PACMan

Coordinated Memory Caching for Parallel Jobs

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Data Analytics Clusters

- Data analytics frameworks are an important driver for modern Internet services
  - E.g., MapReduce, Dryad, Hadoop
  - Jobs are parallel and data-intensive

- Jobs sizes follow the power-law [HotOS'11]
  - 92% of jobs at FB's Hadoop cluster can fit all their data in memory

Cache the data to speed up jobs

- Falling memory prices
  - 64GB/machine at FB in Aug 2011, 192GB/machine not uncommon now

- Memory utilization often low
  - Analyzed Hadoop jobs in Facebook’s production cluster
  - 19% median memory utilization (95th-tile 42%)

We built a memory cache…

- File cache in memory on top of HDFS
  - Cache input data of jobs (accessed by map tasks)

- Schedule map tasks for memory locality

- Simple cache replacement policies
  - Least Recently Used (LRU) and Least Frequently Used (LFU)

We built a memory cache…

- Replayed the Facebook trace of Hadoop jobs
- Jobs sped up by only 10%, hit-ratio of 47% (for LFU) ☹
- Optimal hit-ratio (Belady's MIN Oracle)
  - Hit-ratio 63%
  - Completion time speedup 13%

How can we make caching significantly speedup jobs?

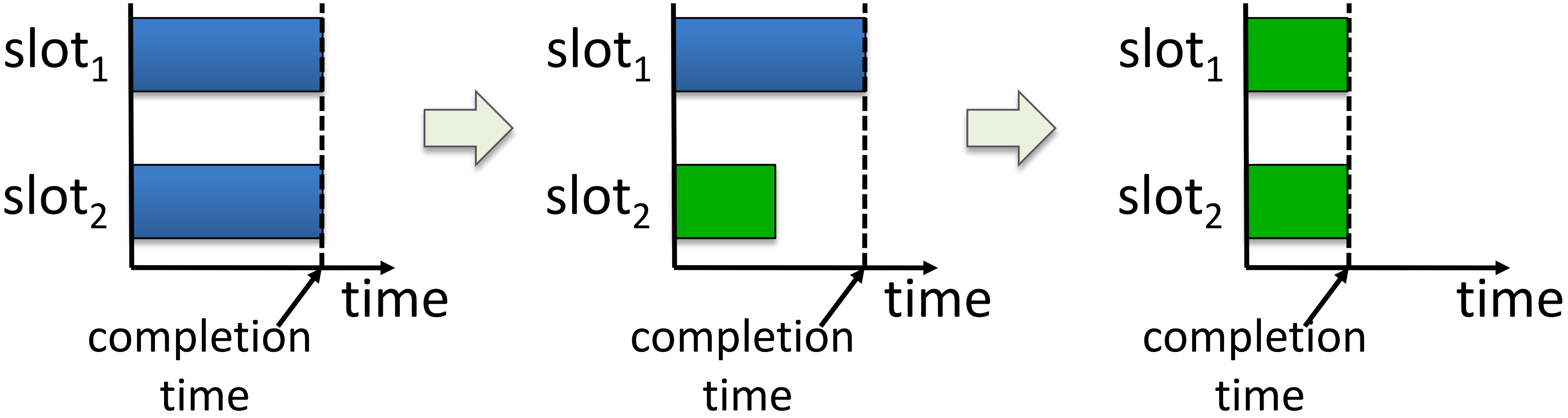
Parallel jobs require a new class of caching algorithms

Parallel Jobs

- Tasks of small jobs run simultaneously in a ***wave***

🟦 Task duration (**uncached** input)

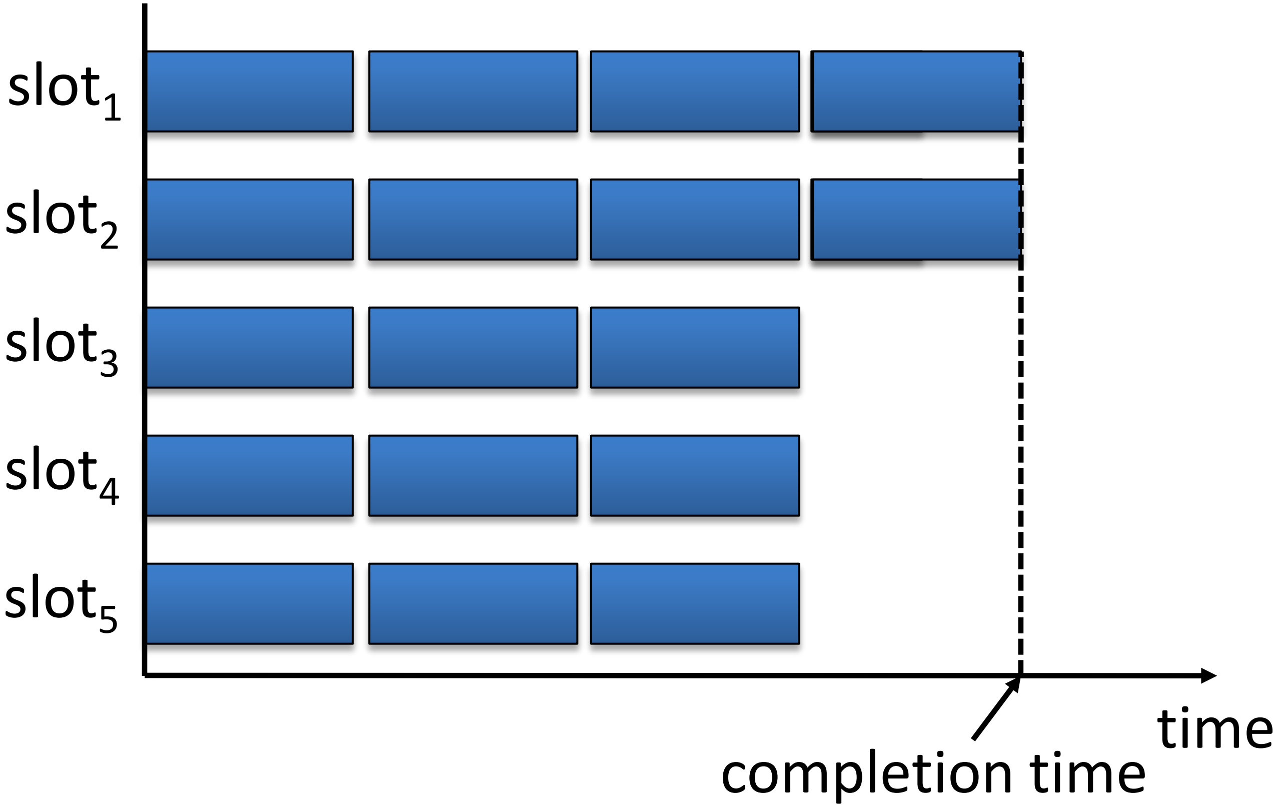
🟩 Task duration (**cached** input)



All-or-nothing: Unless all inputs are cached, there is no benefit

All-or-nothing for multi-waved jobs

- Large jobs run tasks in *multiple waves*
  - Number of tasks is larger than number of slots
  - **Wave-width**: Number of parallel tasks of a job



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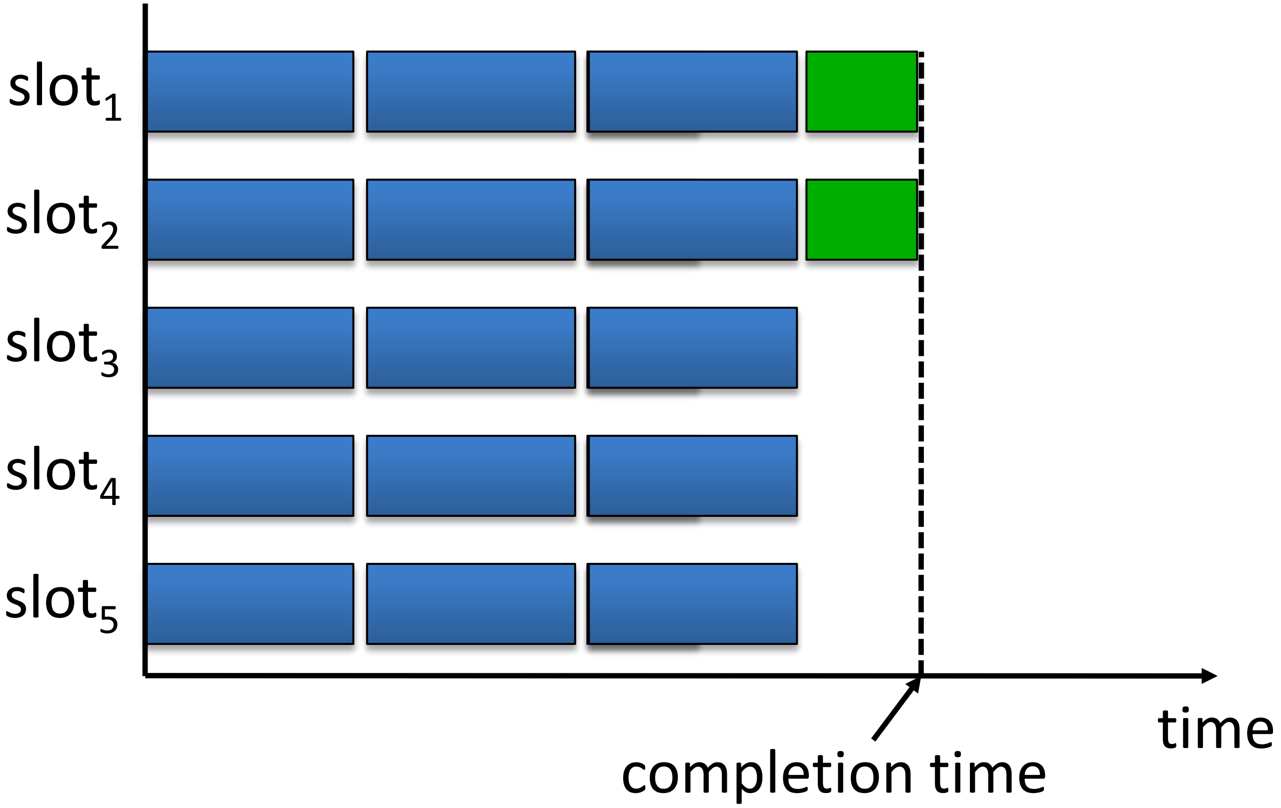

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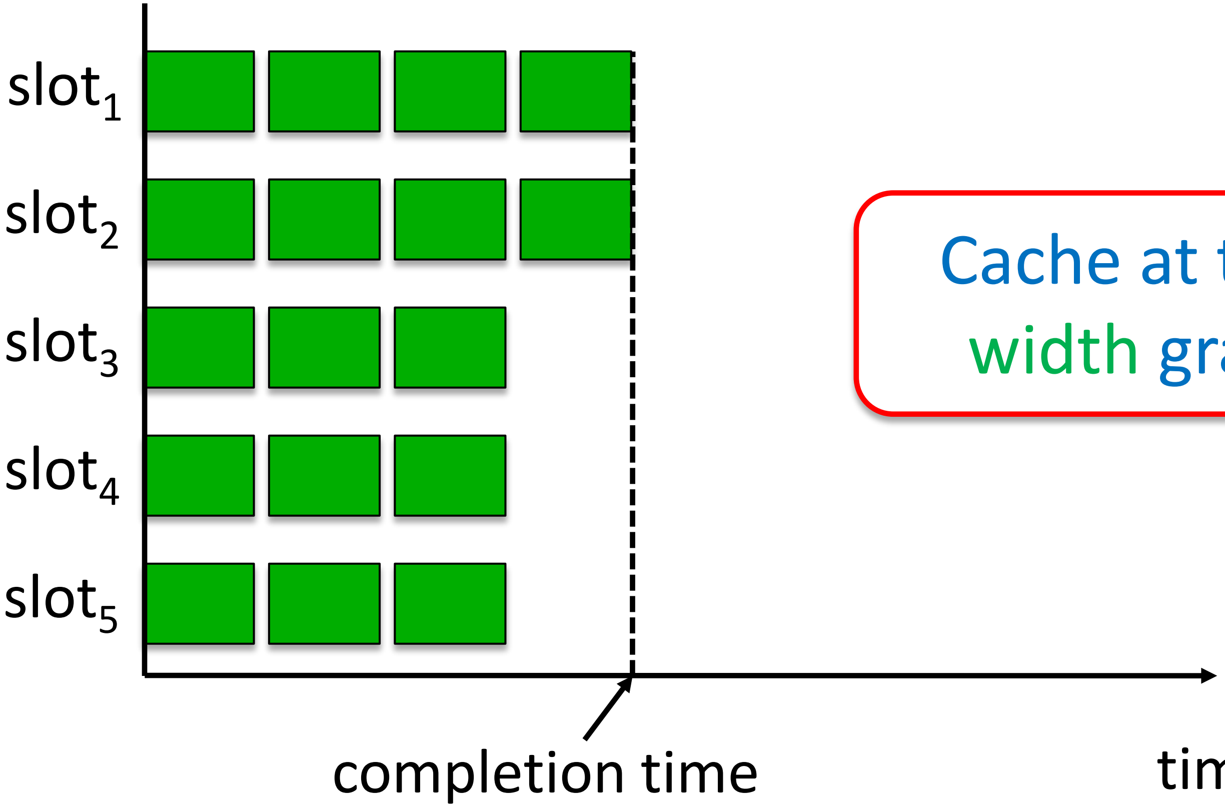


Cache at the wave-width granularity

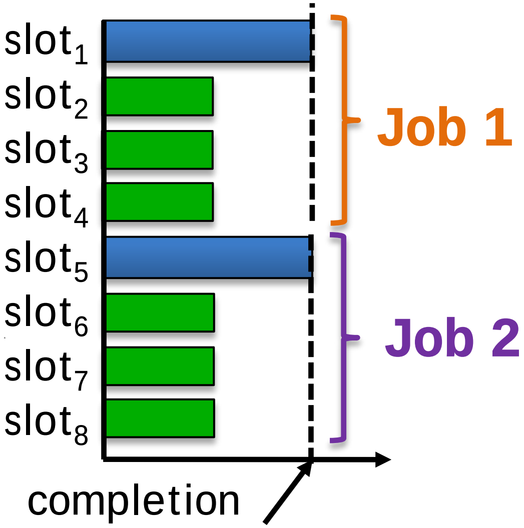
How to evict from cache?

- View at the granularity of a job's input (*file)*
- Focus evictions on incompletely cached waves– **Sticky Policy**

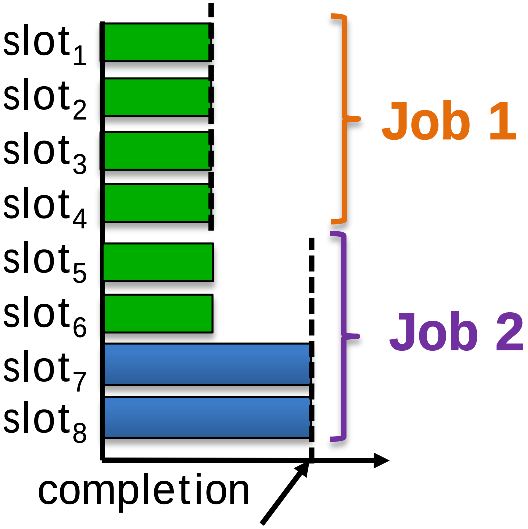
🟦 Task duration (**uncached** input)

🟩 Task duration (**cached** input)

Without Sticky Policy



Hit-ratio: 75%
No speed-up of jobs



With Sticky Policy

Hit-ratio: 75%
Job 1 speeds up

Which file should be evicted?

Depends on metric to optimize:

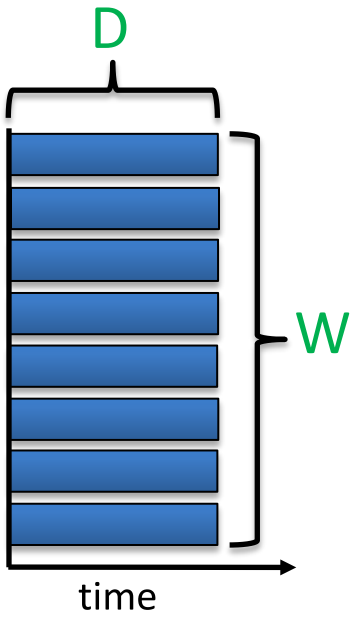
- User centric metric
  - **Completion time** of jobs

- System centric metric
  - **Utilization** of the cluster

What are the eviction policies for these metrics?

Reduction in Completion Time

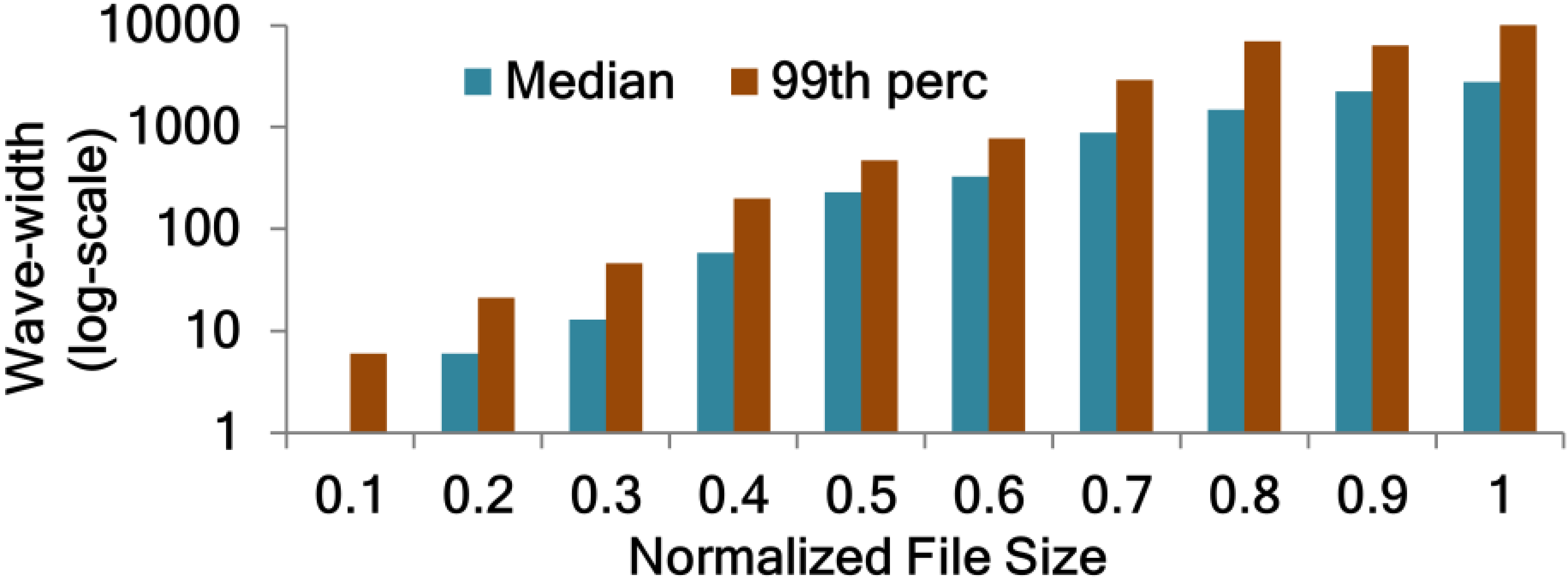
- Idealized model for job:
  - Wave-width for job: W
  - Frequency predicts future access: F
  - Data read is proportional to task length: D
  - Speedup factor for cached tasks: µ



- Cost of caching: W D
- Benefit of caching: µD F
- Benefit/cost: µF/W

Completion Time of Job: frequency/wave-width

How to estimate W for a job?



- Use the size of a file as a proxy for wave-width
  - NSDI paper explains sophisticated approximation

Improvement in Utilization

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  - Wave-width for job: W
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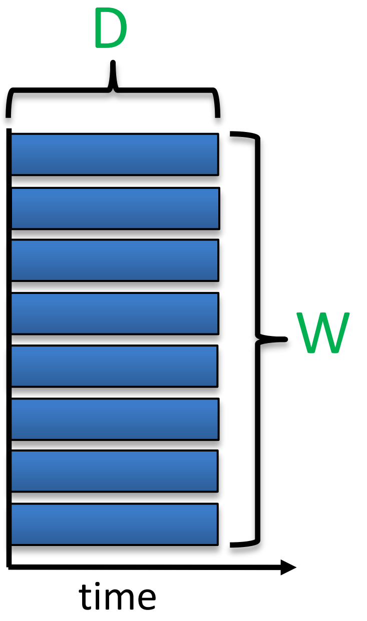
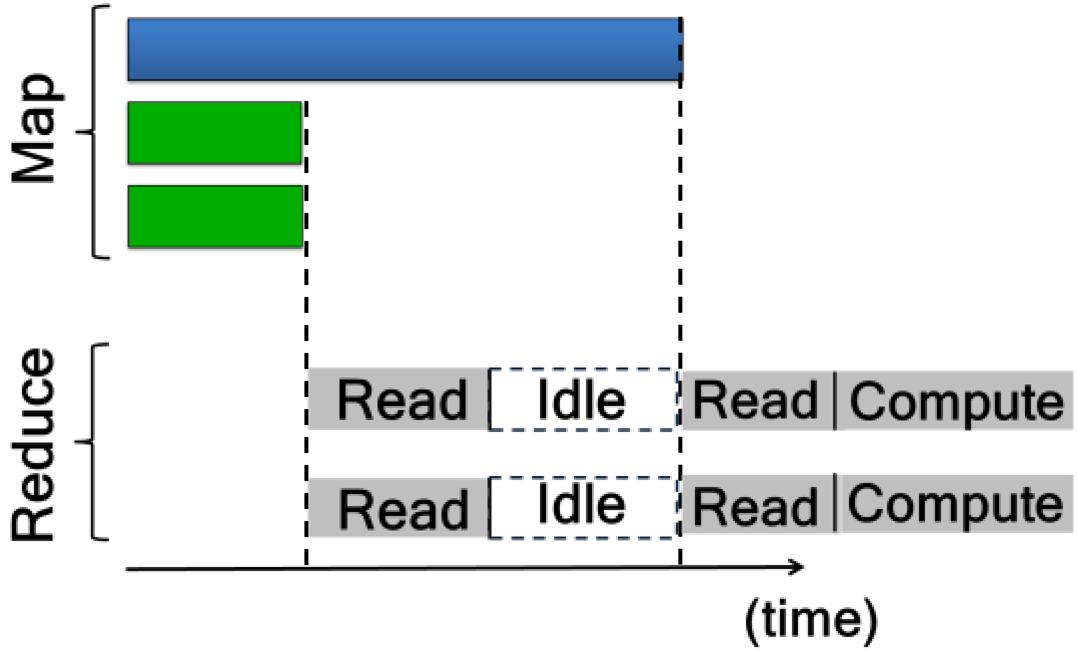


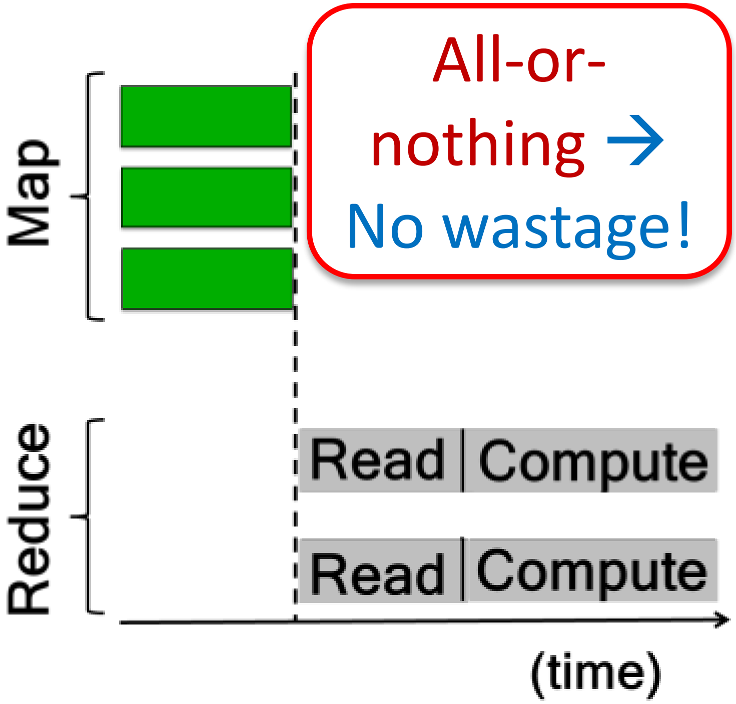
- Cost of caching: W D
- Benefit of caching: W µD F
- Benefit/cost: µF

Utilization of job: frequency

Isn’t this just Least Frequently Used?

- All-or-nothing property matters for utilization
- Tasks of different phases overlap
  - Reduce tasks start before all map tasks finish (to overlap communication)





All-or-nothing → No wastage!

Cache Eviction Policies

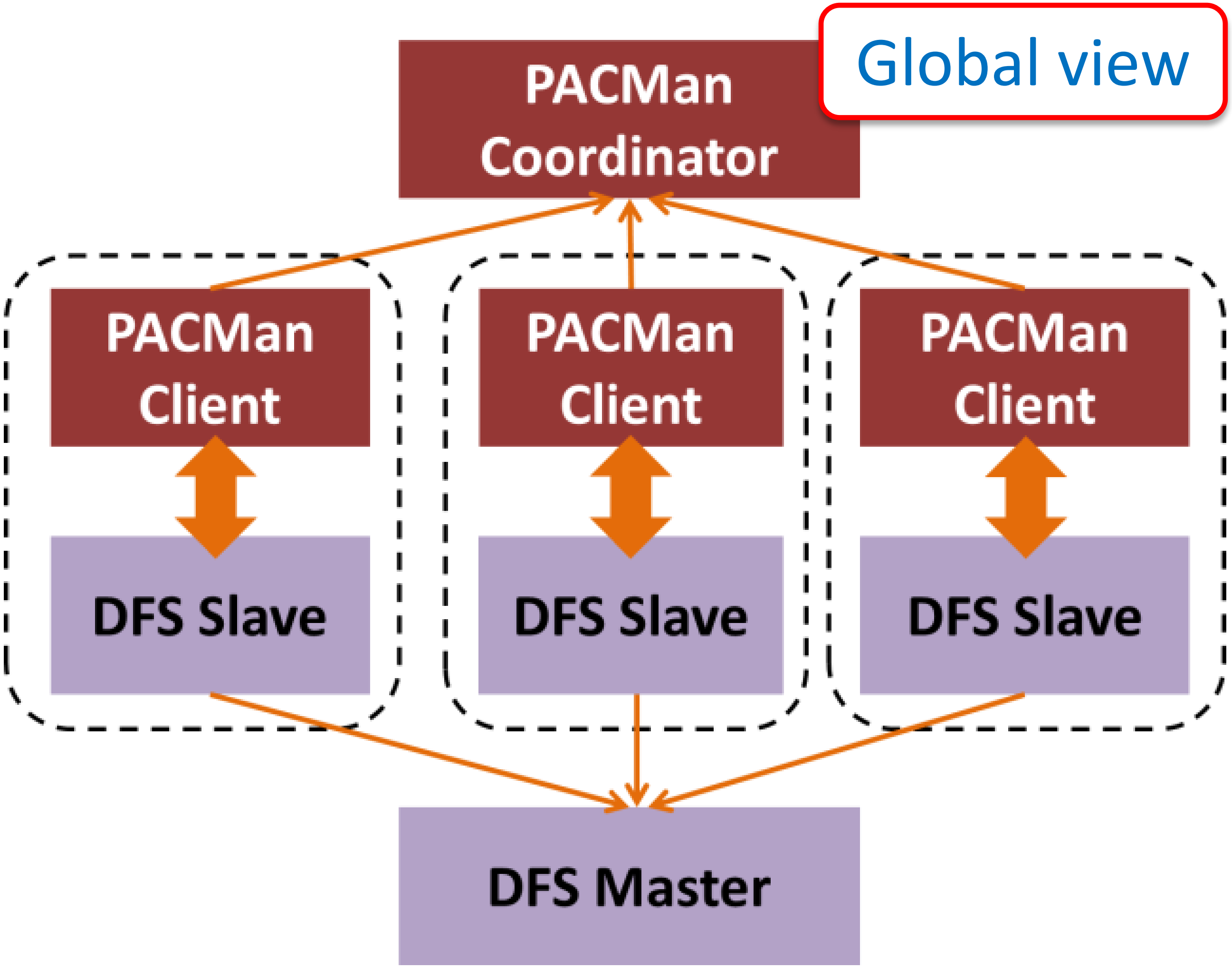
- Completion time policy: LIFE
  - Evict from file with *lowest* (*frequency/wave-width*)
  - Sticky: fully evict file before going to next (all-or-nothing)

- Utilization policy: LFU-F
  - Evict from file with the *lowest frequency*
  - Sticky: fully evict file before going to next (all-or-nothing)

How do we achieve the sticky policy?

- Caches are distributed
- Blocks of files are spread across different machines
- **Coordination**
  - Global view of all the caches
  - …which blocks to evict (sticky policy)
  - …where to schedule tasks (memory locality)

PACMan: Centralized Coordination



Evaluation Setup

- Workload derived from Facebook & Bing traces
  - FB: 3500 node Hadoop cluster, 375K jobs, 1 month
  - Bing: 1000’s of nodes Dryad cluster, 200K jobs, 6 weeks

- Prototype in conjunction with HDFS
- Experiments on 100-node EC2 cluster
  - Cache of 20GB per machine

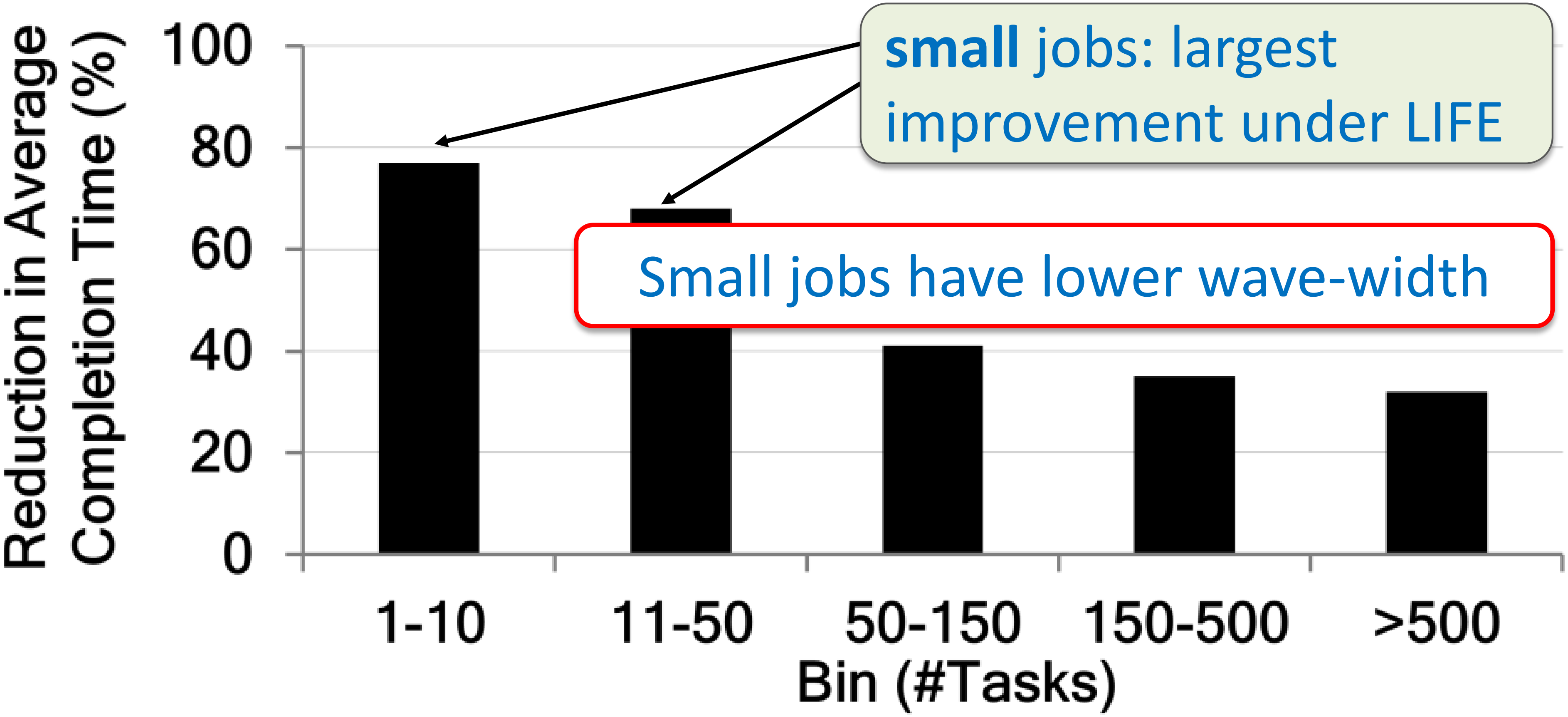
- Simulations
  - Replay of entire traces

Reduction in Completion Time

Replacement Policy	Reduction in average completion time (%)
LRU	9%
LFU	10%
MIN	13%
LIFE	53%

Sticky Policy

Which jobs are sped up?



small jobs: largest improvement under LIFE

Small jobs have lower wave-width

Power law in job sizes → there is space for large jobs too

Improvement in Utilization

Replacement Policy	Improvement in utilization (%)
LRU	13%
LFU	46%
MIN	51%
LFU-F	54%

Sticky Policy

What if we had an oracle?

- Optimal Cache Replacement
  - LP: Minimize average completion
  - 10% improvement in average completion time

- Cache prior to first access
  - One third of tasks read singly-accessed data
  - 27% improvement in average completion time

Pre-fetch & Pre-replace: Adds oracle capability to PACMan → 87% improvement

Related Work

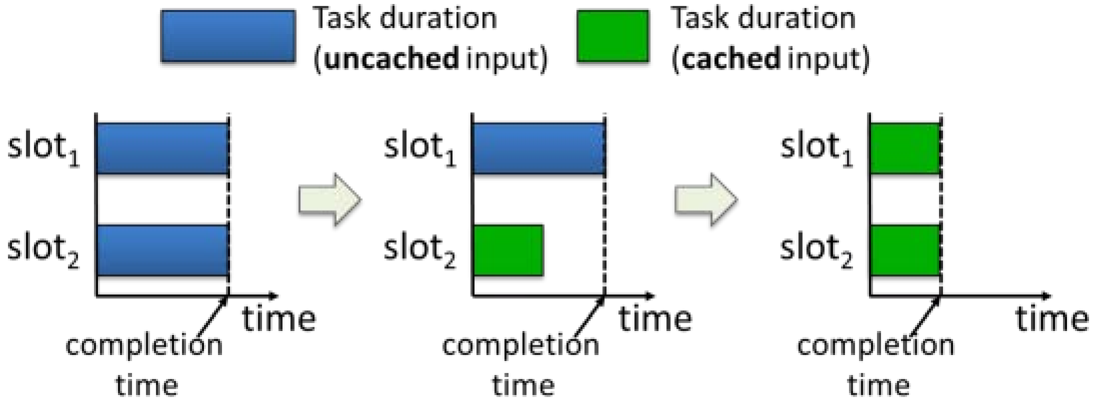
- In-memory computation frameworks [e.g., Spark, Piccolo, Twister]
  - Mediates cache access *across* jobs

- Memory Storage Systems [e.g., RAMCloud]
  - Data-intensive clusters cannot fit all data in memory; 200x more storage on disk than available memory

- Global Memory Systems [e.g., GMS, NOW]
  - Does not replace based on job-level granularity

Conclusions

- All-or-nothing property of parallel jobs
  - Cache all of the inputs of a job



- PACMan: Coordinated Cache Management
  - Sticky policy: Evict from incomplete inputs

- LIFE for completion time, LFU-F for utilization
- Jobs are 53% faster, cluster utilization improves by 54%