732A54 / TDDE31
Big Data Analytics

LINKÖPING UNIVERSITY

Resource Management in Big-Data Clusters

Mesos, YARN

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Multiple Big-Data Programming Models Co-Exist

- No single programming framework is optimal for all kinds of big-data applications

MPI

Pregel

Apache Pig

Apache Storm

Multiple Big-Data Programming Models Co-Exist

- Organizations would like to use the same cluster hardware for multiple programming frameworks, versions, and applications
- Sharing of data to be used across frameworks?
- **Jobs**: Both periodic production runs, development tests, and short ad-hoc queries
  - Most jobs are (relatively) short
  - Jobs consist of (many) **tasks** e.g. mapper and reducer tasks
  - Most tasks are (relatively) short

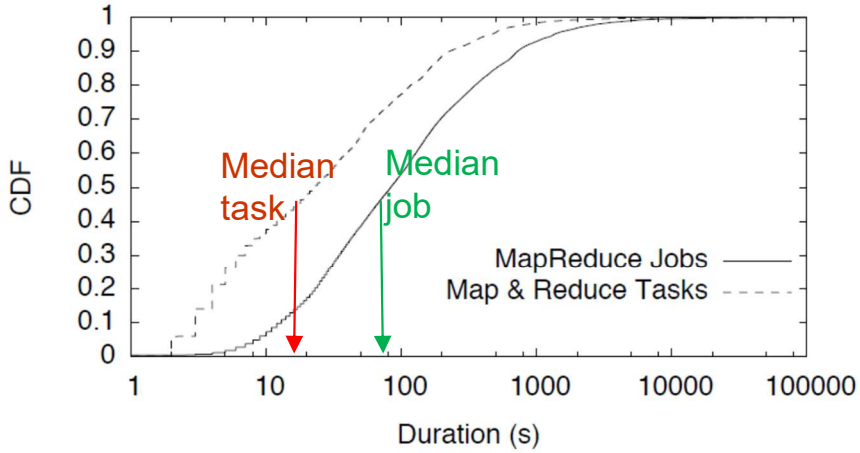

Figure 1: CDF of job and task durations in Facebook's Hadoop data warehouse (data from [38]). Image source: Mesos, 2011

- Need a "cluster-wide OS" for sharing a cluster among different big-data frameworks and jobs that know nothing about each other
  - Fairness, priorities, scalability, protection

    = **Virtualization** of cluster resources

Sharing a Cluster? (1)

MR = Hadoop MapReduce

Dedicated cluster for a single user, single application (e.g. MR)?
→ Low utilization of expensive cluster resources

- **Idea 1**: Support *multiple users* and *multiple MR jobs* that *time-share the cluster*
  - Still one application type (here, MR) per node at a time
  - ”Hadoop-on-demand”
    - Using a *batch scheduler* for cluster jobs

Background:
Batch Scheduling for Large Parallel Systems

Batch queue systems (common in HPC)

- e.g. Slurm, Torque, Maui
- Only 1 application (job) per cluster node
- Parallel jobs use multiple nodes exclusively
  - Job description:
    ask for *N* nodes together for *M* minutes each to run program *A*
- Ahead-of-time reservation of system partitions and time
- Load balancing etc. over this fixed set of resources is up to the programming framework's runtime system e.g. of Hadoop, Spark

Sharing a Cluster? (2)

MR = Hadoop MapReduce

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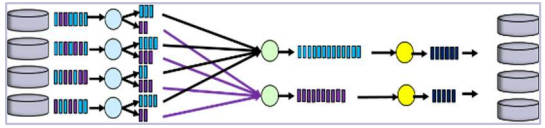
MapReduce computation structure



→ Utilization of cluster resources is usually good during Map phases, but often not good during Reduce phases and I/O

- **Idea 2**: Time-share the *same* cluster nodes for *multiple applications (job types / programming frameworks)* to get better overall utilization (*multi-tenancy*)
  - Mesos, YARN

Mesos, YARN

- **Idea**:
  Separate the resource management functionality
  from the programming model (and its runtime system)
  - ☺ Can run *multiple applications* (e.g. multiple Hadoop MapReduce jobs) on the same cluster
  - ☺ Can *mix* task executions from concurrent applications using *different frameworks* on same cluster,
    e.g. Hadoop MR (incl. different versions of it) and other frameworks (e.g. MPI)
    → Diversity of programming models
  - ☺ Can *reuse the resource management subsystem* for different programming models
    - Cleaner software structure for the framework (e.g. Hadoop MapReduce) itself

Mesos [Hindman *et al*. 2011]

- Mesos *master process* on one node manages all resources
- Mesos *slaves* (daemon processes) offer resources that are currently free
- *Frameworks* (e.g. Hadoop MR) submit requests for allocation and release of resources, to be approved/committed by Mesos master

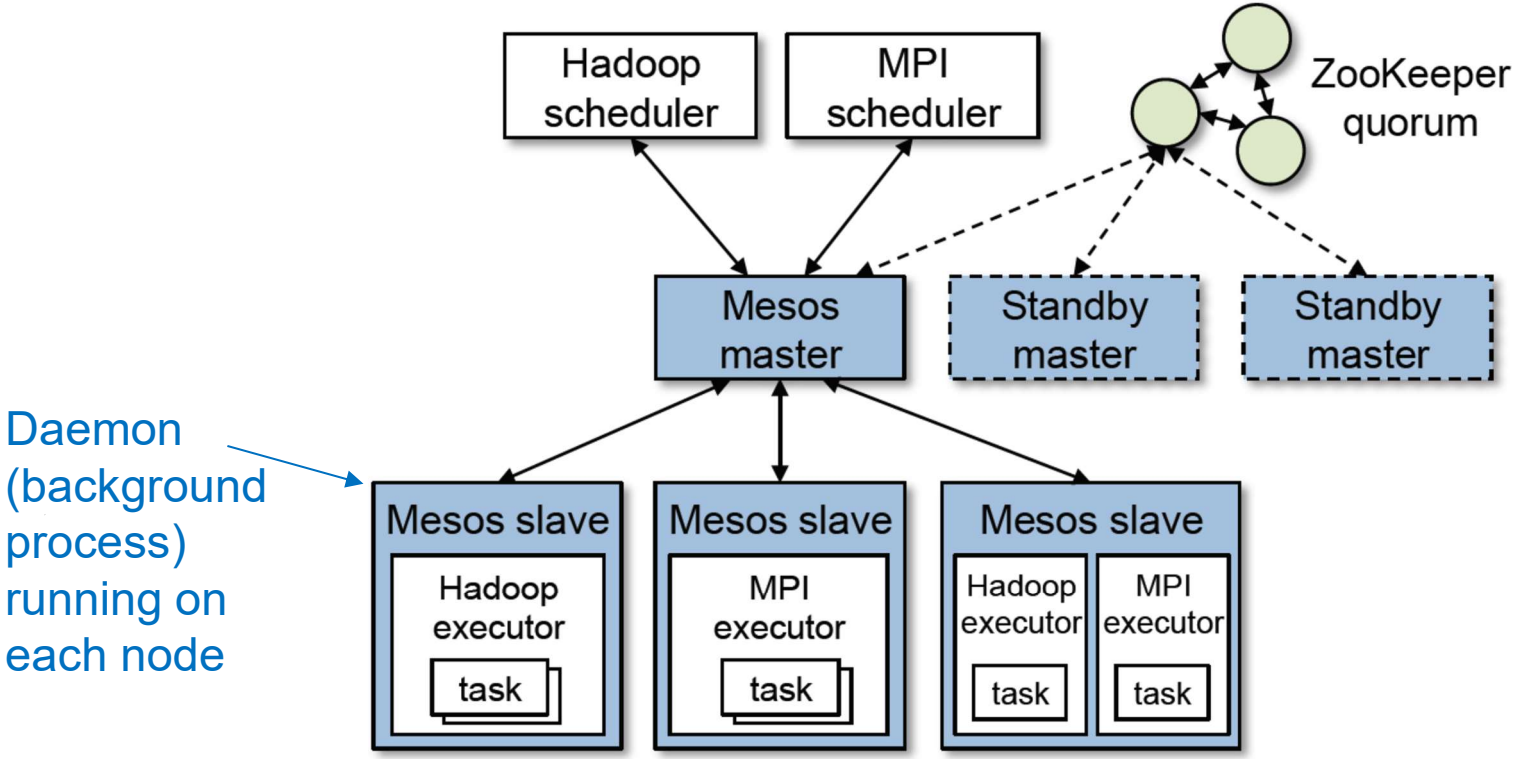
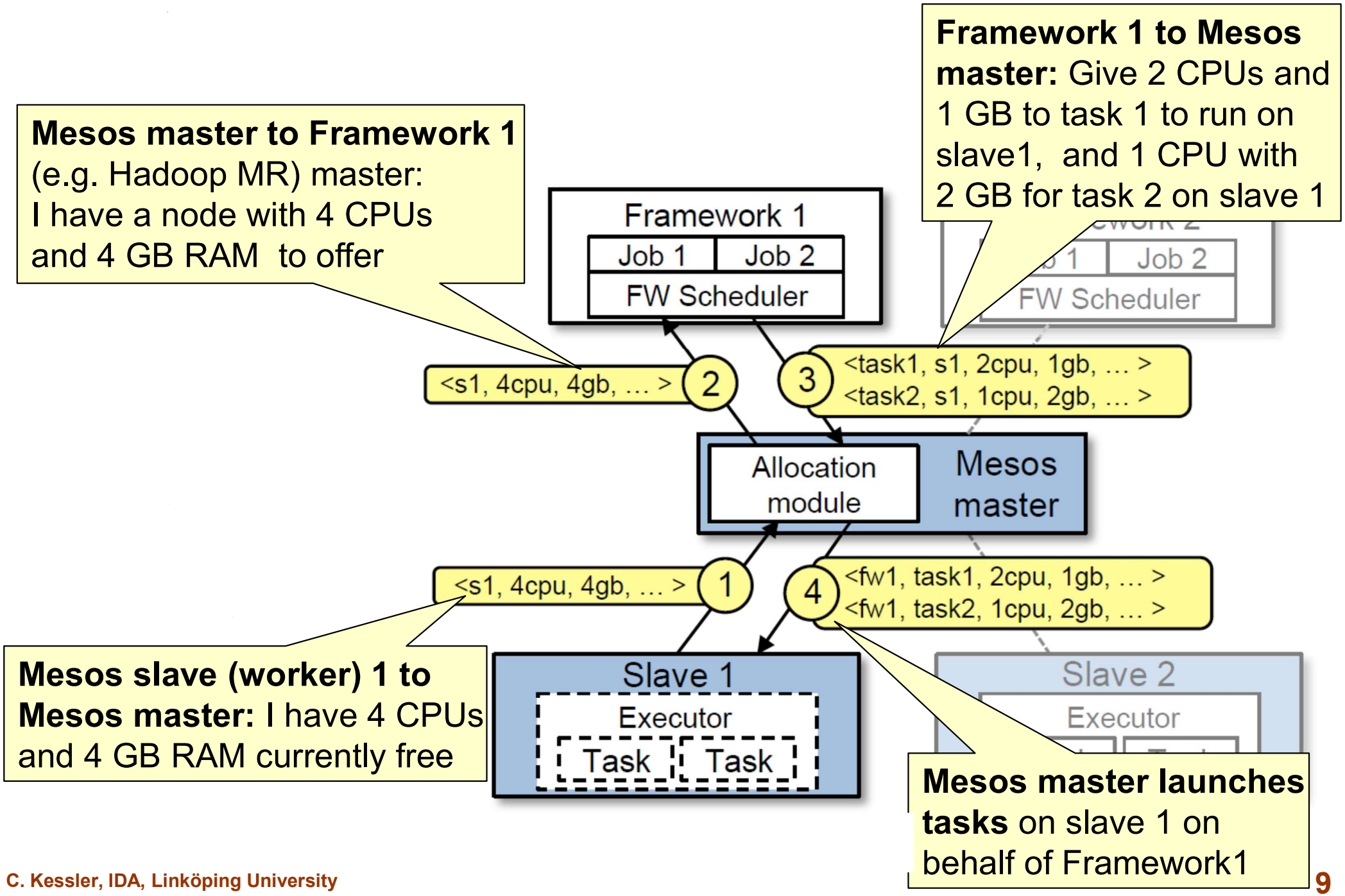


Figure 2: Mesos architecture diagram, showing two running frameworks (Hadoop and MPI).

Mesos Example



YARN

YARN = Yet Another Resource Negotiator

Split up: resource management (global), scheduling/monitoring (application-specific)

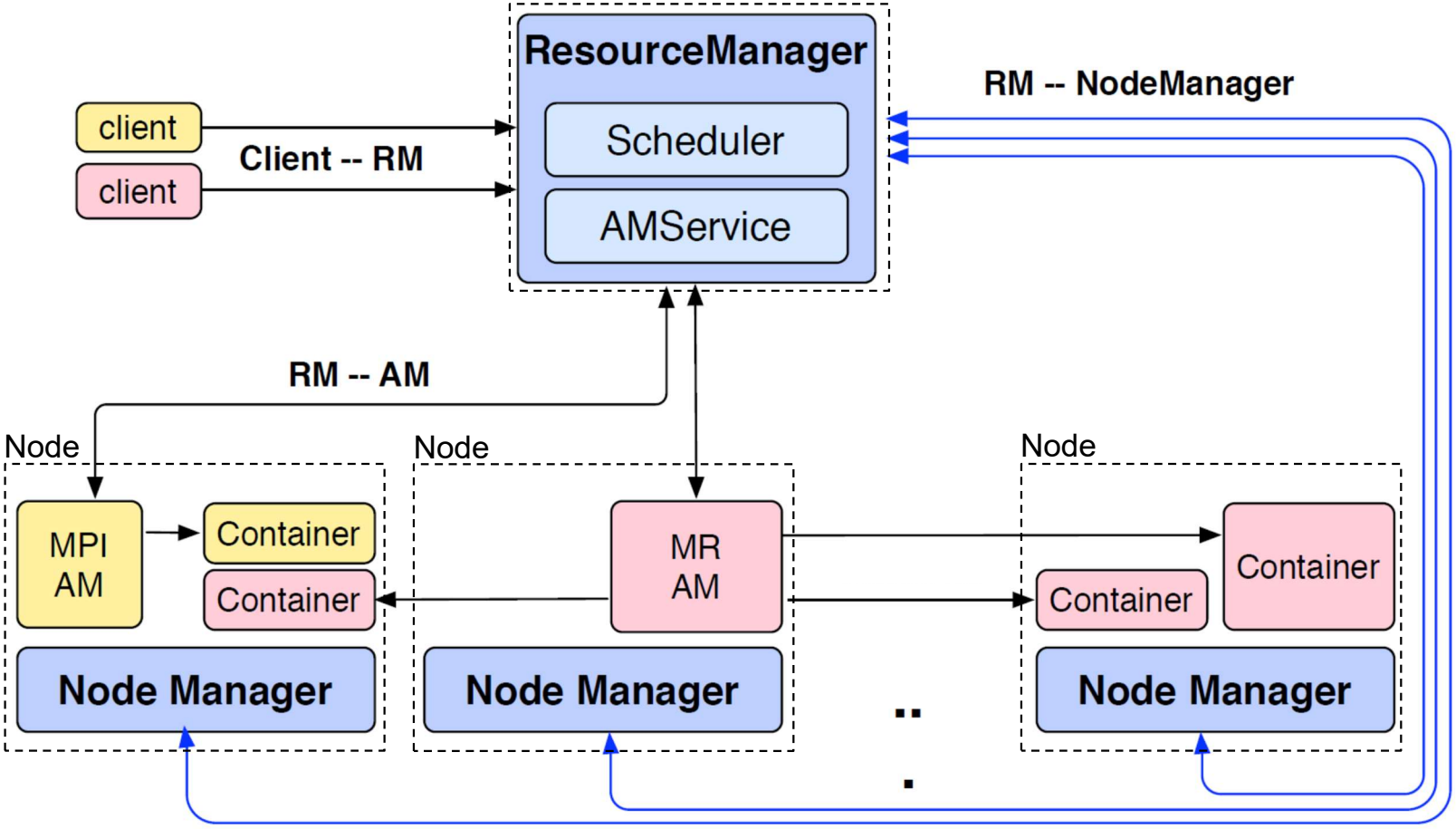
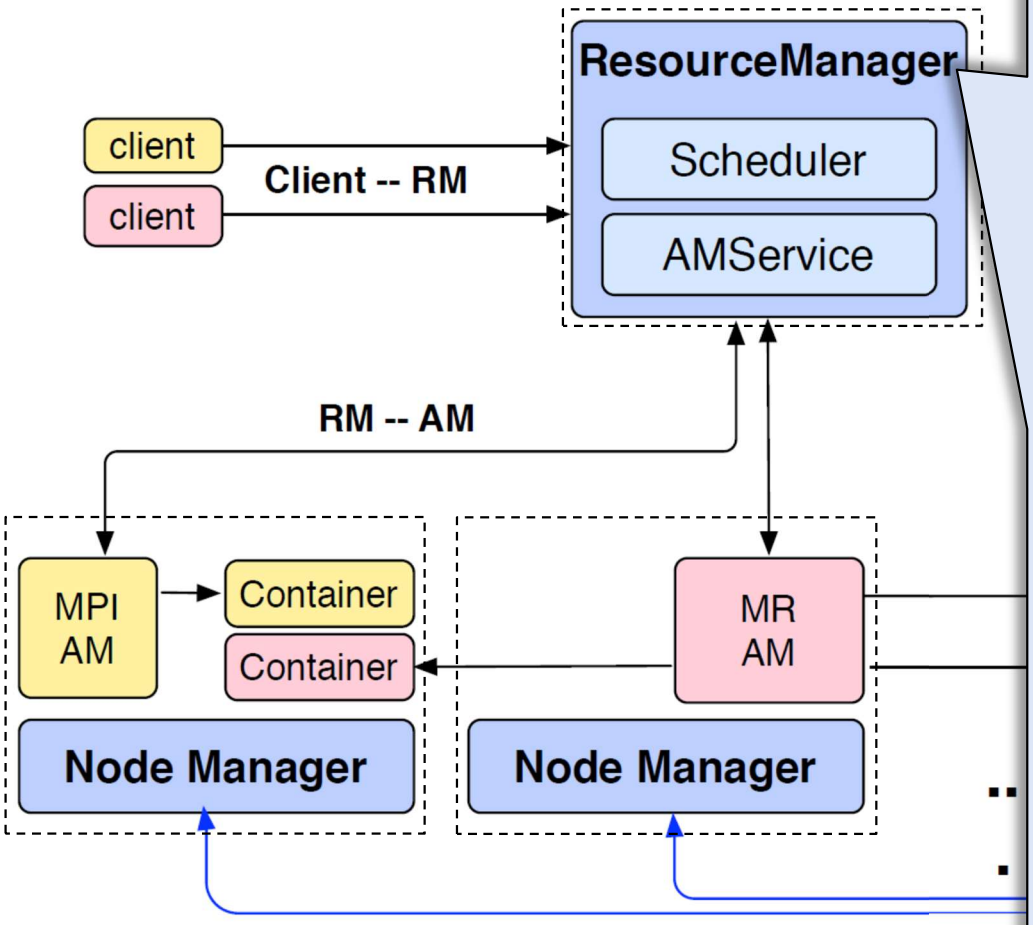


Image adapted from: Vavilapalli *et al.* 2013

- System components (blue)
  - RM – Resource Manager, AM – Application Master, NM – node mgr.
- Two applications running (yellow: using MPI, pink: using Hadoop MR)

YARN



Resource Manager (RM):

- A daemon process running on a dedicated cluster node (e.g. node 0)
- Periodically polls the node managers to check for liveness
- **Jobs** are submitted to the RM with resource requirements (e.g. share of 20% CPU time, …)
- RM performs admission control, checks security credentials, and allocates (leases) a bundle of free resources on particular nodes, e.g. <2GB RAM, 1 CPU>, to a **container** (= virtual node) for the job's execution on each of these nodes.
- RM informs the Node Managers of these nodes about the lease.
- Job **state** is moved from new to admitted to running.

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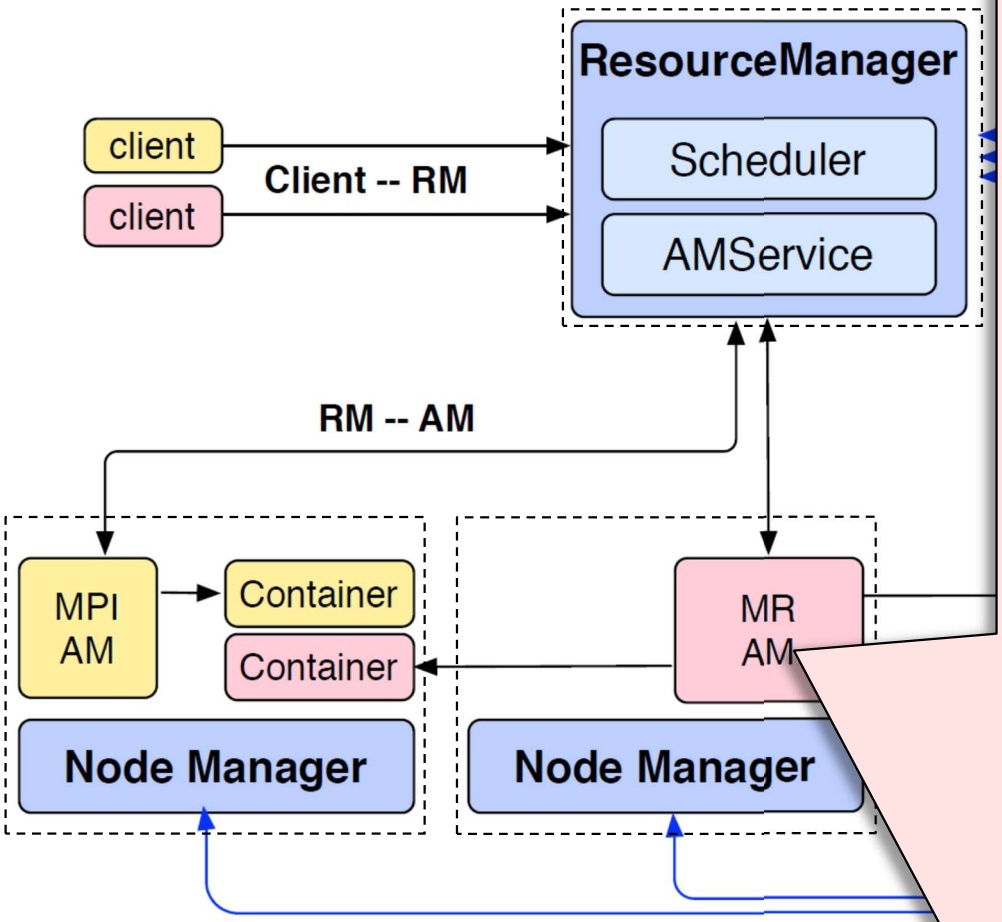
YARN



- System components (blue)
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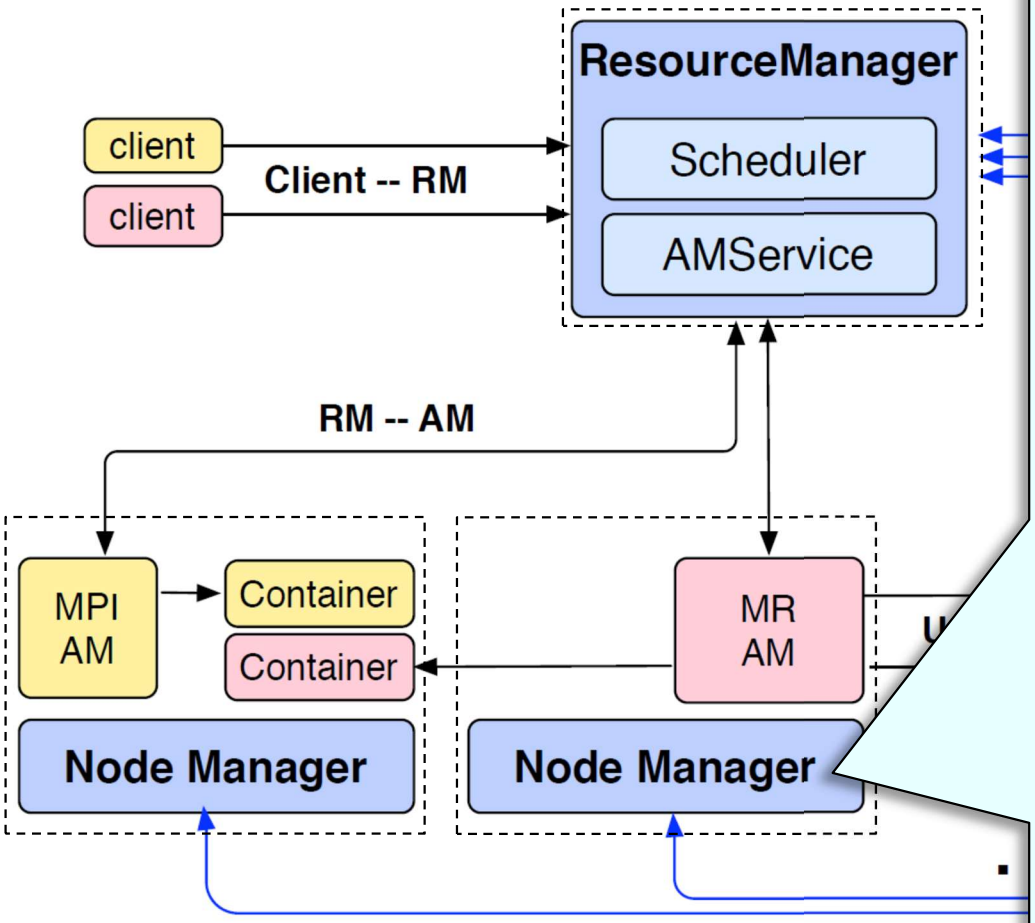
Application Master (AM):

- The ”head” of a job (e.g., a MR job)
  - a daemon process (virtual master node)
  - application / framework - specific
- Manages all *intra-job lifecycle* aspects including dynamically increasing and decreasing resource allocation by issuing resource requests to the RM, *within* the lease obtained from RM
- Manages the flow of execution, e.g. dispatching Mapper and Reducer tasks in Hadoop MapReduce to the job’s containers on the other nodes (= virtual worker nodes) assigned to it
- Handles faults and computation skew (straggling tasks) in a framework-specific way
- YARN itself makes no assumptions about the job’s type of application (programming framework), this is entirely up to the AM
  - Only the protocols to communicate with RM and NM are fixed.

YARN



Node Manager:

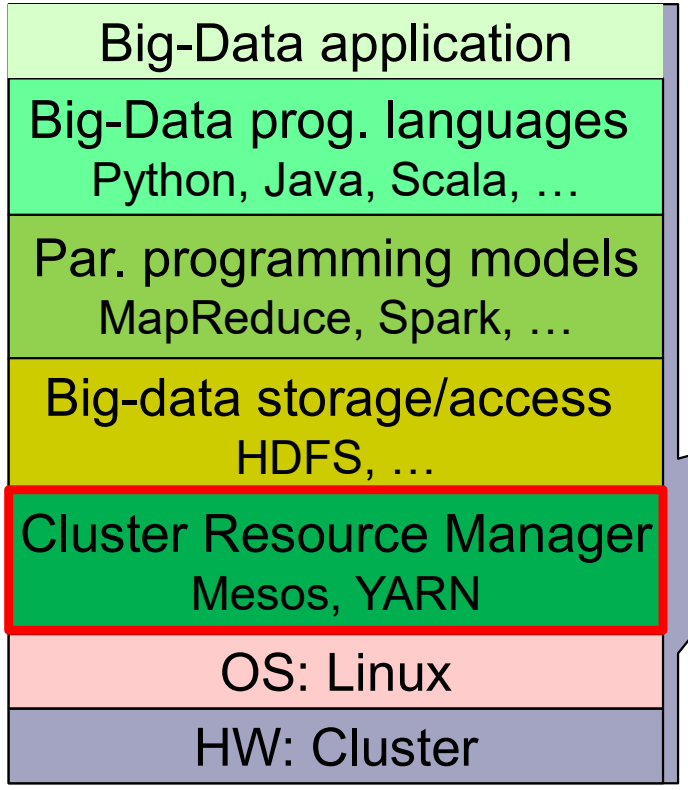
- The ”worker” daemon on each node
- Authenticates container leases, manages container dependences, monitors their execution, provides services to containers
- Deallocates containers on request from AM or RM, when work is finished or when their resources must be preempted for a new higher-priority job
- Monitors health of the physical node
- Log aggregation for the containers
- Handles node-local persistence of data that escape the lifetime of a job.

- System components (blue)
  - RM – Resource Manager, AM – Application Master, NM – node mgr.
- Two applications running (yellow: using MPI, pink: using Hadoop MR)

Summary: Cluster Resource Management

- Cluster-wide ”OS” for **resource sharing across multiple concurrent jobs, programming frameworks, and their versions**
  - Virtualization of cluster resources (with or without using OS containers)
- 2-level resource allocation+management
  - Scheduling e.g. of mapper/reducer tasks to the resources assigned by the cluster manager is still done internally by each framework manager/master
- Mesos, YARN
  - mostly for Hadoop-based programming frameworks (MR, Spark, …)
  - Mesos is offer-based, YARN is request-based.

Big-data system-software stack:



References

- Benjamin Hindman *et al*.: Mesos: A Platform for Fine-Grained Resource Sharing in the Data Center. Proc. *NSDI'11*, USENIX, 2011.
- Apache Mesos: http://mesos.apache.org/
- V. Vavilapalli *et al*.: Apache Hadoop YARN: Yet Another Resource Negotiator. Proc. *SoCC'13*, ACM, 2013.
- Apache Hadoop YARN:
  - https://hadoop.apache.org/docs/r2.7.2/hadoop-yarn/hadoop-yarn-site/YARN.html

Questions for Reflection

- Why is it reasonable that *Application Master*s can request and return resources dynamically from/to the *Resource Manager* (within the maximum lease initially granted to their job by the *RM*), instead of requesting their maximum lease on all nodes immediately and keeping it throughout the job's lifetime?
  - Contrast this mechanism to the resource allocation performed by batch queuing systems for clusters.

- Explain why the *Node Manager*'s tasks are better performed in a daemon process controlled by the *RM* and not under the control of the framework-specific application.