DON'T CRY OVER SPILLED RECORDS
Memory elasticity of data-parallel applications and its application to cluster scheduling

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

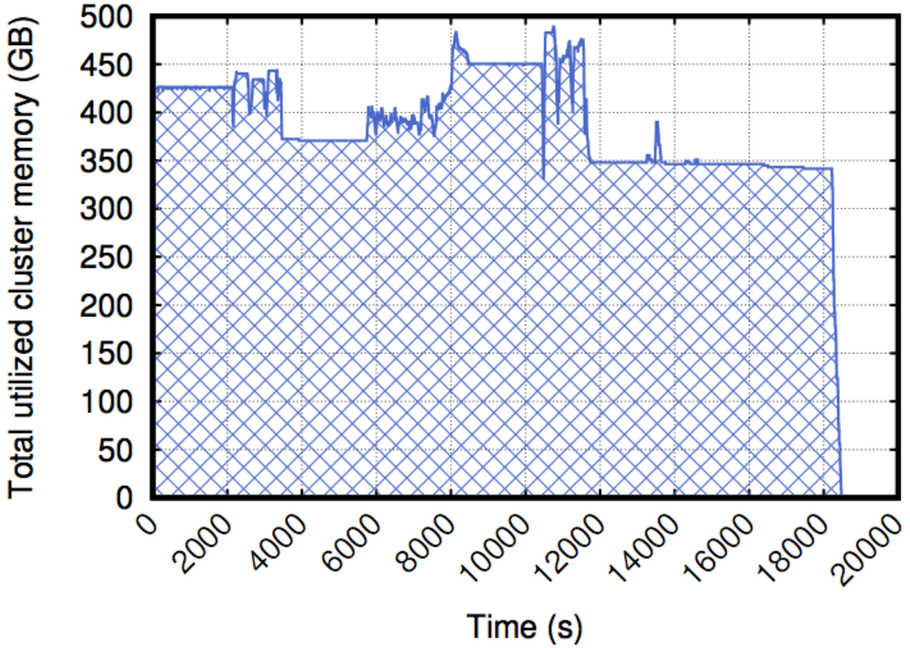
Cluster operators care about resource utilization

✓ Best bang for your buck!

✓ Maximize performance of data-parallel applications

- Idea: Efficient resource utilization through **under-provisioning**

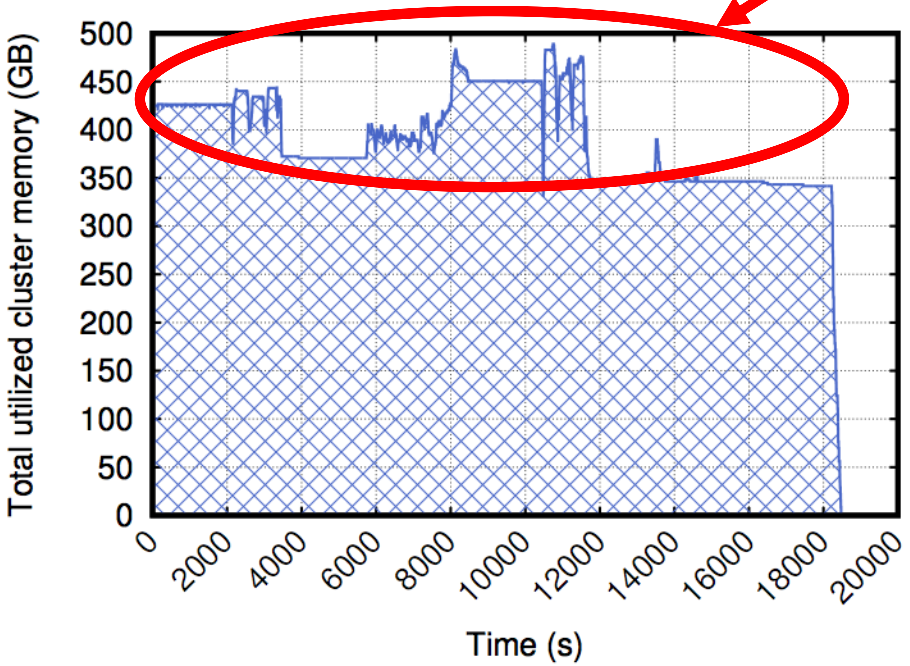
Cluster memory is under-utilized!



Avg. mem. utilization: **78%**

Cluster memory is under-utilized!

Leverage this idle memory!



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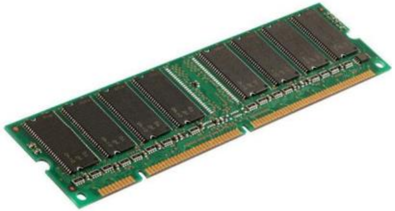
Impact of memory constraining applications

- Conventional wisdom: do not touch memory!



- Risks:
  - crashes
  - severe performance degradation (e.g., thrashing)

Can we safely, deterministically, and with modest impact constrain memory?

Context: batch jobs and their memory usage

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Input

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Ideal memory

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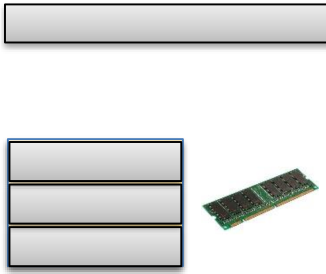
Ideal memory



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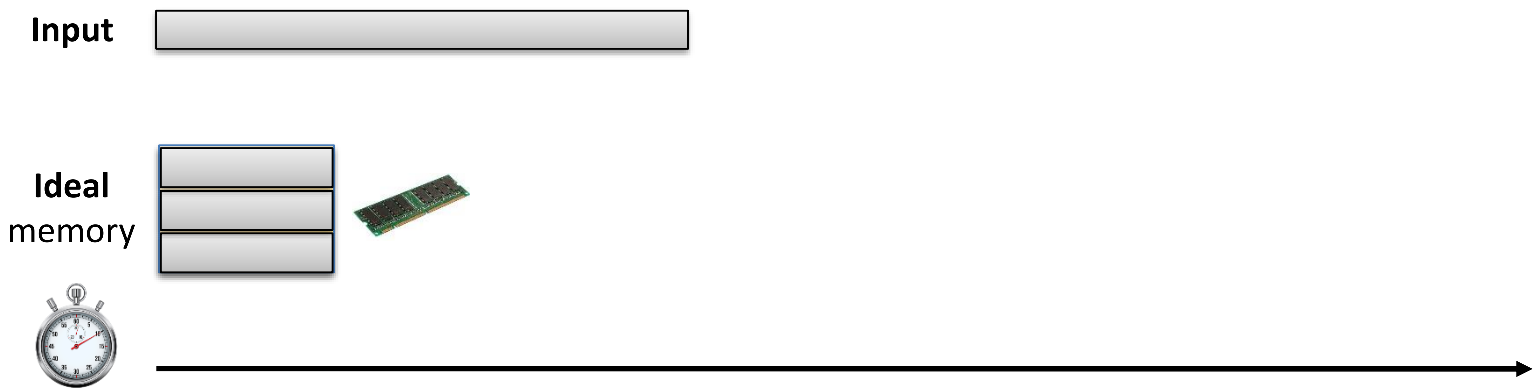

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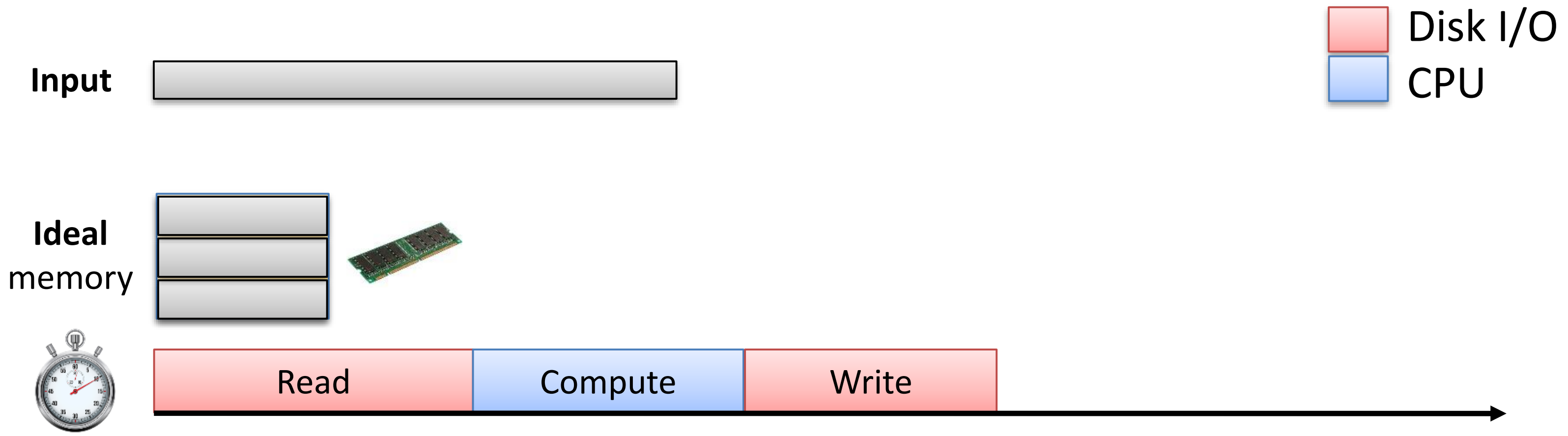

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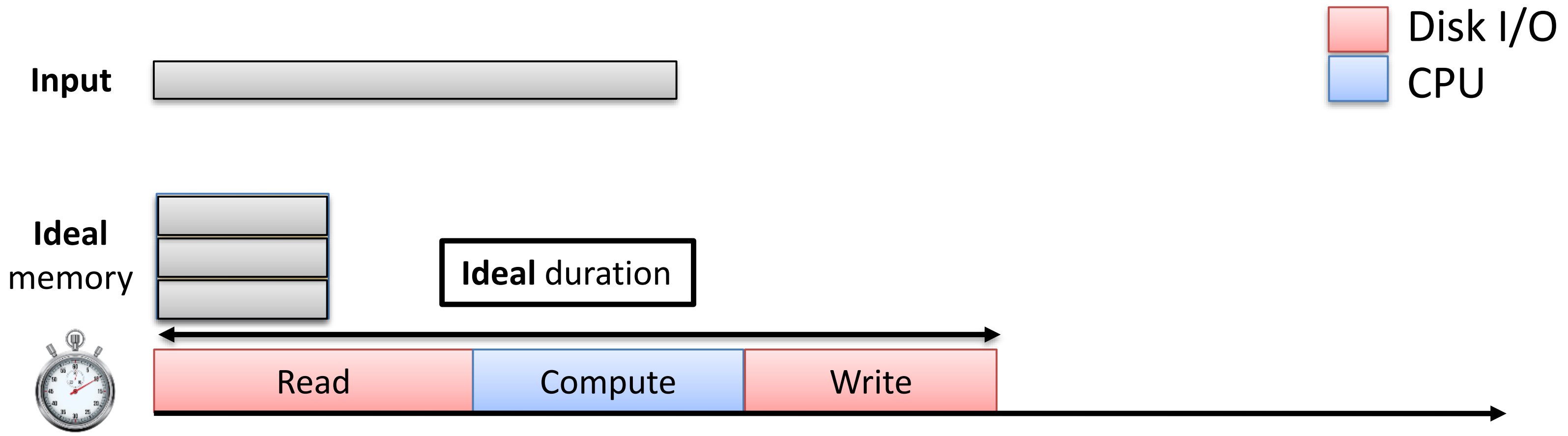

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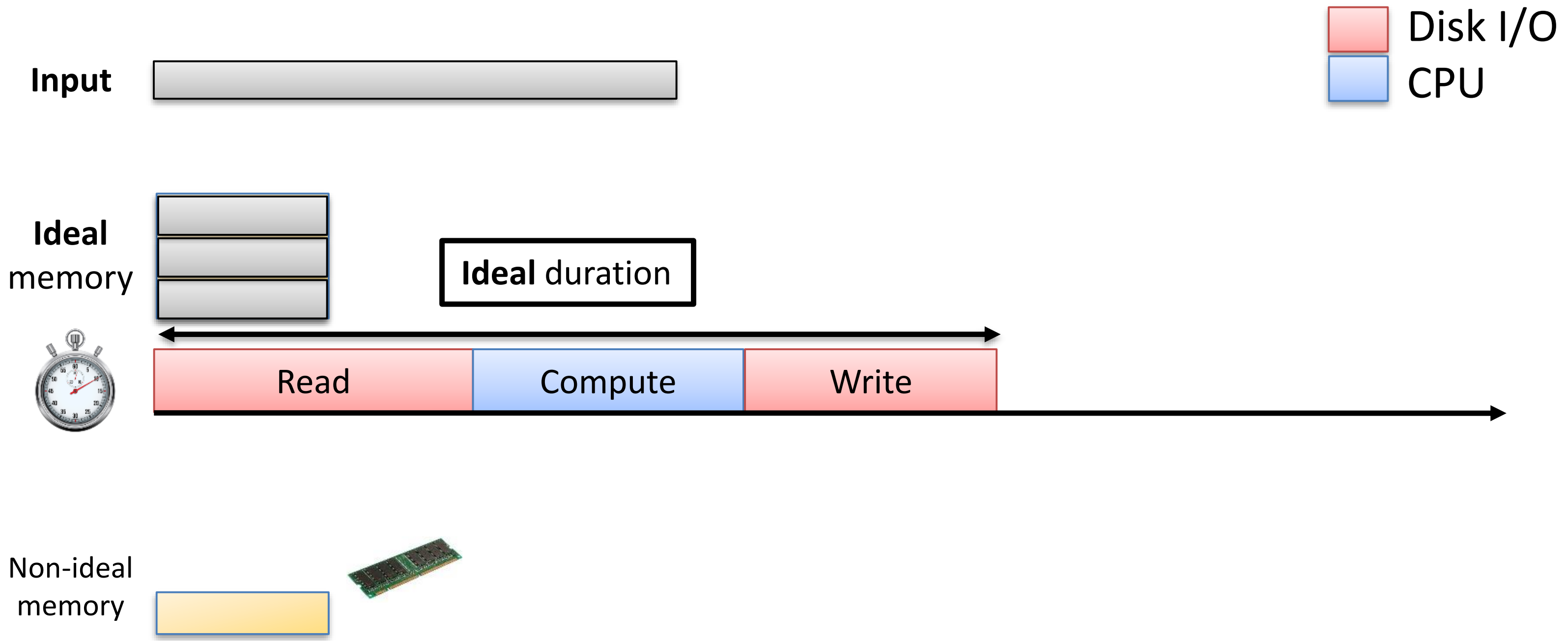

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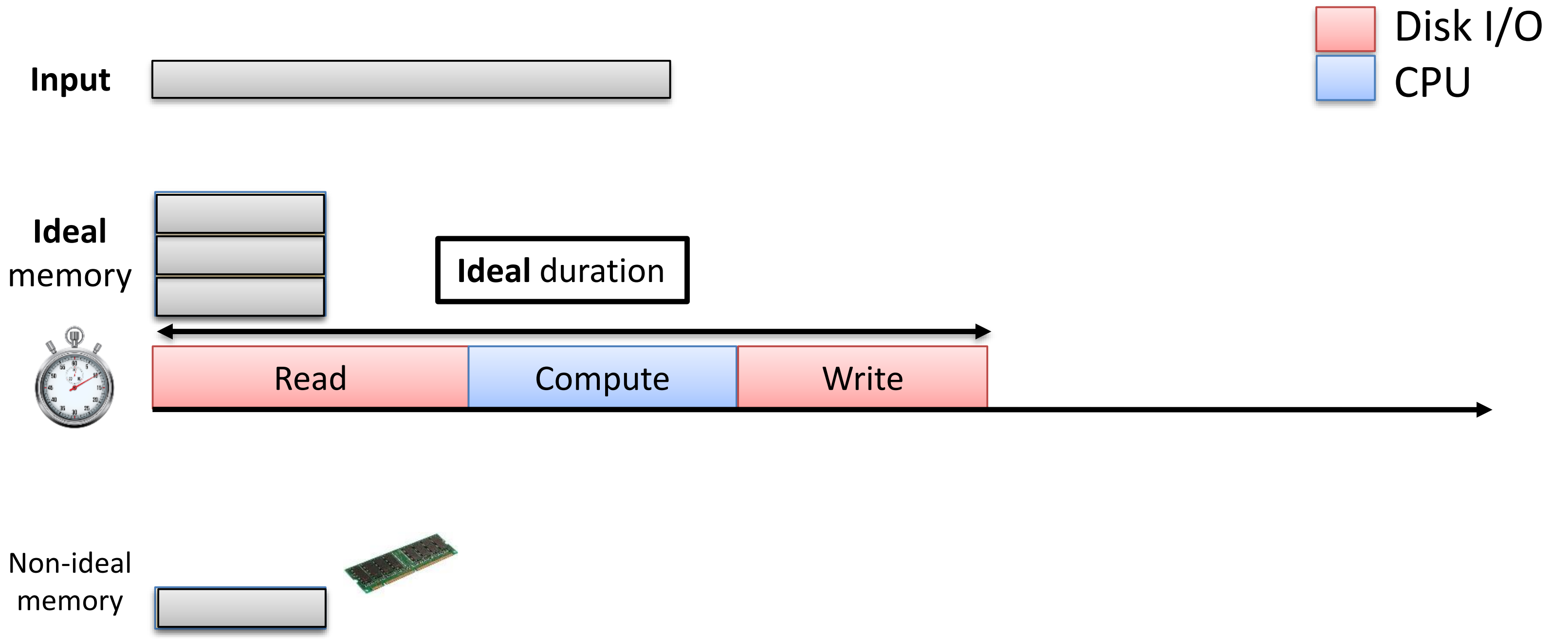

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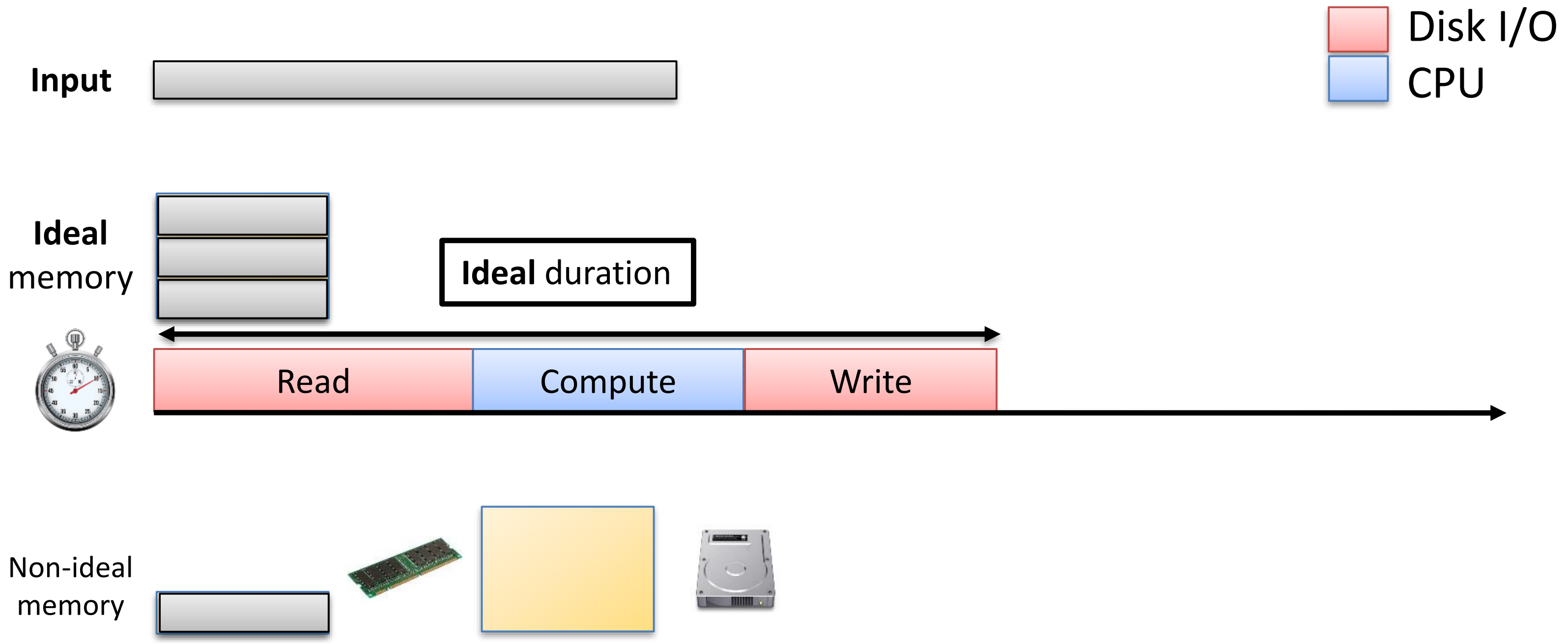

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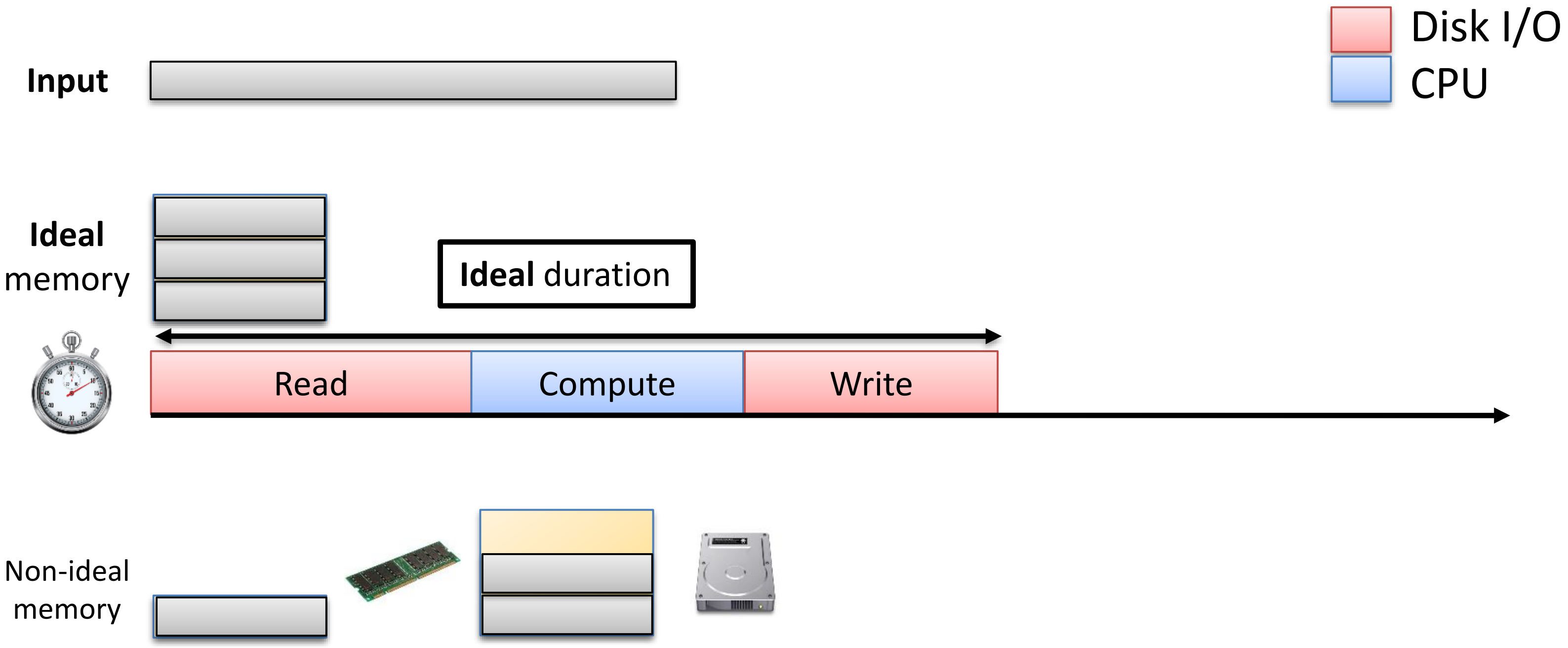

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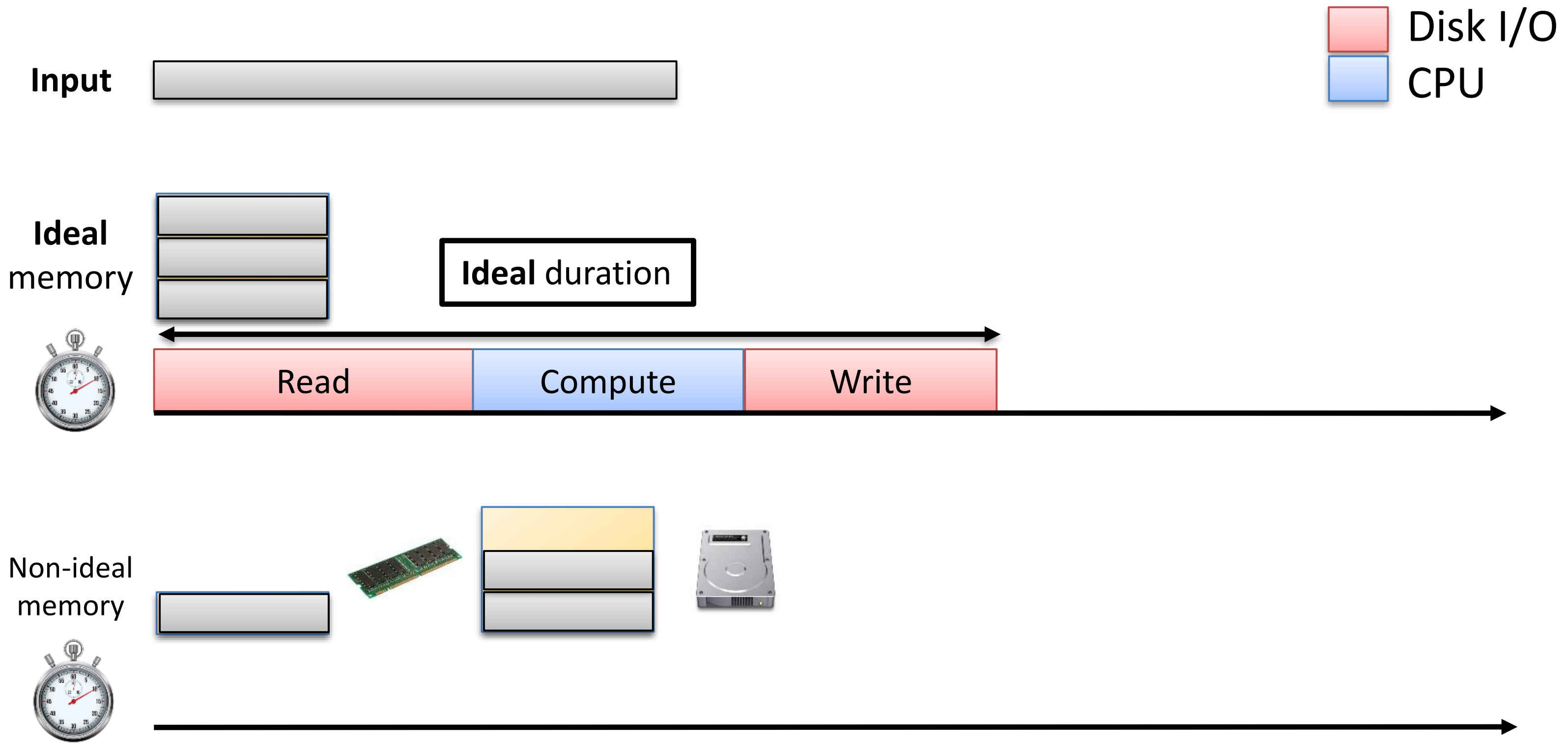

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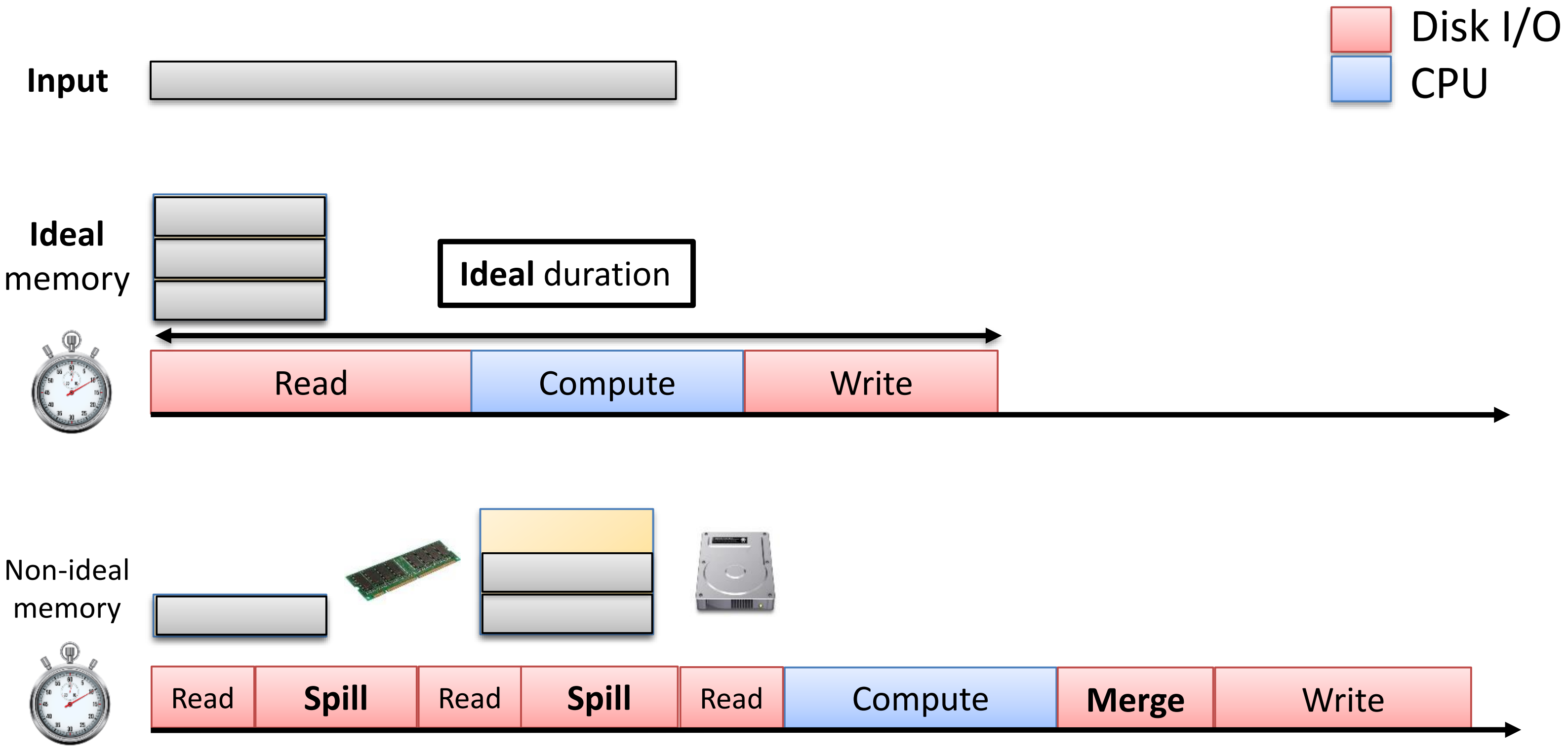

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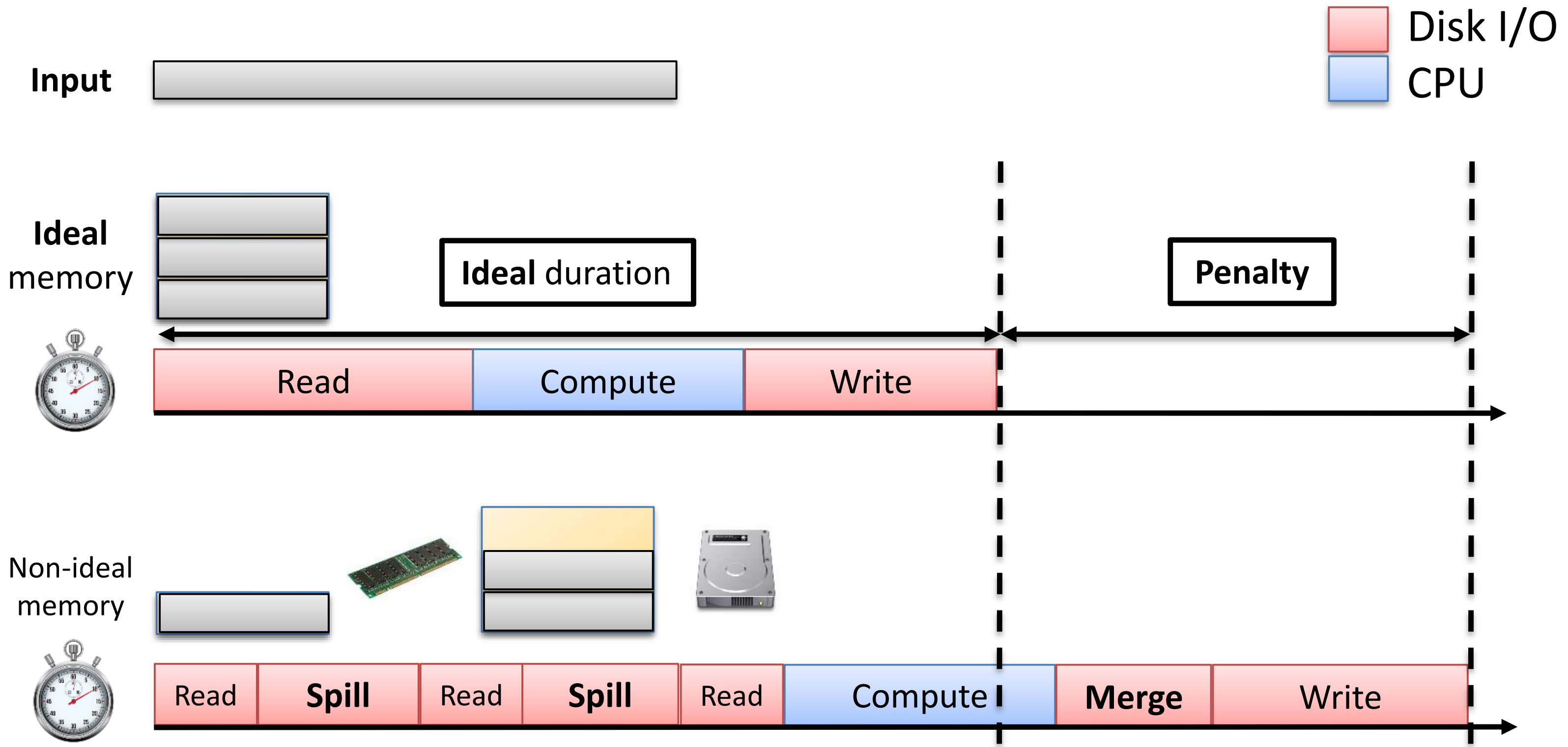

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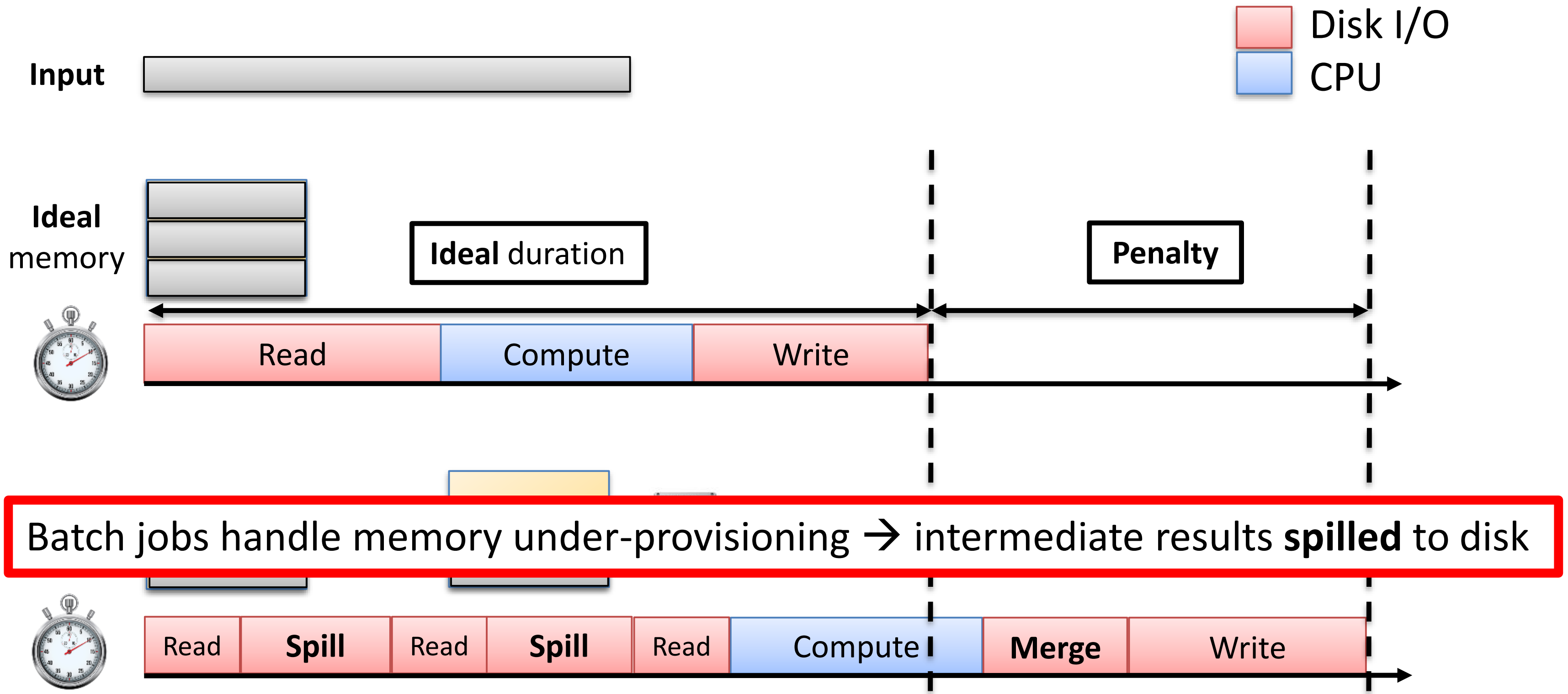
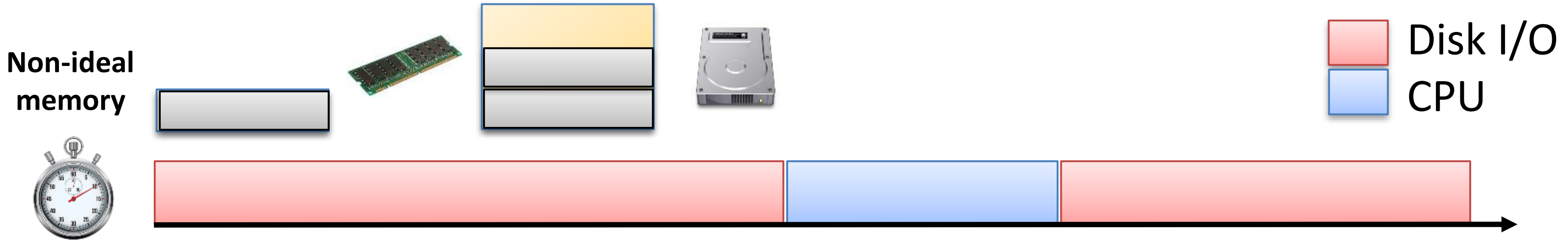


Batch jobs handle memory under-provisioning → intermediate results **spilled** to disk

MEMORY ELASTICITY

What is Memory Elasticity?



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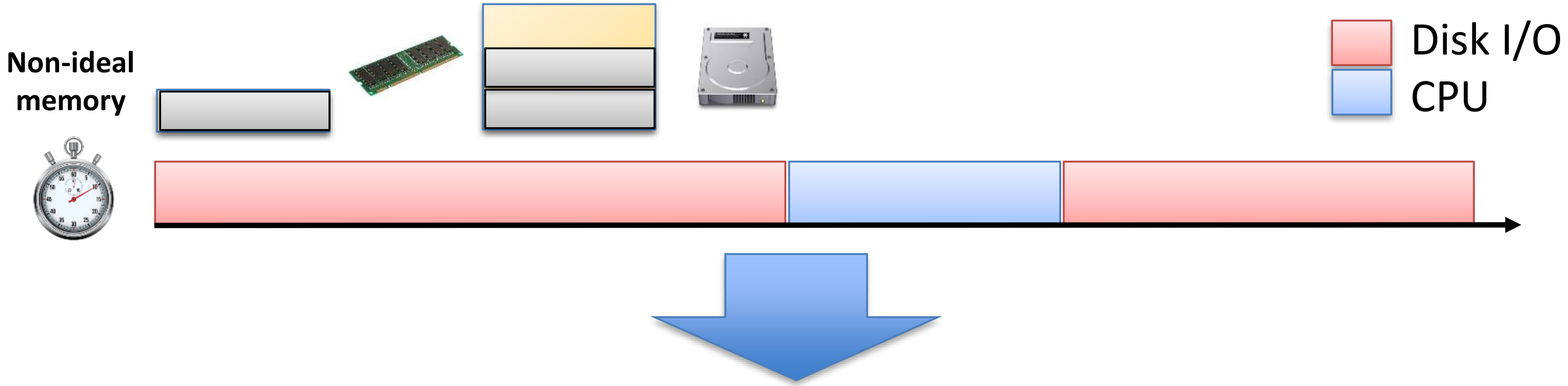

✓ **Safely** constrain memory

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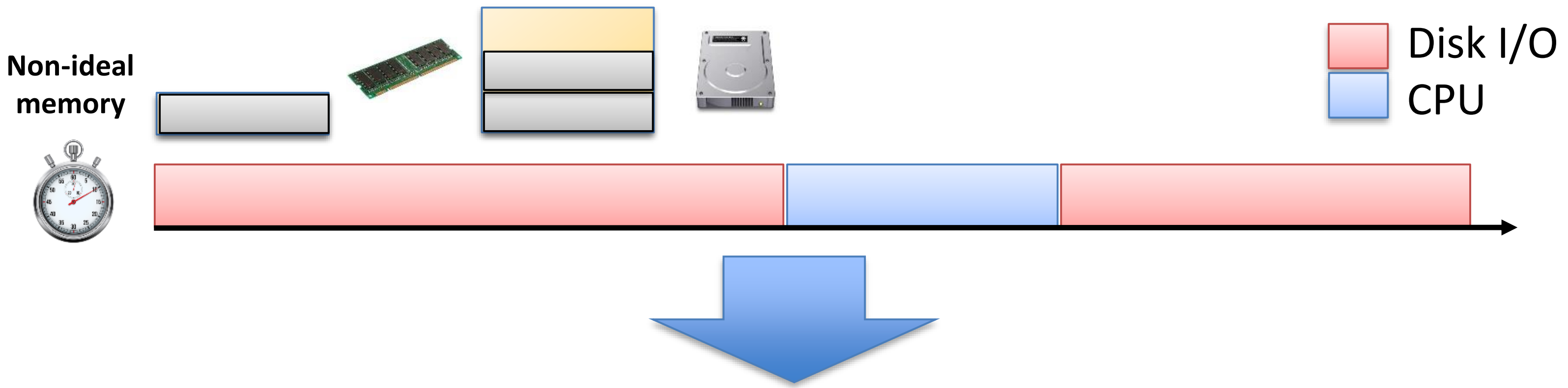

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✓ Moderate **penalties**

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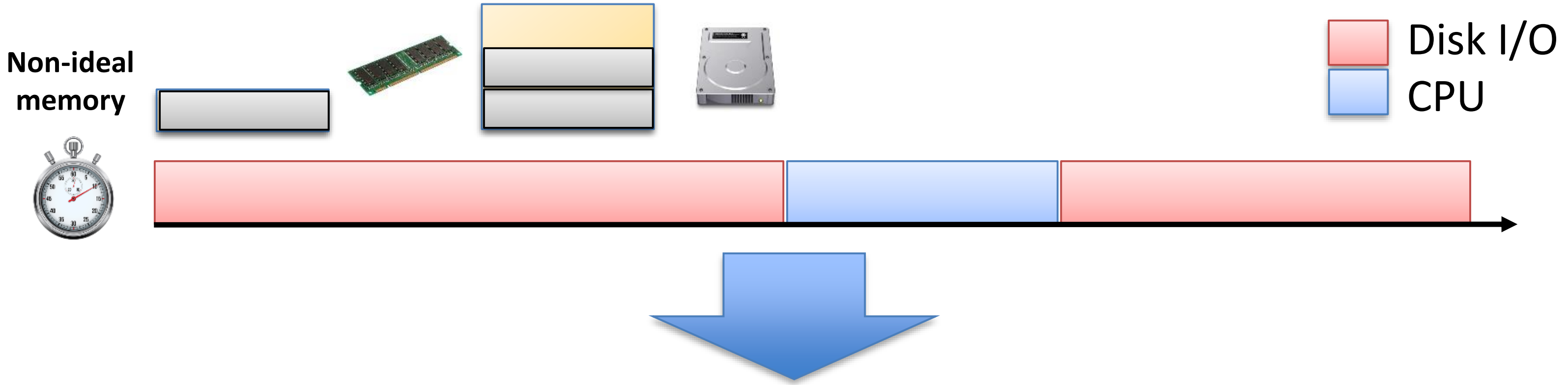

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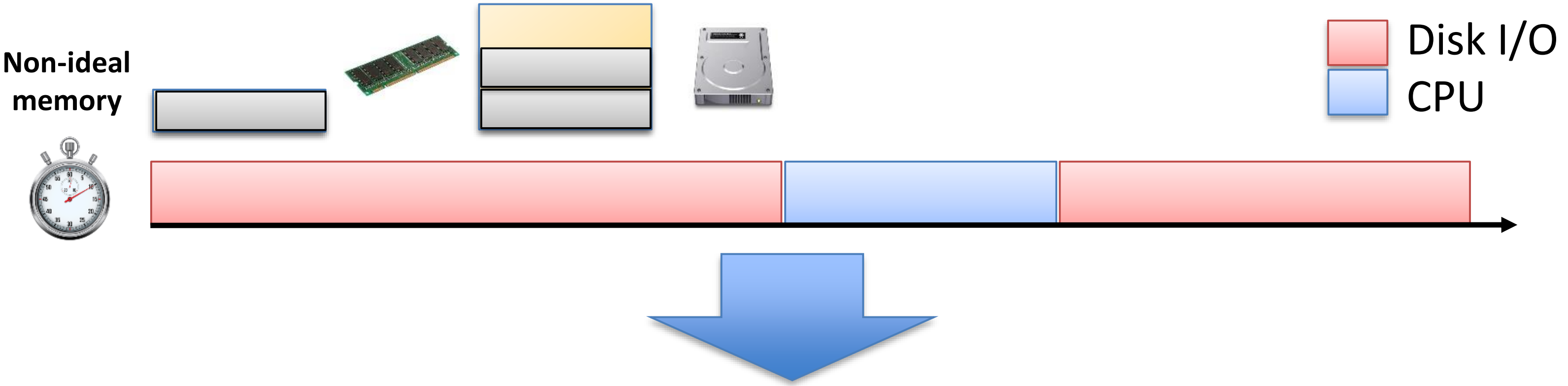

✓ **Safely** constrain memory

✓ Moderate **penalties**

✓ Highly **predictable**

✓ **Ubiquitous** for most data-parallel apps

An empirical study of Memory Elasticity

- Analysis of 18 jobs across 8 different applications
- Constrain tasks' memory → measure **penalty**
- Bypass disk buffer cache (to not mask impact of spilling to disk)

Questions about Memory Elasticity

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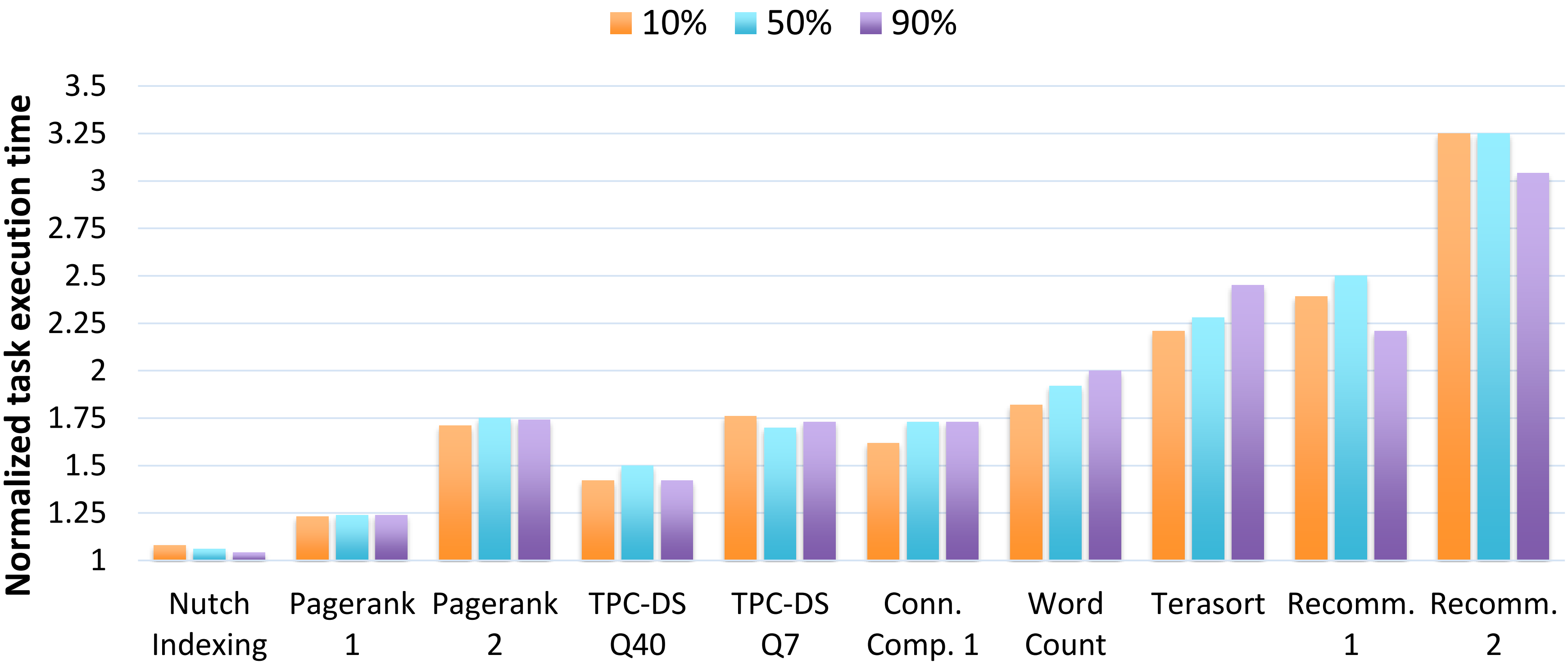
NOT SO MUCH!

Elasticity of Hadoop workloads: **Reducers**



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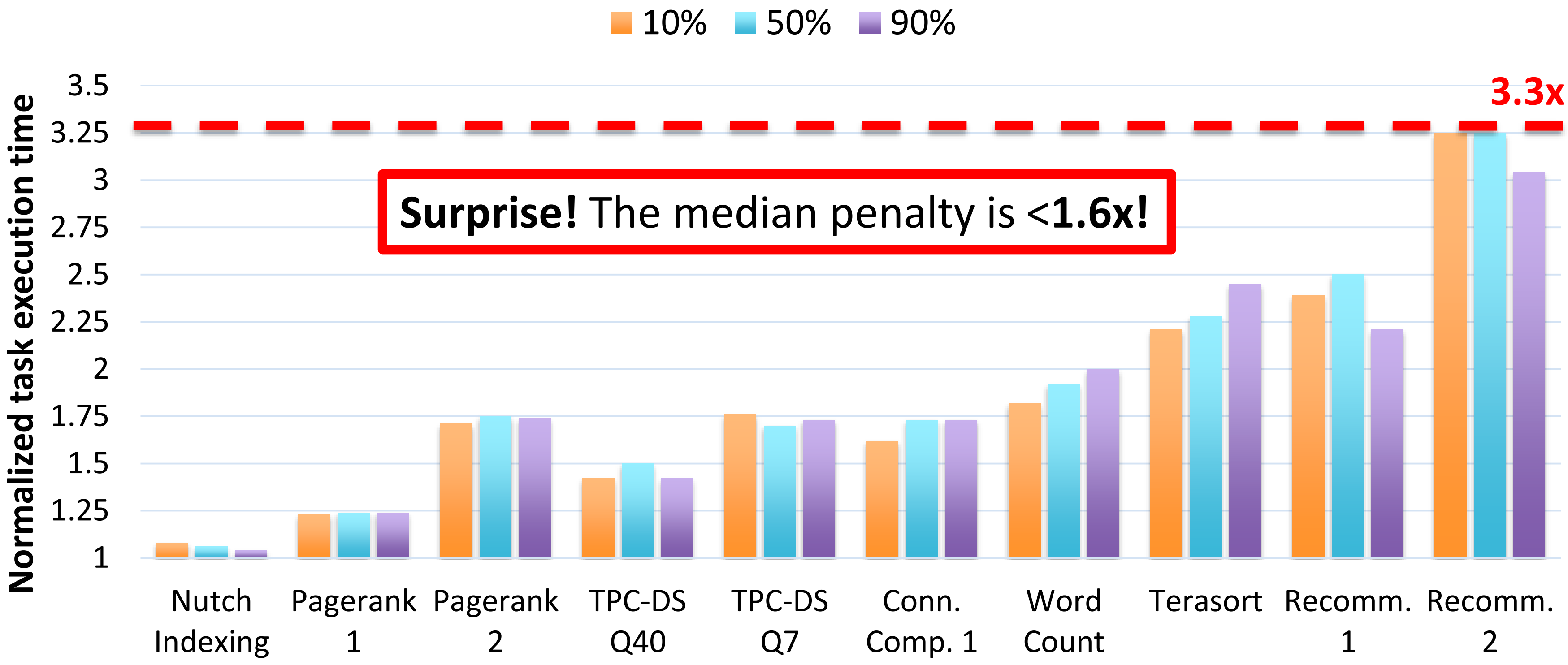

Why are the penalties so modest?

Data buffer – most of app. memory	• Memory pressure absorbed by data buffer
Sequential disk access	• Spilling records to disk is faster than OS paging
Logarithmic external merge algorithms	• Merge steps required << disk spills

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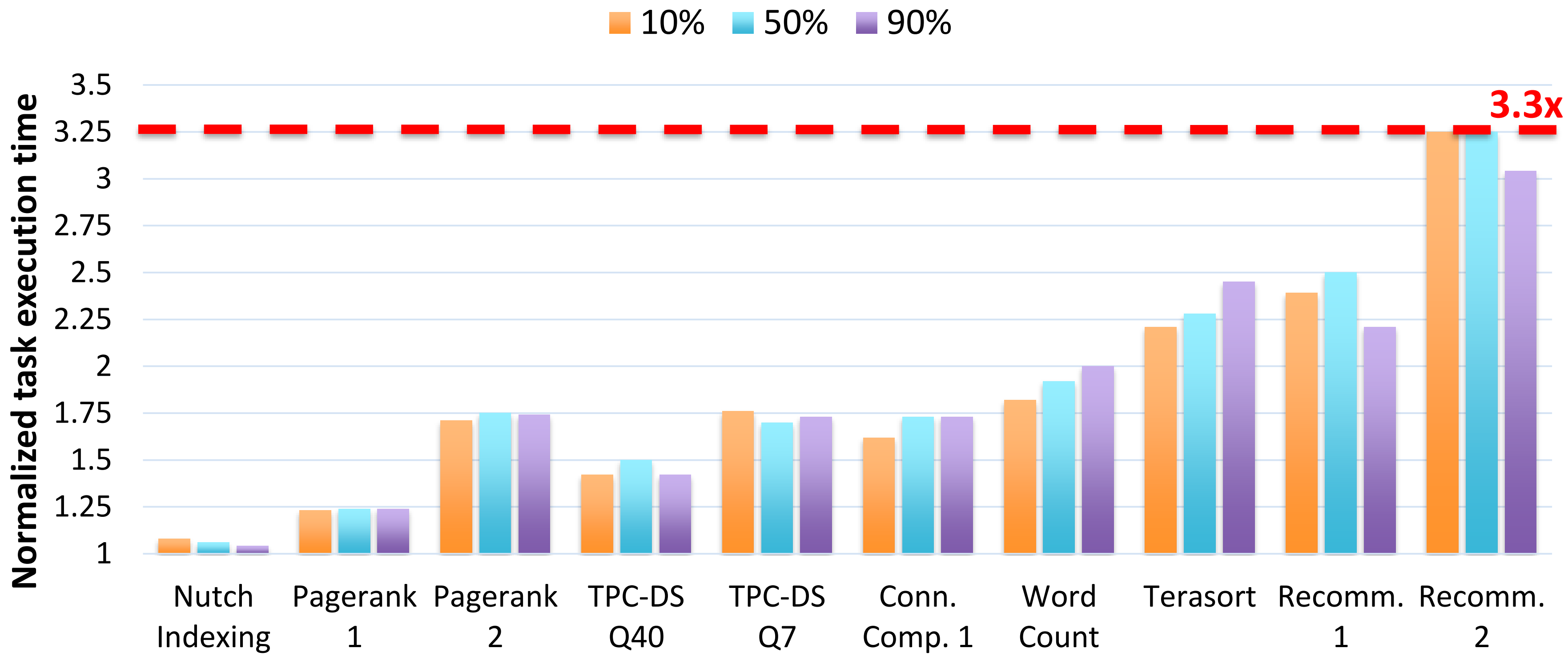

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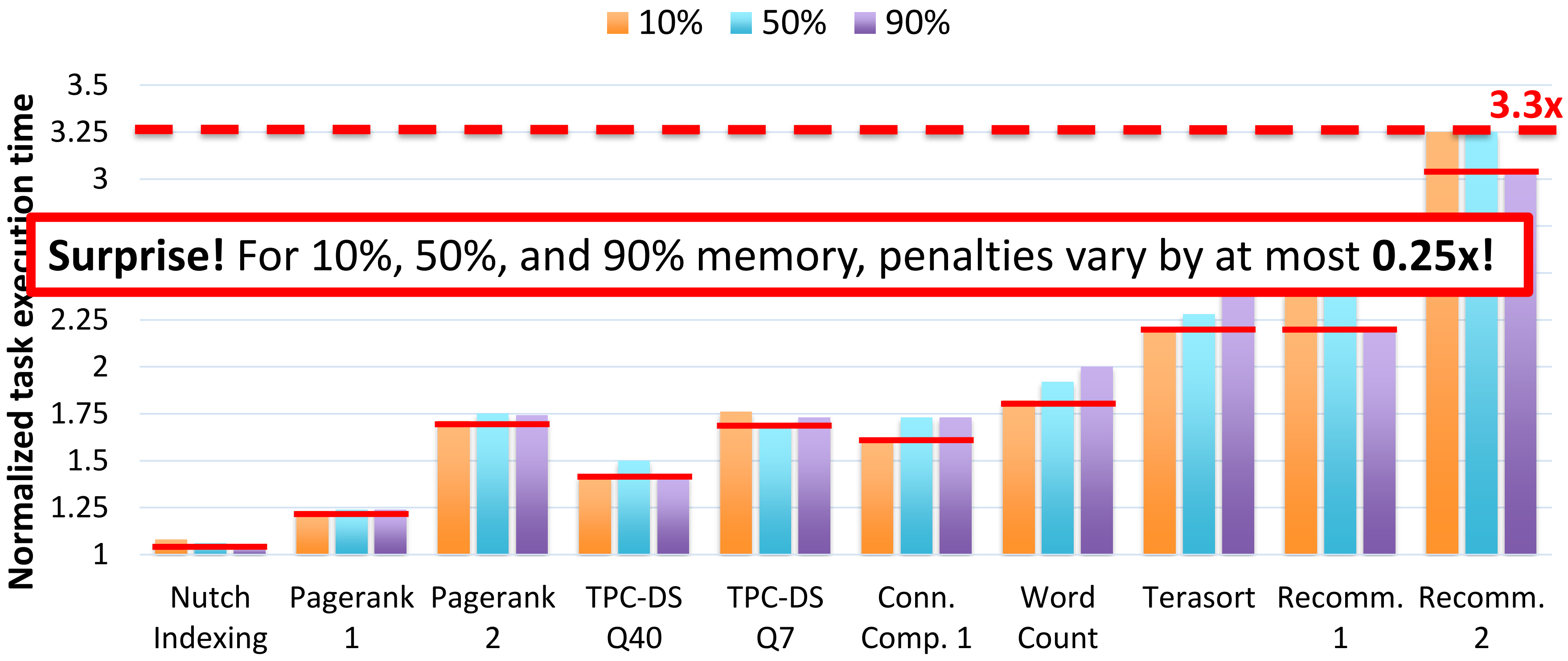

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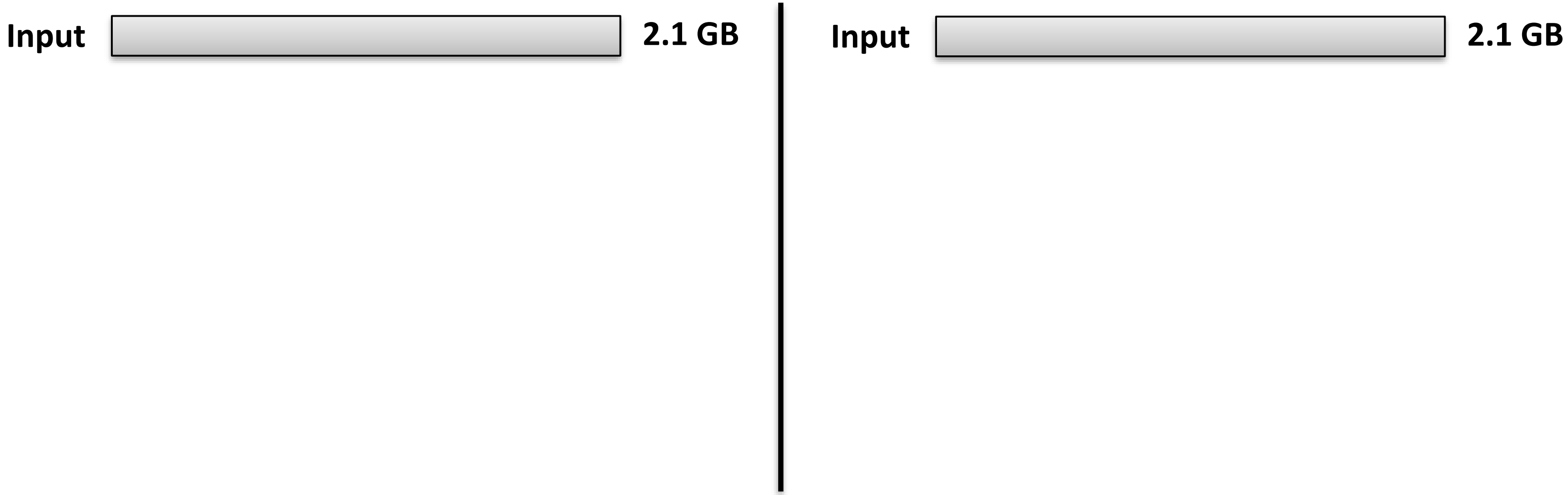

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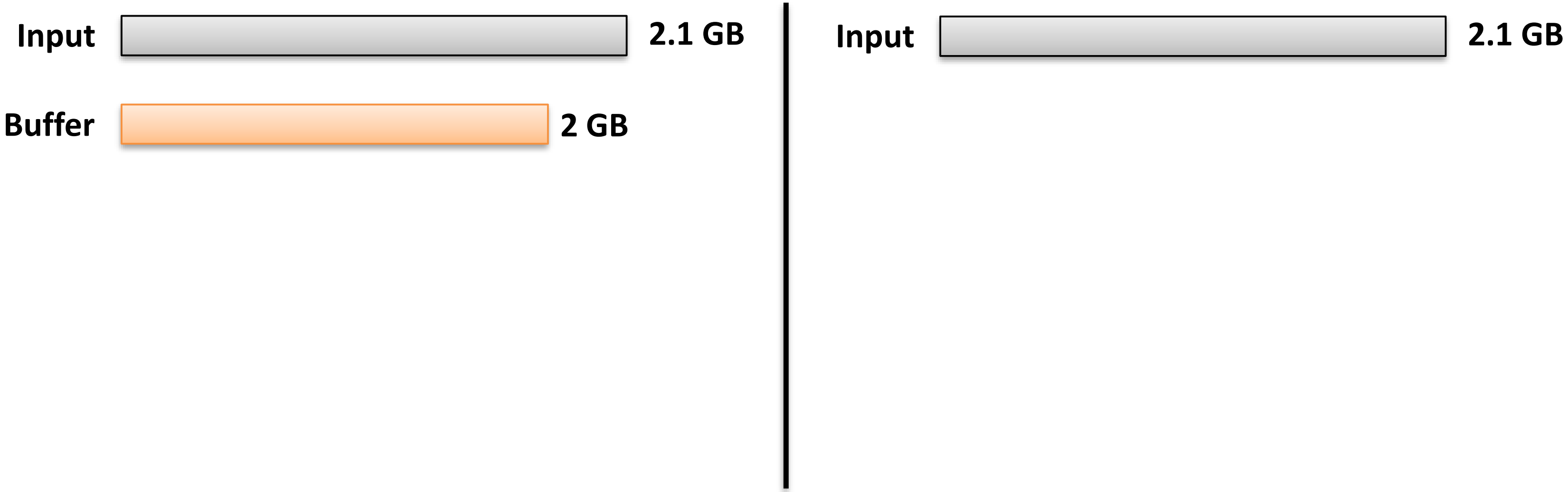

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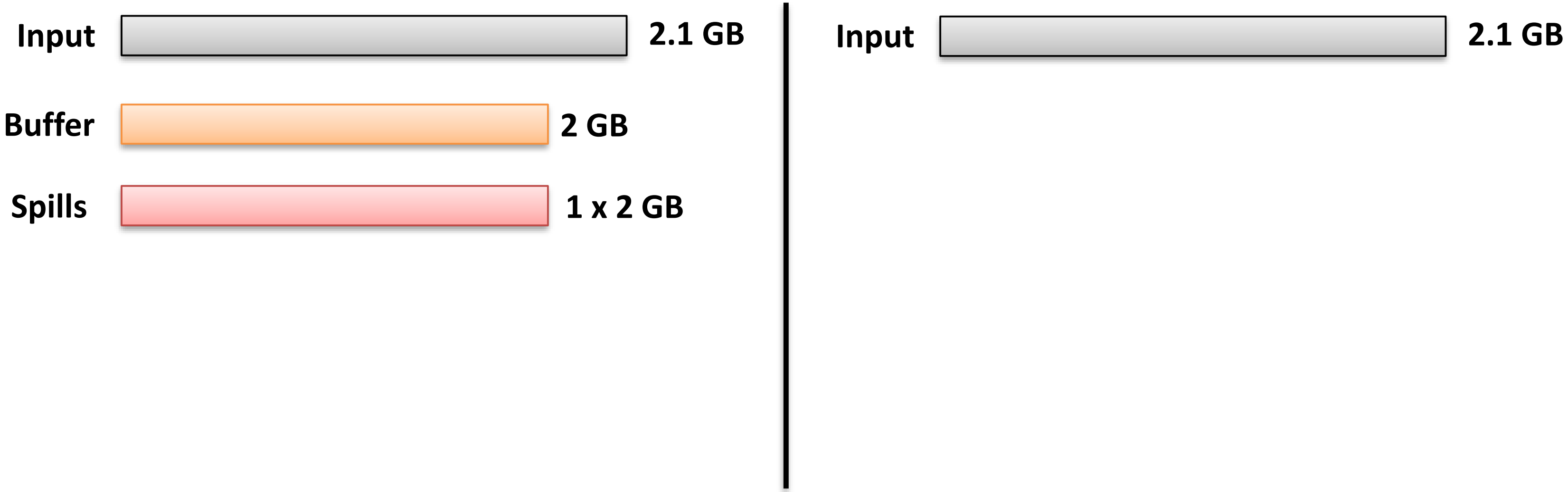

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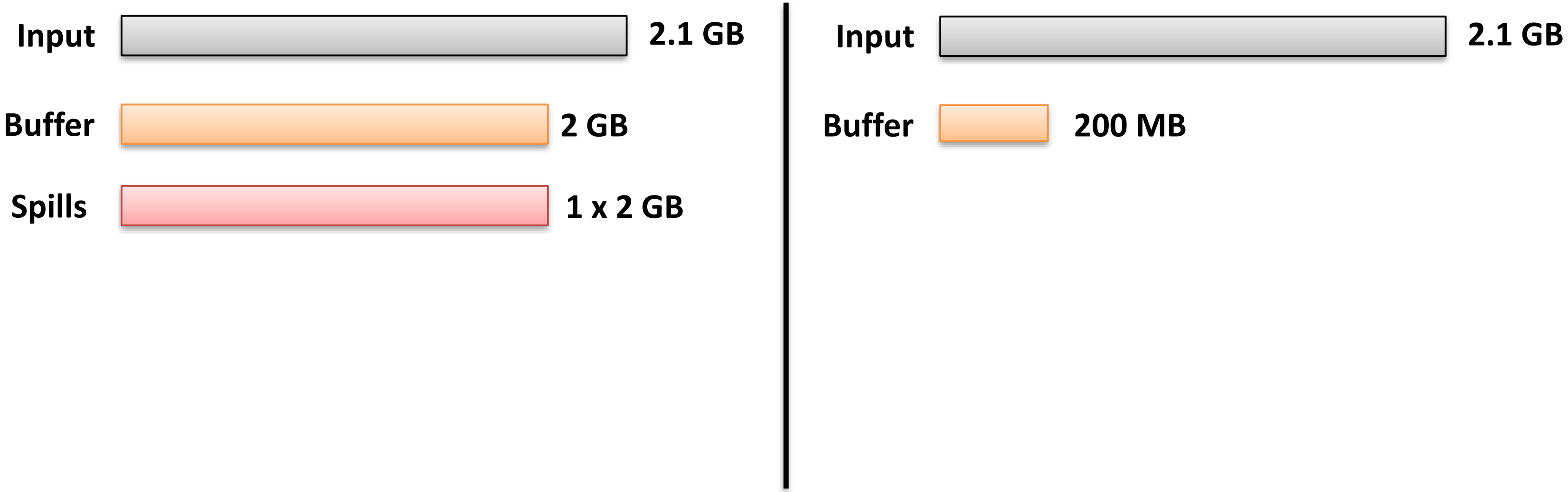

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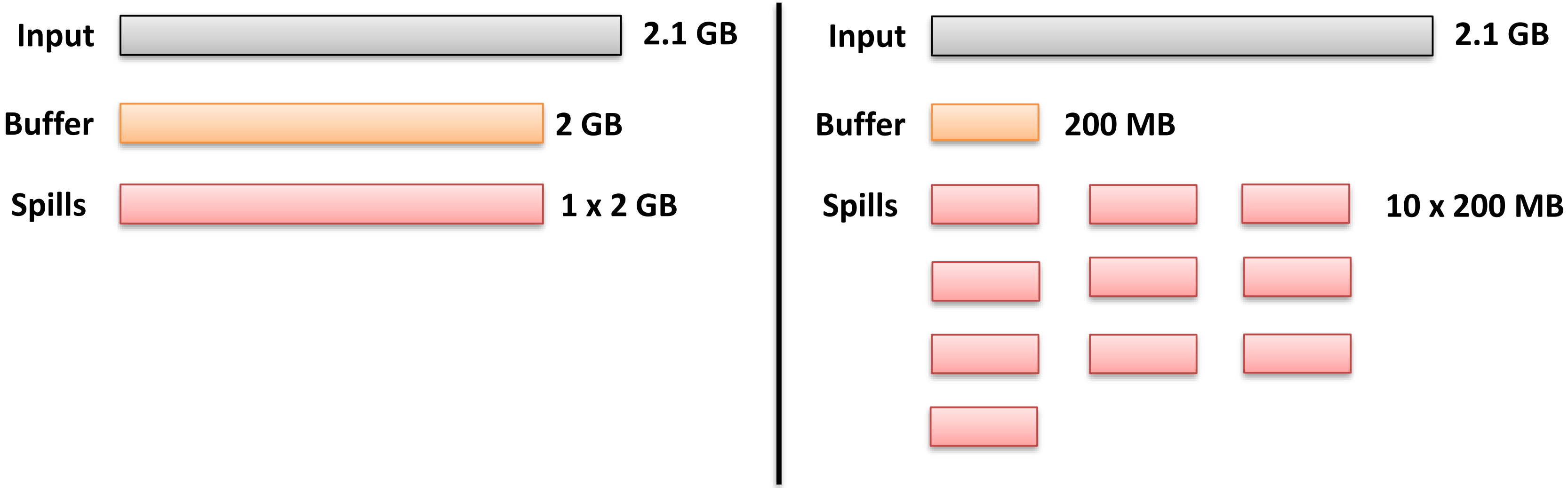

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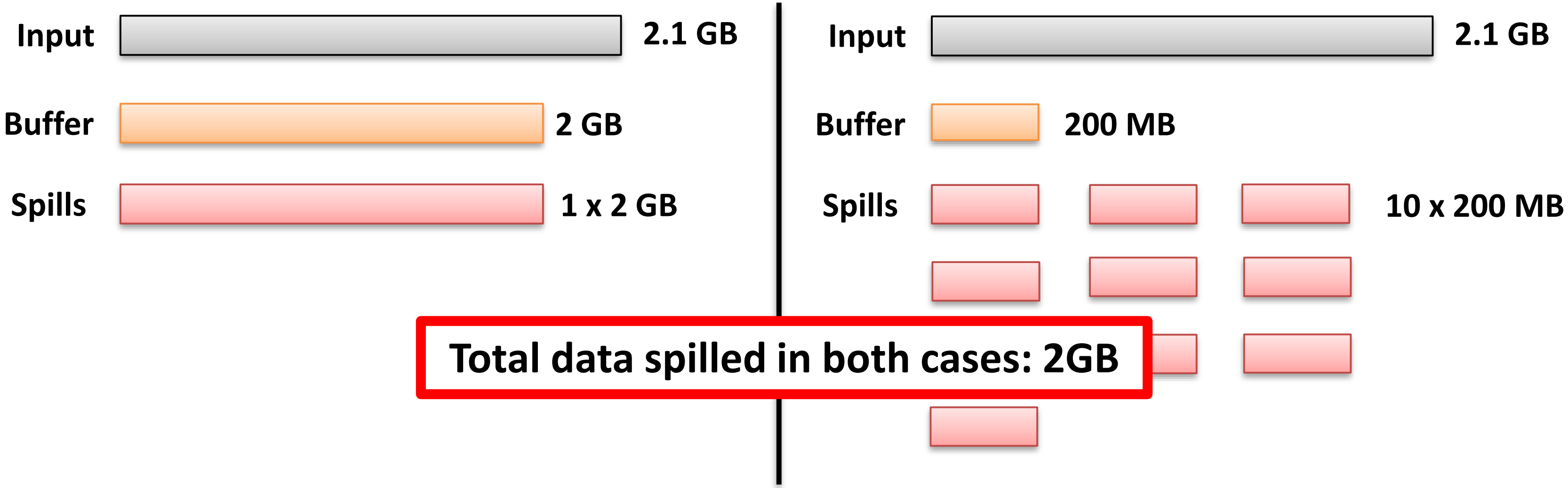
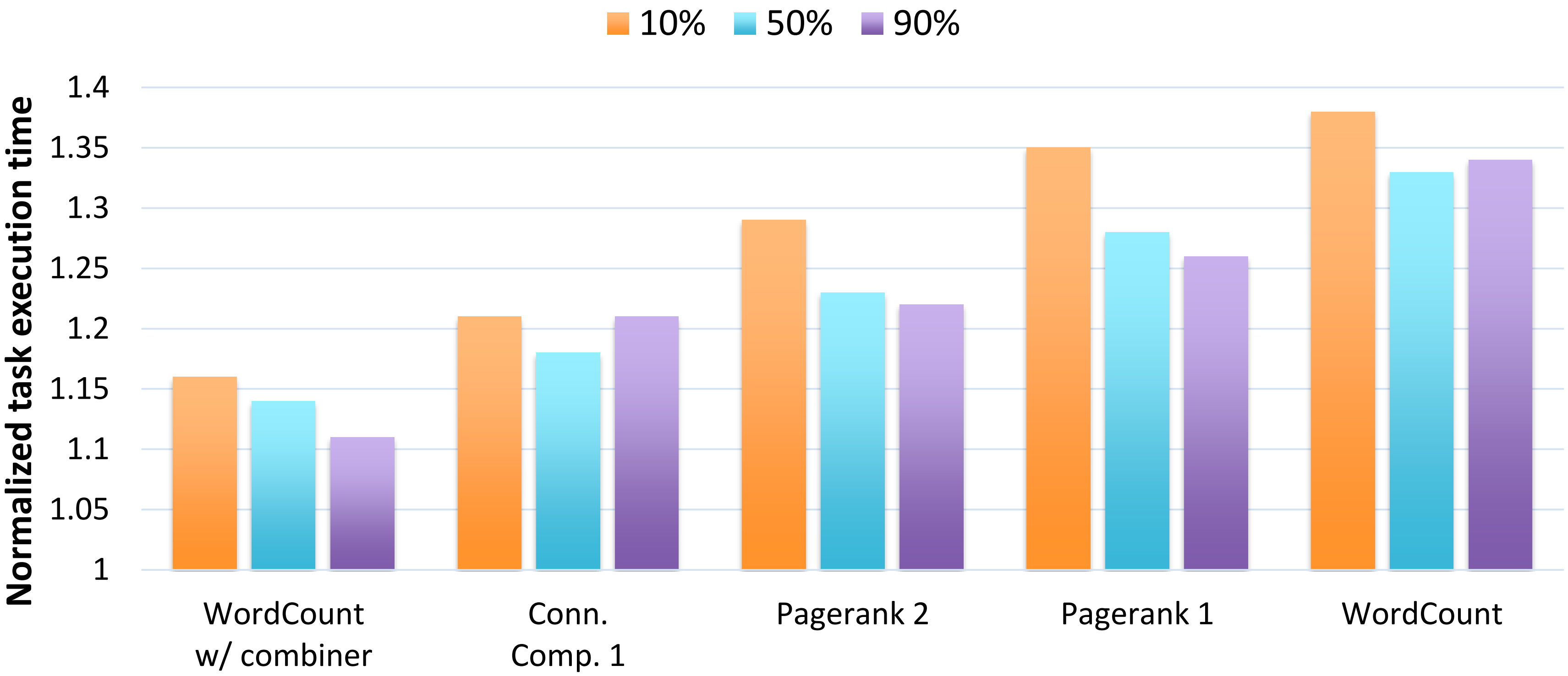


Elasticity of Hadoop workloads: **Mappers**



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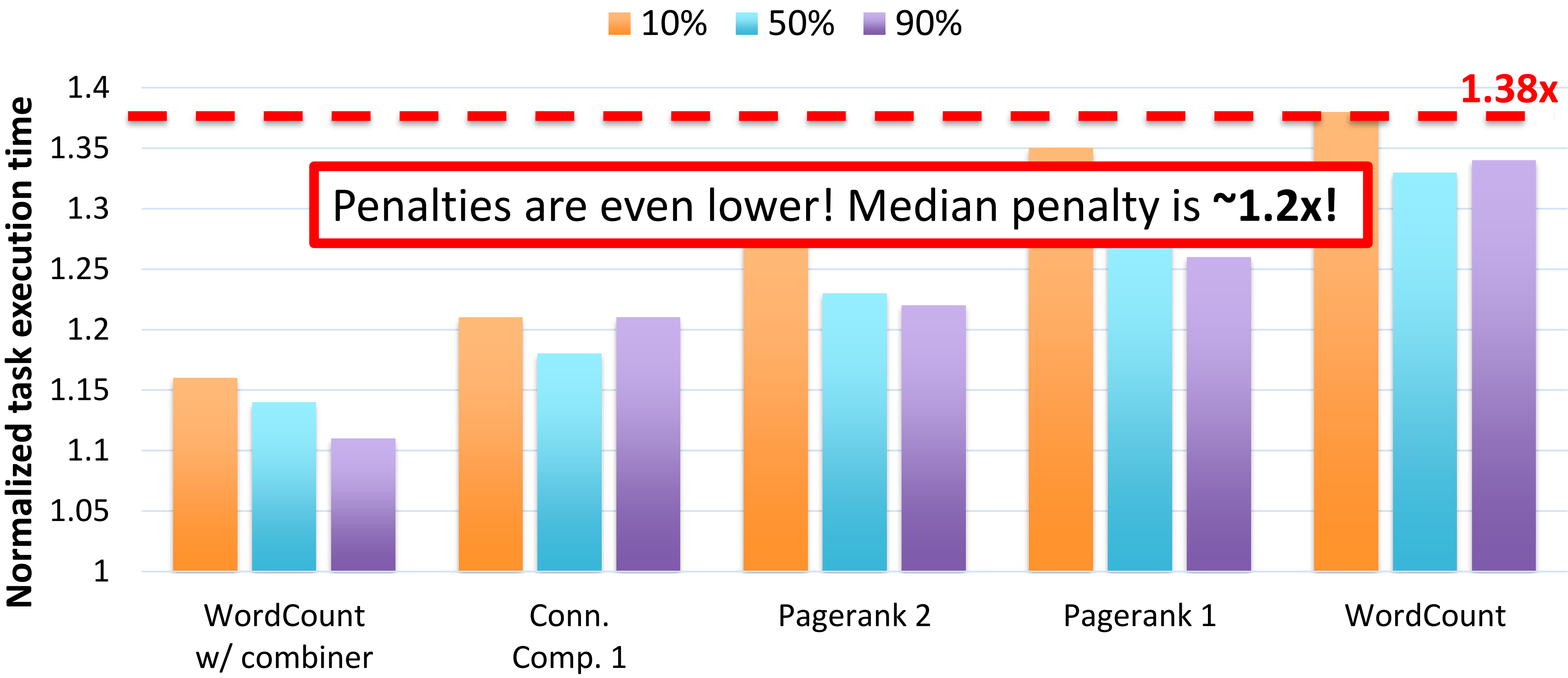

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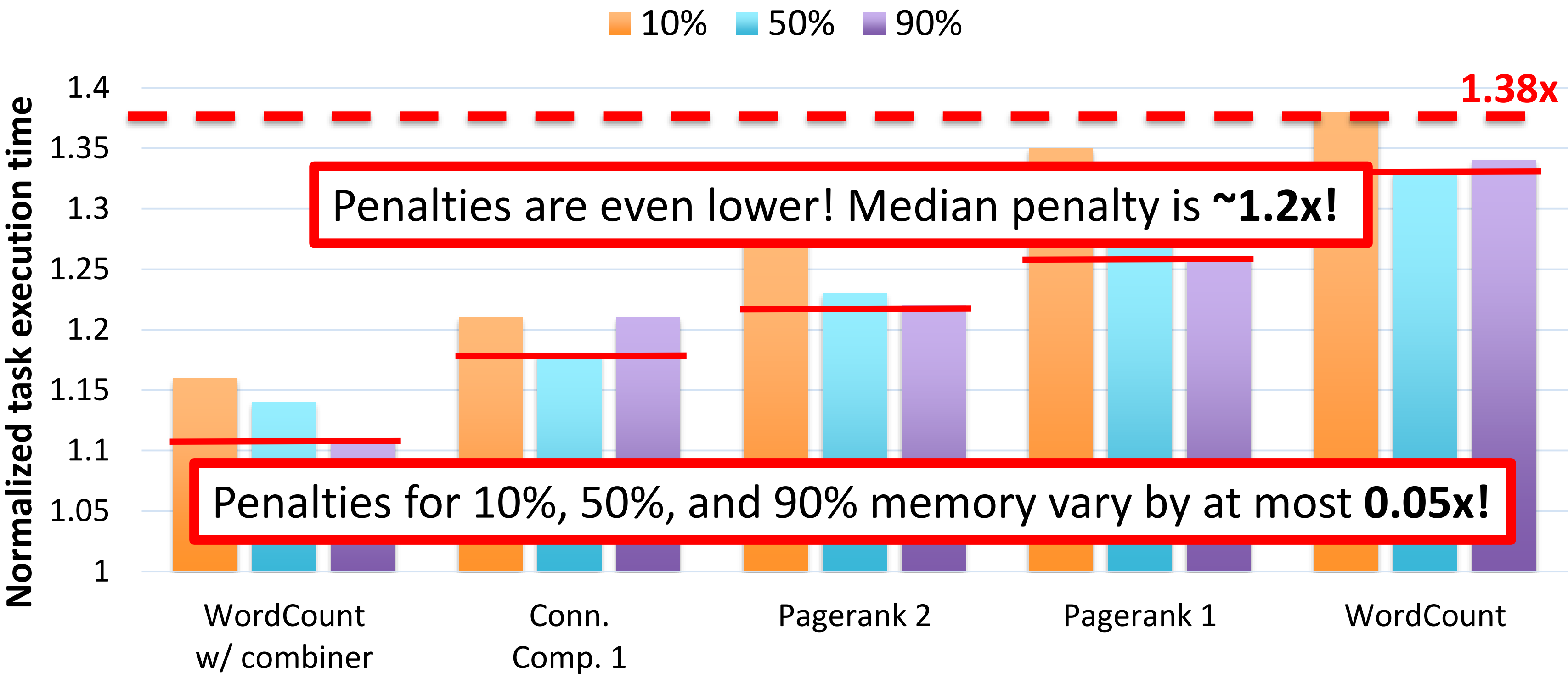
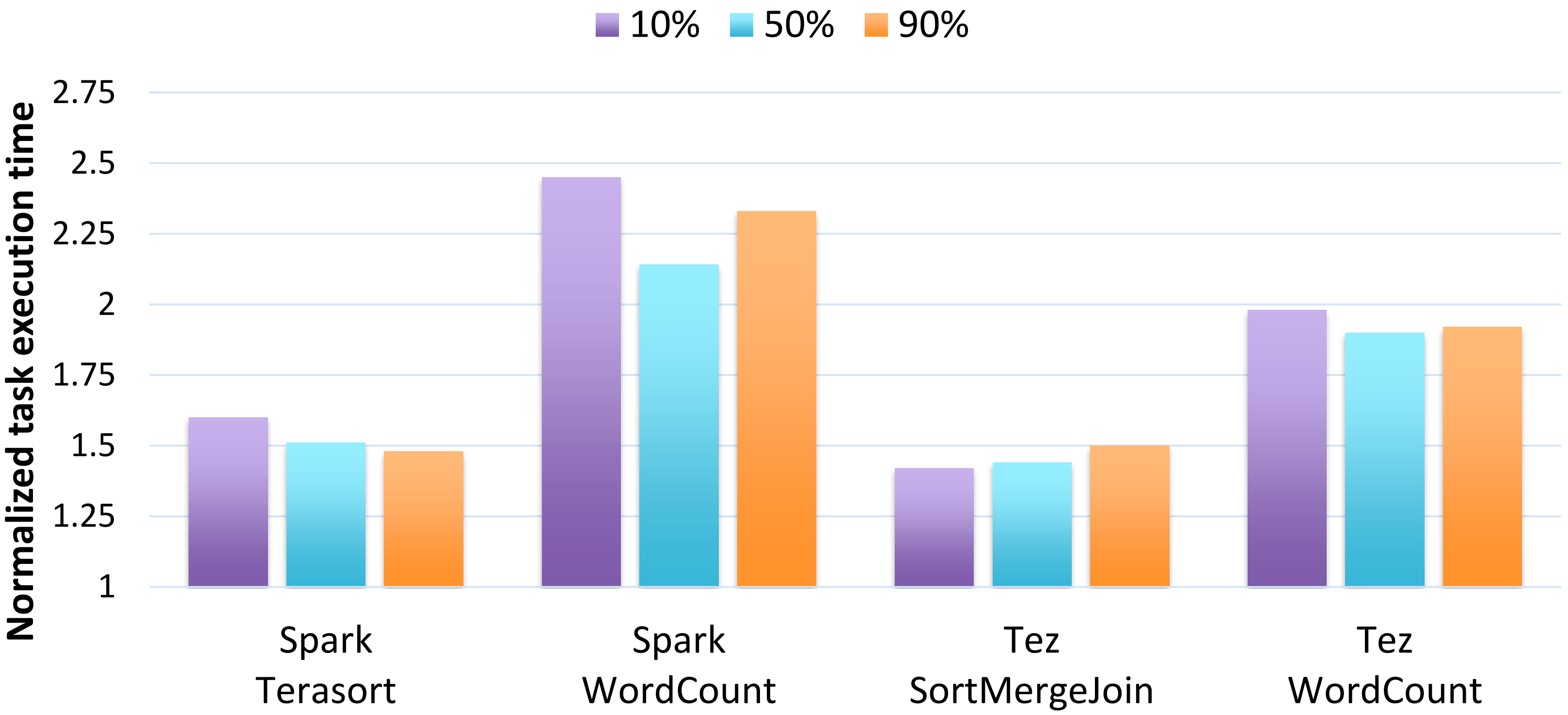


Elasticity of Spark and Tez workloads



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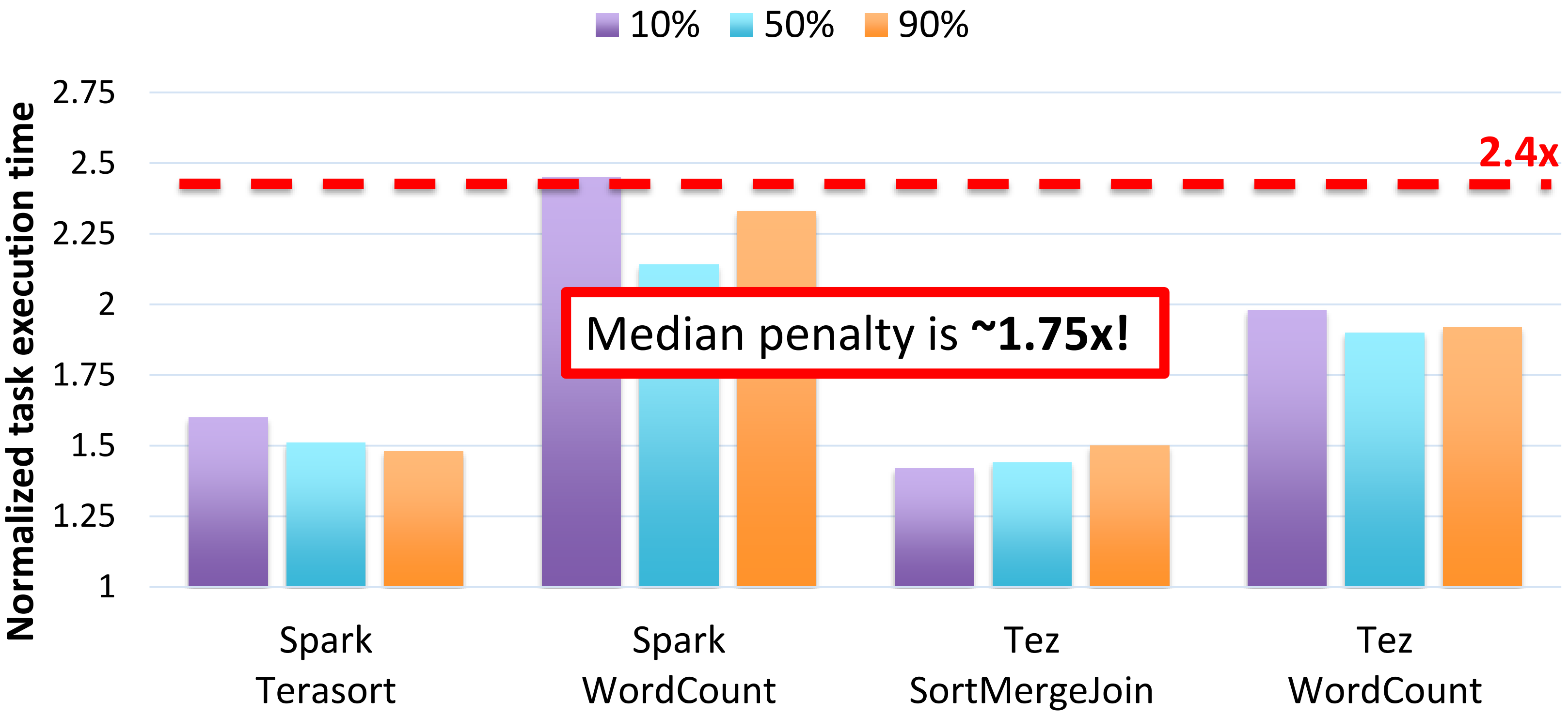

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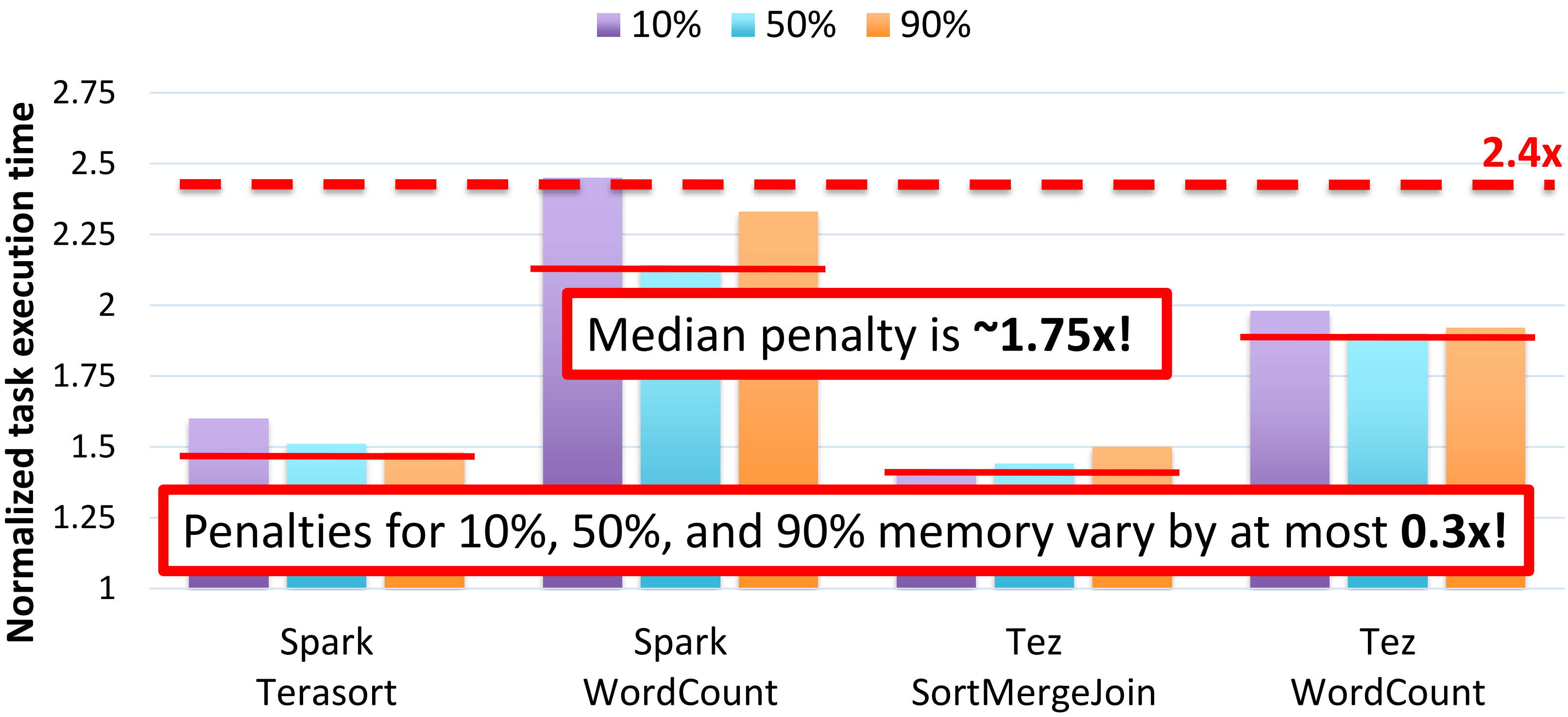
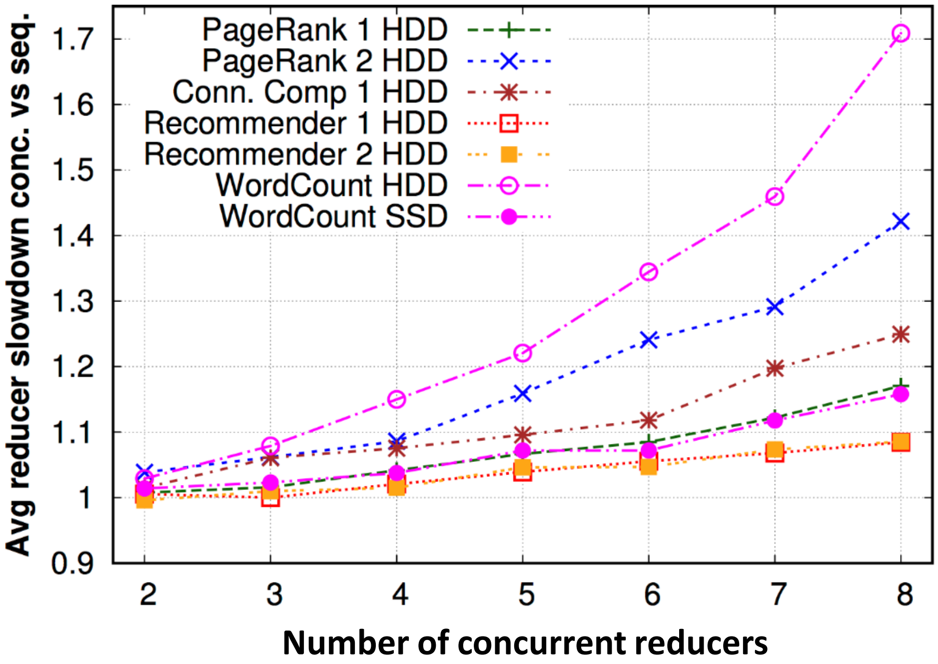


Does the additional I/O cause disk contention?

- Measure slowdown of <u>elastic</u> tasks on same machine spilling to the same disk



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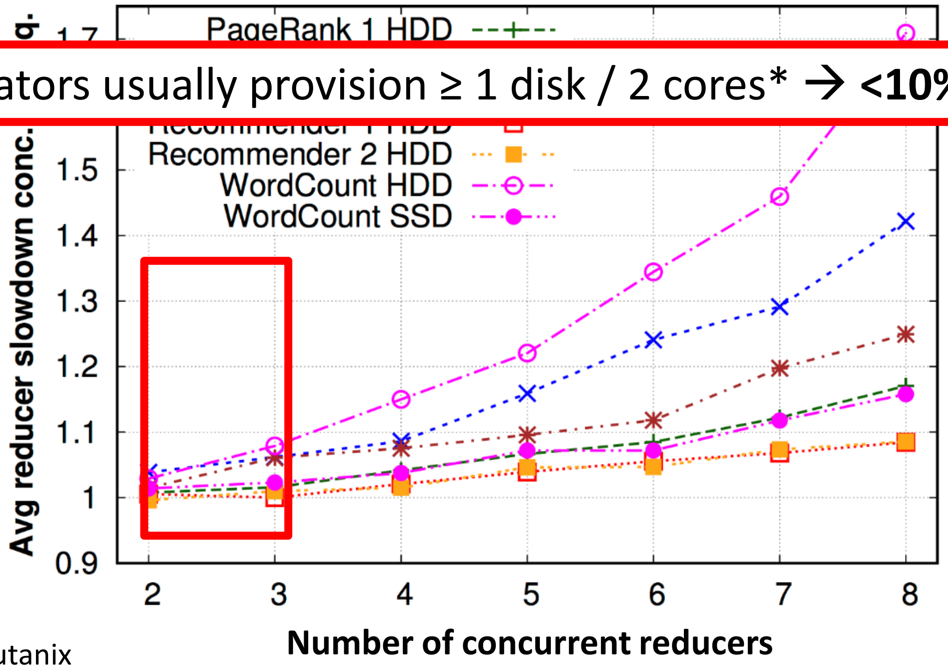
Cluster operators usually provision ≥ 1 disk / 2 cores* → **<10%** slowdown!



* Facebook (2010) and Nutanix

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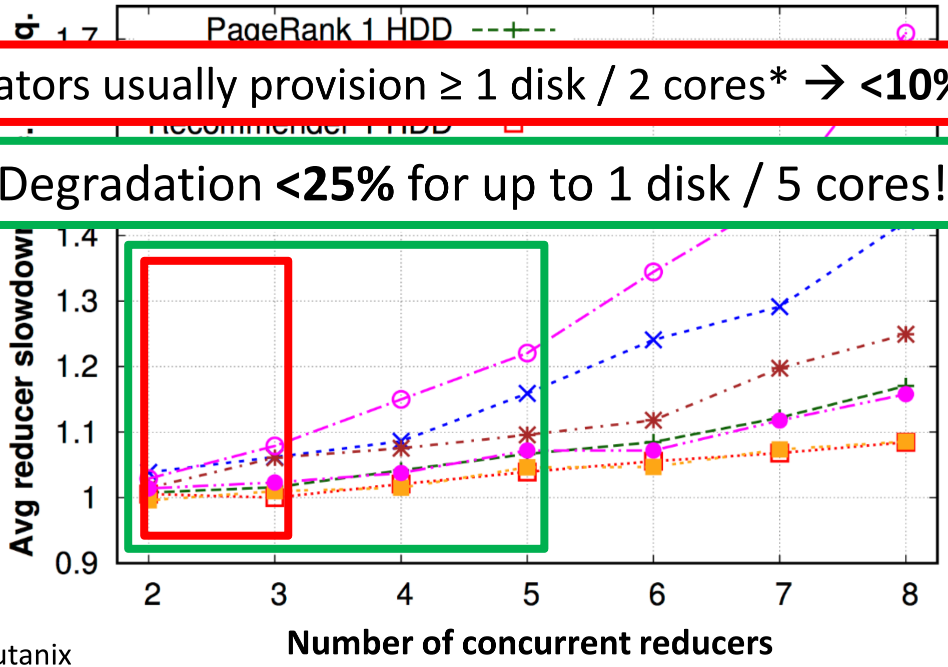
Degradation **<25%** for up to 1 disk / 5 cores!



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Summary: Memory Elasticity of real workloads

✓ **Modest performance penalties (<1.6x median)**

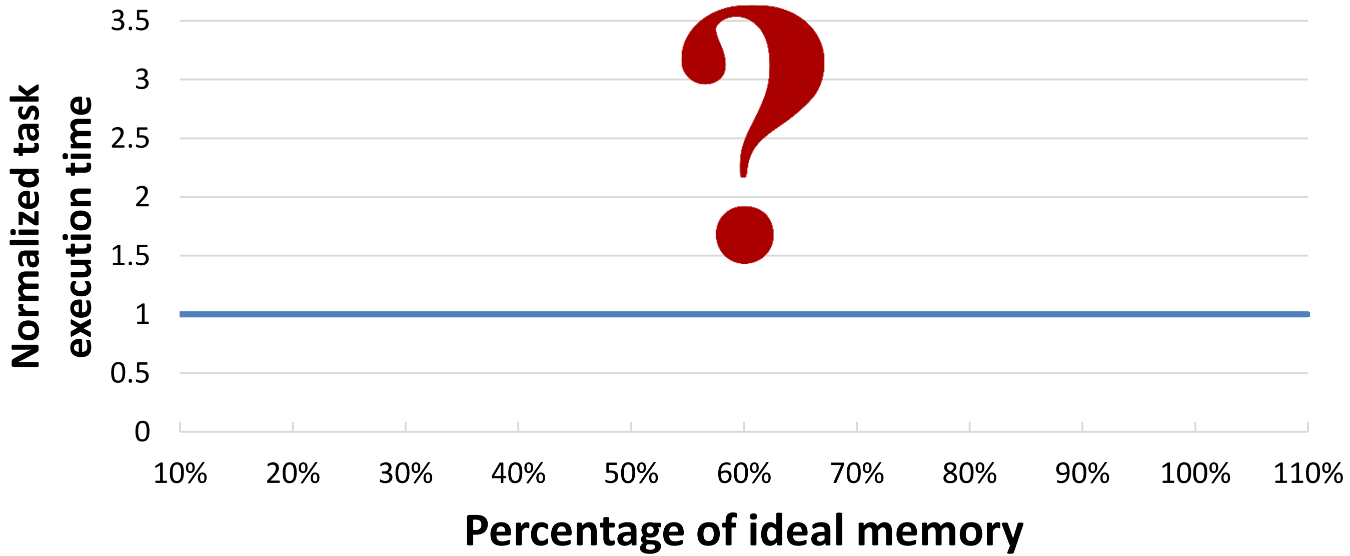
✓ **Similar penalties for 10% and 90% of ideal memory**

✓ **Disk contention negligible for existing clusters' setup (<10%)**

MODELING MEMORY ELASTICITY

Modeling Memory Elasticity

- How does penalty vary for a task?



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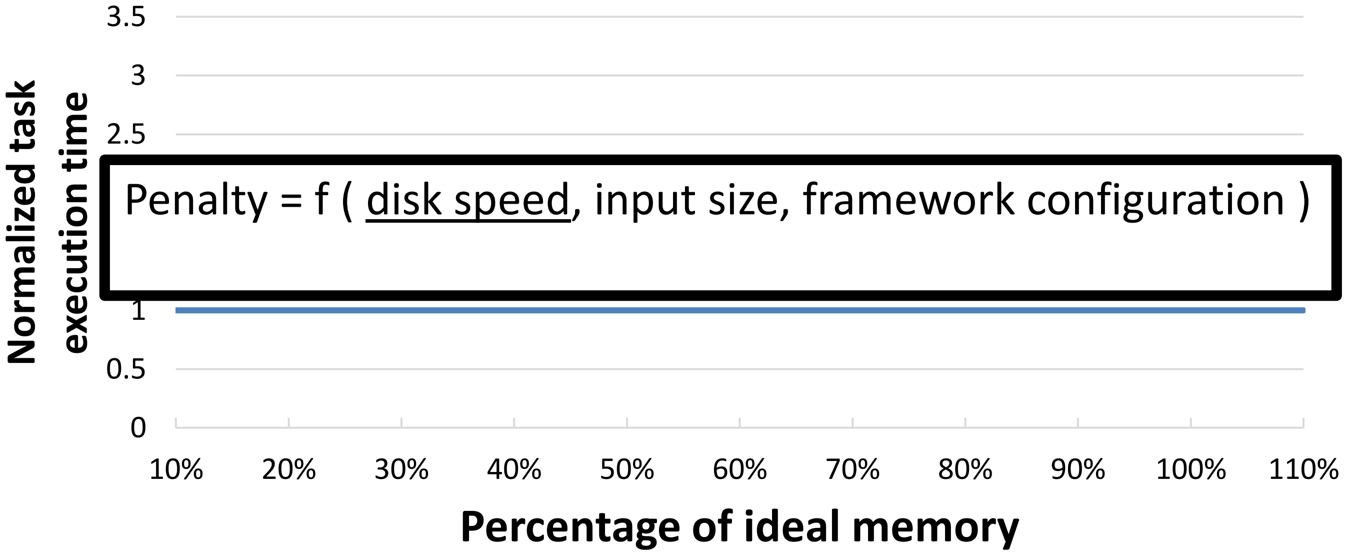
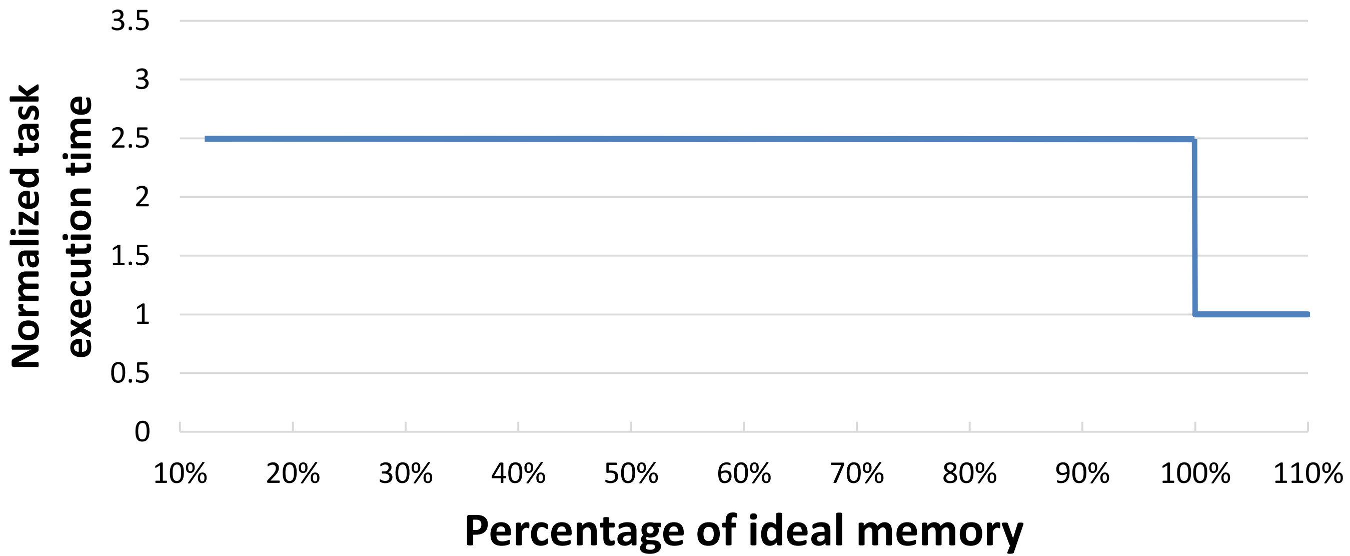


Penalty = f (disk speed, input size, framework configuration)

Modeling Memory Elasticity

- Penalties vary little between percentages → <u>step</u> model



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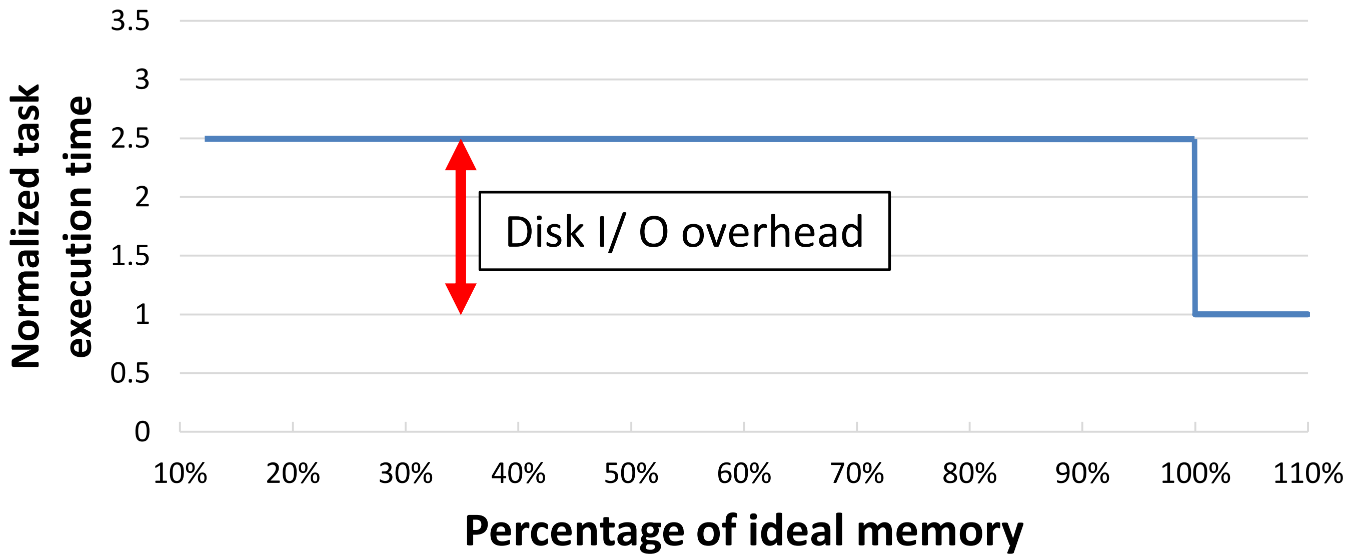
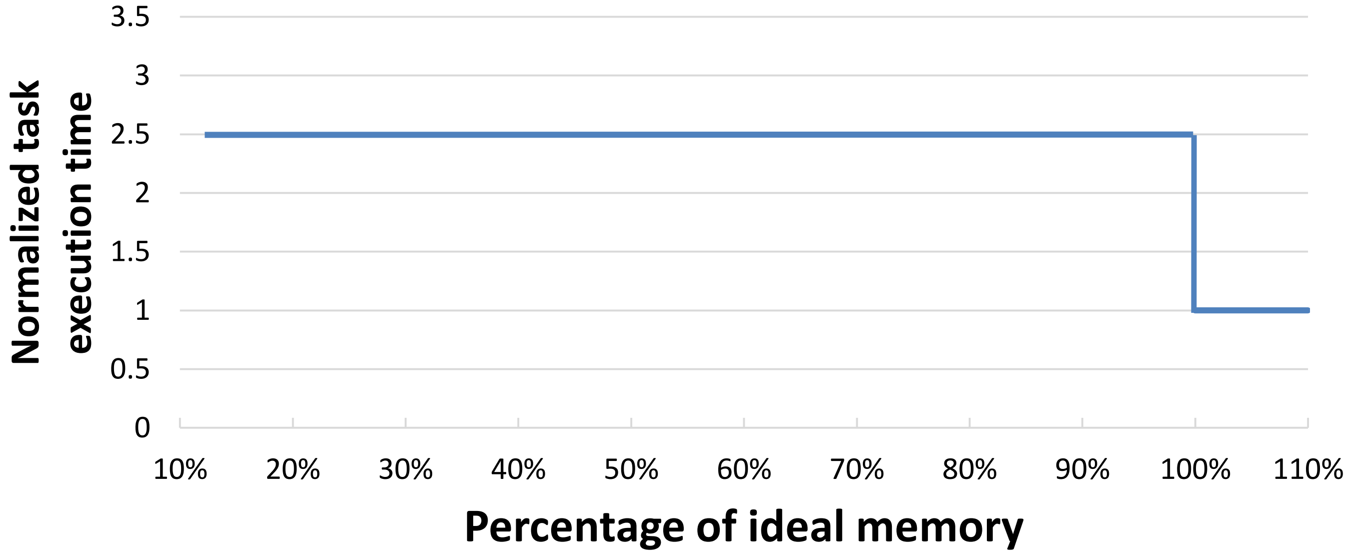


Modeling Memory Elasticity

- Requires 2 profiling runs → infers all other points



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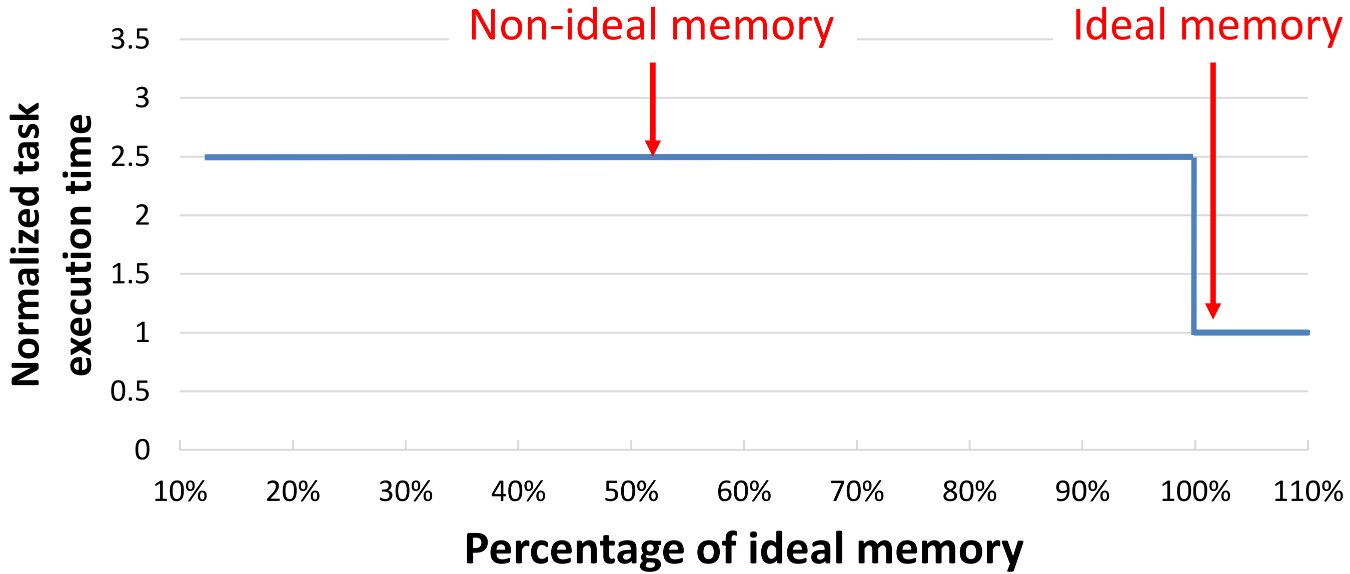

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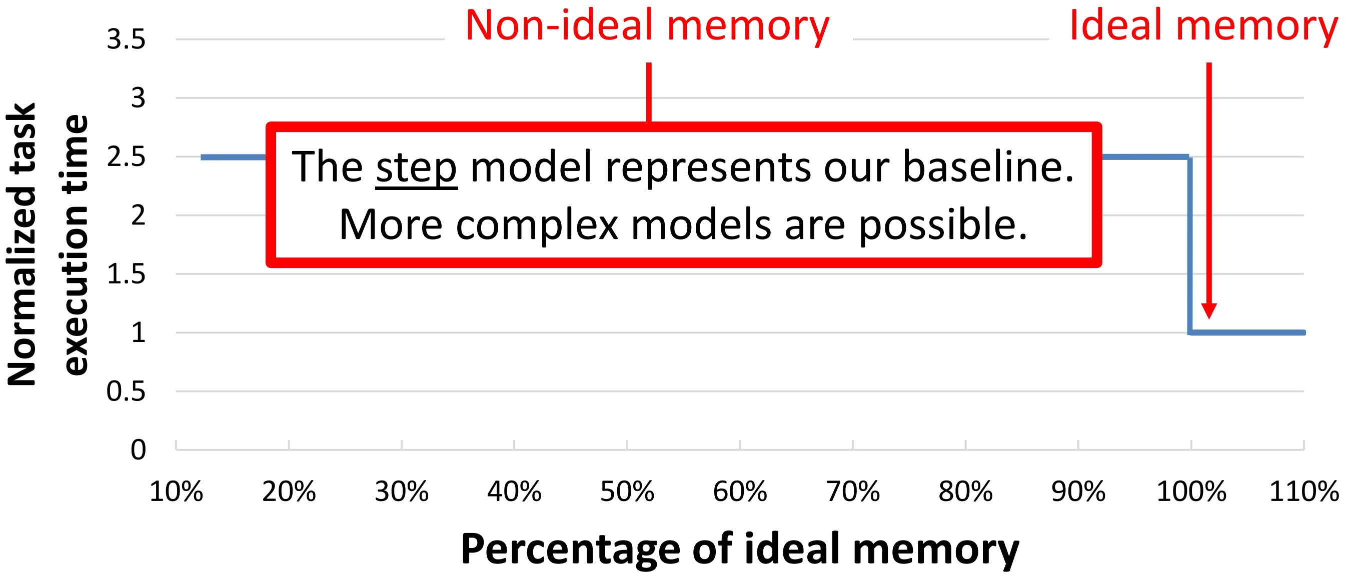
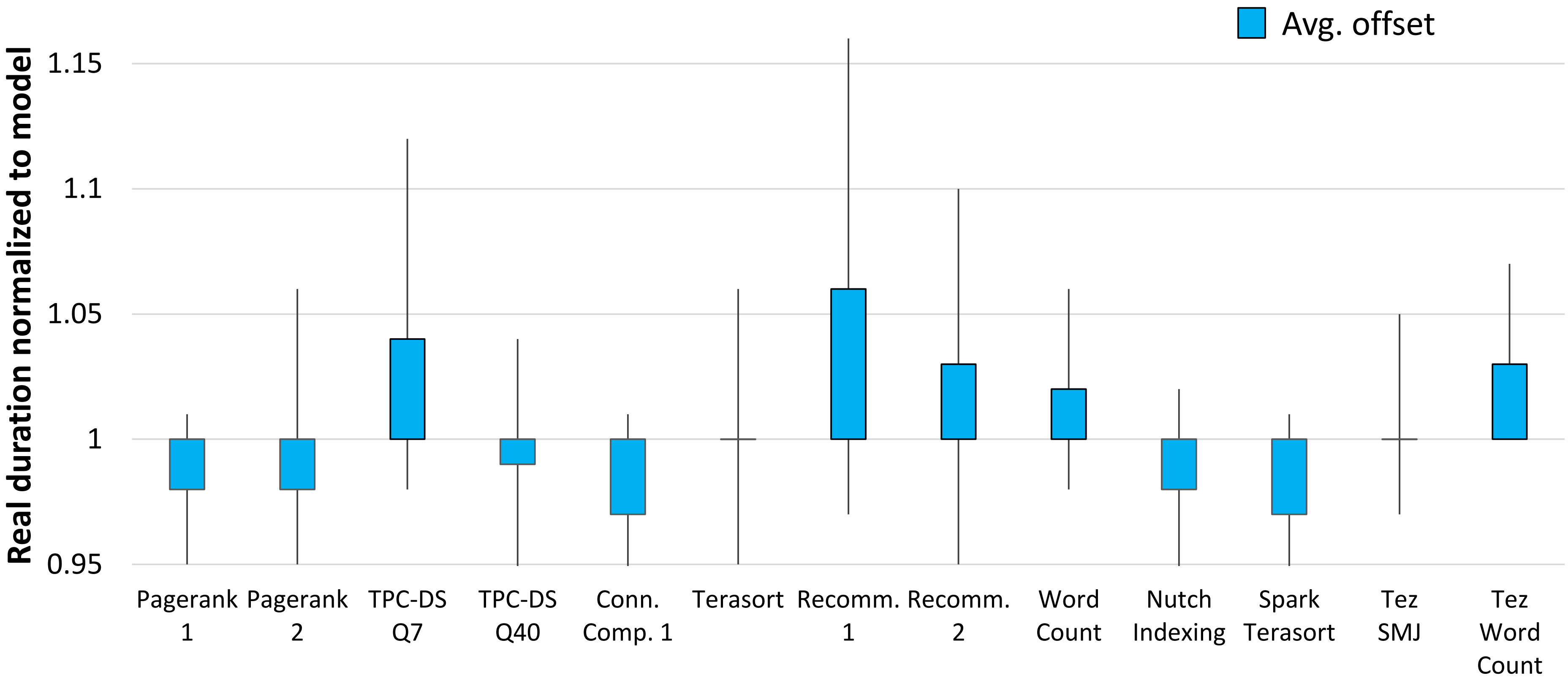


Accuracy of our reducer model



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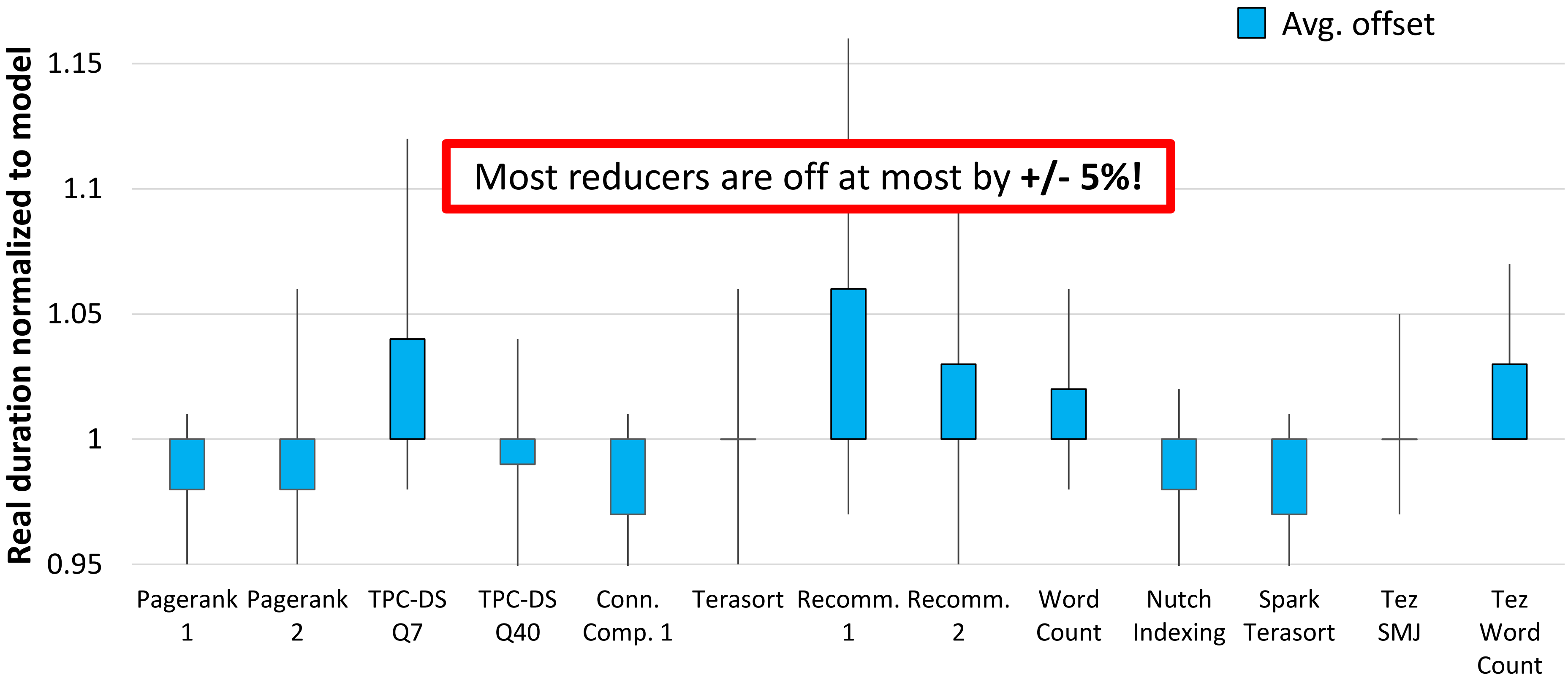


Summary: Modeling memory elasticity

✓ **Step model is adequate (more complex models available)**

✓ **Only 2 profiling points → full model**

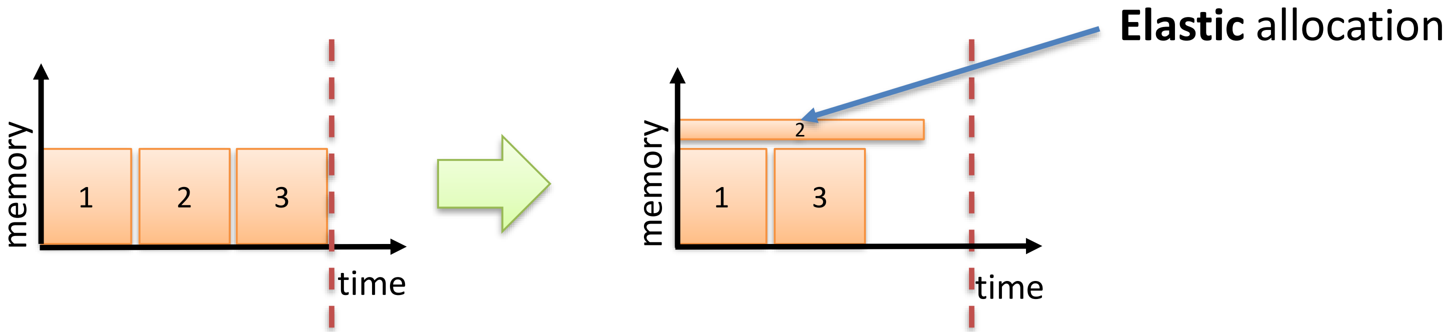
✓ **Models are very robust (+/- 5% error for most reducers)**

LEVERAGING MEMORY ELASTICITY IN CLUSTER SCHEDULING

How can a scheduler reason about Memory Elasticity?

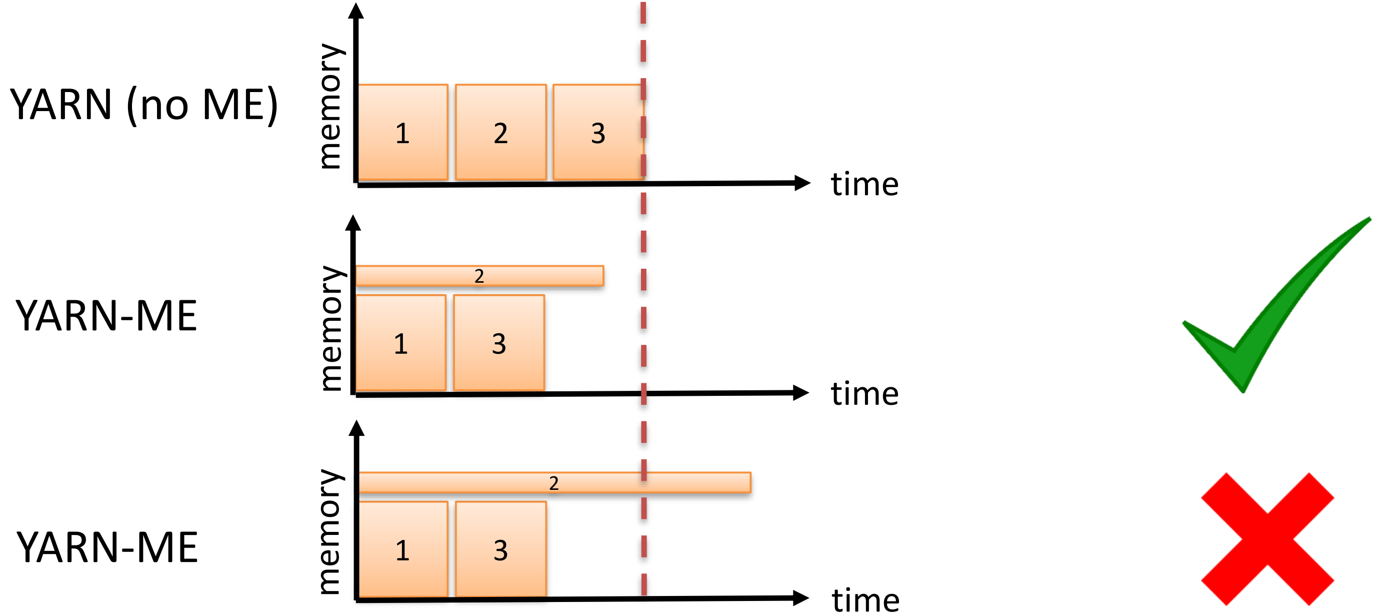
Trade-off between

↓ task **queueing time** ↑ task **execution time**

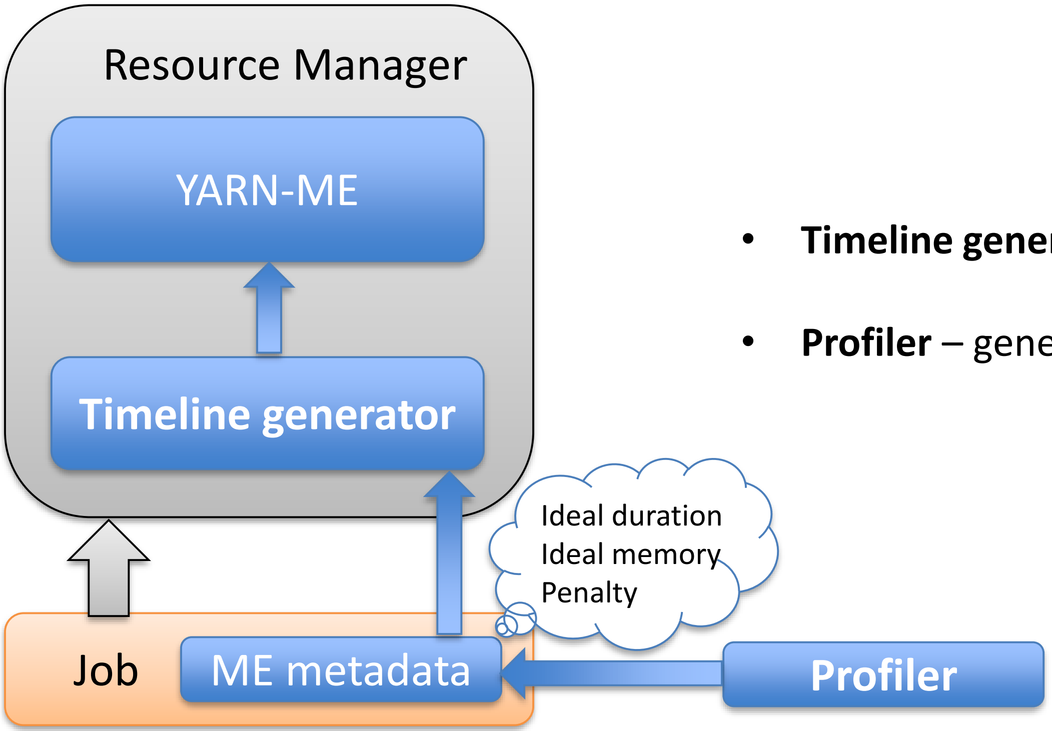


YARN-ME: Decision process

- Make an elastic allocation *iff* it does not exceed the expected job completion time



YARN-ME: Design and components

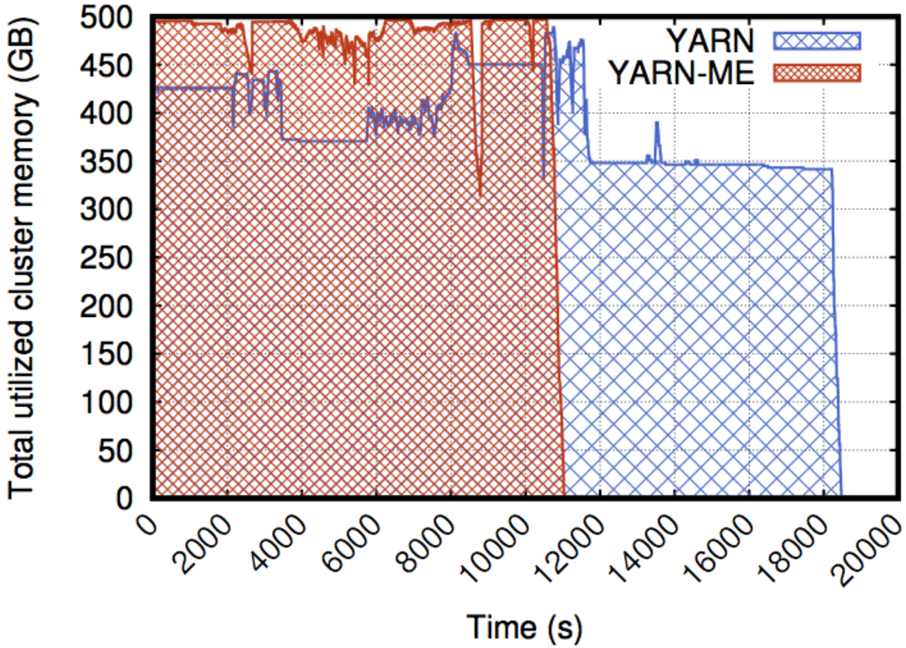


Components

- **Timeline generator** – computes expected JCTs
- **Profiler** – generates the model metadata

Memory utilization analysis for YARN-ME

- 50 node cluster
- <u>Homogeneous trace</u>: 5x Pagerank jobs



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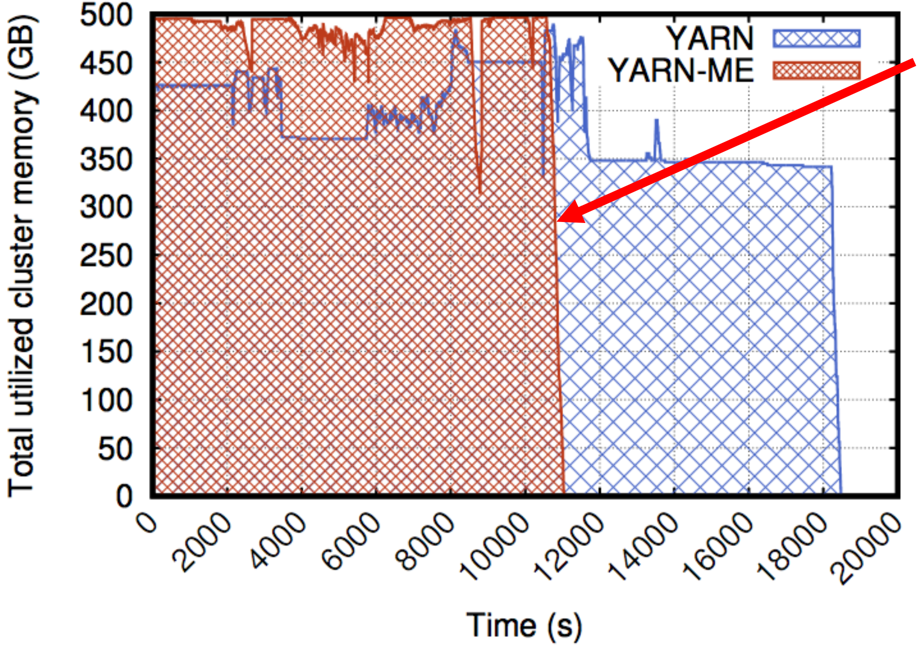
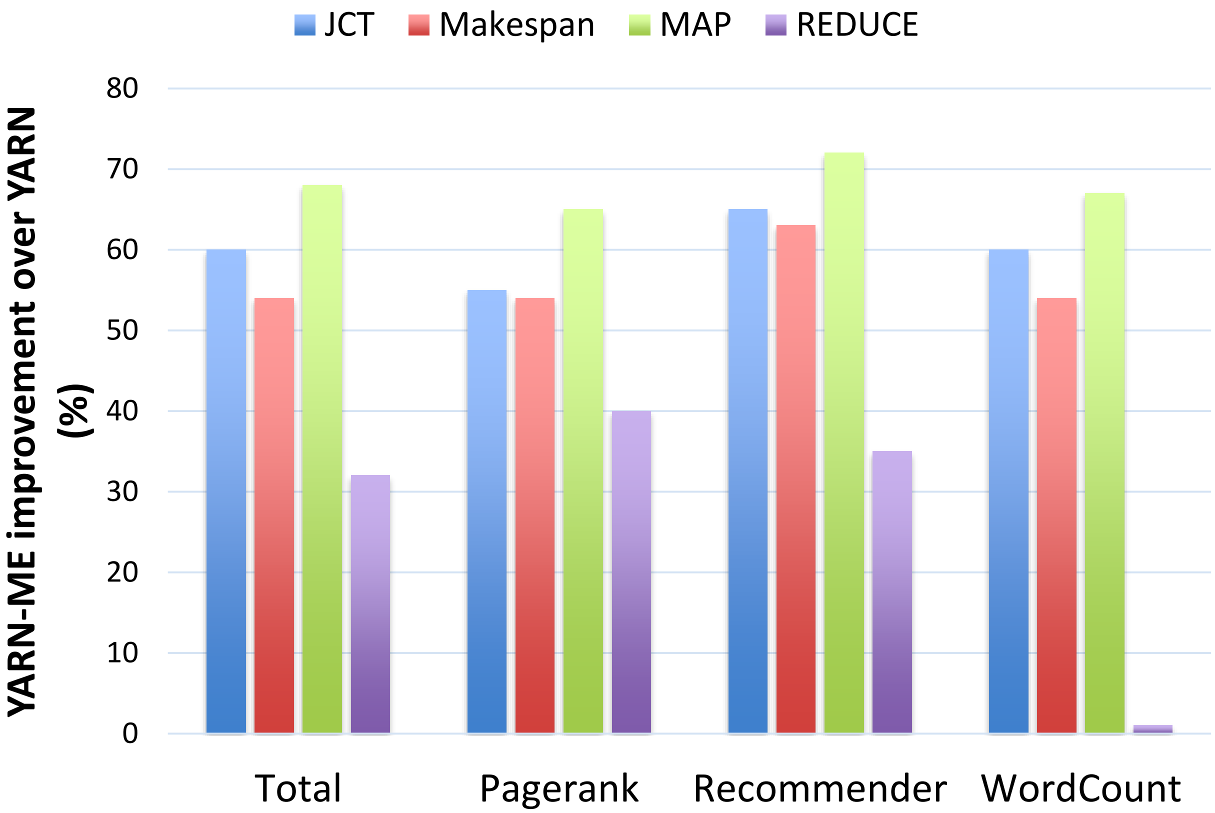


Memory utilization increased to **95%**

What gains can YARN-ME achieve for heterogeneous workloads?



- 50 node cluster
- Mixed trace – 14 jobs
    - 3x PageRank
    - 3x Recommender
    - 8x Wordcount

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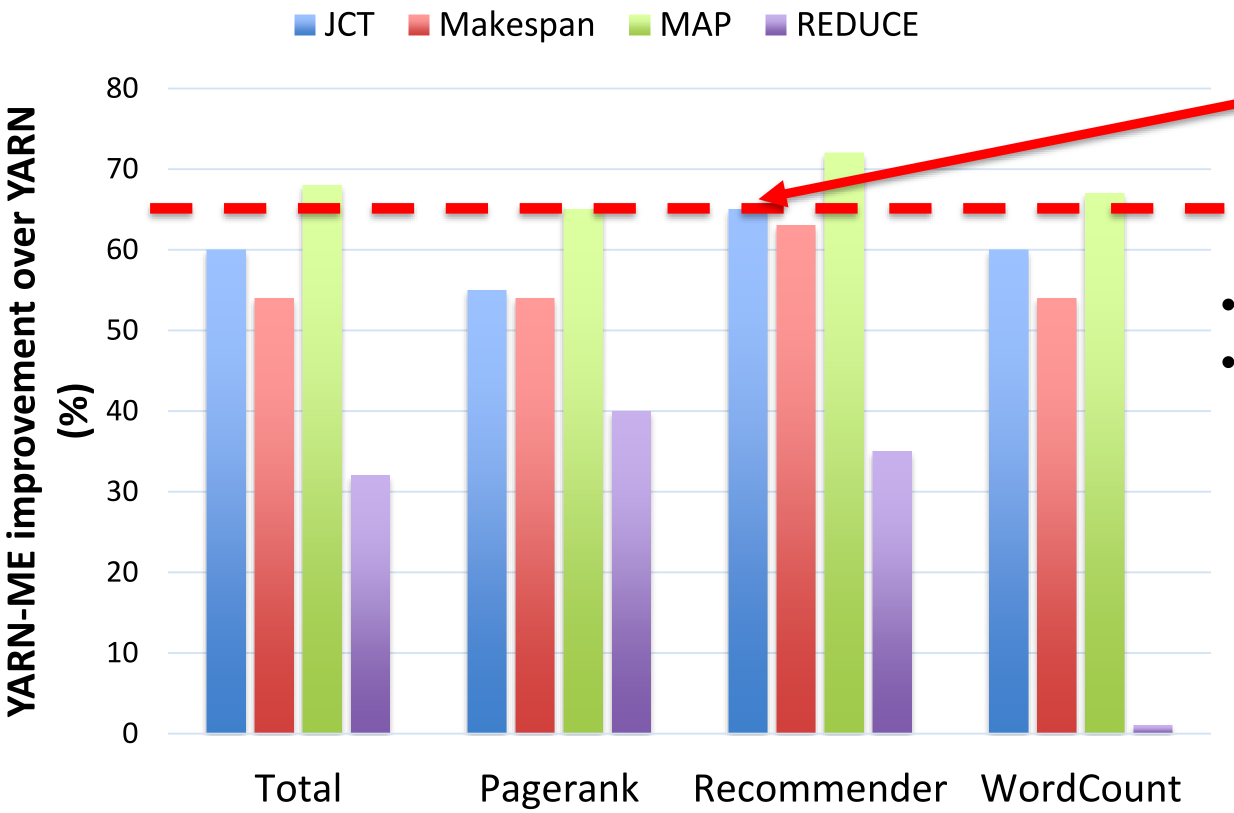

Up to **65% improvement** for **JCT** and **makespan**

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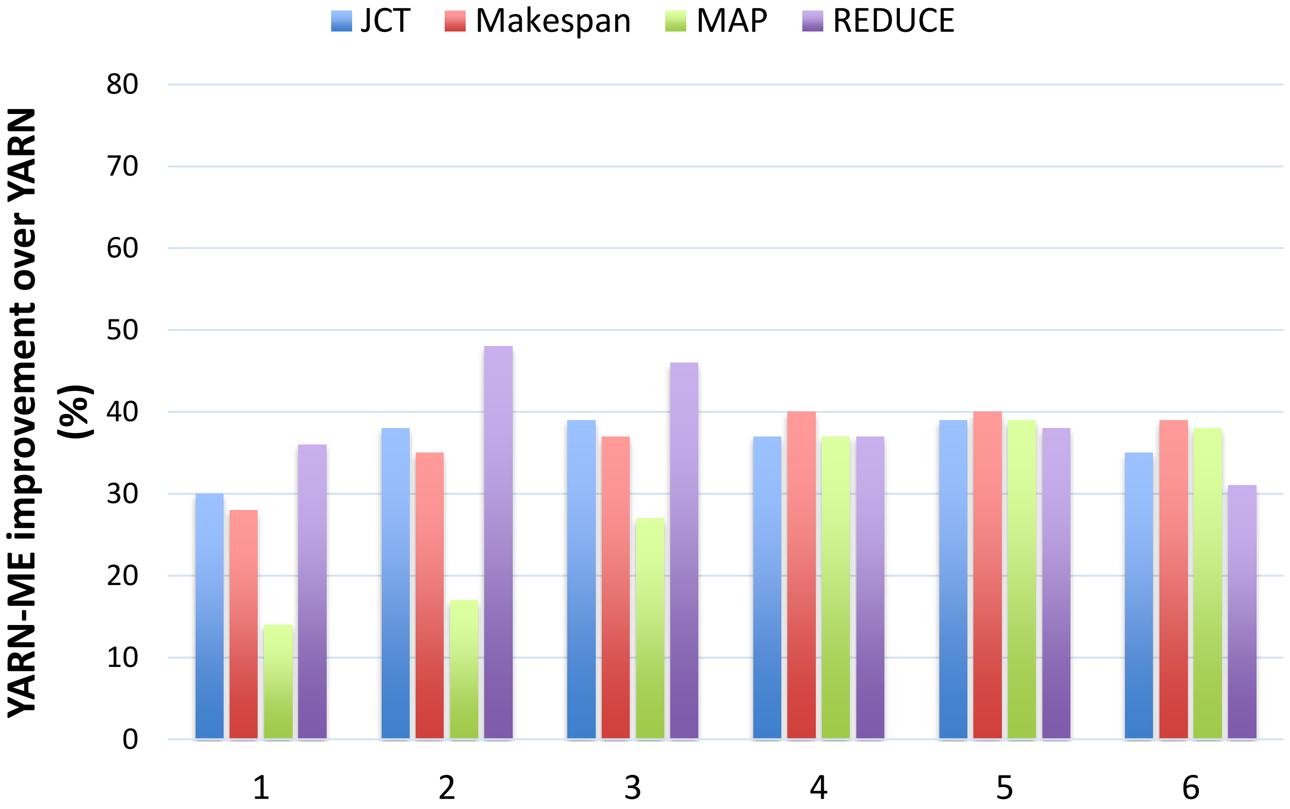

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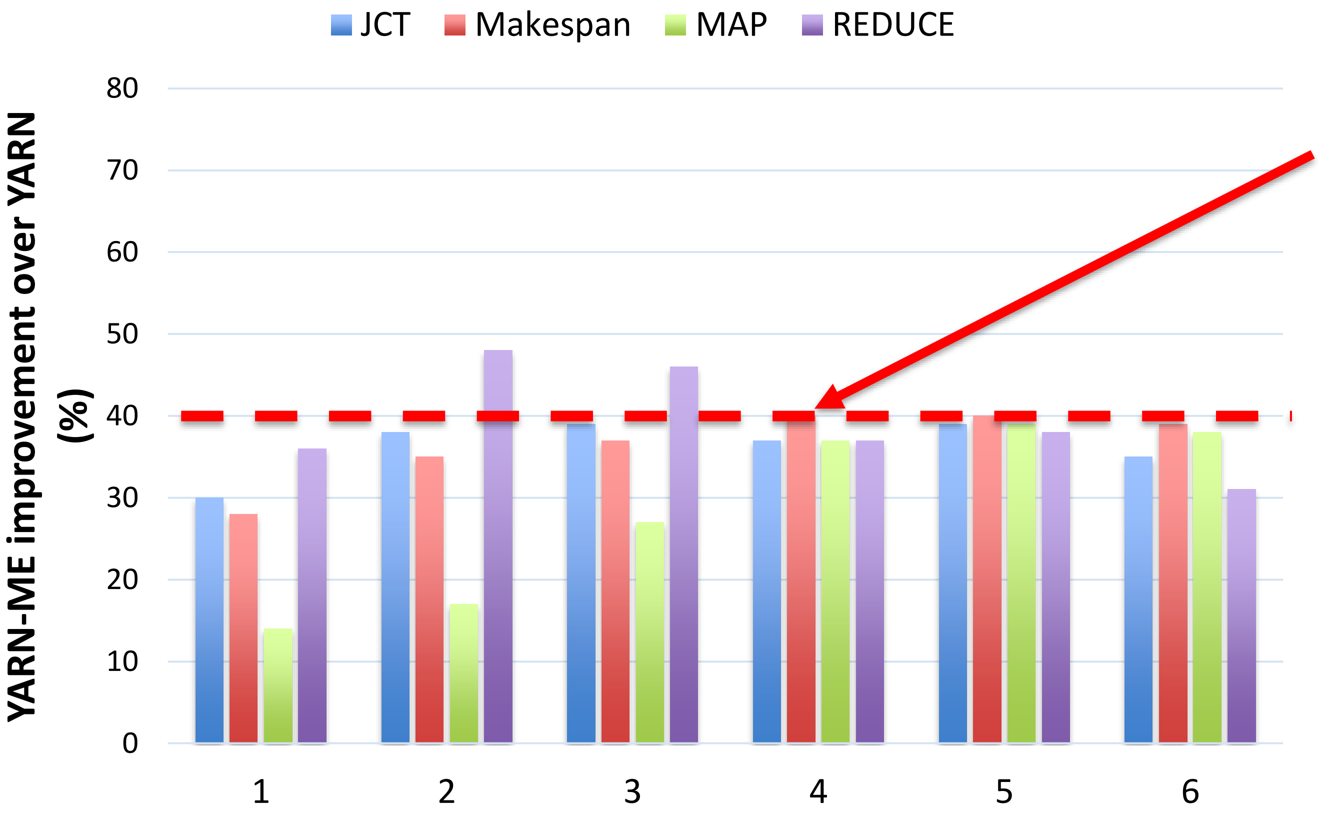

Up to **40% improvement** for **JCT** and **makespan**

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- Pagerank
  - *concurrent runs*

Trace-driven simulation of YARN-ME

- We built DSS (the Discrete Scheduler Simulator)
  - and it is open-source!

<u>Trace parameter sweep</u>

- > 8,000 traces
- up to 3,000 nodes
- results comparable to real workloads

<u>Robustness analysis</u>

- > 20,000 traces
- YARN-ME is robust to model mis-estimations

Related work

- Efficient packing → better resource utilization
  - Tetris [**SIGCOMM ‘14**], GRAPHENE [**OSDI ‘16**]
- Collocate batch-jobs with latency-critical services
  - Heracles [**ISCA ‘15**]
- Resource over-committing
  - Apollo [**OSDI ‘14**], Borg [**EuroSys ‘15**]
- Suspend tasks under memory pressure
  - ITask [**SOSP ‘15**]

Conclusion: Don't cry over spilled records!

Fork us on GitHub

- ✓ Memory Elasticity → highly **predictable**, low penalty
- ✓ Memory Elasticity in scheduling → trade task **queueing-time** for **running-time**
- ✓ YARN-ME → up to 60% improvement in average JCT
- ✓ DSS code available: https://github.com/epfl-labos/dss