Distributed Data processing in a Cloud

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Desiderata

- **Operate scalably**
  - Petabytes of data on thousands on nodes
  - Much larger that RAM, disk I/O required
- **Operate economically**
  - Minimize $ spent on CPU cycles, disk, RAM, network
  - Lash thousands of commodity PCs into an effective compute and storage platform
- **Operate reliably**
  - In a large enough cluster something is always broken
  - Seamlessly protect user data and computations from hardware and software flakiness

Problem: bandwidth to data

- **Need to process 100TB datasets**
- **On 1000 node cluster reading from remote storage (on LAN)**
  - Scanning @ 10MB/s = 165 min
- **On 1000 node cluster reading from local storage**
  - Scanning @ 50-200MB/s = 33-8 min
- **Moving computation is more efficient than moving data**
  - Need visibility into data placement

Problem: scaling reliably is hard

- **Need to store petabytes of data**
  - On 1000s of nodes
  - MTBF < 1 day
  - With so many disks, nodes, switches something is always broken
- **Need fault tolerant store**
  - Handle hardware faults transparently and efficiently
  - Provide reasonable availability guarantees

Distributed File System

- **Fault tolerant, scalable, distributed storage system**
- **Designed to reliably store very large files across machines in a large cluster**
- **Common Namespace for the entire filesystem**
  - Distribute namespace for scalability and failover
- **Data Model**
  - Data is organized into files and directories
  - Files are divided into uniform sized blocks and distributed across cluster nodes
  - Replicate blocks to handle hardware failure
  - Checksums of data for corruption detection and recovery
  - Expose block placement so that computes can be migrated to data

Problem: seeks are expensive

- CPU & transfer speed, RAM & disk size double every 18-24 months
- Seek time nearly constant (~5%/year)
- Time to read entire drive is growing
- Moral: scalable computing must go at transfer rate

Two database paradigms: seek versus transfer

- **B-Tree (Relational Dbs)**
  - operate at seek rate, log(N) seeks/access
- **sort/merge flat files (MapReduce)**
  - operate at transfer rate, log(N) transfers/sort
- **Caveats:**
  - sort & merge is batch based
    - although possible to work around
  - other paradigms (memory, streaming, etc.)

Example: updating a terabyte DB

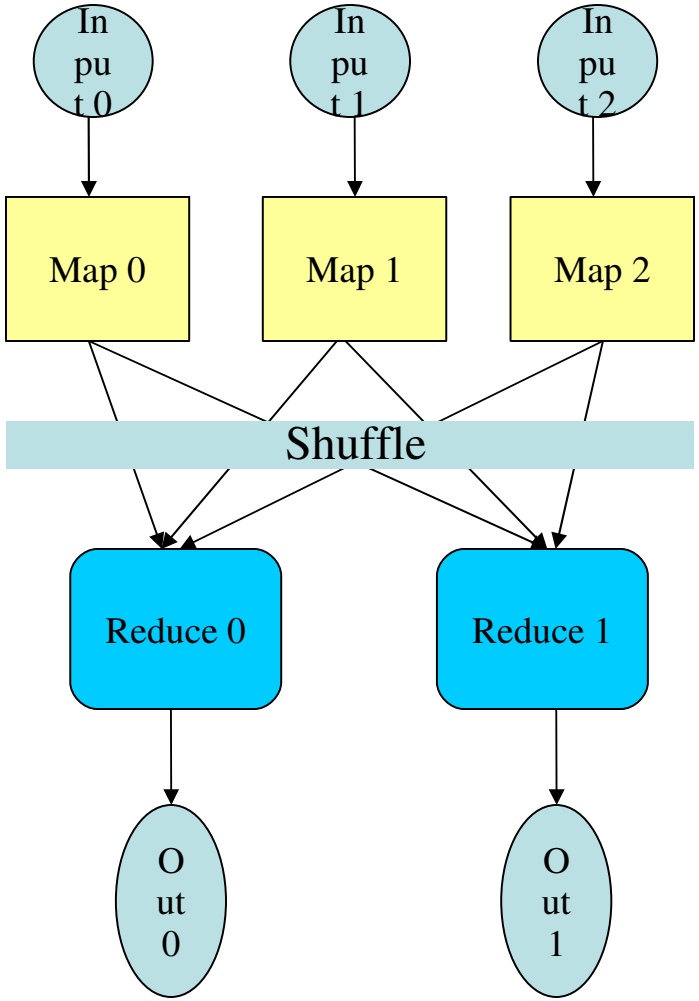
- **given:**
  - 10MB/s transfer
  - 10ms/seek
  - 100B/entry (10B entries)
  - 10kB/page (1B pages)
- **updating 1% of entries (100M) takes:**
  - 1000 days with random B-Tree updates
  - 100 days with batched B-Tree updates
  - 1 day with sort & merge

Map/Reduce: sort/merge based distributed processing

- **Best for batch-oriented processing**
- **Sort/merge is primitive**
  - Operates at transfer rate
- **Simple programming metaphor:**
  - input | map | shuffle | reduce > output
  - cat * | grep | sort | uniq -c > file
- **Pluggable user code runs in generic reusable framework**
  - A natural for log processing, great for most web search processing
  - A lot of SQL maps trivially to this construct (see PIG)
- **Distribution & reliability**
  - Handled by framework

Map/Reduce

- **Application writer specifies**
  - A pair of functions called *Map* and *Reduce* and a set of input files
- **Workflow**
  - *Input* phase generates a number of *FileSplits* from input files (one per Map task)
  - The *Map* phase executes a user function to transform input kv-pairs into a new set of kv-pairs
  - The framework sorts & *Shuffles* the kv-pairs to output nodes
  - The *Reduce* phase combines all kv-pairs with the same key into new kv-pairs
  - The output phase writes the resulting pairs to files
- **All phases are distributed with many tasks doing the work**
  - Framework handles scheduling of tasks on cluster
  - Framework handles recovery when a node fails



Map/Reduce features

- **Fine grained Map and Reduce tasks**
  - Improved load balancing
  - Faster recovery from failed tasks
- **Locality optimizations**
  - With big data, bandwidth to data is a problem
  - Map-Reduce + DFS is a very effective solution
  - Map-Reduce queries DFS for locations of input data
  - Map tasks are scheduled local to the inputs when possible
- **Re-execution and Speculative execution**
  - In a large cluster, some nodes are always slow or flaky
  - Introduces long tails or failures in computation
  - Framework re-executes failed jobs
  - Framework runs multiple instances of last few tasks and uses the ones that finish first

Map/Reduce: pros and cons

- **Developing large scale systems is expensive, this is a shared platform**
  - Reduces development and debug time
  - Leverages common optimizations, tools etc.
- **Not always a natural fit**
  - With moderate force, many things will fit
- **Not always optimal**
  - But not far off, and often cheaper in the end

Hadoop

- **Apache Software Foundation project**
  - Framework for running applications on large clusters of commodity hardware
  - Since we've convinced Doug Cutting to split Hadoop into a separate project, Yahoo! is the main contributor of source code to the infrastructure base.
  - A search startup has adapted Hadoop to run on Amazon's EC2 and S3, and has contributed hBase, a BigTable-like extension.
    - http://hadoop.apache.org/hbase/
- **Includes**
  - HDFS - a distributed filesystem
  - Map/Reduce - offline computing engine
  - Hbase – online data access
- **Still pre-1.0, but already used by many**
  - http://wiki.apache.org/hadoop/PoweredBy
  - alpha (0.16) release available for download
- **http://lucene.apache.org/hadoop**

Hadoop Map/Reduce architecture

- **Master-Slave architecture**
- **Map/Reduce Master "Jobtracker"**
  - Accepts MR jobs submitted by users
  - Assigns Map and Reduce tasks to Tasktrackers
  - Monitors task and tasktracker status, re-executes tasks upon failure
- **Map/Reduce Slaves "Tasktrackers"**
  - Run Map and Reduce tasks upon instruction from the Jobtracker
  - Manage storage and transmission of intermediate output

HDFS Architecture

- Master-Slave architecture
- DFS Master “Namenode”
  - Manages the filesystem namespace
  - Controls read/write access to files
  - Manages block replication
  - Checkpoints namespace and journals namespace changes for reliability
- DFS Slaves “Datanodes”
  - Serve read/write requests from clients
  - Perform replication tasks upon instruction by namenode

HDFS

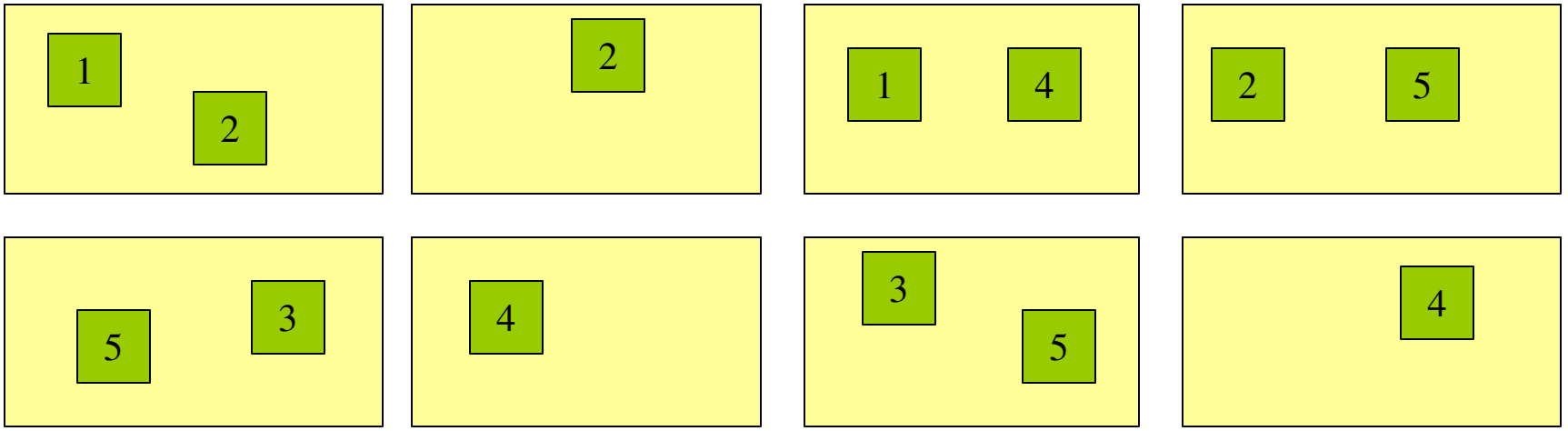
- **Notable differences from mainstream DFS work**
  - Single ‘storage + compute’ cluster vs. Separate clusters
  - Simple I/O centric API vs. Attempts at POSIX compliance
    - Not against POSIX but currently prioritizing scale and reliability

Block Placement

Namenode

name:/users/foo/myFile - copies:2, blocks:{1,3}
name:/users/bar/someData.gz, copies:3, blocks:{2,4,5}

Datanodes



HDFS API

- Most common file and directory operations supported:
  - Create, open, close, read, write, seek, tell, list, delete etc.
- Files are write once and have exclusively one writer
  - Append/truncate coming soon
- Some operations peculiar to HDFS:
  - set replication, get block locations
- Support for owners, permissions (v0.16)

HDFS command line utils

```
gritgw1004:/grid/0/tmp/rajive$ ls -lt
total 1300392
-rw-r--r-- 1 rajive users  244827000 Jan 20 05:02 1.5K-alice30.txt
-rw-r--r-- 1 rajive users    8160900 Jan 20 05:02 50-alice30.txt
-rw-r--r-- 1 rajive users 1077290150 Jan 20 04:58 part-00737
gritgw1004:/grid/0/tmp/rajive$ hadoop dfs -ls
Found 1 items
/user/rajive/rand0      <dir>           2008-01-20 05:00

gritgw1004:/grid/0/tmp/rajive$ hadoop dfs -ls /user/rajive
Found 5 items
/user/rajive/alice      <dir>           2008-01-20 05:15
/user/rajive/alice-1.5k <dir>           2008-01-20 05:20
/user/rajive/rand0      <dir>           2008-01-20 05:00

gritgw1004:/grid/0/tmp/rajive$ hadoop dfs -put 50-alice30.txt /user/rajive/alice

gritgw1004:/grid/0/tmp/rajive$ hadoop dfs -ls /user/rajive/alice
Found 1 items
/user/rajive/alice/50-alice30.txt       <r 3>   8160900 2008-01-20 05:05


gritgw1004:/grid/0/tmp/rajive$ hadoop dfs -cat /user/rajive/alice/50-alice30.txt
***This is the Project Gutenberg Etext of Alice in Wonderland***
*This 30th edition should be labeled alice30.txt or alice30.zip.
***This Edition Is Being Officially Released On March 8, 1994***
**In Celebration Of The 23rd Anniversary of Project Gutenberg***
```

HDFS UI

NameNode 'grit1002.yahooresearchcluster.com:8020'

Started:	Mon Jan 07 23:40:49 UTC 2008
Version:	0.15.1, r596497
Compiled:	Tue Nov 20 01:34:59 UTC 2007 by hadoopqa

Browse the filesystem

Cluster Summary

Capacity	:	953.86 TB
DFS Remaining	:	713.84 TB
DFS Used	:	11.21 TB
DFS Used%	:	1.18 %
Live Nodes	:	365
Dead Nodes	:	6

Live Datanodes : 365

Node	Last Contact	Admin State	Size (TB)	Used (%)	Used (%)	Remaining (TB)	Blocks
grit1007	0	In Service	2.61	0.75		1.97	488
grit1008	0	In Service	2.61	0.27		1.98	420
grit1009	0	In Service	2.61	0.69		1.97	519
grit1010	0	In Service	2.61	0.79		1.96	531
grit1011	0	In Service	2.61	0.28		1.98	664
grit1012	1	In Service	2.61	0.71		1.97	503
grit1013	0	In Service	2.61	0.68		1.97	479
grit1014	1	In Service	2.61	12.52		1.7	3065
grit1015	0	In Service	2.61	0.18		1.98	456
grit1016	1	In Service	2.61	0.79		1.96	549
grit1017	2	In Service	2.61	0.35		1.97	655
grit1018	0	In Service	2.61	0.75		1.97	562
grit1019	1	In Service	2.61	2.04		1.94	1056
grit1020	0	In Service	2.61	0.74		1.97	497
grit1022	1	In Service	2.61	0.78		1.96	530
grit1023	1	In Service	2.61	1.98		1.94	1061
grit1024	1	In Service	2.61	0.81		1.96	558
grit1025	2	In Service	2.61	0.37		1.97	729
grit1026	2	In Service	2.61	0.8		1.96	470
grit1027	2	In Service	2.61	0.84		1.96	516
grit1028	1	In Service	2.61	0.74		1.97	467
grit1029	1	In Service	2.61	0.79		1.96	525
grit1030	1	In Service	2.61	0.72		1.97	520

HDFS UI

Contents of directory /user/rajive

Goto : /user/rajive go

Go to parent directory

Name	Type	Size	Replication	Block Size	Modification Time
alice	dir				2008-01-20 05:15
alice-1.5k	dir				2008-01-20 05:20
rand0	dir				2008-01-20 05:00
wcout	dir				2008-01-20 05:17

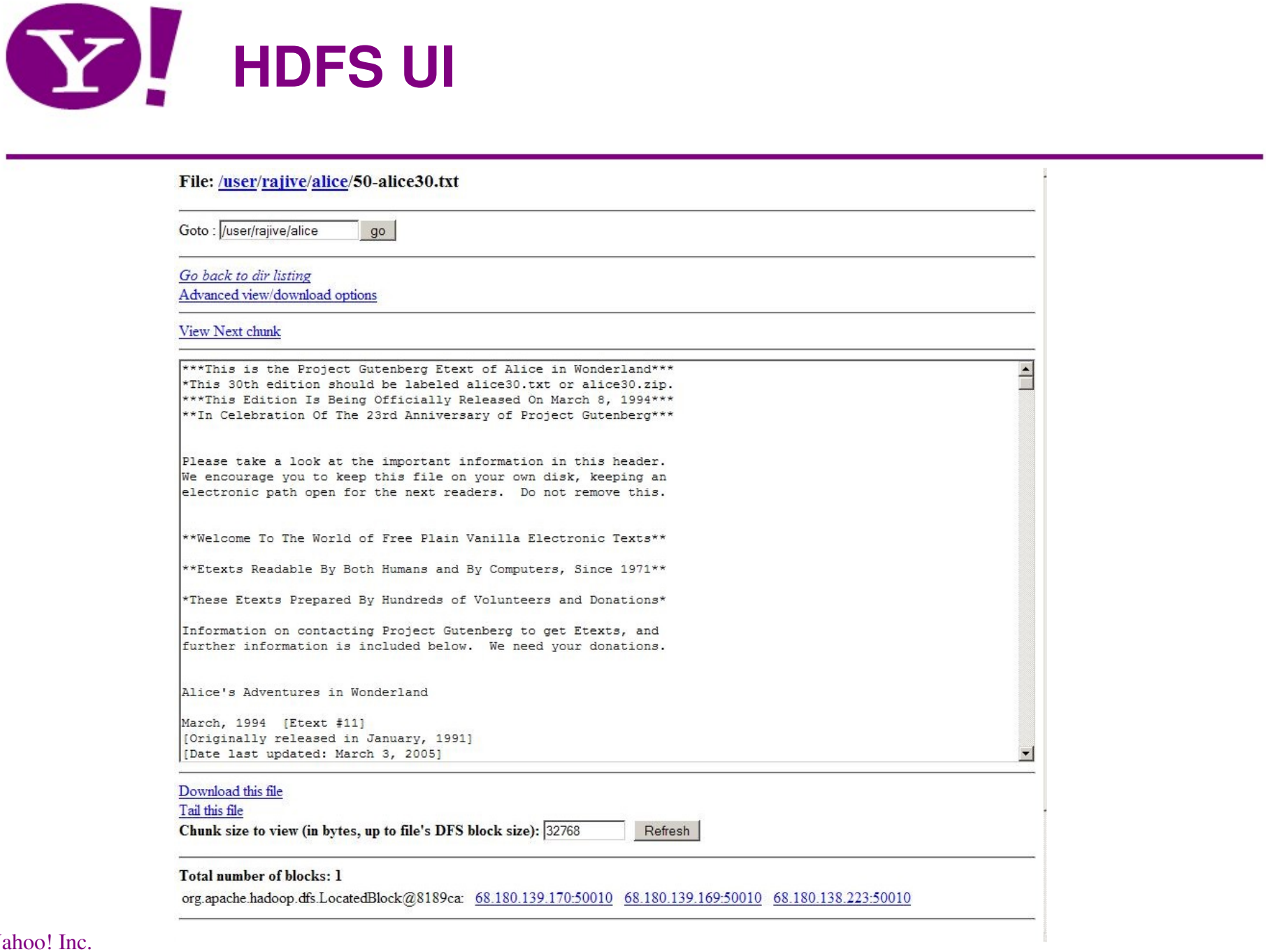
Go back to DFS home

Local logs

Log directory

Hadoop, 2007.

HDFS UI


File: /user/rajive/alice/50-alice30.txt
Goto : /user/rajive/alice go
Go back to dir listing
Advanced view/download options
View Next chunk
This is the Project Gutenberg Etext of Alice in Wonderland
*This 30th edition should be labeled alice30.txt or alice30.zip.
This Edition Is Being Officially Released On March 8, 1994
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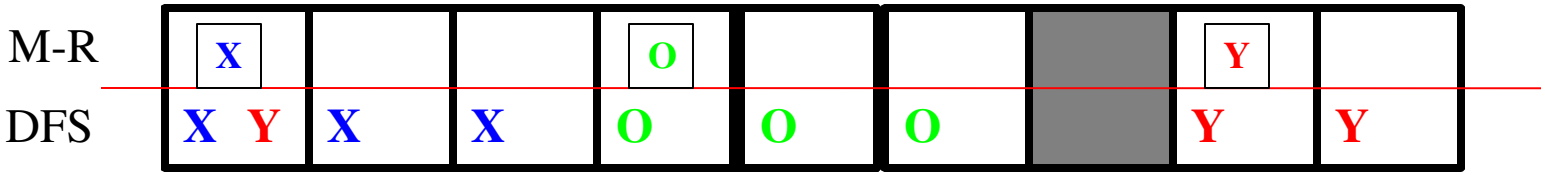
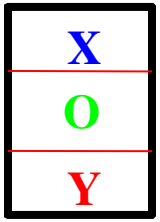
Alice's Adventures in Wonderland
March, 1994 [Etext #11]
[Originally released in January, 1991]
[Date last updated: March 3, 2005]
Download this file
Tail this file
Chunk size to view (in bytes, up to file's DFS block size): 32768 Refresh
Total number of blocks: 1
org.apache.hadoop.dfs.LocatedBlock@8189ca: 68.180.139.170:50010 68.180.139.169:50010 68.180.138.223:50010

Hadoop: Two Services in One

Cluster Nodes run both DFS and M-R
(taking computation to the data)



Input File
(128MB blocks)



HOD (Hadoop on Demand)

- **Map/Reduce is just one programming model**
- **Hadoop is not a resource manager or scheduler**
  - Most sites already have a deployed solution
- **HOD**
  - Bridge between Hadoop and resource managers
  - Currently supports Torque
  - Part of contrib in Hadoop 0.16 release
  - http://hadoop.apache.org/core/docs/current/hod.html

HOD: Provisioning Hadoop

- **Hadoop is submitted like any other job**
- **User specifies number of nodes desired**
- **HOD deals with allocation and setup**
  - Allocates requested nodes
  - Brings up Map/Reduce and (optionally) HDFS daemons
- **User submits Map/Reduce jobs**

HOD Benefits

- **Effective usage of the grid**
  - No need to do ‘social scheduling’
  - No need for static node allocation
- **Automated setup for Hadoop**
  - Users / Ops no longer need to know where and how to bring up daemons

Running Jobs

```
gritgw1004:/grid/0/tmp/rajive$ hod -m 5
HDFS UI on grit1002.yahooresearchcluster.com:50070
Mapred UI on grit1278.yahooresearchcluster.com:55118

Hadoop config file in: /grid/0/kryptonite/hod/tmp/hod-15575-tmp/hadoop-
   site.xml

allocation information:

      1 job tracker node
      4 task tracker nodes
      5 nodes in total


[hod] (rajive) >>
```

Running Jobs

```
[hod] (rajive) >> run jar /grid/0/hadoop/current/hadoop-examples.jar wordcount
    /user/rajive/alice-1.5k /user/rajive/wcout2
08/01/20 05:21:26 WARN mapred.JobConf: Deprecated resource 'mapred-default.xml' is being loaded, please discontinue its
    usage!
08/01/20 05:21:27 INFO mapred.FileInputFormat: Total input paths to process : 1
08/01/20 05:21:30 INFO mapred.JobClient: Running job: job_200801200511_0002
08/01/20 05:21:31 INFO mapred.JobClient:  map 0% reduce 0%
08/01/20 05:21:38 INFO mapred.JobClient:  map 3% reduce 0%
08/01/20 05:21:42 INFO mapred.JobClient:  map 12% reduce 0%
08/01/20 05:21:48 INFO mapred.JobClient:  map 20% reduce 0%
08/01/20 05:22:12 INFO mapred.JobClient:  map 27% reduce 0%
08/01/20 05:22:18 INFO mapred.JobClient:  map 37% reduce 0%
08/01/20 05:22:21 INFO mapred.JobClient:  map 41% reduce 0%
08/01/20 05:22:41 INFO mapred.JobClient:  map 45% reduce 0%
08/01/20 05:22:48 INFO mapred.JobClient:  map 54% reduce 0%
08/01/20 05:22:51 INFO mapred.JobClient:  map 59% reduce 0%
08/01/20 05:22:59 INFO mapred.JobClient:  map 62% reduce 0%
08/01/20 05:23:19 INFO mapred.JobClient:  map 71% reduce 0%
08/01/20 05:23:22 INFO mapred.JobClient:  map 76% reduce 0%
08/01/20 05:23:29 INFO mapred.JobClient:  map 83% reduce 0%
08/01/20 05:23:49 INFO mapred.JobClient:  map 88% reduce 0%
08/01/20 05:23:52 INFO mapred.JobClient:  map 93% reduce 0%
08/01/20 05:23:59 INFO mapred.JobClient:  map 100% reduce 0%
08/01/20 05:24:19 INFO mapred.JobClient:  map 100% reduce 100%
08/01/20 05:24:20 INFO mapred.JobClient: Job complete: job_200801200511_0002
08/01/20 05:24:20 INFO mapred.JobClient: Counters: 11
08/01/20 05:24:20 INFO mapred.JobClient:   Job Counters
08/01/20 05:24:20 INFO mapred.JobClient:     Launched map tasks=2
08/01/20 05:24:20 INFO mapred.JobClient:     Launched reduce tasks=1
08/01/20 05:24:20 INFO mapred.JobClient:   Map-Reduce Framework
08/01/20 05:24:20 INFO mapred.JobClient:     Map input records=5779500
08/01/20 05:24:20 INFO mapred.JobClient:     Map output records=42300000
08/01/20 05:24:20 INFO mapred.JobClient:     Map input bytes=244827000
08/01/20 05:24:20 INFO mapred.JobClient:     Map output bytes=398698500
08/01/20 05:24:20 INFO mapred.JobClient:     Combine input records=42300000
08/01/20 05:24:20 INFO mapred.JobClient:     Combine output records=59080
08/01/20 05:24:20 INFO mapred.JobClient:     Reduce input groups=5908
08/01/20 05:24:20 INFO mapred.JobClient:     Reduce input records=59080
08/01/20 05:24:20 INFO mapred.JobClient:     Reduce output records=5908

[hod] (rajive) >>
```

JobTracker UI

grit1278 Hadoop Map/Reduce Administration

State: RUNNING
Started: Sun Jan 20 05:11:29 UTC 2008
Version: 0.15.1, r596497
Compiled: Tue Nov 20 01:34:59 UTC 2007 by hadoopqa
Identifier: 200801200511

Cluster Summary

Maps	Reduces	Tasks/Node	Total Submissions	Nodes
2	0	2	1	4

Running Jobs

Running Jobs								
Jobid	User	Name	Map % Complete	Map Total	Maps Completed	Reduce % Complete	Reduce Total	Reduces Completed
job_200801200511_0001	rajive	wordcount	0.00%	2	0	0.00%	1	0

Completed Jobs

Completed Jobs
none

Failed Jobs

Failed Jobs
none

Local logs

Log directory, Job Tracker History

Hadoop, 2007.

JobTracker UI

Hadoop job_200801200511_0002 on grit1278

User: rajive
Job Name: wordcount
Job File: /mapredsystem/grit1278.yahooresearchcluster.com/job_200801200511_0002/job.xml
Status: Succeeded
Started at: Sun Jan 20 05:21:30 UTC 2008
Finished at: Sun Jan 20 05:24:19 UTC 2008
Finished in: 2mins, 48sec

Kind	% Complete	Num Tasks	Pending	Running	Complete	Killed	Failed/Killed Task Attempts
map	100.00%	2	0	0	2	0	0 / 0
reduce	100.00%	1	0	0	1	0	0 / 0

	Counter	Map	Reduce	Total
Job Counters	Launched map tasks	0	0	2
	Launched reduce tasks	0	0	1
Map-Reduce Framework	Map input records	5,779,500	0	5,779,500
	Map output records	42,300,000	0	42,300,000
	Map input bytes	244,827,000	0	244,827,000
	Map output bytes	398,698,500	0	398,698,500
	Combine input records	42,300,000	0	42,300,000
	Combine output records	59,080	0	59,080
	Reduce input groups	0	5,908	5,908
	Reduce input records	0	59,080	59,080
	Reduce output records	0	5,908	5,908

Thank you

- Questions?

- Hadoop: http://hadoop.apache.org
- Blog http://developer.yahoo.com/blogs/hadoop
- This presentation: http://public.yahoo.com/rajive/isec2008.pdf
- email: *rajive@yahoo-inc.com*