732A54
Big Data Analytics

Resource Management in Big-Data Clusters

Mesos, YARN

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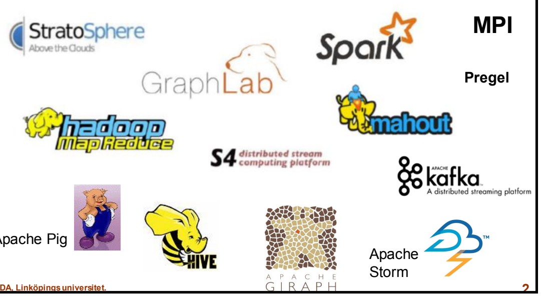
Multiple Big-Data Programming Models Co-Exist

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



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. mappers and reducers
  - Most tasks are (relatively) short

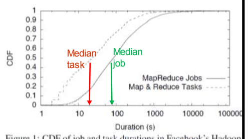


Figure 1: CDF of job and task durations in Facebook's Hadoop data warehouse (data from [38]). Image source: Mesos, 2011

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

  = **Virtualization** of cluster resources

Sharing a Cluster?

Dedicated cluster for a single Hadoop user, single application?
→ Low utilization of expensive cluster resources

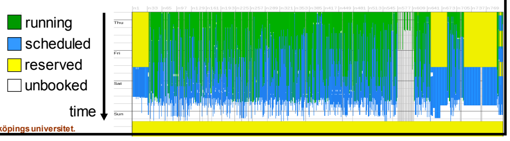
- Idea: Support multiple users and multiple Hadoop jobs that time-share the cluster
  - One application per node at a time
  - Hadoop-on-demand
    - Using Torque/Maui batch scheduler for cluster jobs

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

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

Batch Scheduling for Large Parallel Systems

- Batch queue systems e.g. Torque, Maui, Slurm (common in HPC)
- Only 1 application (job) per node
- Parallel jobs
  - 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



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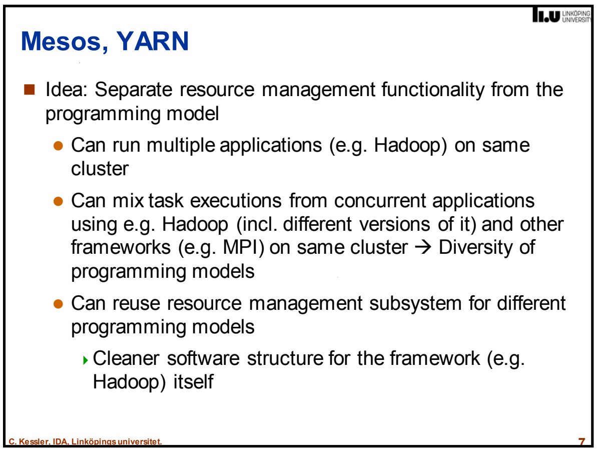
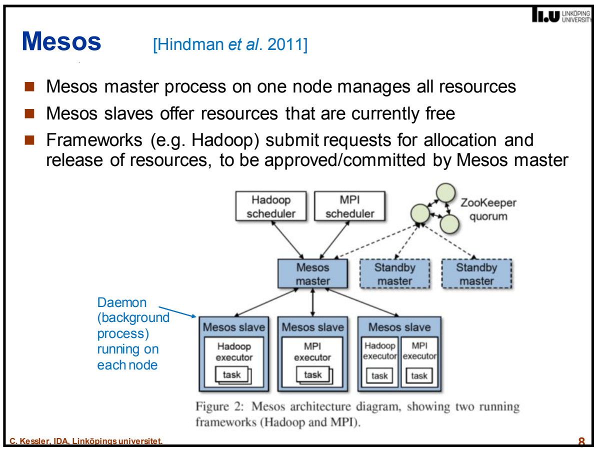


Mesos, YARN

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

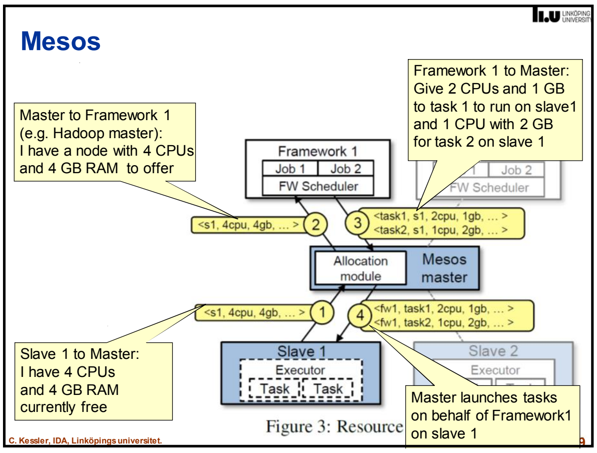


Mesos [Hindman *et al.* 2011]

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

Daemon (background process) running on each node

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



Mesos

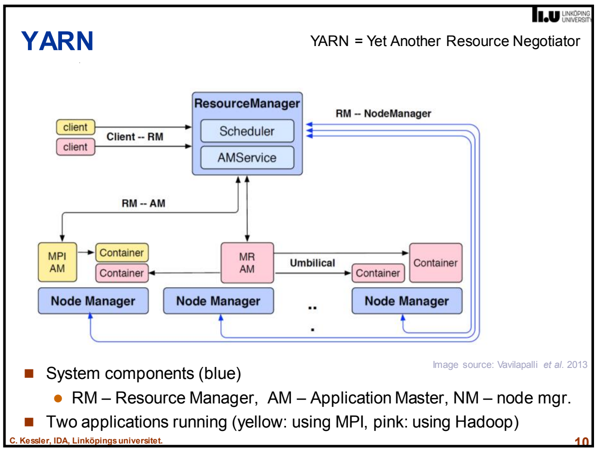
Master to Framework 1 (e.g. Hadoop master): I have a node with 4 CPUs and 4 GB RAM to offer

Framework 1 to Master: Give 2 CPUs and 1 GB to task 1 to run on slave1 and 1 CPU with 2 GB for task 2 on slave 1

Slave 1 to Master: I have 4 CPUs and 4 GB RAM currently free

Figure 3: Resource

Master launches tasks on behalf of Framework1 on slave 1

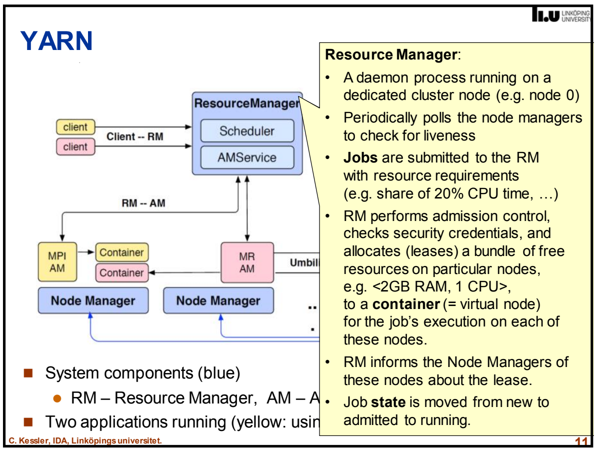


YARN

YARN = Yet Another Resource Negotiator

Image source: 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)



YARN

Resource Manager:

- 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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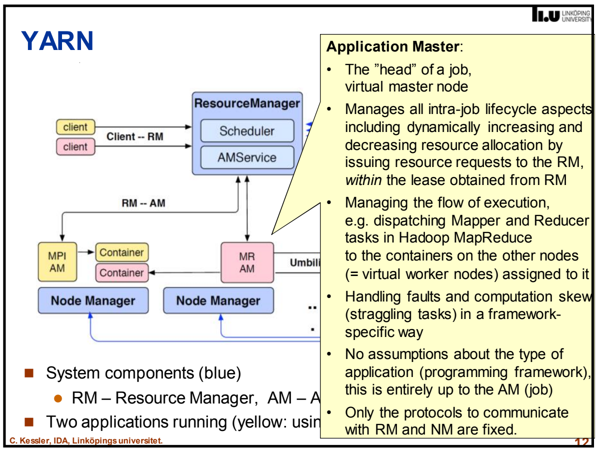

YARN

Application Master:

- The "head" of a job, virtual master node
- 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
- Managing the flow of execution, e.g. dispatching Mapper and Reducer tasks in Hadoop MapReduce to the containers on the other nodes (= virtual worker nodes) assigned to it
- Handling faults and computation skew (straggling tasks) in a framework-specific way
- No assumptions about the type of application (programming framework), this is entirely up to the AM (job)
- Only the protocols to communicate with RM and NM are fixed.

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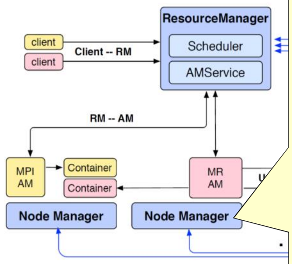
YARN



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.
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Summary: Cluster Resource Management

- Cluster-wide ”OS” for resource sharing across multiple concurrent jobs, programming frameworks, and their versions
- Virtualization of Cluster Resources
- 2-level resource allocation+management
- Mesos is offer-based, YARN is request-based

Big-Data System Software Stack

Big-Data application
Big-Data prog. languages: Java, Scala, Python, …
Par. programming models: MapReduce, Spark, …
Big-data storage/access: HDFS, …
Cluster Resource Manager (Mesos, YARN)
OS: Linux
HW: Cluster

NSC Triolith

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 Masters 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.