MR+
A Technical Overview

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What is MR+?

Port of Hadoop's MR classes to the general computing environment

- Allow execution of MapReduce programs on any cluster, under any resource manager, without modification
- Utilize common HPC capabilities
  - MPI-based libraries
  - Fault recovery, messaging
- Co-exist with other uses
  - No dedicated Hadoop cluster required

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What MR+ is NOT

- An entire rewrite of Hadoop
  - Great effort was made to minimize changes on the Hadoop side
  - No upper-level API changes were made
    - Pig, Hive, etc. do not see anything different
- An attempt to undermine the Hadoop community
  - We want to bring Hadoop to a broader community by expanding its usability and removing barriers to adoption
  - We hope to enrich the Hadoop experience by enabling use of a broader set of tools and systems
    - Increase Hadoop's capabilities w/o reinventing the wheel

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Why did we write it?

- Scalability issues with Hadoop/YARN
  - Launch and file positioning scales linearly
  - Wireup scales quadratically
  - No inherent MPI support
- Performance concerns
  - Data transfer done via http
  - Low performance (high latency, many small transfers)
- Barriers to adoption
  - Integrated RM, dictating use of dedicated system
  - Only supports Ethernet/http

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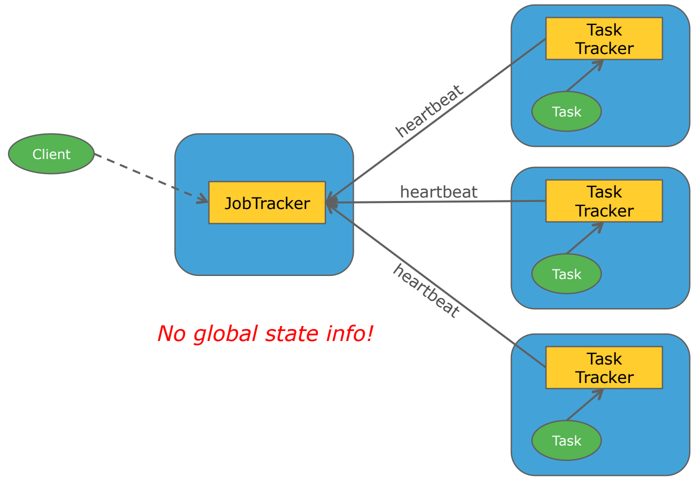
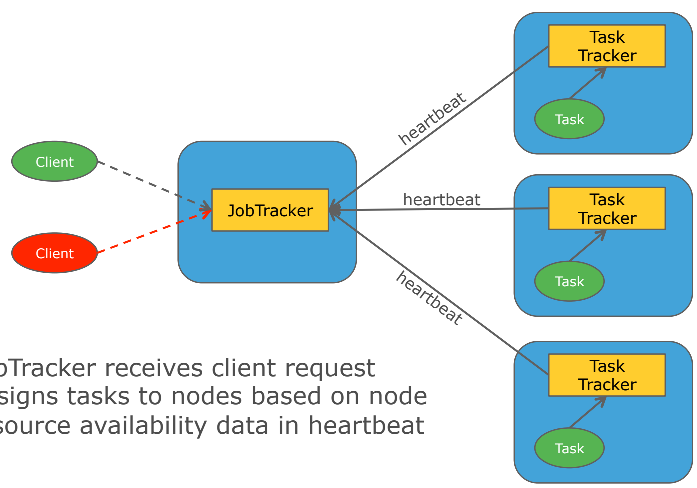
Hadoop 1.0

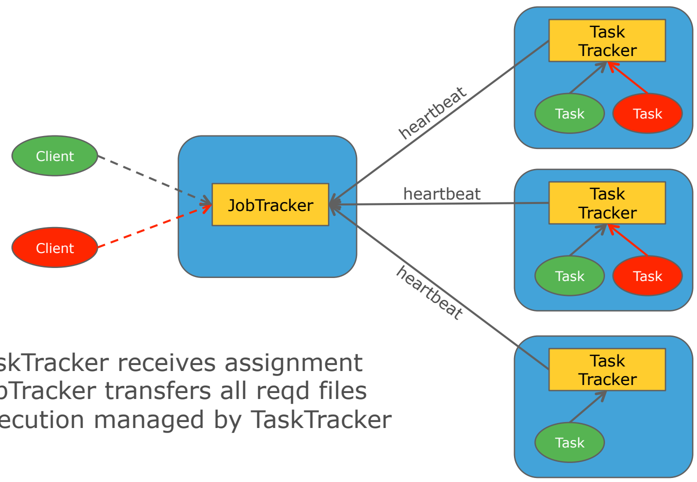


Hadoop 1.0



- JobTracker receives client request
- Assigns tasks to nodes based on node resource availability data in heartbeat

Hadoop 1.0



- TaskTracker receives assignment
- JobTracker transfers all reqd files
- Execution managed by TaskTracker

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Hadoop 1.0

- Task assignment done upon heartbeat
  - JobTracker uses synchronous processing of heartbeats
    - Max transaction rate 200 beats/sec
  - No global status info ⇒ must wait for beat to assign tasks to any node
  - Linear launch scaling
- No internode communication
  - Hub-spoke topology
  - Precludes collective communication for wireup exchange
  - Wireup scales quadratically
- Simple fault recover model

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Hadoop 2.0

- Cleaner separation of roles
  - Node manager: manages nodes, not tasks
  - Create new application master role
- Event-driven async processing of heartbeats
  - Improve throughput for better support of large clusters

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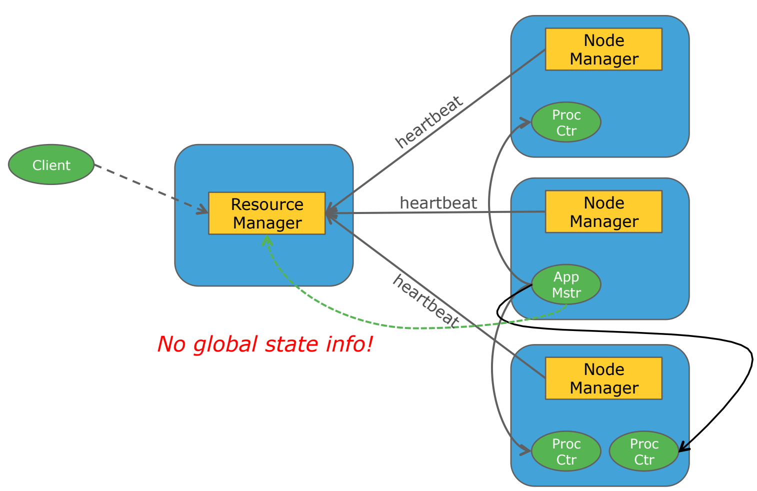
Hadoop 2.0 (YARN)



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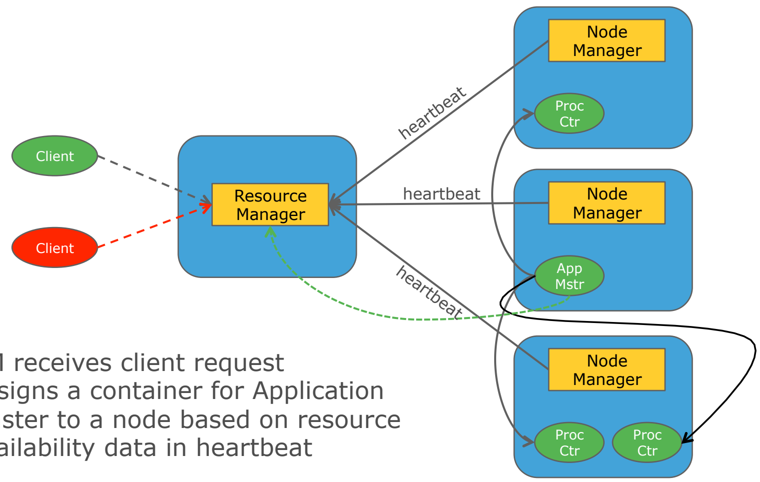
Hadoop 2.0 (YARN)



- RM receives client request
- Assigns a container for Application Master to a node based on resource availability data in heartbeat

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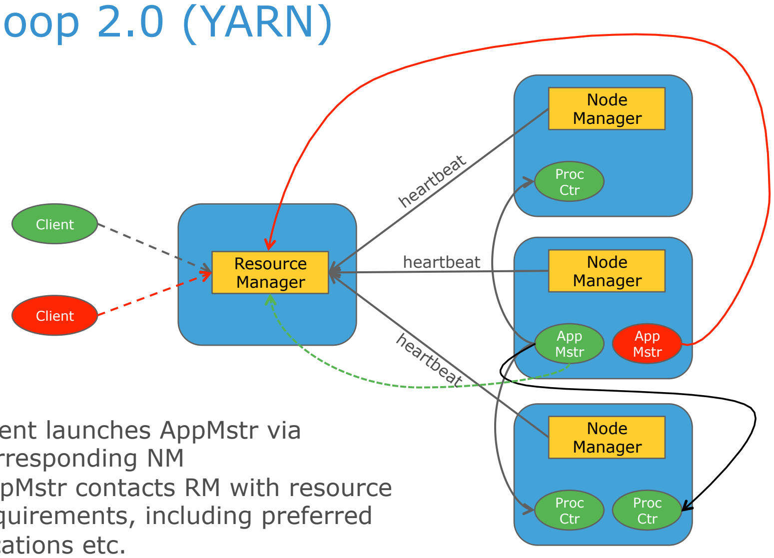
Hadoop 2.0 (YARN)



- Client launches AppMstr via corresponding NM
- AppMstr contacts RM with resource requirements, including preferred locations etc.

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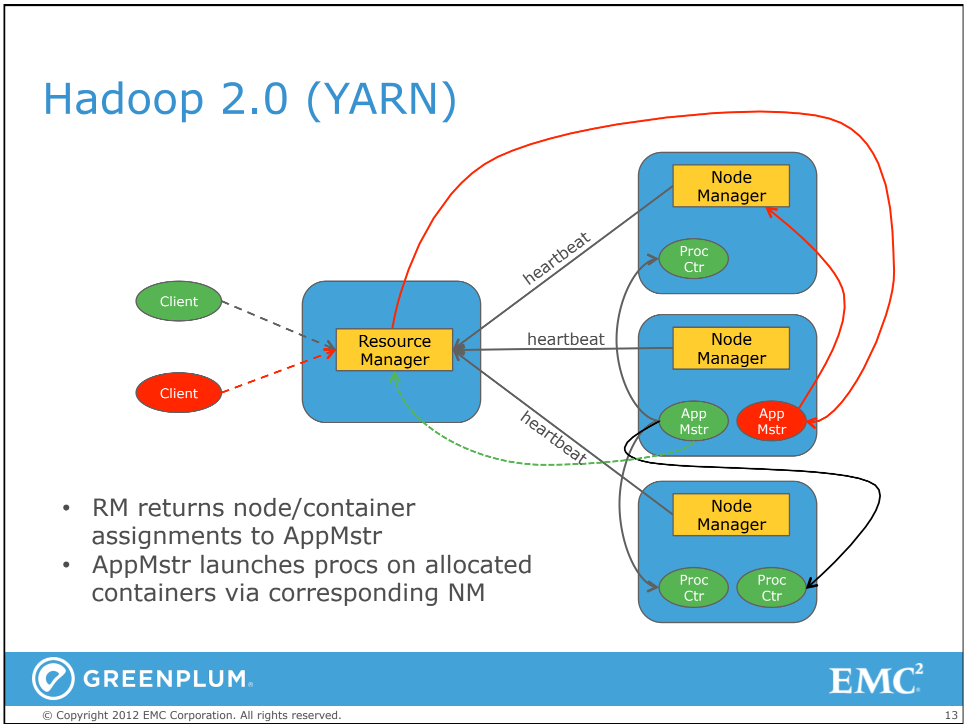
Hadoop 2.0 (YARN)
Client
Client
Resource Manager
heartbeat
heartbeat
heartbeat
Node Manager
Proc Ctr
Node Manager
App Mstr
App Mstr
Node Manager
Proc Ctr
Proc Ctr
• RM returns node/container assignments to AppMstr
• AppMstr launches procs on allocated containers via corresponding NM
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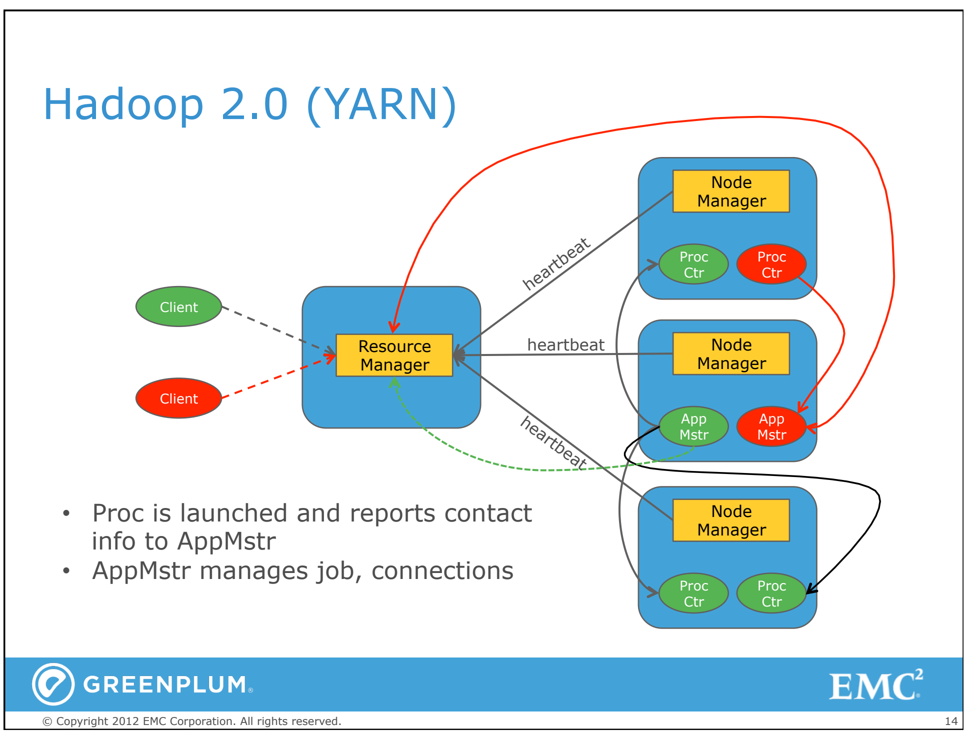
Hadoop 2.0 (YARN)
Client
Client
Resource Manager
heartbeat
heartbeat
heartbeat
Node Manager
Proc Ctr
Proc Ctr
Node Manager
App Mstr
App Mstr
Node Manager
Proc Ctr
Proc Ctr
• Proc is launched and reports contact info to AppMstr
• AppMstr manages job, connections
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Hadoop 2.0

- Two levels of task assignment done upon heartbeat
  - Faster, but now have to do it twice
  - No global status info ⟹ must wait for beat to assign AM and tasks to any node
  - Linear launch scaling
- No internode communication
  - Hub-spoke topology with AM now at the hub
  - Precludes collective communication for wireup exchange
- Simple fault recover model
- Security concerns
  - Nodemanagers are heavyweight daemons operating at privileged level

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Observations

MR+

- SLURM
  - 16,000 processes across 1000 nodes launched in ~20 milliseconds*
  - Wired and running in ~10 seconds
- Cray
  - 139,000 processes across 8500 nodes launched in ~1 second
  - Wired and running in ~60 seconds*

- Hadoop 2.0
- 2 processes on separate nodes
  - Launched in ~5-10 seconds
- 12,768 processes on 3,192 nodes
  - Launched in ~10 min
  - Wired and running in ~45 minutes*

*prepositioned files

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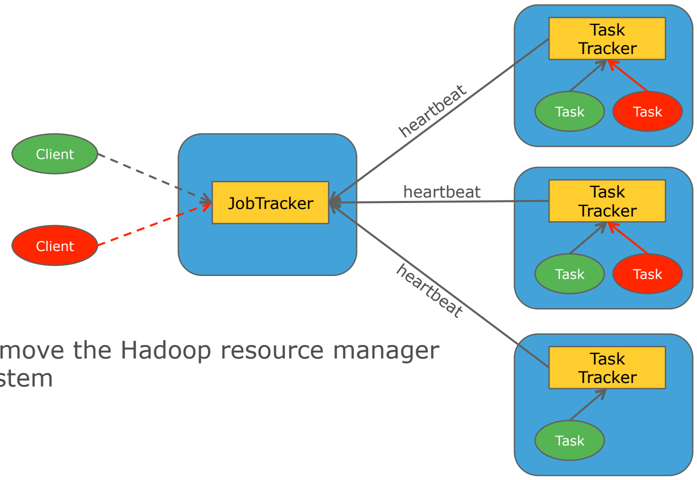
MR+ Approach



- Remove the Hadoop resource manager system

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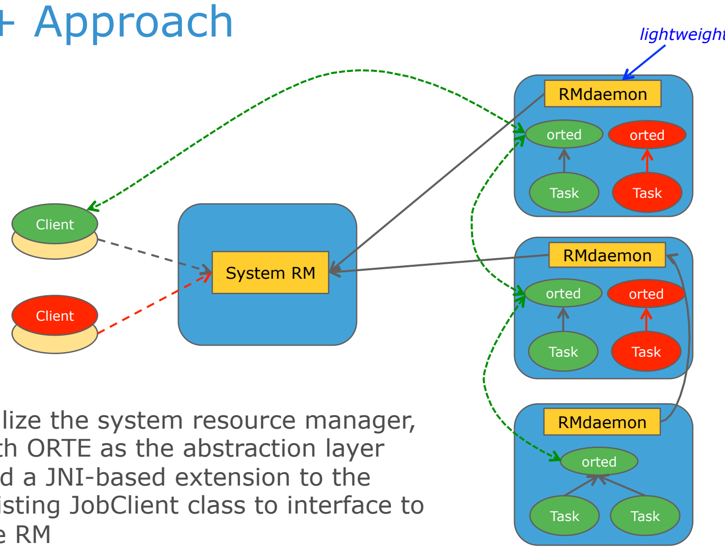
MR+ Approach



- Utilize the system resource manager, with ORTE as the abstraction layer
- Add a JNI-based extension to the existing JobClient class to interface to the RM

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Differences

- RMs maintain system state
  - Don't rely on heartbeats to avoid scalability issues
    - Look at connection state
    - Use multi-path connection topology
  - High availability based on redundant "masters"
  - Allocation can be performed immediately, regardless of scale
- Scalable launch
  - Internode communication allows collective launch and wireup (logN scaling)
- Reduced security concern
  - RM daemons very lightweight
    - Consist solely of fork/exec (no user-level comm or API)
    - Minimal risk for malware penetration
  - Orteds are heavier, but operate at user level

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How does it work?

- "Overlay" JobClient class
  - JNI-based integration to Open MPI's run-time (ORTE)
  - ORTE provides virtualized shim on top of native resource manager
    - Launch, monitoring, and wireup at logN scaling
    - Inherent MPI support, but can run non-MPI apps
    - "Staged" execution to replicate MR behavior
  - Preposition files using logN-scaled system
- Extend FileSystem class
  - Remote access to intermediate files
  - Open, close, read, write access
  - Pre-wired TCP-based interconnect, other interconnects (e.g., Infiniband, UDP) automatically utilized to maximize performance

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What are the biggest differences?

It's all in the daemons…

- Hadoop's node-level daemons do not communicate with each other
  - Only send "heartbeats" to the YARN resource manager
  - Have no knowledge of state of rest of nodes
  - Results in bottleneck at RM, linear launch scaling, quadratic wireup of application processes…but relatively easy fault tolerance
- ORTE's daemons wireup into a communication fabric
  - Relay messages in a logN pattern across the system
  - Retain independent snapshot of state of system
  - Results in logN launch scaling, logN wireup, coordinated action to respond to faults…but more complex fault tolerance design

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What are the biggest differences?

…and in the RM

- Hadoop's RM retains no global state info
  - Allocation requests are queued and wait for heartbeats from nodes that indicate appropriate resources available
  - Results in delays until heartbeats arrive, suboptimal resource allocation unless wait to hear from all nodes (complication: nodes may have failed)…but easy to recover RM on failure
- HPC RMs maintain global state
  - Can immediately allocate, optimize assignment
  - Results in very fast allocation times (>100K/sec)…but more difficult to recover RM on failure (methods have been field proven, but are non-trivial)

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Three new pieces

- Jobclient.c
  - Contains JNI integration to ORTE
  - Serves as "HNP" in the ORTE system
    - Manages launch and sequencing of MR stages
    - Replaces Hadoop execution enging
- Filesystem.c
  - Support distributed file operations (open, close, read, write) using ORTE daemons for shuffle stage
- Mapred.c
  - Send and receive mapper output partition metadata

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Overview of operation: defining the job

- jc = New jobClient
  - If OMPI libs not loaded, then load them and initialize ORTE system
  - Create a new map/reduce instance
- jc.addMapper/addReducer
  - Call as many times as you like, each with its own cmd line
  - Typically called once for each split
  - Includes param indicating relative expected run time
- jc.addFile, addJar
  - Indicate files to be transferred to remote nodes for use by mappers and reducers (archives automatically expanded on remote end)
  - Separately tracked for each map/reduce pair
- jc.runJob
  - Execute this map/reduce pair
  - Execution will commence as resources become available
  - Returns upon completion

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Map/Reduce staging

- Current
  - Only one map/reduce pair can be executing at a time
  - Any number of pairs can be defined in parallel
  - Any sequencing of M/R pairs is allowed
    - Results-based steering
- Future
  - Map/reduce pairs can operate in parallel
    - Sequenced according to resource availability
  - runJob will queue job and immediately return
    - isComplete() polled to determine completion

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Resource definition

- Current
  - Allocation must be defined in advance
    - Obtained from external RM
    - Specified in hostfile – number of slots automatically set to number of cores on each node
  - Java-layer determines what, if any, location preference
    - Can use HDFS to determine locations
  - Provided to jobClient as non-binding "hint" for each M/R split
    - Highest priority given to placing procs there, but will use other nodes if not available
- Future option
  - ORTE can obtain allocation from external RM based on file specifications
    - RM will treat file locations as non-binding "hint", callback with allocation when number of desired slots is met (working on SLURM and Moab integration now)
    - If you give allocation, we will use it

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Some details/constraints

- Execute in ORTE session directory
  - Unique "scratch" directory tree on each node
  - Includes temporary directory for each process
  - All files preloaded to top-level location, and then linked to the individual process' directory
- Jars automatically added to classpath
- Paths must be set*
  - "hadoop" must be in PATH on all nodes
  - OMPI must be installed and in PATH and LD_LIBRARY_PATH on all nodes

*Typical HPC requirement

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Overview of operation: execution

- For each pair, mappers go first
  - Longest expected running mappers have higher priority
    - Executed in priority order as resources permit, so lower priority could run first if resources for higher priority not available
  - Location "hint" used to prioritize available resources
    - If desired location available, it is used
    - Otherwise, alternative locations used
  - "strict" option
    - Limits execution strictly to desired locations
- When mappers fully completed, associated reducer is executed
  - Uses same "hint" rule as mappers

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Resource competition

Variety of schemes by user option

- "eldest": priority to the longest waiting process across all executing M/R pairs
- "greedy": priority to the process expected to require longest running time in the same M/R pair*
- "sequential": priority to the next defined process in the same M/R pair, rotating to next M/R pair if all done
- "eager": priority to process expected to require shortest running time across all executing M/R pairs
- Many schemes can be supported by simply adding components

*current, default

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Overview of operation: data transfer

- Reducers access mapper output via extensions to FileSystem class
  - Open, close, read, write APIs
  - Daemons on remote nodes transfer the data using ORTE/ OMPI transports
    - Fastest method used, point-to-point
- Also support streaming mode
  - Requires mappers and reducers both execute at same time
    - Must have adequate resources to do so
  - Stdout of mappers connected to stdin of reducers
- Future
  - Look at MPI-I/O like solution

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What about MPI?

- MPI permitted when all procs can be run in parallel
  - ORTE detects if MPI attempted and errors out if it cannot be supported
  - Mapper and reducer are treated separately
- MPI support always available
  - No special request required
  - Add flag at some point to indicate "all splits must be executed in parallel"?

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What about faults?

- Processes automatically restarted
  - Time from failure to relocation and restart
    - Hadoop: ~5-10 seconds
    - MR+: ~5 milliseconds
  - Relocation based on fault probabilities
    - Avoid cascading failures
- Future state recovery based on HPC methods
  - Process periodically saves "bookmark"
  - Restart provided with bookmark so it knows where to start processing
  - Prior intermediate results are preserved, appended to new results during communication

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Why would someone use it?

- Flexibility
  - Let customer select their preferred environment
    - Moab/Maui, SLURM, LSF, Gridengine, simple rsh, …
  - Share resources
- Scalability
  - Launch scaling: Hadoop (~N), MR+ (~logN)
  - Wireup: Hadoop ($\sim N^2$), MR+ (~logN)
- Performance
  - Launches ~1000x faster, potentially runs ~10x faster
  - Enables interactive use-case
- MPI library access
  - ScaLAPACK, CompLearn, PetSc, …

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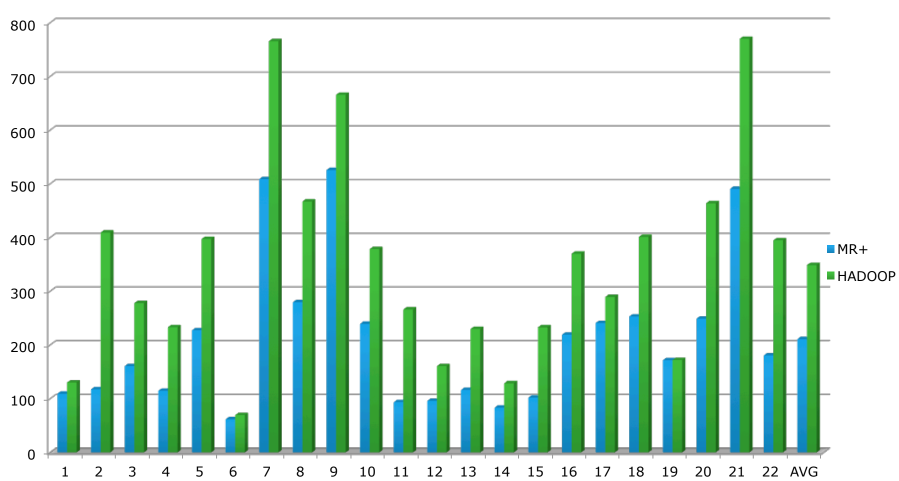
TPCH: 50G (Hive benchmark)



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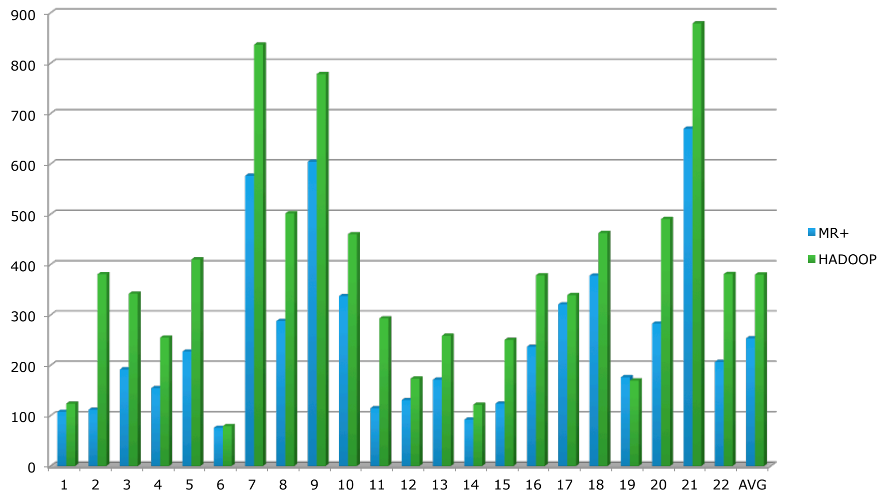
TPCH:100G (Hive benchmark)



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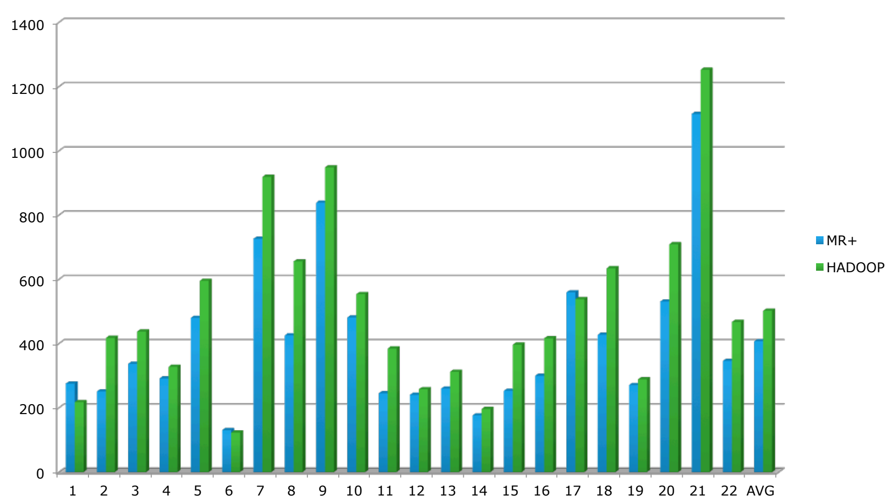
TPCH: 256G (Hive benchmark)



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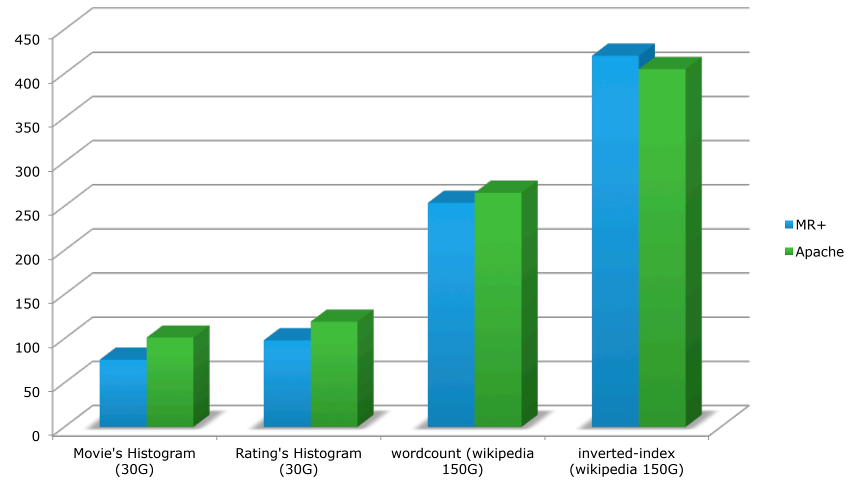
Other Benchmarks



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Lessons Learned

- Running MR using ORTE is feasible, provides benefits
  - Performance, security, execute anywhere
  - Access to MPI
  - Performance benefit drops as computation time increases
- Need improvement
  - Shuffle operation
    - Pre-position data for reducers that haven't started yet
    - Requires pre-knowledge of where reducers are going to execute
    - More efficient, parallel file read access (perhaps MPI-IO)
  - Overlap mappers and reducers (resources permitting)
    - Don't require all mappers to complete before starting corresponding reducers

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Future Directions

- Complete the port
  - Extend range of validated Hadoop tools
  - Add support for HD2.0
- Continue testing and benchmarks
  - Demonstrate fault recovery
  - Large-scale demonstration
- "Alpha" release of code
  - Gain early-adopter feedback
- Pursue improvements
  - Shuffle, simultaneous operations

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