UNIVERSITY OF CAMBRIDGE

# Cloud Computing
# MapReduce in Heterogeneous Environments

# Contents

- Looking at MapReduce performance in heterogeneous clusters
- Material is from the paper:

  "Improving MapReduce Performance in Heterogeneous Environments",

  By Matei Zaharia, Andy Konwinski, Anthony D. Joseph, Randy Katz and Ion Stoica, published in Usenix OSDI conference, 2008
- and their presentation at OSDI

# Motivation: MapReduce is becoming popular

- Open-source implementation, Hadoop, used by Yahoo!, Facebook, Last.fm, …
- Scale: 20 PB/day at Google, O(10,000) nodes at Yahoo, 3000 jobs/day at Facebook

# Stragglers in MapReduce

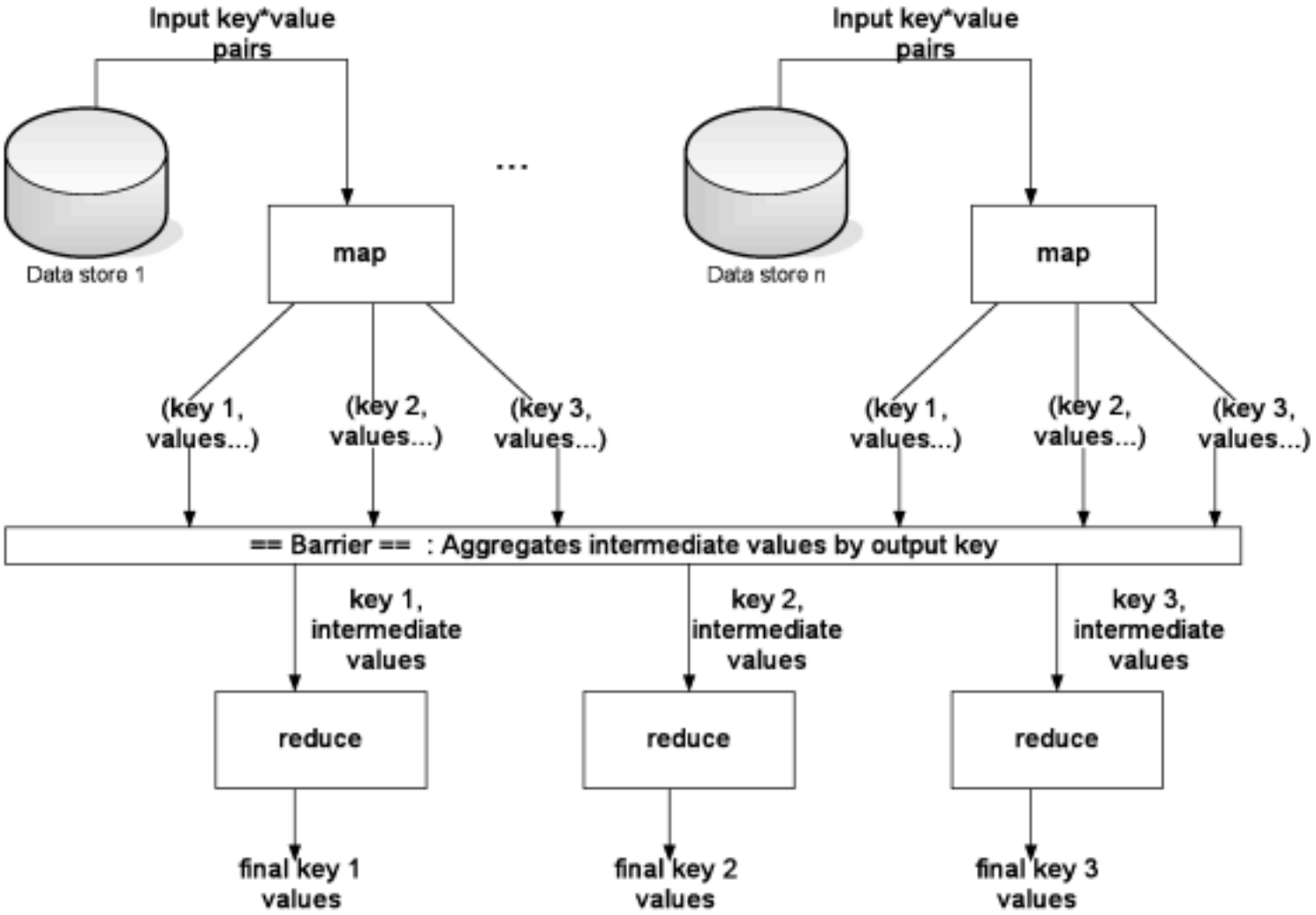
- Straggler is a node that performs poorly or not performing at all.
- Original MapReduce mitigation approach was:
  - To run a speculative copy (called a backup task)
  - Whichever copy or original would finish first would be included
- Without speculative execution, a job would be slow as the slowest sub-task
- Google notes that speculative execution can improve job response times by 44%
- Is this approach good enough for modern clusters?

# Modern Clusters: Heterogeneity is the norm

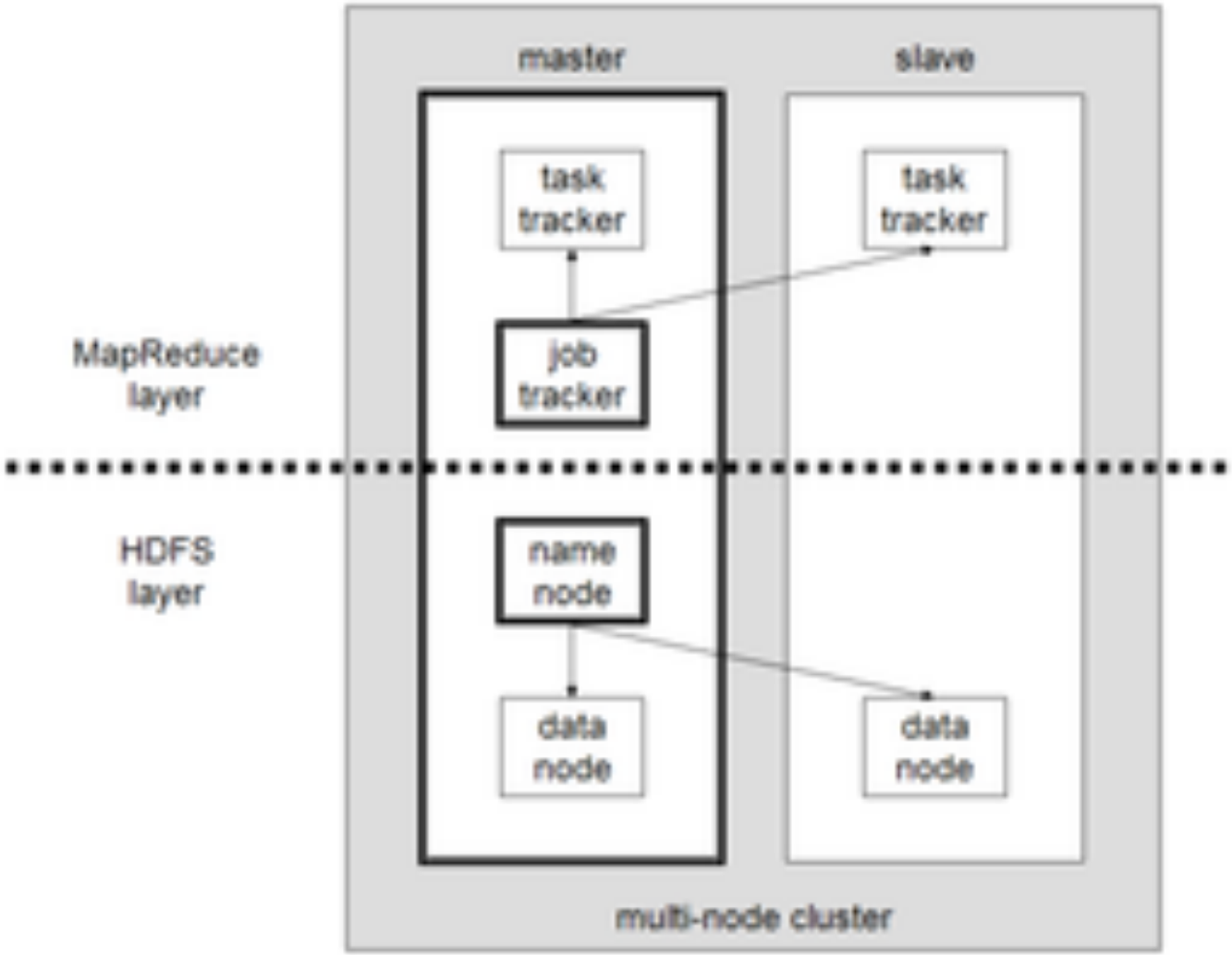
- Cloud computing providers like Amazon's Elastic Compute Cloud (EC2) provide cheap on-demand computing:
  - Price: 2 cents / VM / hour
  - Scale: thousands of VMs
  - Caveat: less control of performance

- Main challenge for Hadoop on EC2 is performance heterogeneity, which breaks task scheduler assumptions
- This lecture/paper is on a new LATE scheduler that can cut response time in half

# MapReduce Revised



# MapReduce Implementation, Hadoop



# Scheduling in MapReduce

- When a node has an empty slot, Hadoop chooses one from the three categories in the following priority:
  1. A failed task is given higher priority
  2. Unscheduled tasks. For maps, tasks with local data to the node are chosen first.
  3. Looks to run a speculative task.

# Deciding on Speculative Tasks

- Which task to execute speculatively?
- Hadoop monitors tasks progress using a *progress score*: a number from 0, …, 1
- For mappers: the score is the fraction of input data read
- For reducers: the execution is divided into three equal phases, 1/3 of the score each:
  - Copy phase: percent of maps that output has been copied from
  - Sort phase: map outputs are sorted by key: percent of data merged
  - Reduce phase: percent of data passed through the reduce function
- Example: a task halfway through the copy phase has progress score = 1/2*1/3 = 1/6.
- Example: a task halfway through the reduce phase has progress score = 1/3 + 1/3 + 1/2 * 1/3 = 5/6

# Deciding on Speculative Tasks (con't)

- Hadoop looks at the average progress of each category of maps and reduces and defines a **threshold:**
- **When a task's progress is less than the average for its category minus 0.2, and the task has run at least one minute, it is marked as a straggler:**

$$\textbf{threshold} = \textbf{avgProgress} - \textbf{0.2}$$

- All tasks with **progress score < threshold** are stragglers
- Ties are broken by data locality

- This approach works reasonably well in homogeneous clusters

# Scheduler's Assumptions

1. Nodes can perform work at roughly the same rate
2. Tasks progress at constant rate all the time
3. There is no cost to starting a speculative task
4. A task's progress is roughly equal to the fraction of its total work
5. Tasks tend to finish in waves, so a task with a low progress score is likely a slow task
6. Different task of the same category (maps or reduces) take roughly the same amount of work

# Revising Scheduler's Assumptions

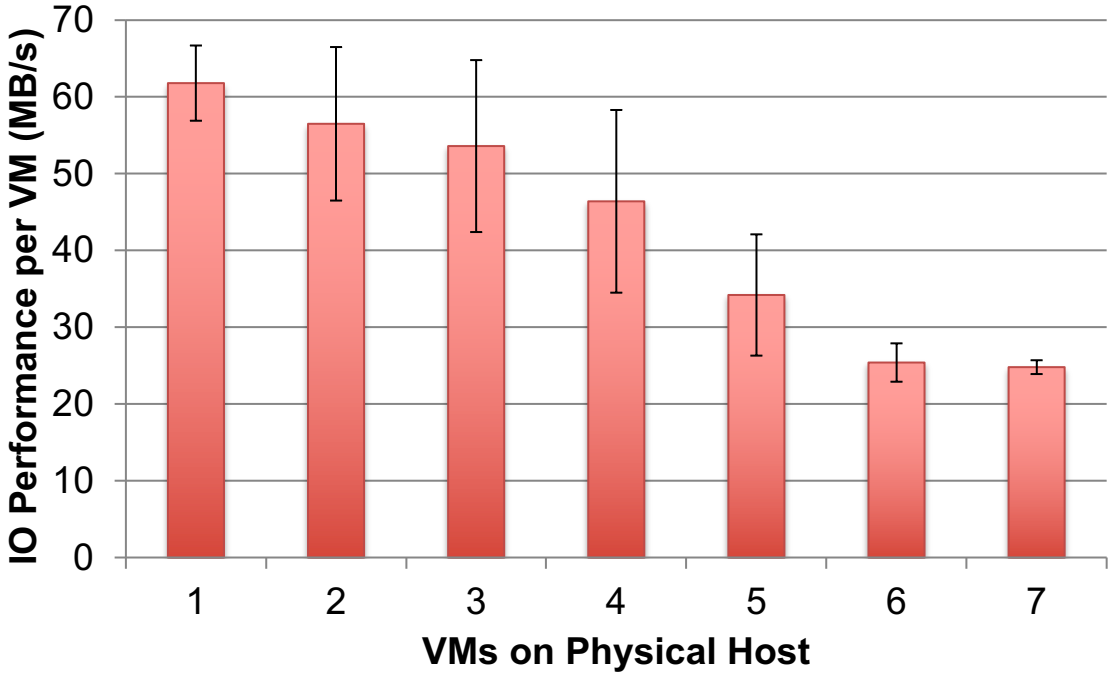
1. Nodes can perform work at roughly the same rate
2. Tasks progress at constant rate all the time

- **(1)** In heterogeneous clusters some nodes are slower (older) than others
- **(2)** Virtualized clusters "suffer" from co-location interference

# Heterogeneity in Virtualized Environments

- VM technology isolates CPU and memory, but disk and network are shared
  - Full bandwidth when no contention
  - Equal shares when there is contention
- Timed a `dd` command that wrote 5000 MB of zeroes from `/dev/zero` to a file in parallel on 871 virtual machines in EC2's production cluster.

- **2.5x** performance difference



# Revising Scheduler's Assumptions

3. There is no cost to starting a speculative task
4. A task's progress is roughly equal to the fraction of its total work
5. Tasks tend to finish in waves, so a task with a low progress score is likely a slow task

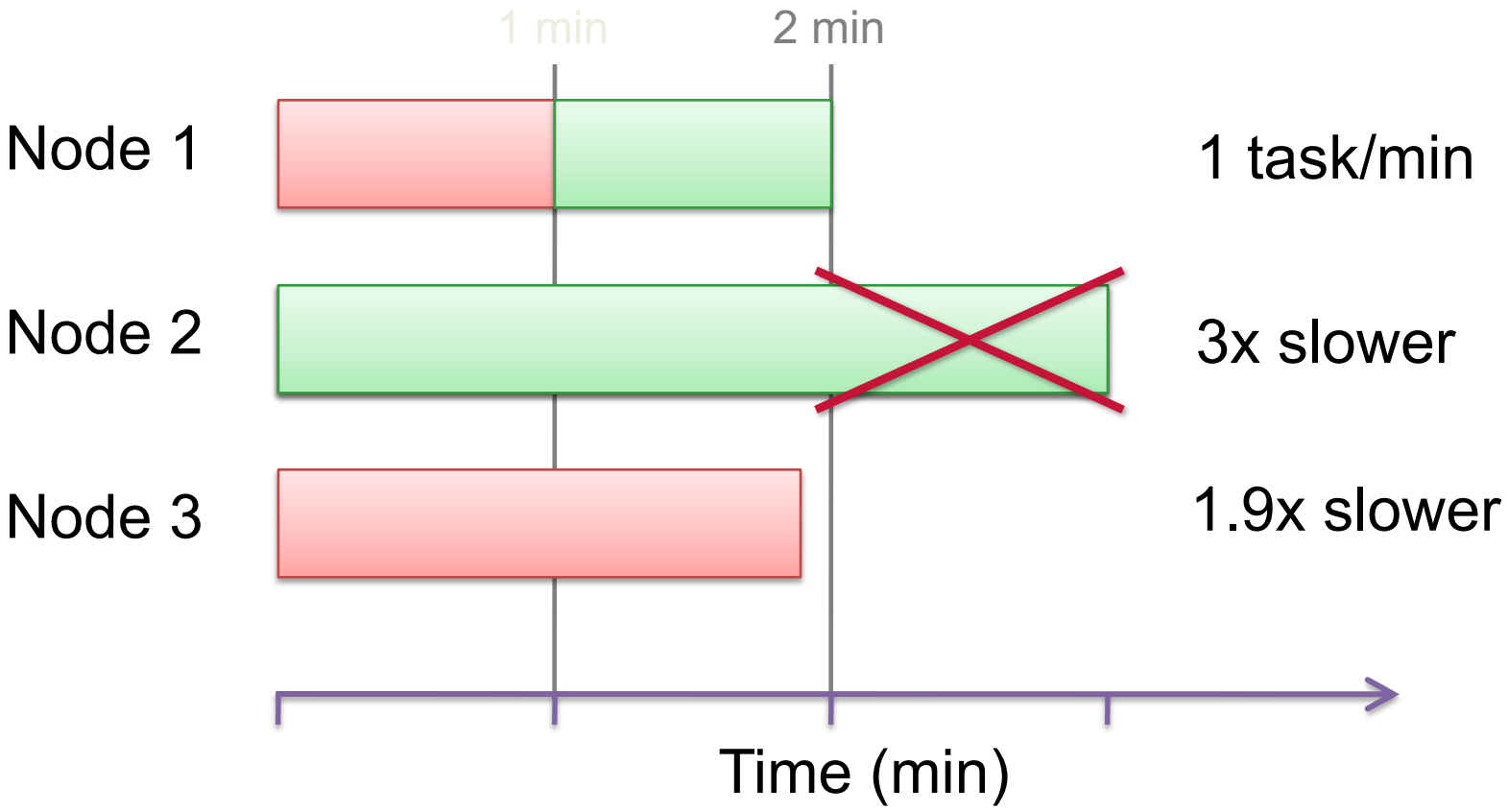
- **(3)** Too many speculative tasks can take away resources from other running tasks
- **(4)** The copy phase of reducers is the slowest part, because it involves all-pairs communications. But this phase counts for 1/3 of the total reduce work.
- **(5)** Tasks from different generations will be executed concurrently. So newer faster tasks are considered with older show tasks, avgProgress changes a lot.

# Idea: Progress Rates

- Instead of using **progress score values**, compute **progress rates**, and back up tasks that are "far enough" below the mean

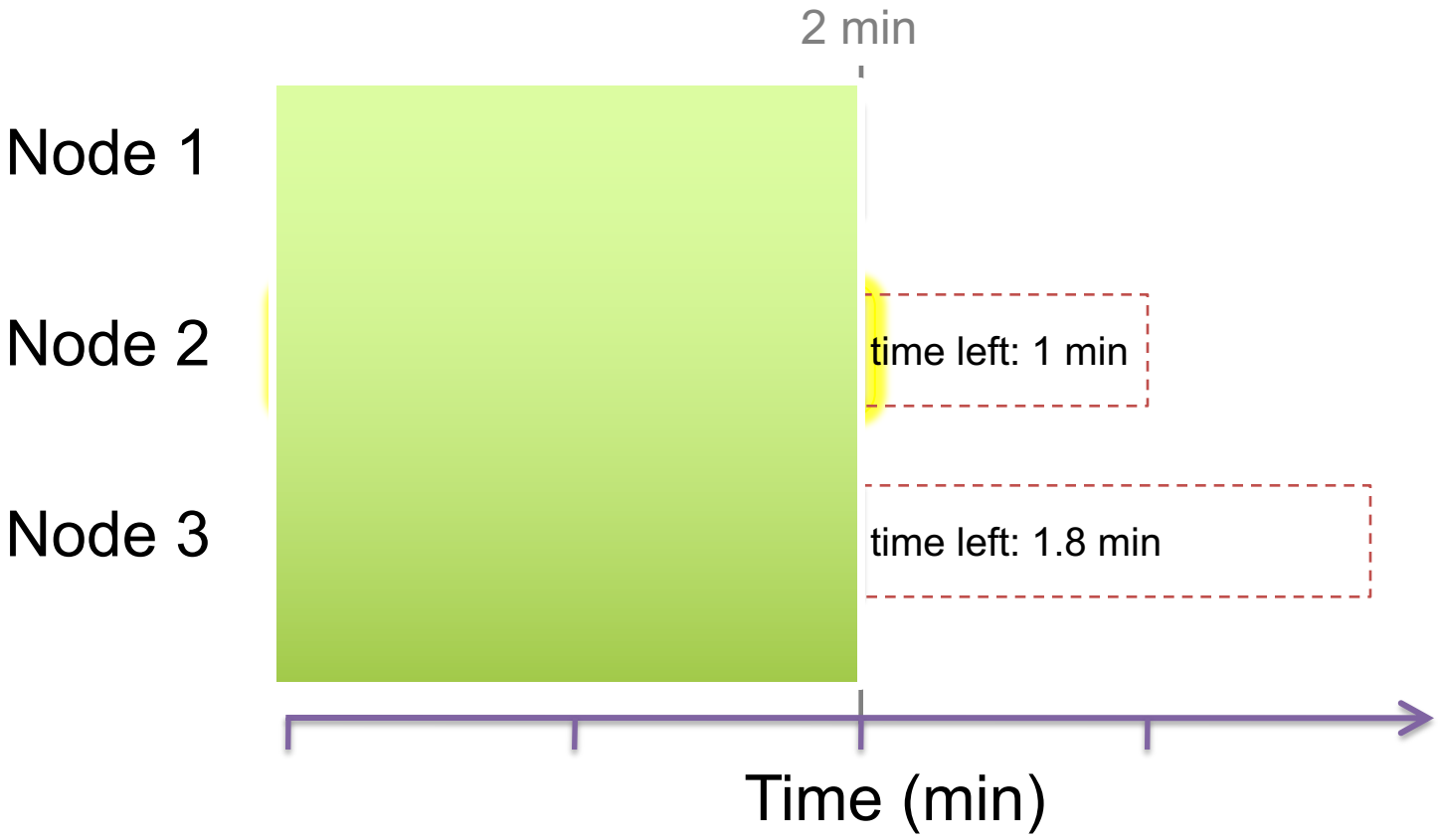
- Problem: can still select the wrong tasks

# Progress Rate Example



# Progress Rate Example

What if the job had 5 tasks?




**Node 2 is slowest, but should back up Node 3's task!**

# Our Scheduler: LATE

- Insight: back up the task with the largest estimated finish time
  - "Longest Approximate Time to End" → LATE
  - Look forward instead of looking backward
- Sanity thresholds:
  - Cap number of backup tasks
  - Launch backups on fast nodes
  - Only back up tasks that are sufficiently slow

# LATE Details

- Estimating finish times:

$$\textit{progress rate} = \frac{\text{progress score}}{\text{execution time}}$$

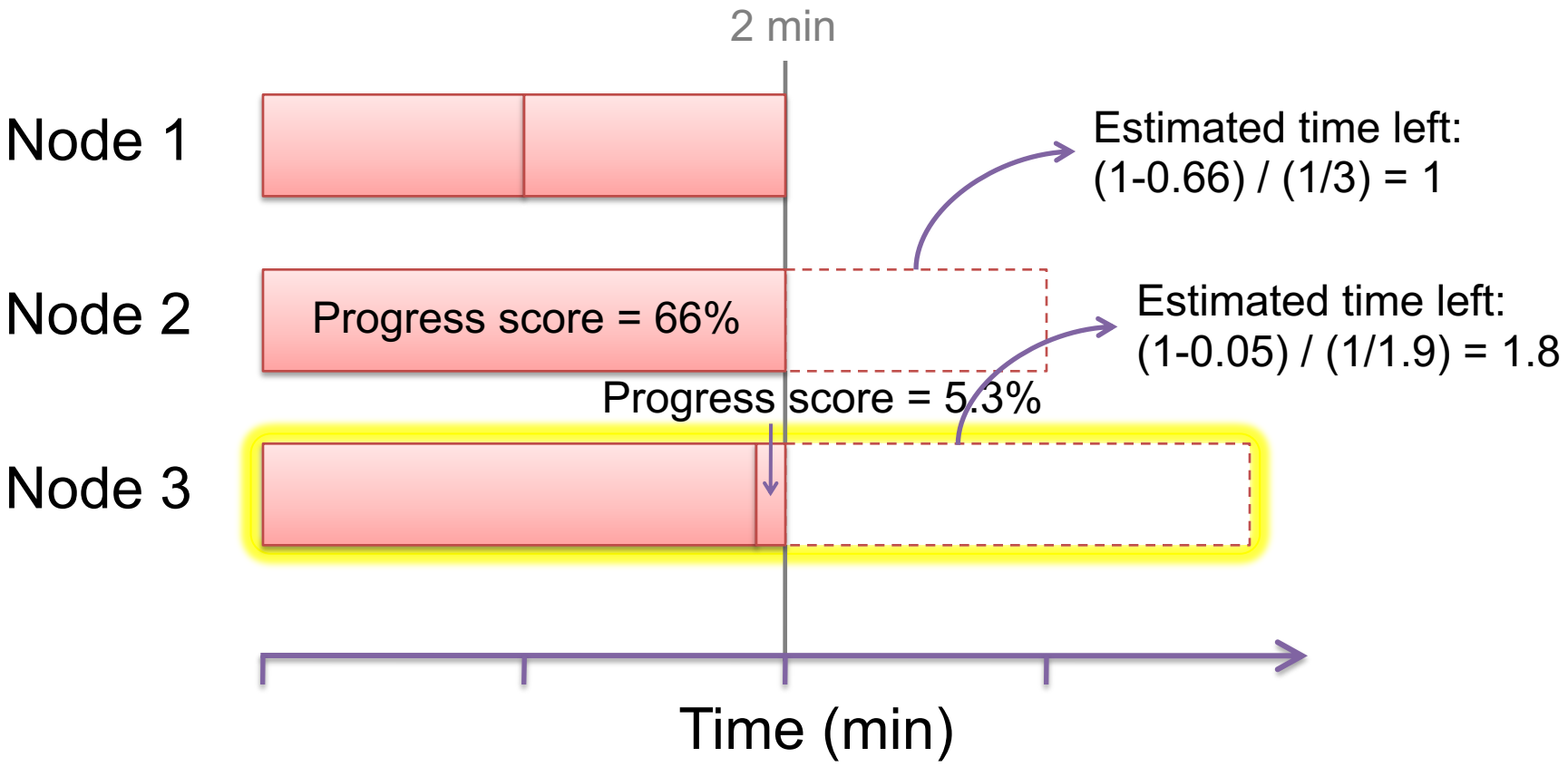
$$\textit{estimated time left} = \frac{1 - \text{progress score}}{\text{progress rate}}$$

# LATE Scheduler

- If a task slot becomes available and there are less than *SpeculativeCap* tasks running, then:
  1. Ignore the request if the node's total progress is below *SlowNodeThreshold (=25$^{th}$ percentile)*
  2. Rank currently running, non-speculatively executed tasks by estimated time left
  3. Launch a copy of the highest-ranked task with progress rate below *SlowTaskThreshold (=25$^{th}$ percentile)*

- Threshold values:
  - 10% cap on backups, 25$^{th}$ percentiles for slow node/task
  - Validated by sensitivity analysis

# LATE Example



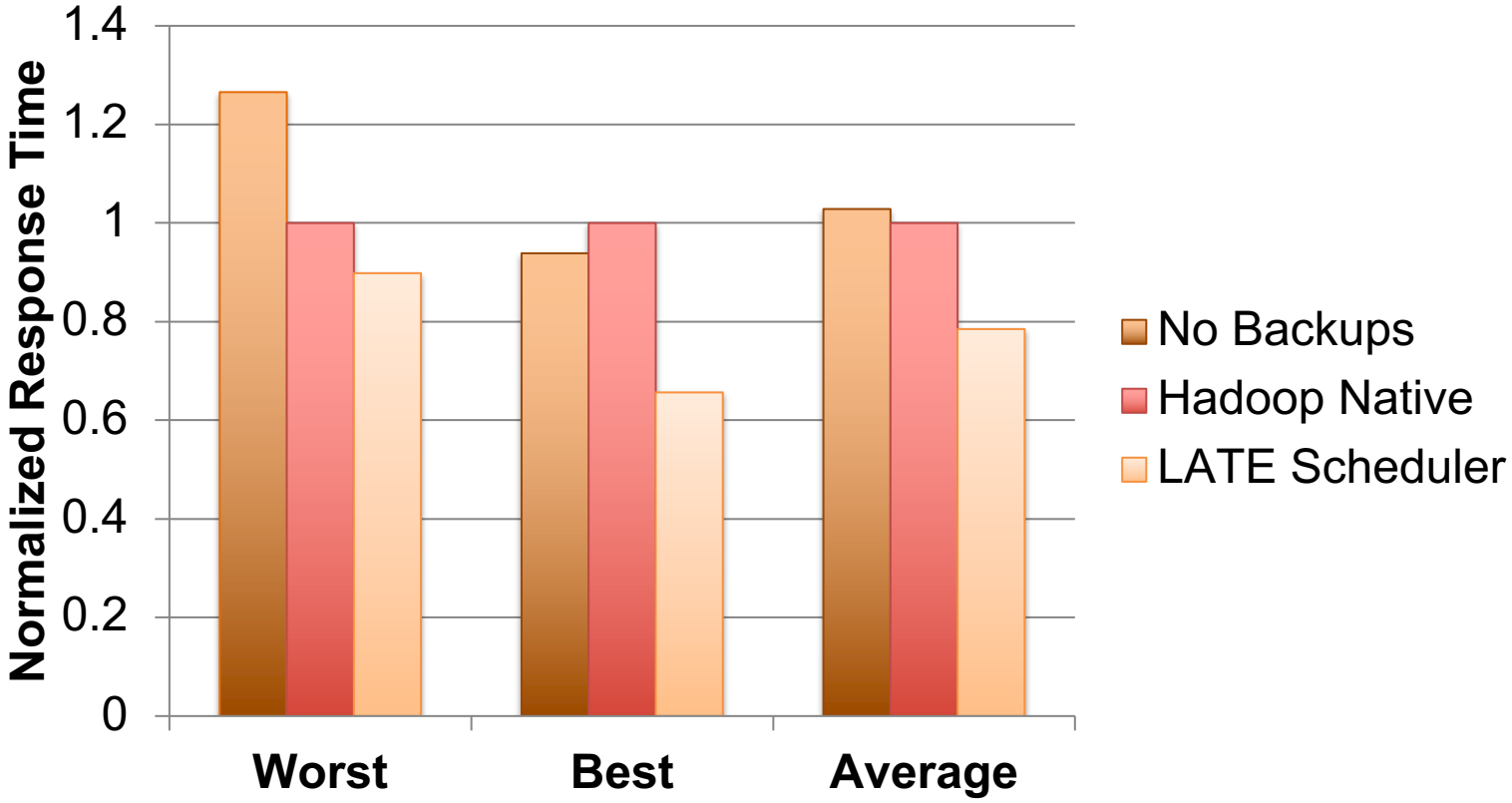

**LATE correctly picks Node 3**

# Evaluation

- Environments:
  - EC2 (3 job types, 200-250 nodes)
  - Small local testbed
- Self-contention through VM placement
- Stragglers through background processes

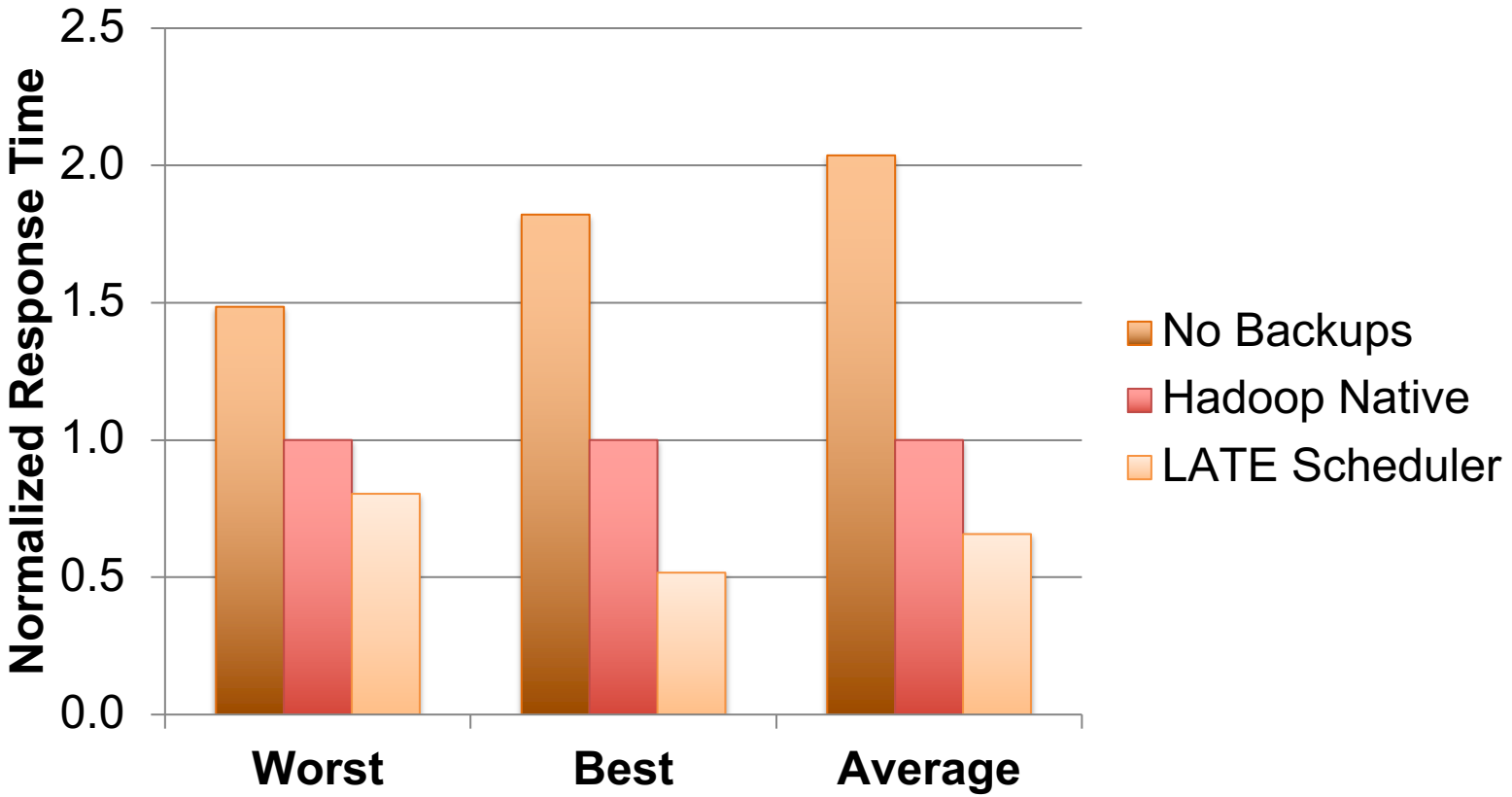
# EC2 Sort without Stragglers (Sec 5.2.1)

- 106 machines , 7-8 VMs per machine → total of 243 VMs
- 128 MB data per host, 30 GB in total
- 486 map tasks and 437 reduce tasks
- average 27% speedup over native, 31% over no backups



# EC2 Sort with Stragglers (Sec 5.2.2)

- 8 VMs are manually slowed down out of 100 VMs in total
- running background of CPU- and disk-intensive jobs
- average 58% speedup over native, 220% over no backups
- 93% max speedup over native



# Conclusion

- Heterogeneity is a challenge for parallel apps, and is growing more important
- Lessons:
  - Back up tasks which hurt response time most
- 2x improvement using simple algorithm

# Summary

- MapReduce is a very powerful and expressive model
- Performance depends a lot on implementation details

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