Theia: Visual Signatures for Problem Diagnosis in Large Hadoop Clusters
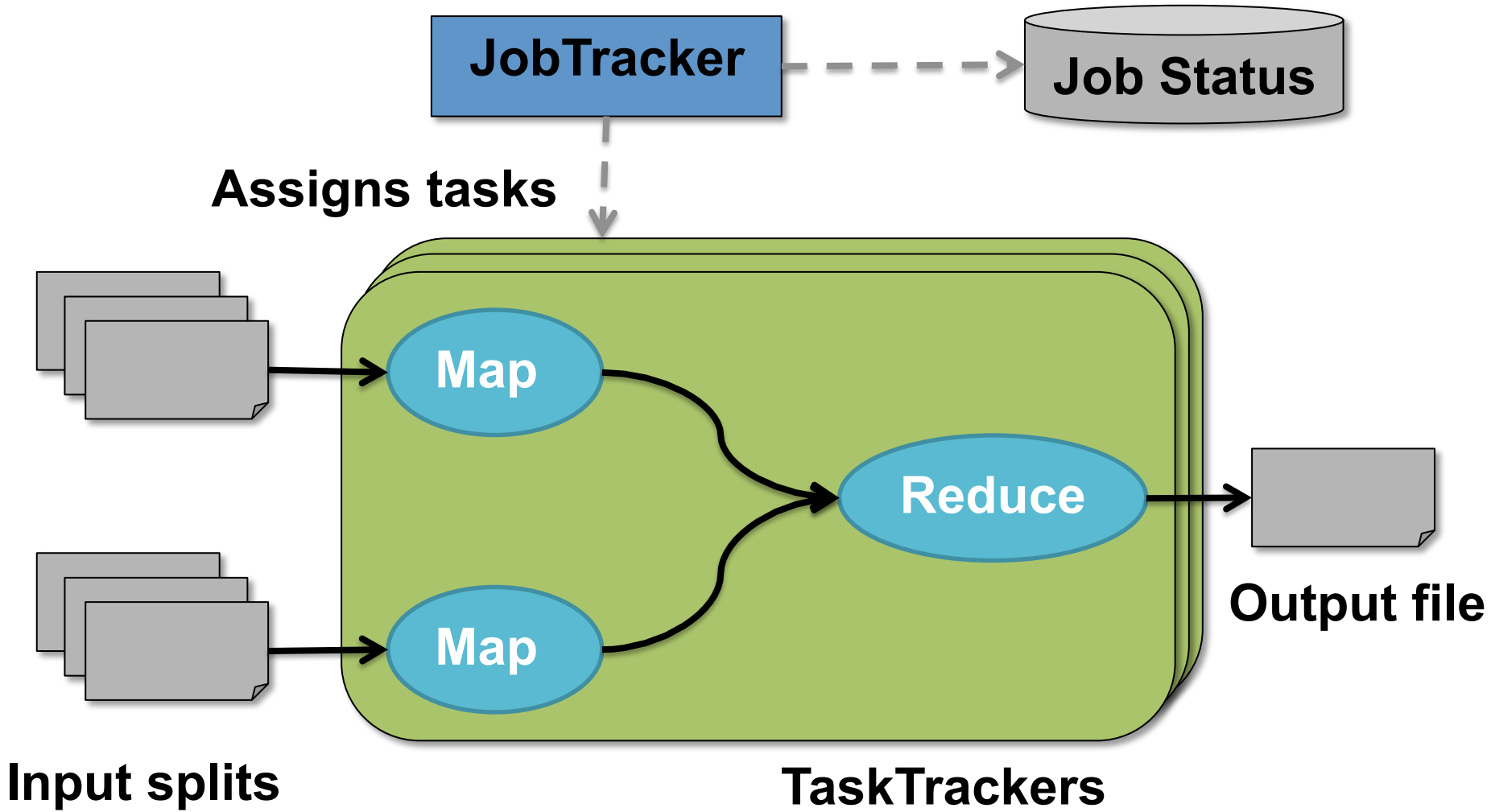
Elmer Garduno, **Soila P. Kavulya**, Jiaqi Tan, Rajeev Gandhi, Priya Narasimhan

Motivation

- Hadoop: Open-source MapReduce framework
  - MapReduce is popular for data-intensive computing
  - 100+ companies powered by Hadoop
    - Yahoo, Facebook, Hulu, …

- Problem diagnosis in Hadoop is challenging
  - Overwhelming volume of monitoring data
  - Complex component interactions obscure root-cause

Goal: Generate visualizations that aid diagnosis

Soila P. Kavulya © Dec12

Background: Hadoop MapReduce

JobTracker

Job Status

Assigns tasks

Map

Map

Reduce

Output file

Input splits
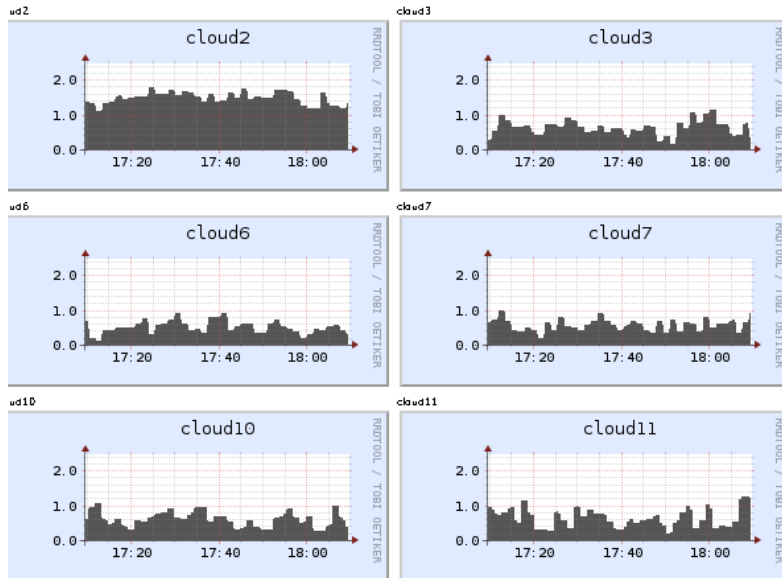
TaskTrackers

OpenCloud Cluster

- OpenCloud: Cluster for data-intensive research
  - 64-nodes worker nodes
  - Each node has 8 cores, 16 GB DRAM,
    4 1TB disks and 10GbE connectivity

- Users are researchers familiar with Hadoop
  - Run diverse kinds of real workloads
    - Graph mining, natural language processing, …

- Tools available for diagnosis
  - Hadoop web console and Ganglia
  - Sysadmins also use Nagios to receive alerts

Carnegie
Mellon
University
Intel Science & Technology
Center for Cloud Computing

Soila P. Kavulya © Dec12

Shortcomings of Current Tools

Ganglia

Large number of monitoring panels can overwhelm user

Hadoop Web Console

Large number of tasks/jobs --- need to click through multiple screens to troubleshoot problem

What Do Users Want?

Users want to distinguish between*:

1. **Problems due to their job**
   - Software bugs, job misconfigurations
   - Legitimately slow tasks due to data skew
   - *Action:* Fix themselves

2. **Problems due to infrastructure**
   - Resource contention
   - Hardware failures
   - *Action:* Report to sysadmins

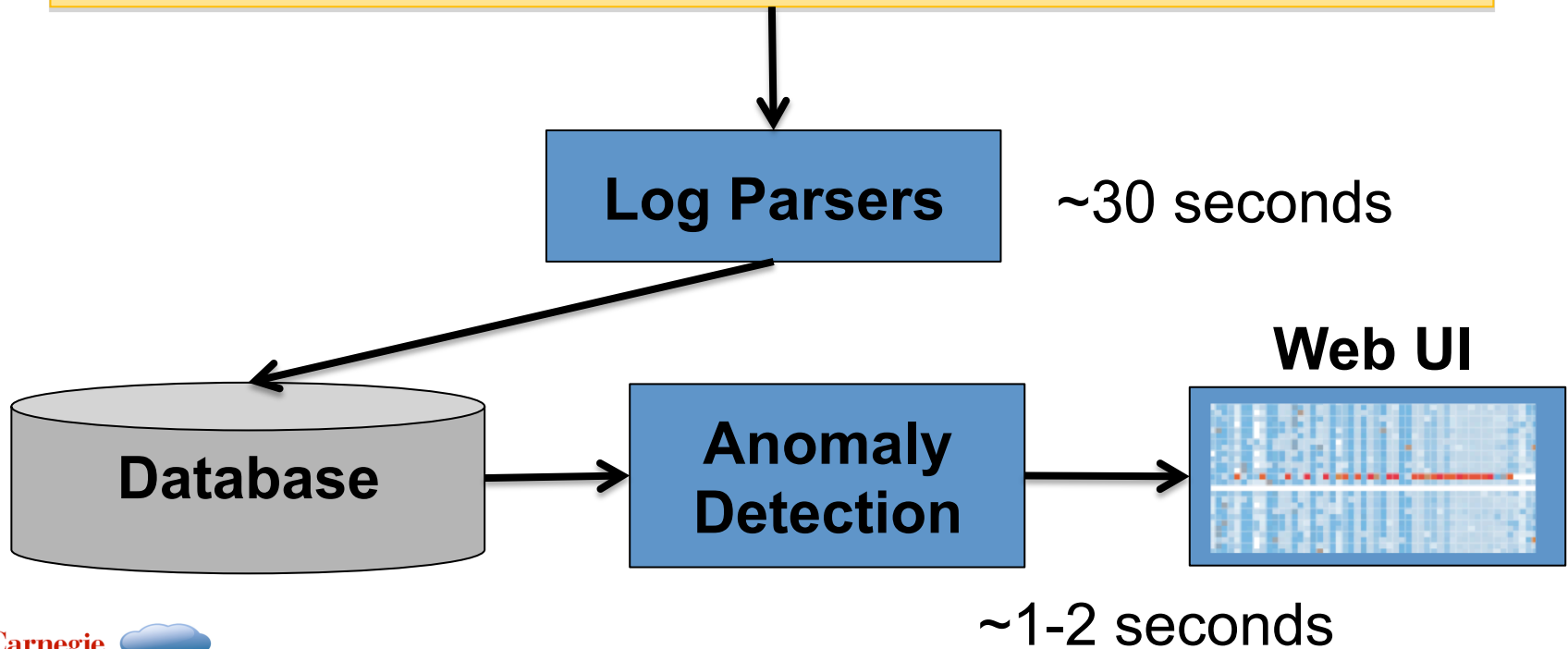*Results from user study published in CHIMIT 2011*

Theia: Visualization Tool

- Visualizes anomalies in Hadoop clusters
  - Maps anomalies observed to broad problem classes
  - i,e., hardware failures, application issue, data skew

- Interactive interface supports data exploration
  - Users drill-down from cluster- to job-level displays
  - Hovering over the visualization gives more context

- Compact representation for scalability
  - Can support clusters with 100s of nodes

Theia Implementation

Job History Logs (100-300MB/day)

TASK_TYPE=*"REDUCE"* TASKID=*"X"*

TASK_STATUS=*"SUCCESS"* HOSTNAME=*node32*

COUNTERS= [(FILE_BYTES_READ)*(229524)*] ….

Log Parsers   ~30 seconds

Database → **Anomaly Detection** → **Web UI**

~1-2 seconds

Carnegie Mellon University
Intel Science & Technology
Center for Cloud Computing

Quantifying Anomalies

- Hadoop balances load across nodes in cluster
  - Typically, tasks in a job perform similarly
  - Significant deviations may signal problems

- Indicators of anomalous behavior used by Theia
  - Large task duration
  - Large deviations in data processed (data skew)
  - Large task failure rates

- Quantify anomalies using z-score
  - Deviation of each observation from the mean
  - Normalized by standard deviation

$$z = \frac{x - \mu}{\sigma}$$

Soila P. Kavulya © Dec12

Heuristics for Visual Signatures

Mapping anomalies to problem classes

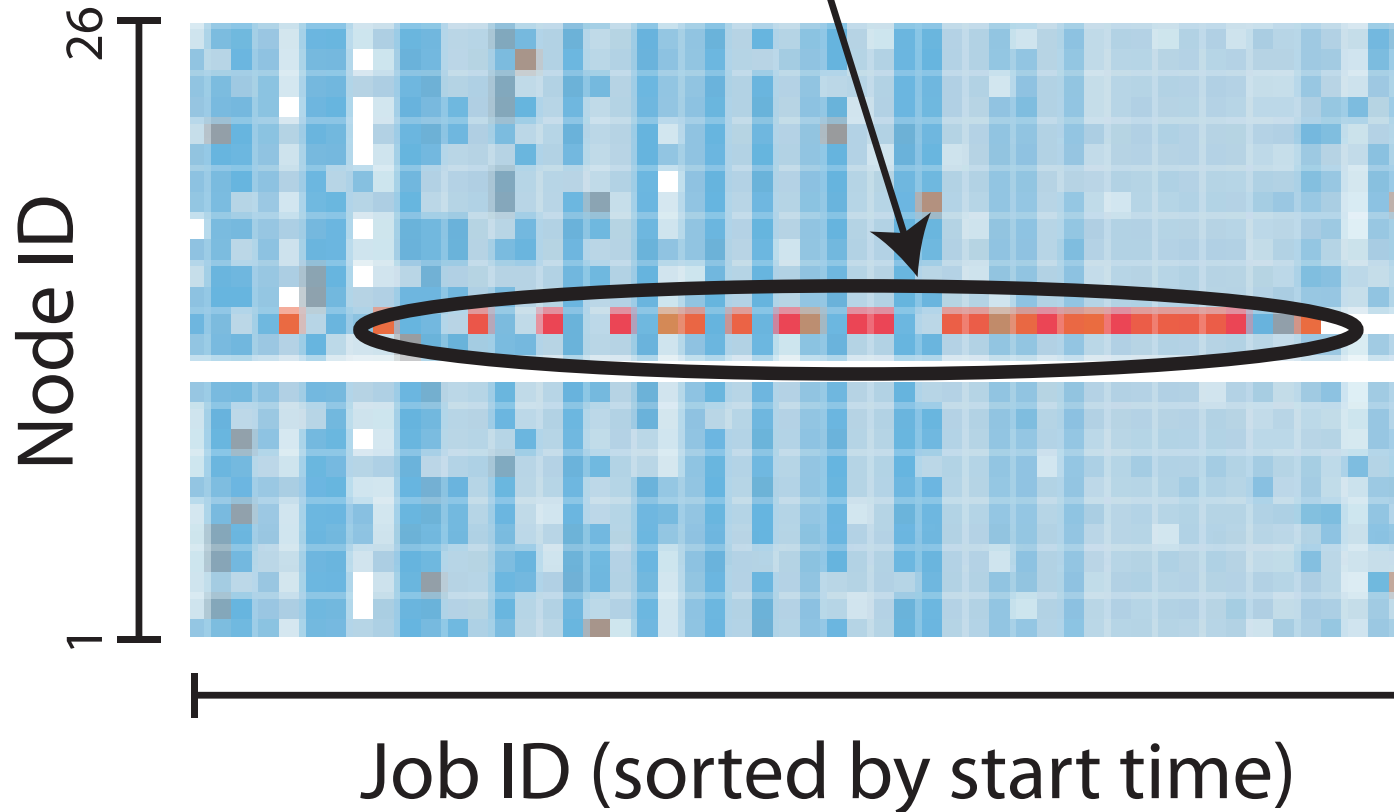|	Application Problem	Infrastructural Problem
Time	*Single* user/job over time	*Multiple* users/jobs over time
Space	Span **multiple nodes**	Affects **single node**, but correlated failures also occur
Value	Slow/failed tasks, or data skew	Slow/failed tasks

Types of Visualizations in Theia

- Anomaly heatmap
  - Visualizes cluster-level anomalies
  - High density overview of nodes in the cluster

- Job execution stream
  - Visualizes job-level anomalies
  - Compact view of aggregate job performance

- Job execution detail
  - Visualizes job-level anomalies
  - Detailed view of job progress over time

Anomaly Heatmap

- ## High density overview of cluster performance
  - Summarizes job performance across nodes
  - Uses color variations to visualize anomalies

- ## Compact representation supports scale
  - Uses 2x2 pixels to represent job/node
  - Fits 1200 jobs x 700 nodes on a 27-inch display

- ## Best-suited for visualizing
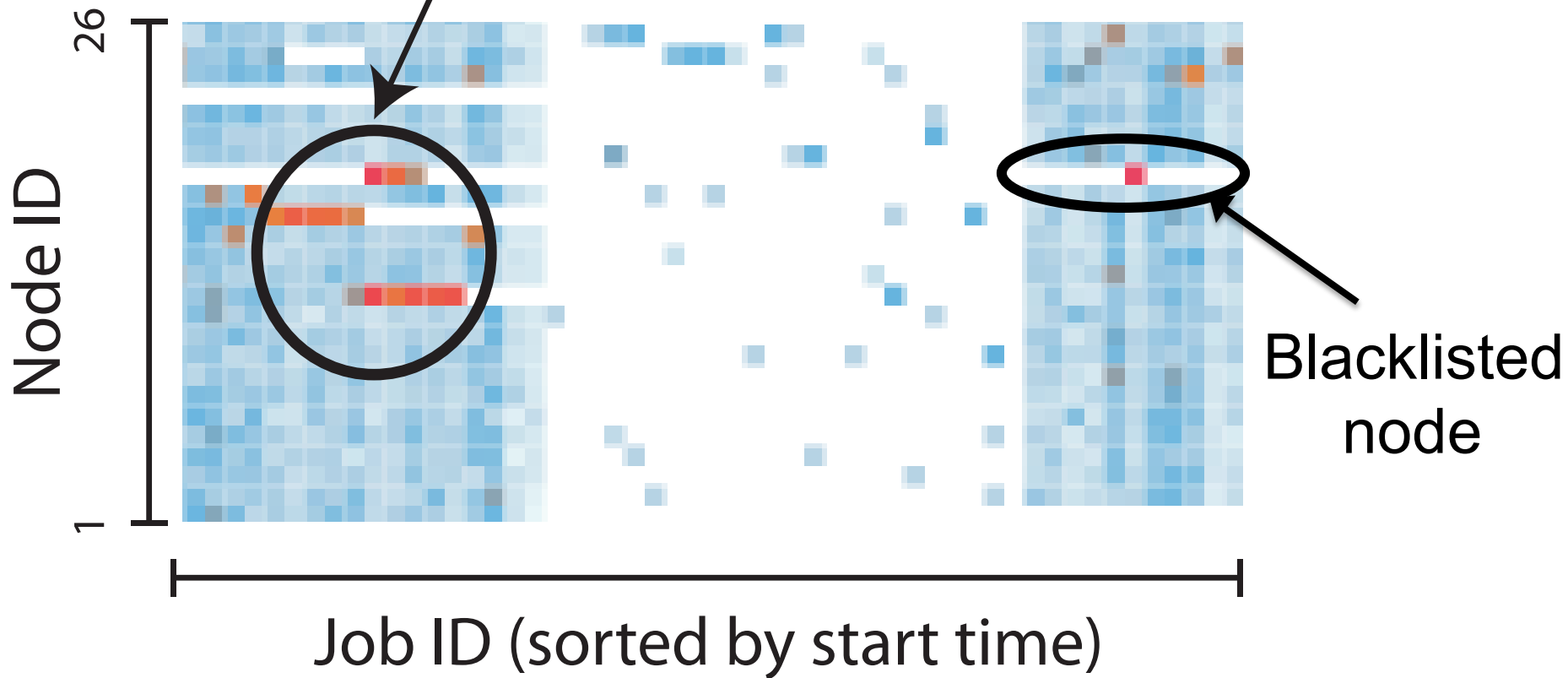 - Infrastructural problems

Carnegie Mellon University
Intel Science & Technology Center for Cloud Computing

Heatmap of Hardware Problem

Performance degradation due to failing disk

Node ID

26

1

Job ID (sorted by start time)

Heatmap of Application Problem

Resource contention due to buggy job

Blacklisted node

Node ID

26

1

Job ID (sorted by start time)

Carnegie Mellon University
Intel Science & Technology Center for Cloud Computing

Job Execution Stream

- Visualizes per-job performance across nodes
  - Scrollable stream of jobs sorted by start time
  - Displays performance of Map and Reduce phases
  - Uses color variations to visualize anomalies

- Shows job execution trace in context
  - Job name, duration, and status
  - Task failure rates
  - Task duration anomalies

- Best-suited for detecting application problems
  - Software bugs, data skew

Soila P. Kavulya © Dec12

Job Execution Stream

Job_9438/HALFCAMS_kmeans_iteration_0 – **SUCCESS**
21:54:47 / 0h 5m 44s / Oct 10
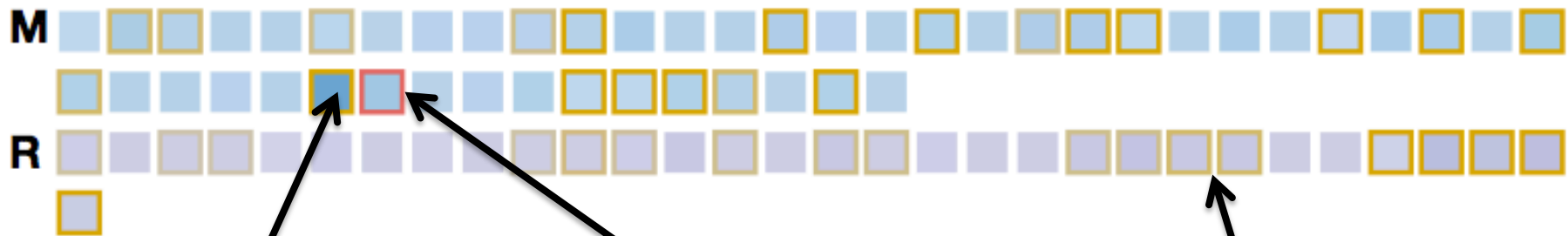
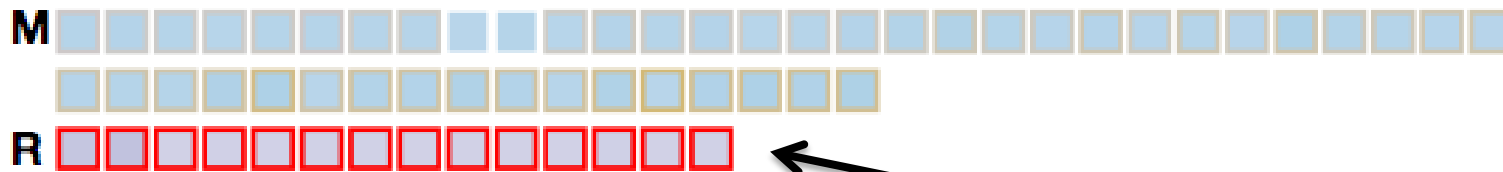Darker colored squares indicate anomalous task durations

Red borders indicate failed tasks

Yellow borders indicate speculative tasks were killed

Carnegie Mellon University Intel Science & Technology Center for Cloud Computing

Visualizing Application Problems

job_9035 / depParseFeatExtract -- FAILED

08:57:16 / 0h 6m 41s / Oct-06

Bug in reduce phase indicated by failed tasks

job_9146 / DocPerLineSentenceExtractor -- SUCCESS

20:25:39 / 0h 17m 36s / Oct-07

Performance degradation due to data skew

Soila P. Kavulya © Dec12

Job Execution Detail

- Detailed view of task execution
  - Less compact than job execution stream
  - Displays progress of job (using color variation)
  - Displays volume of I/O (using size variation)

- Best-suited for detecting application problems
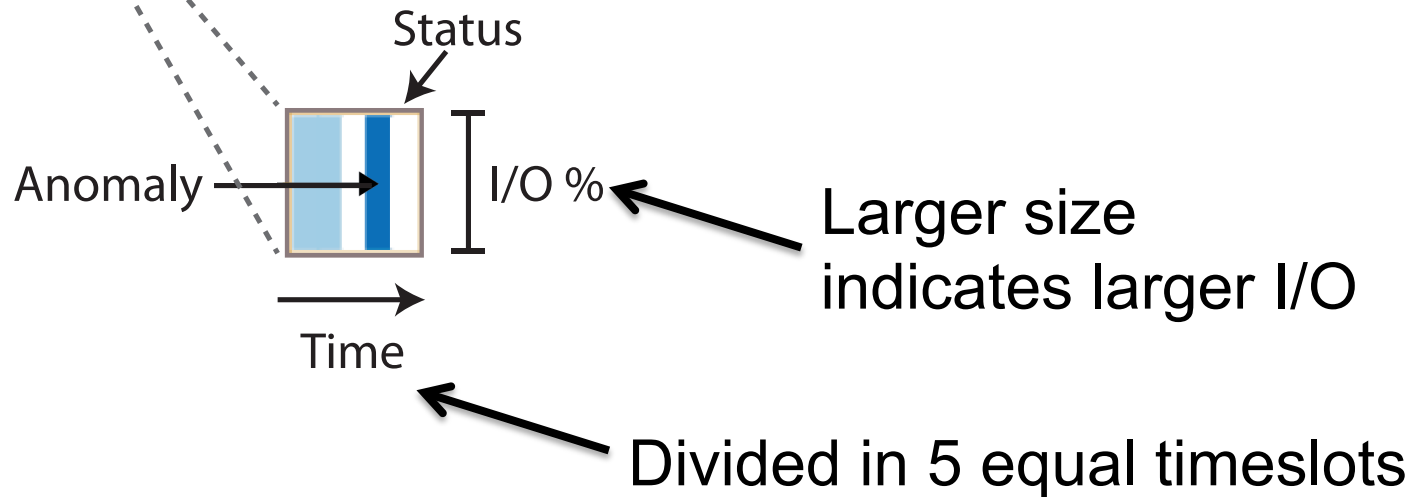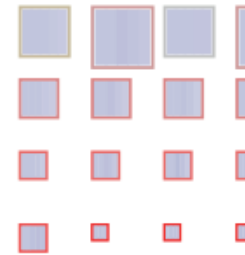 - Software bugs, data skew

Job Execution Detail

job_9036 / depParseFeatExtract -- SUCCESS
09:06:48 / 0h 1m 32s / Oct -10

Maps

Reduces

Status

Anomaly

I/O %

Larger size
indicates larger I/O

Time
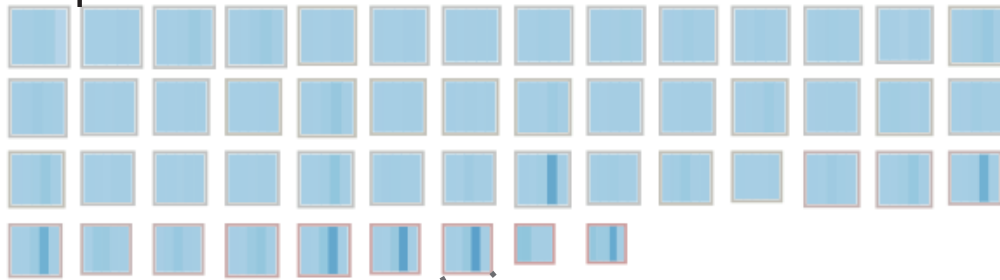
Divided in 5 equal timeslots

Data Skew in Job

job_9146 /

DocPerLineSentenceExtractor -- SUCCESS

20:25:39 / 0h 17m 36s / Oct -07

Maps

Imbalanced workload due to data skew

Soila P. Kavulya © Dec12
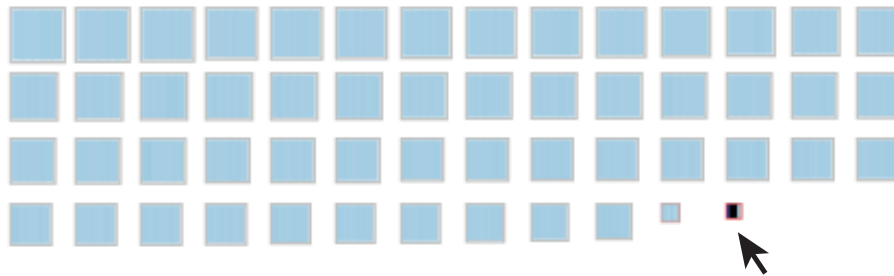
Bad NIC Degrades Performance

job_9627 /
RandomShuffle -- KILLED
06:28:29 / 0h 20m 57s / Oct -09
Maps

Node: nodeX
Successful Tasks: 6
Failed Tasks: 6
Failure Ratio: 0.5
Total I/0: 490 MB
Total Time: 0h 23m 28s

Evaluation of Tool

- Analyzed one-month of data on OpenCloud
  - 1,373 jobs comprising of ~1.83 million tasks
  - Manually identified 157 application problems and 2 data skews

- 45 hardware failures identified by sysadmins
  - 42 disk controller failures
  - 2 full hard drive failures
  - 1 network interface controller (NIC) failure

- Evaluated performance by manually verifying that visualizations matched our heuristics

Performance of Visualizations

Type	Total	Heatmap	Job Execution Stream
Application problem	157	0	157
Infrastructural problem	45	33	10
Data skew	2	2	2

Soila P. Kavulya © Dec12

Conclusion

- Theia: Visualizations for Hadoop
  - Compact, interactive visualizations of job behavior
  - Distinguishes h/w failures, s/w bugs, and data skew
  - Evaluated on real incidents in Hadoop cluster
- Next steps
  - Deploy on production cluster
  - User study
    - Evaluate the effectiveness of our UI for diagnosis

Questions?

Problem Diagnosis Website
http://www.ece.cmu.edu/~fingerpointing/

Related Work

- [Mochi2009] J. Tan, X. Pan, S. Kavulya, R. Gandhi, and P. Narasimhan, "***Mochi: visual log-analysis based tools for debugging Hadoop***," Proceedings of the 2009 conference on Hot topics in cloud computing, ser. HotCloud'09, 2009

- [CHIMIT2011] J. D. Campbell, A. B. Ganesan, B. Gotow, S. P. Kavulya, J. Mulholland, P. Narasimhan, S. Ramasubramanian, M. Shuster, and J. Tan, "***Understanding and improving the diagnostic workflow of MapReduce users***," ACM Symposium on Computer Human Interaction for Management of Information Technology (CHIMIT), 2011

- [Tufte2001] E. R. Tufte, "***The Visual Display of Quantitative Information***", 2nd ed. Graphics Pr., May 2001

- [Bostock2011] M. Bostock, V. Ogievetsky, and J. Heer, "***D3: Data-Driven documents***," IEEE Trans. Visualization & Comp. Graphics (Proc. InfoVis), 2011.

Soila P. Kavulya © Dec12