



北京航空航天大学  
BEIHANG UNIVERSITY



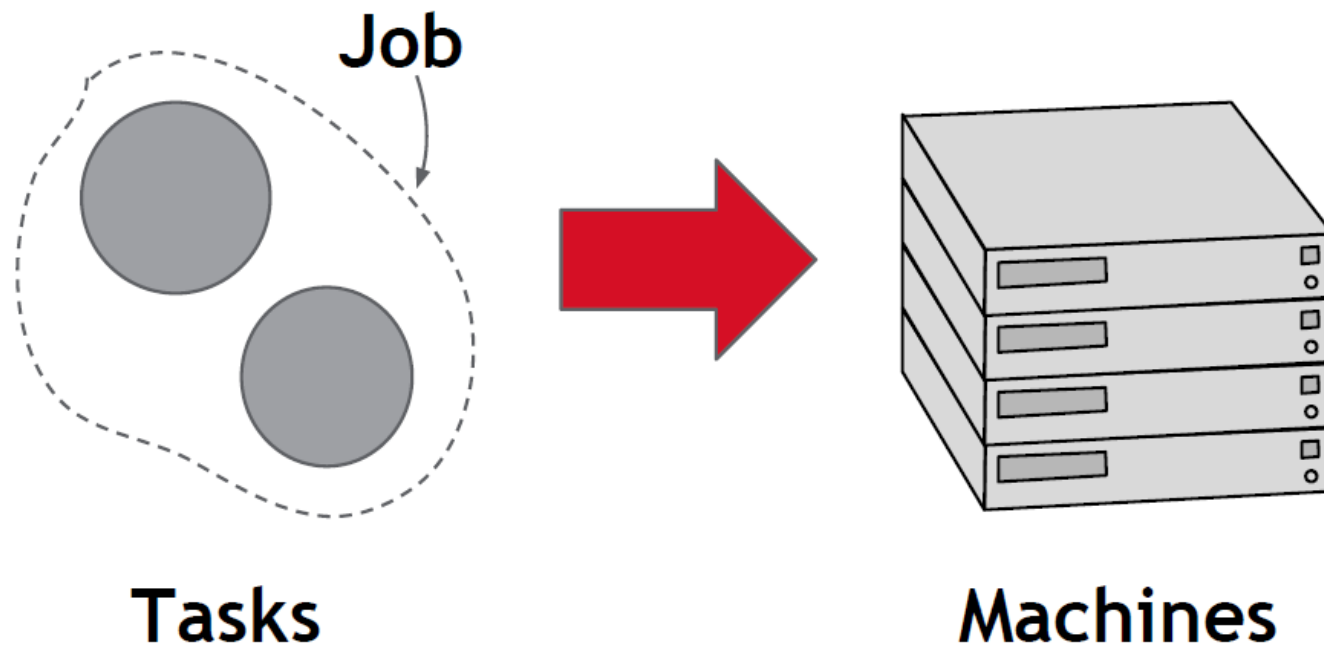
阿里云计算  
Alibaba Cloud Computing

# Resource Scheduling Architectural Evolution at Scale and Distributed Scheduler Load Simulator

Renyu Yang

Supported by Collaborated 863 and 973 Program

# Resource Scheduling Problems



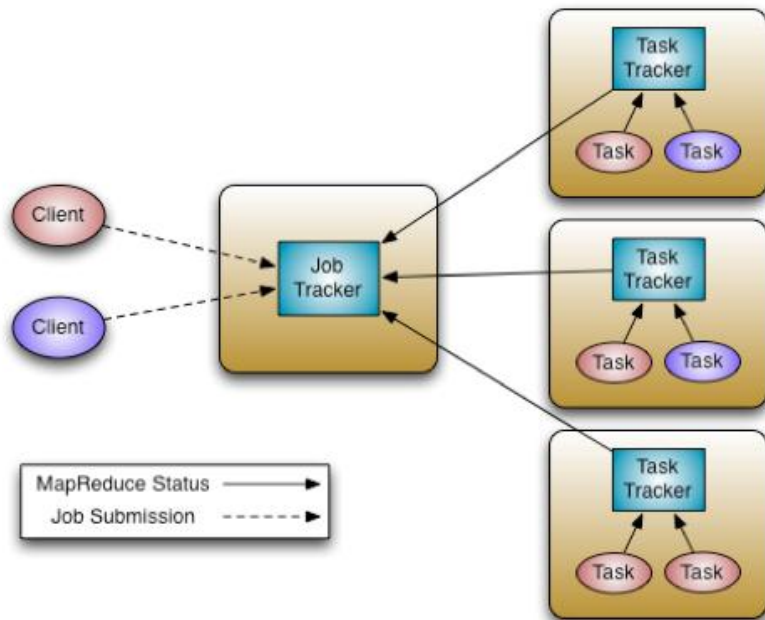
# Challenges at Scale

- Perspectives:
  - Performance
  - Scalability
  - Fault-tolerance
  - Resource Utilization
- Case studies:
  - System Architectural Evolution
  - Design of scheduler load simulator based on different resource management models.

# Data Processing System Overview

- **1<sup>st</sup> Generation(G1):**
  - Hadoop Map Reduce programming paradigm
- **2<sup>nd</sup> Generation(G2):**
  - Mesos
  - Yarn: short for “Yet Another Resource Negotiator”
  - Fuxi: Alibaba Cloud Inc.
- **3<sup>rd</sup> Generation ?**
  - Omega from Google

# G1: Hadoop MR classic



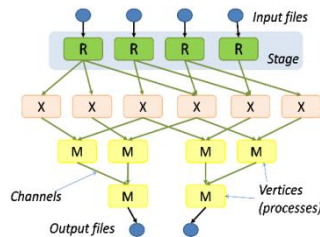
- JobTracker
  - Manages cluster resources
  - Task scheduling
    - how to divide tasks
    - which node, how much resource for execution
- TaskTracker
  - Per-machine agent and daemon
  - Manage each execution individual task

# Limitations

- Problems with large scale
  - > 4000 nodes
  - > 40k concurrent tasks
- Problems with resource utilization
- Only support one one type of computing paradigm (Slots only for Map or Reduce)
- Overloaded Job Tracker, Single point of failure!
- Restart is very tricky due to complex states → weak failover mechanism

# Increasing Requirement

- Rapid innovation in cluster computing frameworks

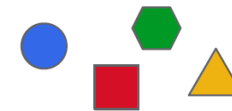


Dryad

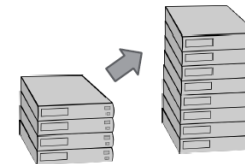
Google  
Pregel

Google  
Percolator

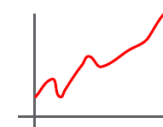
**Trend observed !**



Diverse workloads



Increasing cluster sizes



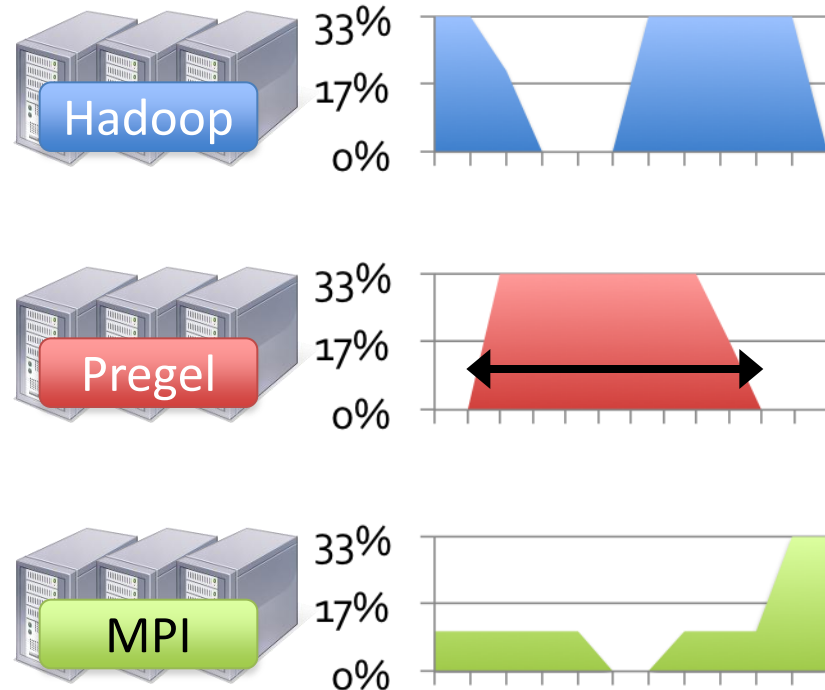
Growing job arrival rates

Users would like to run both existing and new application frameworks on the same physical clusters and at the same time.

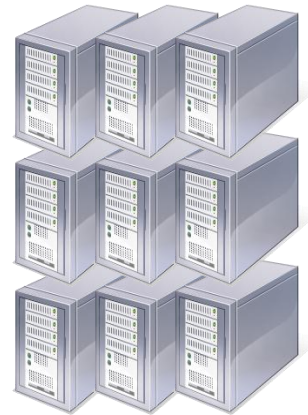
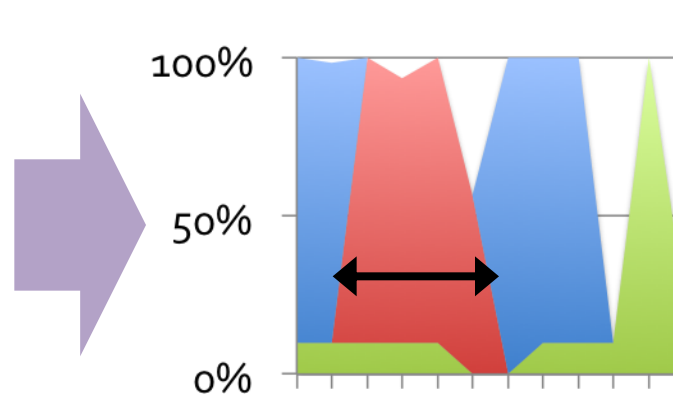
# Motivation

No single framework optimal for all applications

Today: static partitioning



dynamic sharing



Shared cluster

We want to run multiple frameworks in a single cluster

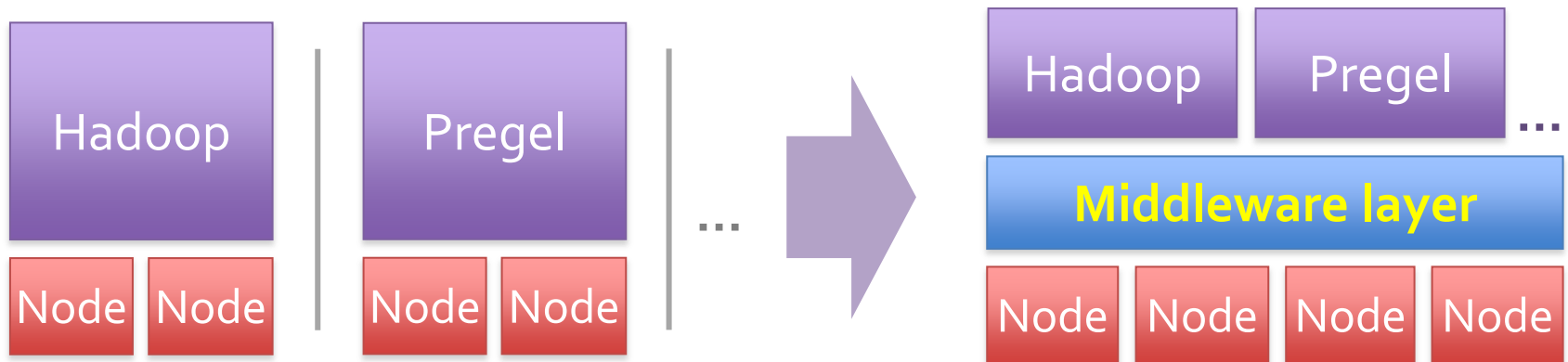
...to maximize utilization

...to share data between frameworks



# 2<sup>nd</sup> Generation(G2) Solutions

- We need a common resource sharing layer over which diverse frameworks can run.

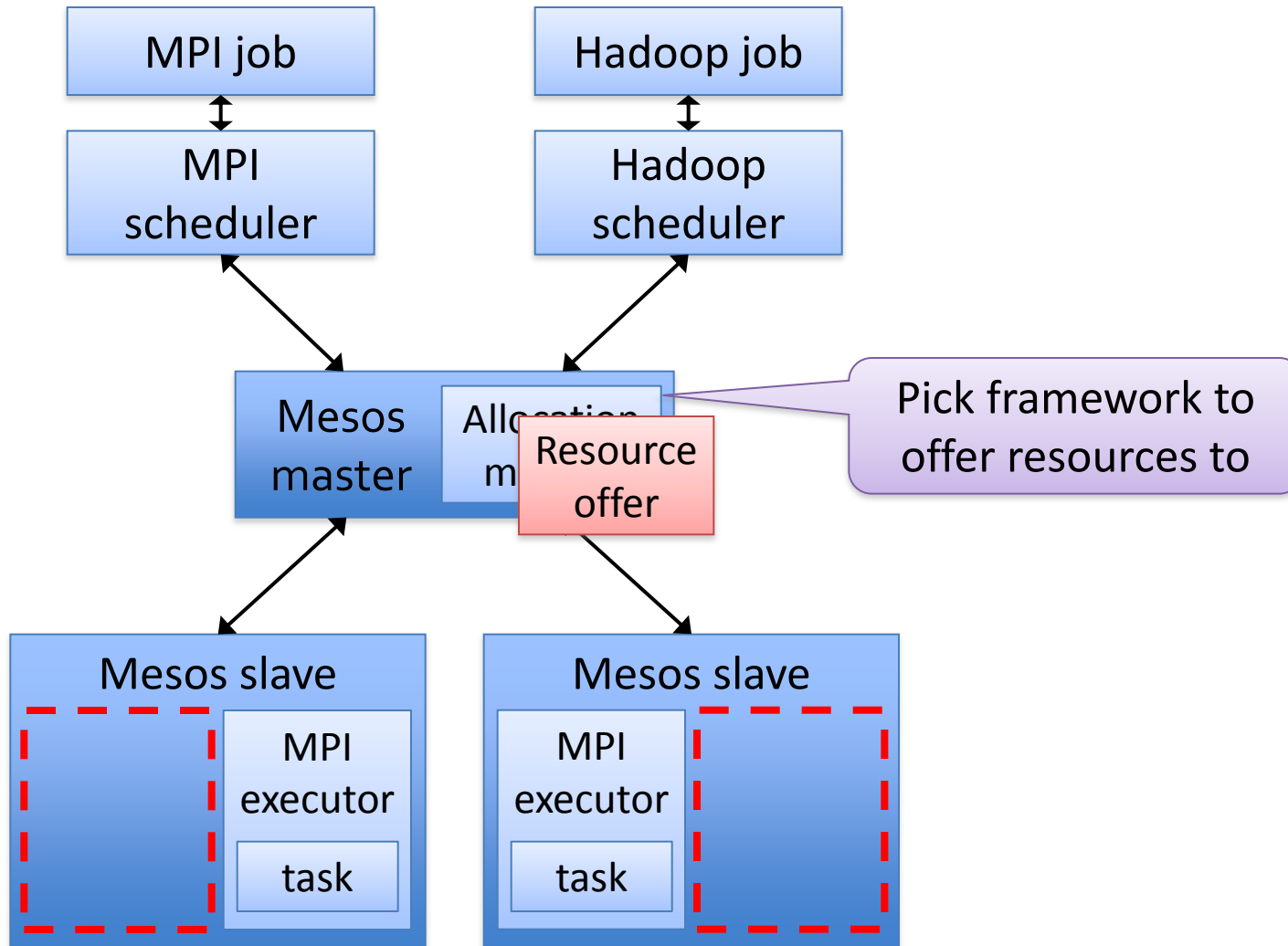


- Goals
  - **High utilization of resources**
  - **Support diverse frameworks**
  - **Better scalability to 10,000's of nodes**
  - **Improved reliability in face of failures**

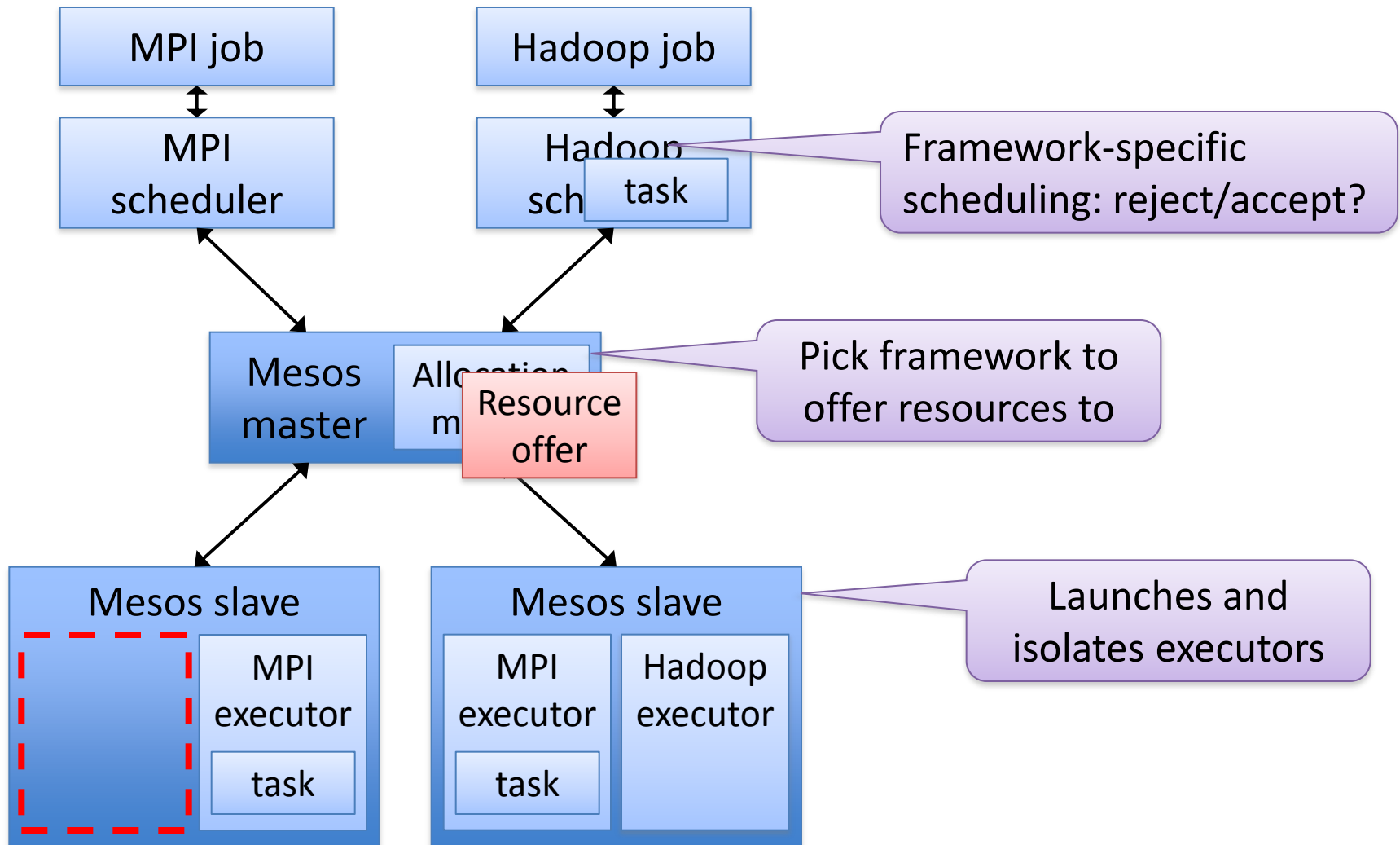
# Mesos from Berkeley

- Philosophy: “**offer and accept**” for resource
- **Resource allocation module in Mesos** decides how many resources should be offered to each application framework, based on an organizational policy such as fair sharing (e.g., DRF)
- Frameworks decide which resources to accept and which tasks to run on them.

# Mesos Architecture



# Mesos Architecture



## Limitations

- Passive offer-based policy
  - Only accept or reject what is on offer but cannot specify any request
  - Severed order of each framework depends on the offering order
  - Risk of long-time resource starving
  - Can not support resource preemption

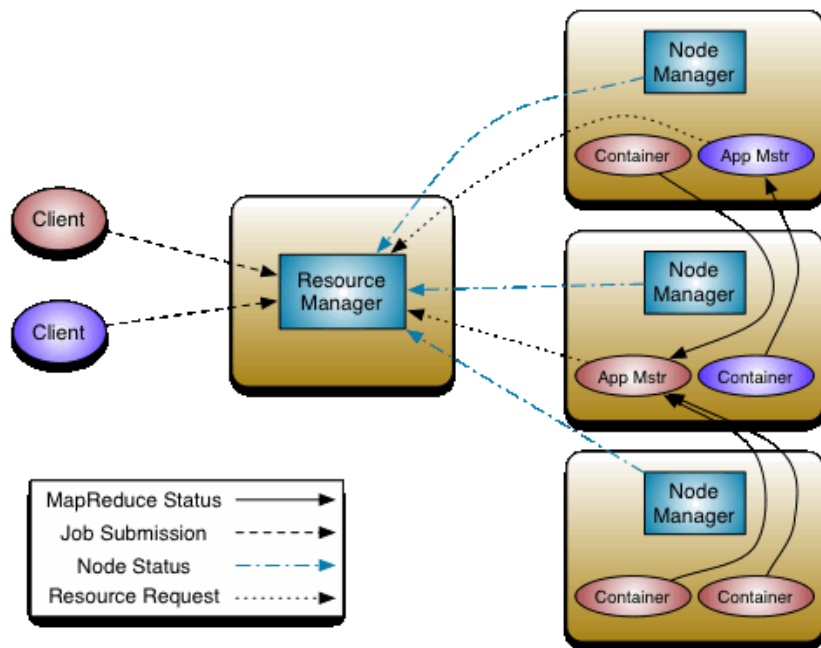
## G2++: Next Generation MRv2

- De-coupling *JobTracker* into:
  - Resource Management
  - Scheduling / Monitoring
- Following a request-based and active approach that improves scalability, resource utilization, fault tolerance.
- Providing slots for jobs other than Map / Reduce

# YARN

- ❖ *JobTracker* is de-coupled into
  - ❖ Global Resource Manager - Cluster resource management
  - ❖ Application Master - Job scheduling and monitoring (one per application). The Application Master negotiates resource containers from the Scheduler, tracking their status and monitoring for progress. Application Master itself runs as a normal container.
- ❖ *TaskTracker* is simplified into
  - ❖ NodeManager (NM) - A new per-node slave that is responsible for launching the applications' containers, monitoring their resource usage (CPU, memory, disk, network, etc) and reporting back to the Resource Manager.
- ❖ YARN maintains compatibility with existing MapReduce applications and users.

# Yarn's Architecture and Workflow



- 1) **Client -> Resource Manager**  
Submit App Master
- 2) **Resource Manager -> Node Manager**  
Start App Master
- 3) **Application Master -> Resource Manager**  
Request containers
- 4) **Resource Manager -> Node Manager**  
Start tasks in containers
- 5) **Node Manager -> Resource Manager**  
report running and *terminated container*, trigger new round of scheduling.



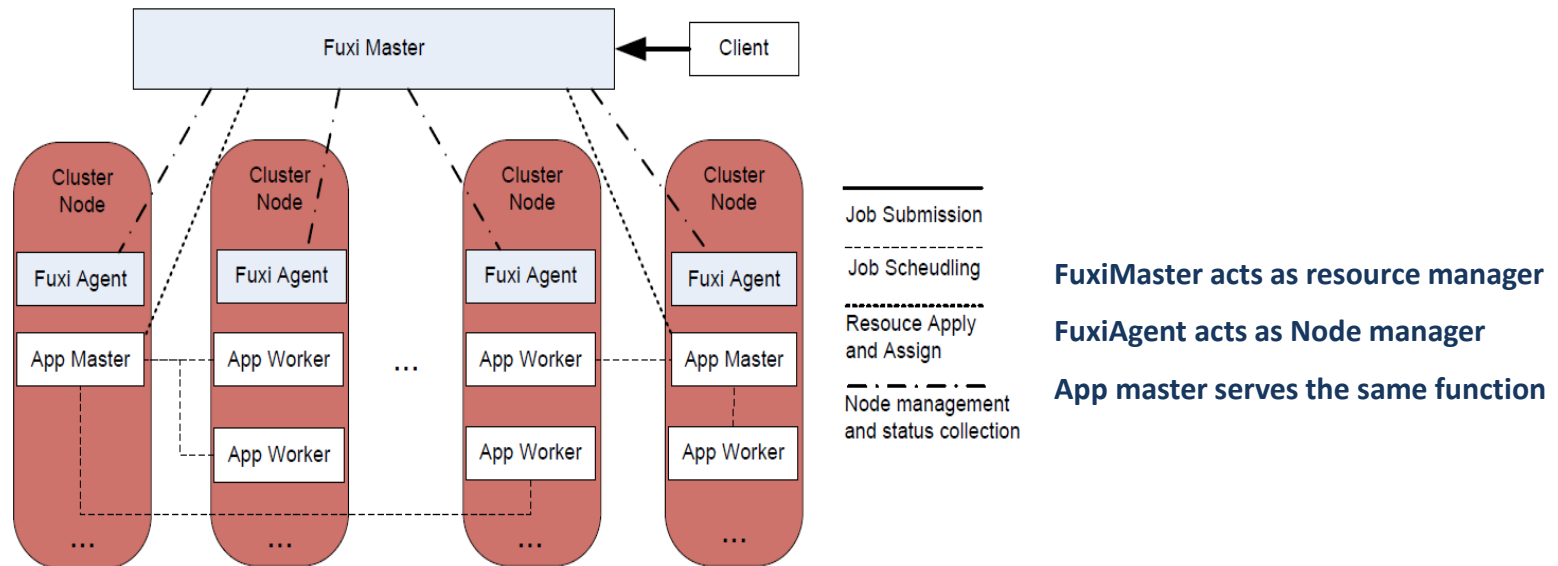
# Limitations

- **Scheduling dimensions**
  - (only CPU and memory) are limited and not easy to extend.
- **Scalability issues**
  - Resource assignment at the granularity of a task instance
  - The allocated resource to each container has to be reclaimed by NM once it terminates even if the application has more ready tasks to run.
  - RM has to conduct additional rounds of rescheduling.
  - At most 4k-nodes.
- **Failover mechanism** is not extremely pool to support larger scale:
  - RM: Non-transparent Resource Manager Failover
    - merely recover and restore its own states. **AMs can not survive RM restart.**
  - NM&AM:
    - It **uses mandatory termination and simply re-dos** failed/killed applications leading to substantial wastes and overheads.



# Fuxi System

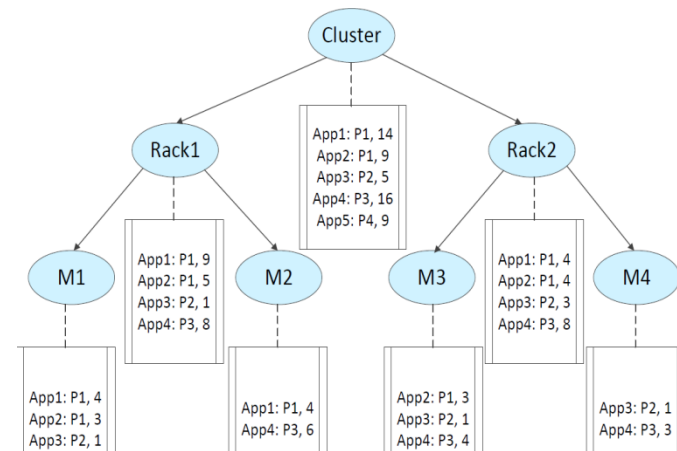
- The Fuxi architecture has similarities to YARN



- Focus on two challenging problems:
  - Scalability (+ Efficiency):**
    - How to support 5k or more nodes but avoiding message floods?
    - How to achieve hundreds of thousands of requests per second?
  - Fault-Tolerance (+ Efficiency):**
    - How to provide transparent failover mechanism?

# Improved Scalability

- **Incremental scheduling and communication**
  - Resource *request* is only sent once until the application master *release* the resources.
    - Scheduling tree and multi-level waiting queue with priority identified.
    - New round of scheduling is triggered only when resources release.
  - An incremental request will be sent only when the resource demands are dynamically adjusted.
    - Reducing frequency of message passing
    - Improving the whole cluster utilization
- **Multi-dimension resource allocation**
  - CPU, mem, other virtual resources



Scheduling tree example  
(multi-level waiting queues)

# Advanced Fault Tolerance

- **User-transparent failover mechanisms**
  - **Resource Manager:**
    - Refill **hard states** (meta-data, configuration file etc.) from light-weight checkpoint with no impact to running applications.
    - collect **soft states** from App Masters, Node Managers in run-time.
  - **Application Master:** can also performs failover to recover the finished and running workers by all task instances' snapshot.
  - **Node Manager:** rebuild the complete states with full granted resource and worker list.
- **Multi-level blacklist: “bad” (frequently failed) node detection**
  - Heartbeat threshold control
  - Application-level information collection
  - Plug-in service to aggregate OS-level information

# Good News

- Collaborated Paper will appear in top international conference VLDB 2014

## ***Fuxi: a Fault-Tolerant Resource Management and Job Scheduling System at Internet Scale***

Zhuo Zhang\*, Chao Li\*, Yangyu Tao\*, Renyu Yang\*, Hong Tang\*, Jie Xu\*  
Alibaba Cloud Computing Inc.\*      Beihang University†      University of Leeds‡  
(zhuo.zhang, li.chao, yangyu.tao, hongtang)@alibaba-inc.com  
yangry@act.buaa.edu.cn      j.xu@leeds.ac.uk

### ABSTRACT

Scalability and fault-tolerance are two fundamental challenges for all distributed computing at Internet scale. Despite many recent advances from both academia and industry, these two problems are still far from settled. In this paper, we present Fuxi, a resource management and job scheduling system that is capable of handling the kind of workload at Alibaba where hundreds of terabytes of data are generated and analyzed everyday to help optimize the company's business operations and user experiences. We employ several novel techniques to enable Fuxi to perform efficient scheduling of hundreds of thousands of concurrent tasks over large clusters with thousands of nodes: 1) an incremental resource management protocol that supports multi-dimensional resource allocation and data locality; 2) user-transparent failure recovery where failures of any Fuxi components will not impact the execution of user jobs; and 3) an effective detection mechanism and a multi-level black-listing scheme that prevents them from affecting job execution. Our evaluation results demonstrate that 95% and 91% scheduled CPU/memory utilization can be fulfilled under synthetic workloads, and Fuxi is capable of achieving 2.36TB/minute throughput in GraySort. Additionally, the same Fuxi job only experiences approximately 16% slowdown under a 5% fault-injection rate. The slowdown only grows to 20% when we double the fault-injection rate to 10%. Fuxi has been deployed in our production environment since 2009, and it now manages hundreds of thousands of server nodes.

### 1. INTRODUCTION

We are now officially living in the *Big Data* era. According to a study by Harvard Business Review in 2012, 2.5 exabytes of data are generated everyday and the speed of data generation doubles every 40 months [13]. To keep up with the pace of data generation, data processing has also been progressively migrating from traditional database-based approaches to distributed systems that scale out much easi-

ly. In recent years, many systems have been proposed from both academia and industry to support distributed data processing with commodity server clusters, such as Mesos [11], Yarn [18] and Omega [16]. However, two major challenges remain unsettled in these systems when faced with the challenges of managing resources for systems at Internet scale:

1) **Scalability:** Resource scheduling can be simply considered as the process of matching demand (requests to allocate resources to run processes) with supply (available resources of cluster nodes). So the complexity of resource management is directly affected by the number of concurrent tasks and the number of server nodes in a cluster. Furthermore, other factors also impact the complexity, including supporting resource allocation over multiple dimensions (such as CPU, memory, and local storage), fairness and quota constraints across competing applications, and scheduling tasks close to data. A naive approach of delegating everything decision to a single master node (as in Hadoop 1.0) would be severely limited by the capability of the master. On the other hand, a fully-decentralized solution would be hard to design to satisfy scheduling constraints that depends on fast-changing global states without high synchronization cost (such as quota management). Both Mesos and Yarn attempt to deal with these issues in slightly different ways. Mesos adopts a multiple-level resource offering framework. However, Mesos master offers free resources in turn among frameworks, the waiting time for each framework to acquire desired resources highly depends upon the resource offering order and other frameworks' scheduling efficiency. Yarn's architecture decouples resource management and programming paradigms. However, the decoupling is only for the separation of code logic between resource management and MapReduce job execution, so that other programming paradigms can be accommodated in Yarn. Nevertheless, it does not reduce the complexity of resource management, and still inherits the linear resource model as in Hadoop 1.0.

In both cases, states are exchanged with periodic messages and the interval configuration is another intricate challenge. A long period could reduce communication overhead but would also hurt utilization when applications wait for resource assignment. On the other hand, frequent adjustments would improve response to demand/supply changes (and thus improve resource utilization); however, it would also aggravate the message flooding phenomenon. In fact, Yahoo! reported that they did not run Hadoop clusters bigger than 4,000 nodes [18] and Yarn had yet to demonstrate its scale limit.

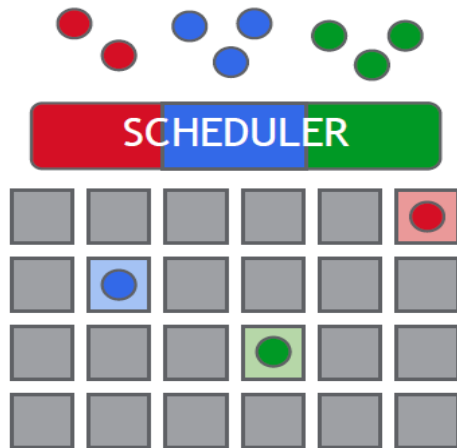
2) **Fault-tolerance:** With increasing scale of a cluster,

Zhuo Zhang, Chao Li, Yangyu Tao, Renyu Yang, Hong Tang, and Jie Xu. ***Fuxi: a Fault-Tolerant Resource Management and Job Scheduling System at Internet Scale***, The 40th International Conference on Very Large Data Base (VLDB 2014), Hangzhou, China, 2014 (to appear)

This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivs 3.0 Unported License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-nd/3.0/>. Obtain permission prior to any use beyond those covered by the license. Contact copyright holder by emailing [info@vldb.org](mailto:info@vldb.org). Articles from this volume were invited to present their results at the 40th International Conference on Very Large Data Bases, September 1st - 5th 2014, Hangzhou, China. Proceedings of the VLDB Endowment, Vol. 7, No. 13 Copyright 2014 VLDB Endowment 2150-4071/14/08.

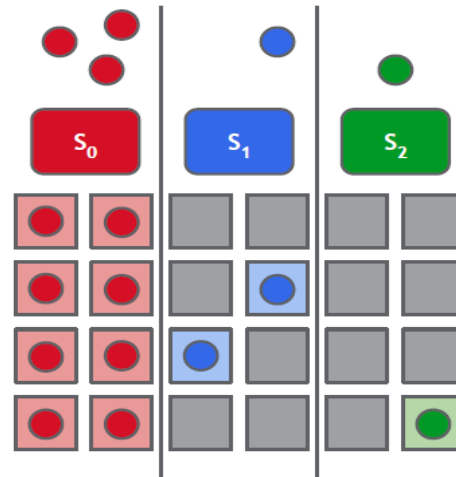
# Google's view of multiple framework mixture

monolithic scheduler



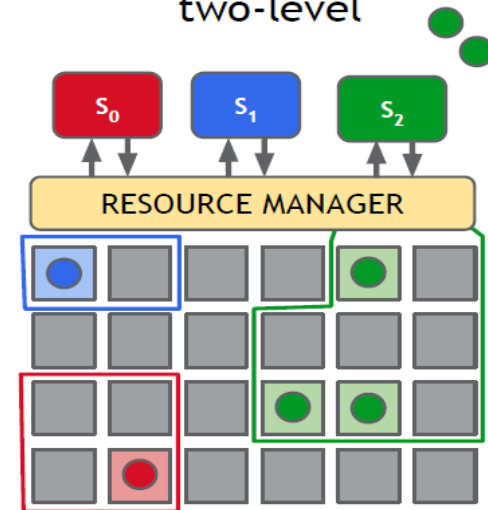
- hard to diversify
- code growth
- scalability bottleneck

static partitioning



- poor utilization
- inflexible

two-level



- hoarding
- information hiding

*Mesos/Yarn/Fuxi*

- Conservative resource-visibility and locking algorithms limit both flexibility and parallelism.
- Hard to place difficult-to-schedule “picky” jobs or to make decisions that require access to the state of the entire cluster.

## Third Generation? – Google's view

- Google proposes ***shared state*** by using lock-free optimistic concurrency control.
  - Lock-free optimistic concurrency control over the shared states, collected timely from different nodes.
  - Each application framework holds the same resources view and competes for the same piece of resource with a central **coordination component** for arbitration.

## Potential Limitations in Google's Omega

- More efficient? Let's wait and see...
- It is hard to enforce global properties such as capacity/fairness/deadlines.
- It may be tough for heterogeneous frameworks outside Google when sharing the same cluster.
- Current simulation-based evaluation needs more real-life experience and practice.

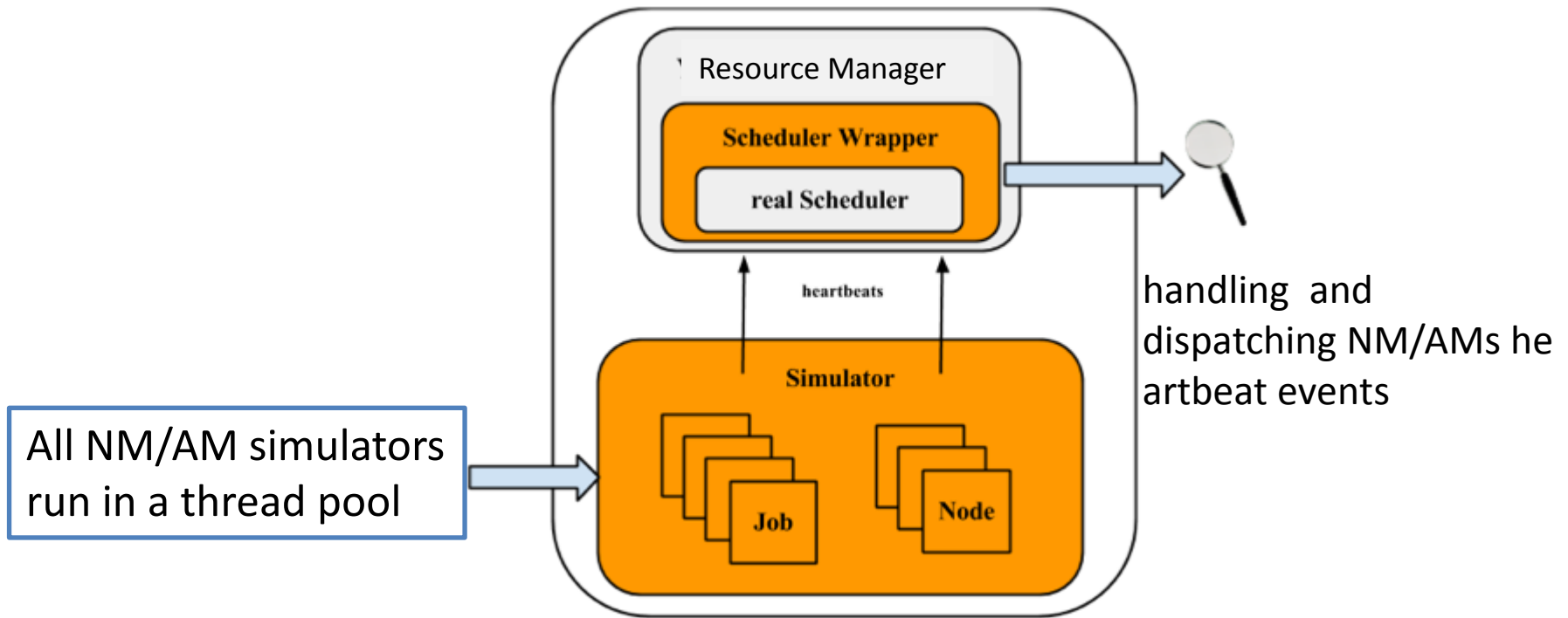


# Scheduler Simulation

- Why we need Scheduler Load Simulation?
  - Evaluating in a real cluster is always time and cost consuming
  - it is also very hard to find a large-enough cluster.
  - It is quite useful predict how well a scheduler algorithm for some specific workload
- Examples:
  - GridSim
  - CloudSim
  - Yarn SLS
  - Etc.

# Simulation Workflow

- UT(Unit Test) or ST(System Test)



- Typical Resource Scheduler Models:
  - Node Manager is proactive
  - App Master is proactive

# Methodology: Trace-driven Simulator Design

- Data Provenances:
  - Light-weighted synthetic workloads:
    - Sampled data;
    - Using parameters drawn from empirical workload distribution;
    - *Similar to what we do (Google trace, work from Beihang & Leeds )*
  - Real trace data:
    - Historical workload traces, e.g., job status tracelog
- Reflexed Metrics:
  - resource request size, tasks per job, job arrival/submission rate, task duration, related constraints

# Methodology

- In small scale cluster, larger scale cluster environment could be simulated by creating Node Managers.
- Emulate app Masters and the interactions with Resource Manager
  - Resource request (when and how many)
  - Resource reclaim (when  $\leftarrow$  task duration)
- Work in progress and see more results in our paper to appear.

# More Details

- Ask Renyu for more details of the design in distributed scheduler load simulator
- Email:
  - [\\_yangry@act.buaa.edu.cn](mailto:yangry@act.buaa.edu.cn)
  - Renyu Yang @ Beihang

# Reference

- [1] V. K. Vavilapalli, A. C. Murthy, C. Douglas, S. Agarwal, M. Konar, R. Evans, T. Graves, J. Lowe, H. Shah, S. Seth, et al. Apache hadoop yarn: Yet another resource negotiator. In Proc. SoCC, page 5. ACM, 2013.
- [2] M. Schwarzkopf, A. Konwinski, M. Abd-El-Malek, and J. Wilkes. Omega: Flexible, scalable schedulers for large compute clusters. In Proc. EuroSys, pages 351-364. ACM, 2013
- [3] B. Hindman, A. Konwinski, M. Zaharia, A. Ghodsi, A. D. Joseph, R. Katz, S. Shenker, and I. Stoica. Mesos: A platform for fine-grained resource sharing in the data center. In Proc. NSDI, Usenix, 2011.
- [4] J. Dean and S. Ghemawat. Mapreduce: simplified data processing on large clusters. Communications of the ACM, 51(1):107-113, 2008.
- [5] Apache Hadoop. <http://hadoop.apache.org/>
- [6] <http://www.pdl.cmu.edu/SDI/2013/slides/wilkes-sdi.pdf>
- [7] Zhuo Zhang, Chao Li, Yangyu Tao, Renyu Yang, Jie Xu. Fuxi: Fault Tolerant Resource Management and Job Scheduling System at Internet Scale (to appear in Proceeding of VLDB 2014 vol.7) , Sept 2014.
- [8] SLS: <http://hadoop.apache.org/docs/r2.3.0/hadoop-sls/SchedulerLoadSimulator.html>

# Thank you for your attention!



**Renyu Yang, Ph.D. student**

School of Computing

Beihang University, Beijing, China

Homepage: <http://act.buaa.edu.cn/yangrenyu>

Email: [yangry@act.buaa.edu.cn](mailto:yangry@act.buaa.edu.cn)