Delay Scheduling

A Simple Technique for Achieving Locality and Fairness in Cluster Scheduling

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Motivation

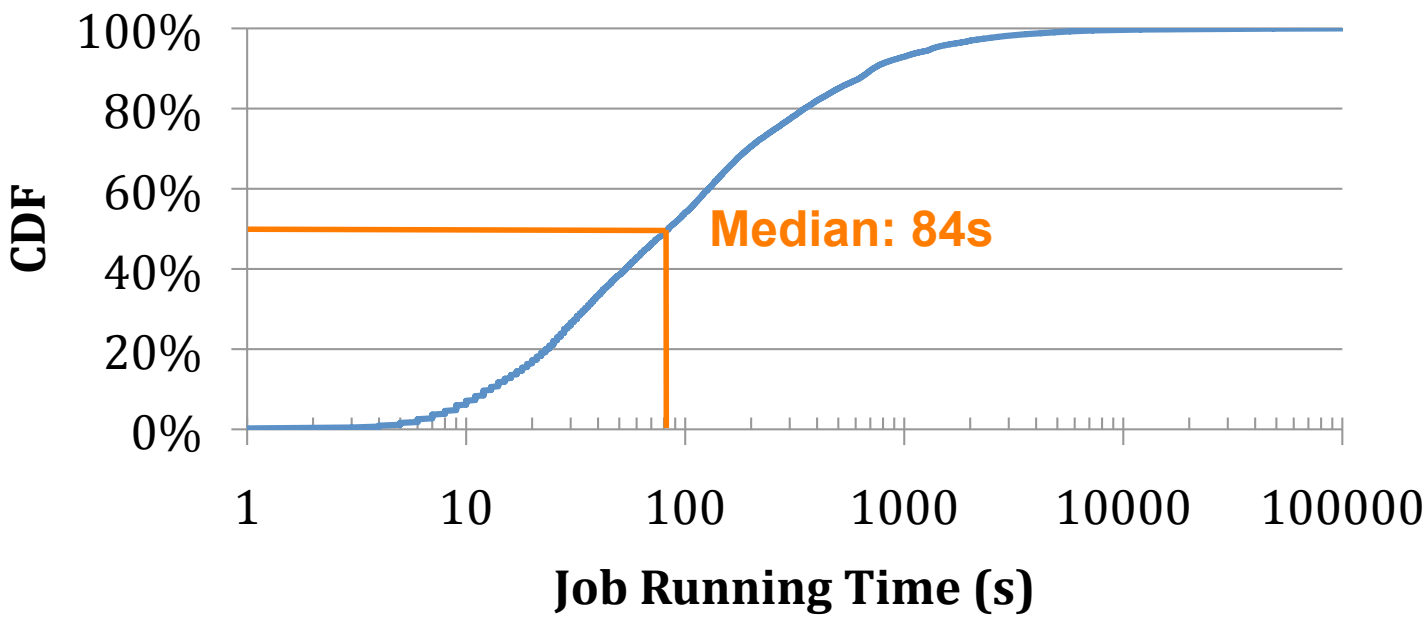
- MapReduce / Hadoop originally designed for high throughput batch processing

- Today's workload is far more diverse:
  - *Many users* want to share a cluster
    - Engineering, marketing, business intelligence, etc
  - Vast majority of jobs are *short*
    - Ad-hoc queries, sampling, periodic reports
  - *Response time* is critical
    - Interactive queries, deadline-driven reports

➢ How can we efficiently share MapReduce clusters between users?

Example: Hadoop at Facebook

- 600-node, 2 PB data warehouse, growing at 15 TB/day
- Applications: data mining, spam detection, ads
- 200 users (half non-engineers)
- 7500 MapReduce jobs / day



Approaches to Sharing

- Hadoop default scheduler (FIFO)
  - **Problem:** short jobs get stuck behind long ones

- Separate clusters
  - **Problem 1:** poor utilization
  - **Problem 2:** costly data replication
    - Full replication across clusters nearly infeasible at Facebook/Yahoo! scale
    - Partial replication prevents cross-dataset queries

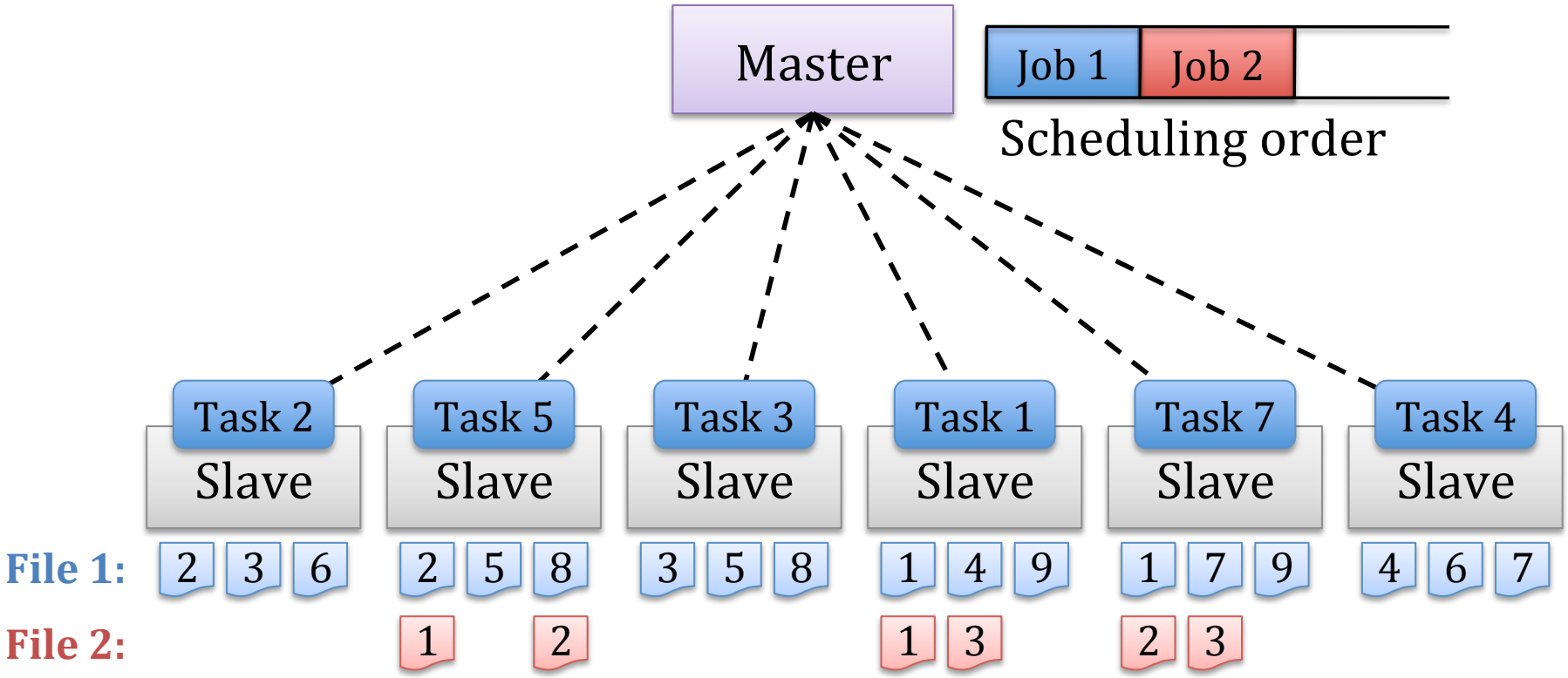
Our Work

- Hadoop Fair Scheduler
  - Fine-grained sharing at level of map & reduce tasks
  - Predictable response times and user isolation

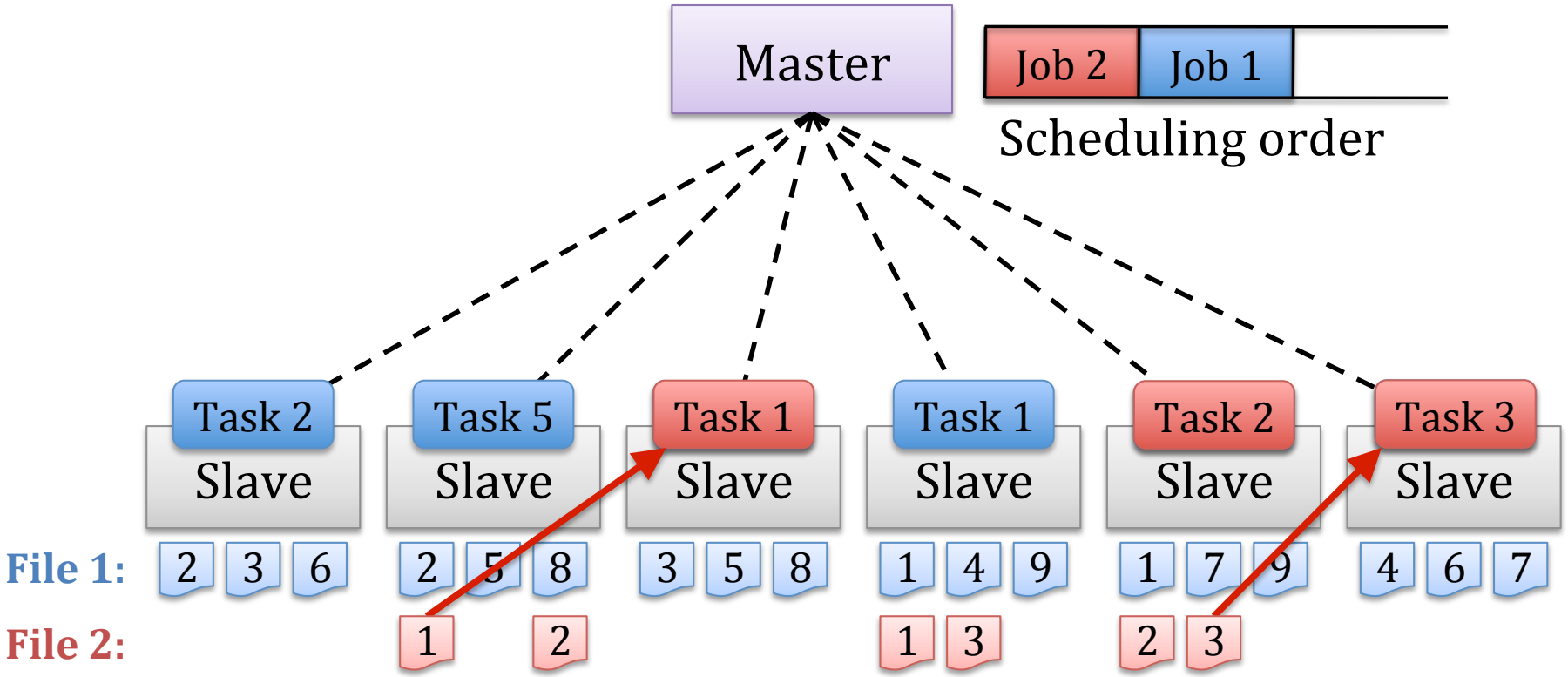
- Main challenge: data locality
  - For efficiency, must run tasks near their input data
  - Strictly following *any* job queuing policy hurts locality: job picked by policy may not have data on free nodes

- Solution: delay scheduling
  - Relax queuing policy for limited time to achieve locality

The Problem


Master
Job 1
Job 2
Scheduling order
Task 2
Slave
Task 5
Slave
Task 3
Slave
Task 1
Slave
Task 7
Slave
Task 4
Slave
File 1:
2 3 6
2 5 8
3 5 8
1 4 9
1 7 9
4 6 7
File 2:
1
2
1 3
2 3

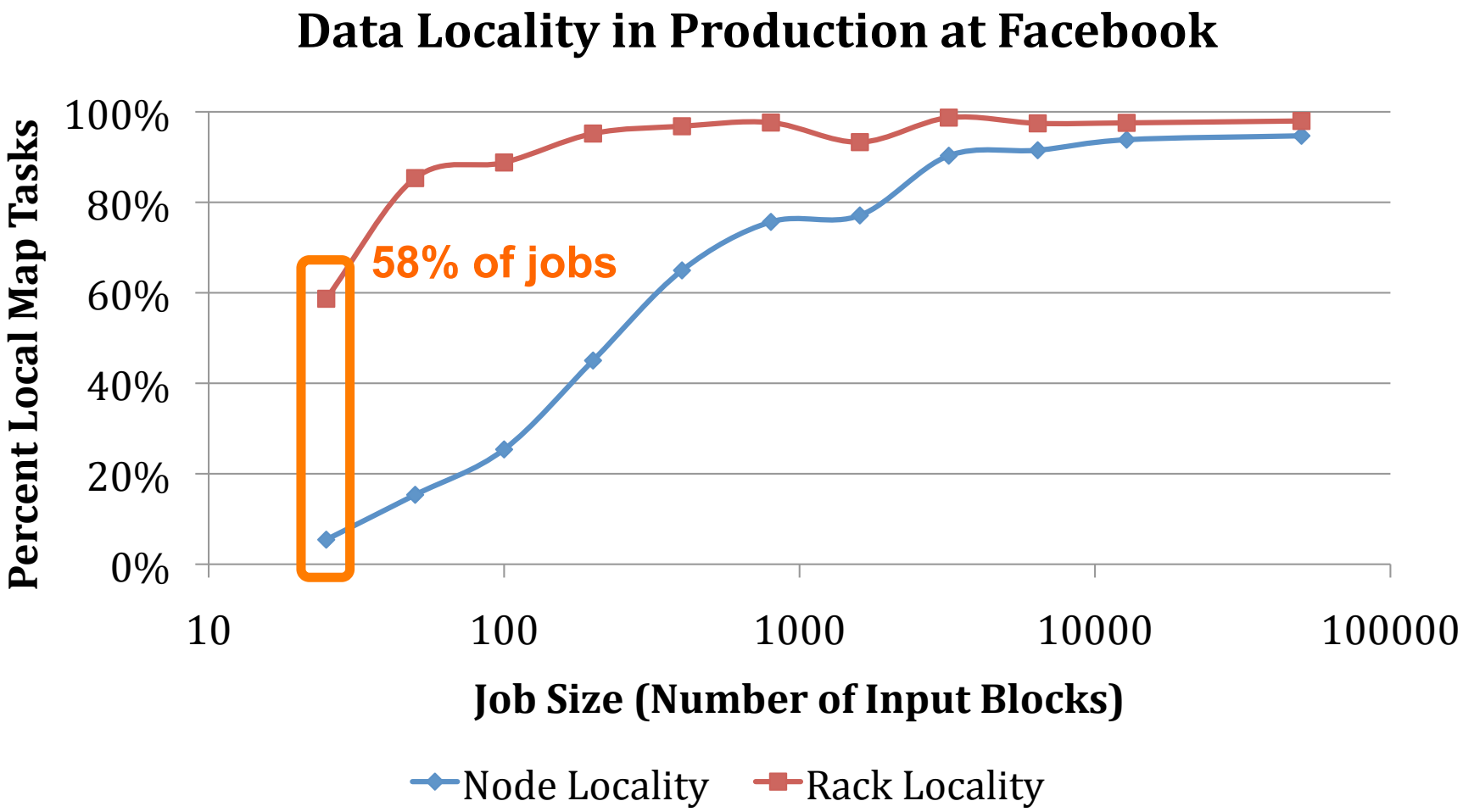
The Problem



Problem: Fair decision hurts locality

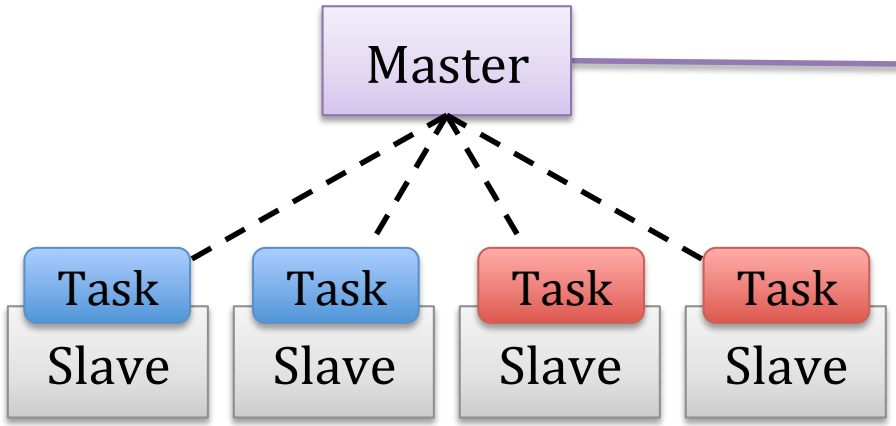
Especially bad for jobs with small input files

Locality vs. Job Size at Facebook



Special Instance: Sticky Slots

- Under fair sharing, locality can be poor even when all jobs have large input files
- Problem: jobs get "stuck" in the same set of task slots
  - When one a task in job *j* finishes, the slot it was running in is given back to *j*, because *j* is below its share
  - Bad because data files are spread out across *all* nodes



Job	Fair Share	Running Tasks
Job 1	2	**1**
Job 2	2	2

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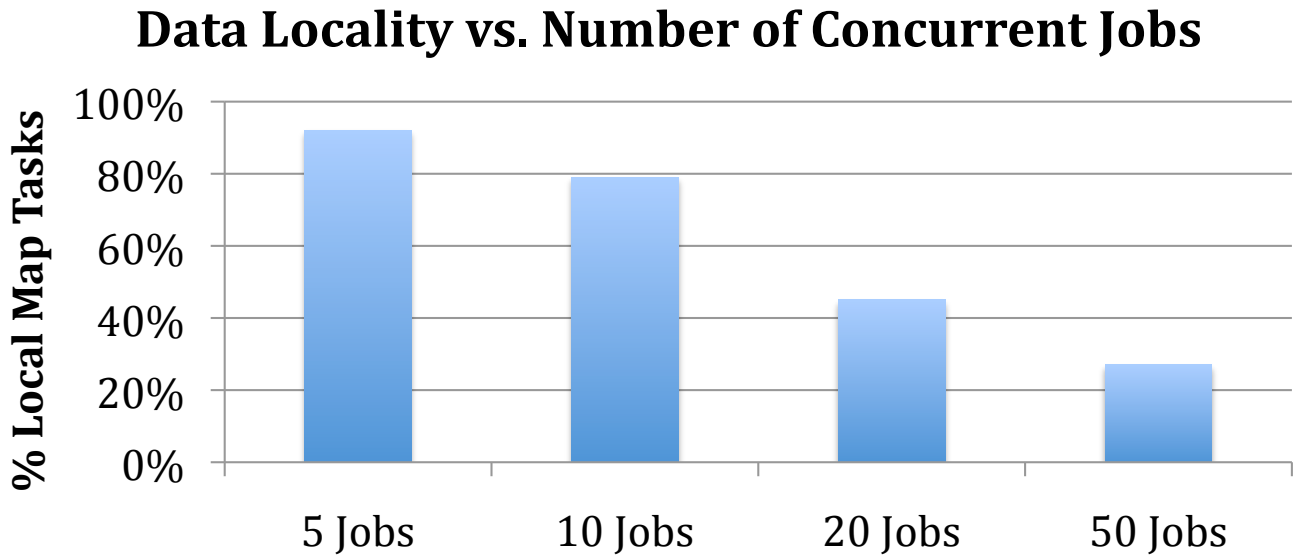
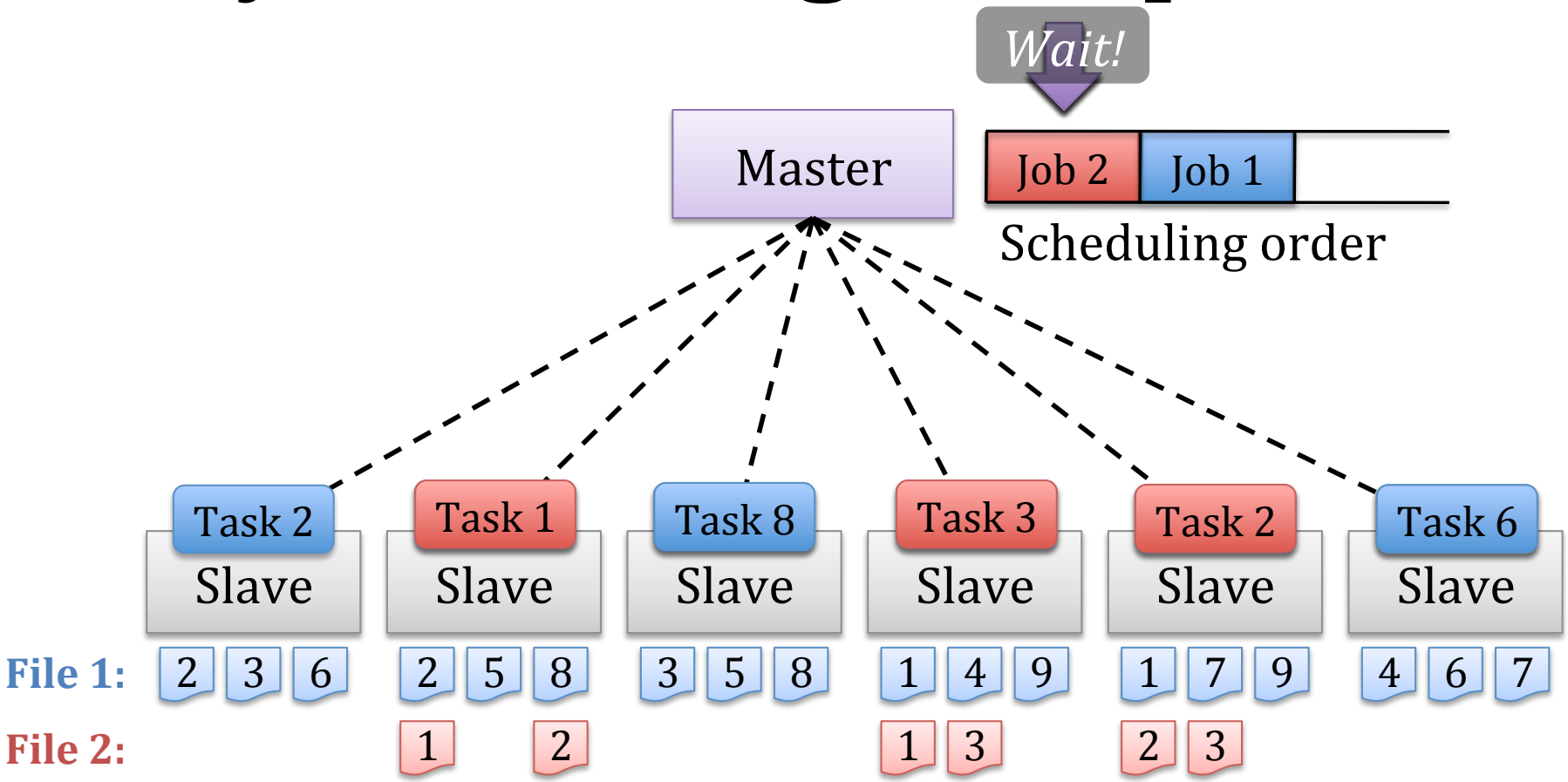


Solution: Delay Scheduling

- *Relax queuing policy* to make jobs wait for a limited time if they cannot launch local tasks

- Result: Very short wait time (1-5s) is enough to get nearly 100% locality

Delay Scheduling Example



Idea: Wait a short time to get data-local scheduling opportunities

Delay Scheduling Details

- Scan jobs in order given by queuing policy, picking first that is permitted to launch a task

- Jobs must wait before being permitted to launch non-local tasks
  - If wait < T_1, only allow node-local tasks
  - If T_1 < wait < T_2, also allow rack-local
  - If wait > T_2, also allow off-rack

- Increase a job's time waited when it is skipped

Analysis

- **When is it worth it to wait, and for how long?**

➢ *Waiting worth it if E(wait time) < cost to run non-locally*

- Simple model: Data-local scheduling opportunities arrive following Poisson process
- Expected response time gain from delay scheduling:

$$E(\text{gain}) = (1 - e^{-w/t})(d - t)$$

Wait amount

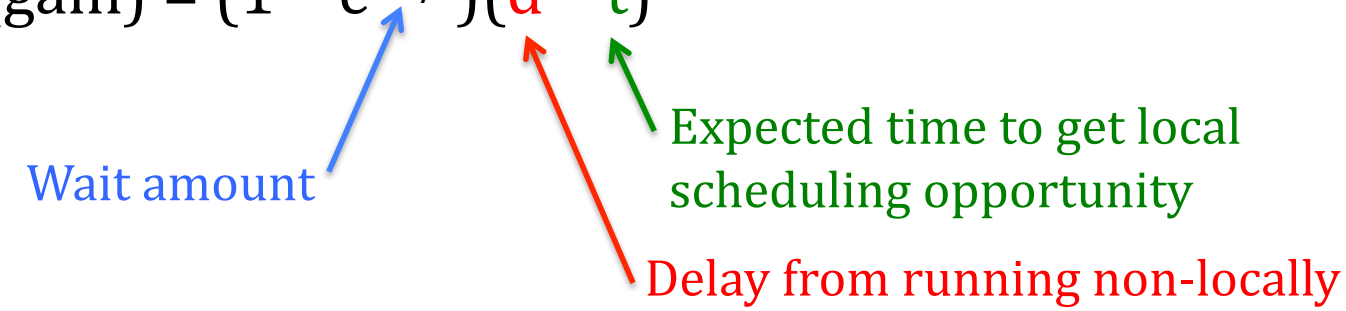
Expected time to get local scheduling opportunity

Delay from running non-locally

➢ *Optimal wait time is infinity*

Analysis Continued

$$E(\text{gain}) = (1 - e^{-w/t})(d - t)$$



- **Typical values of t and d:**

  t = (avg task length) / (file replication × tasks per node)

  d ≥ (avg task length)

  3 6

More Analysis

- What if some nodes are occupied by long tasks?
- Suppose we have:
  - Fraction ϕ of active tasks are long
  - R replicas of each block
  - L task slots per node
- For a given data block,
  P(all replicas blocked by long tasks) = ϕ^{RL}
- With R = 3 and L = 6, this is less than 2% if $\phi < 0.8$

Evaluation

- Macrobenchmark
  - IO-heavy workload
  - CPU-heavy workload
  - Mixed workload
- Microbenchmarks
  - Sticky slots
  - Small jobs
  - Hierarchical fair scheduling
- Sensitivity analysis
- Scheduler overhead

Macrobenchmark

- 100-node EC2 cluster, 4 cores/node
- Job submission schedule based on job sizes and inter-arrival times at Facebook
  - 100 jobs grouped into 9 “bins” of sizes
- Three workloads:
  - IO-heavy, CPU-heavy, mixed
- Three schedulers:
  - FIFO
  - Fair sharing
  - Fair + delay scheduling (wait time = 5s)

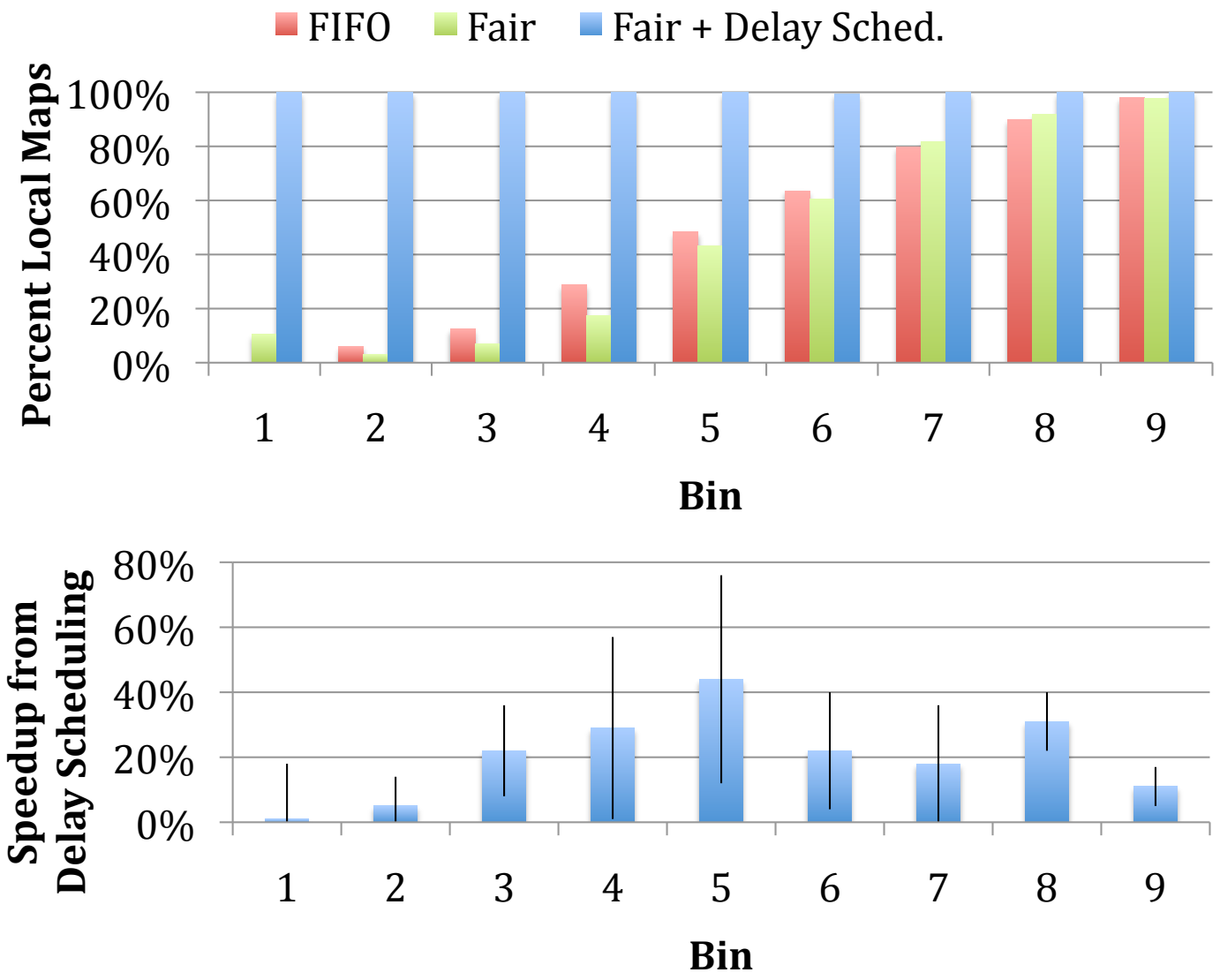
Results for IO-Heavy Workload

Small Jobs
(1-10 input blocks)

Medium Jobs
(50-800 input blocks)

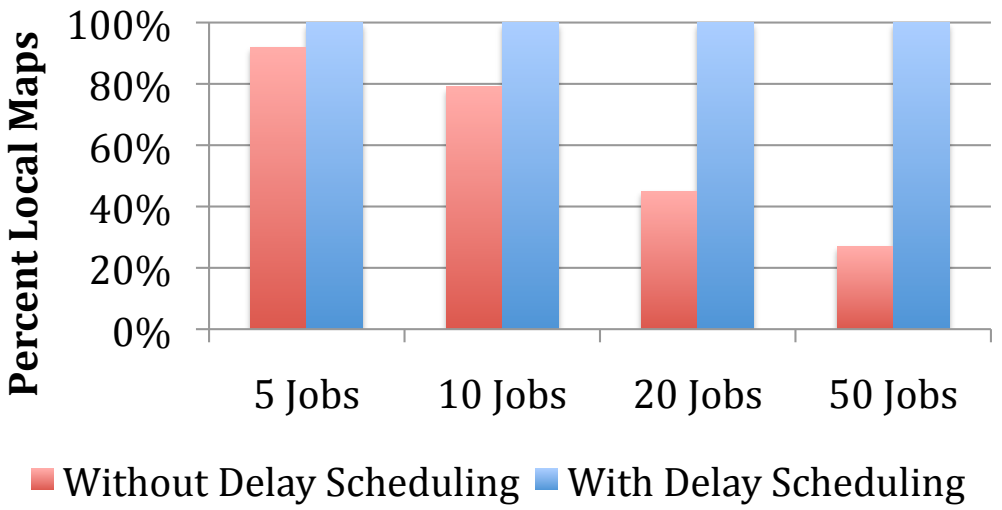
Large Jobs
(4800 input blocks)

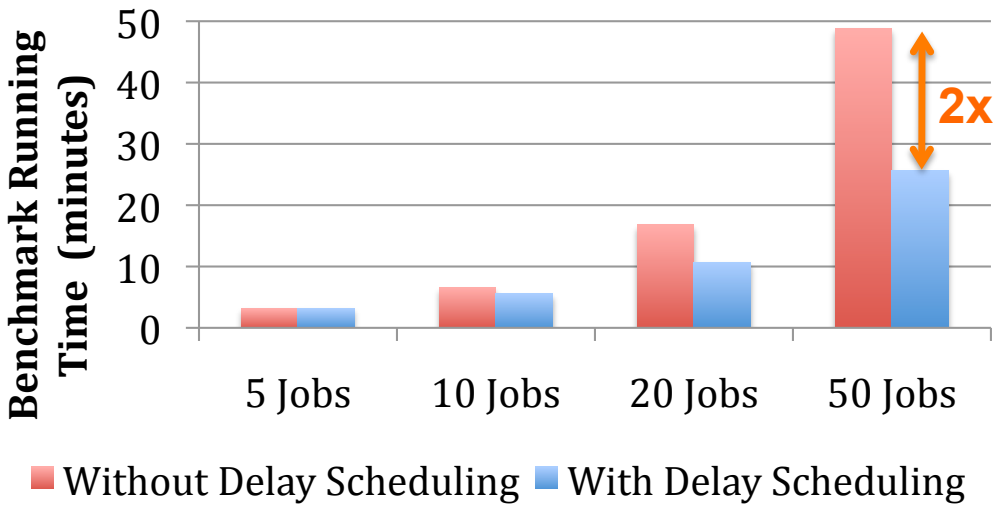
Results for IO-Heavy Workload



Sticky Slots Microbenchmark

- 5-50 jobs on EC2
- 100-node cluster
- 4 cores / node
- 5s delay scheduling





Conclusions

- Delay scheduling works well under two conditions:
  - Sufficient fraction of tasks are *short* relative to jobs
  - There are *many locations* where a task can run efficiently
    - Blocks replicated across nodes, multiple tasks/node
- Generalizes beyond MapReduce and fair sharing
  - Applies to any queuing policy that gives ordered job list
    - Used in Hadoop Fair Scheduler to implement hierarchical policy
  - Applies to placement needs other than data locality

Thanks!

- This work is open source, packaged with Hadoop as the Hadoop Fair Scheduler
  - Old version without delay scheduling in use at Facebook since fall 2008
  - Delay scheduling will appear in Hadoop 0.21

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Related Work

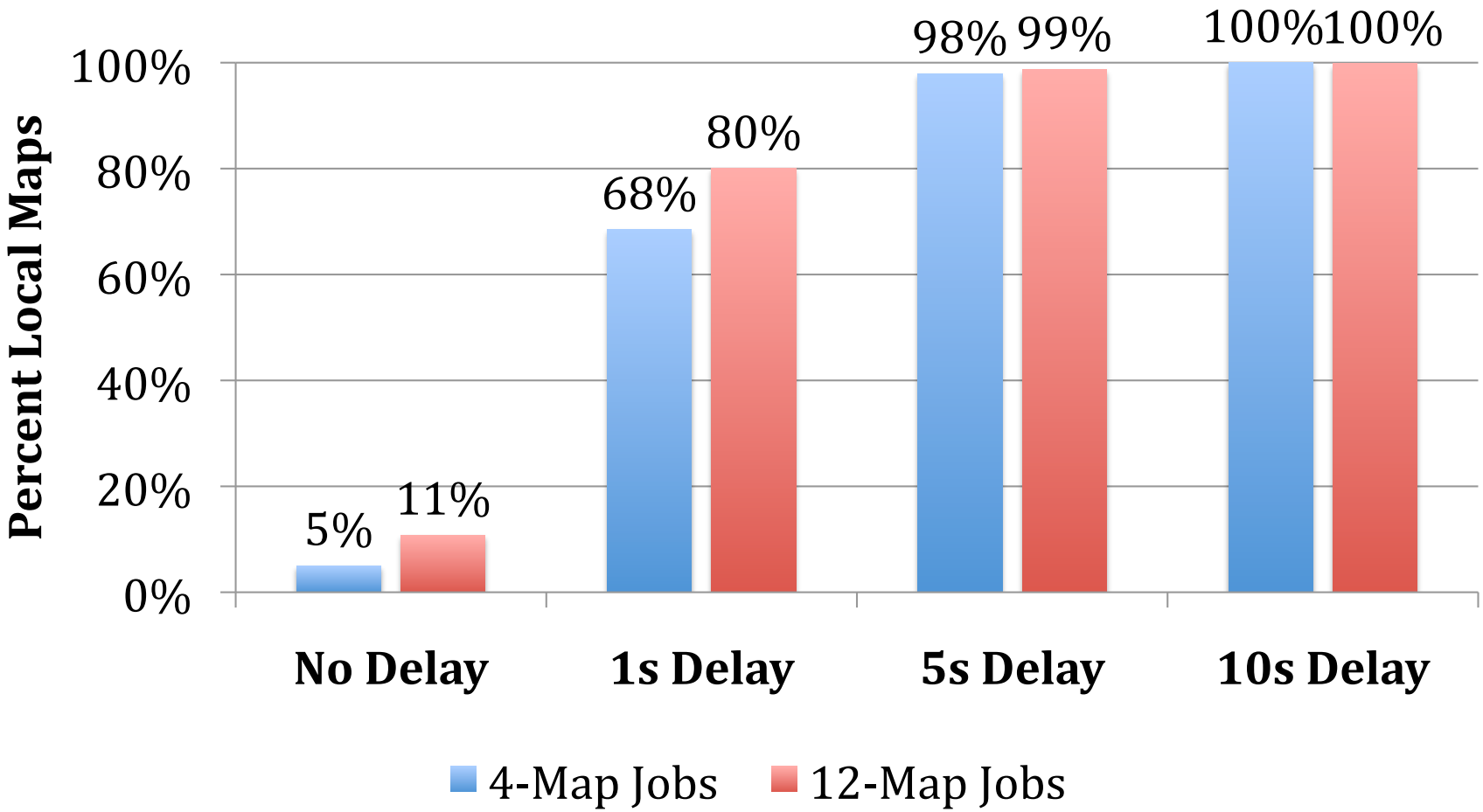
- Quincy (SOSP '09)
  - Locality aware fair scheduler for Dryad
  - Expresses scheduling problem as min-cost flow
  - Kills tasks to reassign nodes when jobs change
  - One task slot per machine
- HPC scheduling
  - Inelastic jobs (cannot scale up/down over time)
  - Data locality generally not considered
- Grid computing
  - Focused on common interfaces for accessing compute resources in multiple administrative domains

Delay Scheduling Details

when there is a free task slot on node *n*:

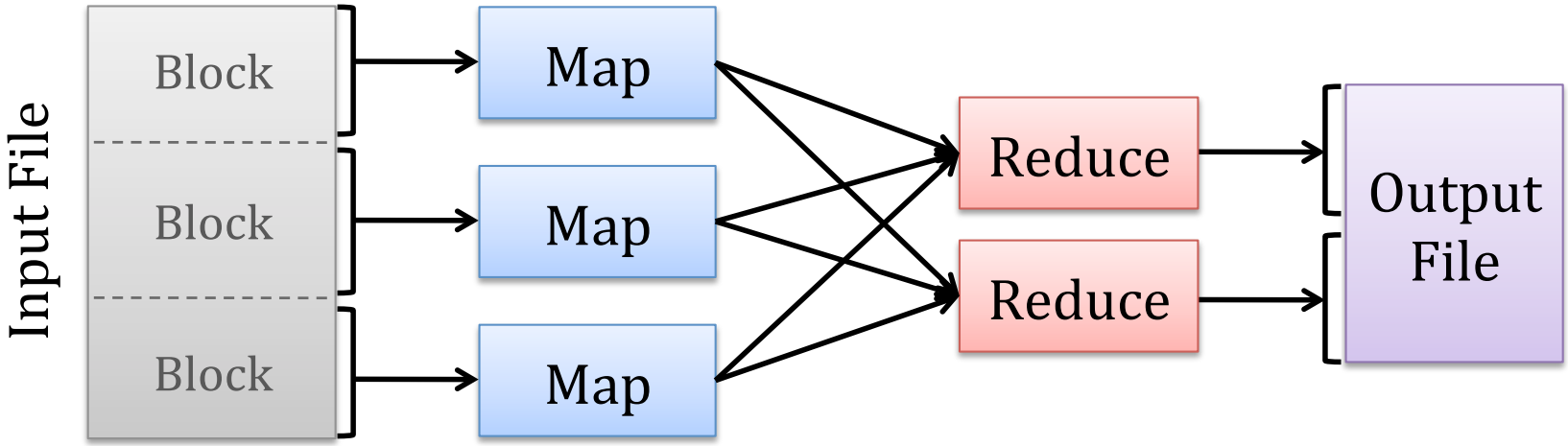
    sort *jobs* according to queuing policy
    for *j* in jobs:
        if *j* has node-local task *t* on *n*:
            j.level := 0; *j.wait* := 0; **return** *t*
        else if *j* has rack-local task *t* on *n* and (*j.level* ≥ 1 or *j.wait* ≥ T_1):
            j.level := 1; *j.wait* := 0; **return** *t*
        else if *j.level* = 2 or (*j.level* = 1 and *j.wait* ≥ T_2)
                or (*j.level* = 0 and *j.wait* ≥ $T_1 + T_2$):
            j.level := 2; *j.wait* := 0; **return** *t*
        else:
            j.wait += time since last scheduling decision

Sensitivity Analysis



Hadoop Terminology

- **Job** = entire MapReduce computation; consists of map & reduce *tasks*
- **Task** = unit of work that is part of a job
- **Slot** = location on a slave where a task can run



Analysis

- Required waiting time is a fraction of the average task length as long as there are *many locations where a task can run*
  - Ex: with 3 replicas / block and 8 tasks / node, wait $1/24^{th}$ of average task length

- Non-locality decreases exponentially with waiting time

Analysis

- Suppose we have:
  - M machines
  - L slots/machine
  - T second average task length
  - Job with data on fraction *f* of nodes

- Let D = max # of scheduling opportunities skipped

- P(non-local) = $(1-f)^D$ ← Decreases exponentially with D

- waiting time = D * T/(ML) ← Fraction of mean task length
  Decreases with # slots/node

Small Jobs Experiment

- 10-20 min benchmark consisting of several hundred IO-heavy jobs
- Job sizes: 3, 10 and 100 map tasks
- Environment: 100-node cluster on 4 racks; 5 map slots per node

Job Size	Default Scheduler		With Delay Sched.	
	Node Loc.	Rack Loc.	Node Loc.	Rack Loc.
3 maps	2%	50%	75%	94%
10 maps	37%	98%	99%	99%
100 maps	84%	99%	94%	99%