Using Map-Reduce to Teach Parallel Programming Concepts

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Workshop site

CSinParallel.org -> Workshops -> WMR Workshop

See also workshop handout

Introductory comments

- Role of undergraduate researchers: There would be no workshop without them!
- Thanks to Amazon Web Services for providing credits to host our WMR instance

- Disclaimer: We are not proposing map-reduce as the only approach to introducing parallelism, concurrency
- A value: Honor thy neighbor's curricular approach

Goals

- Introduce map-reduce computing, using the *WebMapReduce (WMR)* simplified interface to Hadoop
  - Why use map-reduce in the curriculum?
- Hands-on exercises with WMR for foundation courses

Goals

Part 1 – Introduction

- Map-reduce computing, and the *WebMapReduce (WMR)* simplified interface to Hadoop
- Hands-on exercises with WMR for foundation courses

Part 2 – Teaching with WMR

- Why use map-reduce in the curriculum?
- Use of WMR for intermediate and advanced courses
- Hands-on exercises for more advanced use

Part 3 (optional) – What's under the hood?

Sneak Preview: Materials available

(In case you already know your map-reduce…)

- CSinParallel module: *Map-reduce Computing for Introductory Students using WebMapReduce*
  - See `csinparallel.org`

Part 1: Introduction to Map-Reduce Computing and WMR

Introduction to Map-Reduce Computing

History

- The computational model of using map and reduce operations was developed decades ago, for LISP
- Google developed MapReduce system for search engine, published (Dean and Ghemawat, 2004)
- Yahoo! created Hadoop, an open-source implementation (under Apache); Java mappers and reducers

Map-Reduce: The 2-minute overview

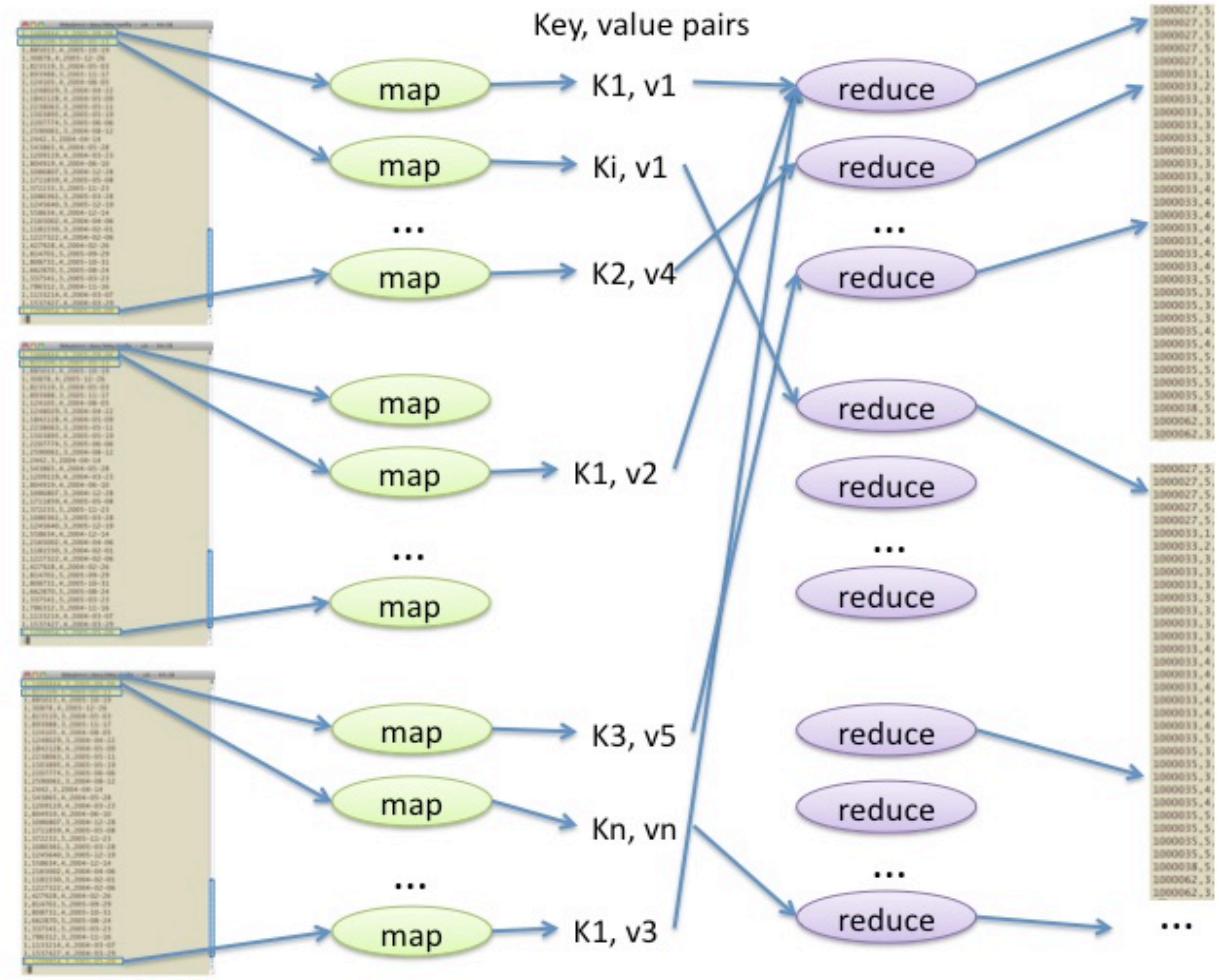
What if you wanted to
count the frequencies of all words
in 1,000,000 books?

Map-Reduce: The 2-minute overview

What if you wanted to
count the frequencies of all words
in 1,000,000 books?

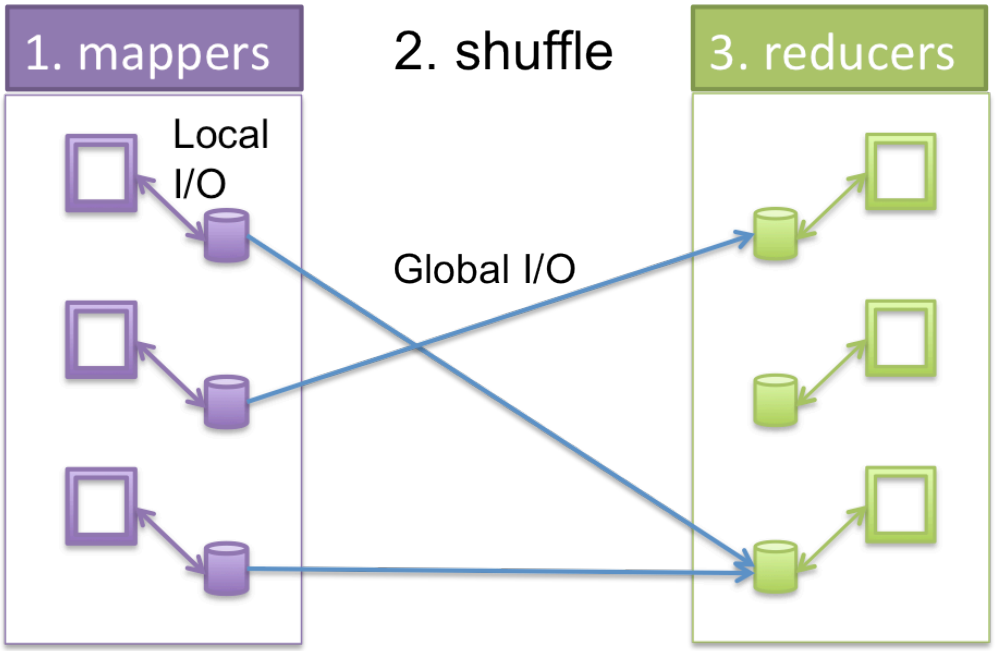
1. Break up the lines of text:
   generate one *labelled piece* per word
   - Use that word as label; value 1 for each piece
2. Group the pieces according to label (word)
3. Add up the 1's in each group

Map-Reduce Concept



The map-reduce computational model

- Map-reduce is a two-stage process with a "shuffle twist" between the stages.



- Stages are controlled by functions: mapper() , reducer()

The map-reduce computational model

- mapper() function:
  - Argument is one line of input from a file
  - Produces (key, value) pairs

- Example: word-count mapper()

"the cat in the hat"

--> [mapper for this line]

("the", "1"), ("cat", "1"), ("in", "1"),
("the", "1"), ("hat", "1")

The map-reduce computational model

- Shuffle stage:
  - group all mappers' (key, value) pairs together that have the same key, and feed each group to its own call of reduce()
  - Input: all (key,value) pairs from all mappers
  - Output: Those pairs rearranged, sent to calls of reduce() according to key

- Note: Shuffle also sorts (optimization)

The map-reduce computational model

- reducer() function:
  - Receives all key-value pairs for one key
  - Produces an aggregate result

- Example: word-count reducer()

("the", "1"), ("the", "1")
    -->
("the", "2")

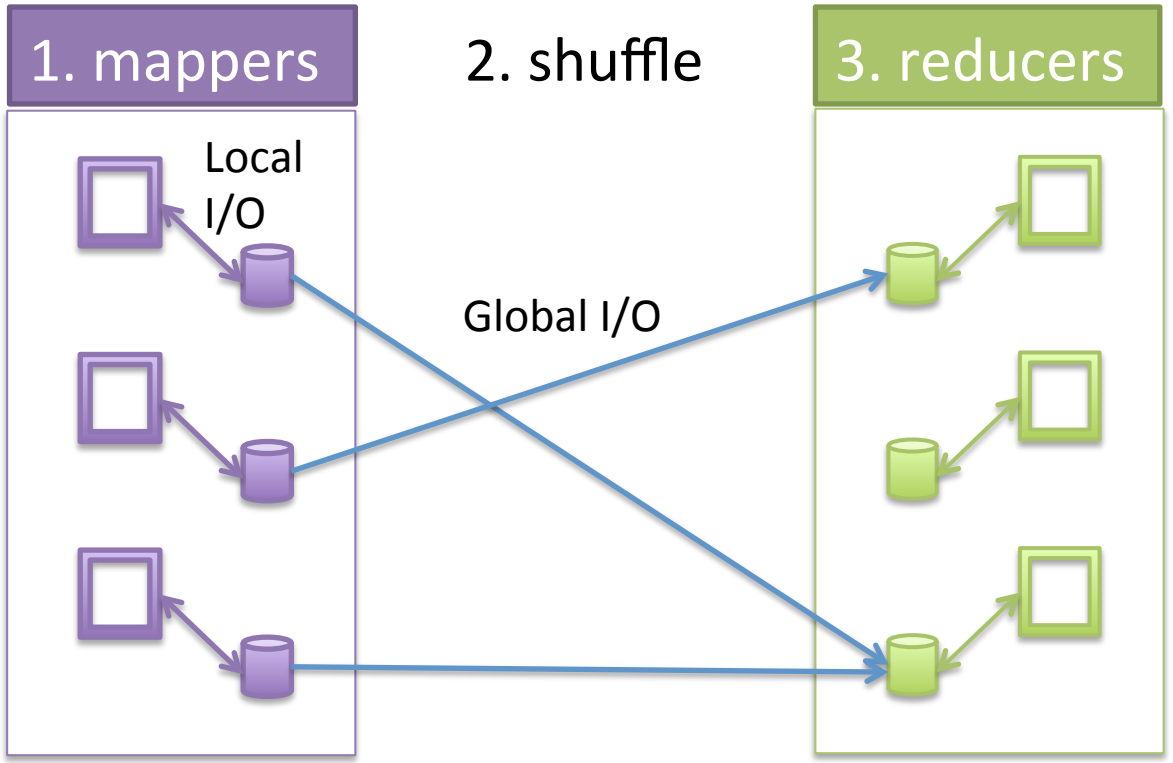
[reducer for "the"]

The map-reduce computational model

- In map-reduce, a programmer codes only two functions (plus config information)
  - A model for future parallel-programming frameworks
- Underlying map-reduce system reuses code for
  - Partitioning the data into chunks and lines,
  - Runs mappers/reducers where the chunks are *local*
  - Moving data between mappers and reducers
  - Auto-recovering from any crashes that may occur
  - …
- Optimized, Distributed, Fault-tolerant, Scalable

The map-reduce computational model

- Optimized, Distributed, Fault-tolerant, Scalable



Demo of WMR

cumulus.cs.stolaf.edu/wmr

Intro module

Materials available

- CSinParallel module: *Map-reduce Computing for Introductory Students using WebMapReduce*
  - See `csinparallel.org`

Overview of suggested exercises

Available on the csinparallel.org site

- Run word count (provided), with small and large data
- Modify, run variations on word count: strip punctuation; case insensitive; etc.

- Alternative exercises

Additional exercises

Beyond your first simple exercises, consider exploring the following:

- Various data sets
  - ***Note:*** *Please avoid large Gutenberg "groups" for this workshop*
- Extended set of exercises for CS1 (text analysis)

Hands-on exploration of WMR

Part 2: Teaching with WMR

Why map-reduce?

Why WMR?

Teaching WMR in CS1; in other courses

Why teach map-reduce?

Why map-reduce for teaching notions of parallelism/concurrency?

– Concepts:
  - data parallelism;
  - task parallelism;
  - locality;
  - effects of scale;
  - example effective parallel programming model;
  - distributed data with redundancy for fault tolerance; ...

Why map-reduce for teaching notions of parallelism/concurrency?

- Real-World: Hadoop widely used
- Exciting: the appeal of Google, Facebook, etc.
- Useful: for appropriate applications
- Powerful: scalability to large clusters, large data

Why WMR?

- Introduce concepts of parallelism
- Low bar for entry, feasible for CS1 (and beyond)
- Capture the imaginations of students

- Supports rapid introduction of concepts of parallelism for every CS student
  - Intro module designed for 1-3 days of class

WebMapReduce (WMR)

- Simplified web interface for Hadoop computations
- Goals:
  - Strategically Simple
    suitable for CS1, but not a toy
  - Configurable
    write mappers/reducers in any language
  - Accessible web application
  - Multi-platform, front-end and back-end

WMR Features (Briefly)

- Testing interface
  - Error feedback
  - Bypasses Hadoop -- small data only!
- Students enter the following information:
  - **choice of language**
  - data to process
  - definition of mapper in that language
  - definition of reducer in that language

WMR system information

– Languages currently supported:
  Java, C++, Python, Scheme, C, C#, Javascript
  - R coming soon

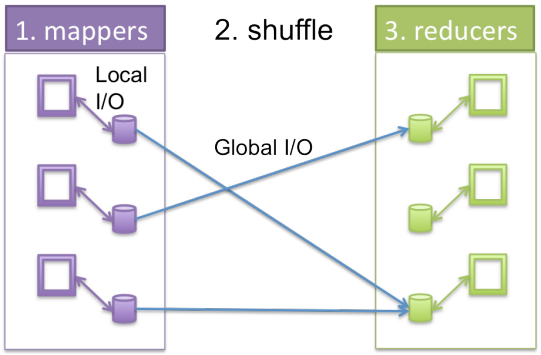
– Back ends to date:
  local cluster, Amazon EC2 cloud images
  - Version limits and more back ends coming soon

More details about the system in (optional) Part 3 of the workshop

Teaching map-reduce with WMR in the introductory sequence

Kinesthetic student activity

- Visualizations of map-reduce computations are enough for some students, but not all



- An **in-class activity** to act out the map/shuffle/reduce process helps others
- Also helpful: images of clusters; sequential versions; context of well-known web services

WMR in advanced courses

Example: PDC elective

- CS1 module
- Map-reduce programming techniques
  - Features of WMR
  - *Context forwarding*
  - *Structured values; structured keys*
  - *Multi-case mappers; multi-case reducers*
  - *Broadcasting data values*

Examples for Text Processing Techniques

- Combining data within a mapper
  - Mapper: Tally counts of words before sending to reducer
- Computational linguistics:
  - words that are co-located
    - Find and count pairs

      Example In: the cat in the cat hat

      Emits:

      1 cat|in
      1 in|the
      1 cat|hat
      2 the|cat
    - Use combining procedure to find 'stripes'

      Example In: the cat and the dog fought over the dog bone

      Emits: (the, {cat:1, dog:2}

Thanks to:

Data Intensive Text Processing, by Jimmy Lin and Chris Dyer

Application ideas

- Examples in the introductory module
- Big data sets people care about

- Especially for unstructured data
- Convenient for certain kinds of **projects**
  - E.g., most common medical terminology

WMR Hands-on, continued

Module exercises

Extended exercise set

Data sets available

/shared/MovieLens2/movieRatings

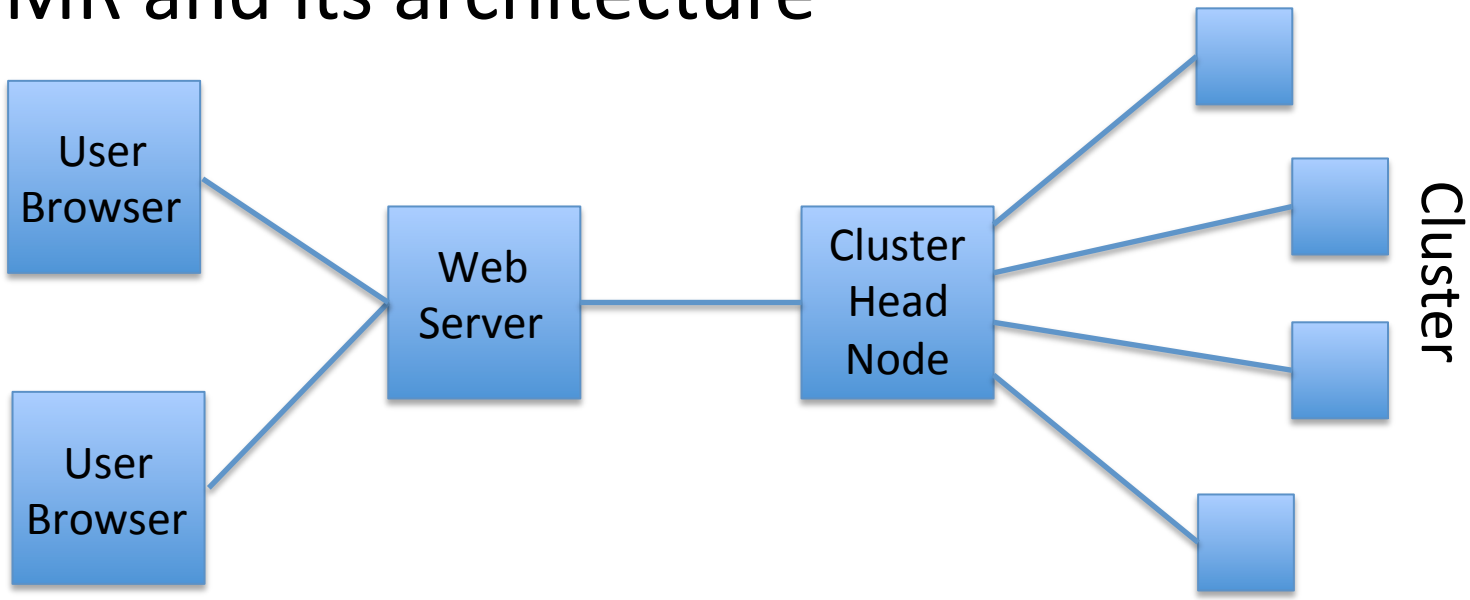
/shared/gutenberg/WarAndPeace.txt

/shared/gutenberg/CompleteShakespeare.txt

Part 3: What's under the hood

About WMR

- WMR and its architecture



- Obtaining and installing WMR
  - WebMapReduce.sf.com

Basic Hadoop components

- Internals:
  - Job management (per cluster)
  - Task management (per computation node)
- Some components visible to the user:
  - Hadoop API – Java, or arbitrary executables ("Streaming")
  - Hadoop Distributed File System (HDFS)
  - Support tools, including `hadoop` command
  - Limited job monitoring…

Goals

- Introduce map-reduce computing, using the *WebMapReduce (WMR)* simplified interface to Hadoop
  - Why use map-reduce in the curriculum?
- Hands-on exercises with WMR for foundation courses
- Use of WMR for intermediate and advanced courses
  - What's under the hood with WMR
  - A peek at Hadoop…
- Hands-on exercises for more advanced use

WMR in advanced courses

Inverting

"Chapter 1: Call me Ishmael. Some …"
"Chapter 2: I stuffed a shirt or two ..."
"Chapter 3: Entering that gable-ended ..."

--> [mapper]

("call", "1"), ("me", "1"), ..., ("i", "2"),
("stuffed", "2"), ..., ("entering", "3"), ...

--> [reducer]

"a" "1,1,1,1,...,2,2,2,..."
"aback" "3,7,7,8,..."
...

When is map-reduce appropriate?

- Massive, unstructured or irregularly structured "big data" (*Terascale* and upward)
  - Raw text
  - Web pages
  - XML
  - Unstructured streams of data
- Other approaches may fit structured "big data"
  - Scalable databases
  - Large-scale statistical approaches

Using Hadoop directly (Java)

WordCount.java example

Direct Hadoop Examples

- Word count
  - Java

Quick questions/comments so far?

Hands-on

Overview of suggested exercises

- Computations with MovieLens2 data; multiple map-reduce cycles
- Traffic data analysis
- Network analysis using Flixter data
- The Million Song dataset

Discussion

Evaluations!

Links at:

CSinParallel.org -> Workshops -> WMR Workshop

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Some considerations with Hadoop

- Numbers of mappers and reducers
- DFS
- Fault tolerance
- I/O formats

- Note: we have further slides with additional information about these aspects, for you to look at on your own.

Direct Hadoop exercise setup

- Edit your own files, locally
- scp to cluster's admin node (on cloud)
- ssh to compile, launch job
- Percentage progress output is provided
- Multiple cycle support via DFS
- (Cleanup)

Additional Details about Hadoop

The hadoop project documentation

- http://hadoop.apache.org/common/docs/current/index.html

How many mappers?

- The Hadoop Map/Reduce framework spawns one mapper task for each InputSplit generated by the InputFormat for the job.

- The number of mappers is usually driven by the total size of the inputs, that is, the total number of blocks of the input files.

How many reducers?

- The number of reducers for the job is set by the user via JobConf.setNumReduceTasks(int)

- The size of your eventual output may dictate how many reducers you choose.

HDFS

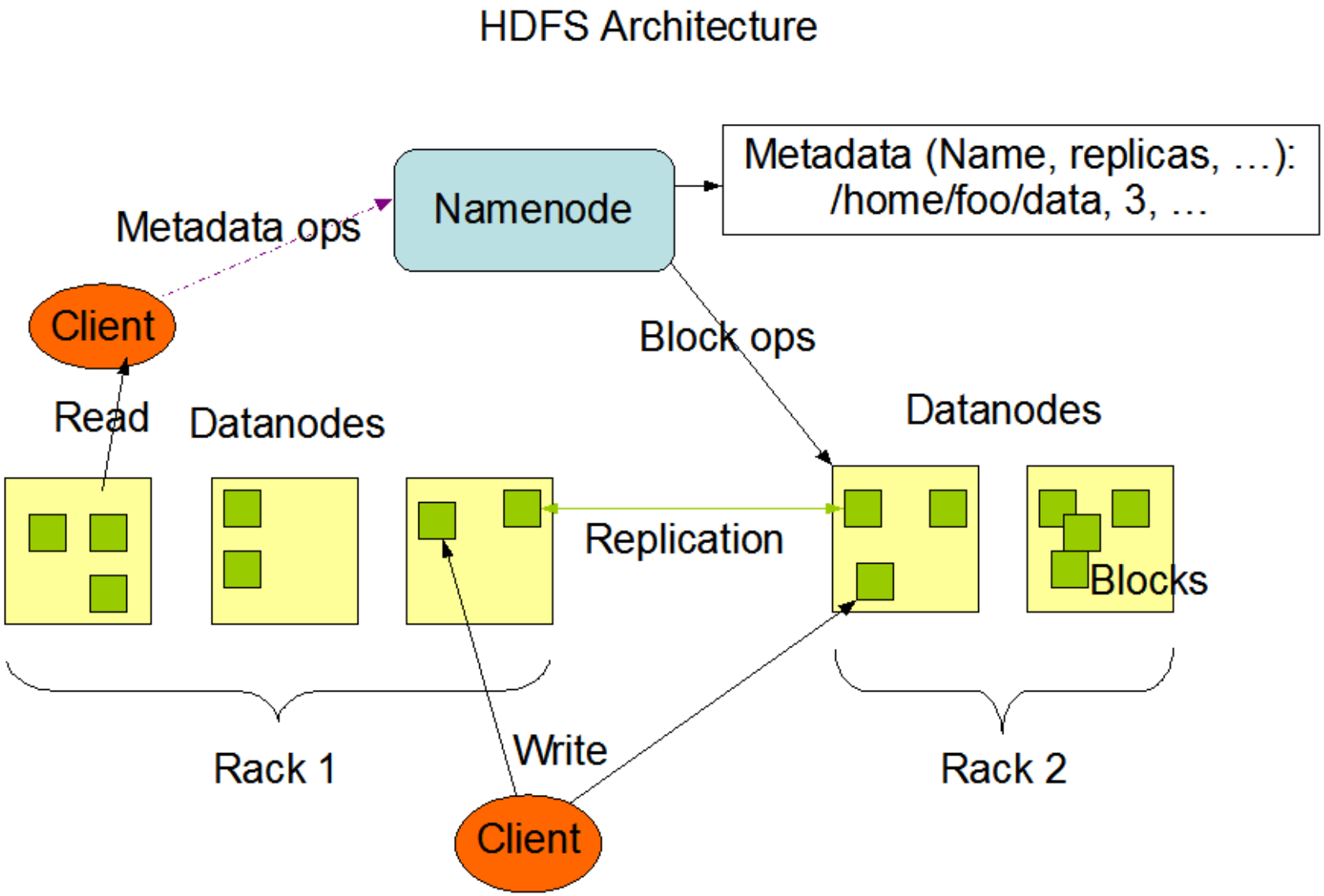
- Fault-tolerant distributed file system modeled after the Google File System
  - we've had students read the original GFS paper in an advanced course
- http://hadoop.apache.org/hdfs/docs/current/index.html
- Note the section about the file system commands you can run from the command line:

  hadoop fs -ls

  Hadoop fs -get or -put

HDFS Assumptions and Goals

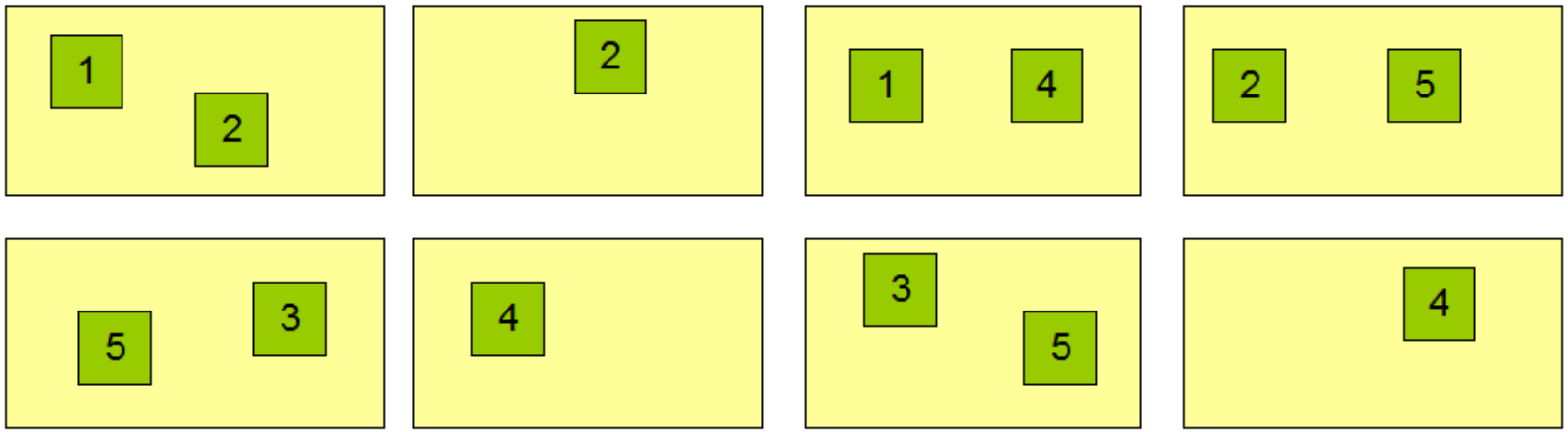
- Hardware failure
  - Hardware failure is the norm rather than the exception.
- Streaming data access
  - Applications that run on HDFS need streaming access to their data sets. They are not general purpose applications that typically run on general purpose file systems.
- Large Data Sets
- Simple coherency model
  - Read many, write once
- Moving computations is simpler than moving data
- Portability across various hardware/software


HDFS Architecture
Metadata ops
Namenode
Metadata (Name, replicas, …):
/home/foo/data, 3, …
Client
Block ops
Read
Datanodes
Datanodes
Replication
Blocks
Rack 1
Write
Rack 2
Client

Block Replication

Namenode (Filename, numReplicas, block-ids, …)
/users/sameerp/data/part-0, r:2, {1,3}, …
/users/sameerp/data/part-1, r:3, {2,4,5}, …

Datanodes



Input/Output formats

- Input into mappers are interpreted using classes implementing the interface InputFormat, and out put from reducers are implemented using classes implementing the interface OutputFormat.
- In WMR, the mapper input and reducer output is performed with key-value pairs. This corresponds to using the classes KeyValueTextInputFormat and TextOutputFormat.
- In direct Hadoop, the default input format is TextInputFormat, in which values are lines of the file and keys are positions within that file.

Some further features of Hadoop

- Combiner, an optimization: perform some "reduction" during the map phase, after mapper() and before shuffle
- Sorting control
  - Note: hard to sort on secondary key
- Three programming interfaces: Java; pipes (C++); streaming (executables)

Page rank algorithm ideas

- Original data: one web page per line
  - mapper produces ("dest", "1/k Pn") for each link in page Pn
    where k links appear within that page Pn

    reducer produces ("dest", "weight_0 P1 P2 P2 P3 P4 ...")
    where weight is sum of the weights from key value pairs emitted by P1, P2, ...
  - Subsequent mappers and reducers produce refined weights that take into account deeper chains of pages pointing to pages
  - Final reducer delivers ("dest", "weight_k") [drop Pns]