lfu.setNumReduceTasks(0);
        Job loadUsers = new Job(lfu);

        JobConf join = new JobConf(MRExample.class);
        join.setJobName("Join Users and Pages");
        join.setInputFormat(KeyValueTextInputFormat.class);
        join.setOutputKeyClass(Text.class);
        join.setOutputValueClass(Text.class);
        join.setMapperClass(IdentityMapper.class);
        join.setReducerClass(Join.class);
        FileInputFormat.addInputPath(join, new
Path("/user/gates/tmp/indexed_pages"));
        FileInputFormat.addInputPath(join, new
Path("/user/gates/tmp/filtered_users"));
        FileOutputFormat.setOutputPath(join, new
Path("/user/gates/tmp/joined"));
        join.setNumReduceTasks(50);
        Job joinJob = new Job(join);
        joinJob.addDependingJob(loadPages);
        joinJob.addDependingJob(loadUsers);

        JobConf group = new JobConf(MRExample.class);
        group.setJobName("Group URLs");
        group.setInputFormat(KeyValueTextInputFormat.class);
        group.setOutputKeyClass(Text.class);
        group.setOutputValueClass(LongWritable.class);
        group.setOutputFormat(SequenceFileOutputFormat.class);
        group.setMapperClass(LoadJoined.class);
        group.setCombinerClass(ReduceUrls.class);
        group.setReducerClass(ReduceUrls.class);
        FileInputFormat.addInputPath(group, new
Path("/user/gates/tmp/joined"));
        FileOutputFormat.setOutputPath(group, new
Path("/user/gates/tmp/grouped"));
        group.setNumReduceTasks(50);
        Job groupJob = new Job(group);
        groupJob.addDependingJob(joinJob);

        JobConf top100 = new JobConf(MRExample.class);
        top100.setJobName("Top 100 sites");
        top100.setInputFormat(SequenceFileInputFormat.class);
        top100.setOutputKeyClass(LongWritable.class);
        top100.setOutputValueClass(Text.class);
        top100.setOutputFormat(SequenceFileOutputFormat.class);
        top100.setMapperClass(LoadClicks.class);
        top100.setCombinerClass(LimitClicks.class);
        top100.setReducerClass(LimitClicks.class);
        FileInputFormat.addInputPath(top100, new
Path("/user/gates/tmp/grouped"));
        FileOutputFormat.setOutputPath(top100, new
Path("/user/gates/top100sitesforusers18to25"));
        top100.setNumReduceTasks(1);
        Job limit = new Job(top100);
        limit.addDependingJob(groupJob);

        JobControl jc = new JobControl("Find top 100 sites for users
18 to 25");
        jc.addJob(loadPages);
        jc.addJob(loadUsers);
        jc.addJob(joinJob);
        jc.addJob(groupJob);
        jc.addJob(limit);
        jc.run();
    }
}
```

In Pig Latin

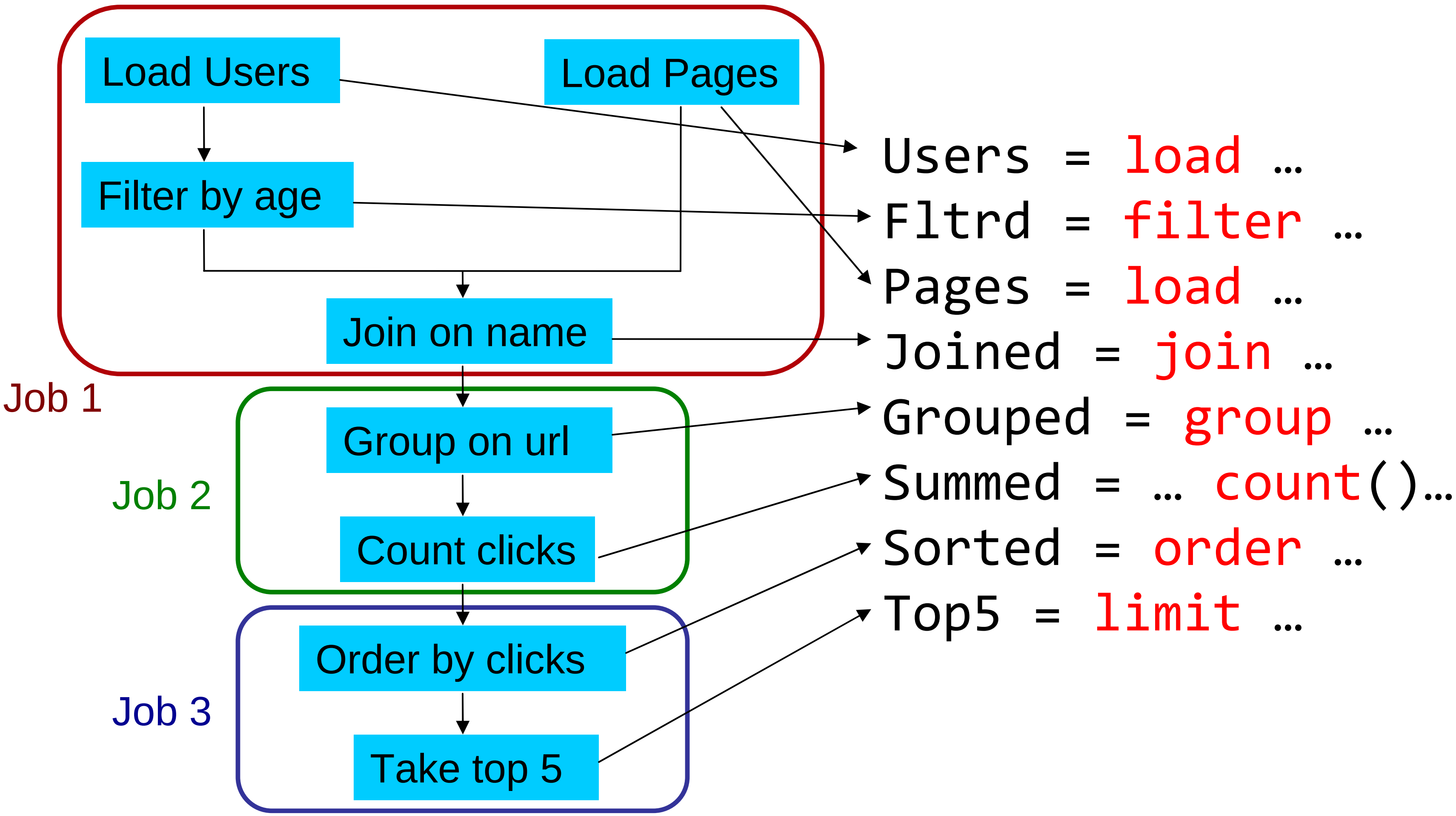
```
Users = load ‘users’ as (name, age);
Filtered = filter Users by age >= 18 and age <=
   25;
Pages = load ‘pages’ as (user, url);
Joined = join Filtered by name, Pages by user;
Grouped = group Joined by url;
Summed = foreach Grouped generate group,
                 count(Joined) as clicks;
Sorted = order Summed by clicks desc;
Top5 = limit Sorted 5;
store Top5 into ‘top5sites’;
```

Ease of Translation




```
Users = load …
Fltrd = filter …
Pages = load …
Joined = join …
Grouped = group …
Summed = … count()…
Sorted = order …
Top5 = limit …
```

Ease of Translation



HBase

Original Slides by

Tom White

Lexeme Ltd.

HBase - What?

- Modeled on Google's Bigtable
- Row/column store
- Billions of rows/millions on columns
- Column-oriented - nulls are free
- Untyped - stores byte[]

HBase - Data Model

Row	Timestamp	Column family: animal:		Column family repairs:
		animal:type	animal:size	repairs:cost
enclosure1	t2	zebra		1000 EUR
	t1	lion	big	
enclosure2	…	…	…	…

HBase - Data Storage

Column family animal:

(enclosure1, t2, animal:type)	zebra
(enclosure1, t1, animal:size)	big
(enclosure1, t1, animal:type)	lion

Column family repairs:

(enclosure1, t1, repairs:cost)	1000 EUR

HBase - Code

```
Htable table = …
Text row = new Text(“enclosure1”);
Text col1 = new Text(“animal:type”);
Text col2 = new Text(“animal:size”);
BatchUpdate update = new BatchUpdate(row);
update.put(col1, “lion”.getBytes(“UTF-8”));
update.put(col2, “big”.getBytes(“UTF-8));
table.commit(update);

update = new BatchUpdate(row);
update.put(col1, “zebra”.getBytes(“UTF-8”));
table.commit(update);
```

HBase - Querying

- Retrieve a cell

```
Cell = table.getRow(“enclosure1”).getColumn(“animal:type”).getValue();
```

- Retrieve a row

```
RowResult = table.getRow( “enclosure1” );
```

- Scan through a range of rows

```
Scanner s = table.getScanner( new String[] { “animal:type” } );
```

Hive

Original Slides by

Matei Zaharia

UC Berkeley RAD Lab

Hive

- Developed at Facebook
- Used for majority of Facebook jobs
- "Relational database" built on Hadoop
  - Maintains list of table schemas
  - SQL-like query language (HiveQL)
  - Can call Hadoop Streaming scripts from HiveQL
  - Supports table partitioning, clustering, complex data types, some optimizations

Creating a Hive Table

```
CREATE TABLE page_views(viewTime INT, userid BIGINT,
                    page_url STRING, referrer_url STRING,
                    ip STRING COMMENT 'User IP address')
COMMENT 'This is the page view table'
PARTITIONED BY(dt STRING, country STRING)
STORED AS SEQUENCEFILE;
```

- Partitioning breaks table into separate files for each (dt, country) pair

  Ex: /hive/page_view/dt=2008-06-08,country=USA

  /hive/page_view/dt=2008-06-08,country=CA

A Simple Query

- Find all page views coming from xyz.com on March 31st:

```
SELECT page_views.*
FROM page_views
WHERE page_views.date >= '2008-03-01'
AND page_views.date <= '2008-03-31'
AND page_views.referrer_url like '%xyz.com';
```

- Hive only reads partition `2008-03-01,*` instead of scanning entire table

Aggregation and Joins

- Count users who visited each page by gender:

```
SELECT pv.page_url, u.gender, COUNT(DISTINCT u.id)
FROM page_views pv JOIN user u ON (pv.userid = u.id)
GROUP BY pv.page_url, u.gender
WHERE pv.date = '2008-03-03';
```

- Sample output:

page_url	gender	count(userid)
home.php	MALE	12,141,412
home.php	FEMALE	15,431,579
photo.php	MALE	23,941,451
photo.php	FEMALE	21,231,314

Using a Hadoop Streaming Mapper Script

```
SELECT TRANSFORM(page_views.userid,
                                               page_views.date)
USING 'map_script.py'
AS dt, uid CLUSTER BY dt
FROM page_views;
```