Hadoop MapReduce

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Outline

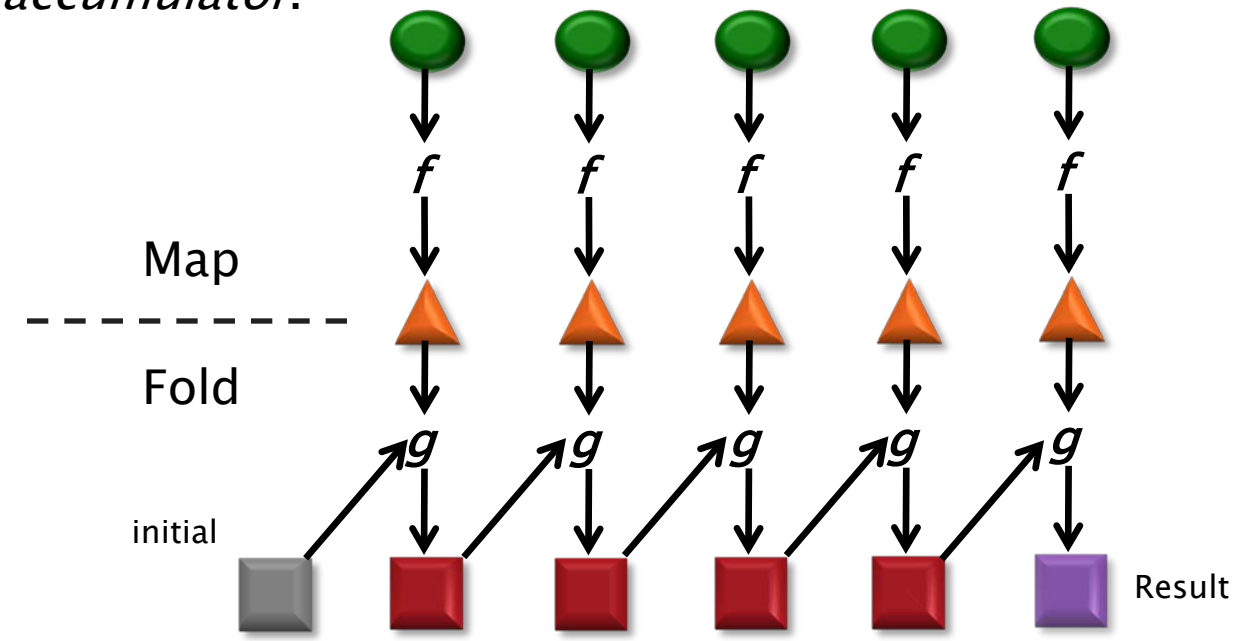
- MapReduce Overview
- Hadoop-WordCount Demo
- Hadoop-Blast Demo
- Q&A

MapReduce in Simple Terms

- Mapreduce – The Story of Tom
  - By Saliya Ekanayake

Mapeduce in Functional Programming

- Map
  - Apply the same function *f* to all the elements of a list
- Fold
  - Moves across a list, applying function *g* to each element plus an *accumulator*.



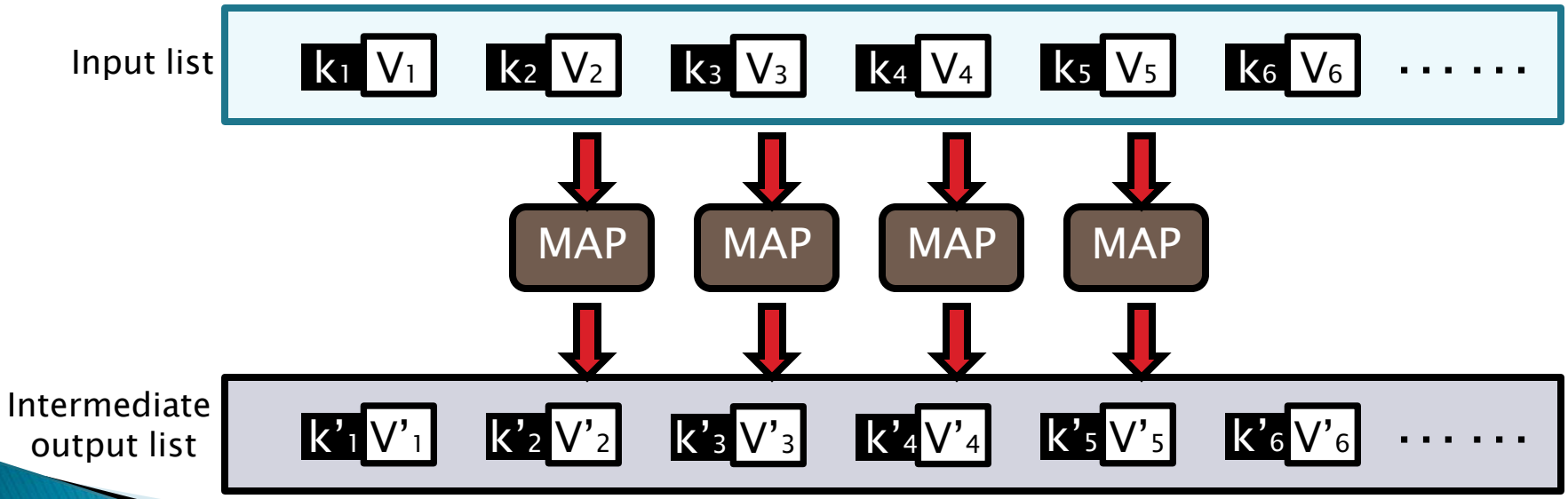
MapReduce Programming Model

- influenced by Functional Programming constructs
- Users implement interface of two functions:
  - **`map (in_key, in_value) -> (out_key, intermediate_value) list`**
  - **`reduce (out_key, intermediate_value list) -> out_value list`**

Source: http://code.google.com/edu/parallel/mapreduce-tutorial.html

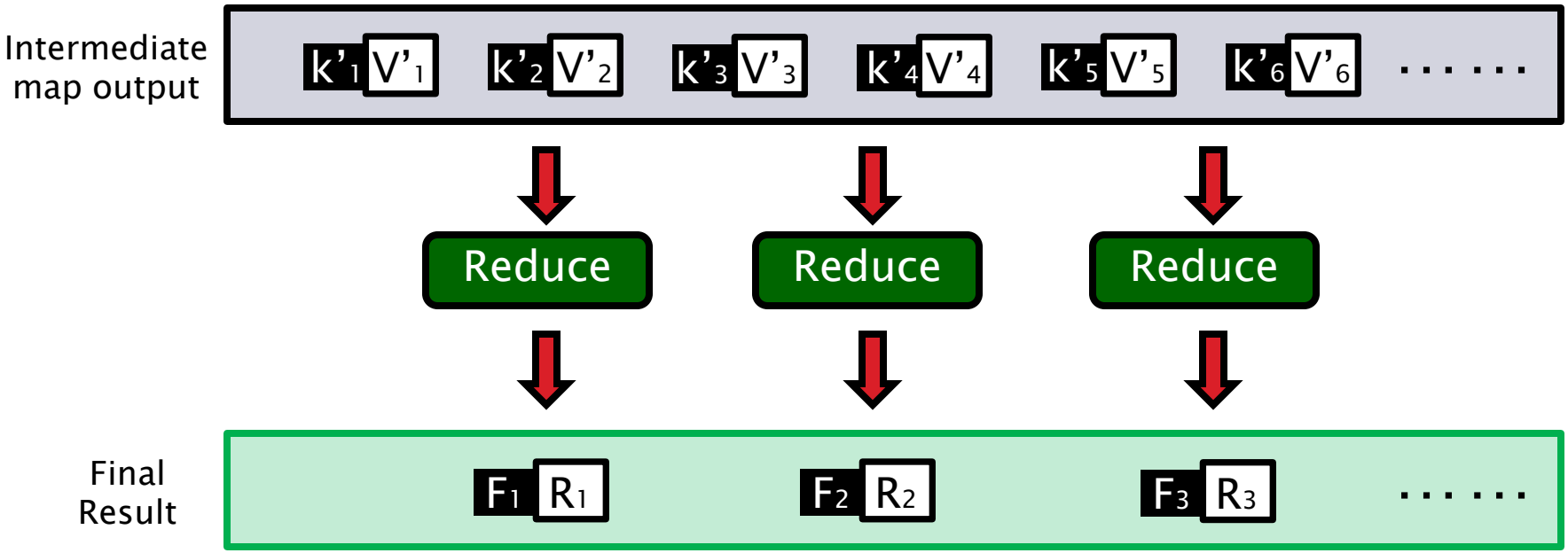
Map

- A list of data elements are passed, one at a time, to map() functions which transform each data element to an individual output data element.
- A map() produces one or more *intermediate* <key, values> pair(s) from the input list.



Reduce

- After map phase finish, those intermediate values with same output key are reduced into one or more *final values*



Parallelism

- map() functions run in parallel, creating different intermediate values from different input data elements
- reduce() functions also run in parallel, working with assigned output key
- All values are processed *independently*
- Reduce phase can't start until map phase is completely finished.

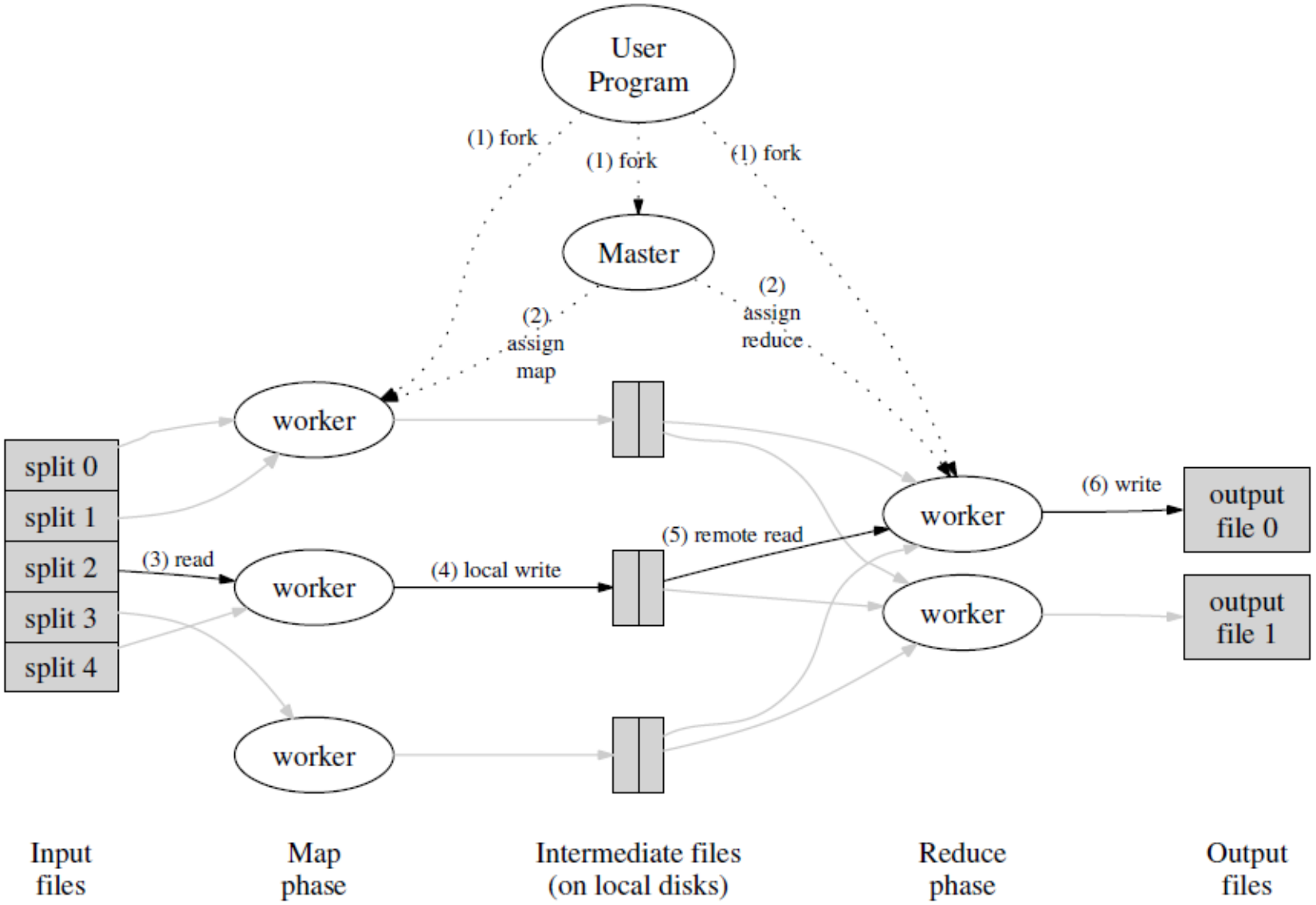
Source: http://code.google.com/edu/parallel/mapreduce-tutorial.html

Apache Hadoop

- Open Source MapReduce framework implementation
- Widely used by
  - Amazon Elastic MapReduce
  - EBay
  - FaceBook
  - TeraSort in Yahoo!
  - …
- Active community
- Many sub projects
  - HDFS
  - Pig Latin
  - Hbase
  - …

Source: http://wiki.apache.org/hadoop/PoweredBy

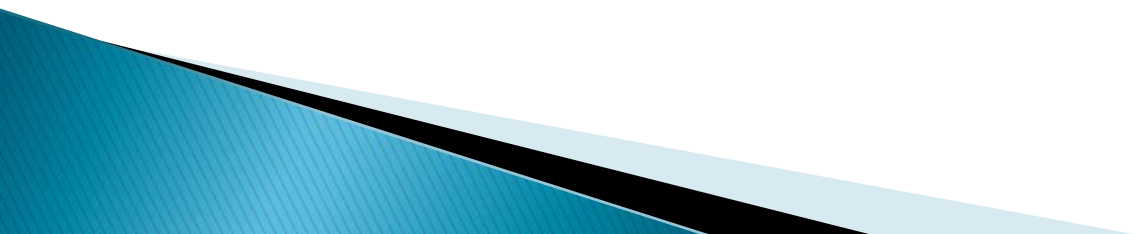
Execution Overview



Source: http://code.google.com/edu/parallel/mapreduce-tutorial.html

MapReduce in Apache Hadoop

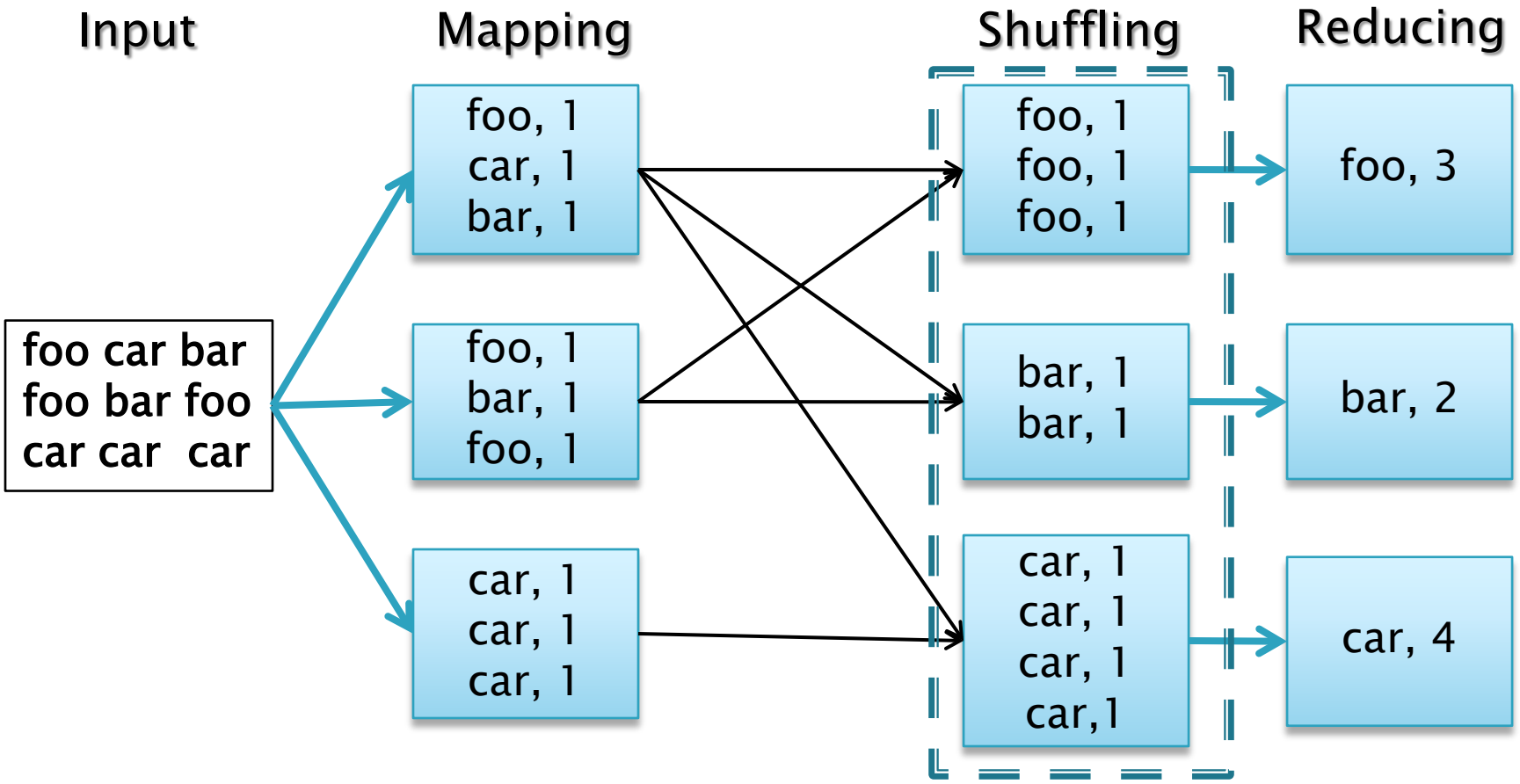
- Autoparallelization
- data distribution
- Fault-tolerant
- Status monitoring
- Simple programming constructs



Demo 1 – WordCount

- “Hello World” in MapReduce programming style
- Fits well with the MapReduce programming model
  - count occurrence of each word in given files
  - each file (may be split) run in parallel
  - need reduce phase to collect final result
- Three main parts:
  - Mapper
  - Reducer
  - Driver

Word Count


Input
Mapping
Shuffling
Reducing
foo car bar
foo bar foo
car car car
foo, 1
car, 1
bar, 1
foo, 1
bar, 1
foo, 1
car, 1
car, 1
car, 1
foo, 1
foo, 1
foo, 1
bar, 1
bar, 1
car, 1
car, 1
car, 1
car,1
foo, 3
bar, 2
car, 4

WordCount Map

```
void Map (key, value) {
        for each word x in value:
            output.collect(x, 1);
}
```

WordCount Map

```
public static class Map
        extends 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, Context context )
      throws IOException, InterruptedException {
      StringTokenizer itr = new StringTokenizer(value.toString());

      while (itr.hasMoreTokens()) {
          word.set(itr.nextToken());
          context.write(word, one);
      }
  }
}
```

WordCount Reduce

```
void Reduce (keyword, <list of value>){
        for each x in <list of value>:
                sum+=x;
        output.collect(keyword, sum);
}
```

WordCount Reduce

```
public static class Reduce
      extends Reducer<Text,IntWritable,Text,IntWritable> {
    private IntWritable result = new IntWritable();

    public void reduce(Text key, Iterable<IntWritable> values,
                       Context context) throws …..{
        int sum = 0; // initialize the sum for each keyword
        for (IntWritable val : values) {
                sum += val.get();
        }
        result.set(sum);

        context.write(key, result);
  }
}
```

Log in to FutureGrid

- qsub -I
  - Get a FutureGrid Work node
- hostname
  - e.g. i51
  - Public hostname name should be
    - i51r.idp.iu.futuregrid.org
    - http://salsahpc.indiana.edu/tutorial/futuregrid_access.html

Building WordCount program

- cd Hadoop-WordCount
- cat WordCount.java
- cat build.sh
- ./build.sh
- ls -l

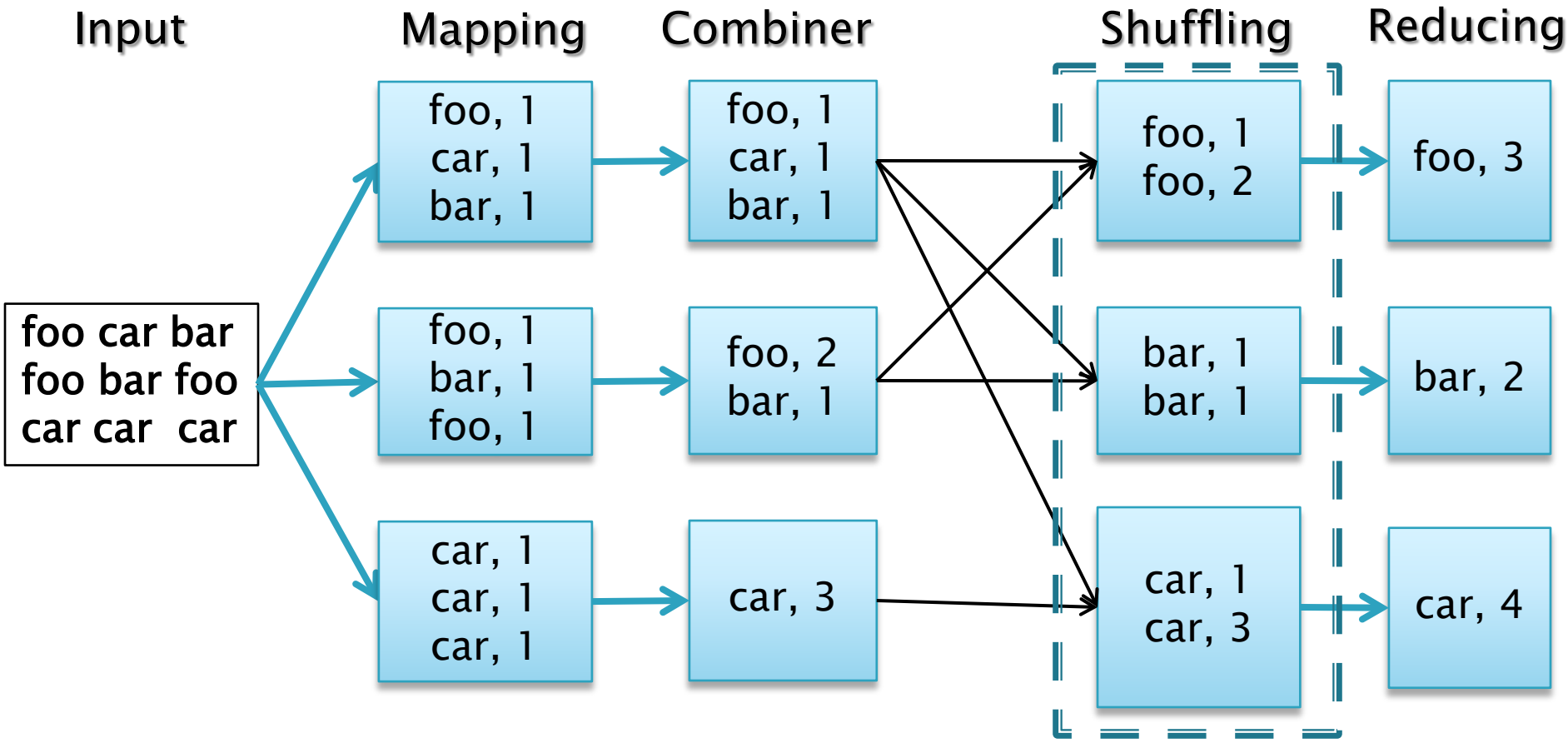
Running WordCount using Hadoop standalone

- cd ~/hadoop-0.20.2-standalone/bin
- cp ~/Hadoop-WordCount/wordcount.jar ~/hadoop-0.20.2-standalone/bin
- ./hadoop jar wordcount.jar WordCount ~/Hadoop-WordCount/input ~/Hadoop-WordCount/output
  - Simulate HDFS using the local directories
- cd ~/Hadoop-WordCount/
- cat output/part-r-00000

Optimizations

- Reduce phase can only be activated until all map tasks finish
  - It will be a waste if there is a extremely long map task
- “Combiner” functions can run on same machine as a mapper
- Causes a mini-reduce phase to occur before the real reduce phase, to save bandwidth

Word Count with Combiner



Terminology

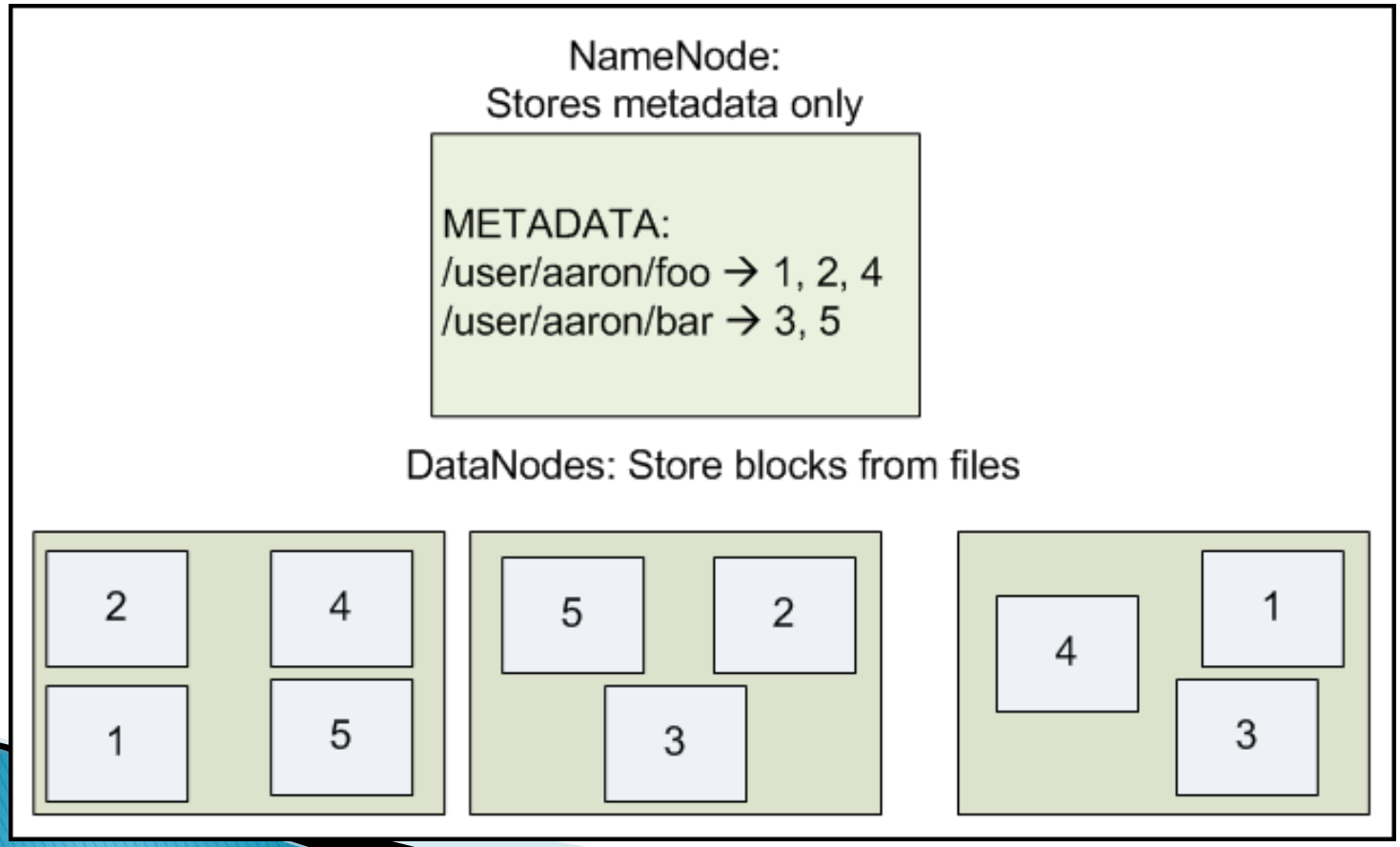
- Job
- Jobtracker
- Task
- TaskTracker
- Shard

HDFS

- Based on Google File System
- Run on commodity low-cost hardware
- Fault tolerance
  - Redundant storage
- High throughput access
- Suitable for large data sets
- Large capacity
- Integration with MapReduce

Architecture

- Single NameNode
- Multiple Data Nodes



Source: http://developer.yahoo.com/hadoop/tutorial/index.html

Configuring HDFS

- dfs.name.dir
  - Dir in the namenode to store metadata
- dfs.data.dir
  - Dir in data nodes to store the data blocks
  - Must be in a local disk partition

conf/hdfs-site.xml

```
<property>
  <name>dfs.name.dir</name>
   <value>/tmp/hadoop-test/name</value>
</property>
<property>
  <name>dfs.data.dir</name>
   <value>/tmp/hadoop-test/data</value>
</property>
```

Configuring HDFS

- fs.default.name
  - URI of the namenode

conf/core-site.xml

```
<property>
  <name>fs.default.name</name>
  <value>hdfs://149.79.89.113:9000/</value>
</property>
```

- conf/masters
  - ip address of the master node
- conf/slaves
  - ip address of the slave nodes
- Should have password-less SSH access to all the nodes

HDFS Cluster

- Starting HDFS
  - cd ~/hadoop-0.20.2/bin
  - ./hadoop namenode -format
  - ./start-dfs.sh
- NameNode logs
  - cd ~/hadoop-0.20.2
  - logs/hadoop-<username>-namenode-<nodeid>.log
- Monitoring web interface
  - http://<public_ip>:50070

HDFS Commands

- ./bin/hadoop fs -[command]
  - put
  - get
  - ls
  - cp
  - mkdir
  - rm
- http://hadoop.apache.org/common/docs/current/hdfs_shell.html
- Programmatic API

Configuring Hadoop MapREduce

- mapred.job.tracker
- mapred.local.dir
- mapred.tasktracker.map.tasks.maximum

conf/mapred-site.xml

```
<property>
  <name>mapred.job.tracker</name>
  <value>149.79.89.113:9001</value>
</property>
<property>
  <name>mapred.local.dir</name>
  <value>/tmp/hadoop-test/local</value>
</property>
<property>
  <name>mapred.tasktracker.map.tasks.maximum</name>
  <value>8</value>
</property>
```

Starting Hadoop MapReduce Cluster

- Starting Hadoop MapReduce
  - cd ~/hadoop-0.20.2/bin
  - ./start-mapred.sh
- JobTracker logs
  - cd ~/hadoop-0.20.2
  - logs/hadoop-<username>-tasktracker<nodeid>.log
- Monitoring web interface
  - http://<public_ip>:50030

Running WordCount on Distributed Hadoop Cluster

- Upload input to HDFS
  - cd ~/hadoop-0.20.2/bin
  - ./hadoop fs -put ~/Hadoop-WordCount/input/ input
  - ./hadoop fs -ls input
- Run word count
  - ./hadoop jar wordcount.jar WordCount input output
  - ./hadoop fs -ls output
  - ./hadoop fs -cat output/*

Demo 2 : Hadoop-Blast

- An advance MapReduce implementation
- Use Blast (*Basic Local Alignment Search Tool*), a well-known bioinformatics application written in C/C++
- Utilize the Computing Capability of Hadoop
- Use Distributed Cache for the Blast Program and Database
- No Reducer in practice

Map

```
public void map(String key, String value, Context context)
    throws IOException,   InterruptedException {
      ...
      // download the file from HDFS
      …
      fs.copyToLocalFile(inputFilePath, new Path(localInputFile));// Prepare the argume
    nts to the executable
       ...
      execCommand = this.localBlastProgram + File.separator + execName + " " + exe
    cCommand + " -db " + this.localDB;

      //Create the external process
      Process p = Runtime.getRuntime().exec(execCommand);
      ...
      p.waitFor();
      //Upload the results to HDFS
      …
      fs.copyFromLocalFile(new Path(outFile),outputFileName);
      ...
} // end of overriding the map
```

Driver

```
…
// using distributed cache
DistributedCache.addCacheArchive(new URI(BlastProgramAndDB), jc);
…
// other parts
…
// input and output format
job.setInputFormatClass(DataFileInputFormat.class);
job.setOutputFormatClass(SequenceFileOutputFormat.class);
…
```

Preparation

- Make sure the HDFS and Map-Reduce daemon start correctly
- Put Blast queries on HDFS
  - cd ~/hadoop-0.20.2/bin
  - ./hadoop fs -put ~/hadoop-0.20.2/apps/Hadoop-Blast/input HDFS_blast_input
  - ./hadoop fs -ls HDFS_blast_input
- Copy Blast Program and DB to HDFS
  - ./hadoop fs -copyFromLocal $BLAST_HOME/BlastProgramAndDB.tar.gz BlastProgramAndDB.tar.gz
  - ./hadoop fs -ls BlastProgramAndDB.tar.gz

Execution & result

- Run the Hadoop-Blast program
  - cd ~/hadoop-0.20.2/bin
  - ./hadoop jar ~/hadoop-0.20.2/apps/Hadoop-Blast/executable/blast-hadoop.jar BlastProgramAndDB.tar.gz bin/blastx /tmp/hadoop-test/ db nr HDFS_blast_input HDFS_blast_output '-query #_INPUTFILE_# -outfmt 6 -seg no -out #_OUTPUTFILE_#'
- Check the Result
  - cd ~/hadoop-0.20.2/bin
  - ./hadoop fs -ls HDFS_blast_output
  - ./hadoop fs -cat HDFS_blast_output/pre_1.fa

Performance Tips at the end

- More Map tasks
  - Much more than the Map task capacity of the cluster
- Number of reduce tasks
  - 95% of the Reduce task capacity
  - Interleave computation with communication
- Data locality
- Map/Reduce task capacity of a worker
- Logs
  - Don’t store in NFS. They grow pretty fast.

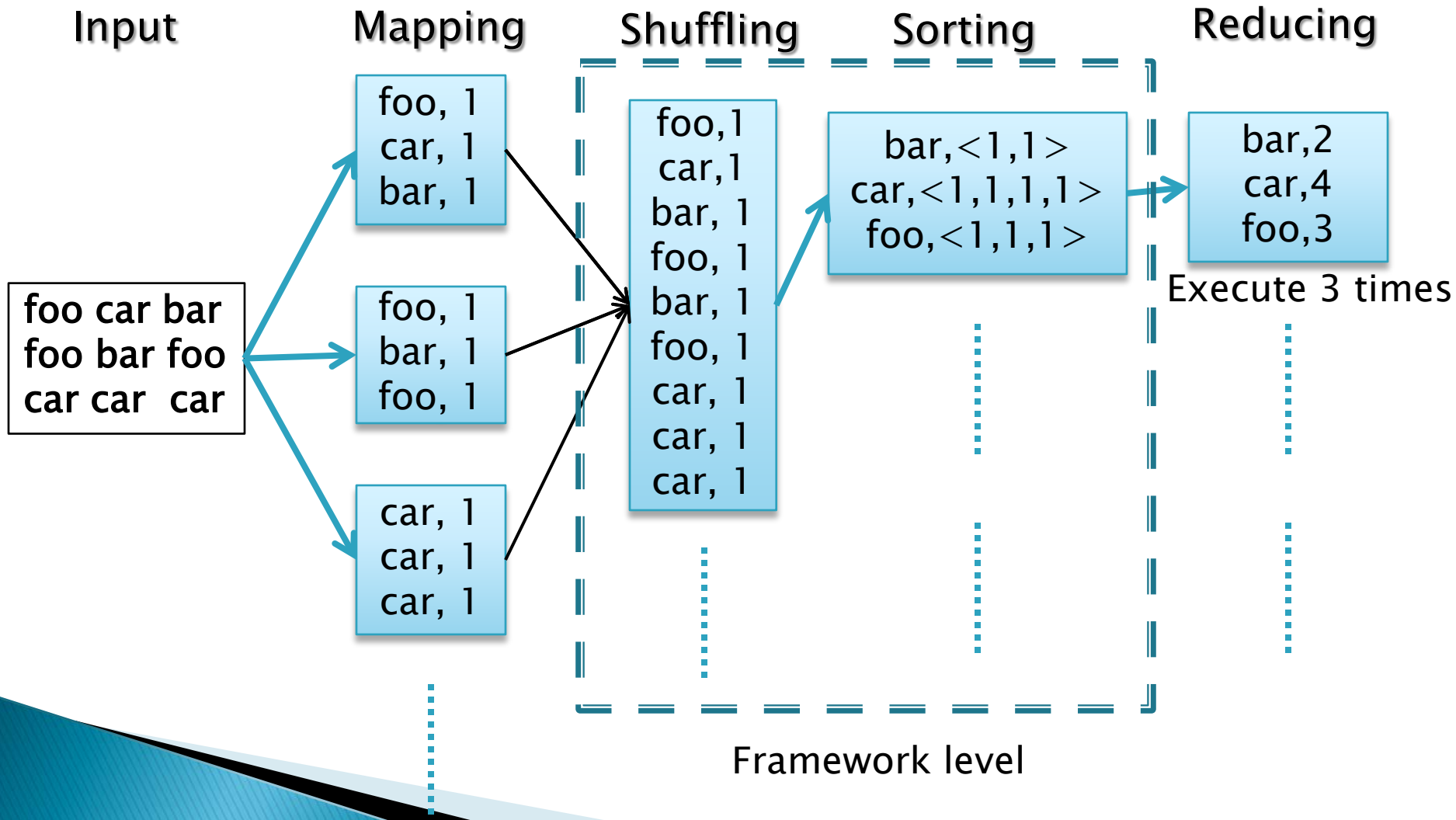
References

- Big Data for Science Tutorial
- Yahoo! Hadoop Tutorial
- Hadoop wiki
- Apache Hadoop Map/Reduce Tutorial
- Google: Cluster Computing and MapReduce

Questions?

Thank You!!

WordCount


Input
Mapping
Shuffling
Sorting
Reducing
foo car bar
foo bar foo
car car car
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car, 1
bar, 1
foo, 1
bar, 1
foo, 1
car, 1
car, 1
car, 1
foo,1
car,1
bar, 1
foo, 1
bar, 1
foo, 1
car, 1
car, 1
car, 1
bar,<1,1>
car,<1,1,1,1>
foo,<1,1,1>
bar,2
car,4
foo,3
Execute 3 times
Framework level

MapReduce Fault Tolerance

- MasterNode handles failures
  - detects worker failures
  - rerun completed & in-progress map() tasks
  - rerun in-progress reduce() tasks
  - If particular input key/values cause crashes in map phase, and skips those values on re-execution.
    - Partly output

Source: http://code.google.com/edu/parallel/mapreduce-tutorial.html

MapReduce Locality

- Master program tries to have map() tasks on same machine as physical file data, or at least on same rack
- map task inputs are spilt into blocks with default sizes as 64MB.

Source: http://code.google.com/edu/parallel/mapreduce-tutorial.html

HDFS Assumptions

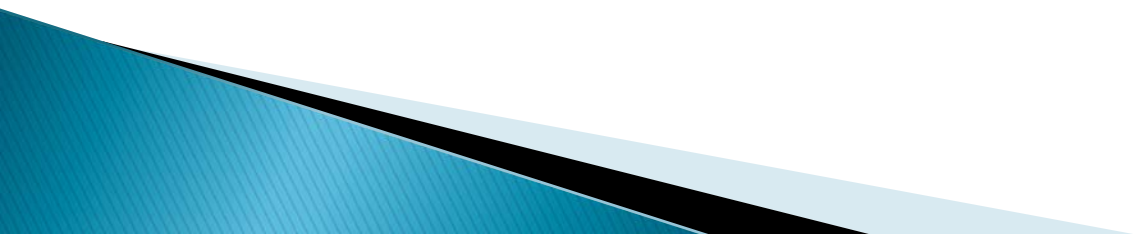
- High component failure rates
  - Inexpensive commodity components fail all the time
- "Modest" number of HUGE files
  - Just a few million
  - Each is 100MB or larger; multi-GB files typical
- Files are write-once, read many times
- Large streaming reads
- High sustained throughput favored over low latency

HDFS Design Decisions

- Files stored as blocks
  - Blocks stored across cluster
  - Default block size 64MB
- Reliability through replication
  - *Default is 3*
- Single master (NameNode) to coordinate access, keep metadata
  - Simple centralized management
- No data caching
  - Little benefit due to large data sets, streaming reads
- Focused on distributed applications

Advanced Hadoop

- Input formats
- Output formats
- Data types
- Distributed Cache



Input Formats

- Defines how to break the inputs
- Provides RecordReader objects to read the files
  - Read data and converts to <key,value> pairs
- It's possible to write custom input formats
- Hadoop Built-in input formats
  - TextInputFormat
    - Treats each line as value
  - KeyValueInputFormat
    - Each line as key-value (tab delimited)
  - SequenceFileInputFormat
    - Hadoop specific binary representation

Output Formats

- How the result <key,value> pairs are written in to files
- Possible to write custom output formats
- Hadoop default OutputFormats
  - TextOutputFormat
    - <key TAB value>
  - SequenceFileOutputFormat
    - Hadoop specific binary representation

Data Types

- Implement Writable interface
  - Text, IntWritable, LongWritable, FloatWritable, BooleanWritable, etc…
- We can write custom types which Hadoop will serialize/deserialize as long as following is implemented.

```
public interface Writable {
    void readFields(DataInput in);
    void write(DataOutput out);
}
```

Distributed Cache *

- Distributes a given set of data to all the mappers
  - Common data files, librararies, etc..
  - Similar to a broadcast
  - Available in the local disk
  - Automatically extract compressed archives
- First upload the files to HDFS
- DistributedCache.addCacheFile()
- DistributedCache.getLocalCacheFiles()