Resource Management in Large Shared Clusters

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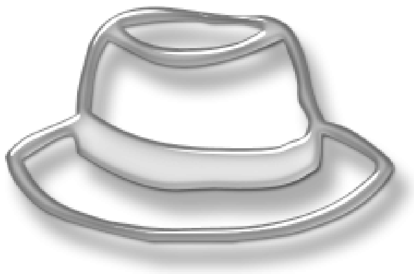
Microsoft CISL

University of Washington, Database Day

December 2, 2016

The 3 hats we wear in CISL



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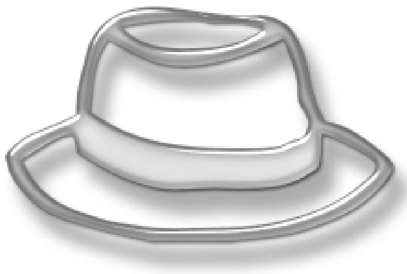

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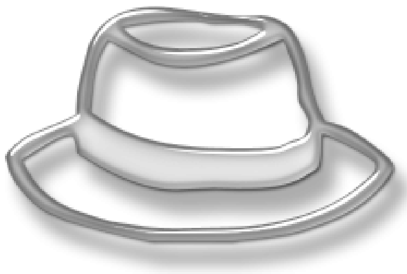

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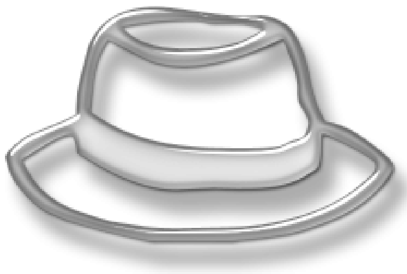

Open-sourcing our code

Apache Hadoop, REEF, Heron

CISL focus

Resource management

Distributed tiered storage

Query optimization

Log analytics

Stream processing

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- Distributed tiered storage
- Query optimization
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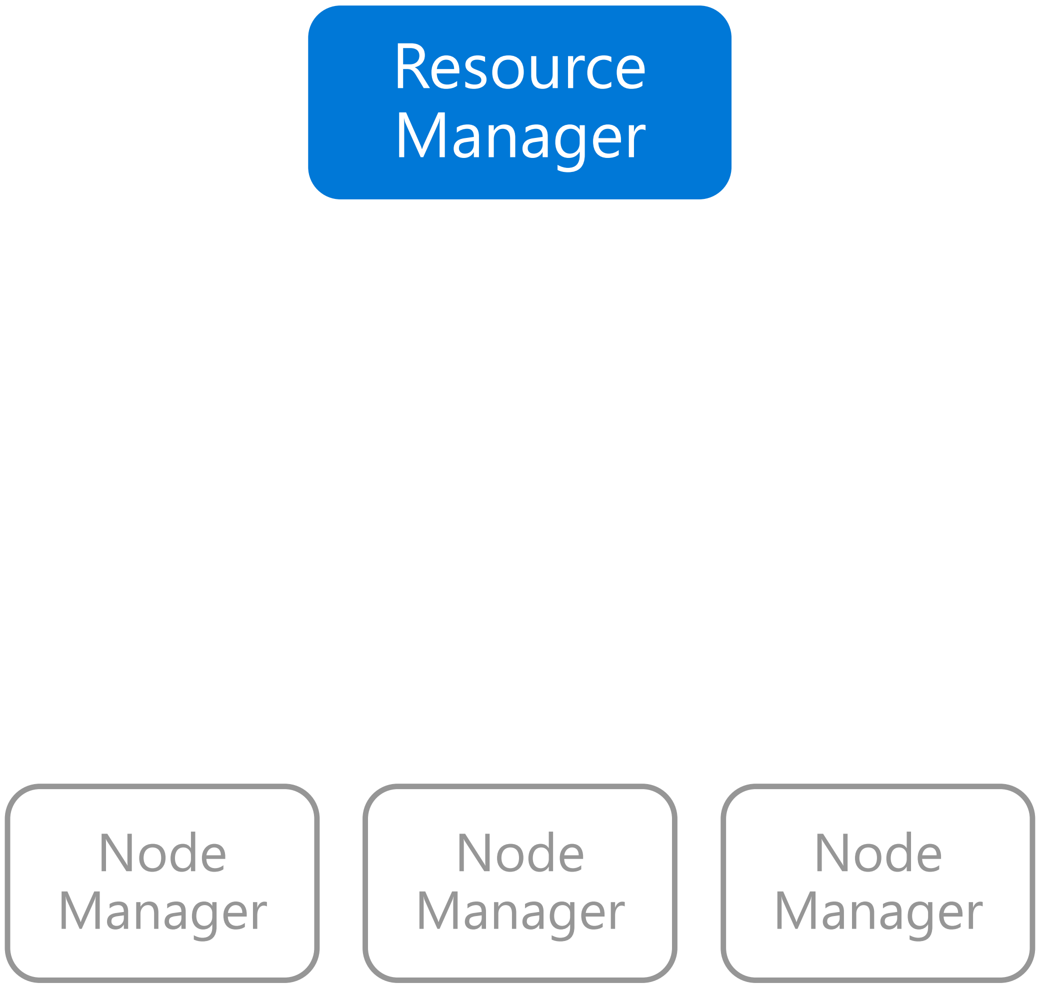
What is a Resource Manager?



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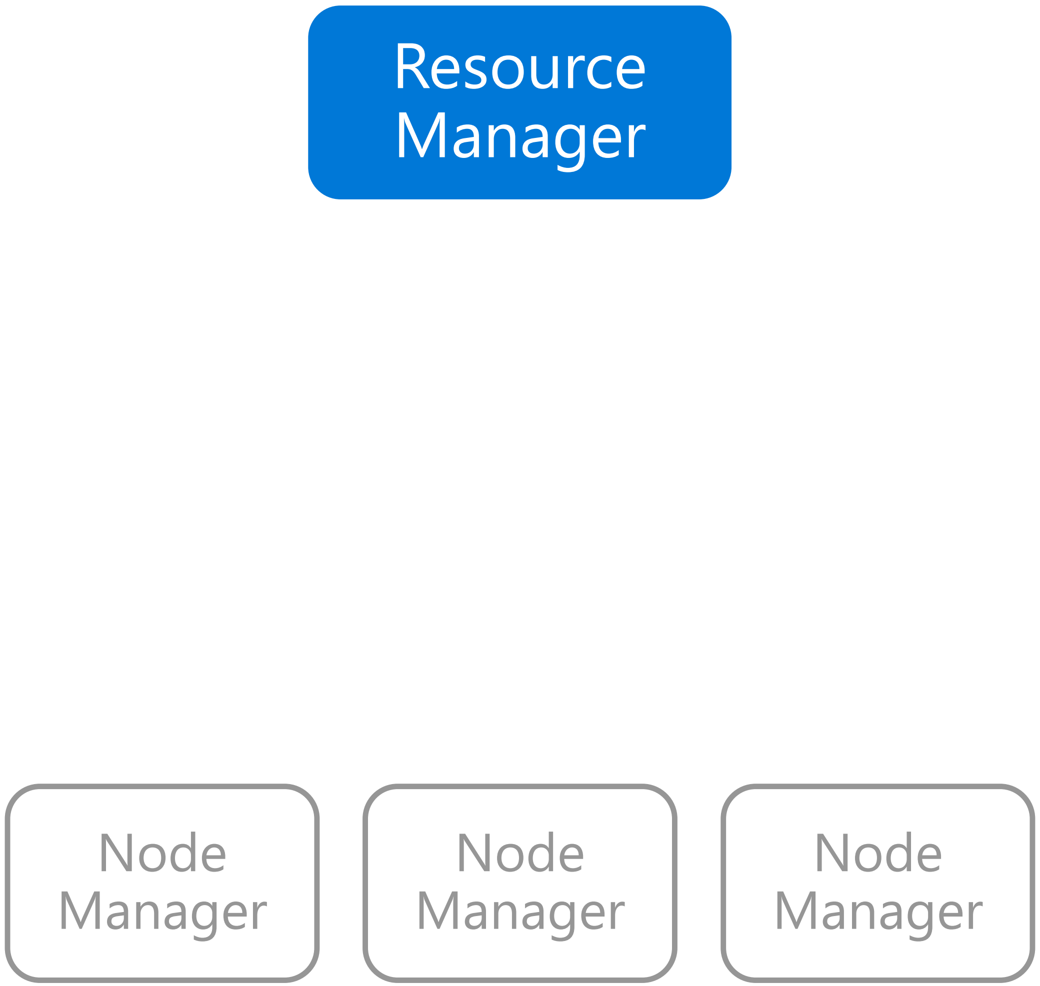

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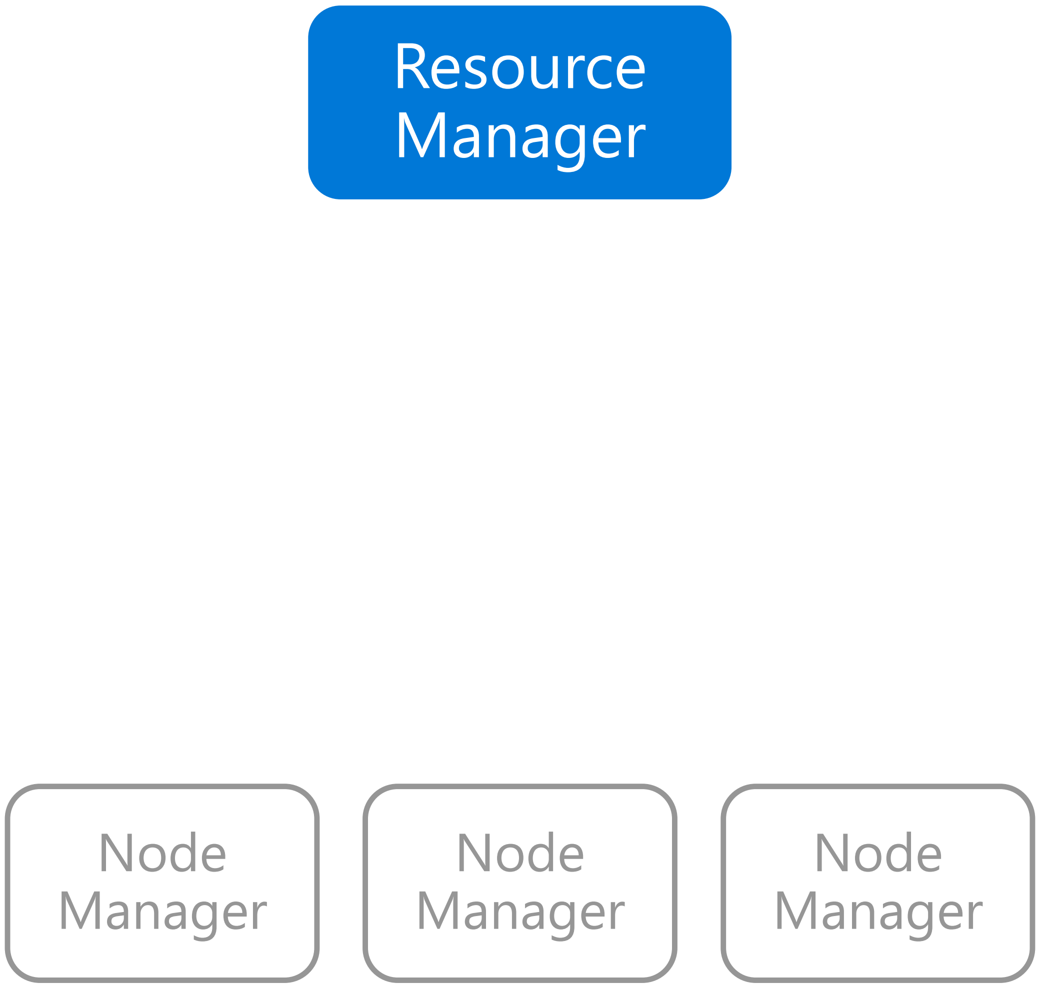

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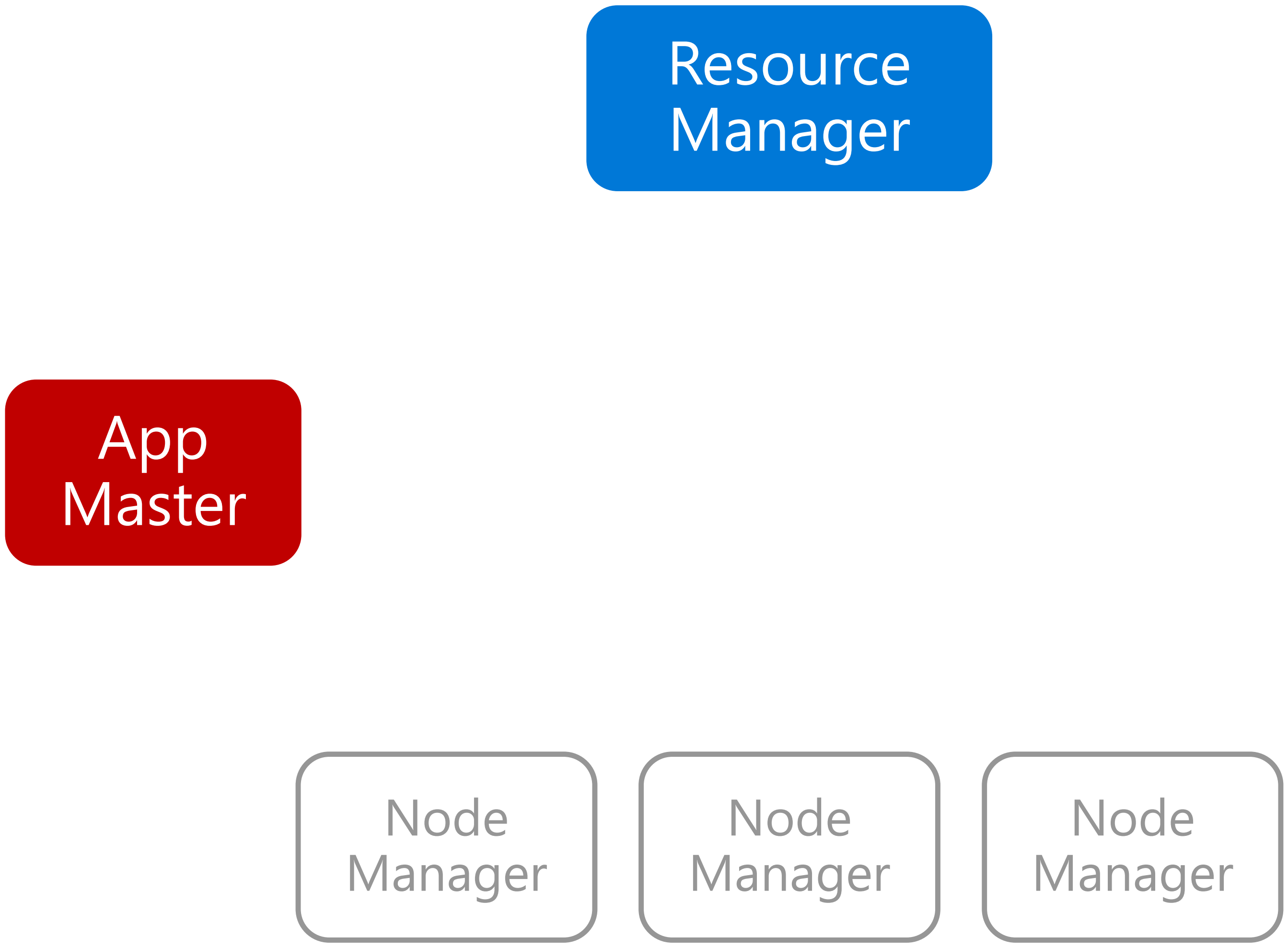

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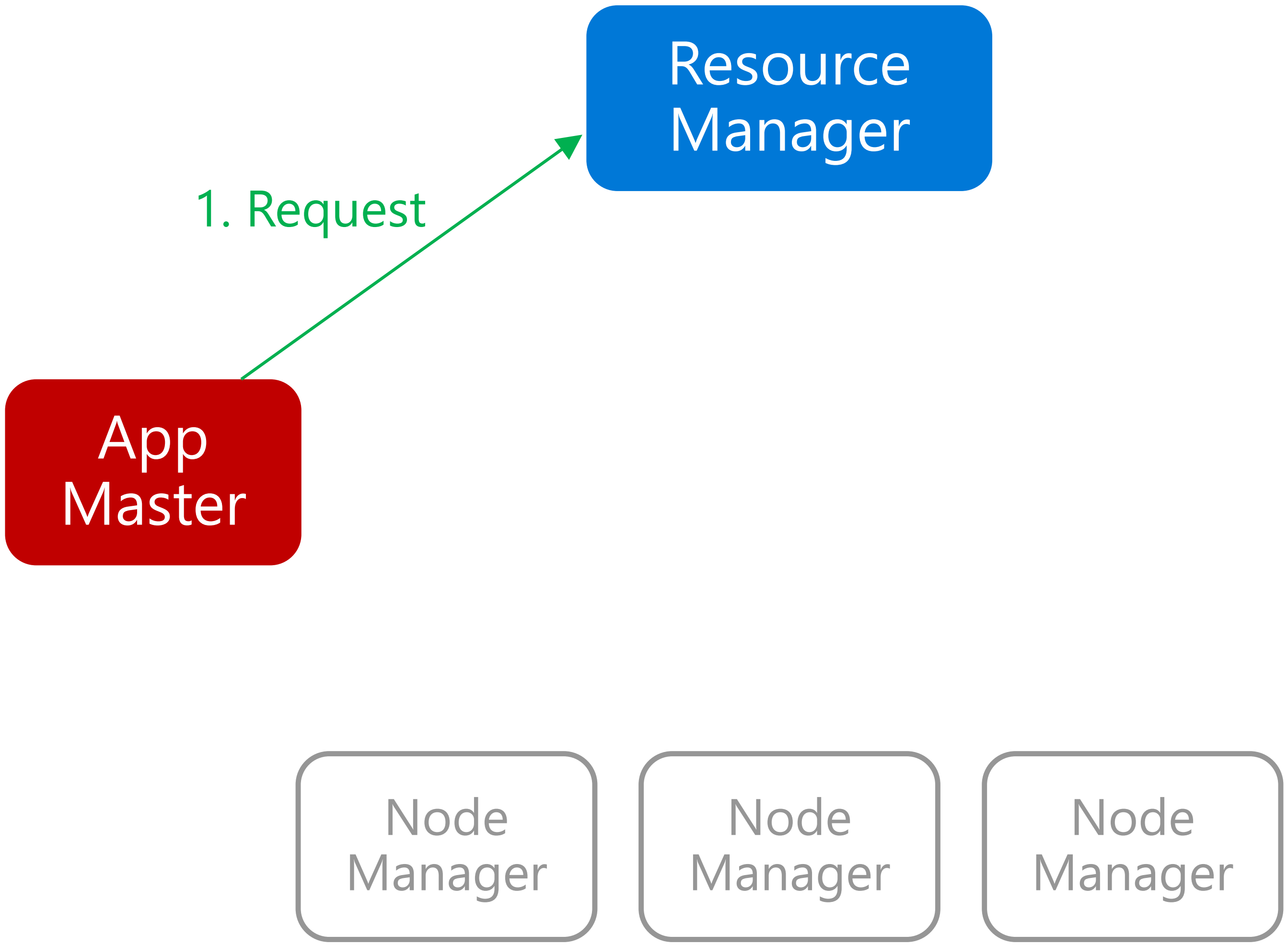

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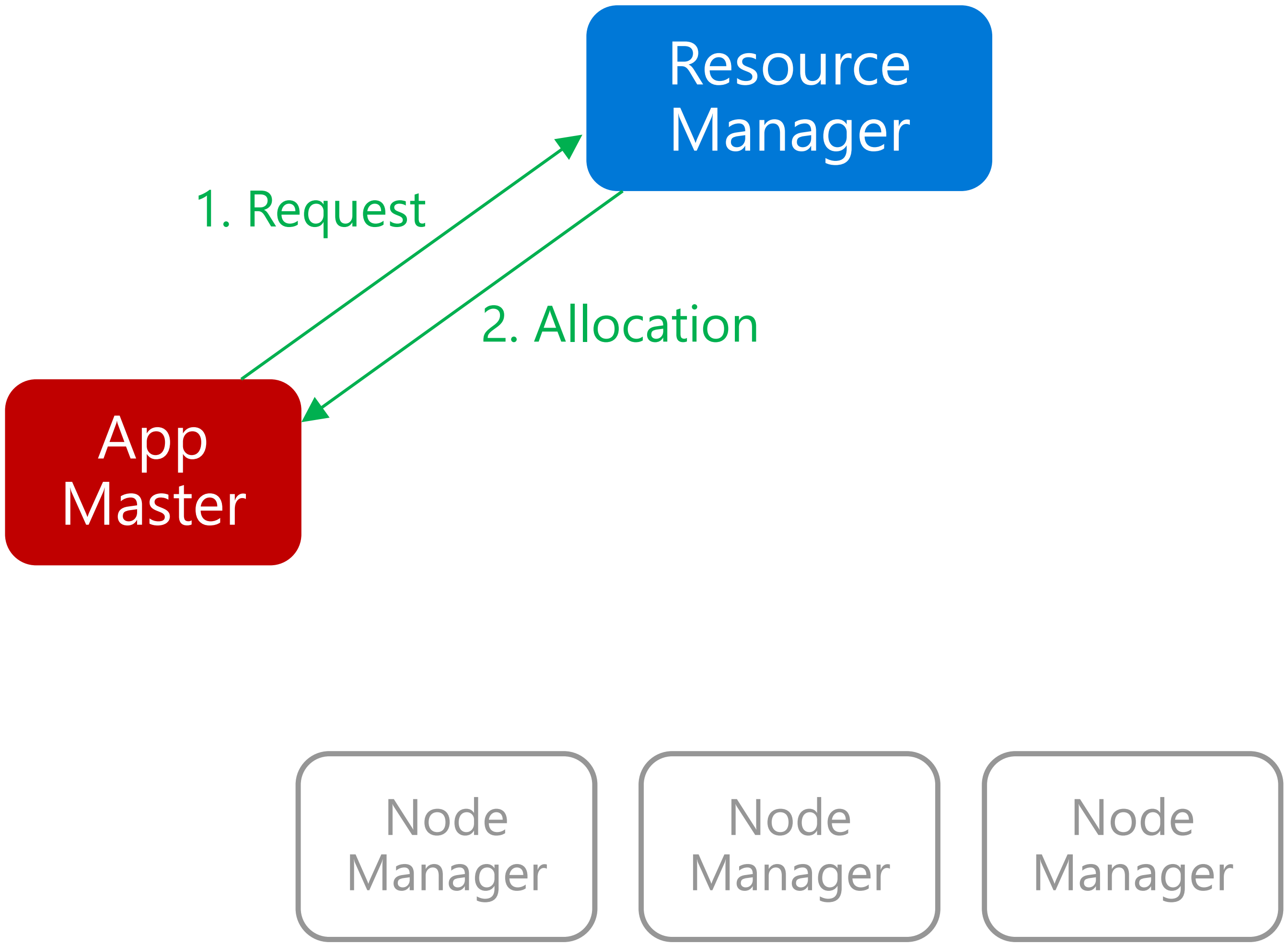

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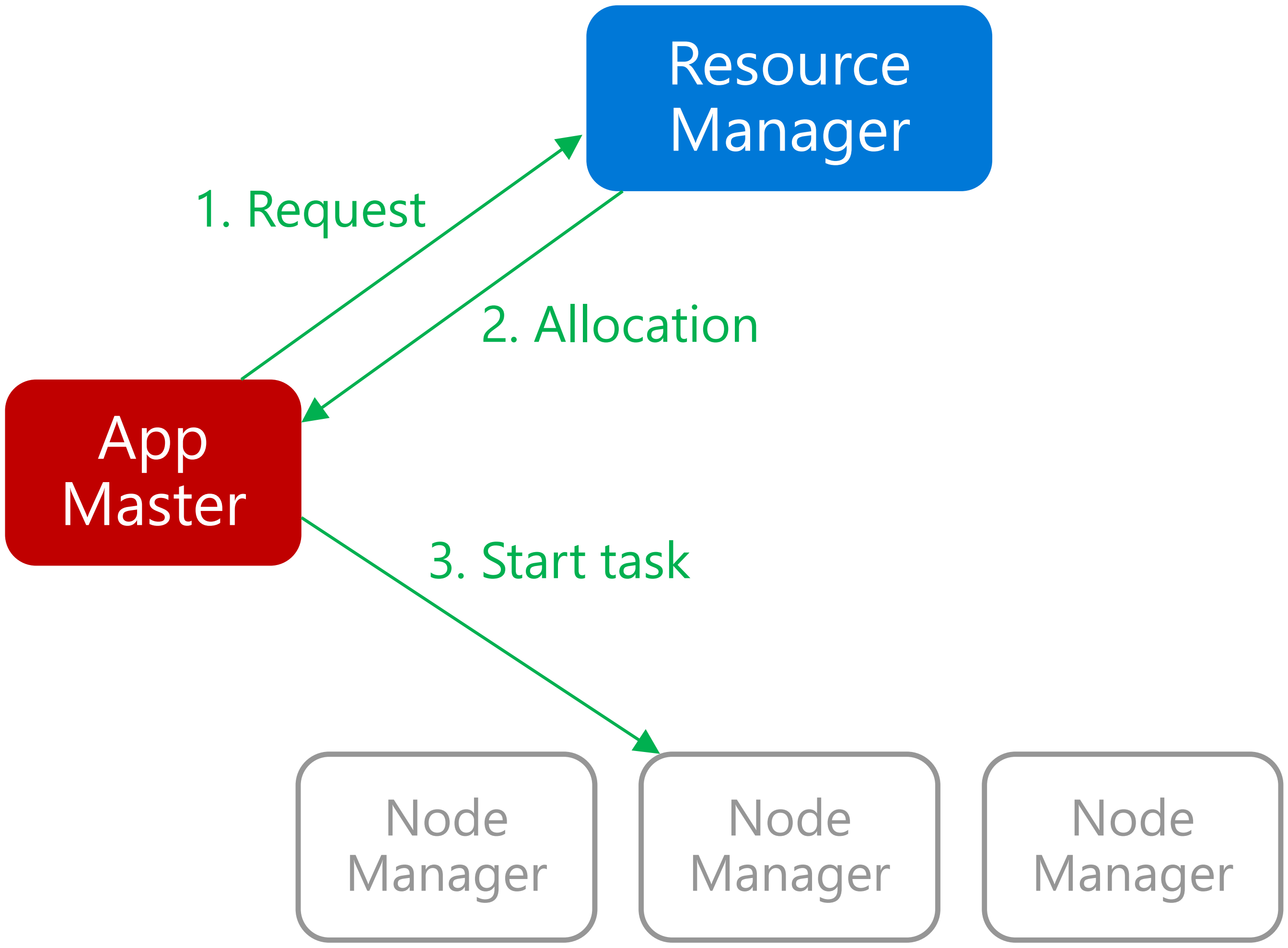

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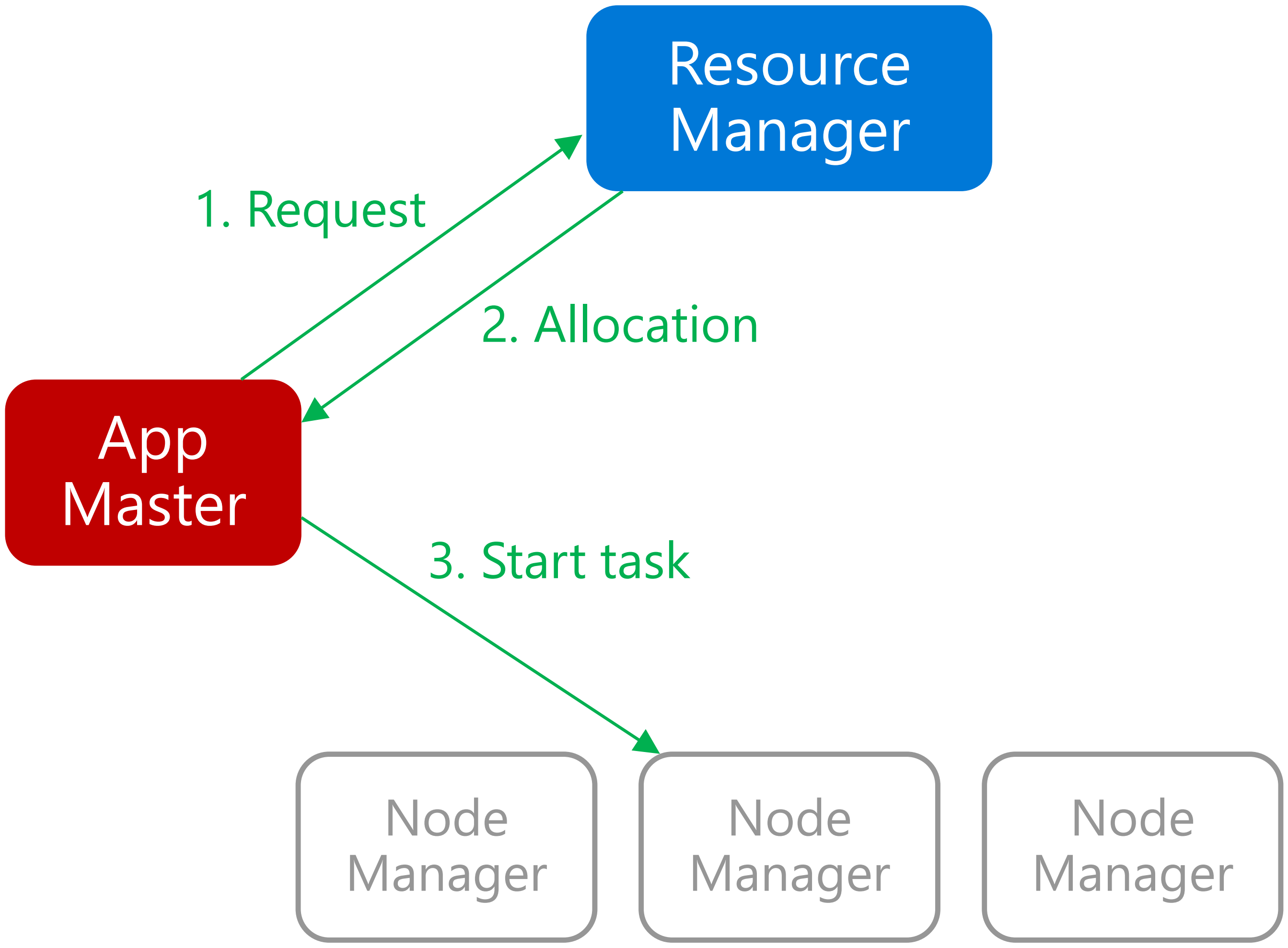

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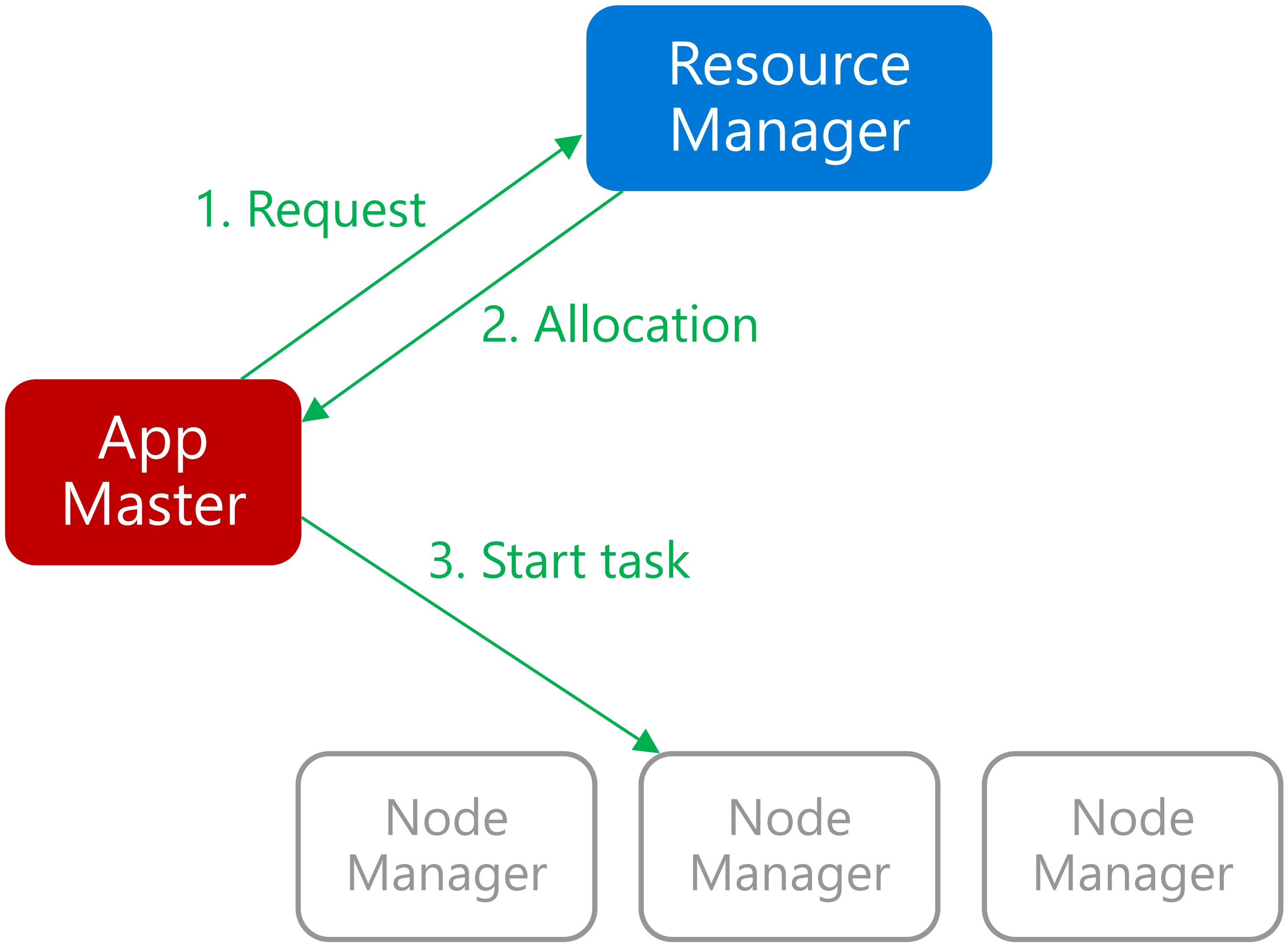

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- Same end goal, different designs
  - Centralized/distributed
  - Targeting batch/interactive jobs, production/best-effort jobs, services

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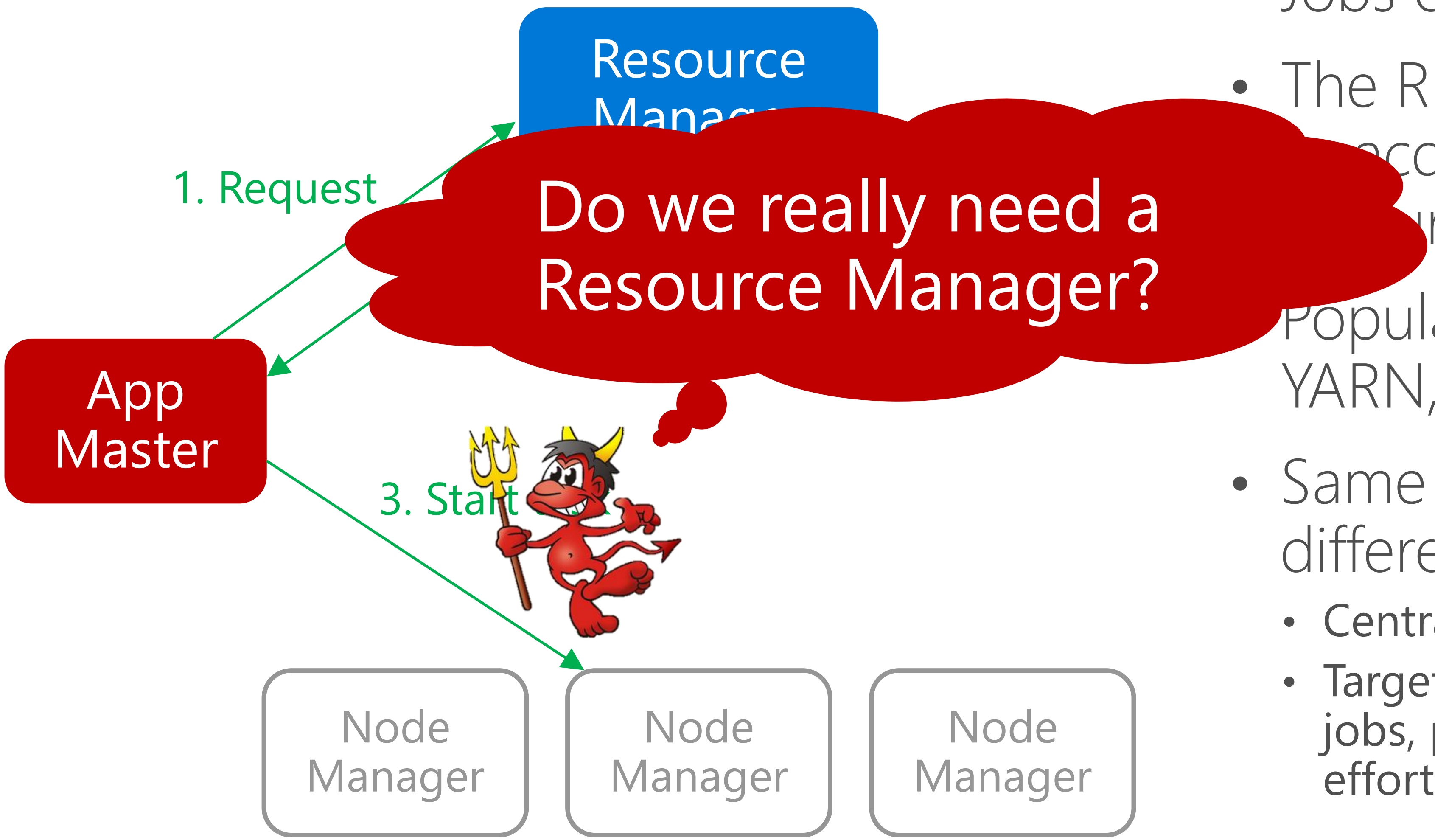

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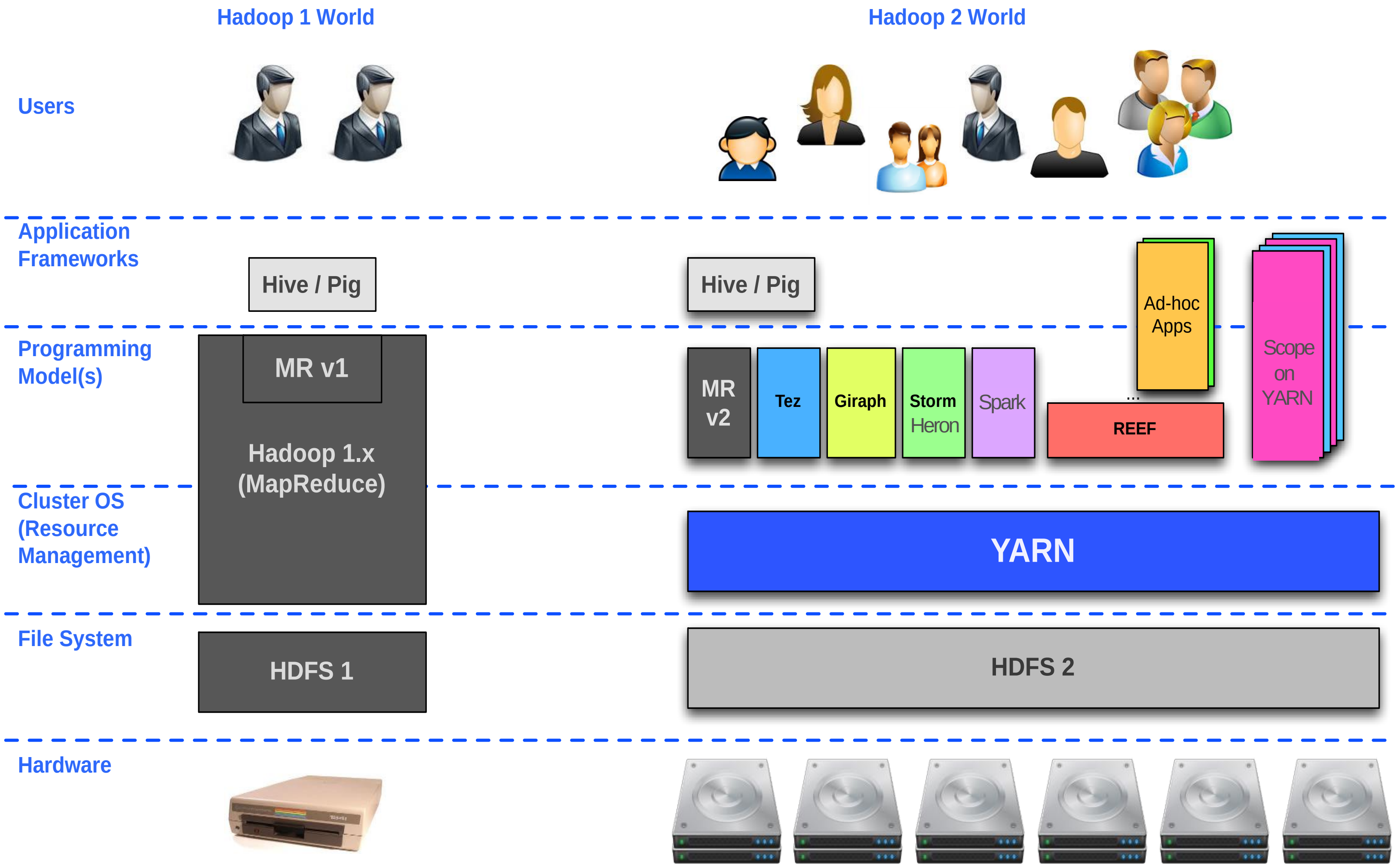
Lessons learned: Abstracting out the RM layer



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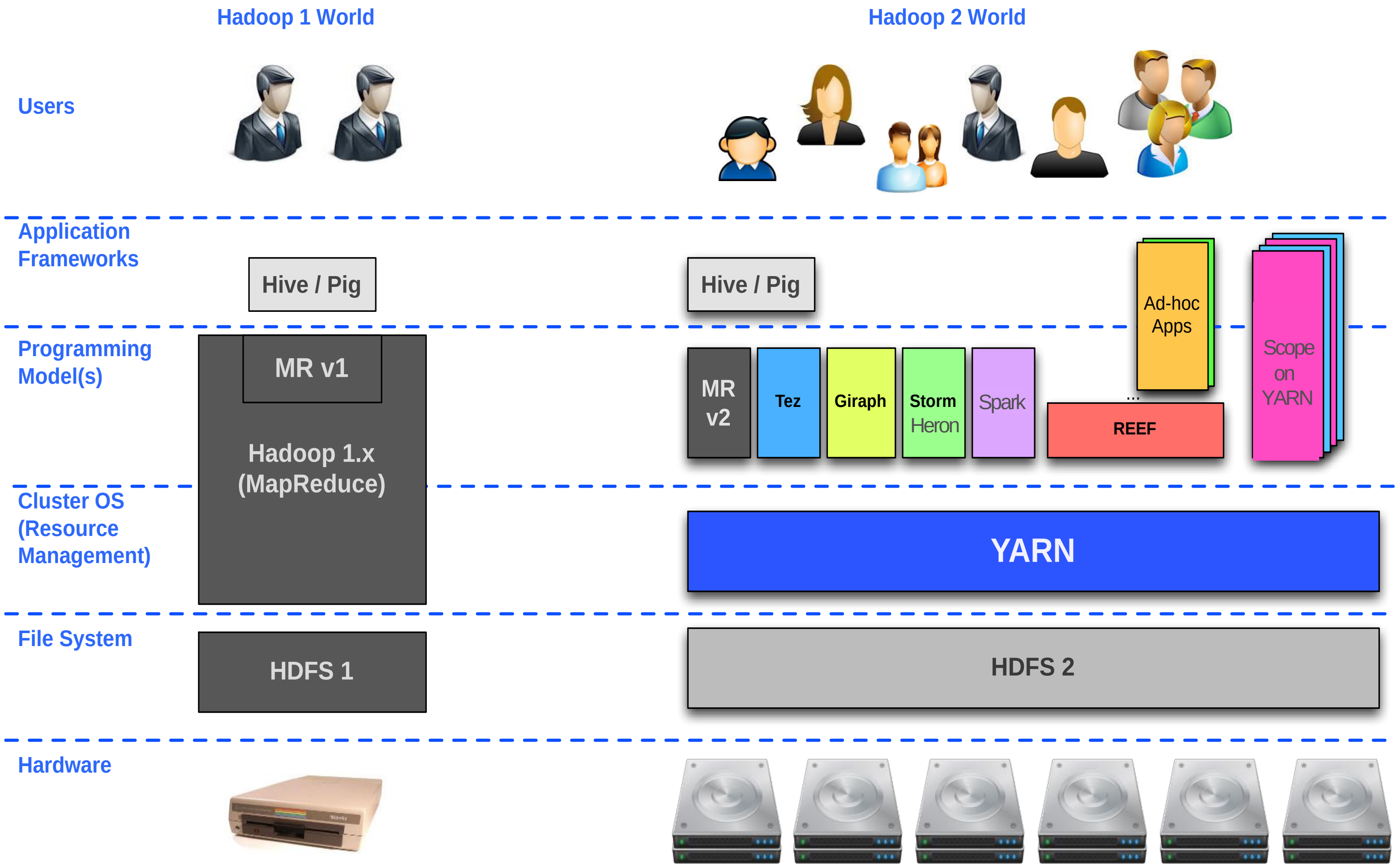

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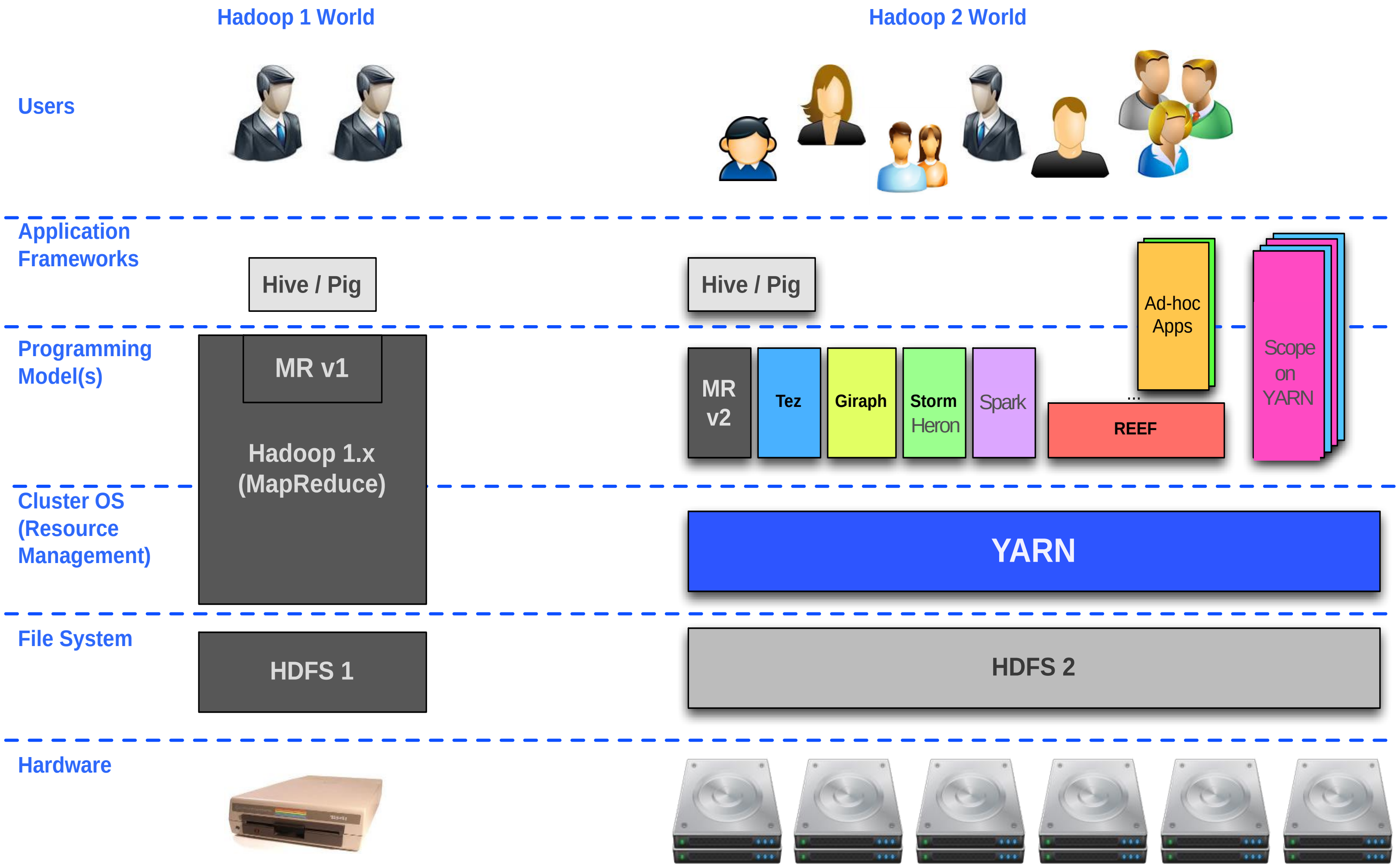

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- Reuse of RM component by multiple applications
- We focus on YARN, but most systems follow layering abstractions

Why YARN?

- Centralized scheduler
  - High-quality scheduling decisions
- Initial target: batch analytics jobs
  - Long task durations
- Sharing constraints
  - Fairness/capacity guarantees across users
- Scalability
  - Works well with clusters up to ~5000 nodes
- Mature open-source code base
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But is all this good *enough* for the Microsoft clusters?

A closer look to our cluster needs

High resource utilization

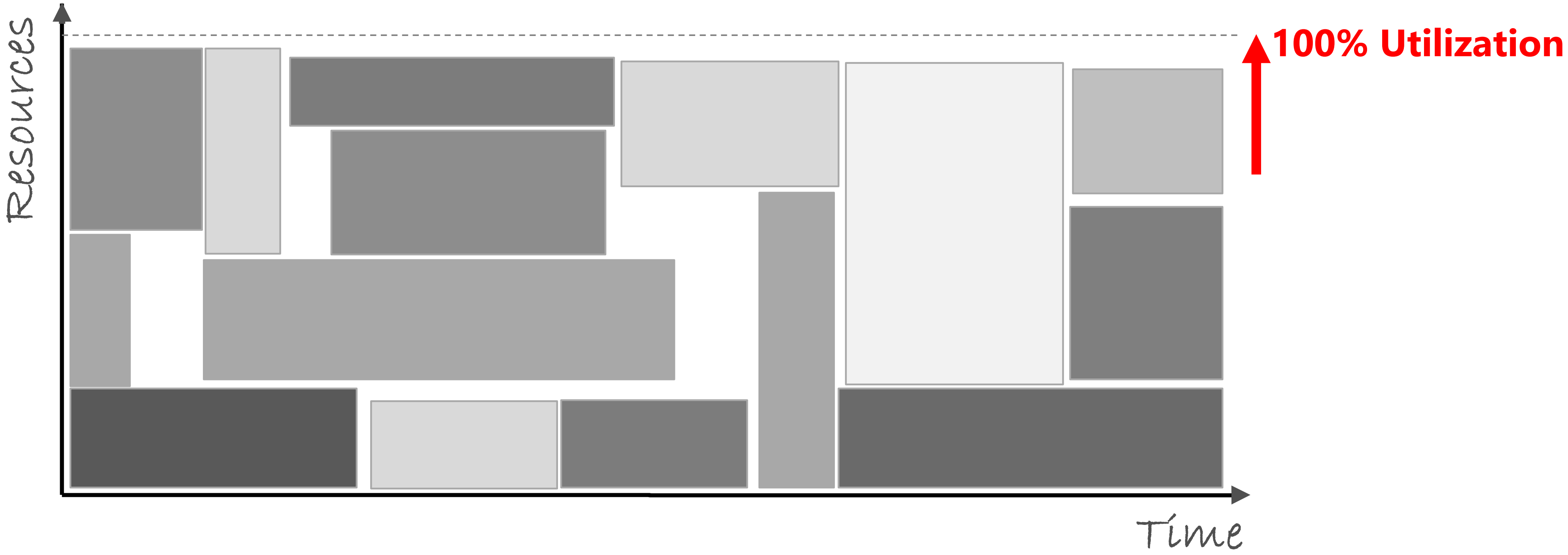
Scalability

Workload heterogeneity

Production jobs and predictability

Resource utilization

- Higher utilization → higher RoI
- Pack as many tasks as possible at each moment



Scalability

Scale to 5000   nodes

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- Wide variety of workloads…
  - Production SLA jobs, best-effort jobs, services, interactive queries
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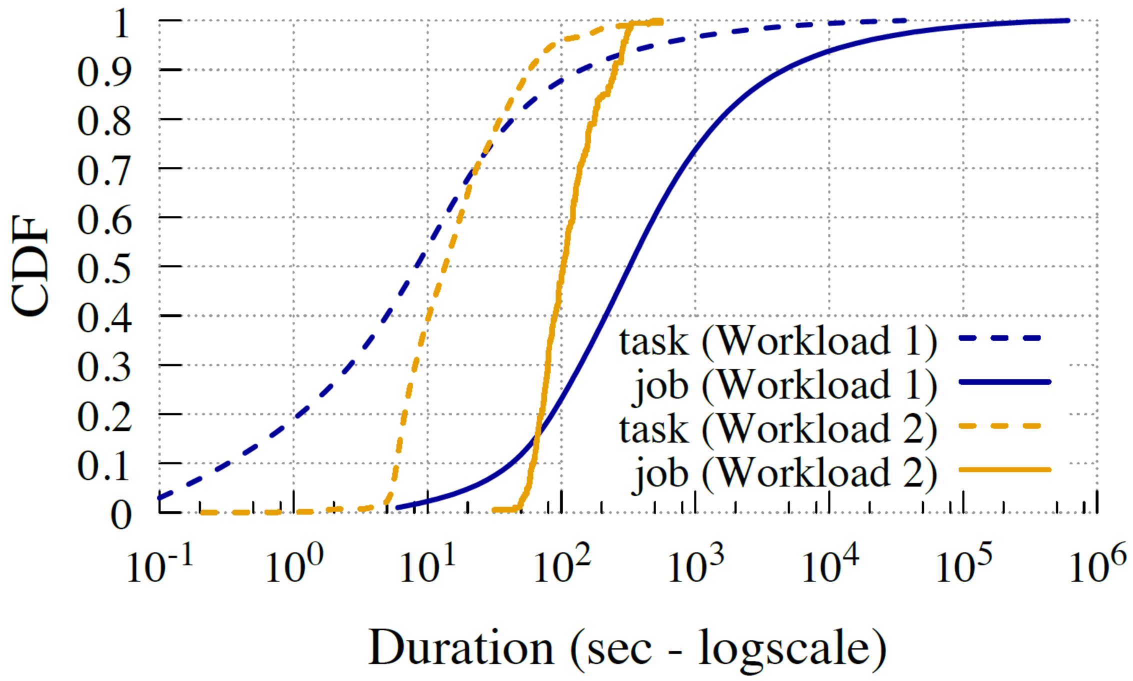

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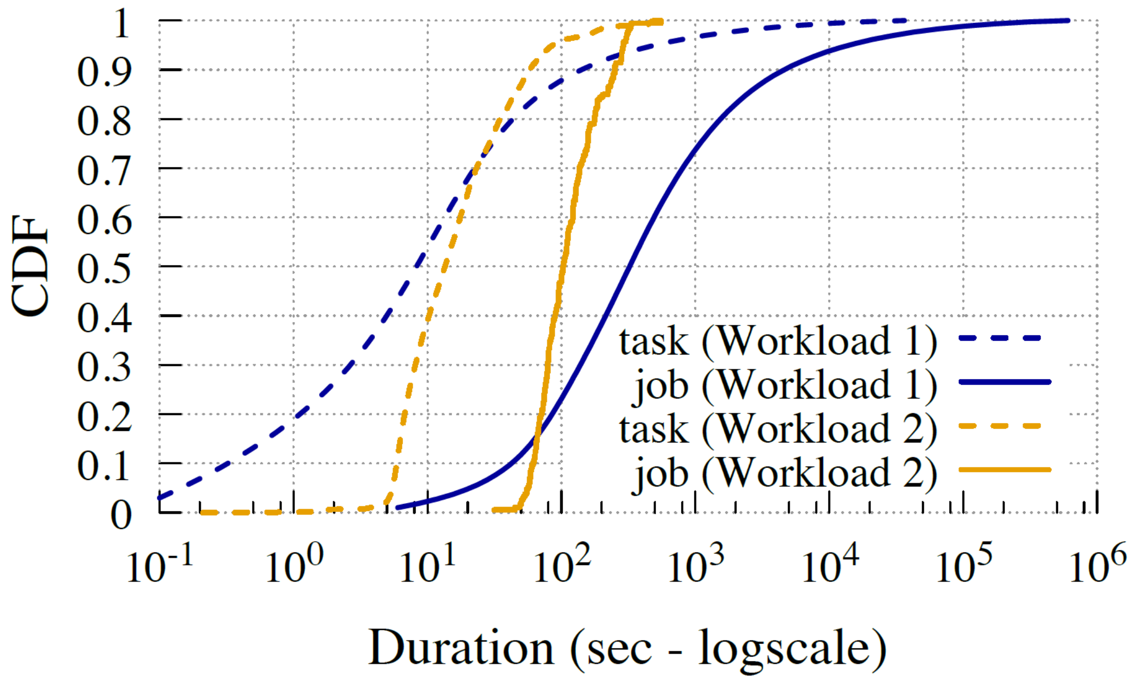

Workload heterogeneity in Cosmos

- Task runtime varies from sub-sec to 10,000+ sec
- 50% of tasks are shorter than 10 sec

Production jobs and predictability

- Production jobs typically have deadlines
  - "Job shows up at 3pm, deadline at 6am, requires X resources for 50 mins"
- Many SLA jobs are recurring
  - Empirically >60% of jobs in our clusters
- Predictability is crucial
  - "Why is my job running slower than yesterday?"
  - 25% of user tickets due to unpredictability
- Current work-around
  - >75% of our jobs are over-provisioned

Our solutions

4 Hadoop committers in CISL
404 patches as of last night

- Rayon/Morpheus: support SLOs via reservations
  - OSS: in Hadoop 2.6 [YARN-1051], Publications: SoCC 2014, OSDI 2016
- Mercury/Yaq: improve utilization via container types and node-side queuing
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- YARN Federation: scale-out YARN by federating multiple clusters
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- Medea: support for long-running applications with complex placement constraints
  - Research prototype

Microsoft is transitioning its Big-Data clusters to (the above) YARN-based RM infrastructure

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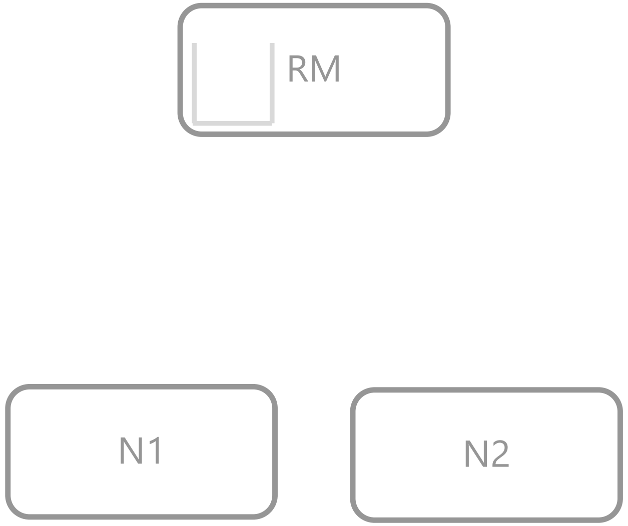
Mercury/Yaq

Improve resource utilization (and job completion time)

[Hadoop 3.0; ATC 2015, EuroSys 2016]

Resource utilization in YARN



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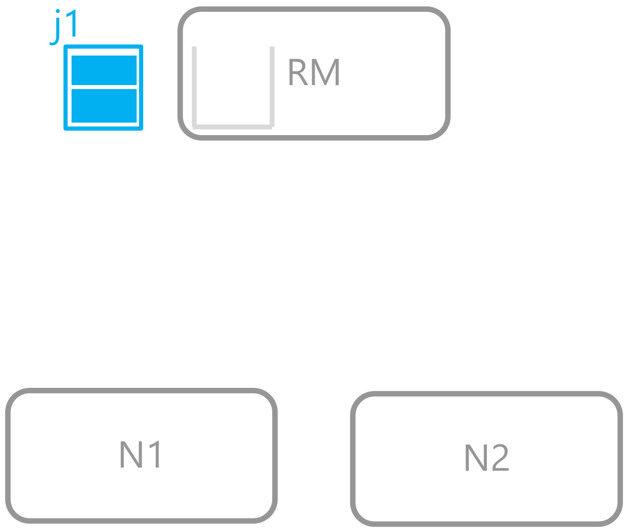

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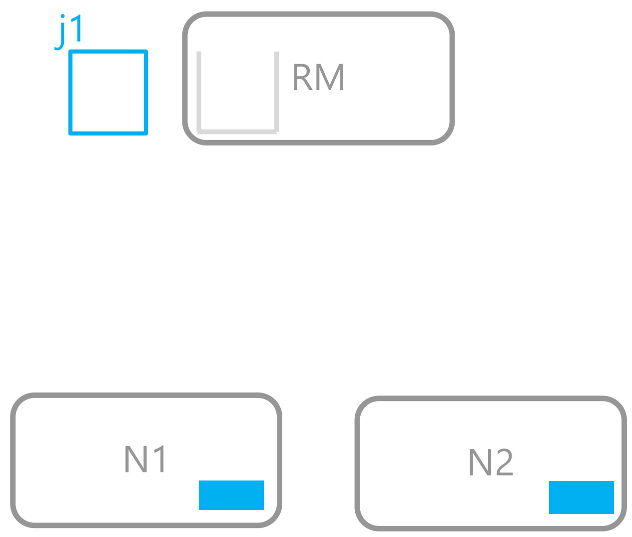

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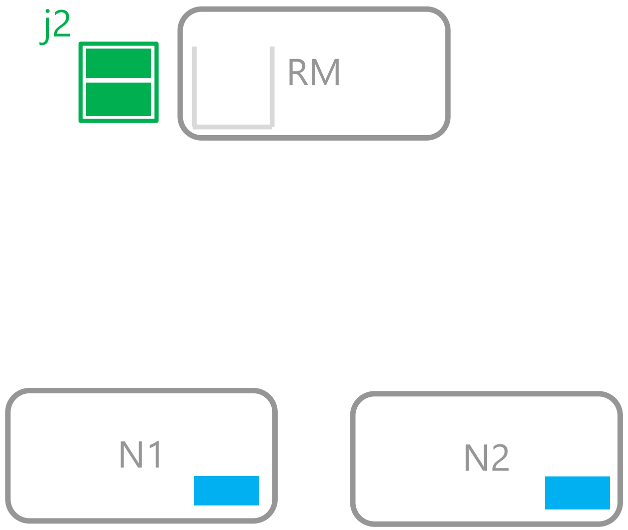

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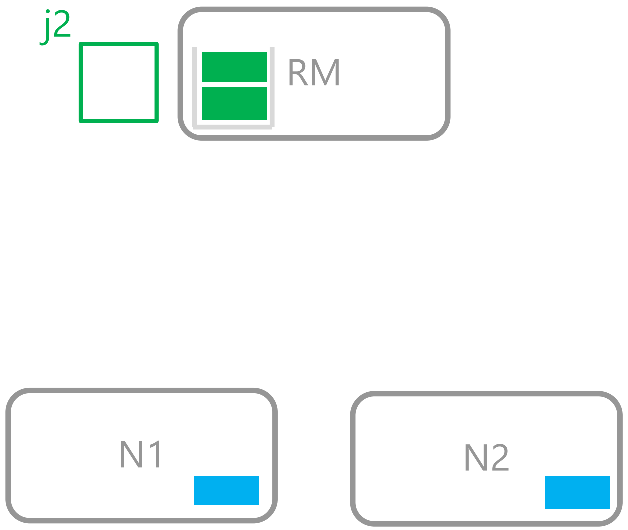

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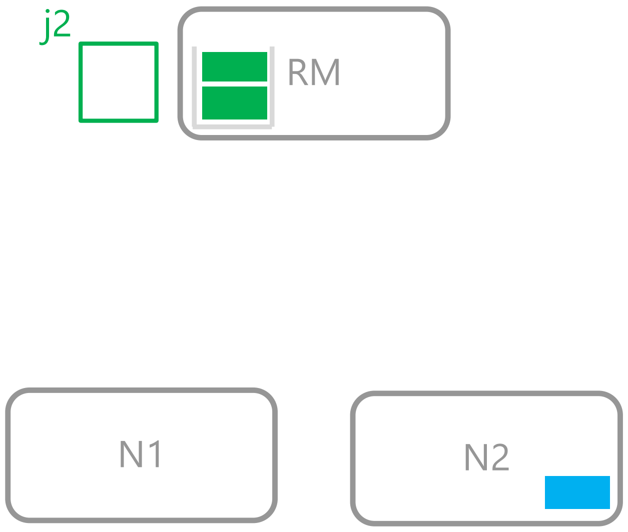

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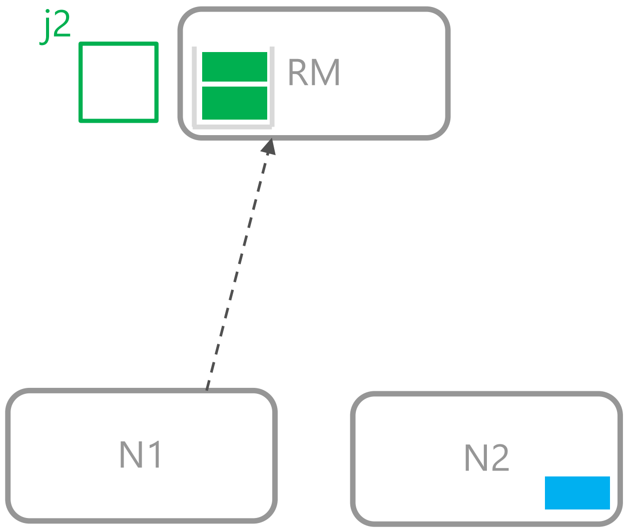

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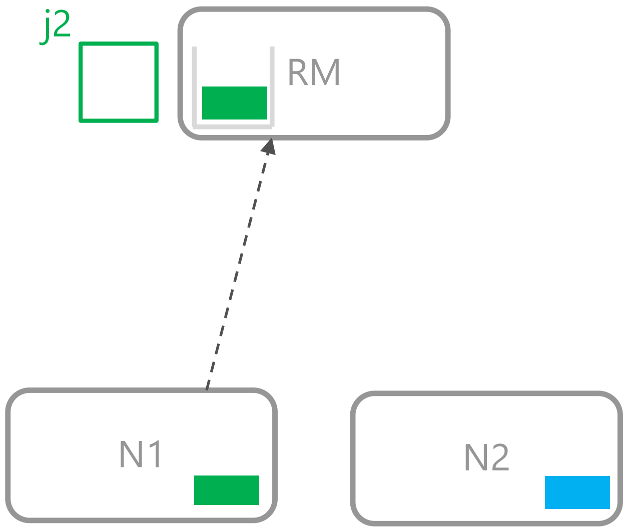
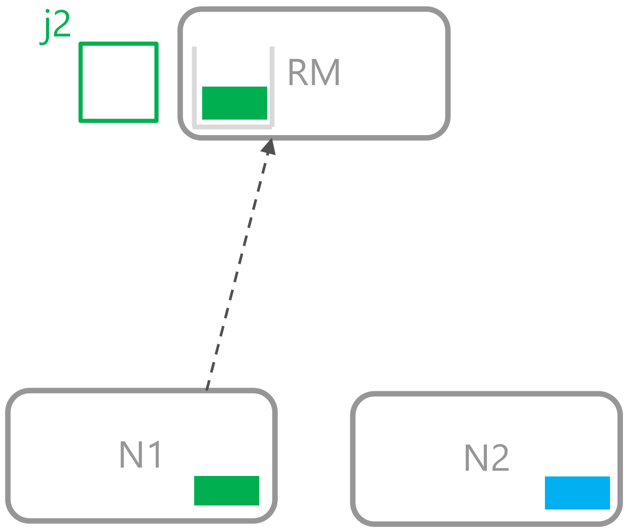


Resource utilization in YARN

- Feedback delays impact cluster utilization
  - RM in the critical path of all scheduling decisions
  - Resources can remain idle between allocations
  - Resource utilization suboptimal, especially for shorter tasks



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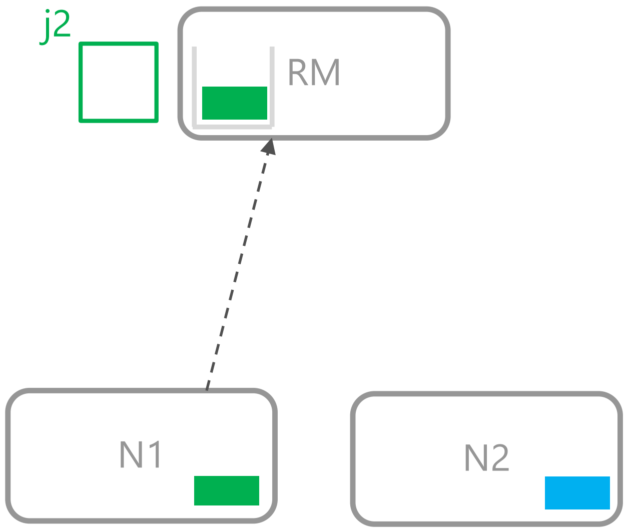

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Average allocated resources for varying workloads.

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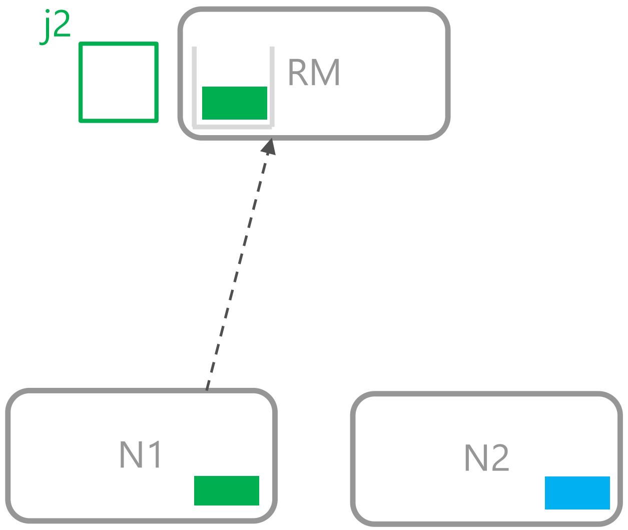

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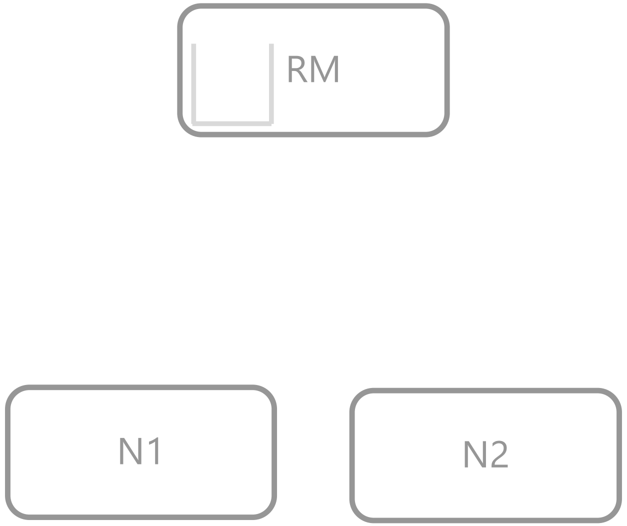
Average allocated resources for varying workloads.

- Actual resource utilization is even lower
  - E.g., a task using 1GB out of a 4GB allocated container
  - Resource overprovisioning makes matters worse

Mercury: Key ideas

- Introduce task queuing at nodes
  - Mask feedback delays
  - Improve cluster utilization
  - Improve task throughput (by up to 40%)
- Container types
  - GUARANTEED and OPPORTUNISTIC
  - Keep guarantees for important jobs
  - Use opportunistic execution to improve utilization

Node-side queuing



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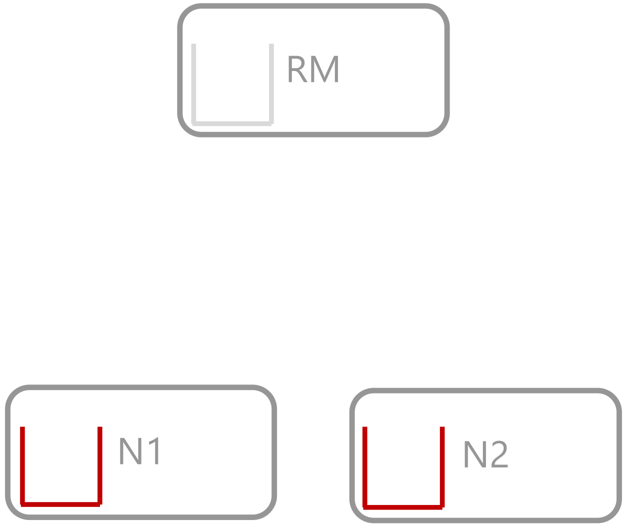

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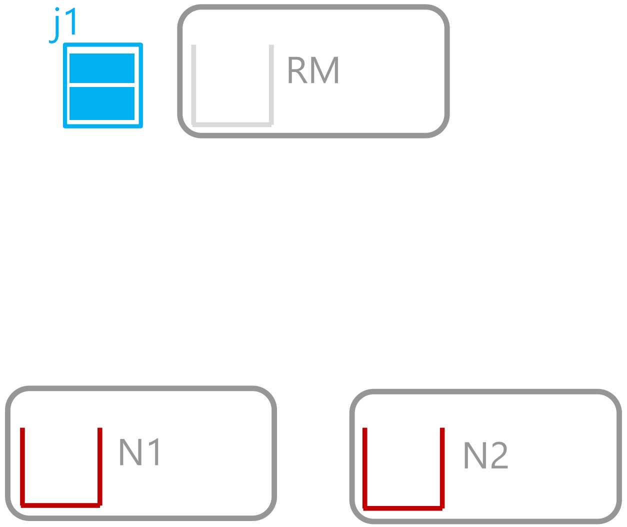

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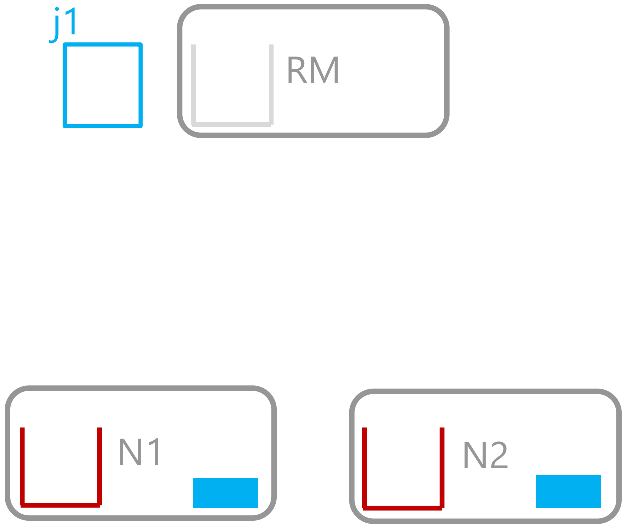

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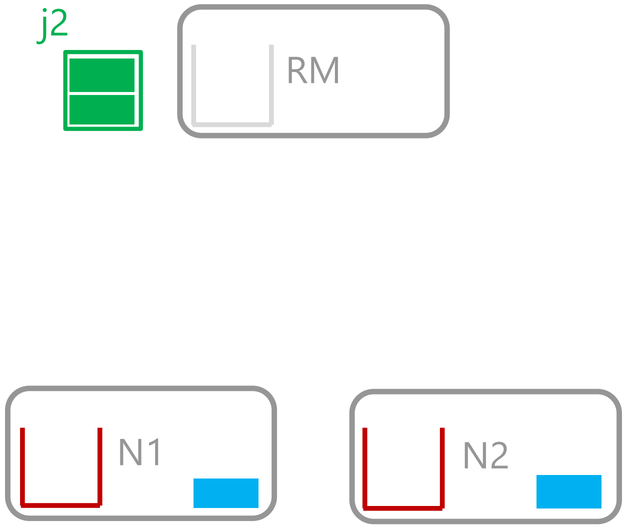

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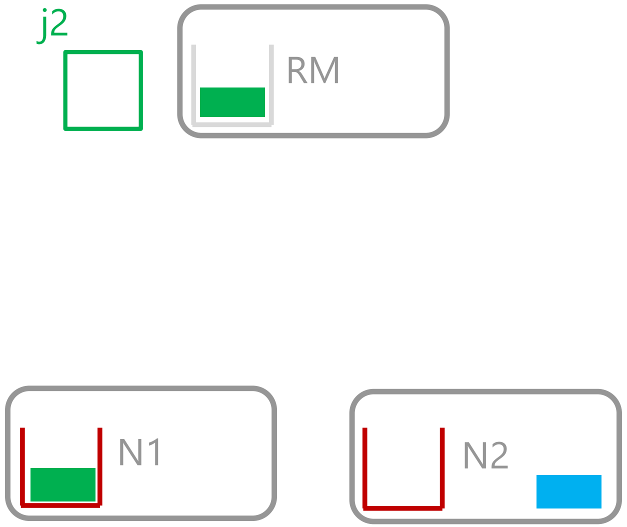

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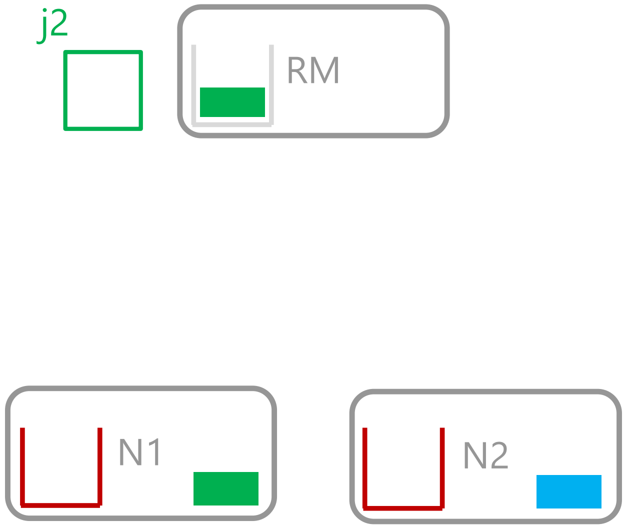

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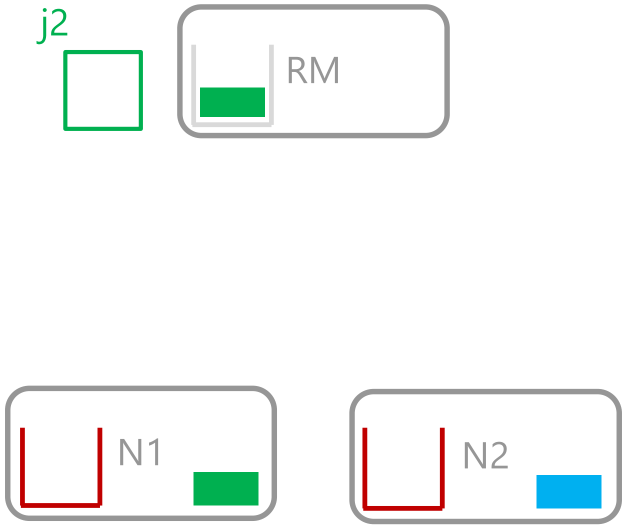

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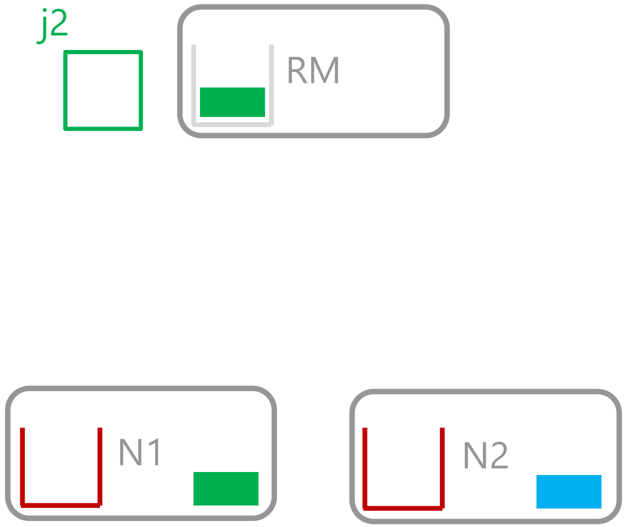

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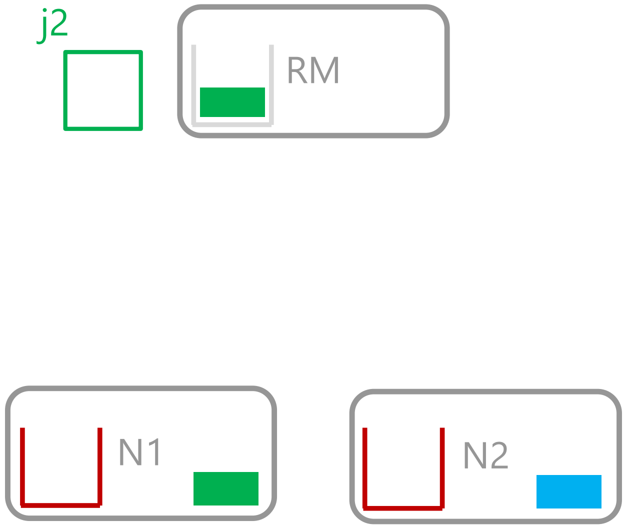

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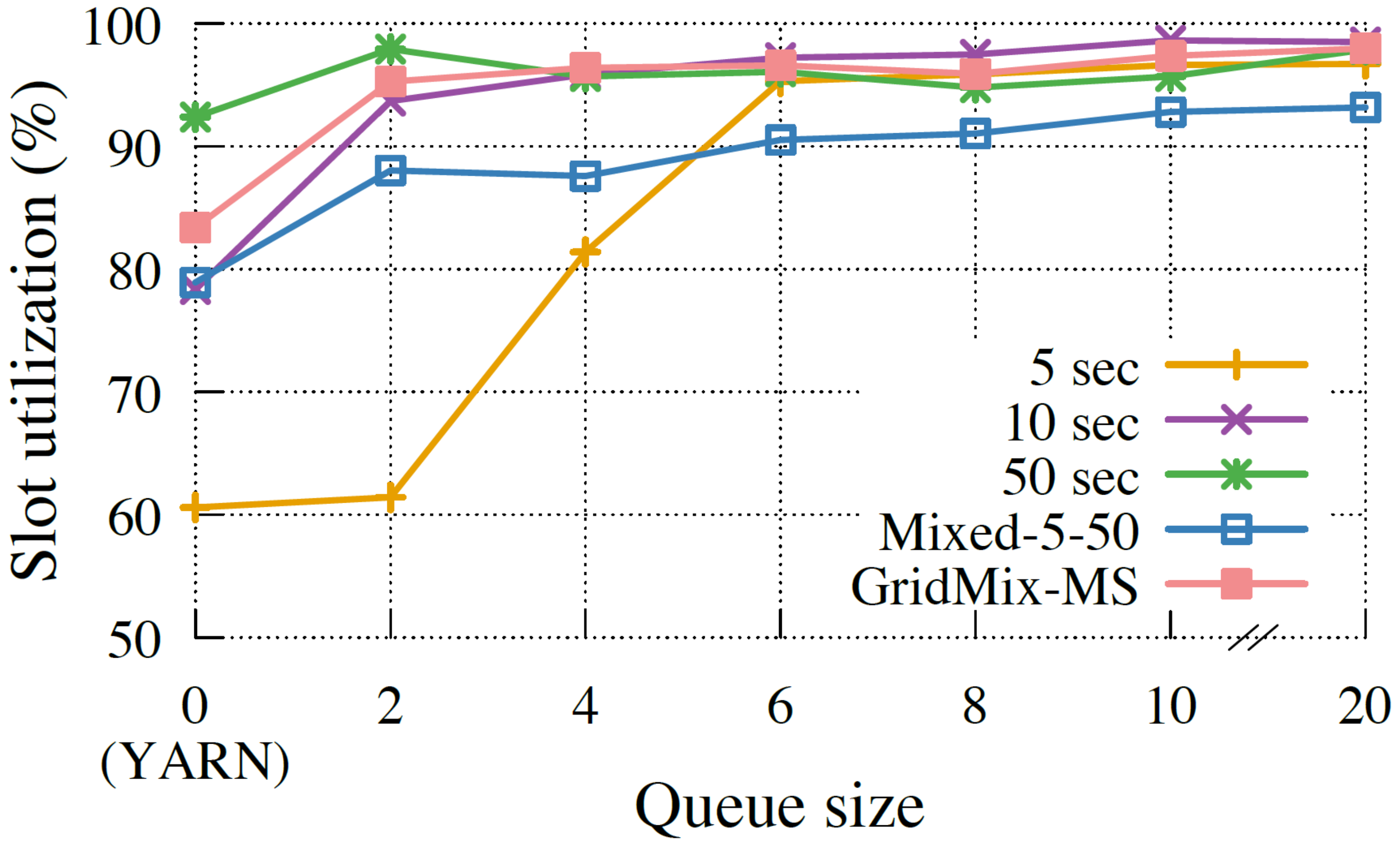
- Existing centralized schedulers do *not* queue tasks at nodes
  - Challenging to get right

Utilization gains



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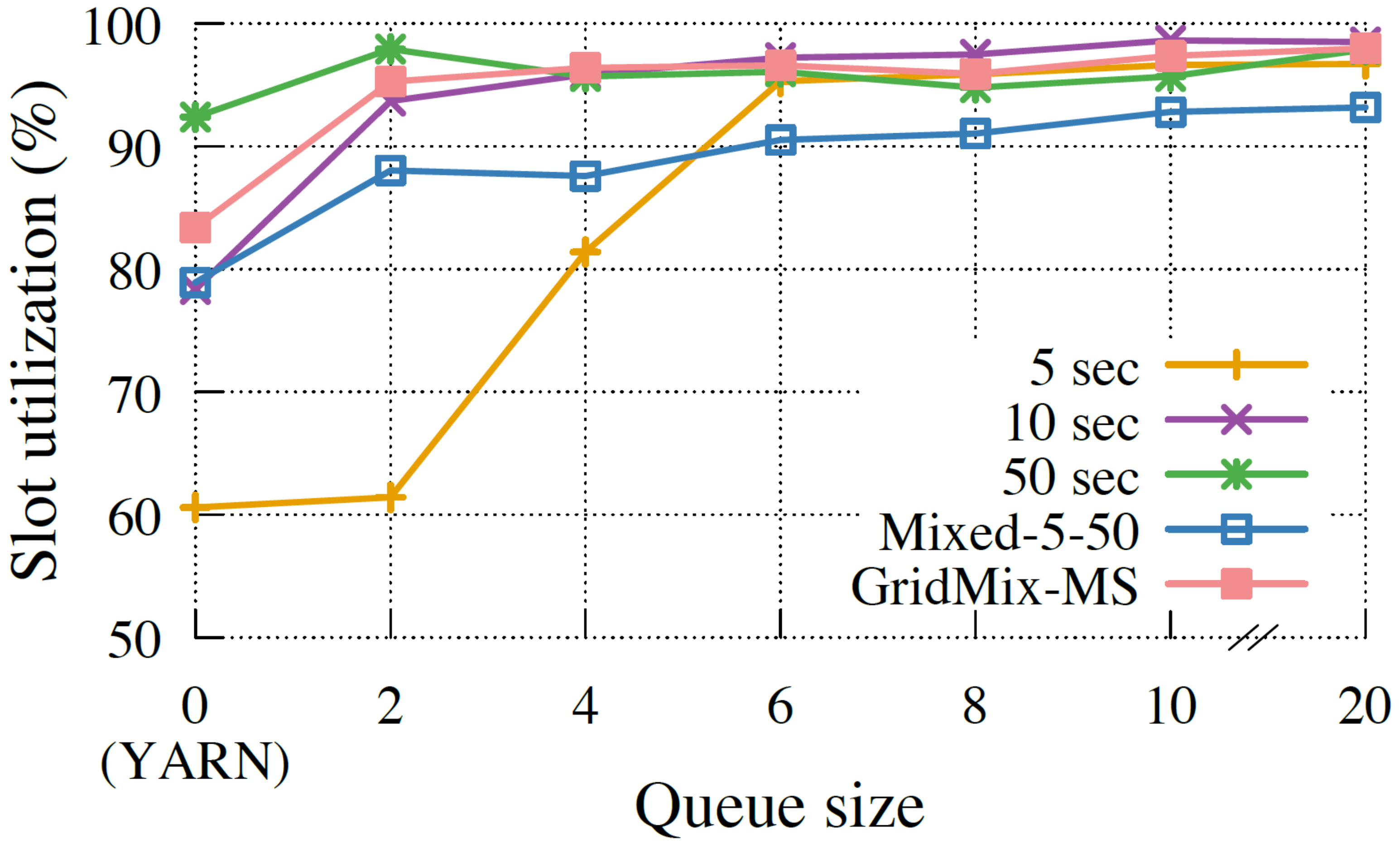

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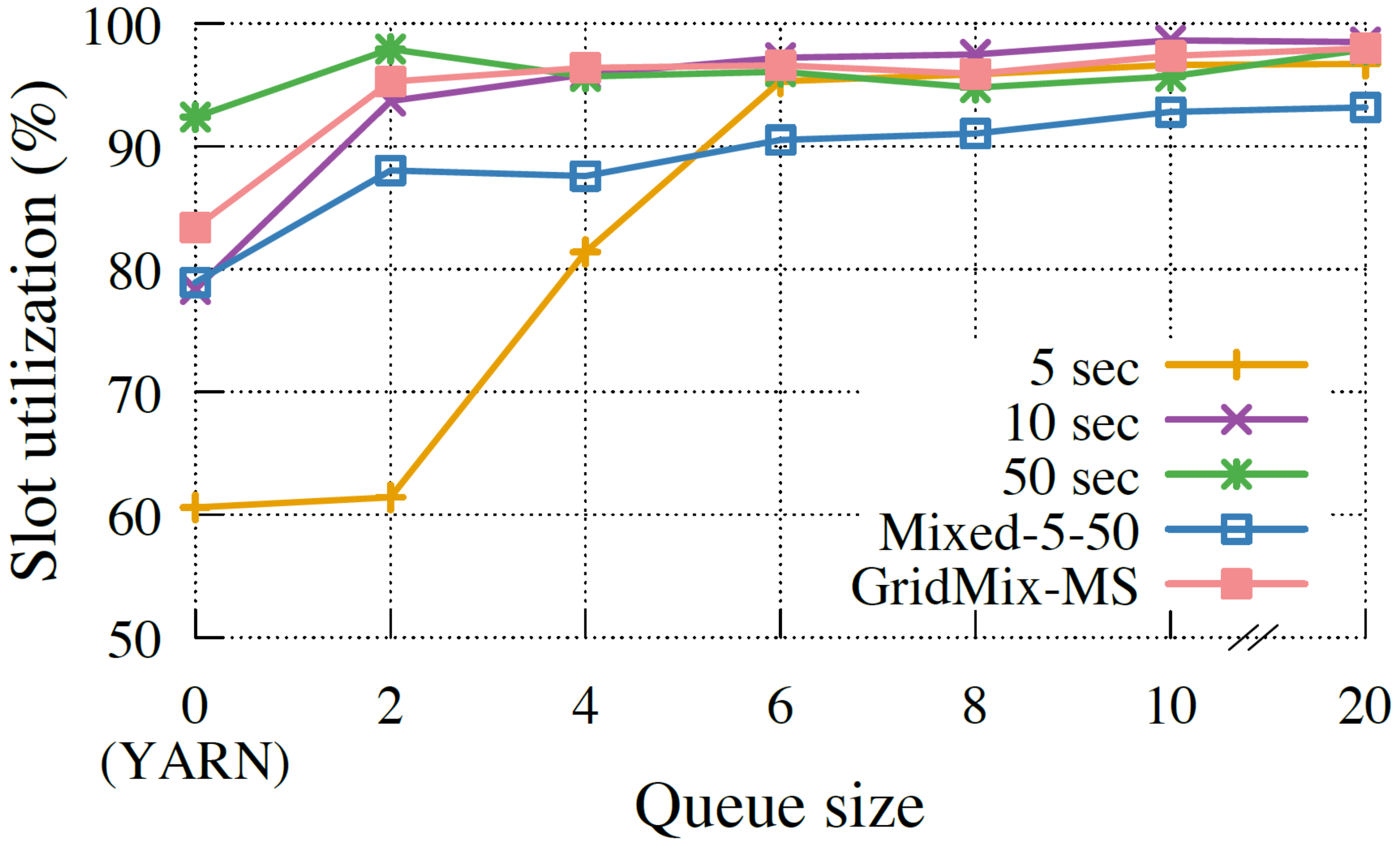

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- The shorter the tasks the longer the queues need to be

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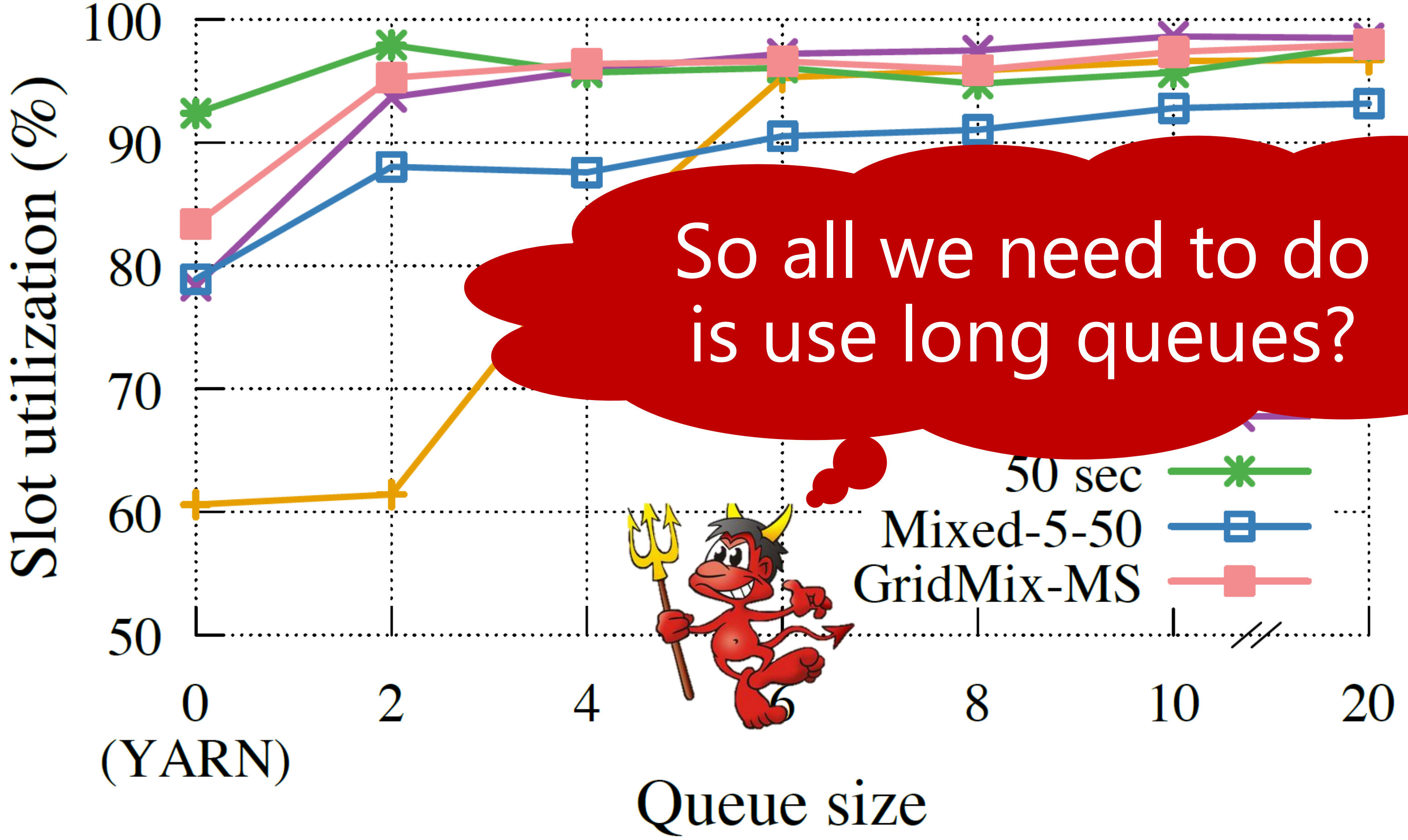

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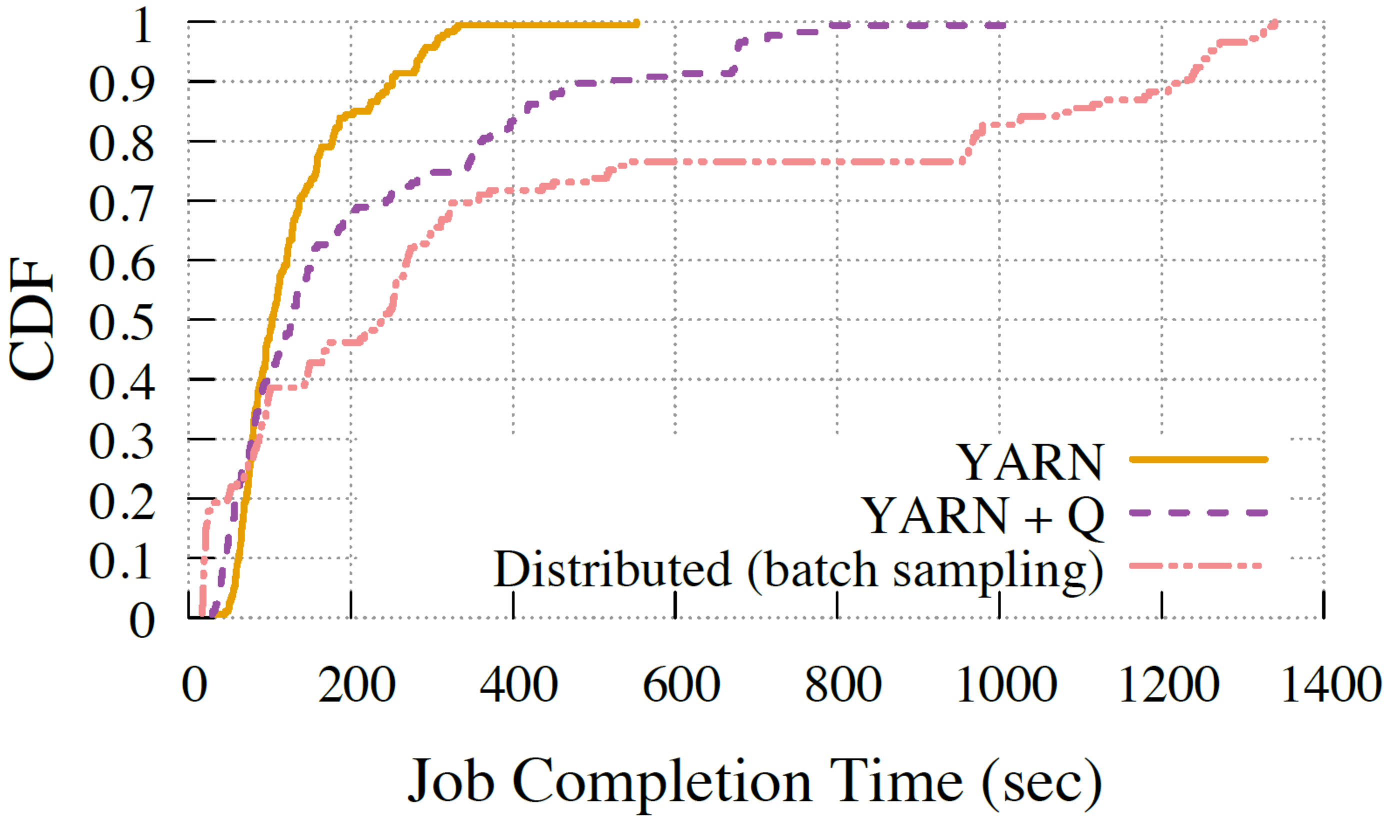
Job completion times with node-side queuing



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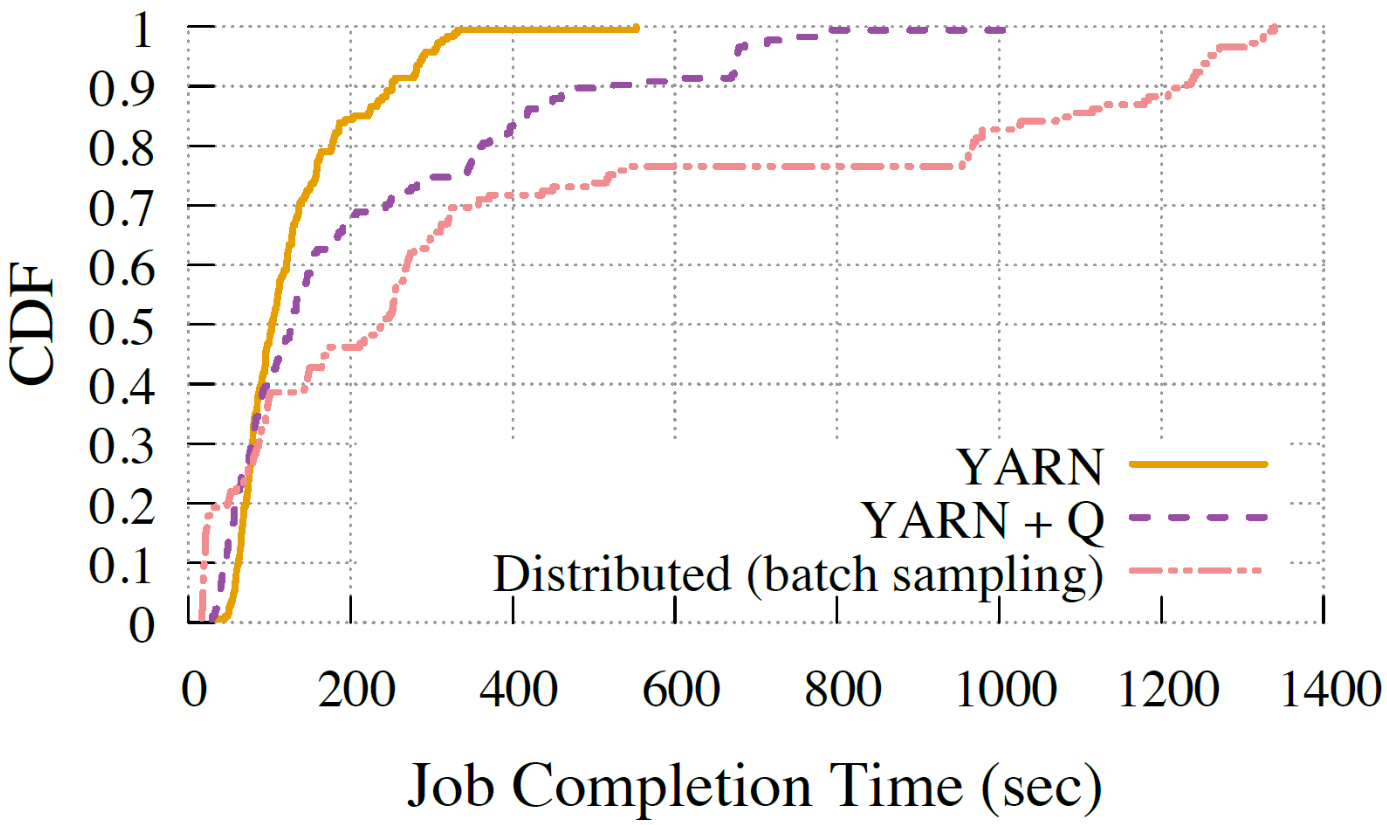

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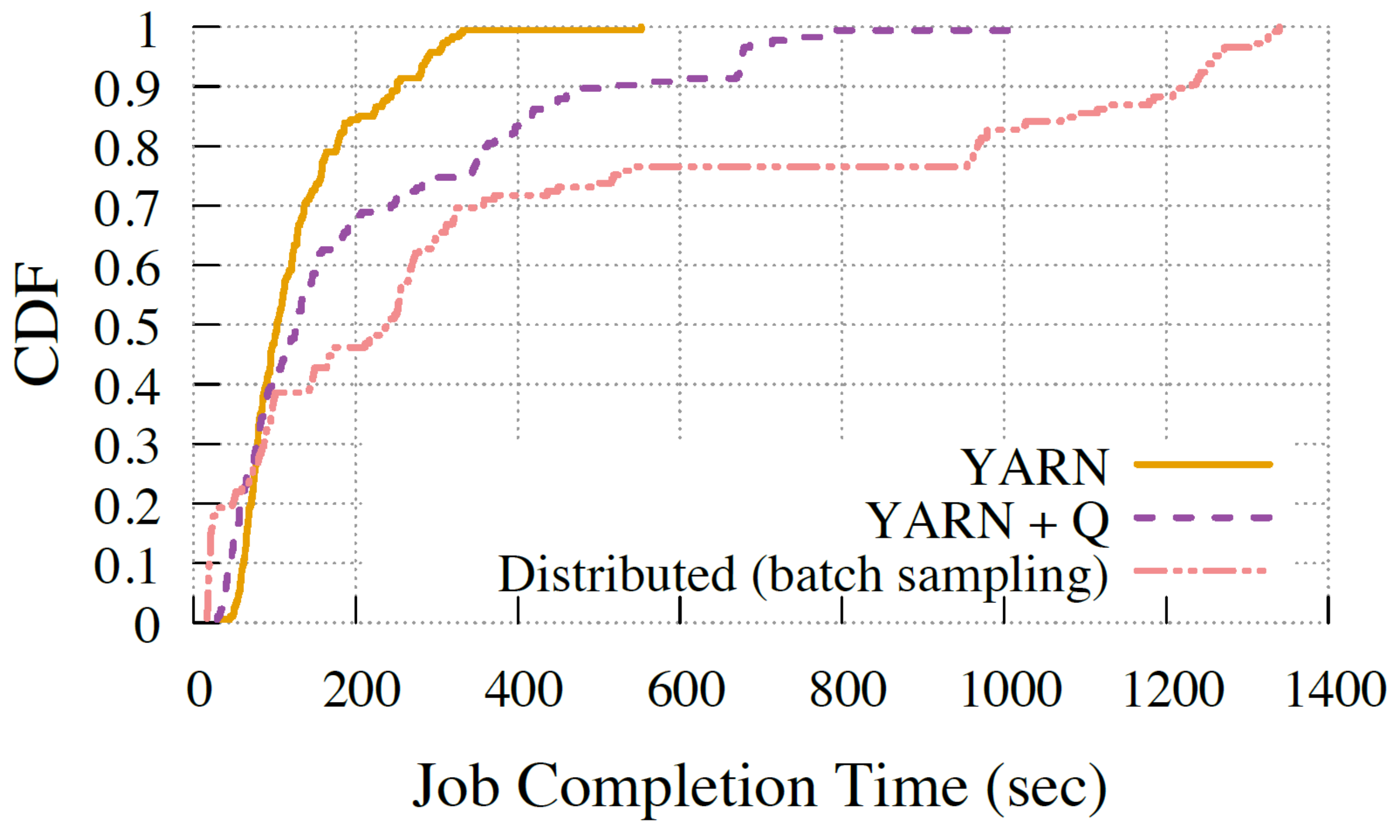

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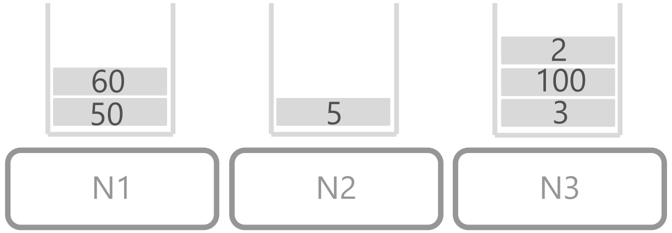
Proper queue management techniques are required

Problems with node-side queuing



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- Load imbalance across nodes
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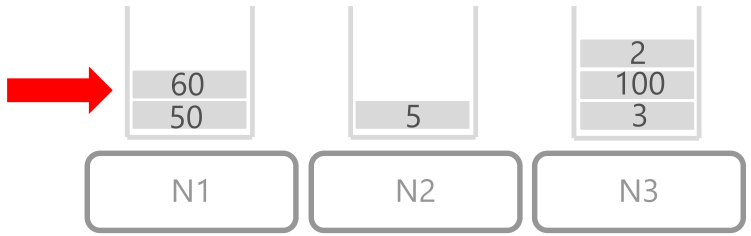

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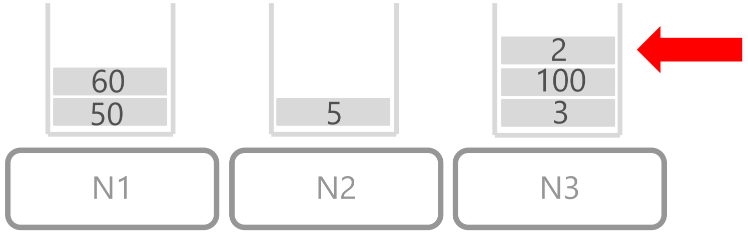

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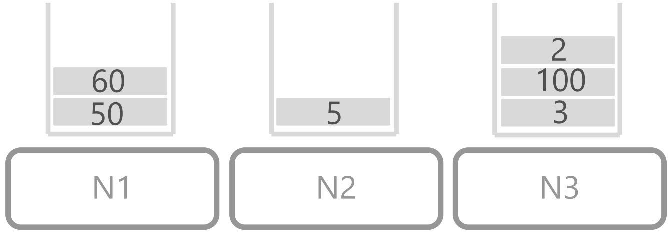
- Early binding of tasks to nodes



Yaq: Queue management techniques

Place tasks to node queues

Prioritize task execution (queue reordering)

Bound queue lengths

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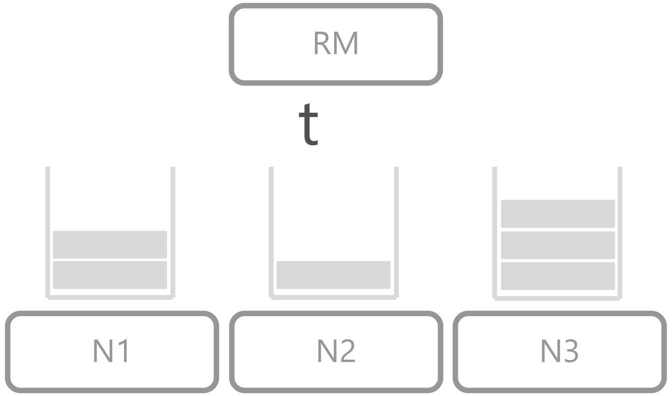
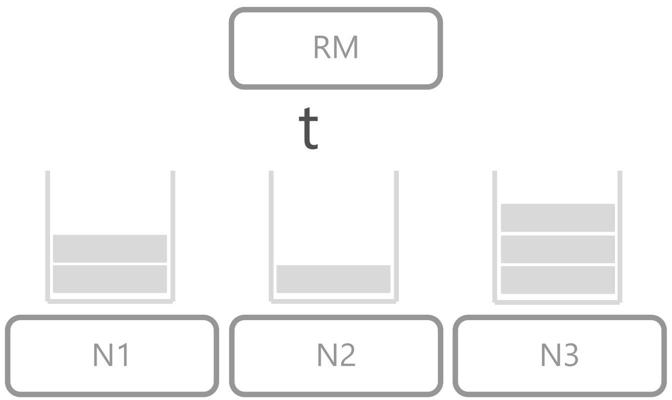
Yaq improves median job completion time by 1.7x over YARN

Placement of Tasks to Queues



Placement of Tasks to Queues

- Placement based on queue length
  - Agnostic of task characteristics
  - Suboptimal placement for heterogeneous workloads



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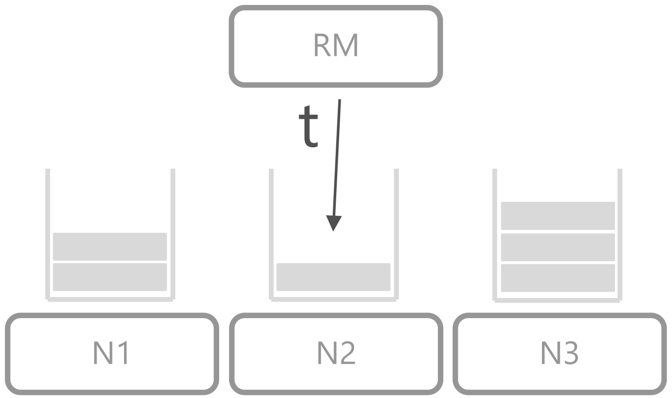

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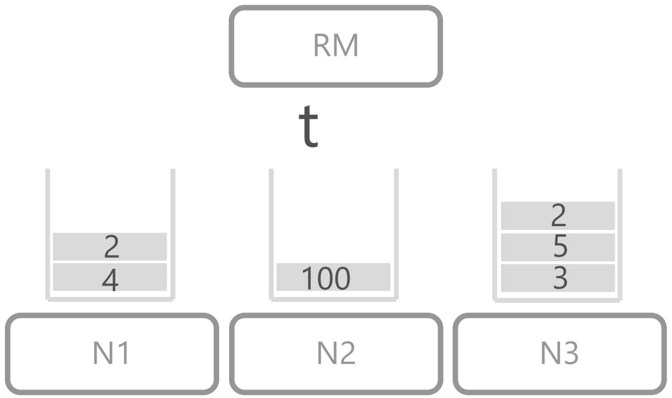

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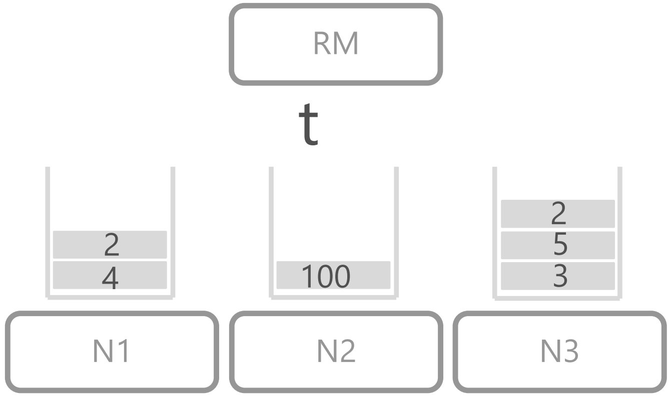
- Placement based on queue wait time
  - Better for heterogeneous workloads
  - Requires task duration estimates



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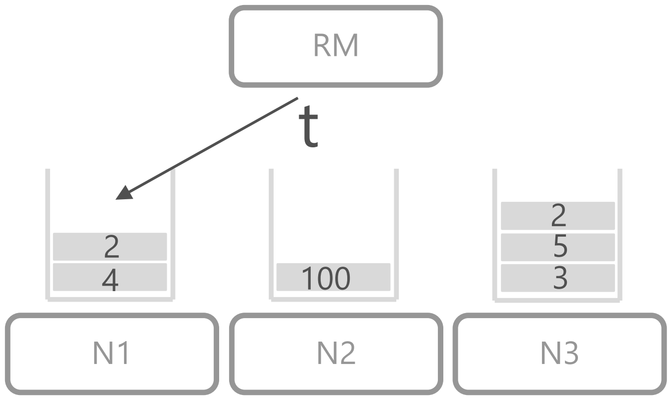

Task Prioritization

- Queue reordering strategies
  - Shortest Remaining Job First (SRJF)
  - Least Remaining Tasks First (LRTF)
  - Shortest Task First (STF)
  - Earliest Job First (EJF)

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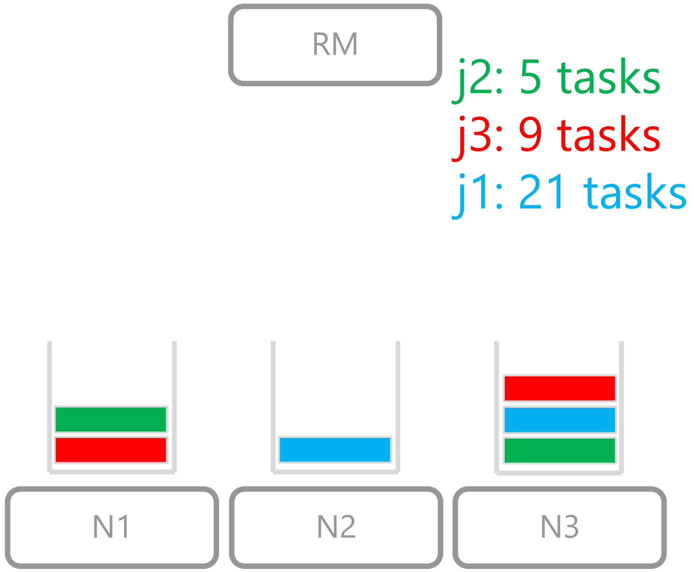

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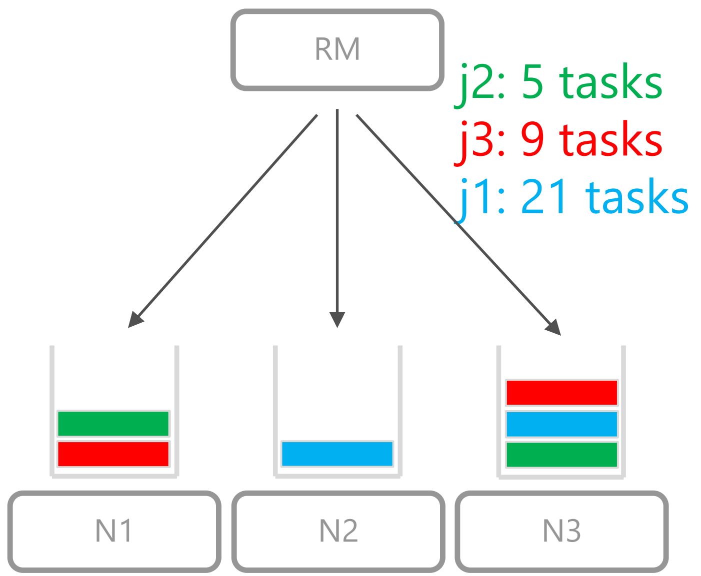

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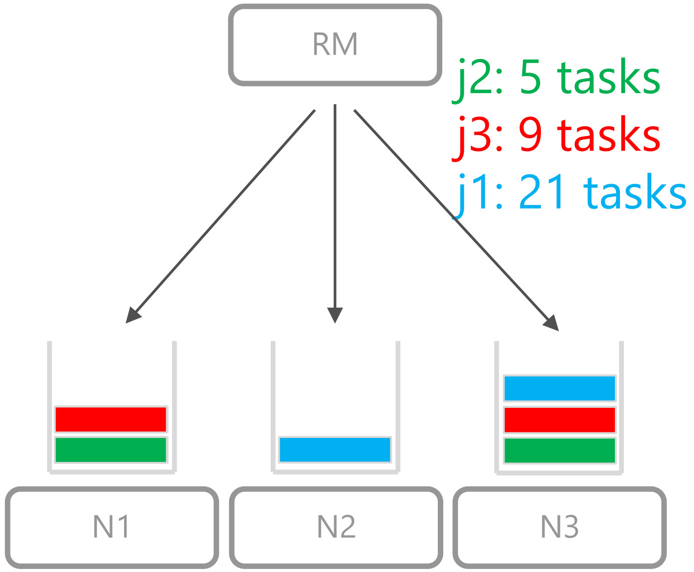

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- Queue reordering strategies
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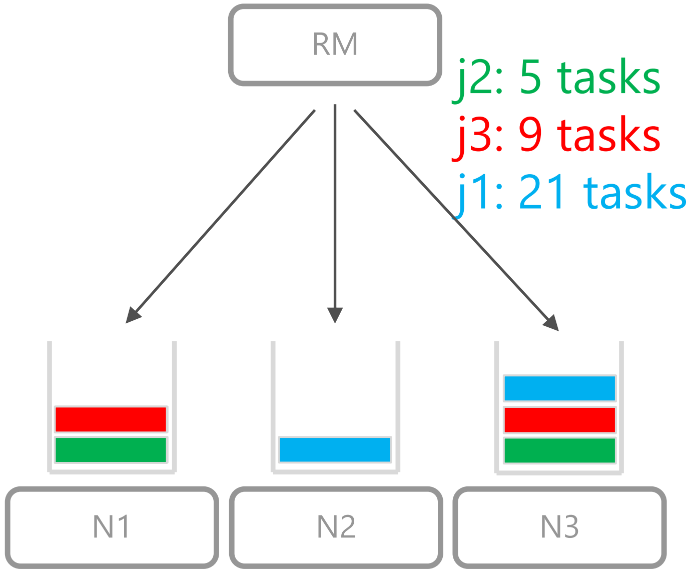
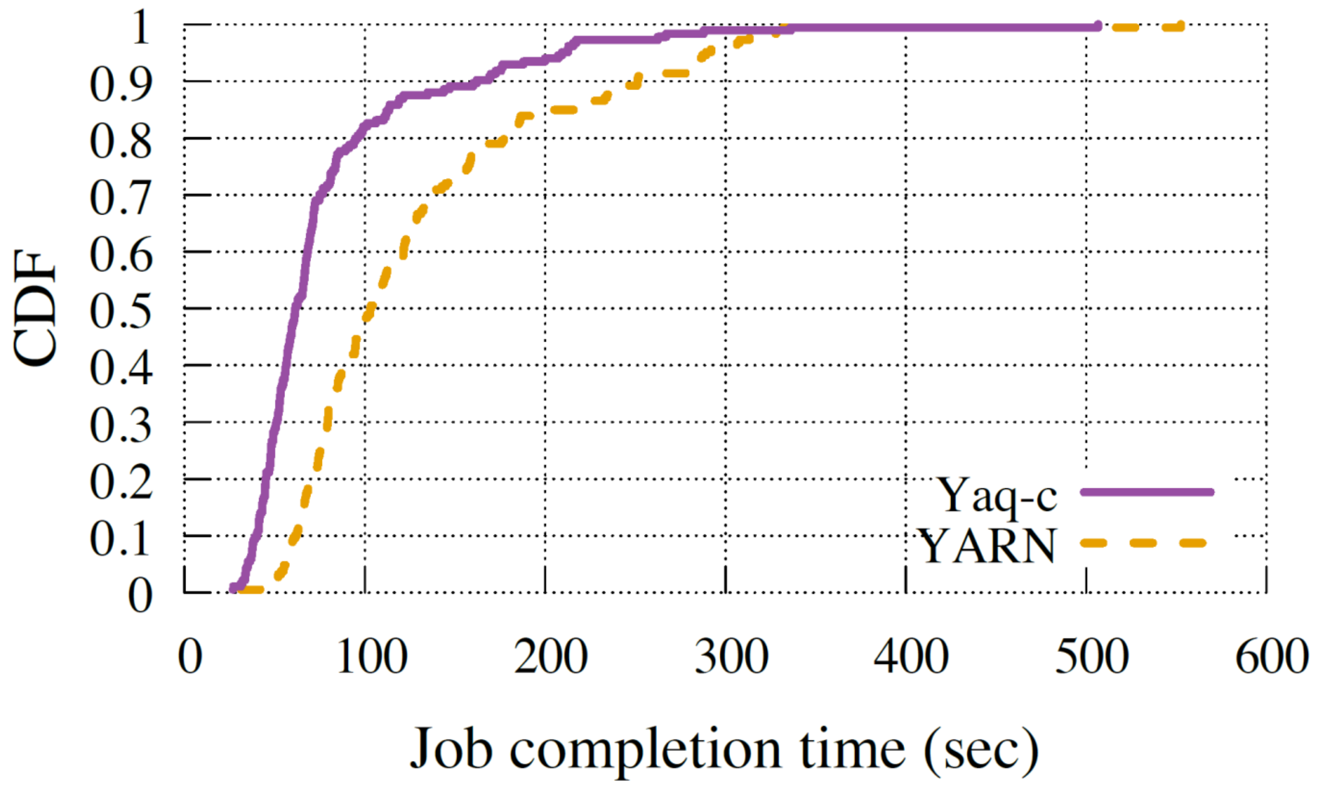
- SRJF and LRTF are job-aware
  - Dynamically reorder tasks based on job progress
- Starvation freedom
  - Give priority to tasks waiting more than *X* secs



Bounding Queue Lengths

- Determine max number of tasks at a queue
  - Trade-off between short and long queues
- Short queues
  - Resource idling
    → lower throughput
- Long queues
  - High queuing delays, early binding of tasks to queues
    → longer job completion times
- Static and dynamic queue bounding

Evaluating Yaq



	Task queuing delay (sec)		
	Mean	Stdev	Median
Yaq-c	8.5	21.4	1.1
Yaq-c (unbounded)	65.5	85.1	30.4
Yaq-c (no reorder)	53.2	78.2	25.4
YARN	-	-	-

- Setup
  - 80-node cluster
  - 185 Hive production queries
  - Queue length of 4 slots
  - Queue wait time-based placement
  - SRJF prioritization
- 1.7x improvement in median JCT over YARN
- 1.1 sec median task queuing delay
  - Both bounding and reordering are crucial

More on Mercury/Yaq

- Container types
  - Scheduling and execution
  - When to choose each type
- Support for distributed scheduling of containers
- Apply techniques on any distributed scheduler
  - 9.3x better median job completion over Sparrow-like batch sampling

- Next steps
  - Resource over-commitment
  - Support for multi-tenancy (YARN as a secondary tenant)
  - Pricing models for different container types

Mercury/Yaq: Wrap-up

- Improvement of cluster utilization
  - Queuing of tasks at NMs
  - Container types
- Need for queue management techniques
  - Queue bounding
  - Task placement to queues
  - Prioritization of tasks in queues
- Improvement in median job completion time
  - 1.7x over YARN
  - 9.3x over Sparrow-like batch sampling

Thank you!