Mesos and Borg and Kubernetes Lecture 13, cs262a

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UC Berkeley
March 5, 2018

Today's Papers

Mesos: A Platform for Fine-Grained Resource Sharing in the Data Center,

Benjamin Hindman, Andy Konwinski, Matei Zaharia,

Ali Ghodsi, Anthony D. Joseph, Randy Katz, Scott Shenker, Ion Stoica, NSDI'11

https://people.eecs.berkeley.edu/~alig/papers/mesos.pdf

Large-scale cluster management at Google with Borg,

Abhishek Verma, Luis Pedrosa, Madhukar R. Korupolu, David Oppenheimer, Eric Tune, John Wilkes, EuroSys'15

http://static.googleusercontent.com/media/research.google.com/en//pubs/archive/43438.pdf

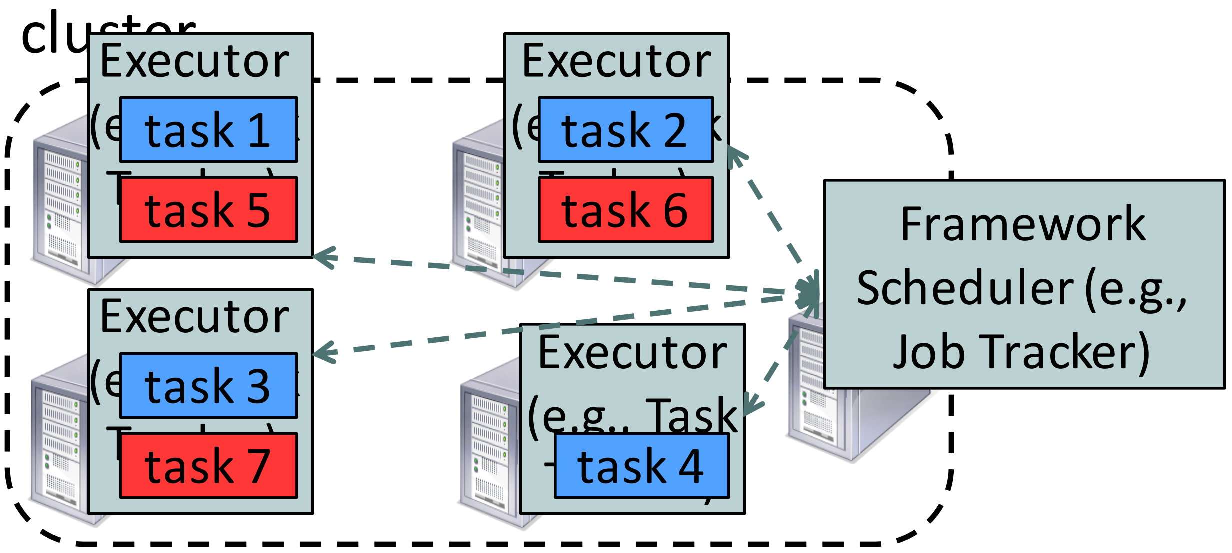
Motivation

- Rapid innovation in cloud computing

- Today
  - No single framework optimal for all applications
  - Each framework runs on its dedicated cluster or cluster partition

Computation Model: Frameworks

- A ***framework*** (e.g., Hadoop, MPI) manages one or more ***jobs*** in a computer cluster
- A ***job*** consists of one or more ***tasks***
- A ***task*** (e.g., map, reduce) is implemented by one or more processes running on a single machine

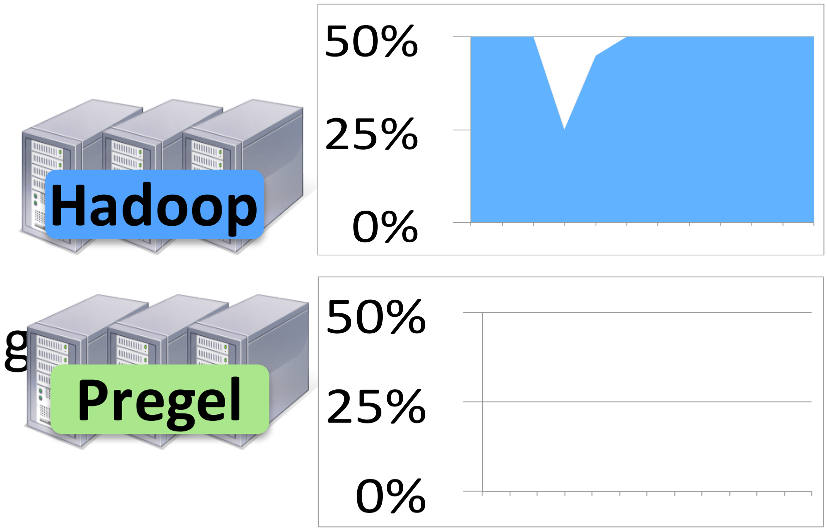


Job 1: tasks 1, 2, 3, 4

Job 2: tasks 5, 6, 7

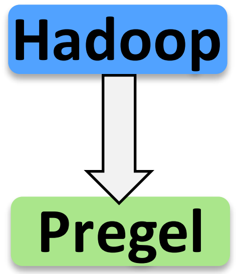
One Framework Per Cluster Challenges

- Inefficient resource usage
  - E.g., Hadoop cannot use available resources from Pregel's cluster
  - No opportunity for stat. multiplexing



- Hard to share data
  - Copy or access remotely, expensive

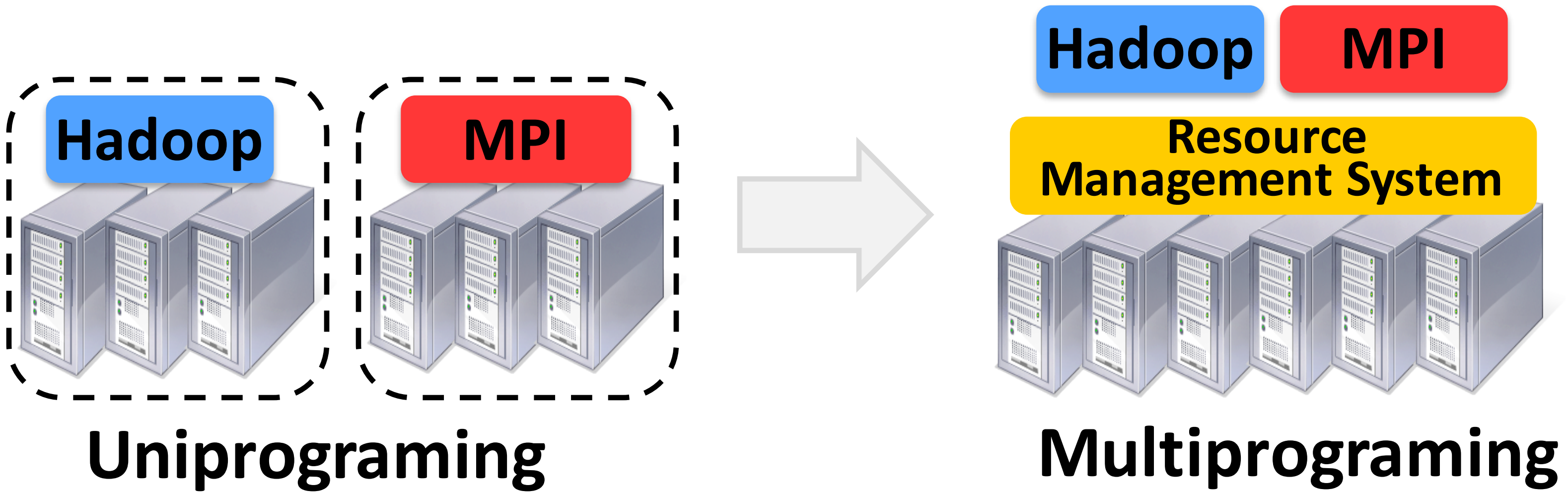
- Hard to cooperate
  - E.g., Not easy for Pregel to use graphs generated by Hadoop



Need to run multiple frameworks on same cluster

What do we want?

- Common resource sharing layer
  - Abstracts ("virtualizes") resources to frameworks
  - Enable diverse frameworks to share cluster
  - Make it easier to develop and deploy new frameworks (e.g., Spark)



Fine Grained Resource Sharing

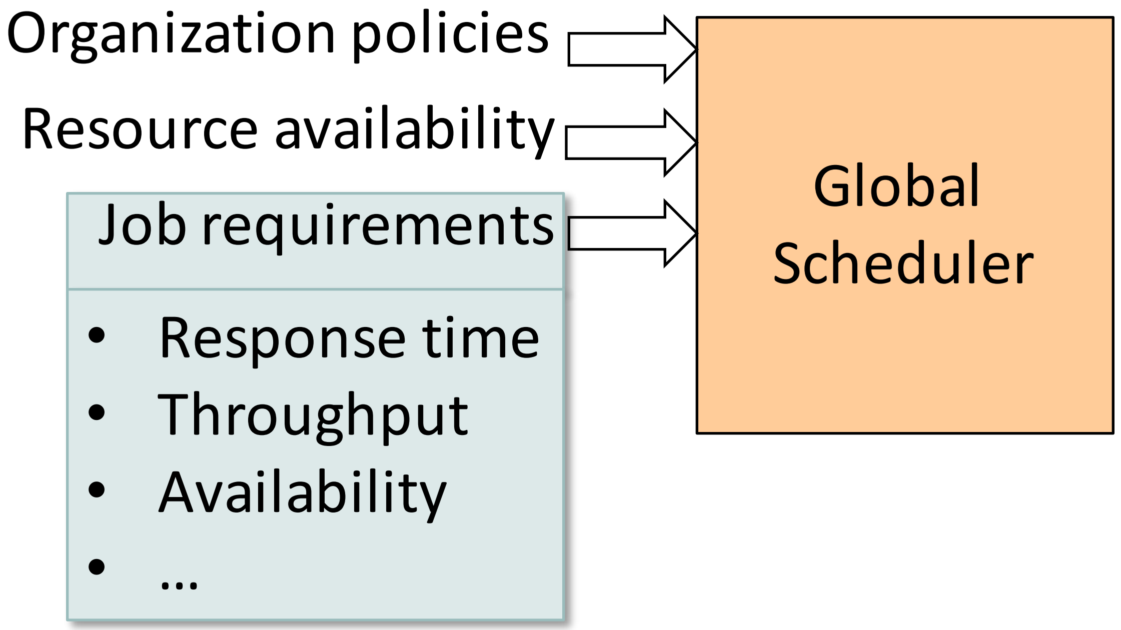
- Task granularity both in **time** & **space**
  - Multiplex node/time between tasks belonging to different jobs/frameworks
- Tasks typically short; median ~= 10 sec, minutes

- Why fine grained?
  - Improve data locality
  - Easier to handle node failures

Goals

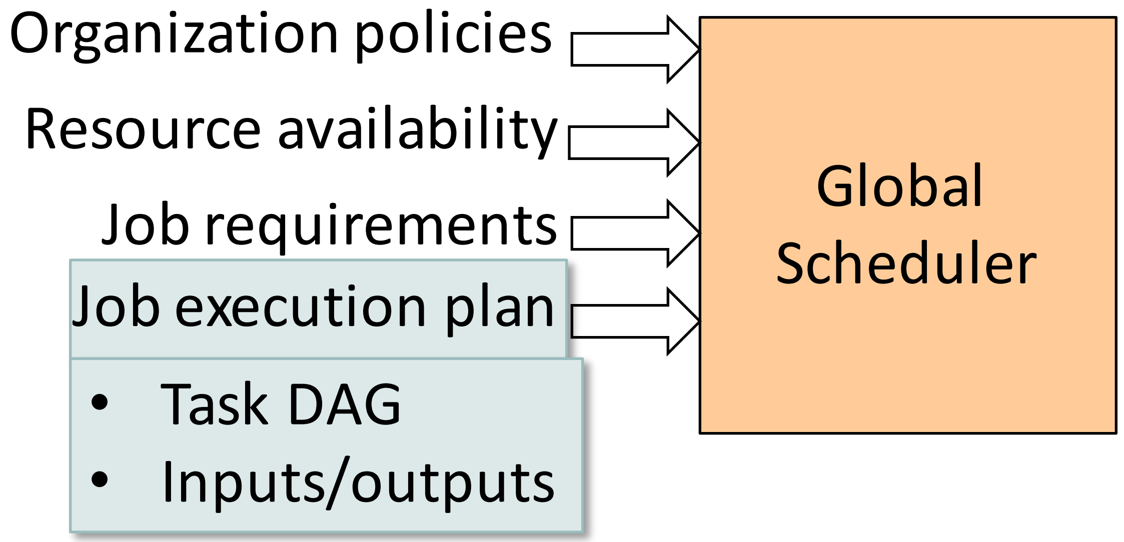
- **Efficient utilization** of resources
- **Support diverse frameworks** (existing & future)
- **Scalability** to 10,000's of nodes
- **Reliability** in face of node failures

Approach: Global Scheduler

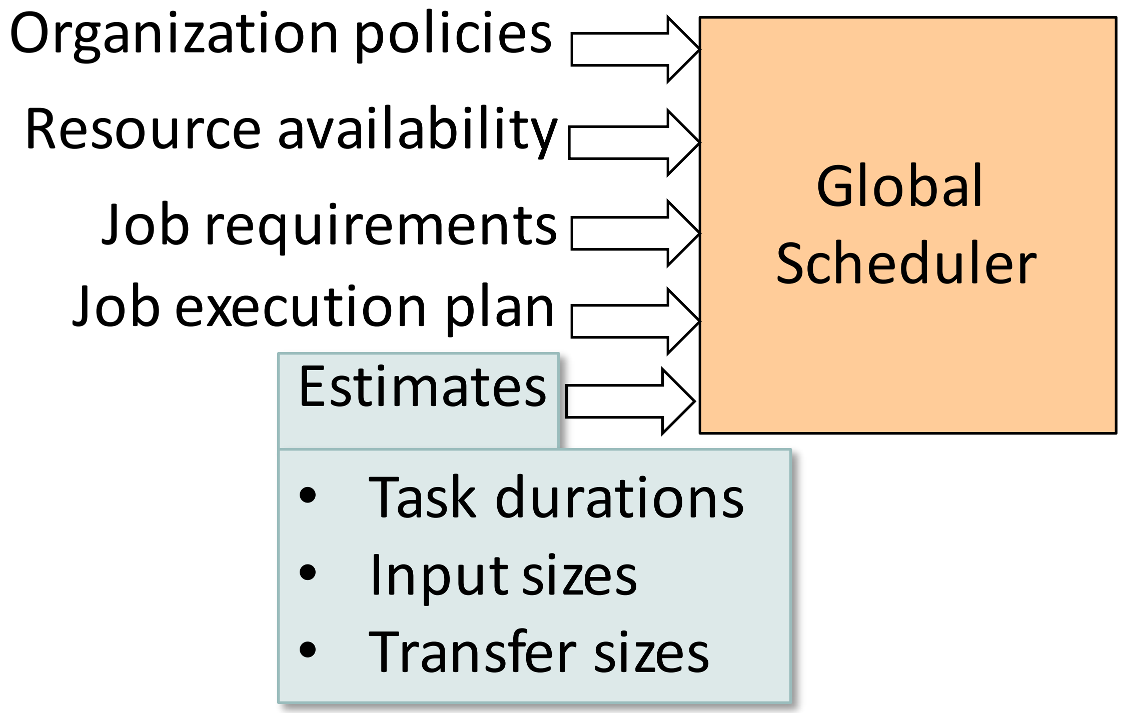


- Response time
- Throughput
- Availability
- …

Approach: Global Scheduler

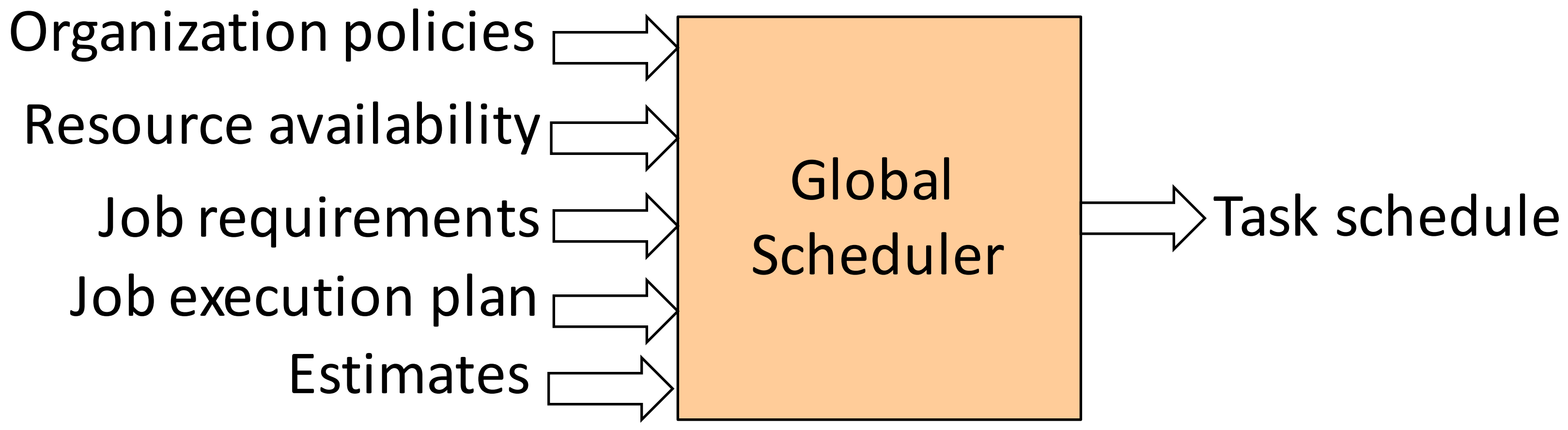


Approach: Global Scheduler



- Task durations
- Input sizes
- Transfer sizes

Approach: Global Scheduler



- Advantages: can achieve optimal schedule
- Disadvantages:
  - Complexity → hard to scale and ensure resilience
  - Hard to anticipate future frameworks' requirements
  - Need to refactor existing frameworks

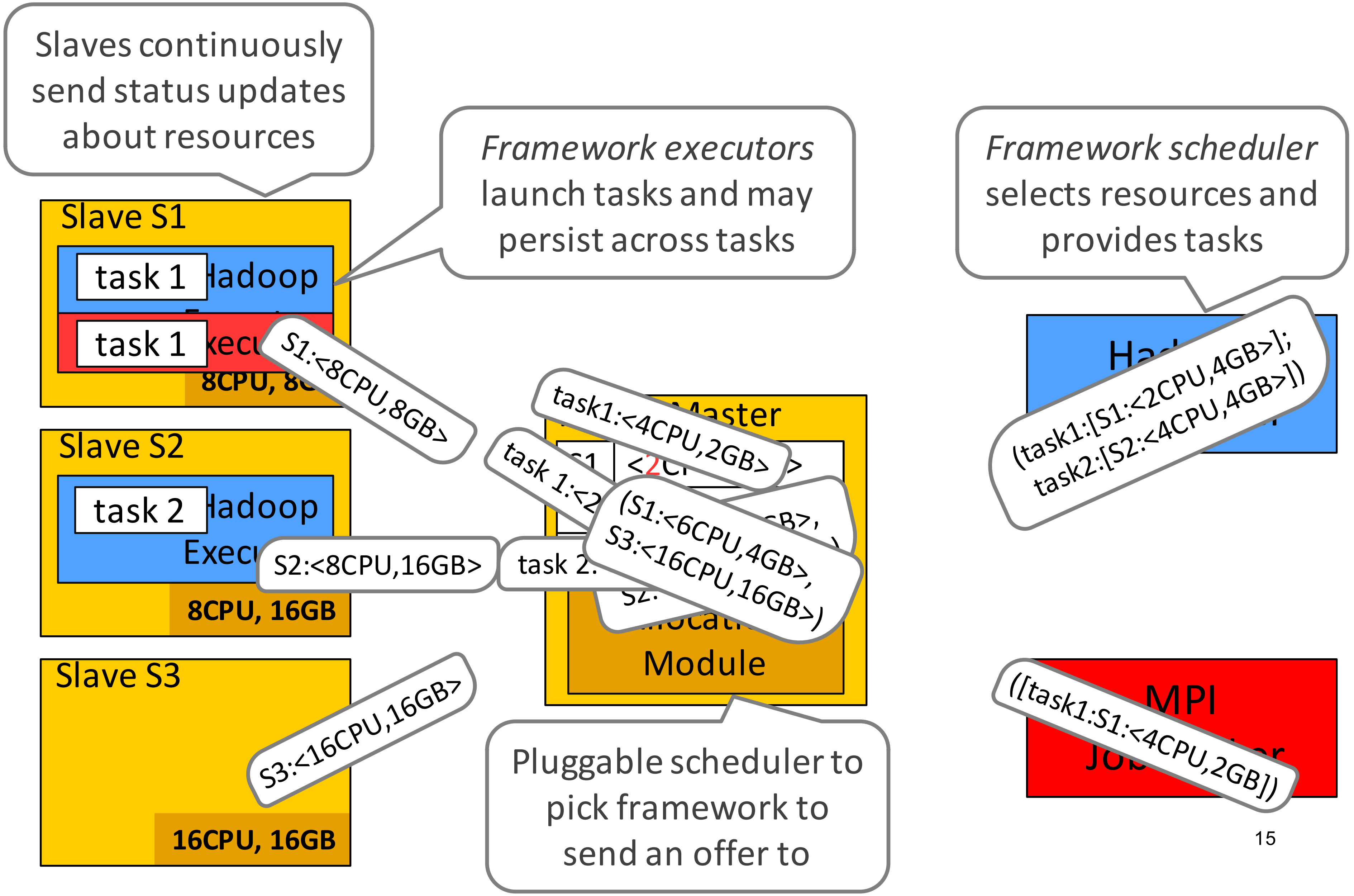
Mesos

Resource Offers

- Unit of allocation: ***resource offer***
  - Vector of available resources on a node
  - E.g., node1: <1CPU, 1GB>, node2: <4CPU, 16GB>
- Master sends resource offers to frameworks
- Frameworks select which offers to accept and which tasks to run

Push task scheduling to frameworks

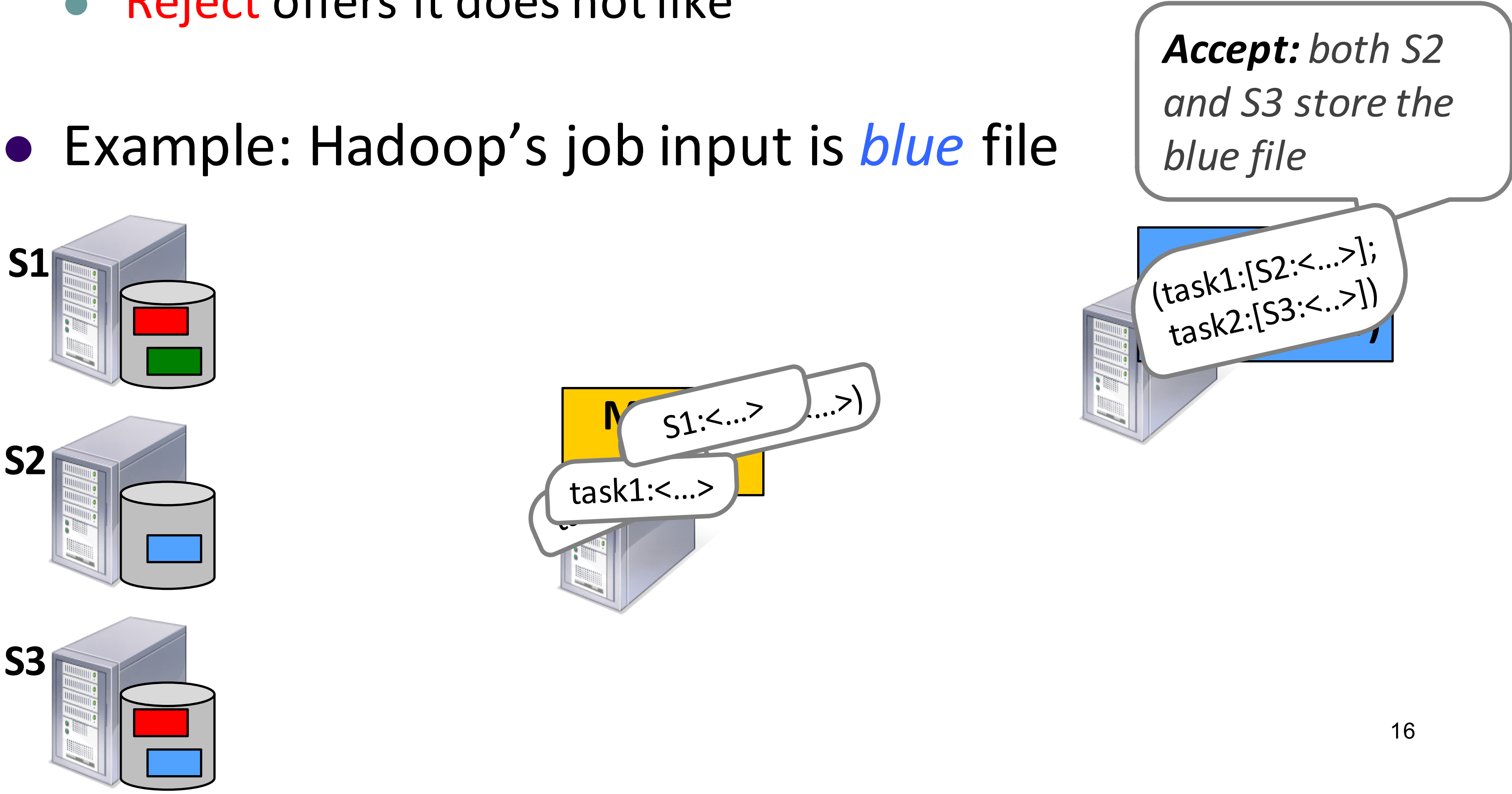
Mesos Architecture: Example


Slaves continuously send status updates about resources
Framework executors launch tasks and may persist across tasks
Framework scheduler selects resources and provides tasks
Slave S1
task 1
Hadoop
task 1
8CPU, 8
S1:<8CPU,8GB>
Slave S2
task 2
Hadoop
Execu
S2:<8CPU,16GB>
8CPU, 16GB
Slave S3
S3:<16CPU,16GB>
16CPU, 16GB
task1:<4CPU,2GB>
task 1:<2
task 2:
Master
(S1:<6CPU,4GB>, S3:<16CPU,16GB>)
Module
(task1:[S1:<2CPU,4GB>]; task2:[S2:<4CPU,4GB>])
Ha
MPI
Job
([task1:S1:<4CPU,2GB])
Pluggable scheduler to pick framework to send an offer to

Why does it Work?

- A framework can just wait for an offer that matches its constraints or preferences!
  - Reject offers it does not like

- Example: Hadoop's job input is *blue* file



Accept: *both S2 and S3 store the blue file*
S1
S2
S3
S1:<…>
…>)
task1:<…>
(task1:[S2:<…>]; task2:[S3:<..>])

Two Key Questions

- How long does a framework need to wait?
- How do you allocate resources of different types?
    - E.g., if framework A has (1CPU, 3GB) tasks, and framework B has (2CPU, 1GB) tasks, how much we should allocate to A and B?

Two Key Questions

- How long does a framework need to wait?

- How do you allocate resources of different types?

How Long to Wait?

- Depend on
  - Distribution of task duration
  - "Pickiness" – set of resources satisfying framework **constraints**

- **Hard constraints:** cannot run if resources violate constraints
  - Software and hardware configurations (e.g., OS type and version, CPU type, public IP address)
  - Special hardware capabilities (e.g., GPU)
- **Soft constraints:** can run, but with degraded performance
  - Data, computation locality

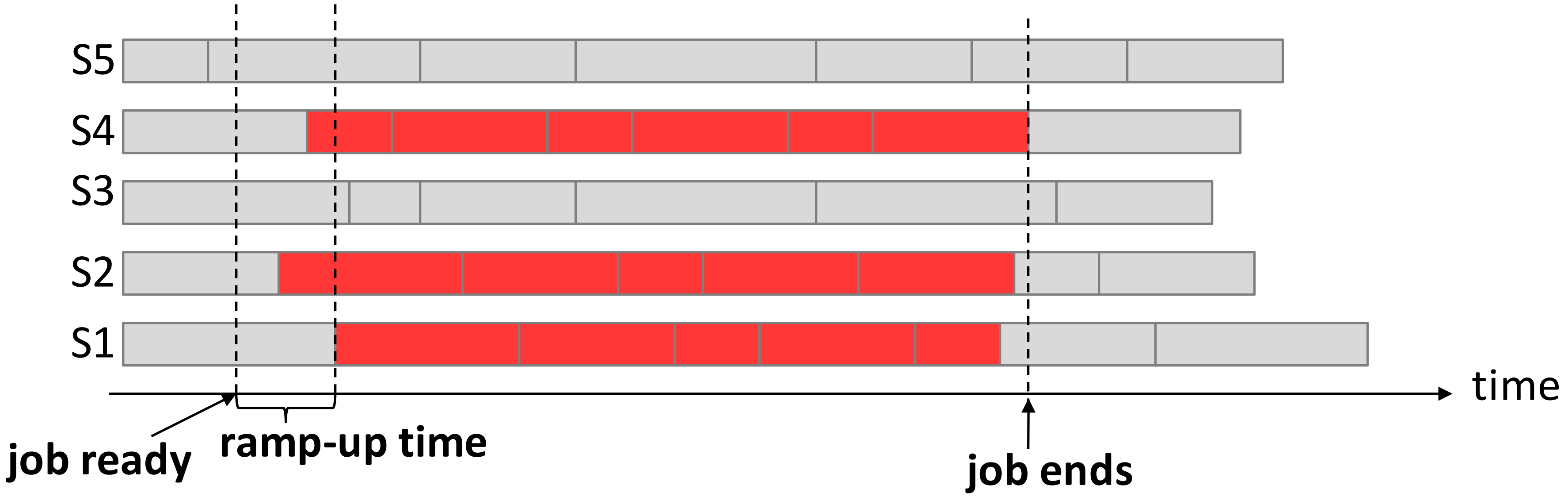
Model

- One job per framework
- One task per node
- No task preemption

- **Pickiness, $\boldsymbol{p} = k/n$**
  - k – number of nodes required by job, e.g., it’s target allocation
  - n – number of nodes satisfying framework’s constraints in the cluster

Ramp-Up Time

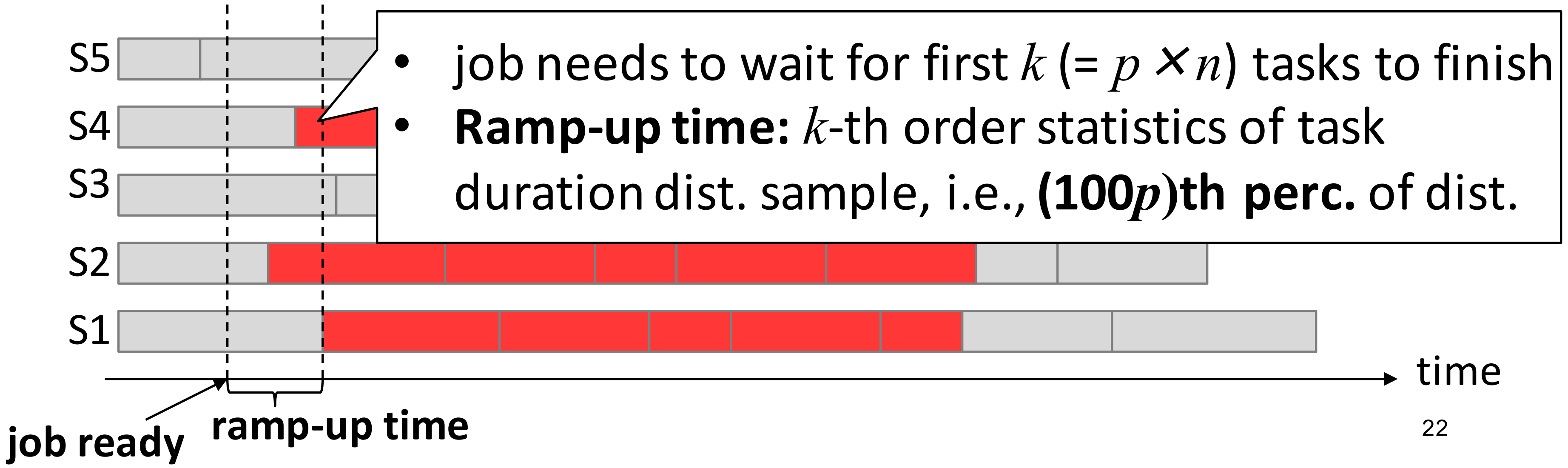
- **Ramp-Up Time**: time job waits to get its target allocation
- Example:
  - Job's target allocation, $k = 3$
  - Number of nodes job can pick from, $n = 5$



Pickiness: Ramp-Up Time

Estimated **ramp-up** time of a job with pickiness $\boldsymbol{p}$ is ≅ **(100$\boldsymbol{p}$)-th percentile** of task duration distribution

- E.g., if p = 0.9, estimated ramp-up time is the 90-th percentile of task duration distribution (T)
- Why? Assume: $k = 3,\ n = 5,\ p = k/n$



- job needs to wait for first k (= $p \times n$) tasks to finish
- **Ramp-up time:** k-th order statistics of task duration dist. sample, i.e., **(100$\boldsymbol{p}$)th perc.** of dist.

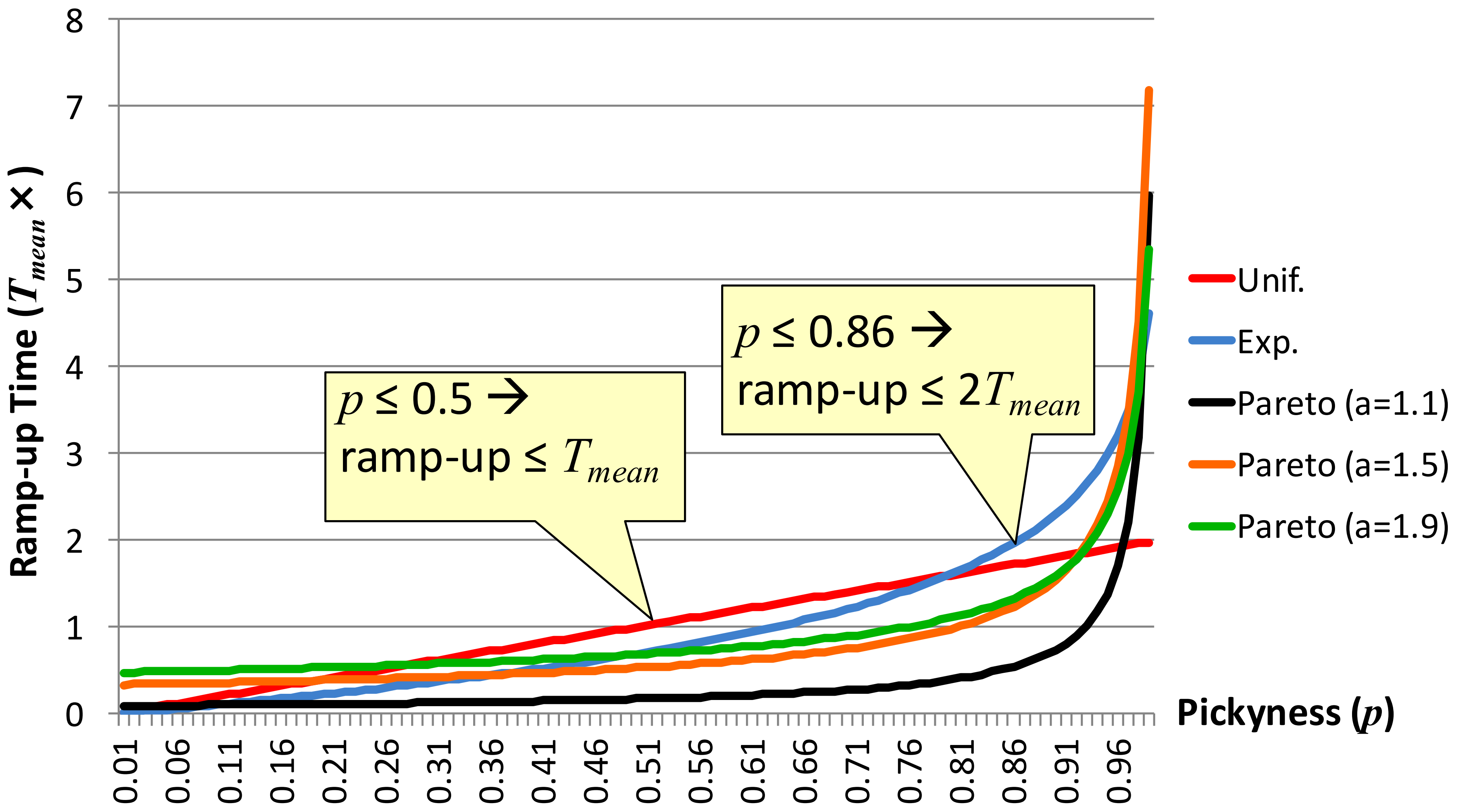
Alternate Interpretations

- If p = 1, estimated time of a job getting fraction q of its allocation is ≅ (100q)-th percentile of T
  - E.g., estimate time of a job getting 0.9 of its allocation is the 90-th percentile of T

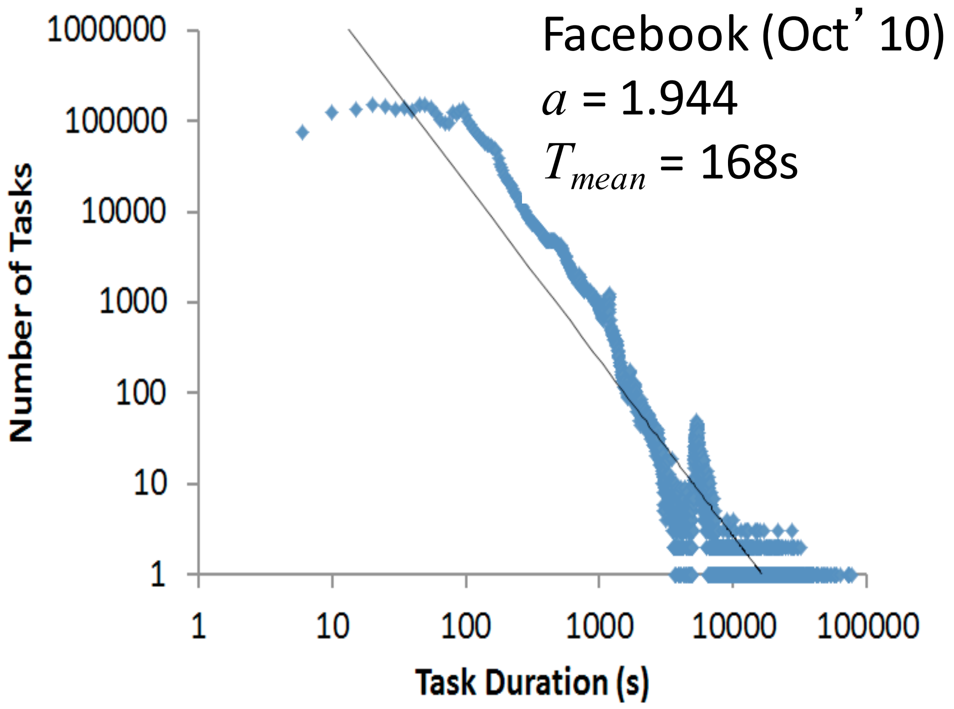
- If utilization of resources satisfying job's constraints is q, estimated time to get its allocation is ≅ (100q)-th perc. of T
  - E.g., if resource utilization is 0.9, estimated time of a job to get its allocation is the 90-th percentile of T

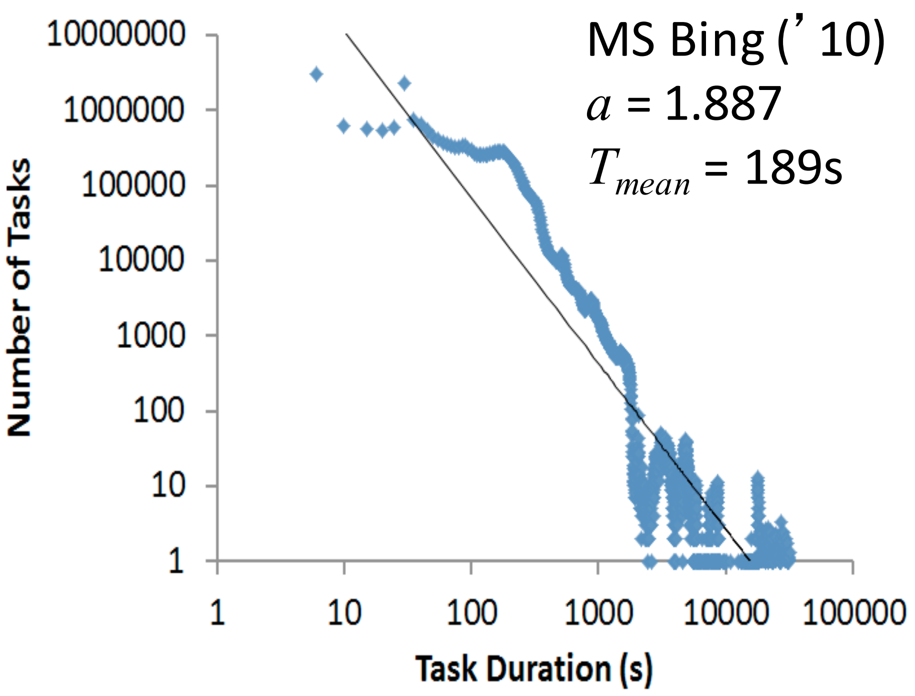
Ramp-Up Time: Mean

- Impact of heterogeneity of task duration distribution



Ramp-up Time: Traces





shape parameter, $a = 1.9$

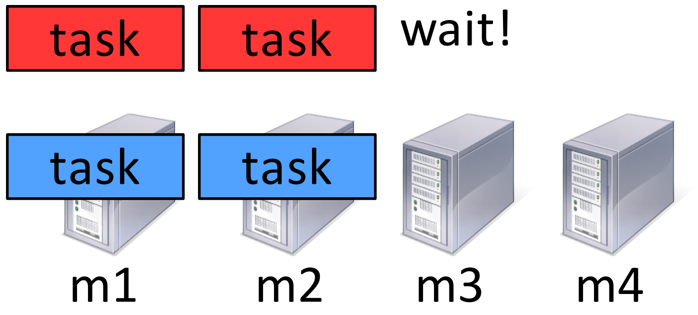
Ramp-up	formula	p =0.1	p =0.5	p =0.9	p =0.98
mean (μ)	$\frac{(a-1)}{a} \times \frac{T_{mean}}{(1-p)^{1/a}}$	0.5 T_{mean}	0.68 T_{mean}	1.59 T_{mean}	3.71T_{mean}
stdev (σ)	$\frac{\mu}{a} \times \sqrt{\frac{p}{n(1-p)}}$	0.01 T_{mean}	0.04 T_{mean}	0.25 T_{mean}	1.37T_{mean}

Improving Ramp-Up Time?

- **Preemption:** preempt tasks
- **Migration:** move tasks around to increase choice, e.g.,

Job 1 constraint set = {m1, m2, m3, m4}

Job 2 constraint set = {m1, m2}



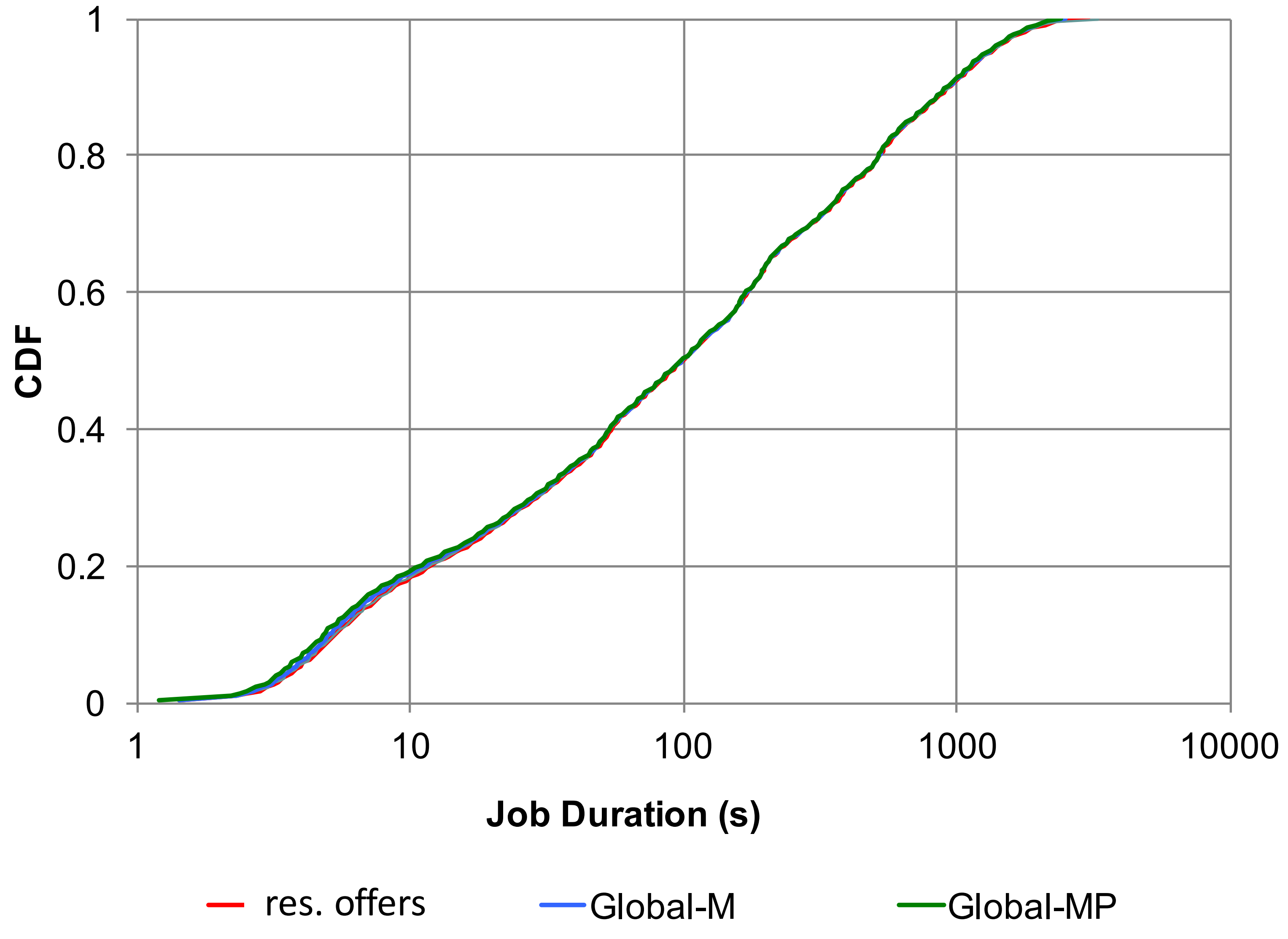
- Existing frameworks implement
  - **No** migration: expensive to migrate short tasks
  - Preemption with task killing (e.g., Dryad's Quincy): expensive to checkpoint data-intensive tasks

Macro-benchmark

- Simulate an 1000-node cluster
  - Job and task durations: Facebook traces (Oct 2010)
  - Constraints: modeled after Google*
- Allocation policy: fair sharing
- Scheduler comparison
  - **Resource Offers**: no preemption, and no migration (e.g., Hadoop's Fair Scheduler + constraints)
  - **Global-M**: global scheduler with migration
  - **Global-MP**: global scheduler with migration and preemption

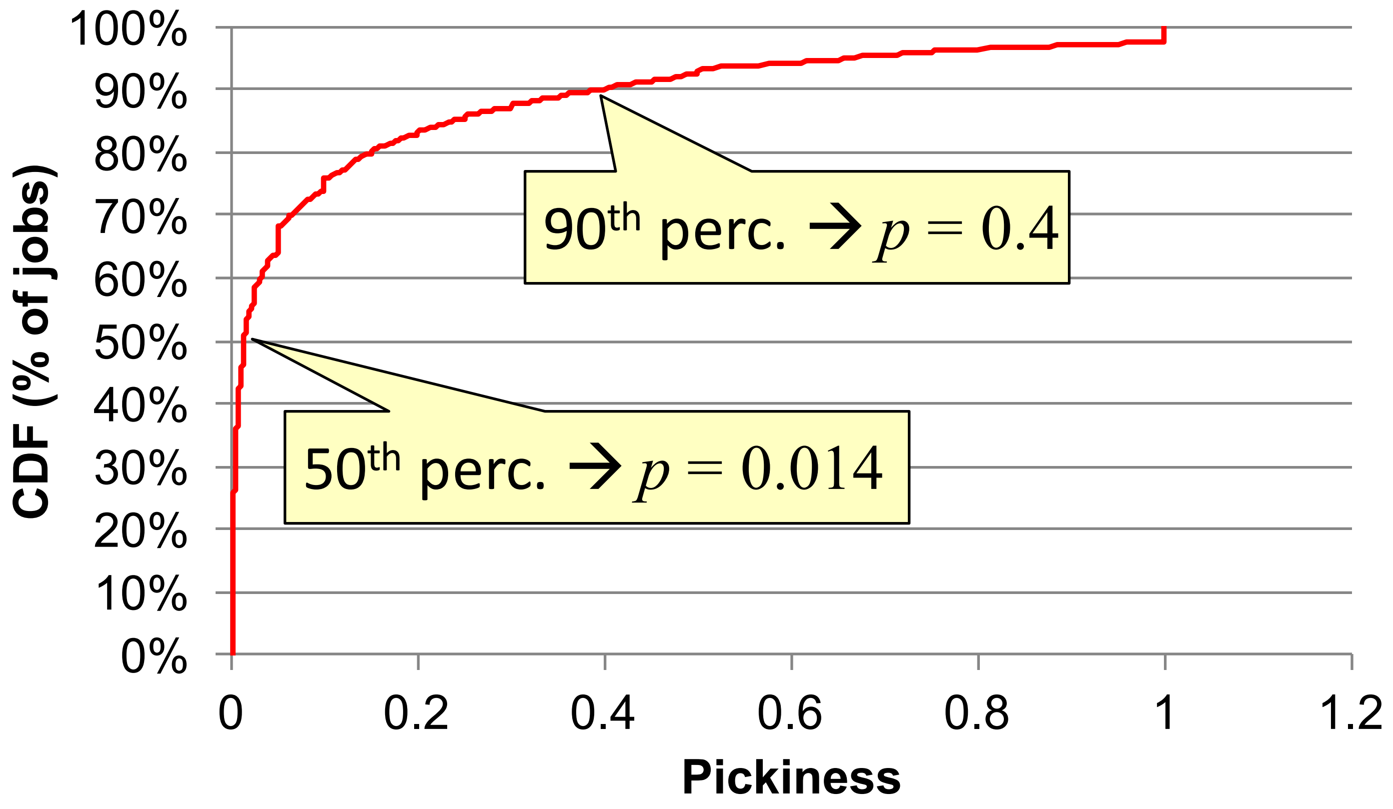
*Sharma et al., "Modeling and Synthesizing Task Placement Constraints in Google Compute Clusters", ACM SoCC, 2011.

Facebook: Job Completion Times



Facebook: Pickiness

- Average cluster utilization: 82%
  - Much higher than at Facebook, which is < 50%
- Mean pickiness: 0.11

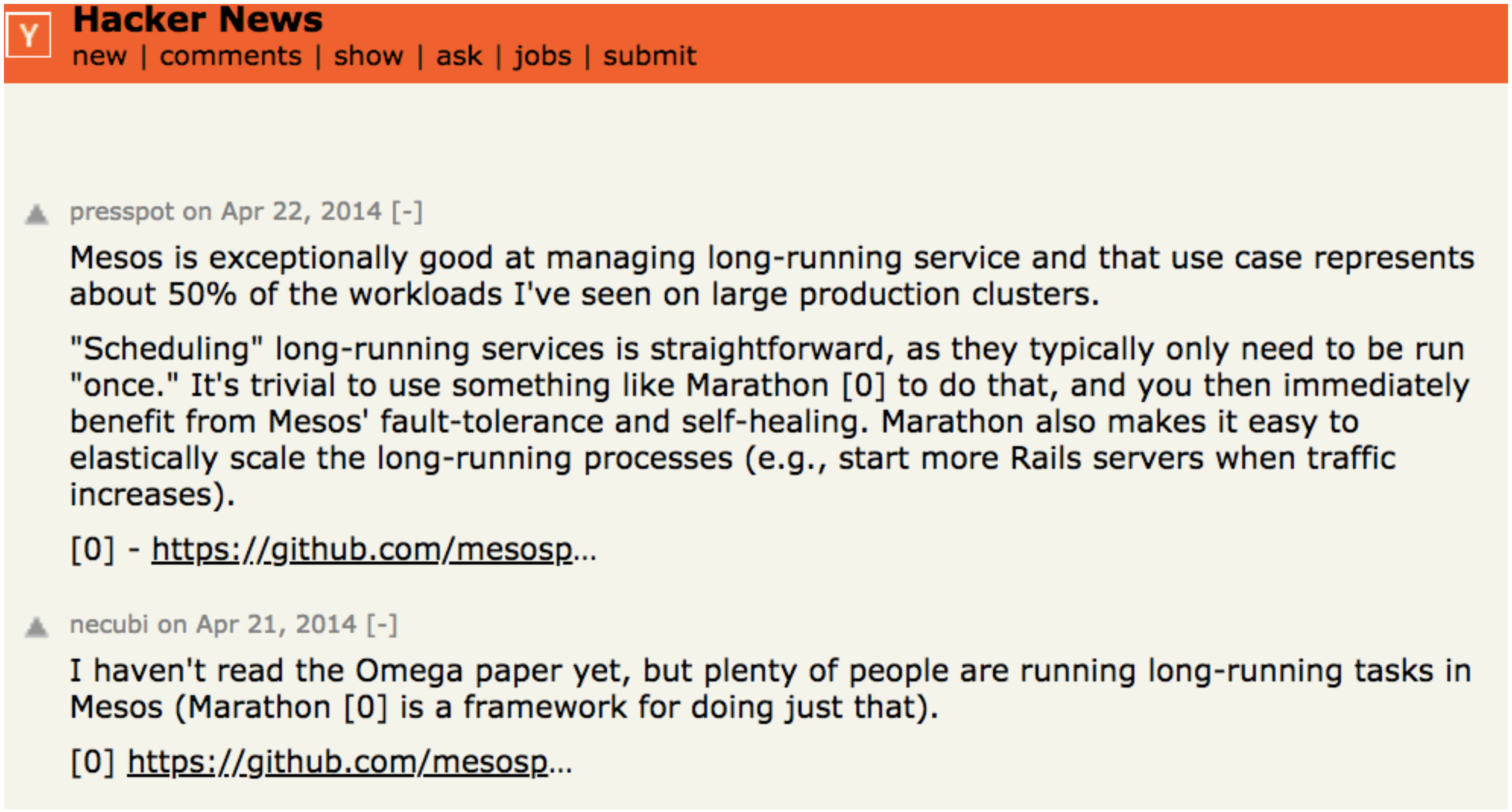


Summary: Resource Offers

- Ramp-up time low under most scenarios
- Barely any performance differences between global and distributed schedulers in Facebook workload
- Optimizations
  - Master doesn't send an offer already rejected by a framework (negative caching)
  - Allow frameworks to specify white and black lists of nodes

Lookback

- Why resource offers?
- What was the main contribution?
- How important was fine grained task scheduling?



presspot on Apr 22, 2014 [-]

Mesos is exceptionally good at managing long-running service and that use case represents about 50% of the workloads I've seen on large production clusters.

"Scheduling" long-running services is straightforward, as they typically only need to be run "once." It's trivial to use something like Marathon [0] to do that, and you then immediately benefit from Mesos' fault-tolerance and self-healing. Marathon also makes it easy to elastically scale the long-running processes (e.g., start more Rails servers when traffic increases).

[0] - https://github.com/mesosp...

necubi on Apr 21, 2014 [-]

I haven't read the Omega paper yet, but plenty of people are running long-running tasks in Mesos (Marathon [0] is a framework for doing just that).

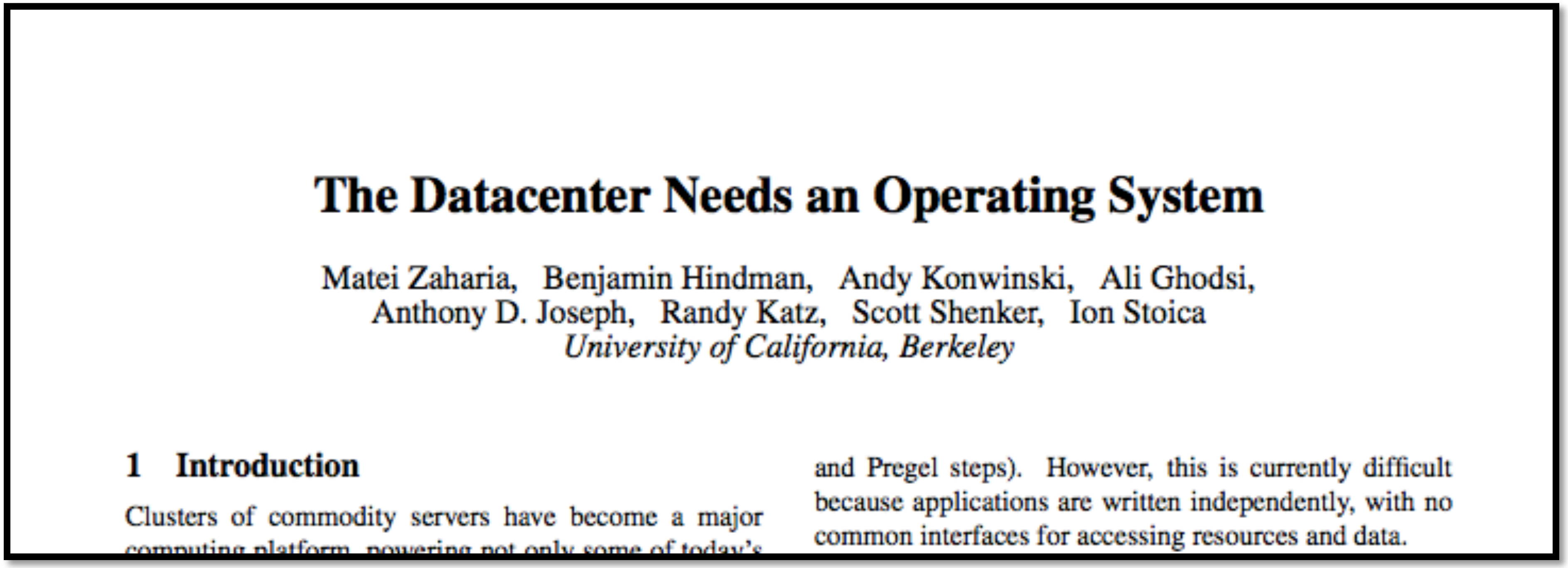
[0] https://github.com/mesosp...

My biased summary

- AirBnB built Marathon, a framework for Mesos that takes detailed job descriptions and schedules long running tasks
  - Ben's high school friend, was behind Marathon. It was written in Scala and was dubbed "crontab for Mesos". Both are co-founders of Mesosphere
- Ben joined Twitter full time to ensure Mesos adoption
  - Twitter mainly used Mesos for long-running tasks
  - Twitter was important when other companies adopted Mesos

My biased summary

- Mesos "heavily" influenced the YARN design



The Datacenter Needs an Operating System

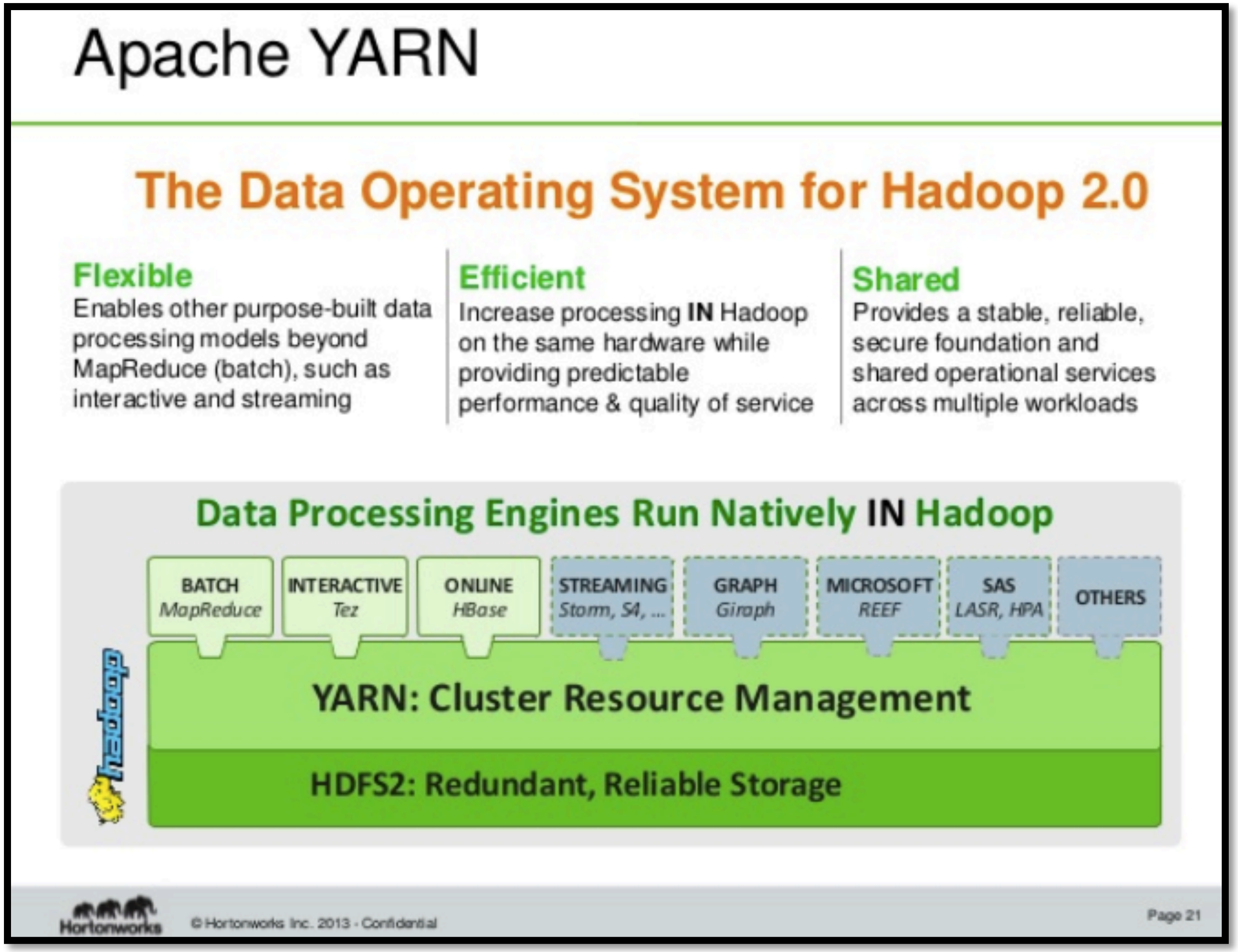
Matei Zaharia, Benjamin Hindman, Andy Konwinski, Ali Ghodsi, Anthony D. Joseph, Randy Katz, Scott Shenker, Ion Stoica
University of California, Berkeley

1 Introduction

Clusters of commodity servers have become a major

and Pregel steps). However, this is currently difficult because applications are written independently, with no common interfaces for accessing resources and data.

My biased summary



Apache YARN

The Data Operating System for Hadoop 2.0

Flexible
Enables other purpose-built data processing models beyond MapReduce (batch), such as interactive and streaming

Efficient
Increase processing **IN** Hadoop on the same hardware while providing predictable performance & quality of service

Shared
Provides a stable, reliable, secure foundation and shared operational services across multiple workloads

Hortonworks © Hortonworks Inc. 2013 - Confidential Page 21

My biased summary

- Why was Mesos so successful?
  - Ben working at Twitter?
  - The Datacenter OS vision?
  - The availability of open source software that worked with modern tech (Hadoop etc)?
  - The academic impact? The Berkeley brand?
  - The fact that it solved a real and important problem?

Borg

Borg

Cluster management system at Google that achieves high utilization by:

- Admission control
- Efficient task-packing
- Over-commitment
- Machine sharing

The User Perspective

- Users: Google developers and system administrators mainly
- The workload: Production and batch, mainly
- Cells, around 10K nodes
- Jobs and tasks

The User Perspective

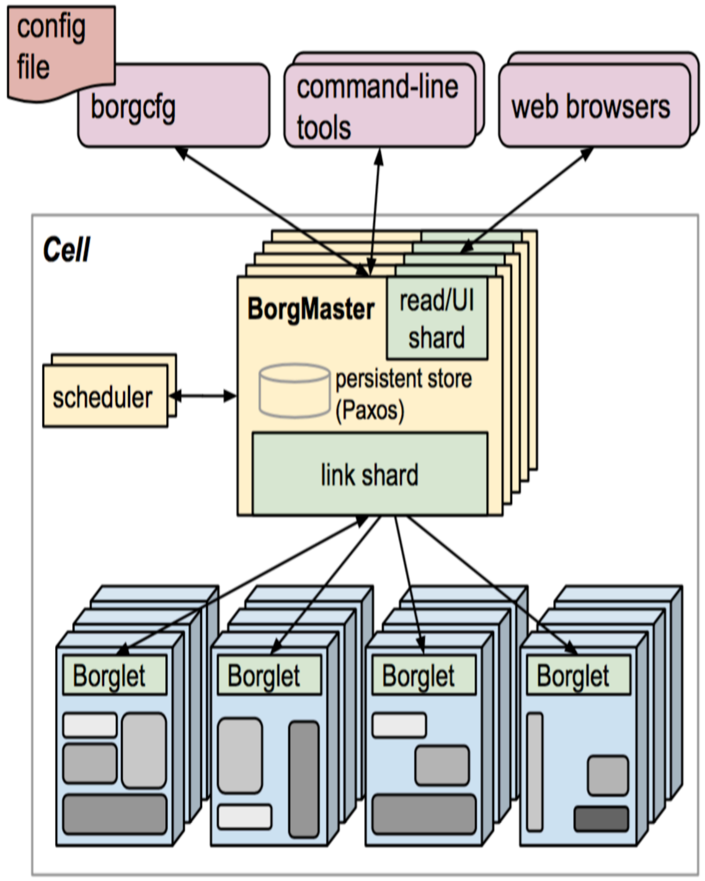
- Allocs
  - Reserved set of resources
- Priority, Quota, and Admission Control
  - Job has a priority (preempting)
  - Quota is used to decide which jobs to admit for scheduling
- Naming and Monitoring
  - 50.jfoo.ubar.cc.borg.google.com
  - Monitoring health of the task and thousands of performance metrics

Scheduling a Job

```
job hello_world = {
  runtime = { cell = “ic” } //what cell should run it in?
  binary = ‘../hello_world_webserver’ //what program to run?
  args = { port = ‘%port%’ }
  requirements = {
    RAM = 100M
    disk = 100M
    CPU = 0.1
  }
  replicas = 10000
}
```

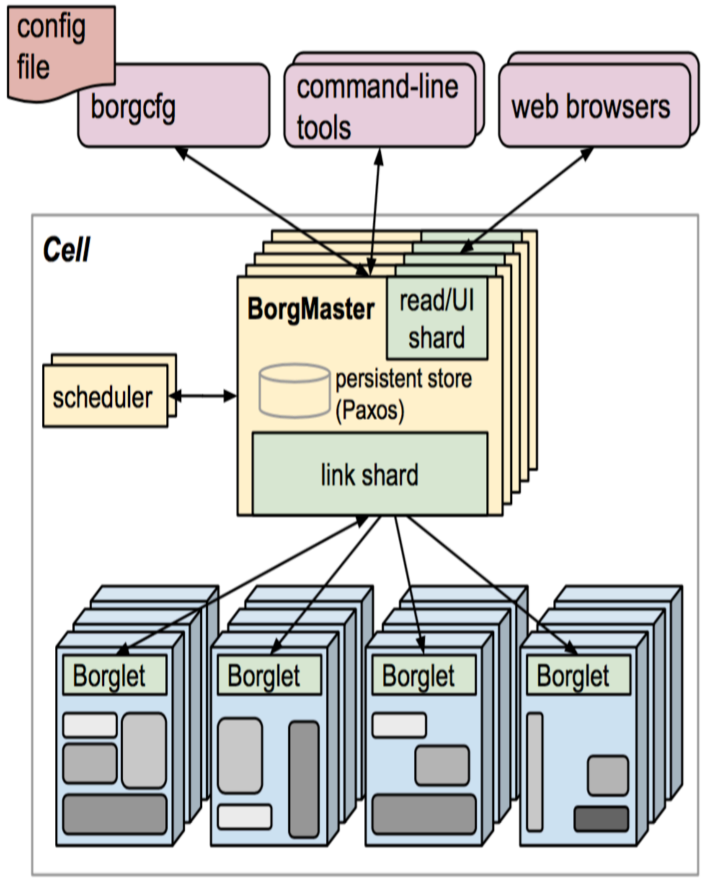
Borg Architecture

- Borgmaster
  - Main Borgmaster process & Scheduler
  - Five replicas
- Borglet
  - Manage and monitor tasks and resource
  - Borgmaster polls Borglet every few seconds



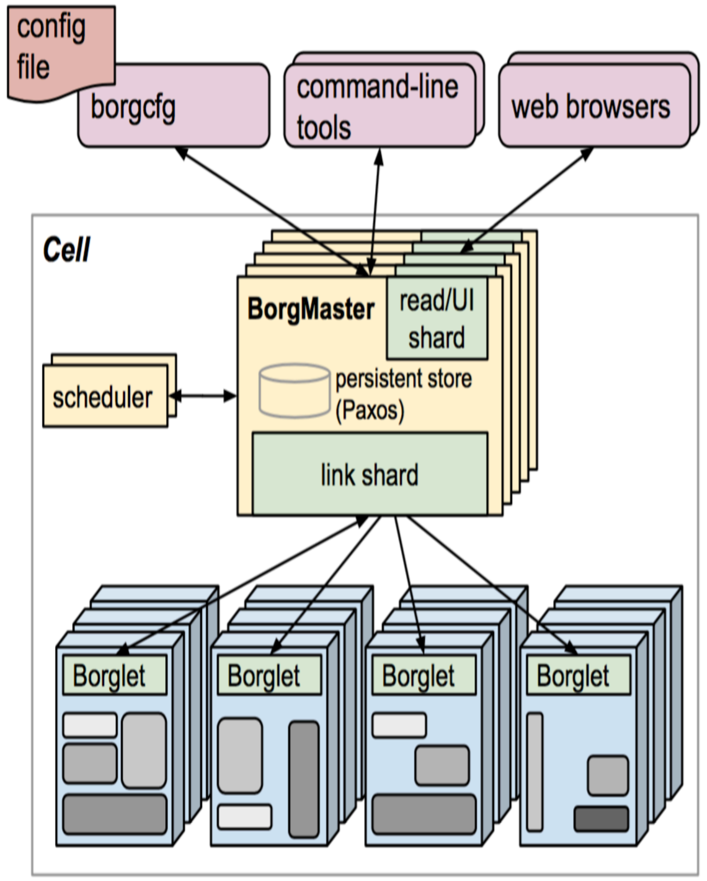
Borg Architecture

- Fauxmaster: high-fidelity Borgmaster simulator
  - Simulate previous runs from checkpoints
  - Contains full Borg code
- Used for debugging, capacity planning, evaluate new policies and algorithms



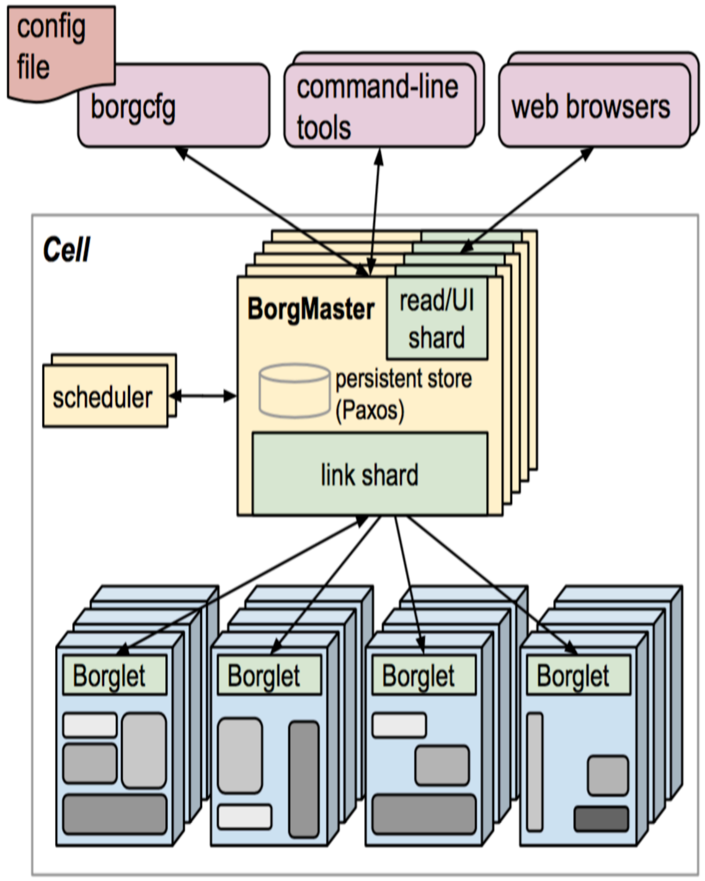
Scalability

- Separate scheduler
- Separate threads to poll the Borglets
- Partition functions across the five replicas
- Score caching
- Equivalence classes
- Relaxed randomization



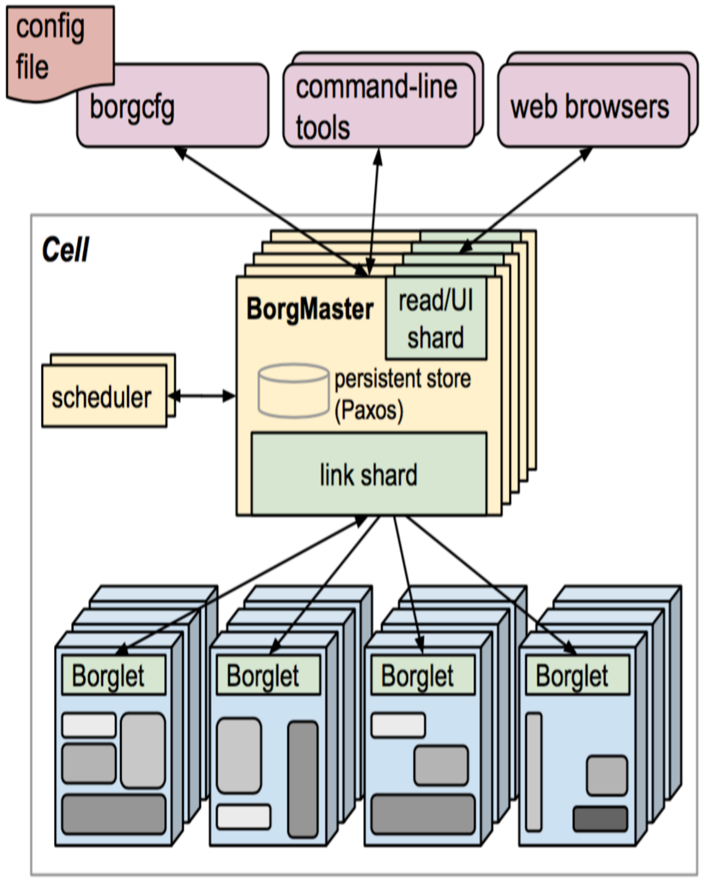
Scheduling

- Feasibility checking: find machines for a given job
- Scoring: pick one machines
  - User prefs & built-in criteria
    - Minimize the number and priority of the preempted tasks
    - Picking machines that already have a copy of the task's packages
    - spreading tasks across power and failure domains
    - Packing by mixing high and low priority tasks



Scheduling

- Feasibility checking: find machines for a given job
- Scoring: pick one machines
  - User prefs & build-in criteria
  - E-PVM (Enhanced-Parallel Virtual Machine) vs best-fit
    - Hybrid approach



Borg's Allocation Algorithms and Policies

Advanced Bin-Packing algorithms:

- Avoid stranding of resources

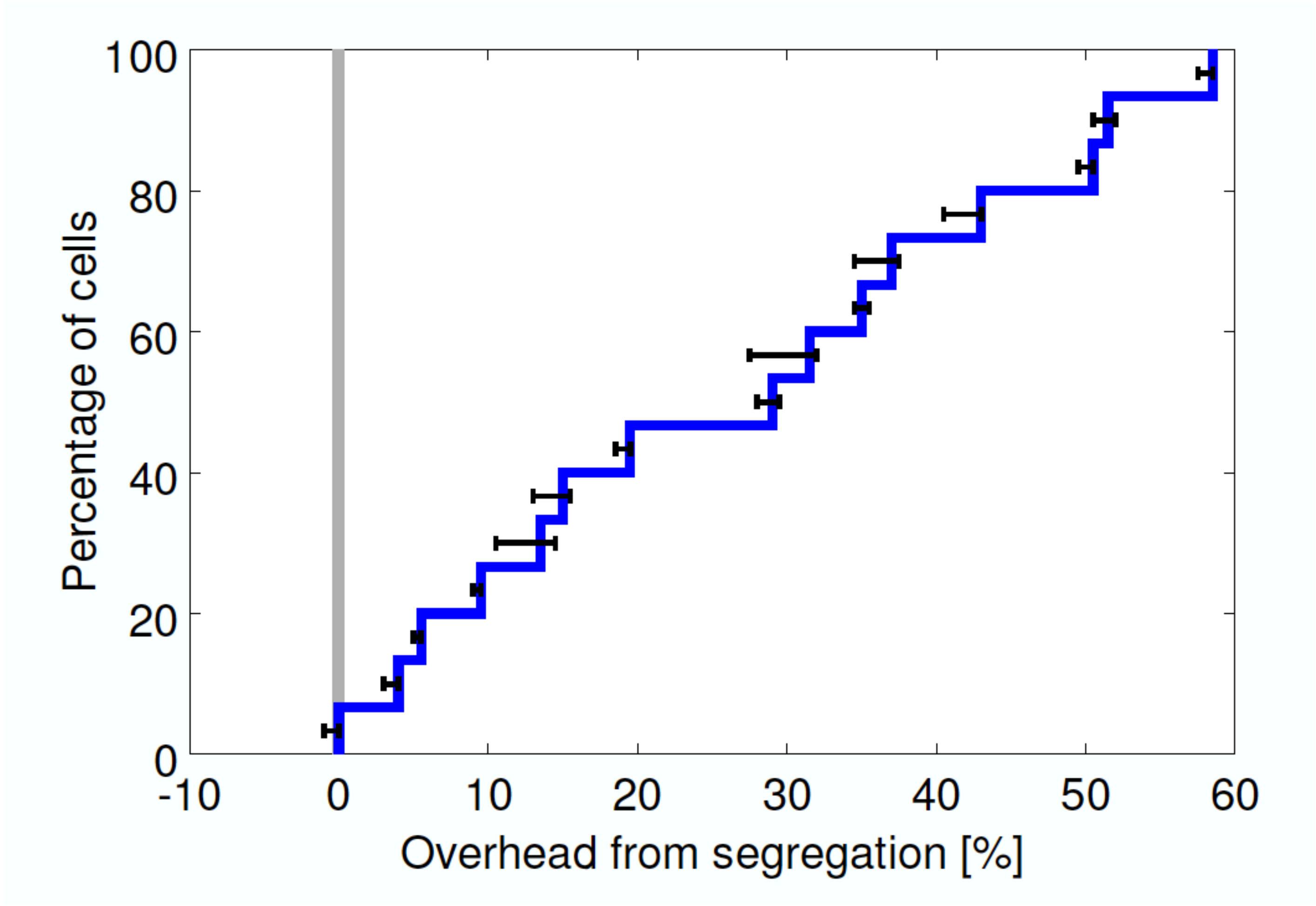
Evaluation metric: Cell-compaction

- Find smallest cell that we can pack the workload into…
- Remove machines randomly from a cell to maintain cell heterogeneity

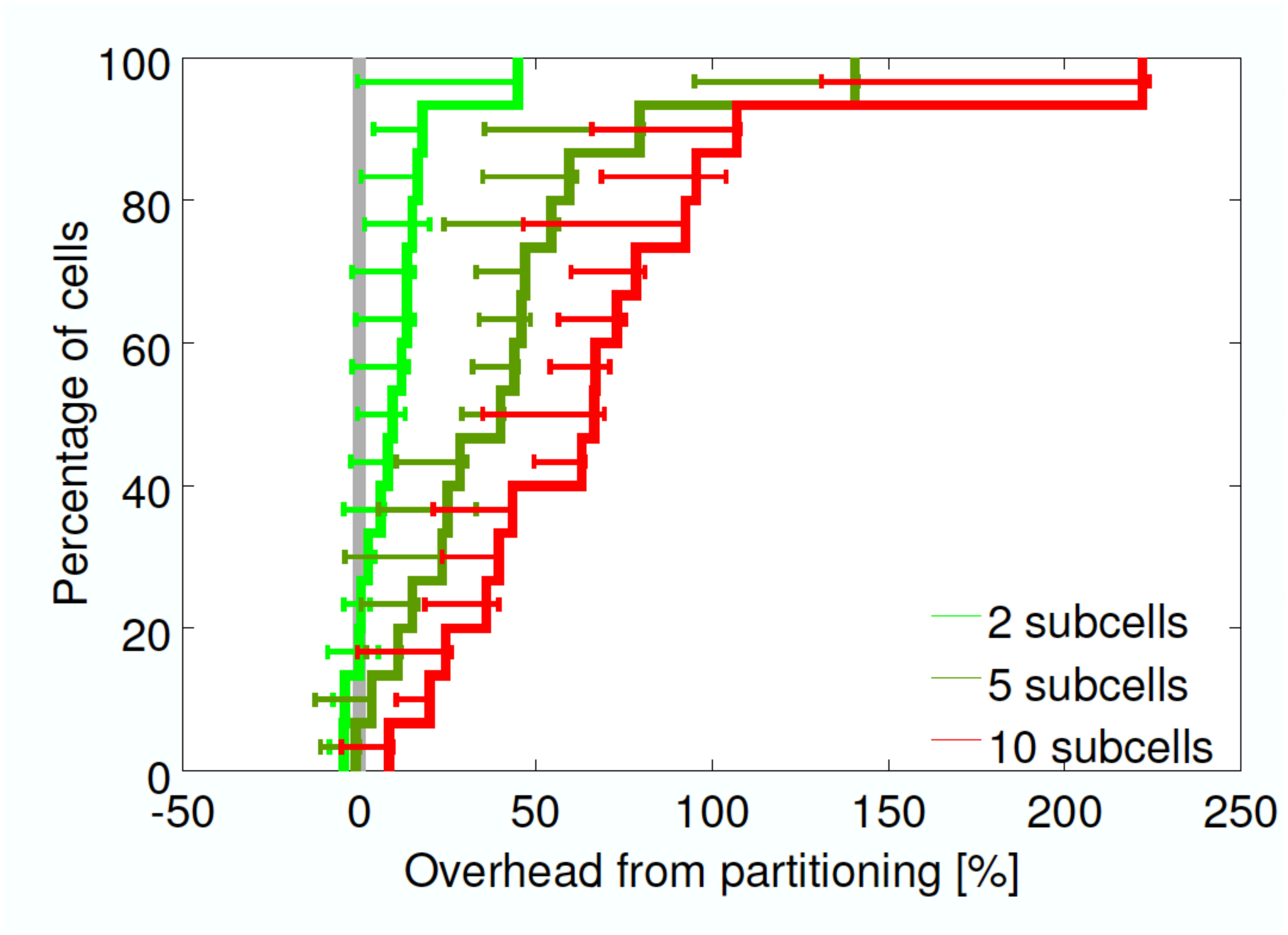
Evaluated various policies to understand the cost, in terms of extra machines needed for packing the same workload

Should we Share Clusters…

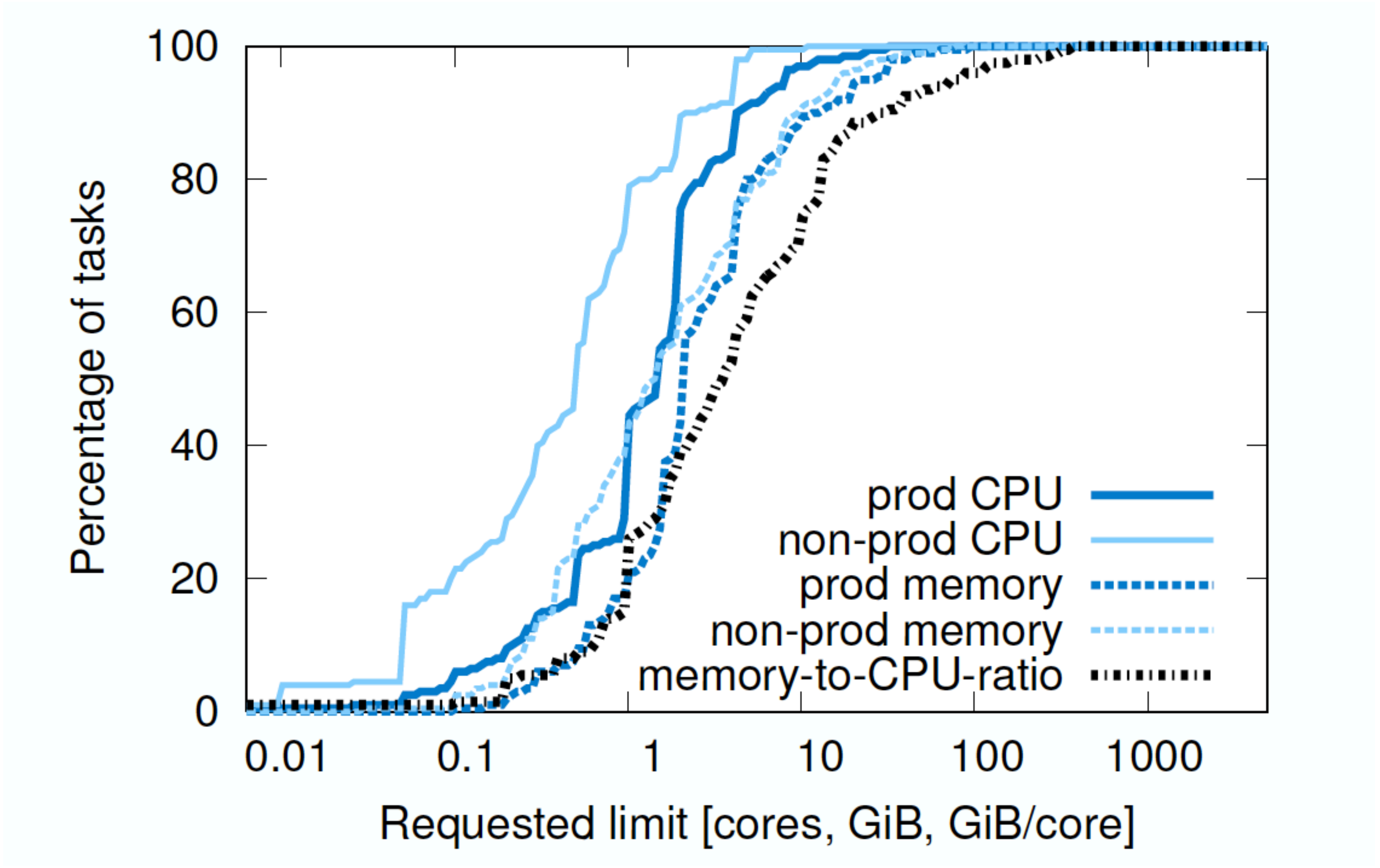
- … between production and non-production jobs?



Should we use Smaller Cells?

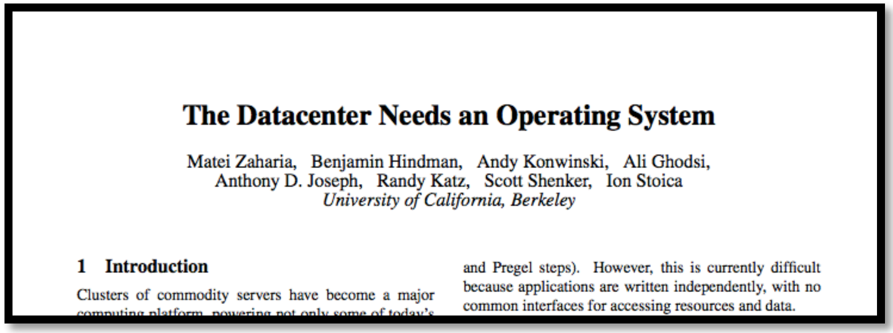


Would fixed resource bucket sizes be better?



Kubernetes (K8s)

Vision of Mesos


The Datacenter Needs an Operating System

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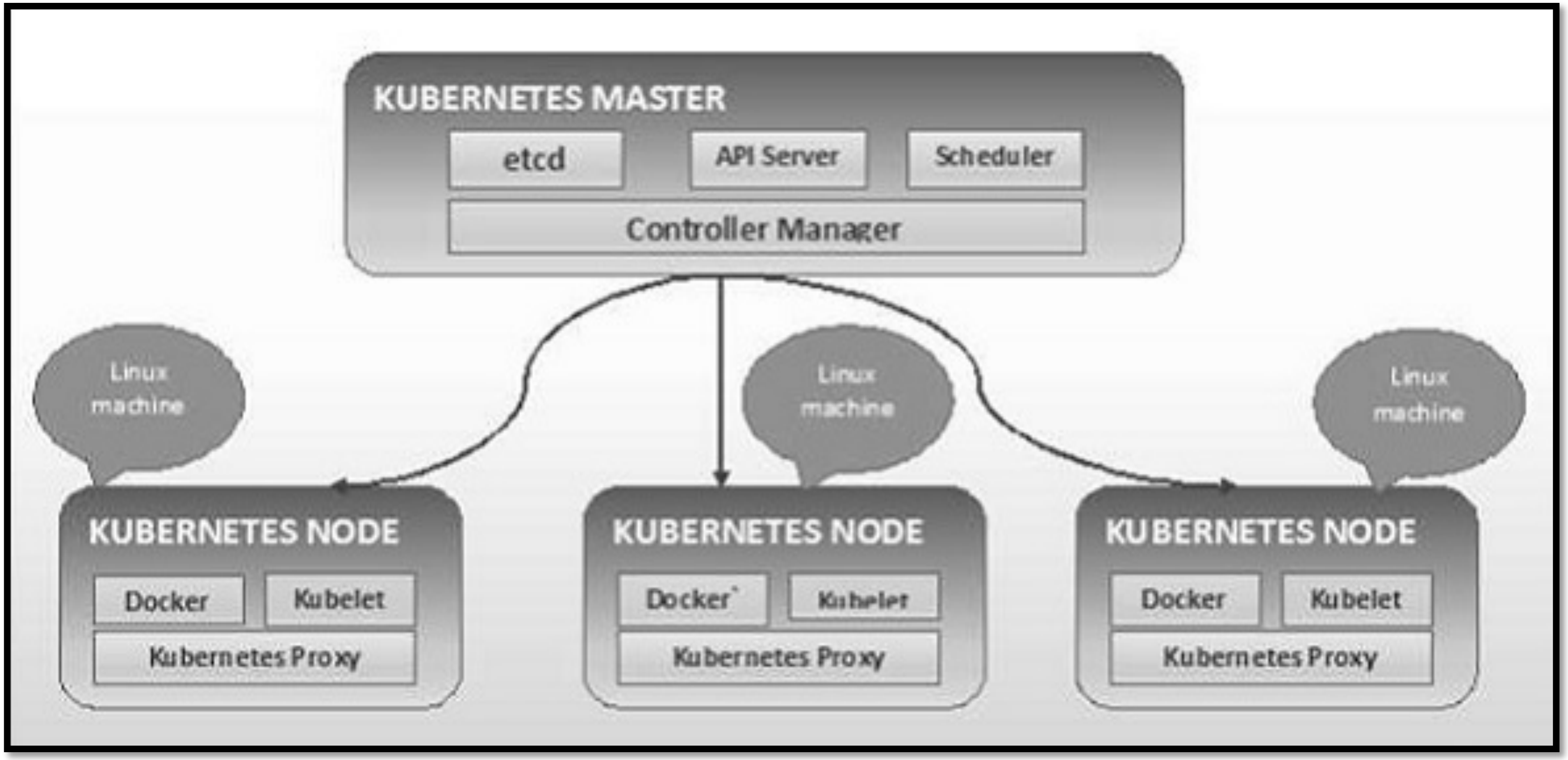
1 Introduction

Clusters of commodity servers have become a major

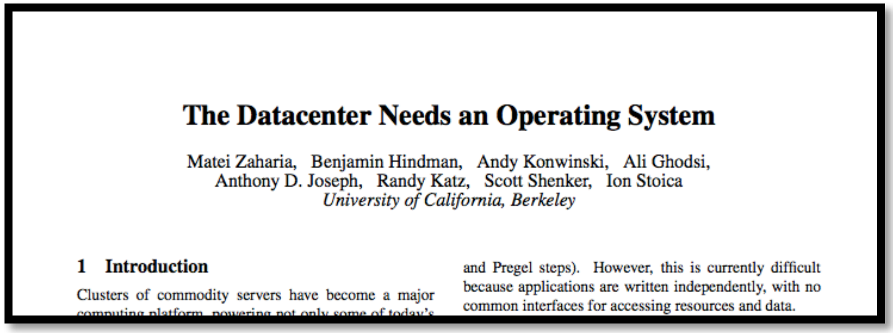
and Pregel steps). However, this is currently difficult because applications are written independently, with no common interfaces for accessing resources and data.

- The datacenter is the new computer!
  - Modern apps will be distributed on the datacenter
- It needs everything an OS had
  - Processes
  - Filesystem
  - IPC
  - Scheduler
  - Cache
  - Software patches (+)
  - Hardware upgrades (++)
  - Fault-tolerance



- https://www.tutorialspoint.com/kubernetes/kubernetes_architecture.htm

Kubernetes Project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1 Introduction

Clusters of commodity servers have become a major computing platform, powering not only some of today's

and Pregel steps). However, this is currently difficult because applications are written independently, with no common interfaces for accessing resources and data.

- The datacenter is the new computer!
  - Modern apps will be distributed on the datacenter
- It needs everything an OS had
  - Processes → Docker (threads?) & PODs (processes?)
  - Filesystem → volumes
  - IPC → K8s Proxy
  - Scheduler → K8s Scheduler
  - Cache → etcd
  - Software patches (+) → blue/green updates
  - Hardware upgrades (++) → pod migration and services
  - Fault-tolerance → replicasets

Summary

- Kubernetes implements a full fledged operating system for the datacenter
  - Write useful software that solves practical problems
  - OSS enables massive impact
    1,605 contributors
  - Important to make the system useable

- **Potential for you to have software impact is greater than ever!**

Kubernetes

Google open source project loosely inspired by Borg

Directly derived

- Borglet => Kubelet
- alloc => pod
- Borg containers => docker
- Declarative specifications

Improved

- Job => labels
- managed ports => IP per pod
- Monolithic master => micro-services