Hadoop Design and *k*-Means Clustering

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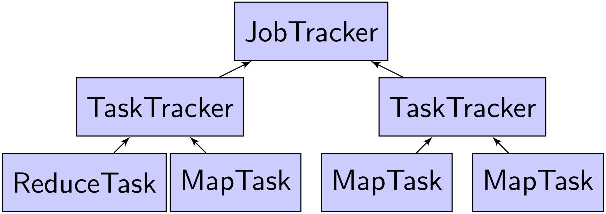
Hadoop Design

1. Fault Tolerance
2. Data Flow
   - Input
   - Output
3. MapTask
   - Map
   - Partition
4. ReduceTask
   - Fetch and Sort
   - Reduce

Later in this talk: Performance and *k*-Means Clustering

Managing Tasks



Design

- TaskTracker reports status or requests work every 10 seconds
- MapTask and ReduceTask report progress every 10 seconds

Issues

+ Detects failures and slow workers quickly
- JobTracker is a single point of failure

Coping With Failure

Failed Tasks

Rerun map and reduce as necessary.

Slow Tasks

Start a second backup instance of the same task.

Consistency

- Any MapTask or ReduceTask might be run multiple times
- Map and Reduce should be functional

Use of Random Numbers

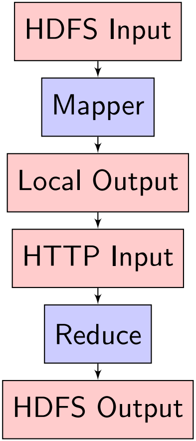
Purpose

Support randomized algorithms while remaining consistent

Sampling Mapper

```
private Random rand;
void configure(JobConf conf) {
  rand.setSeed((long)conf.getInt("mapred.task.partition"));
}
void map(WritableComparable key, Writable value,
         OutputCollector output, Reporter reporter) {
  if (rand.nextFloat() < 0.1) {
    output.collect(key, value);
  }
}
```

Data Flow



InputFormat splits and reads files

SequenceFileOutputFormat writes serialized values

Map outputs are retrieved over HTTP and merged

OutputFormat writes a SequenceFile or text

InputSplit

Purpose

Locate a single map task's input.

Important Functions

```
Path FileSplit.getPath();
```

Implementations

- `MultiFileSplit` is a list of small files to be concatenated.
- `FileSplit` is a file path, offset, and length.
- `TableSplit` is a table name, start row, and end row.

RecordReader

Purpose

Parse input specified by `InputSplit` into keys and values. Handle records on split boundaries.

Important Functions

```
boolean next(Writable key, Writable value);
```

Implementations

- `LineRecordReader` reads lines. Key is an offset, value is the text.
- `KeyValueLineRecordReader` reads delimited key-value pairs.
- `SequenceFileRecordReader` reads a `SequenceFile`, Hadoop's binary representation of key-value pairs.

InputFormat

Purpose

Specifies input file format by constructing `InputSplit` and `RecordReader`.

Important Functions

```
RecordReader getRecordReader(InputSplit split, JobConf job,
                             Reporter reporter);
InputSplit[] getSplits(JobConf job, int numSplits);
```

Implementations

- `TextInputFormat` reads text files.
- `TableInputFormat` reads from a table.

OutputFormat

Purpose

- Machine or human readable output.
- Makes `RecordWriter`, which is analogous to `RecordReader`

Important Functions

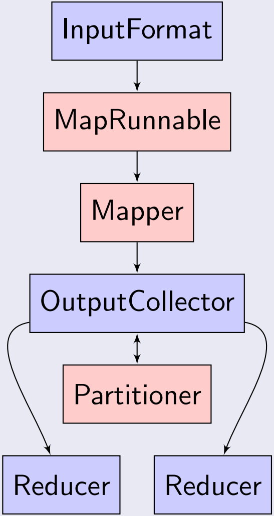
```
RecordWriter getRecordWriter(FileSystem fs, JobConf job,
  String name, Progressable progress);
```

Formats

- `SequenceFileOutputFormat` writes a binary `SequenceFile`
- `TextOutputFormat` writes text files

MapTask

Default Setup



Split files and read records

Map all records in the task

Map a record

Consult Partitioner and save files

Assign key-value pairs to reducers

Reducers retrieve files over HTTP

MapRunnable

Purpose

Sequence of map operations

Default Implementation

```
public void run(RecordReader input, OutputCollector output,
                Reporter reporter) throws IOException {
  try {
    WritableComparable key = input.createKey();
    Writable value = input.createValue();
    while (input.next(key, value)) {
      mapper.map(key, value, output, reporter);
    }
  } finally {
    mapper.close();
  }
}
```

Mapper

Purpose

Single map operation

Important Functions

```
void map(WritableComparable key, Writable value,
         OutputCollector output, Reporter reporter);
```

Pre-defined Mappers

- `IdentityMapper`
- `InverseMapper` flips key and value.
- `RegexMapper` matches regular expressions set in `job`.
- `TokenCountMapper` implements word count map.

Partitioner

Purpose

Decide which reducer handles map output.

Important Functions

```
int getPartition(WritableComparable key, Writable value,
                 int numReduceTasks);
```

Implementations

- `HashPartitioner` uses `key.hashCode() % numReduceTasks`.
- `KeyFieldBasedPartitioner` hashes only part of key.

Fetch and Sort

Fetch

- TaskTracker tells Reducer where mappers are
- Reducer requests input files from mappers via HTTP

Merge Sort

- Recursively merges 10 files at a time
- 100 MB in-memory sort buffer
- Calls key's Comparator, which defaults to key.compareTo

Important Functions

```
int WritableComparable.compareTo(Object o);
int WritableComparator.compare(WritableComparable a,
                               WritableComparable b);
```

Reduce

Important Functions

```
void reduce(WritableComparable key, Iterator values,
            OutputCollector output, Reporter reporter);
```

Pre-defined Reducers

- `IdentityReducer`
- `LongSumReducer` sums `LongWritable` values

Behavior

Reduce cannot start until all Mappers finish and their output is merged.

Using Hadoop

5. Performance
   - Combiners

6. *k*-Means Clustering
   - Algorithm
   - Implementation

Performance

Why We Care

- $\geq 10,000$ programs
- Average $100,000$ jobs/day
- ≥ 20 petabytes/day

Source: Dean, Jeffrey and Ghemawat, Sanjay. MapReduce: Simplified Data Processing on Large Clusters. Commun. ACM **51** (2008), 107–113.

Barriers

Concept

Barriers wait for N things to happen

Examples

- Reduce waits for all Mappers to finish
- Job waits for all Reducers to finish
- Search engine assembles pieces of results

Moral

Worry about the maximum time. This implies balance.

Combiner

Purpose

Lessen network traffic by combining repeated keys in MapTask.

Important Functions

```
void reduce(WritableComparable key, Iterator values,
            OutputCollector output, Reporter reporter);
```

Example Implementation

- `LongSumReducer` adds `LongWritable` values

Behavior

- Framework decides when to call.
- Uses `Reducer` interface, but called with partial list of values.

Extended Combining

Problem

- 1000 map outputs are buffered before combining.
- Keys can still be repeated enough to unbalance a reduce.

Two Phase Reduce

1. Run a MapReduce to combine values
   - Use `Partitioner` to balance a key over Reducers
   - Run Combiner in Mapper and Reducer
2. Run a MapReduce to reduce values
   - Map with `IdentityMapper`
   - Partition normally
   - Reduce normally

General Advice

Small Work Units

- More inputs than Mappers
- Ideally, more reduce tasks than Reducers
- Too many tasks increases overhead
- Aim for constant-memory Mappers and Reducers

Map Only

- Skip `IdentityReducer` by setting `numReduceTasks` to −1

Outside Tables

- Increase HDFS replication before launching
- Keep random access tables in memory
- Use multithreading to share memory

Netflix data

Goal

Find similar movies from ratings provided by users

Vector Model

- Give each movie a vector
- Make one dimension per user
- Put origin at average rating (so poor is negative)
- Normalize all vectors to unit length
  - Often called cosine similarity

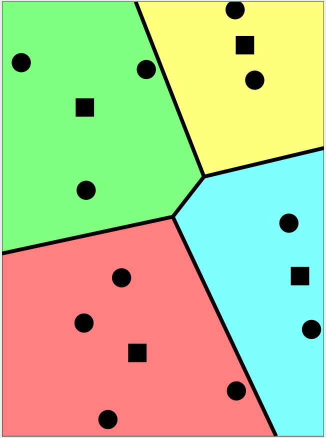
Issues

- Users are biased in the movies they rate

+ Addresses different numbers of raters

k-Means Clustering

Two Dimensional Clusters



d is sum of squares

Goal

Cluster similar data points

Approach

Given data points $x[i]$ and distance d:

- Select k centers c
- Assign $x[i]$ to closest center $c[i]$
- Minimize $\sum_i d(x[i], c[i])$

Lloyd's Algorithm

Algorithm

1. Randomly pick centers, possibly from data points
2. Assign points to closest center
3. Average assigned points to obtain new centers
4. Repeat 2 and 3 until nothing changes

Issues

- Takes superpolynomial time on some inputs
- Not guaranteed to find optimal solution

\+ Converges quickly in practice

Lloyd's Algorithm in MapReduce

Reformatting Data

Create a `SequenceFile` for fast reading. Partition as you see fit.

Initialization

Use a seeded random number generator to pick initial centers.

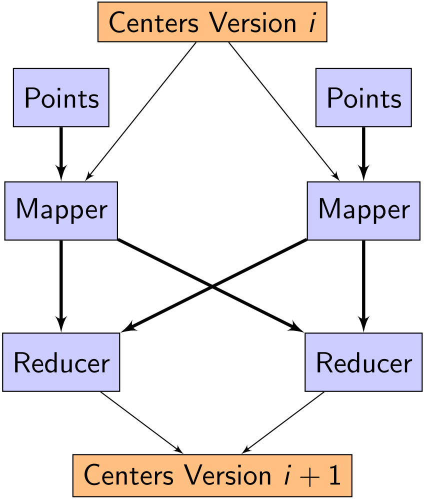
Iteration

Load centers table in `MapRunnable` or `Mapper`.

Termination

Use `TextOutputFormat` to list movies in each cluster.

Iterative MapReduce



Find Nearest Center

Key is Center, Value is Movie

Average Ratings

Direct Implementation

Mapper

- Load all centers into RAM off HDFS
- For each movie, measure distance to each center
- Output key identifying the closest center

Reducer

- Output average ratings of movies

Issues

- Brute force distance and all centers in memory
- Unbalanced reduce, possibly even for large k

Two Phase Reduce

Implementation

1. Combine
   - Mapper key identifies closest center, value is point.
   - Partitioner balances centers over reducers.
   - Combiner and Reducer add and count points.
2. Recenter
   - `IdentityMapper`
   - Reducer averages values

Issues

+ Balanced reduce
- Two phases
- Mapper still has all k centers in memory

Large *k*

Implementation

- Map task responsible for part of movies and part of *k* centers.
  - For each movie, finds closest of known centers.
  - Output key is point, value identifies center and distance.
- Reducer takes minimum distance center.
  - Output key identifies center, value is movie.
- Second phase averages points in each center.

Issues

+ Large *k* while still fitting in RAM
- Reads data points multiple times
- Startup and intermediate storage costs

Exercises

Recommended: PageRank

- Finish iterative step
- Balance pages with many incoming links

Optional: *k*-Means

- Run on part of Netflix
- Read about and implement Canopies: http://www.kamalnigam.com/papers/canopy-kdd00.pdf