A Case Study

- Internet radio and community-driven music discovery service founded in 2002.
- Users transmit information to Last.fm servers indicating which songs they are listening to.
- The received data is processed and stored so the user can access it in the form of charts and so Last.fm can make intelligent taste and compatibility decisions for generating recommendations and radio stations.
- The track listening data is obtained from one of two sources:
  - The listen is a **scrobble** when a user plays a track of his or her own and sends the information to Last.fm through a client application.
  - The listen is a **radio listen** when the user tunes into a Last.fm radio station and streams a song.
- Last.fm applications allow users to **love**, **skip** or **ban** each track they listen to. This track listening data is also transmitted to the server.
Big Data at Last.fm

- Over 40M unique visitors and 500M pageviews each month

  - **Scrobble stats:**
    - Up to 800 scrobbles per second
    - More than 40 million scrobbles per day
    - Over 75 billion scrobbles so far

  - **Radio stats:**
    - Over 10 million streaming hours per month
    - Over 400 thousand unique stations per day

- Each scrobble and radio listen generates at least one log line.
- In other words...**lots of data!!**
Last.FM’s “Herd of Elephants”
- 100 Nodes
- 8 cores per node (dual quad-core)
- 24GB memory per node
- 8TB (4 disks of 2TB each)
- Hive integration to run optimized SQL queries for analysis.
Started using Hadoop in 2006 as users grew from thousands to millions.

Hundreds of daily, monthly, and weekly jobs including,

- Site stats and metrics
- Chart generation (track statistics)
- Metadata corrections (e.g. misspellings of artists)
- Indexing for search and combining/formatting data for recommendations
- Data insights, evaluations, reporting

This case study will focus on the chart generation (Track Statistics) job, which was the first Hadoop implementation at Last.fm.
Features of the case study

- Shows how to handle $k$-tuples, where $k > 2$ using the `Writable` and `WritableComparable` interfaces from the Hadoop library.
- Shows how to have multiple map-reduce phases using the `ToolRunner`, `Tool` and `Configuration` classes/interfaces.
- Shows how to merge data from two different streams using map-reduce.
The goal of the Track Statistics program is to take incoming listening data and summarize it into a format that can be used to display on the website or used as input to other Hadoop programs.
Track Statistics Program

Two jobs to calculate values from the data, and a third job to merge the results.
Track Statistics Jobs

- **Input:** Gigabytes of space-delimited text files of the form (userID trackID scrobble radioPlay skip), where the last three fields are 0 or 1.

<table>
<thead>
<tr>
<th>UserId</th>
<th>TrackId</th>
<th>Scrobble</th>
<th>Radio</th>
<th>Skip</th>
</tr>
</thead>
<tbody>
<tr>
<td>111115</td>
<td>222</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>111113</td>
<td>225</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>111117</td>
<td>223</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>111115</td>
<td>225</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Output:** Charts require the following statistics per track:
  - Number of unique listeners
  - Number of scrobbles
  - Number of radio listens
  - Total number of listens
  - Number of radio skips

<table>
<thead>
<tr>
<th>TrackId</th>
<th>numListeners</th>
<th>numPlays</th>
<th>numScrobbles</th>
<th>numRadioPlays</th>
<th>numSkips</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
</tr>
<tr>
<td>222</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>223</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>225</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
UniqueListeners Job

Calculates the number of *unique* listeners per track.

- **UniqueListenersMapper input:**
  - key is the line number of the current log entry.
  - value is the space-delimited log entry.

<table>
<thead>
<tr>
<th>LineOfFile</th>
<th>UserId</th>
<th>TrackId</th>
<th>Scrobble</th>
<th>Radio</th>
<th>Skip</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>111115</td>
<td>222</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>111113</td>
<td>225</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>111117</td>
<td>223</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>111115</td>
<td>225</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **UniqueListenersMapper function:**
  - if(scrobbles <= 0 && radioListens <=0) output nothing;
  - else output(trackId, userId)
  - map(0, '111115 222 0 1 0') → <222, 111115>

- **UniqueListenersMapper output:**

<table>
<thead>
<tr>
<th>TrackId</th>
<th>UserId</th>
</tr>
</thead>
<tbody>
<tr>
<td>222</td>
<td>111115</td>
</tr>
<tr>
<td>225</td>
<td>111113</td>
</tr>
<tr>
<td>223</td>
<td>111117</td>
</tr>
<tr>
<td>225</td>
<td>111115</td>
</tr>
</tbody>
</table>
public static class UniqueListenersMapper extends Mapper<LongWritable, Text, IntWritable, IntWritable> {
    public void map(LongWritable offset, Text line, Context context)
        throws IOException, InterruptedException {
        String[] parts = (line.toString()).split(" ");

        int scrobbles = Integer.parseInt(parts[TrackStatistics.COL_SCROBBLE]);
        int radioListens = Integer.parseInt(parts[TrackStatistics.COL_RADIO]);

        /* Ignore track if marked with zero plays */
        if (scrobbles <= 0 && radioListens <= 0)
            return;

        /* Output user id against track id */
        IntWritable trackId = new IntWritable(Integer.parseInt(parts[TrackStatistics.COL_TRACKID]));
        IntWritable userId = new IntWritable(Integer.parseInt(parts[TrackStatistics.COL_USERID]));
        context.write(trackId, userId);
    }
}
UniqueListenersReducer

- **UniqueListenersReducer input:**
  - **key** is the TrackID output by UniqueListenersMapper.
  - **value** is the iterator over the list of all UserIDs who listened to the track.

<table>
<thead>
<tr>
<th>TrackId</th>
<th>Iterable&lt;UserIds&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>Iterable&lt;IntWritable&gt;</td>
</tr>
<tr>
<td>222</td>
<td>111115</td>
</tr>
<tr>
<td>225</td>
<td>111113 111115</td>
</tr>
<tr>
<td>223</td>
<td>111117</td>
</tr>
</tbody>
</table>

- **UniqueListenersReducer function:**
  - Add userIds to a HashSet as you iterate the list. Since a HashSet doesn't store duplicates, the size of the set will be the number of unique listeners.
  - reduce(225, '111115 111113') → <225, 2>

- **UniqueListenersReducer output:**

<table>
<thead>
<tr>
<th>TrackId</th>
<th>numListeners</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>IntWritable</td>
</tr>
<tr>
<td>222</td>
<td>1</td>
</tr>
<tr>
<td>223</td>
<td>1</td>
</tr>
<tr>
<td>225</td>
<td>2</td>
</tr>
</tbody>
</table>
/**
 * Receives a list of user IDs per track ID and puts them into a
 * set to remove duplicates. The size of this set (the number of
 * unique listeners) is emitted for each track.
 */
public static class UniqueListenersReducer extends
    Reducer<IntWritable, IntWritable, IntWritable, IntWritable> {

    public void reduce(IntWritable trackId, Iterable<IntWritable> values,
        Context context)
    throws IOException, InterruptedException {

        Set<Integer> userIds = new HashSet<Integer>();

        /* Add all users to set, duplicates automatically removed */
        while (values.hasNext()) {
            IntWritable userId = values.next();
            userIds.add(Integer.valueOf(userId.get()));
        }

        /* Output trackId -> number of unique listeners per track */
        context.write(trackId, new IntWritable(userIds.size()));
    }
}
SumTrackStats Job

Adds up the scrobble, radio and skip values for each track.

- **SumTrackStatsMapper input**: The same as UniqueListeners.

  - **LineOfFile** | **UserId** | **TrackId** | **Scrobble** | **Radio** | **Skip**
  - LongWritable | IntWritable | IntWritable | Boolean | Boolean | Boolean
  - 0 | 111115 | 222 | 0 | 1 | 0
  - 1 | 111113 | 225 | 1 | 0 | 0
  - 2 | 111117 | 223 | 0 | 1 | 1
  - 3 | 111115 | 225 | 1 | 0 | 0

- **SumTrackStatsMapper function**:
  - Simply parse input and output the values as a new TrackStats object (see next slide).
  - `map(0, '111115 222 0 1 0') → <222, new TrackStats(0, 1, 0, 1, 0)>`

- **SumTrackStatsMapper output**:

  - **TrackId** | **numListeners** | **numPlays** | **numScrobbles** | **numRadioPlays** | **numSkips**
  - IntWritable | IntWritable | IntWritable | IntWritable | IntWritable
  - 222 | 0 | 1 | 0 | 1 | 0
  - 225 | 0 | 1 | 1 | 0 | 0
  - 223 | 0 | 1 | 0 | 1 | 1
  - 225 | 0 | 1 | 1 | 0 | 0
public class TrackStats implements WritableComparable<TrackStats> {

    private IntWritable listeners;
    private IntWritable plays;
    private IntWritable scrobbles;
    private IntWritable radioPlays;
    private IntWritable skips;

    public TrackStats(int numListeners, int numPlays, int numScrobbles,
                      int numRadio, int numSkips) {
        this.listeners = new IntWritable(numListeners);
        this.plays = new IntWritable(numPlays);
        this.scrobbles = new IntWritable(numScrobbles);
        this.radioPlays = new IntWritable(numRadio);
        this.skips = new IntWritable(numSkips);
    }

    public TrackStats() {
        this(0, 0, 0, 0, 0);
    }

    ...

}
public static class SumTrackStatsMapper extends Mapper<LongWritable, Text, IntWritable, TrackStats> {
    public void map(LongWritable offset, Text line, Context context)
        throws IOException, InterruptedException {
        String[] parts = (line.toString()).split(" ");
        int trackId = Integer.parseInt(parts[TrackStatistics.COL_TRACKID]);
        int scrobbles = Integer.parseInt(parts[TrackStatistics.COL_SCROBBLE]);
        int radio = Integer.parseInt(parts[TrackStatistics.COL_RADIO]);
        int skip = Integer.parseInt(parts[TrackStatistics.COL_SKIP]);

        TrackStats trackstat = new TrackStats(0, scrobbles + radio,
                                              scrobbles, radio, skip);
        context.write(new IntWritable(trackId), trackstat);
    }
}
**SumTrackStatsReducer**

- **SumTrackStatsReducer input:**
  - `key` is the `TrackID` output by the mapper.
  - `value` is the iterator over the list of `TrackStats` associated with the track.

<table>
<thead>
<tr>
<th>TrackId</th>
<th>Iterable&lt;TrackStats&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>Iterable&lt;TrackStats&gt;</td>
</tr>
<tr>
<td>222</td>
<td>(0,1,0,1,0)</td>
</tr>
<tr>
<td>225</td>
<td>(0,1,1,0,0)</td>
</tr>
<tr>
<td>223</td>
<td>(0,1,0,1,1)</td>
</tr>
</tbody>
</table>

- **SumTrackStatsReducer function:**
  - Create new `TrackStats` object to hold totals for current track.
  - Iterate through values and add the stats of each value to the stats of the object we created.
  - `reduce(225, (0,1,1,0,0) (0,1,1,0,0)) \rightarrow <225, (0,2,2,0,0)>`

- **SumTrackStatsReducer output:**

<table>
<thead>
<tr>
<th>TrackId</th>
<th>numListeners</th>
<th>numPlays</th>
<th>numScrobbles</th>
<th>numRadioPlays</th>
<th>numSkips</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
</tr>
<tr>
<td>222</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>223</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>225</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
public static class SumTrackStatsReducer extends 
  Reducer<IntWritable, TrackStats, IntWritable, TrackStats> { 

  public void reduce(IntWritable trackId, Iterable<TrackStats> values,
    Context context)
  throws IOException, InterruptedException 
  {
/* Hold totals for this track */
TrackStats sum = new TrackStats();
while (values.hasNext()) {
  TrackStats trackStats = (TrackStats) values.next();
  sum.setListeners(sum.getListeners() + trackStats.getListeners());
  sum.setPlays(sum.getPlays() + trackStats.getPlays());
  sum.setSkips(sum.getSkips() + trackStats.getSkips());
  sum.setScrobbles(sum.getScrobbles() + trackStats.getScrobbles());
  sum.setRadioPlays(sum.getRadioPlays() + trackStats.getRadioPlays());
}
context.write(trackId, sum);
} 
}
Merging the Results: MergeResults Job

Merges the output from the UniqueListeners and SumTrackStats jobs.

- Specify a mapper for each input type:
  
  ```java
  MultipleInputs.addInputPath(conf, sumInputDir, 
  SequenceFileInputFormat.class, IdentityMapper.class);
  
  MultipleInputs.addInputPath(conf, listenersInputDir, 
  SequenceFileInputFormat.class, MergeListenersMapper.class);
  ```

- `IdentityMapper` simply emits the `trackId` and `TrackStats` object output by the `SumTrackStats` job.

- `IdentityMapper` input and output:

<table>
<thead>
<tr>
<th>TrackId</th>
<th>numListeners</th>
<th>numPlays</th>
<th>numScrobbles</th>
<th>numRadioPlays</th>
<th>numSkips</th>
</tr>
</thead>
<tbody>
<tr>
<td>222</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>223</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>225</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
MergeListenersMapper

Prepares the data for input to the final reducer function by mapping the TrackId to a TrackStats object with the number of unique listeners set.

- **MergeListenersMapper input**: The UniqueListeners job output.

<table>
<thead>
<tr>
<th>TrackId</th>
<th>numListeners</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>IntWritable</td>
</tr>
<tr>
<td>222</td>
<td>1</td>
</tr>
<tr>
<td>223</td>
<td>1</td>
</tr>
<tr>
<td>225</td>
<td>2</td>
</tr>
</tbody>
</table>

- **MergeListenersMapper function**:
  - Create a new TrackStats object per track and set the numListeners attribute.
  - `map(225, 2) → <225, new TrackStats(2, 0, 0, 0, 0)>`

- **MergeListenersMapper output**:

<table>
<thead>
<tr>
<th>TrackId</th>
<th>numListeners</th>
<th>numPlays</th>
<th>numScrobbles</th>
<th>numRadioPlays</th>
<th>numSkips</th>
</tr>
</thead>
<tbody>
<tr>
<td>222</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>223</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>225</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
public static class MergeListenersMapper extends Mapper<IntWritable, IntWritable, IntWritable, TrackStats> {
    public void map(IntWritable trackId, IntWritable uniqueListenerCount, Context context)
            throws IOException, InterruptedException {
        TrackStats trackStats = new TrackStats();
        trackStats.setListeners(uniqueListenerCount.get());
        context.write(trackId, trackStats);
    }
}
Finally, we have two partially defined TrackStats objects for each track. We can reuse the SumTrackStatsReducer to combine them and emit the final result.

**SumTrackStatsReducer input:**
- **key** is the TrackID output by the two mappers.
- **value** is the iterator over the list of TrackStats associated with the track (in this case, one contains the unique listener count and the other contains the play, scrobble, radio listen, and skip counts).

<table>
<thead>
<tr>
<th>TrackId</th>
<th>Iterable&lt;TrackStats&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>Iterable&lt;TrackStats&gt;</td>
</tr>
<tr>
<td>222</td>
<td>(1,0,0,0,0) (0,1,0,1,0)</td>
</tr>
<tr>
<td>223</td>
<td>(1,0,0,0,0) (0,1,0,1,1)</td>
</tr>
<tr>
<td>225</td>
<td>(2,0,0,0,0) (0,2,2,0,0)</td>
</tr>
</tbody>
</table>

**SumTrackStatsReducer function:**
- reduce(225,’(2,0,0,0,0) (0,2,2,0,0)’) → <225, (2,2,2,0,0)>

**SumTrackStatsReducer output:**

<table>
<thead>
<tr>
<th>TrackId</th>
<th>numListeners</th>
<th>numPlays</th>
<th>numScrobbles</th>
<th>numRadioPlays</th>
<th>numSkips</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
<td>IntWritable</td>
</tr>
<tr>
<td>222</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>223</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>225</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
public static class SumTrackStatsReducer extends
    Reducer<IntWritable, TrackStats, IntWritable, TrackStats> {

    public void reduce(IntWritable trackId, Iterable<TrackStats> values,
        Context context)
        throws IOException, InterruptedException {
        /* Hold totals for this track */
        TrackStats sum = new TrackStats();
        while (values.hasNext()) {
            TrackStats trackStats = (TrackStats) values.next();
            sum.setListeners(sum.getListeners() + trackStats.getListeners());
            sum.setPlays(sum.getPlays() + trackStats.getPlays());
            sum.setSkips(sum.getSkips() + trackStats.getSkips());
            sum.setScrobbles(sum.getScrobbles() + trackStats.getScrobbles());
            sum.setRadioPlays(sum.getRadioPlays() + trackStats.getRadioPlays());
        }
        context.write(trackId, sum);
    }
}
Putting it all together

- All job classes should extend Configured and implement Tool.
  ```java
  public class MergeResults extends Configured implements Tool
  ```
- Then override the `run` method with specific job configuration.
  ```java
  public class MergeResults extends Configured implements Tool {
      /* mapper and reducer classes */
      public int run(String[] args) throws Exception {
          Configuration conf = new Configuration();
          Path sumInputDir = new Path(args[1] + Path.SEPARATOR_CHAR + "sumInputDir");
          Path listenersInputDir = new Path(args[1] + Path.SEPARATOR_CHAR + "listenersInputDir");
          Path output = new Path(args[1] + Path.SEPARATOR_CHAR + "finalSumOutput");

          Job job = new Job(conf, "merge-results");
          job.setJarByClass(UniqueListeners.class);

          MultipleInputs.addInputPath(job, sumInputDir,
              SequenceFileInputFormat.class, Mapper.class);
          MultipleInputs.addInputPath(job, listenersInputDir,
              SequenceFileInputFormat.class, MergeListenersMapper.class);

          job.setReducerClass(SumTrackStats.SumTrackStatsReducer.class);
          job.setOutputKeyClass(IntWritable.class);
          job.setOutputValueClass(TrackStats.class);
          FileOutputFormat.setOutputPath(job, output);
          if (job.waitForCompletion(true))
              return 0;
          else
              return 1;
      }
  }
  ```
Putting it all together

Hadoop provides a **ToolRunner** to simplify “job chaining”. The driver class simply runs each job in the correct order using ToolRunner.

```java
public class GenerateTrackStats {
    public static void main(String[] args) throws Exception {
        if (args.length != 2) {
            System.out.println("Usage: GenerateTrackStats <input path> <output path>");
            System.exit(0);
        }
        int exitCode = ToolRunner.run(new UniqueListeners(), args);
        if (exitCode == 0)
            exitCode = ToolRunner.run(new SumTrackStats(), args);
        else {
            System.err.println("GenerateTrackStats: UniqueListeners map-reduce phase failed!!");
            System.exit(1);
        }
        if (exitCode == 0)
            exitCode = ToolRunner.run(new MergeResults(), args);
        else {
            System.err.println("GenerateTrackStats: SumTrackStats map-reduce phase failed!!");
            System.exit(1);
        }
        System.exit(exitCode);
    }
}
```
References

- Thanks to Marissa Hollingsworth for the full last.fm code example and slides. Converted to new API by Amit Jain.