Split-level I/O Scheduling

Suli Yang, Tyler Harter, Anand Krishnamurphy,
Salini Kowsalya, Samer Al-Kiswany,
Andrea C. Arpaci-Dusseau, Remzi H. Arpaci-Dusseau

What is Scheduling?

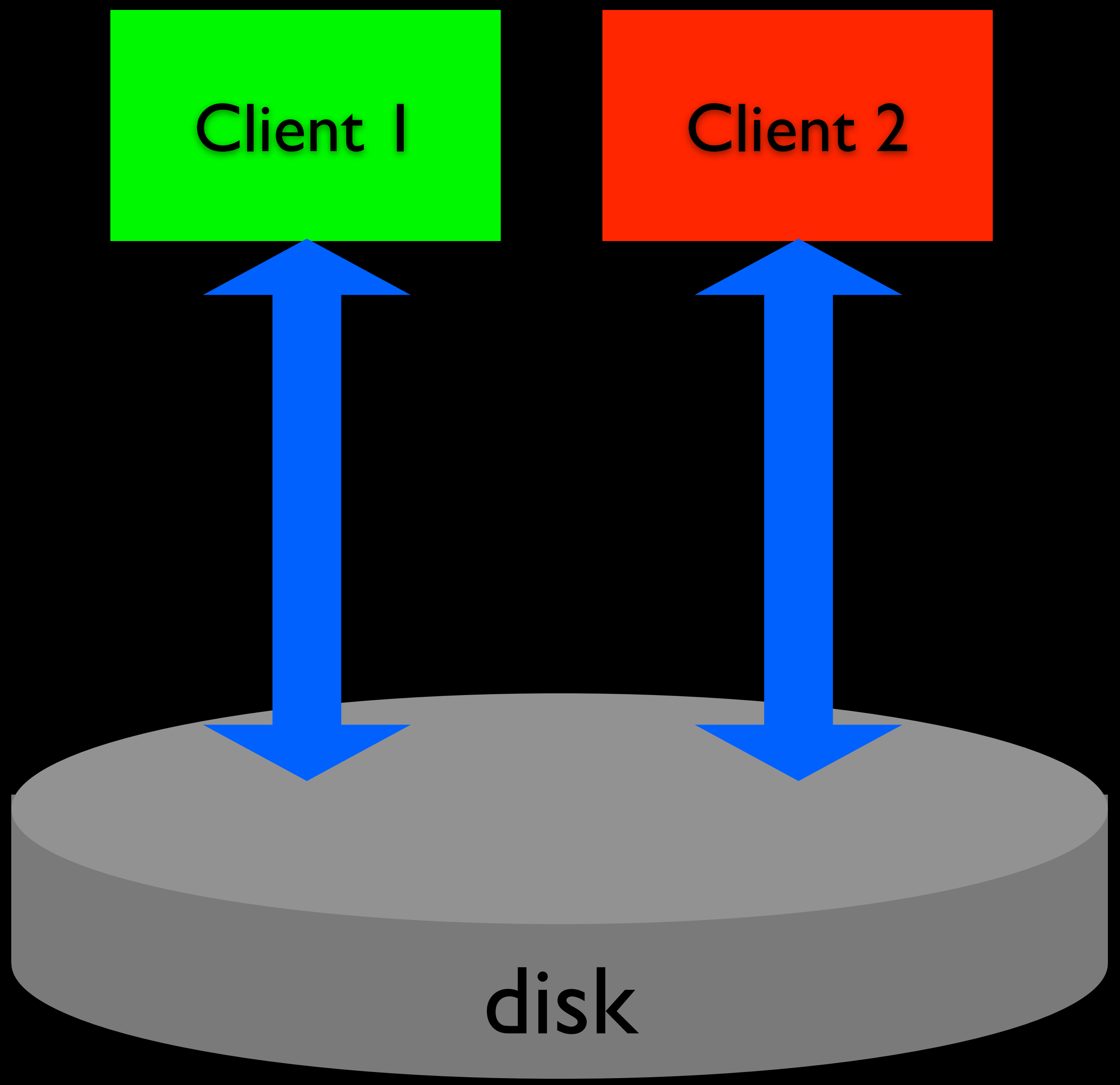
Scheduling Involves:

- Specifying
- Accounting
- Reordering

What is (disk) Scheduling?

Scheduling Involves:

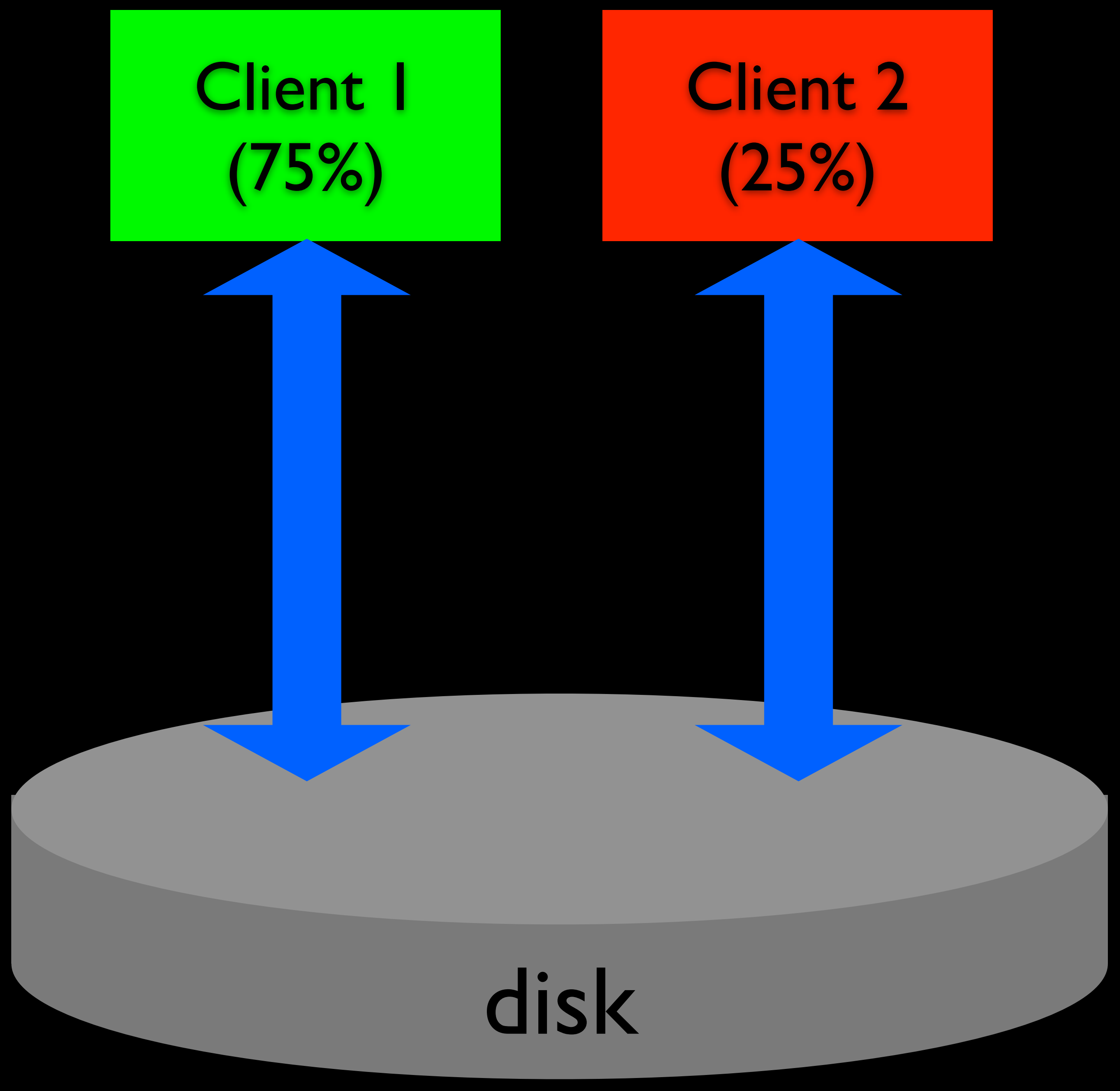
- Specifying
- Accounting
- Reordering



What is (disk) Scheduling?

Scheduling Involves:

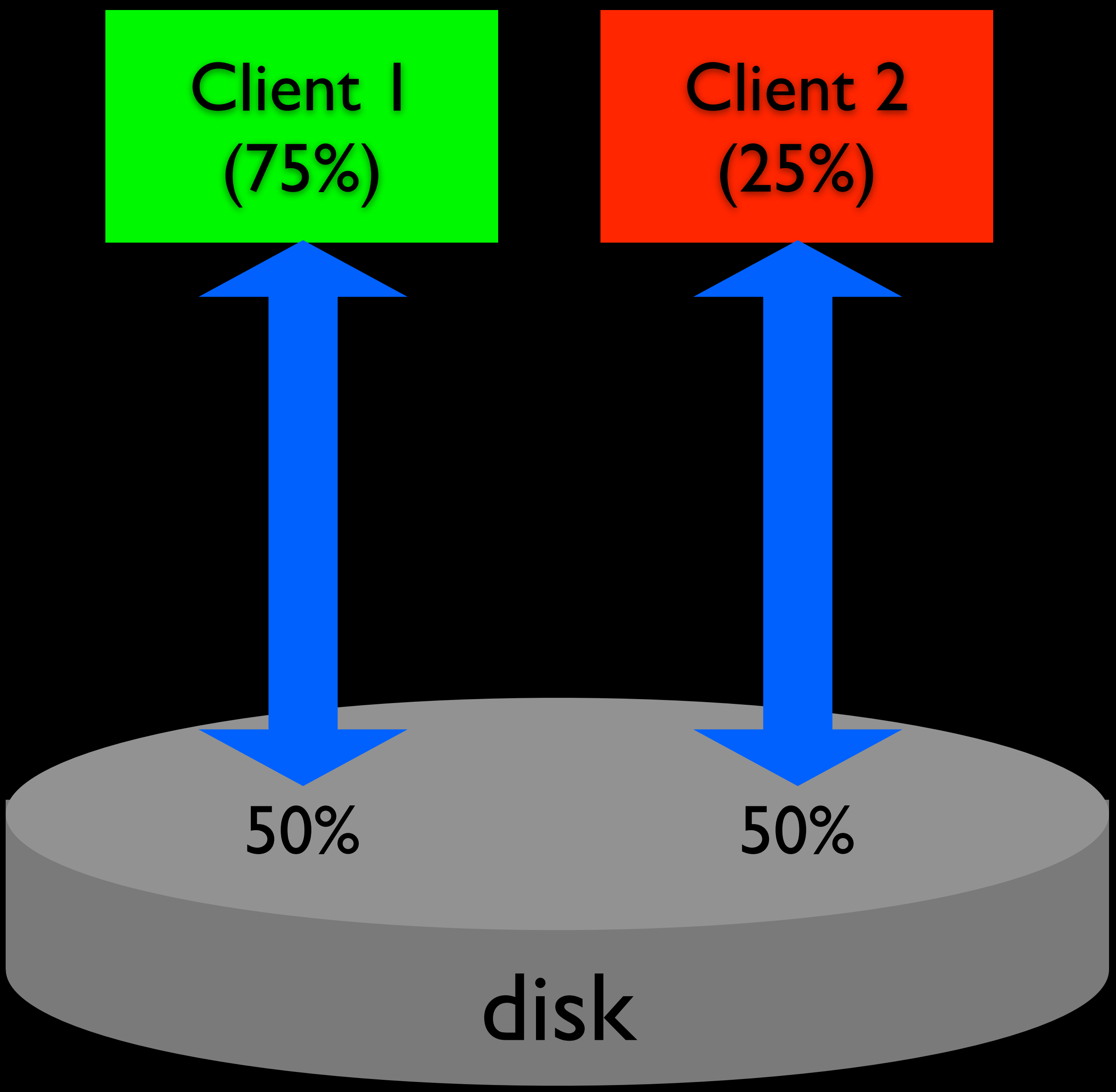
- Specifying
- Accounting
- Reordering



What is (disk) Scheduling?

Scheduling Involves:

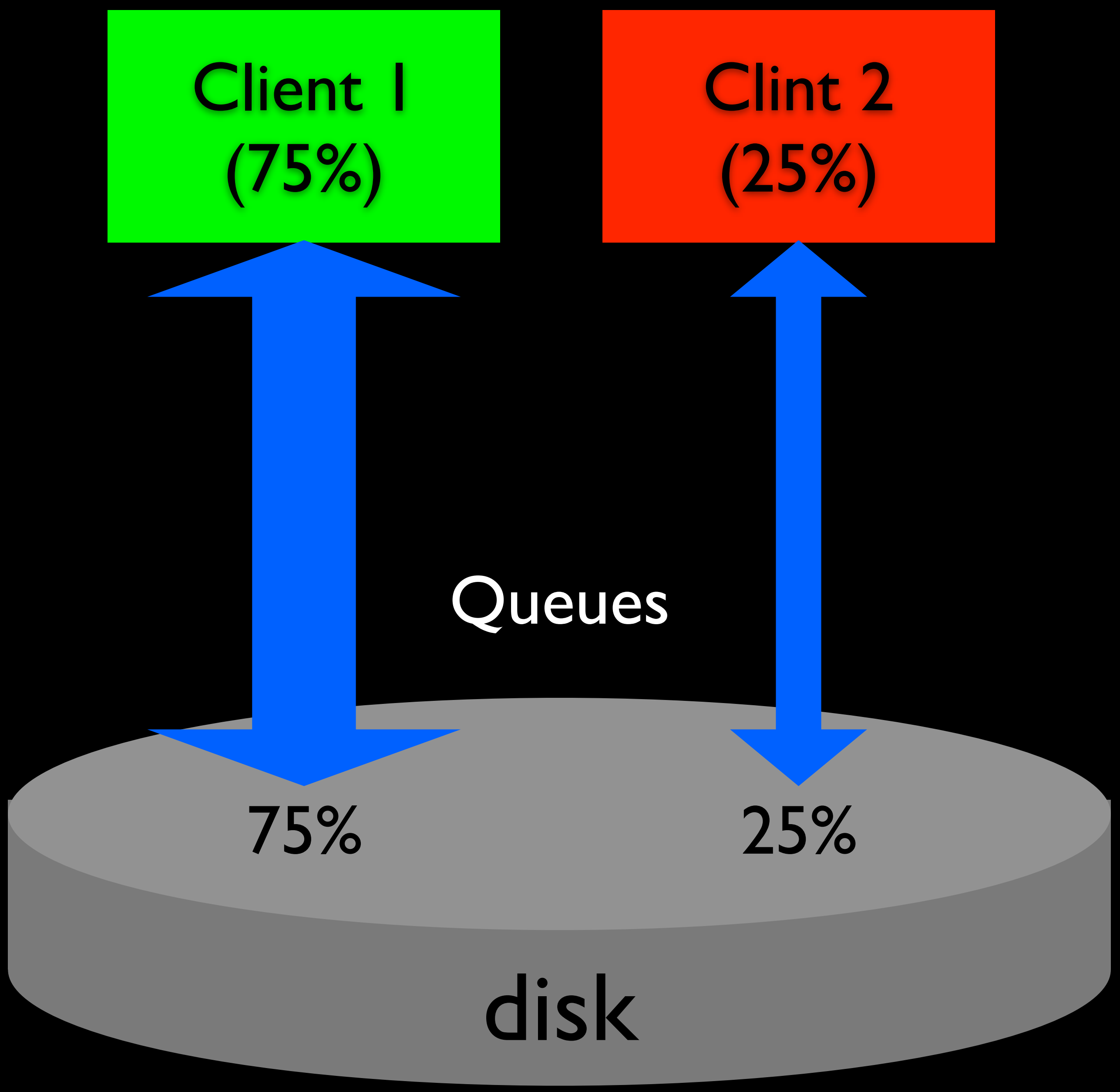
- Specifying
- Accounting
- Reordering



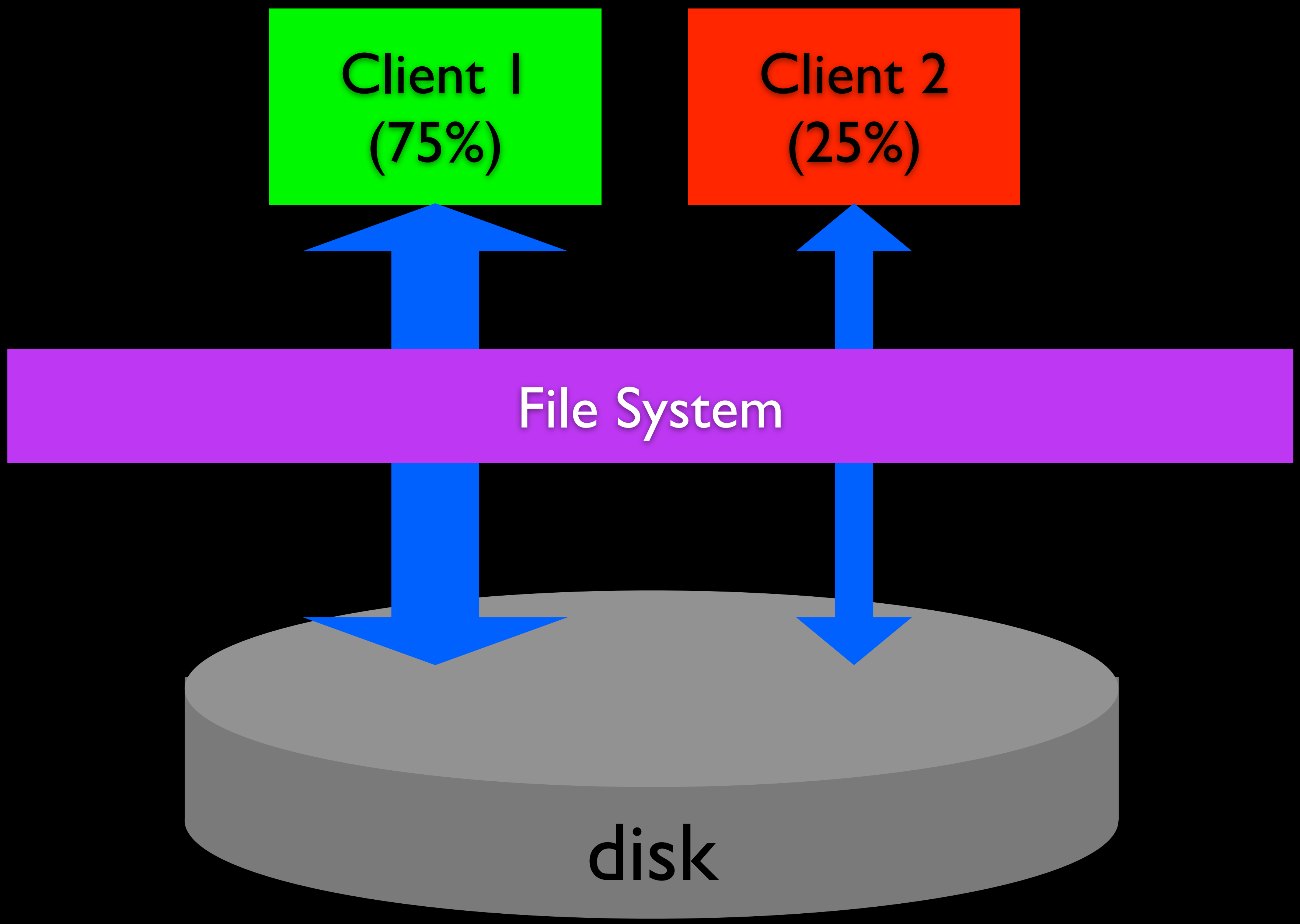
What is (disk) Scheduling?

Scheduling Involves:

- Specifying
- Accounting
- Reordering



Problem Preview: FS



Outline

Intro: disk scheduling basics

CFQ isn't fair!

FS Scheduling Challenges (ext4 case study)

Naive approach (not our idea)

Split-Level Scheduling

Conclusions

CFQ Eval (Linux Default)

"Completely" Fair Queue

Maintains per-task queues

Time-share across queues

Higher priority => bigger time slice

Prios are 0-7, with 0 highest (fastest)

Eval Workloads

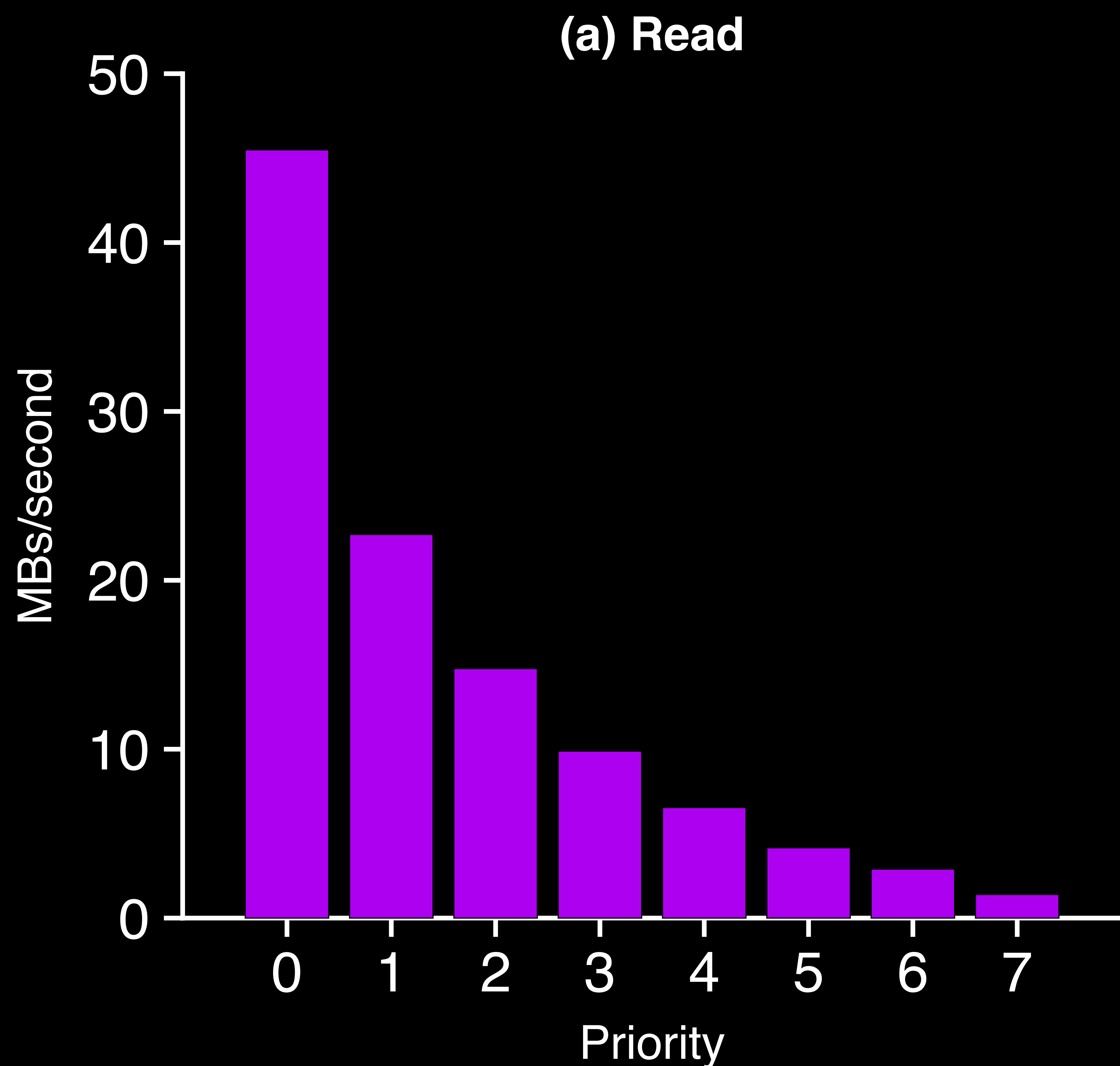
8 tasks, priorities from 0-7

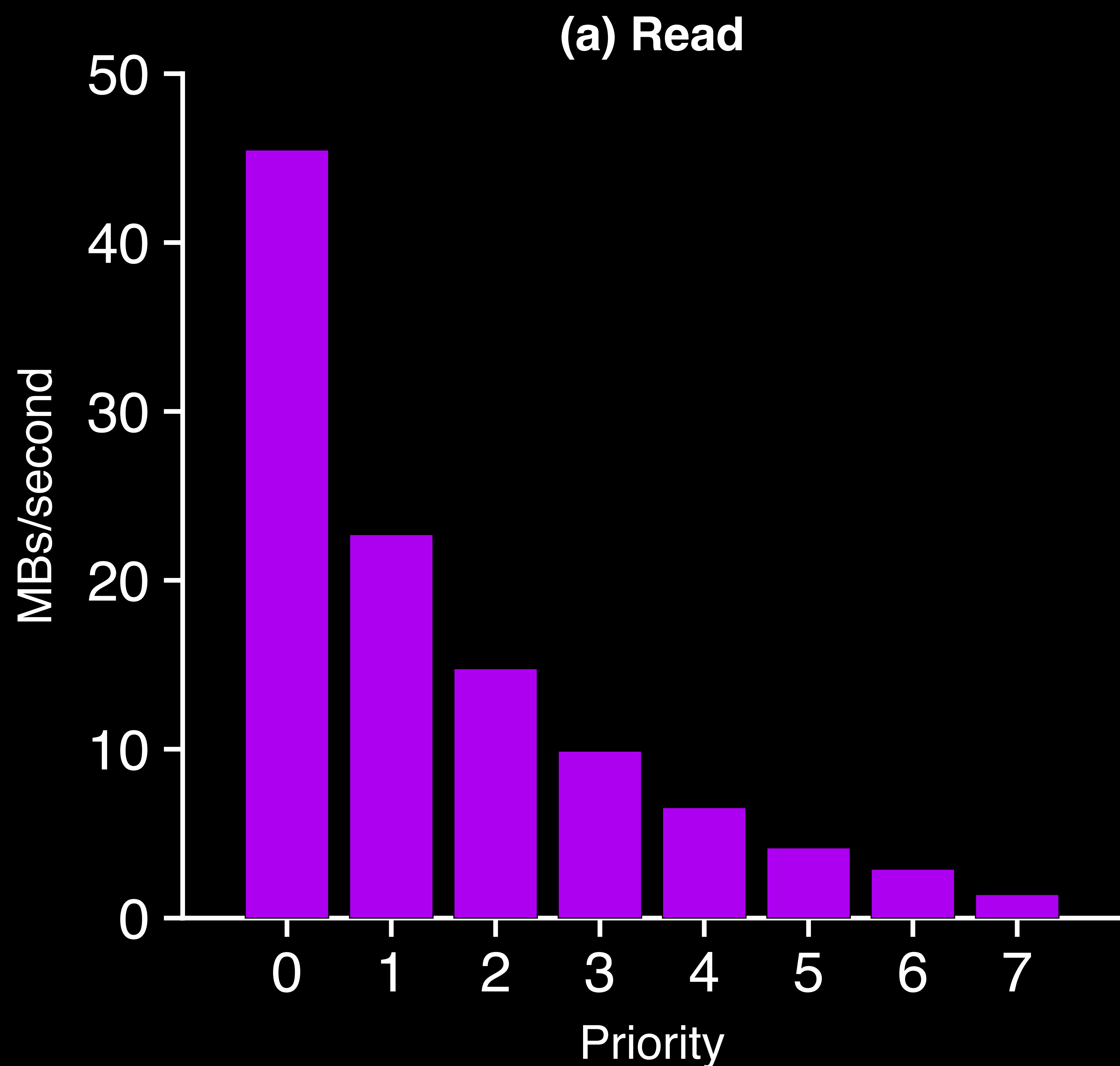
Each task accesses its own file

Sequential I/O only

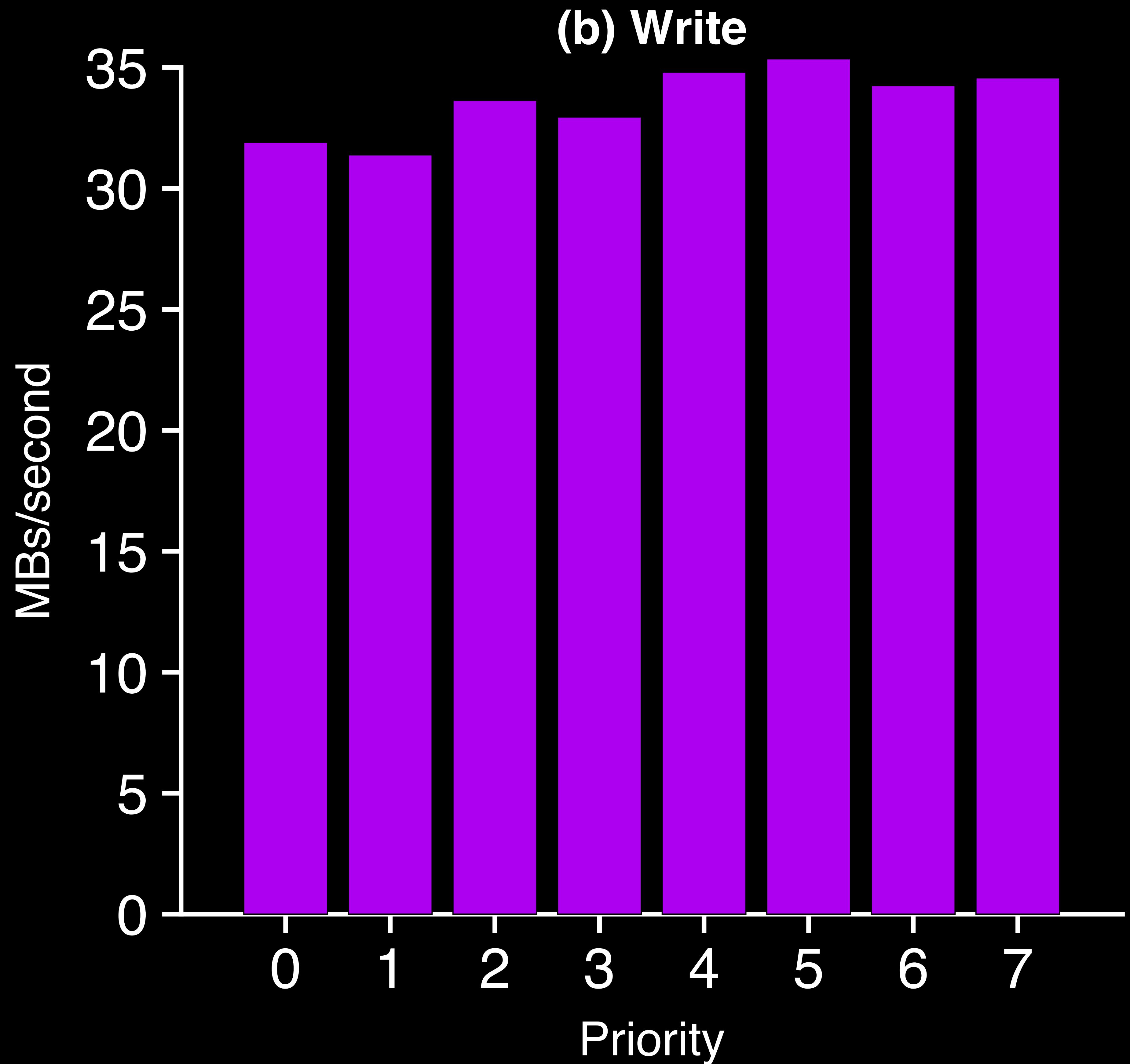
4KB requests

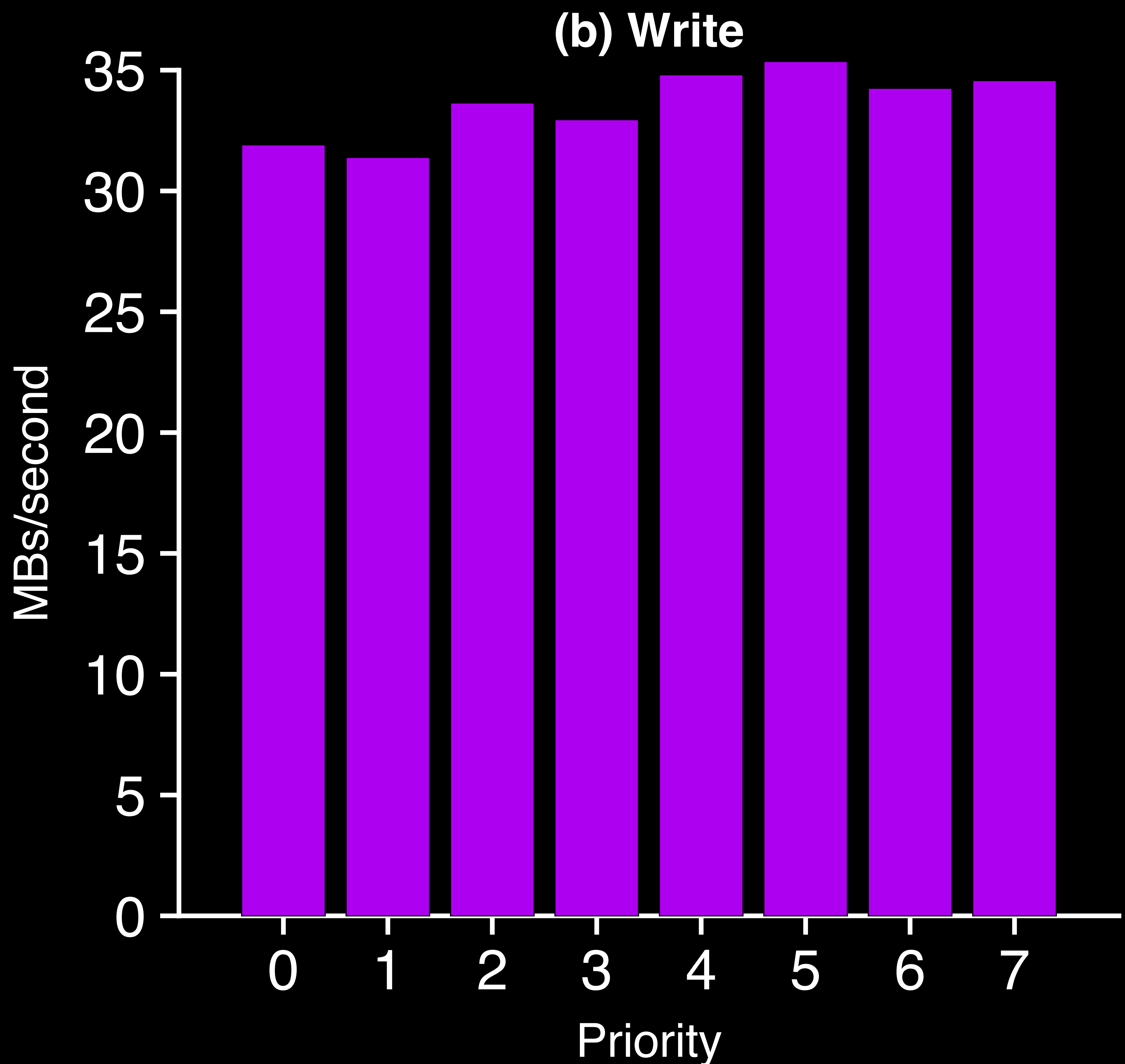
Does CFQ respect priorities
for basic reads and writes?


(a) Read
50
40
30
20
10
0
MBs/second
0
1
2
3
4
5
6
7
Priority

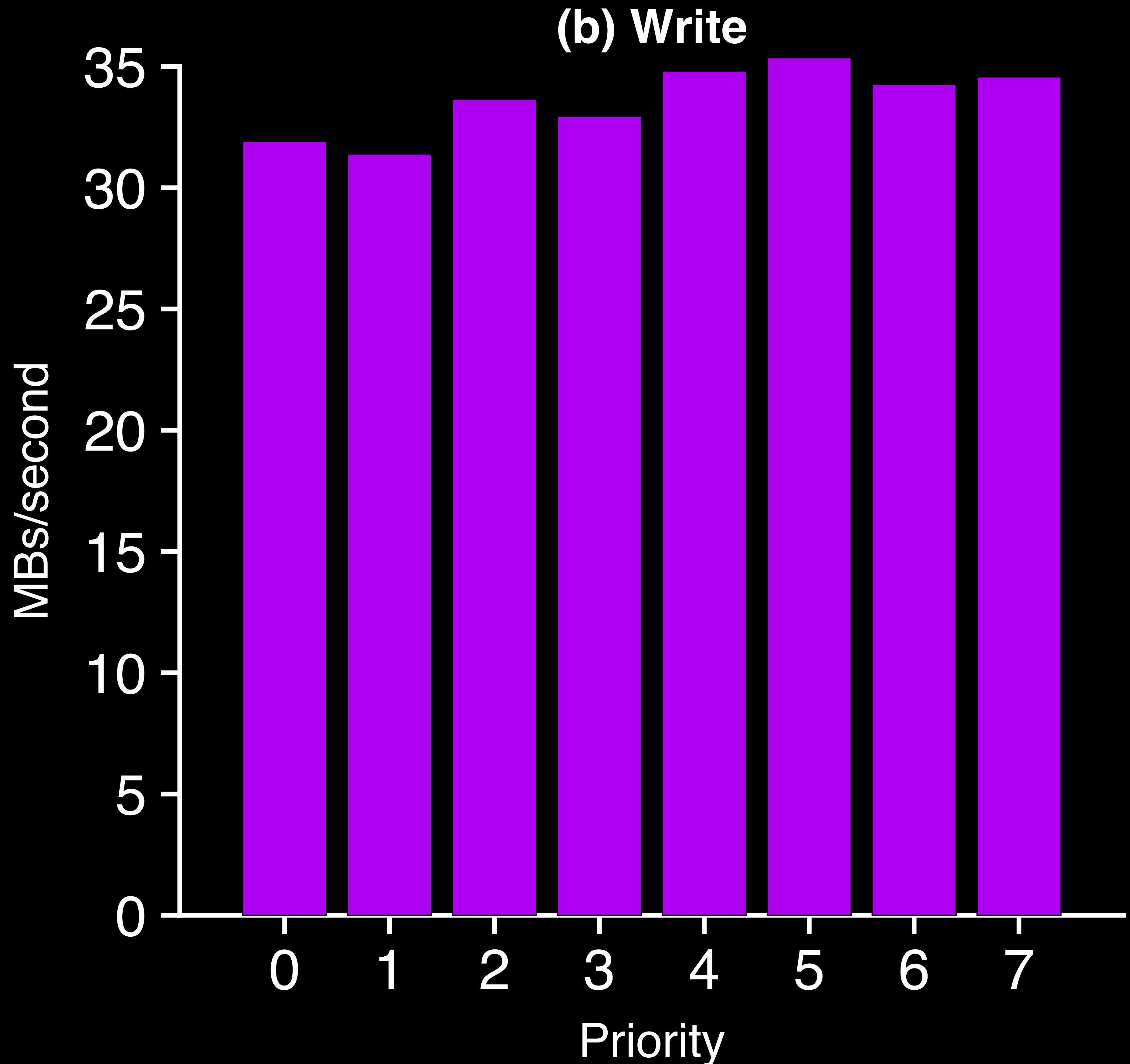


Conclusion: CFQ respects read priorities -- good!


(b) Write
MBs/second
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
Priority



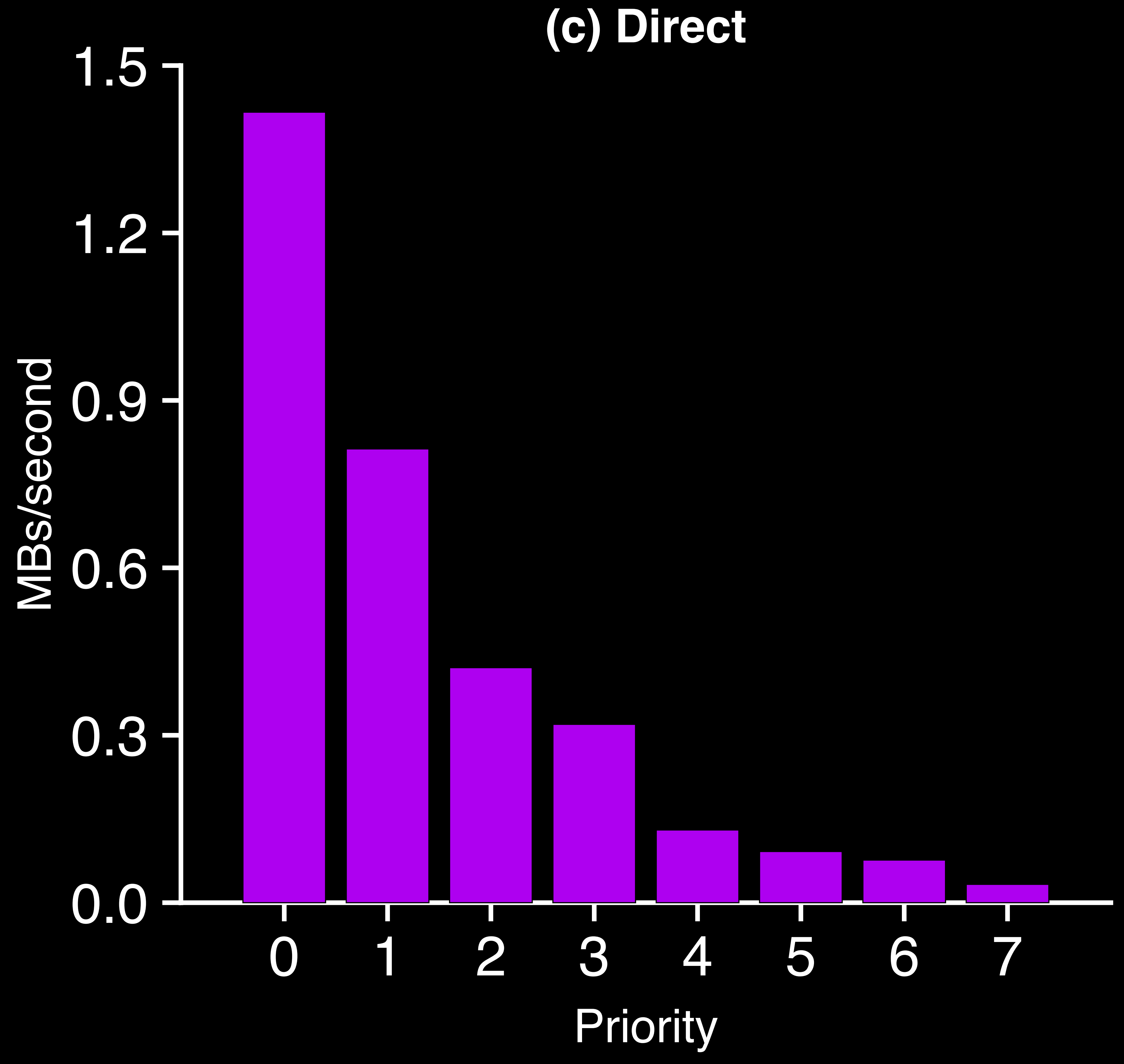
Conclusion: write priorities not respected

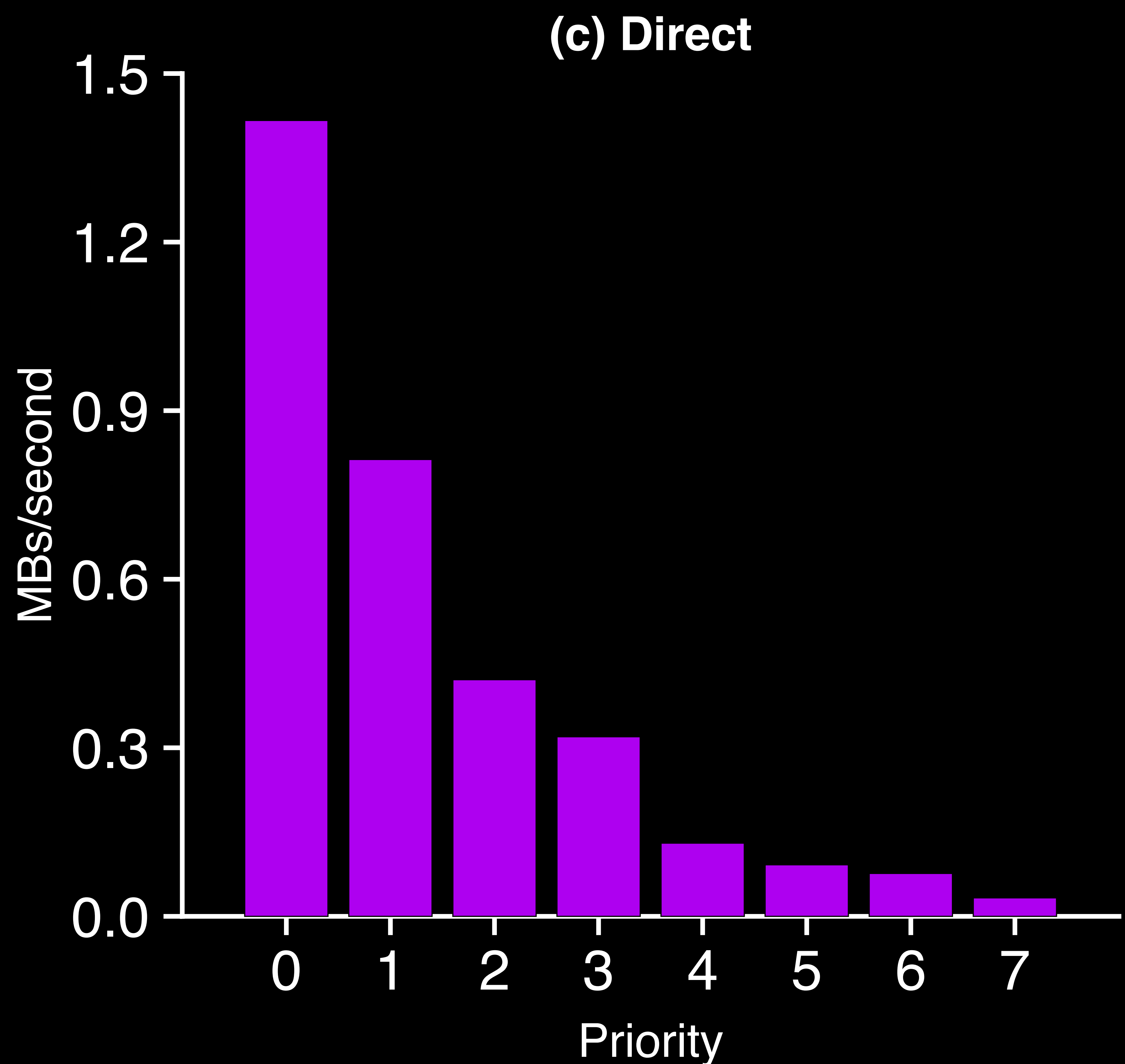


Why? >99% of I/O blamed on writeback task

What if we force each process does its own writing?

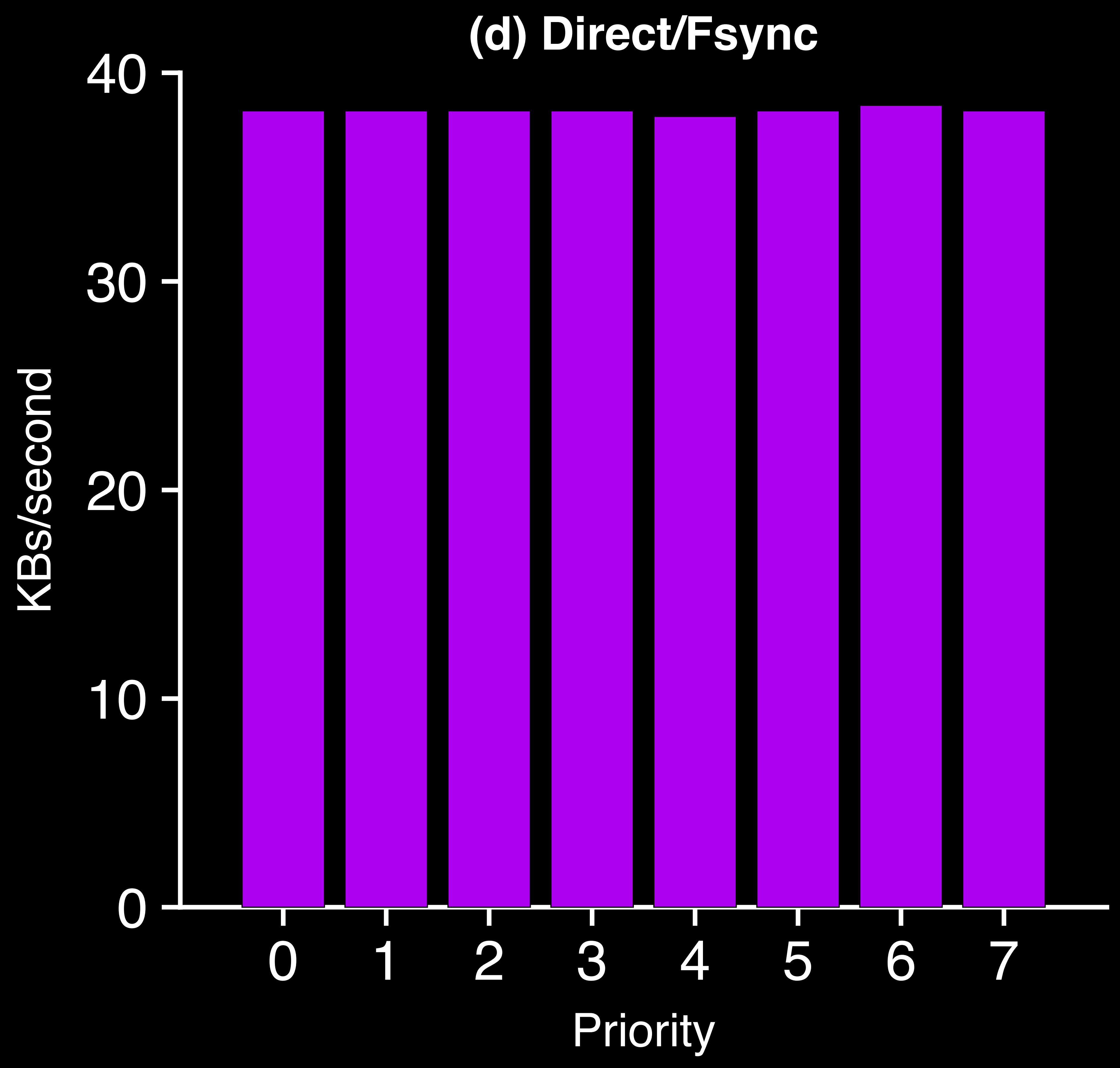
(with `O_DIRECT`)


(c) Direct
1.5
1.2
0.9
0.6
0.3
0.0
MBs/second
0
1
2
3
4
5
6
7
Priority

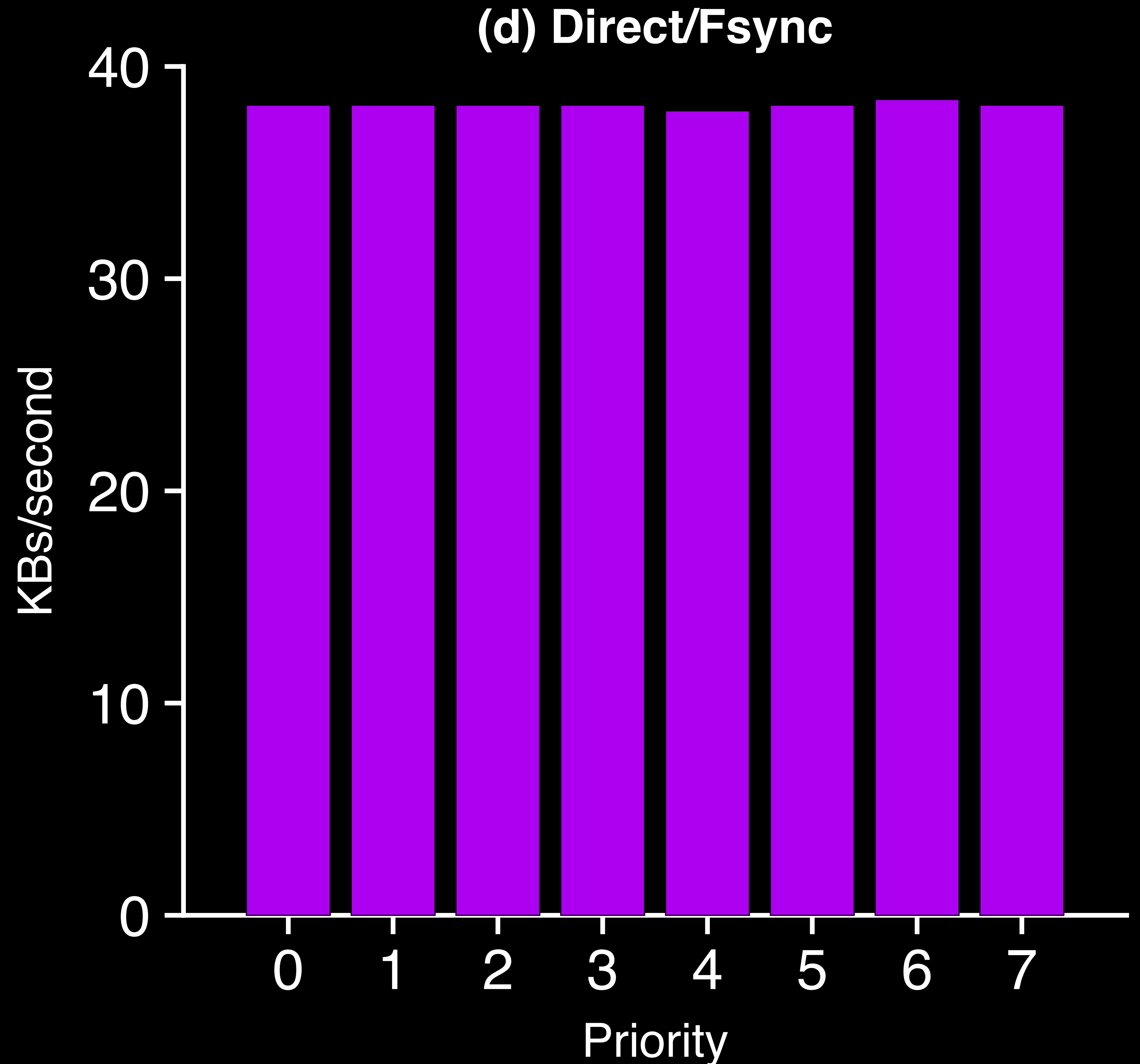


Conclusion: yes, but performance suffers

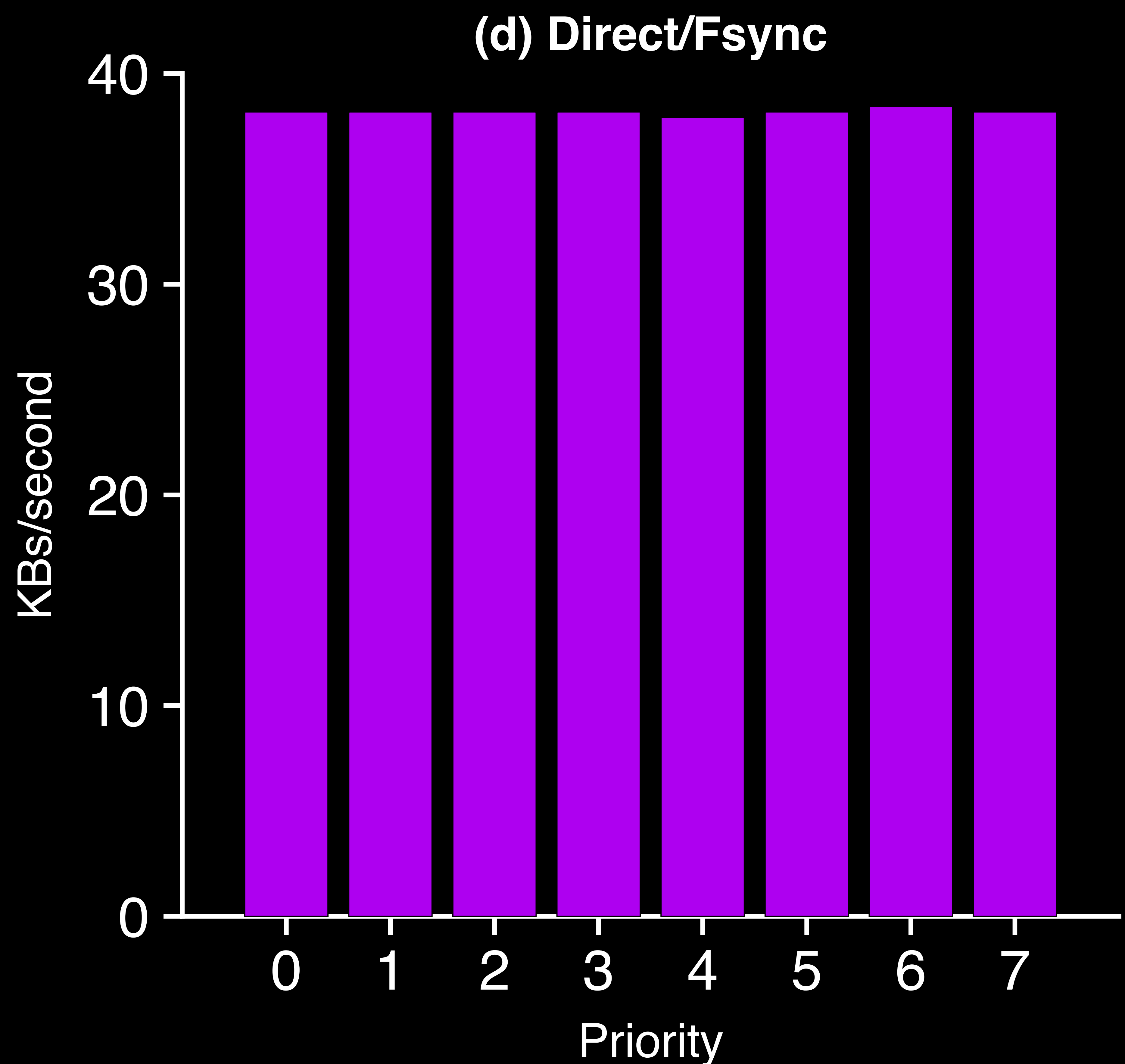
Does `O_DIRECT` trick work if metadata is flushed often?



(d) Direct/Fsync
KBs/second
40
30
20
10
0
0
1
2
3
4
5
6
7
Priority



Conclusion: no, priorities not respected



Why? Fsync enforces global ordering which CFQ cannot help with.

CFQ Eval Conclusion

Rename CFQ => SFQ (sometimes fair queueing)

Is CFQ just a bad implementation?

No, the whole scheduling framework and architecture is bad

FS/block interface gives schedulers little/no *knowledge of* or *control over* FS features important to scheduling

Outline

Intro: disk scheduling basics

CFQ isn't fair!

FS Scheduling Challenges (ext4 case study)

Naive approach (not our idea)

Split-Level Scheduling

Conclusions

What makes CFQ's life hard?

- …Writes!
- Write delegation prevents correct accounting.
- *Ordering requirement* prevents priority-based re-ordering

An ext4 Case Study

Problematic FS Features

	Accounting	Ordering
Journaling		
Shared Metadata		
Write Buffering		
Delayed Allocation		

Problematic FS Features

	Accounting	Ordering
Journaling		
Shared Metadata		
Write Buffering		
Delayed Allocation		

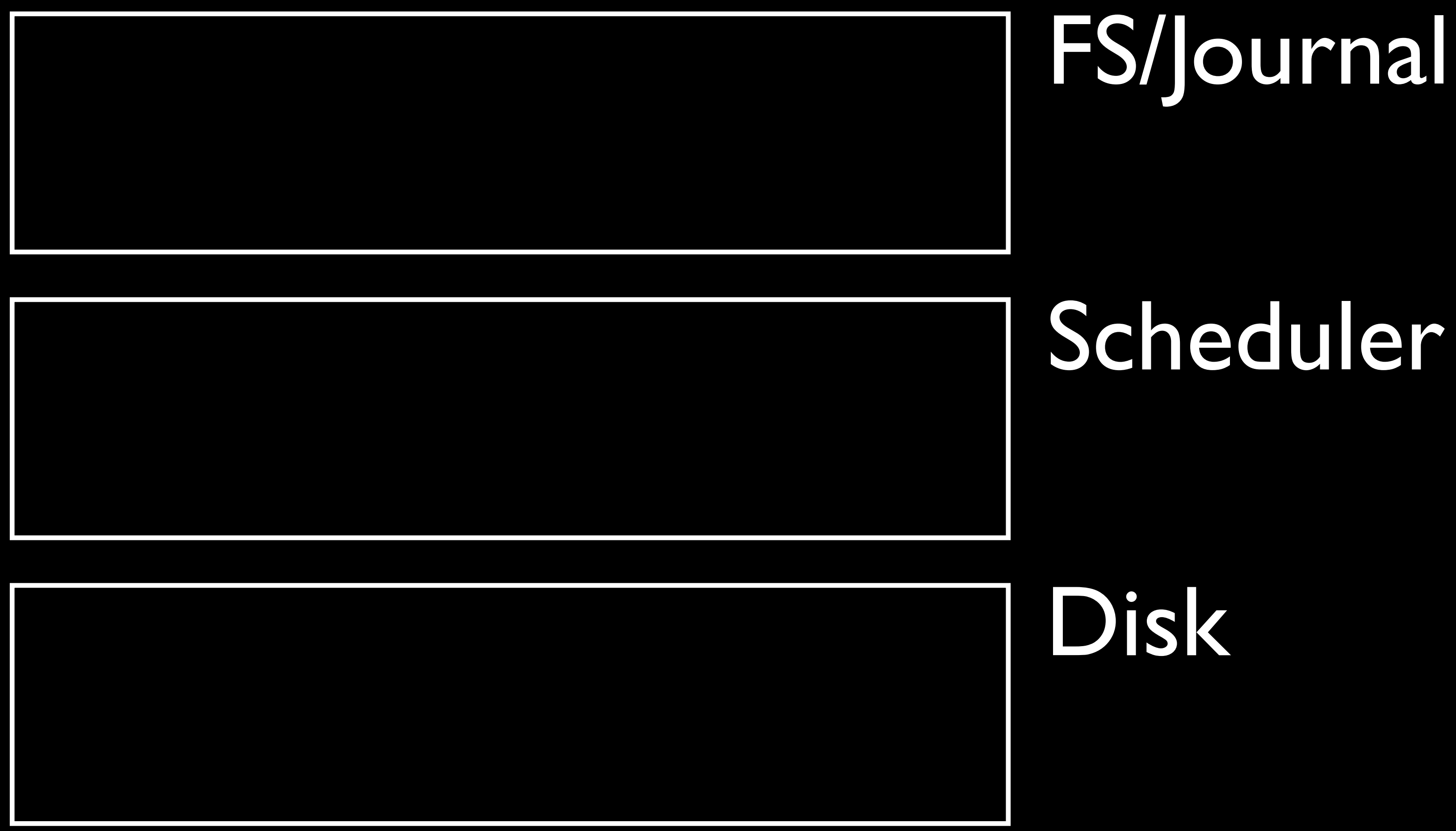
Journal

Conflict of interest!

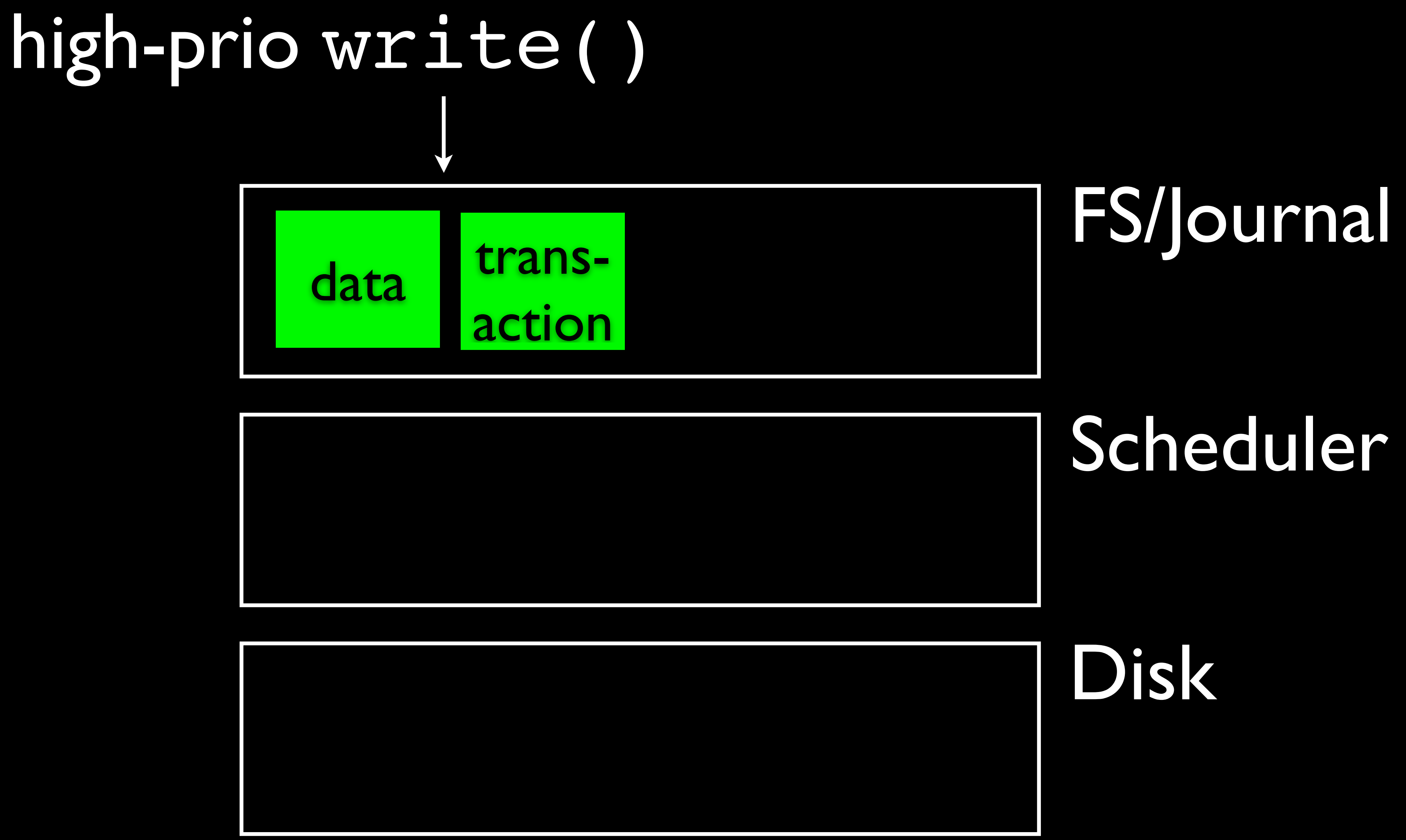
Journal has ordering requirement for *consistency*

Scheduler wants to re-order for *fairness*

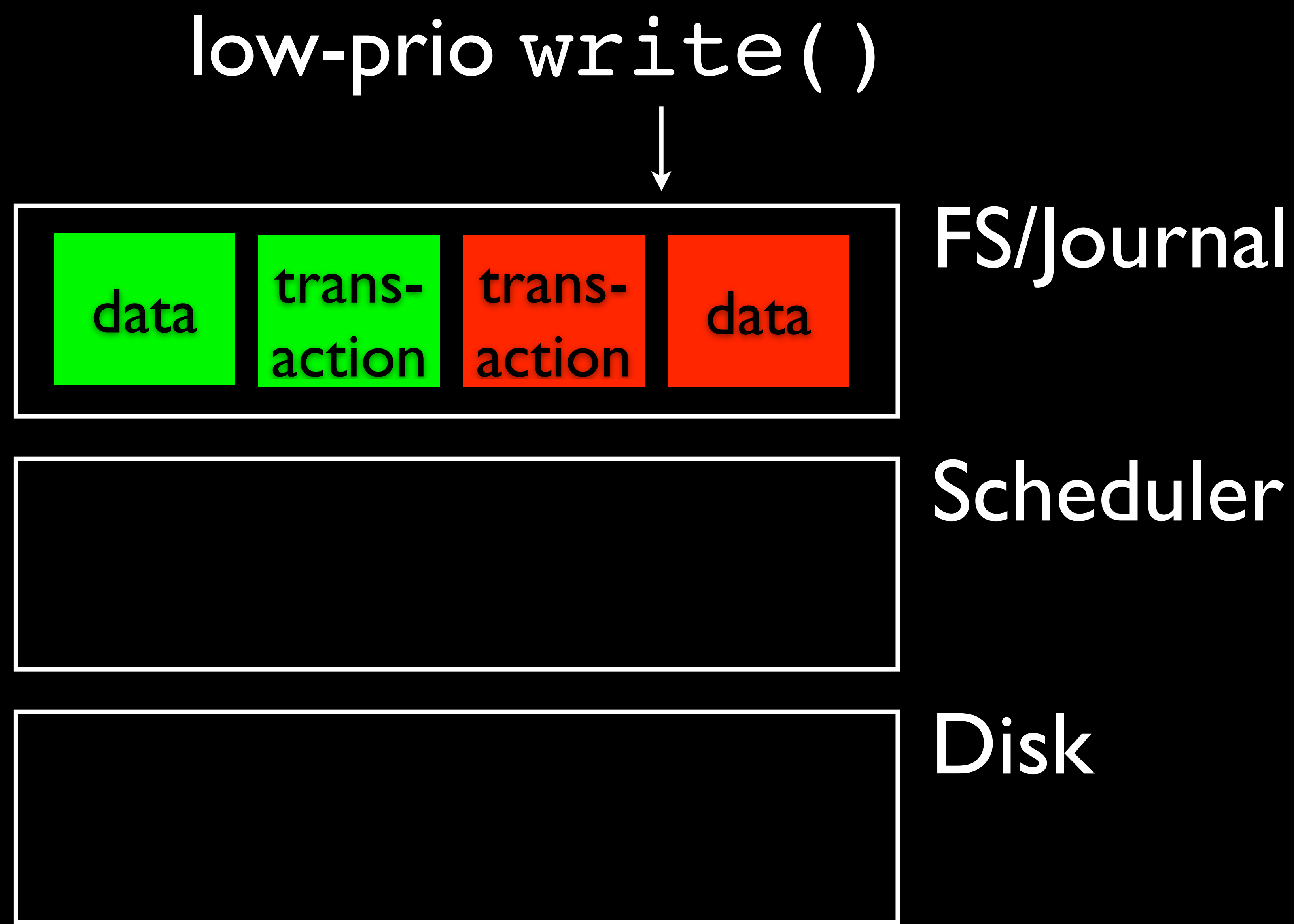
Review (ordered mode)



Review (ordered mode)

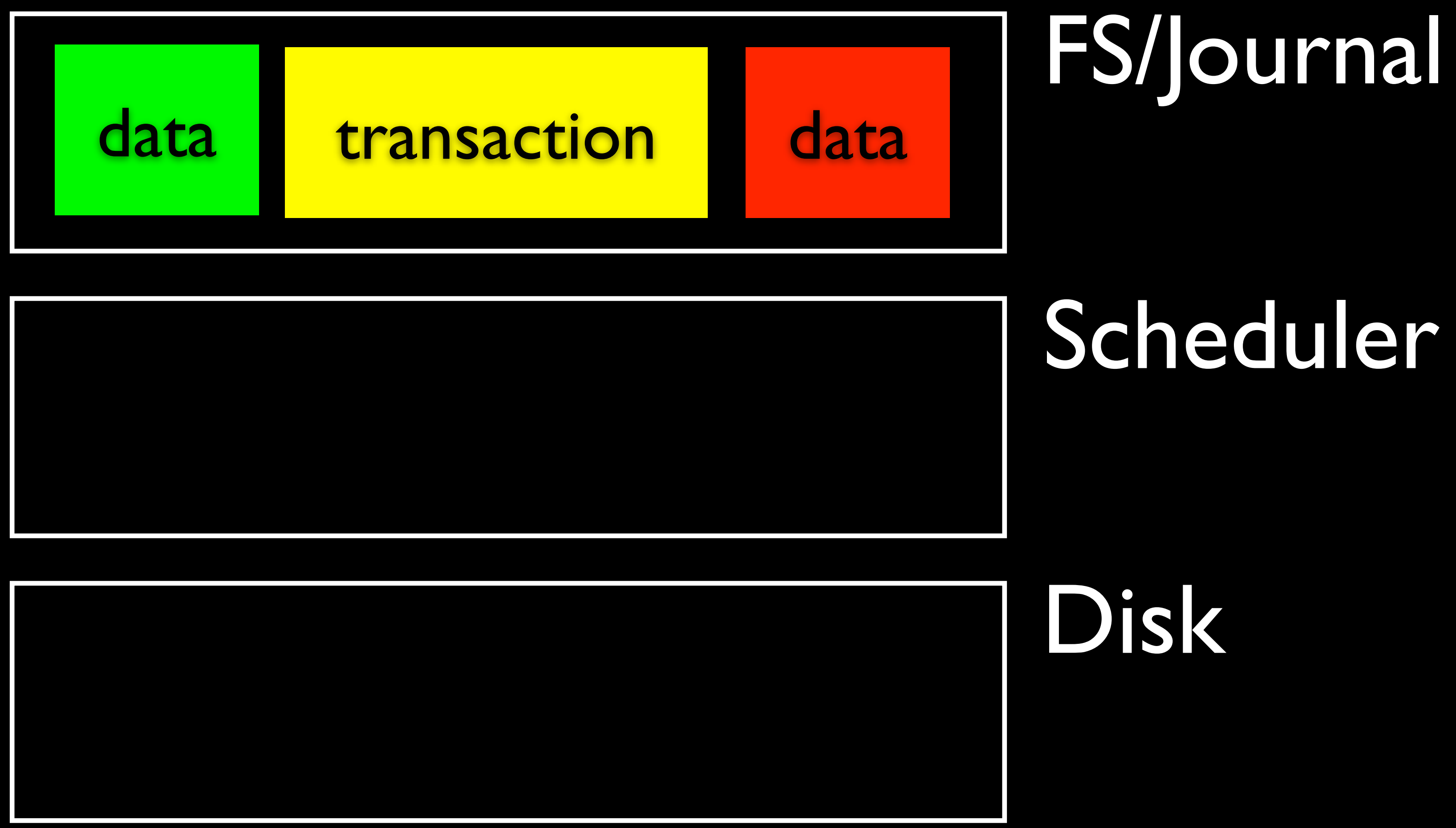


Review (ordered mode)



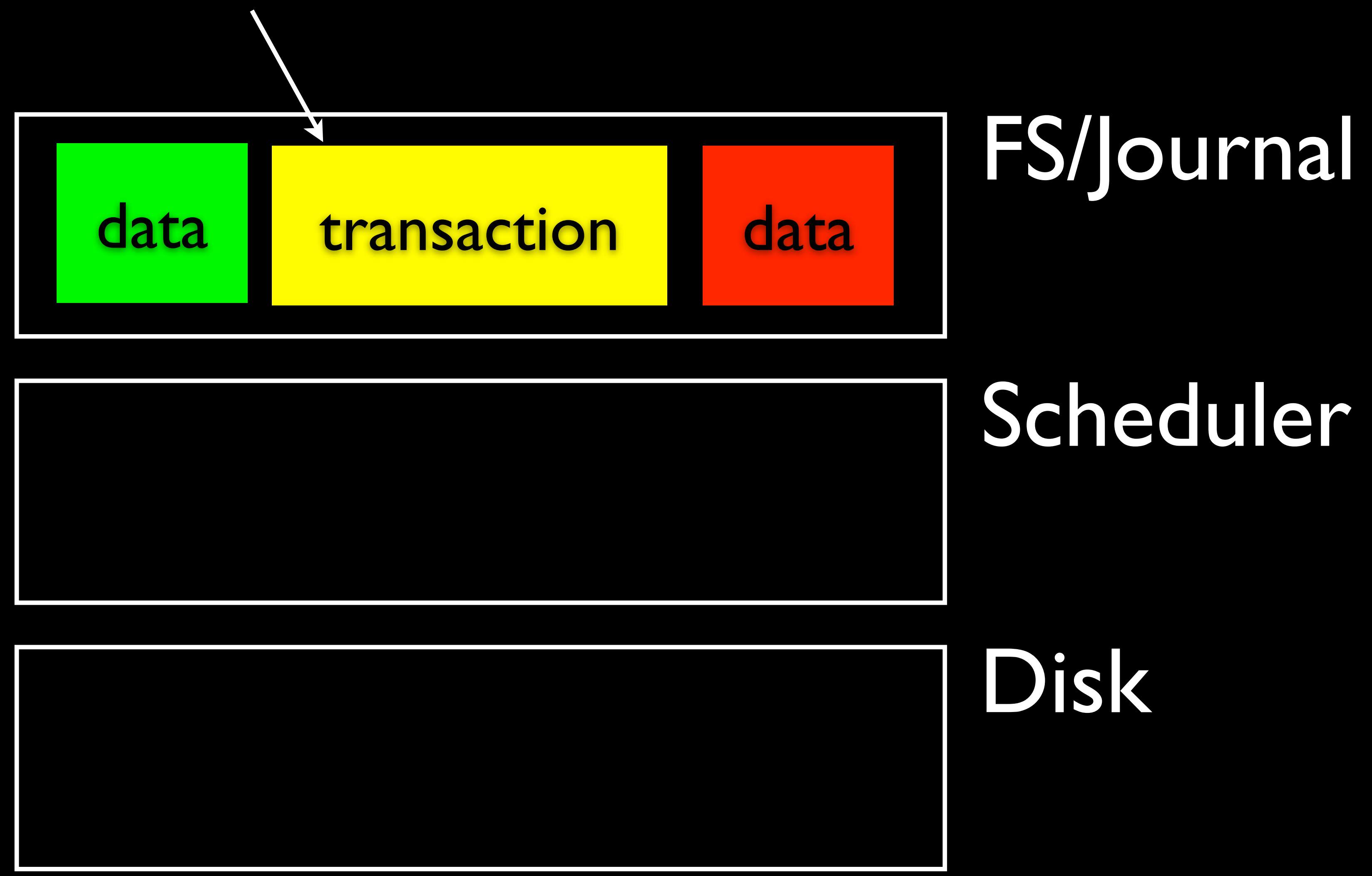
Review (ordered mode)

batching combines two small transactions
into one big one for performance



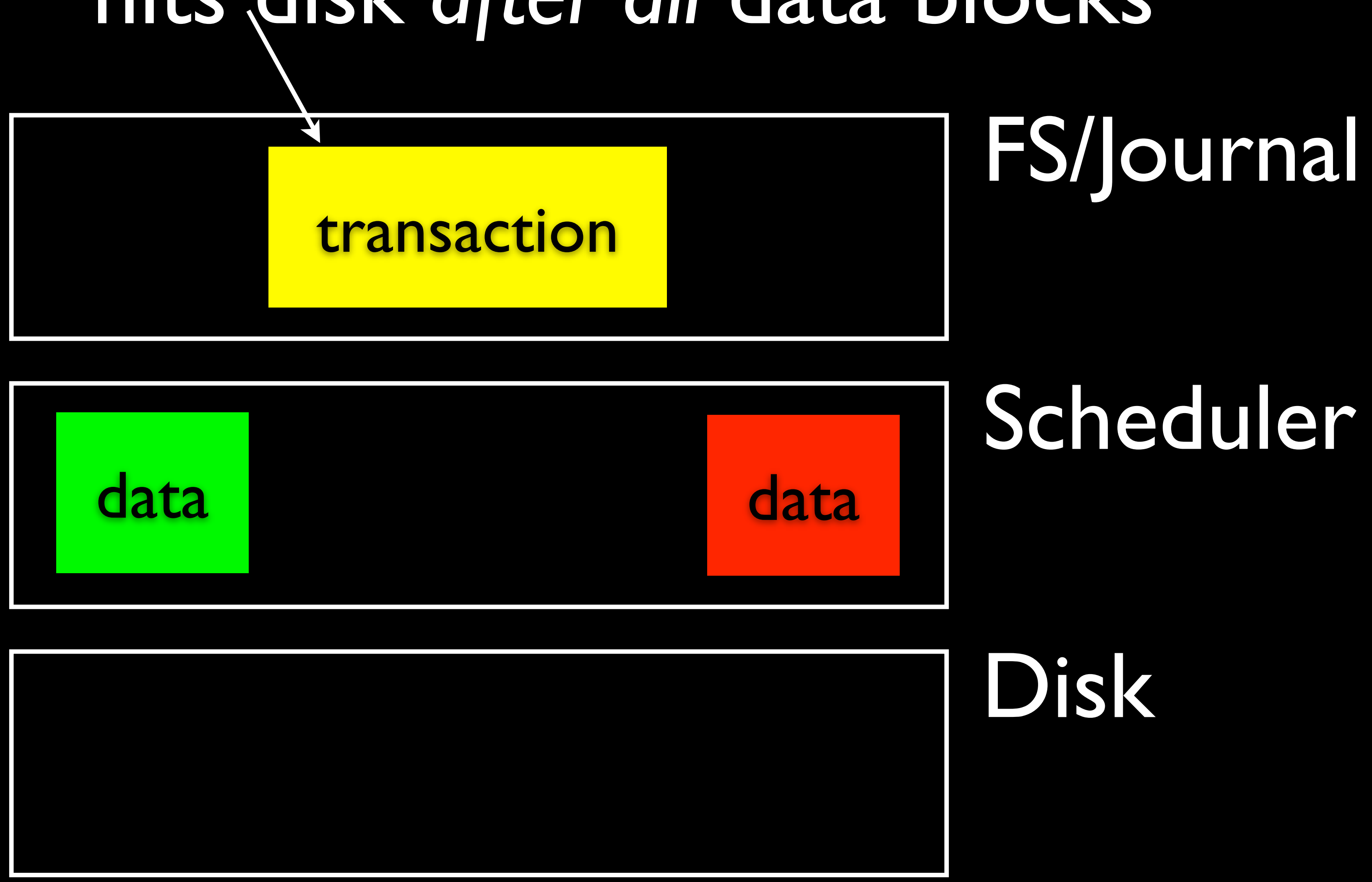
Review (ordered mode)

high-prio `fsync()` blocks til transaction on disk



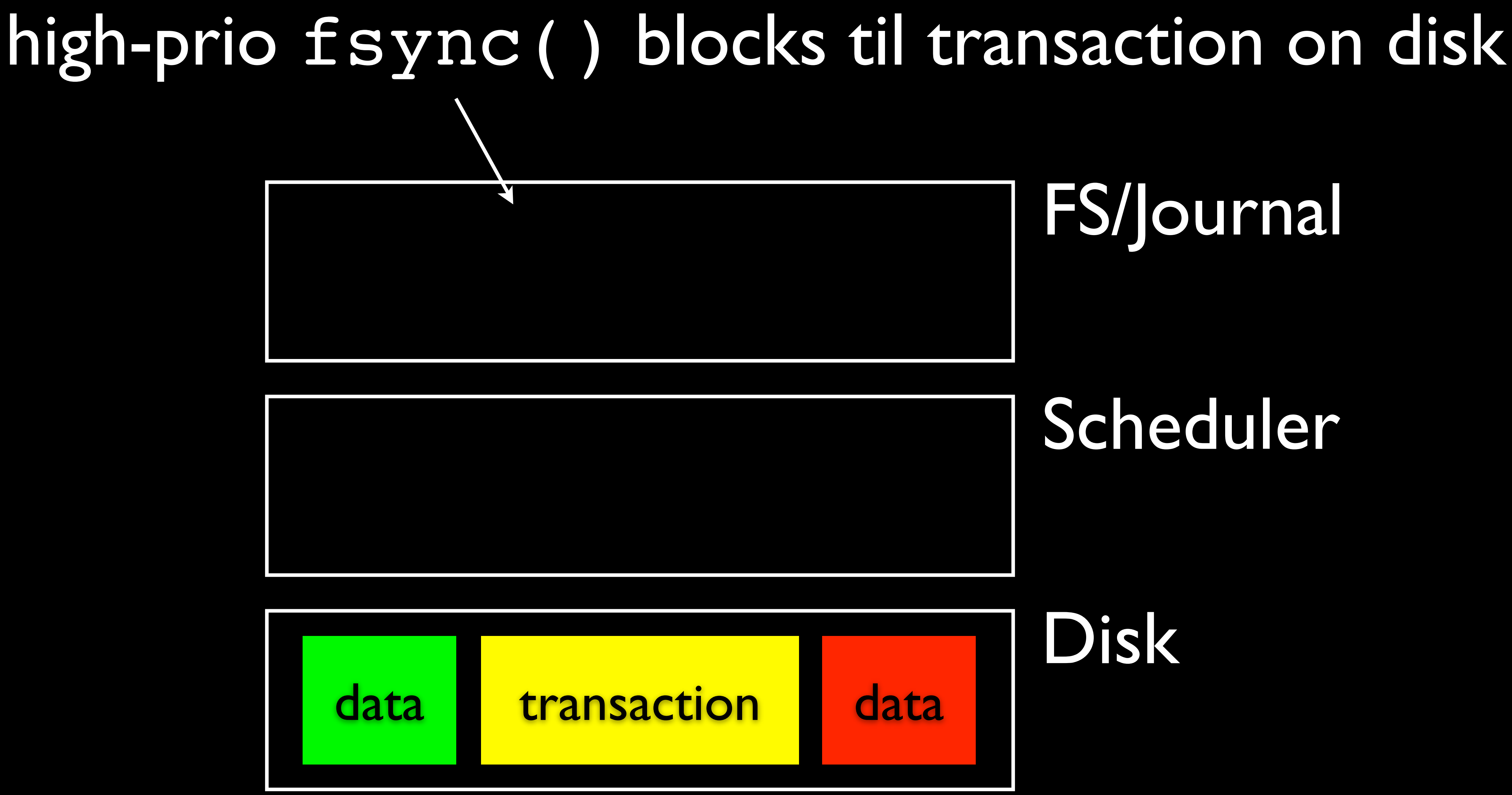
Review (ordered mode)

consistency imposes requirement that transaction hits disk *after all* data blocks



It doesn't matter which block the scheduler flushes first.
Scheduler can't unbatch the transaction to help the fsync().

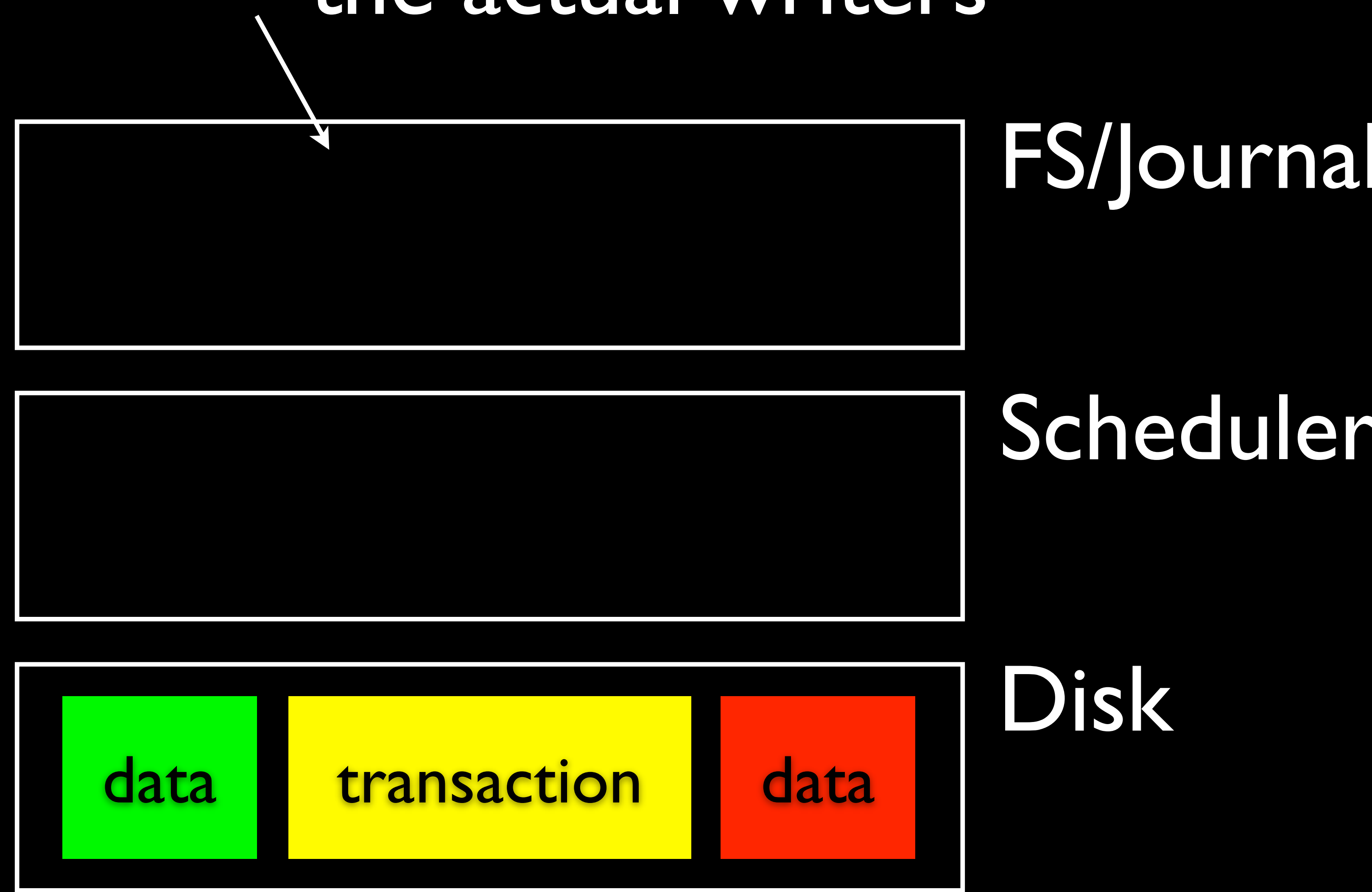
Review (ordered mode)



Priority inversion! High-prio fsync depends on low-prio block

Review (ordered mode)

file system journal writes transaction *on behalf of* the actual writers



Also, who to blame for the transaction write?

Problematic FS Features

	Accounting	Ordering
Journaling	bad	bad
Shared Metadata		
Write Buffering		
Delayed Allocation		

Problematic FS Features

	Accounting	Ordering
Journaling	bad	bad
Shared Metadata		
Write Buffering		
Delayed Allocation		

Problematic FS Features

	Accounting	Ordering
Journaling	bad	bad
Shared Metadata	bad	bad
Write Buffering		
Delayed Allocation		

Problematic FS Features

	Accounting	Ordering
Journaling	bad	bad
Shared Metadata	bad	bad
Write Buffering	bad	neutral
Delayed Allocation		

Problematic FS Features

	Accounting	Ordering
Journaling	bad	bad
Shared Metadata	bad	bad
Write Buffering	bad	neutral
Delayed Allocation	bad	good

Just ext4?

- Almost all file systems use ordering requirements to ensure crash consistency (Soft updates: FFS, Journaling: CFS, Copy-on-Write: ZFS)
- Write delegation everywhere (Write-back built in kernel, delaying work for performance)

Just ext4?

- Write delegation and ordering requirements are *universal* file system properties
- Makes block level write scheduling inherently hard (if not impossible)

Outline

Intro: disk scheduling basics

CFQ isn't fair!

FS Scheduling Challenges (ext4 case study)

Naive approach (not our idea)

Split-Level Scheduling

Conclusions

System Call Scheduling

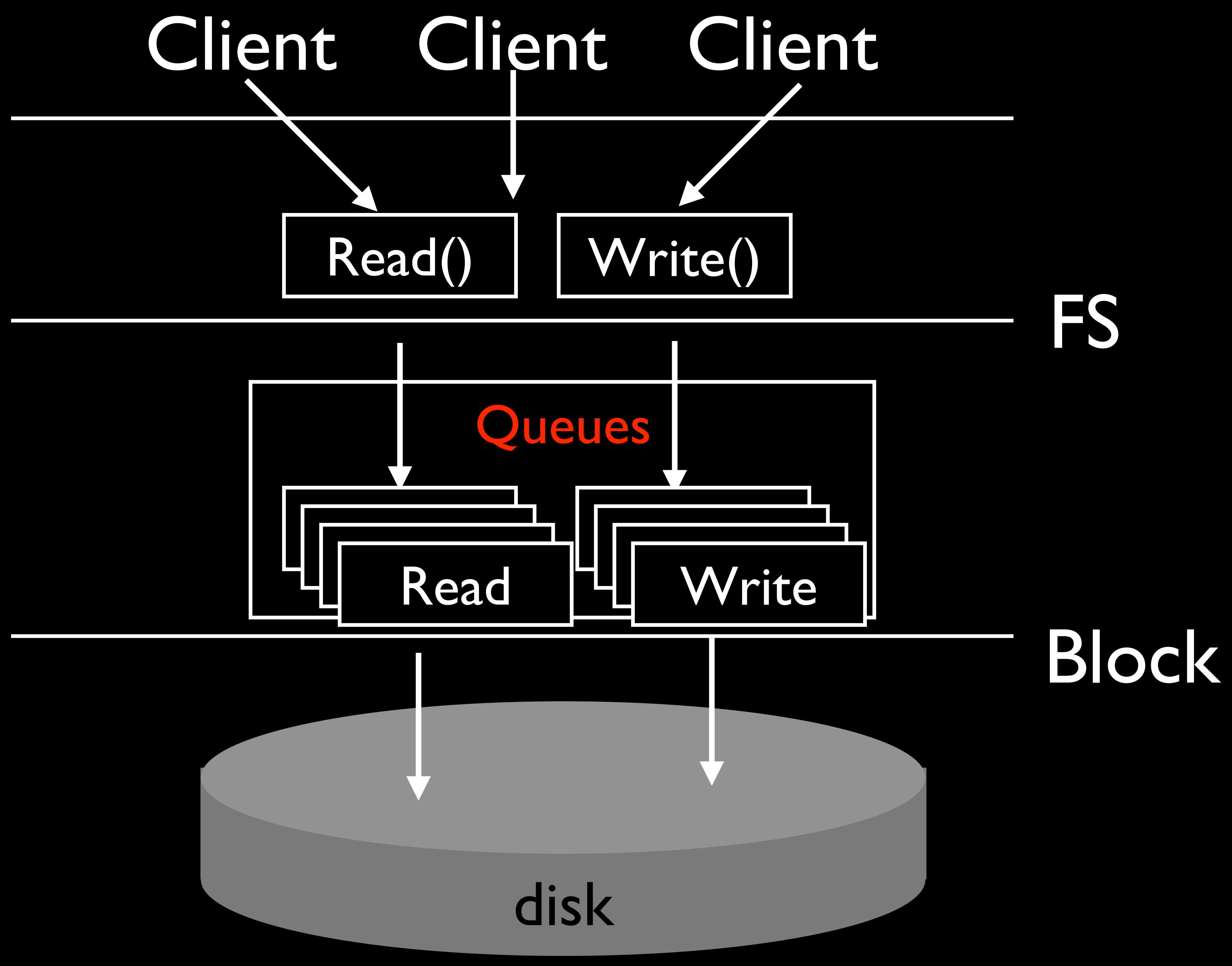
Idea: hold back read and write system calls instead of holding back block I/O

Craciunas etal, SIGOPS OSR '08

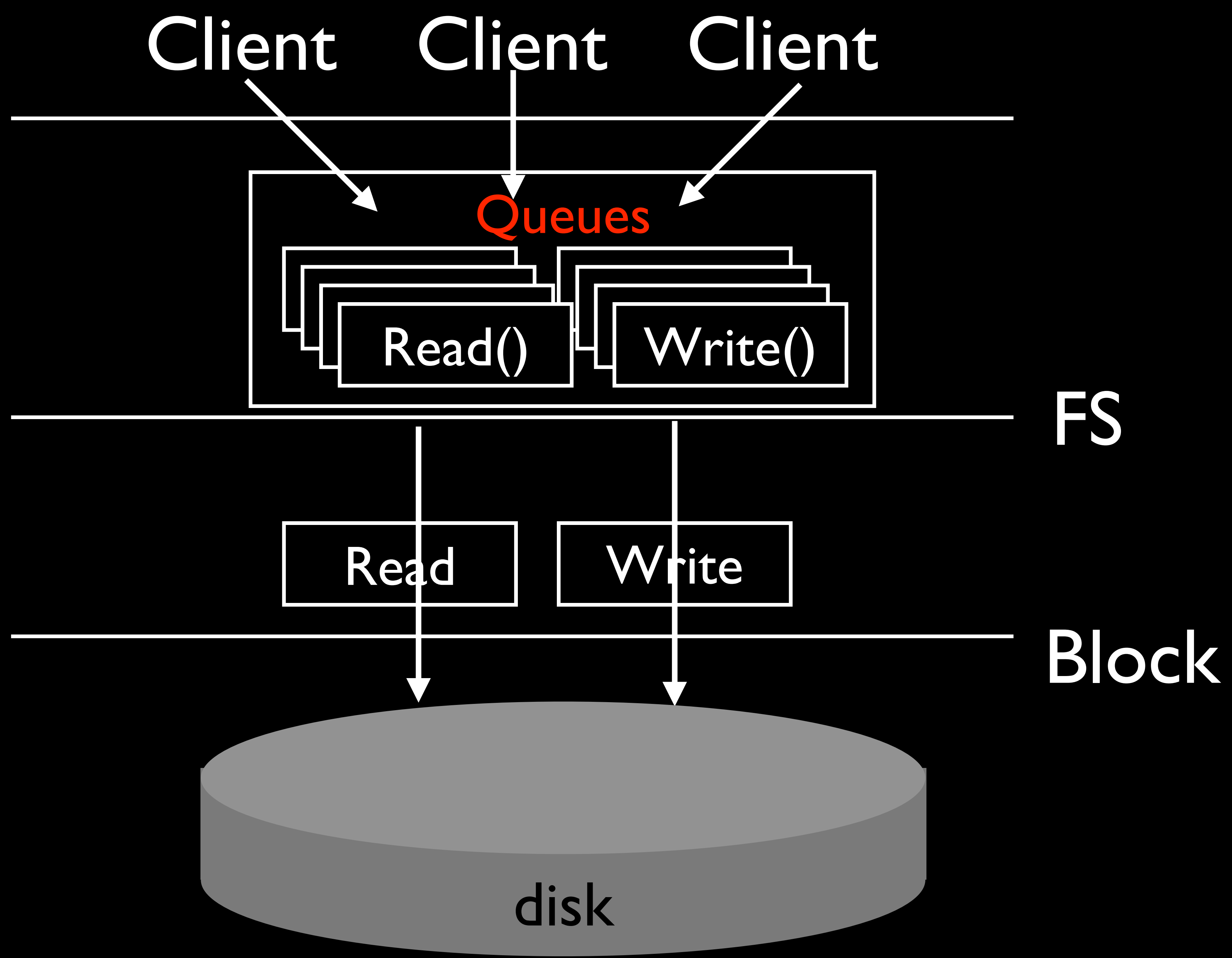
Advantages:

- Simple
- Does scheduling above the messy FS level

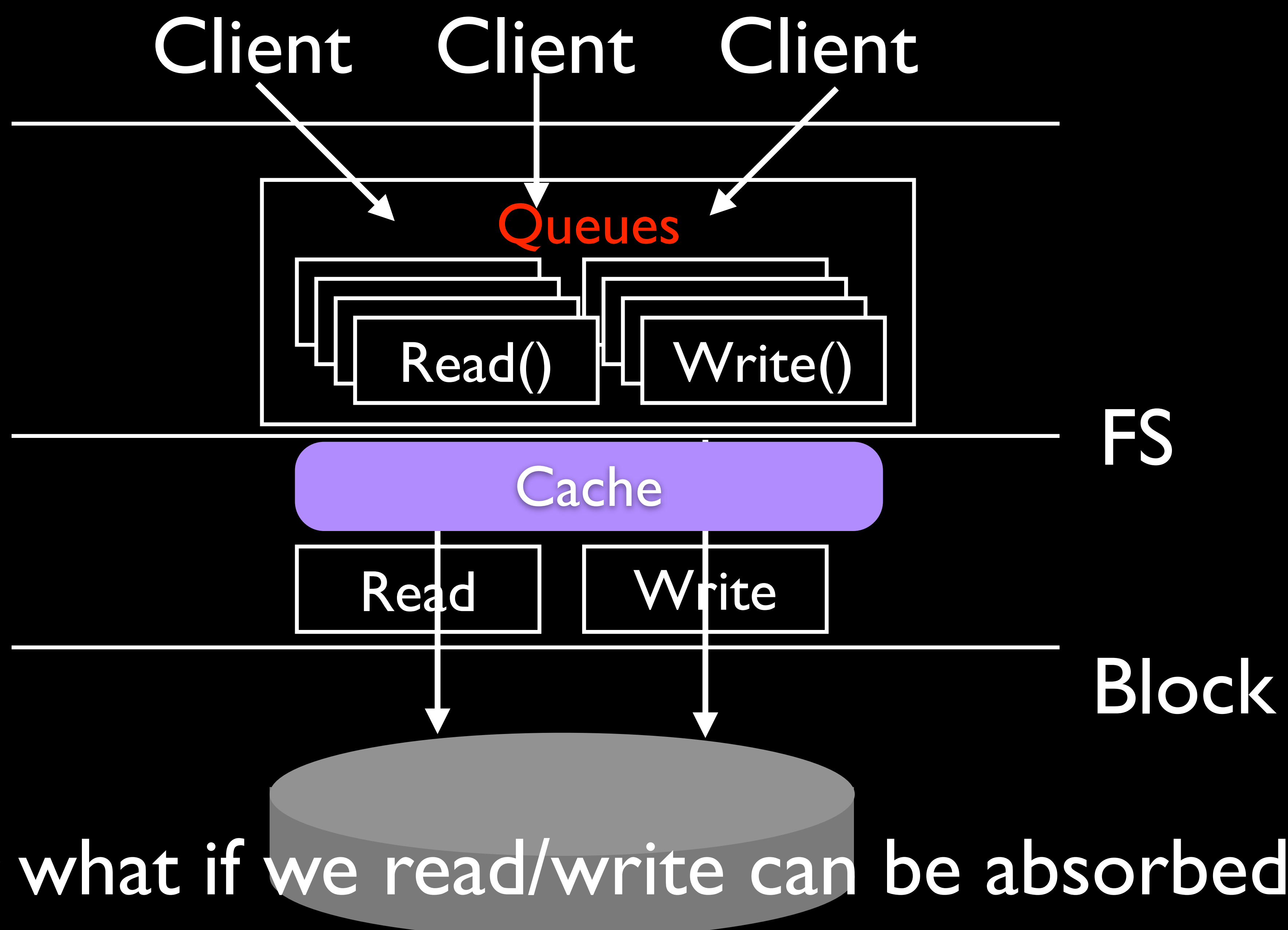
Traditional Scheduling



System Call Scheduling

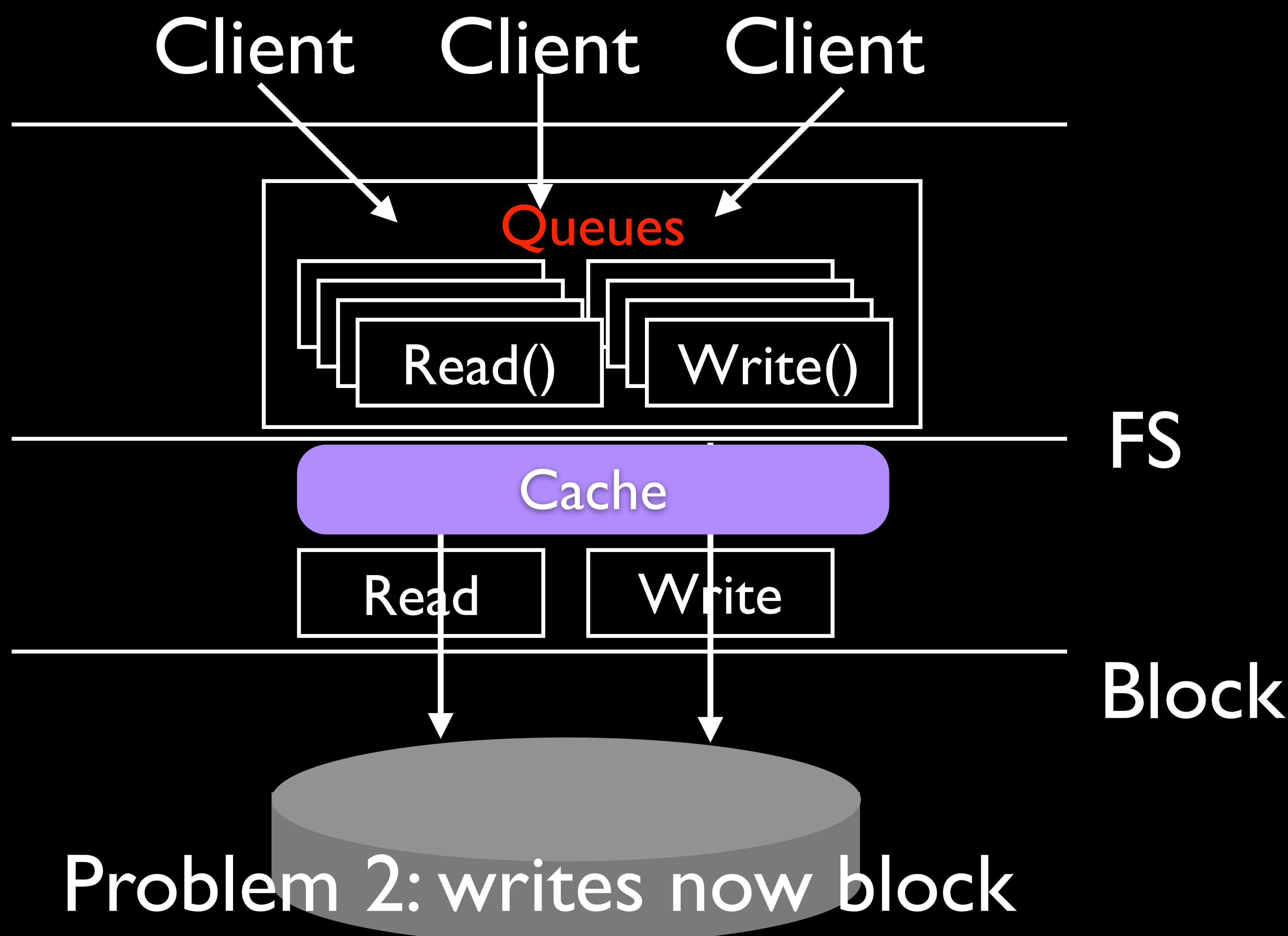


System Call Scheduling



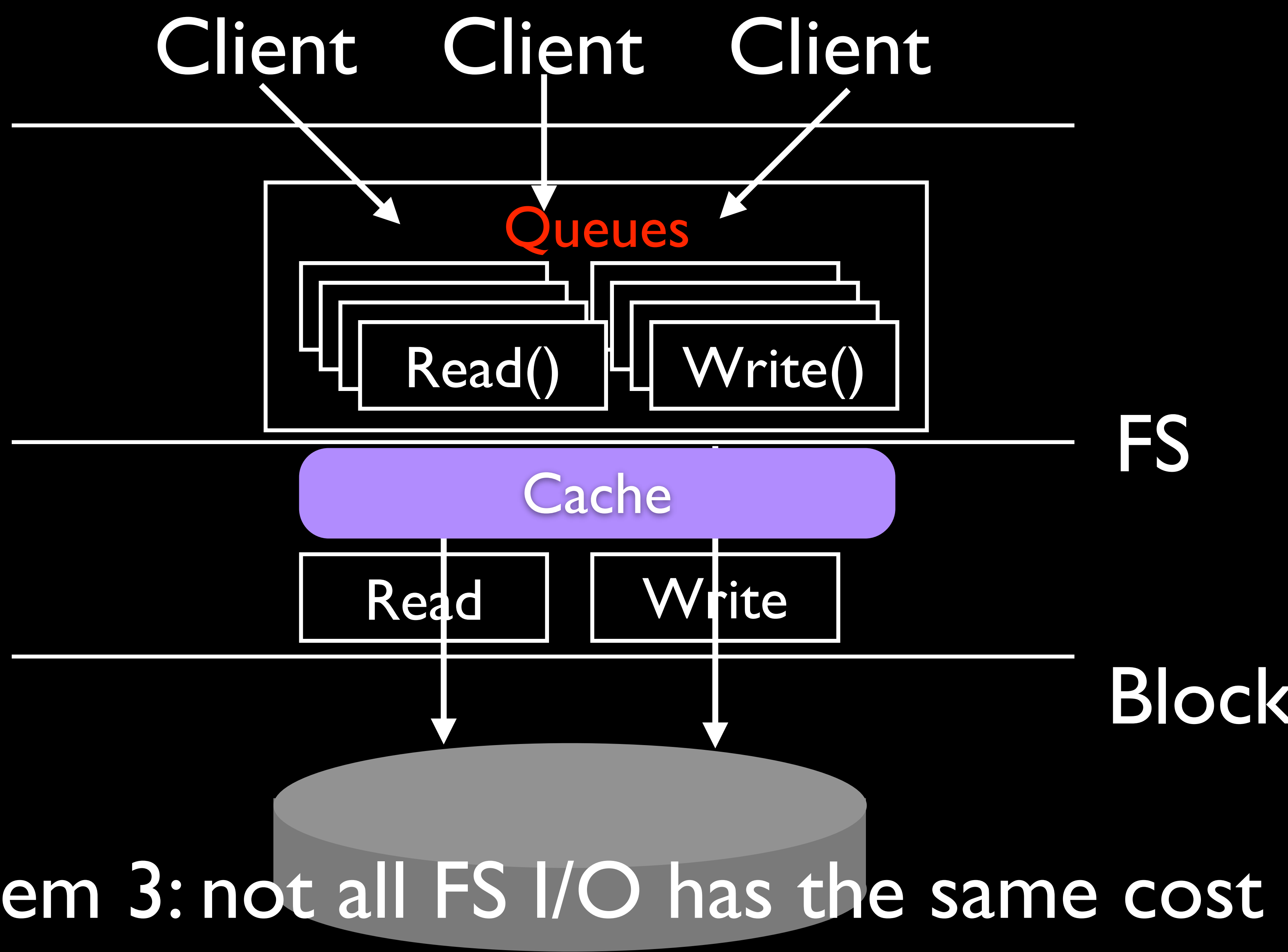
Problem 1: what if we read/write can be absorbed by cache?

System Call Scheduling



Problem 2: writes now block
(previously asynchronous)

System Call Scheduling



Problem 3: not all FS I/O has the same cost (e.g., random I/O), or that involving metadata

Outline

Intro: disk scheduling basics

CFQ isn't fair!

FS Scheduling Challenges (ext4 case study)

Naive approach (not our idea)

Split-Level Scheduling

Conclusions

New Cross Layer Scheduler Framework

- New notification to scheduler: *file system events* (write/fsync called/completed, write back happened)
- New action available: queue *system calls* in addition to block level requests, *flush* file cache
- New info of accou*nting*: *io-tag* for client *identification*

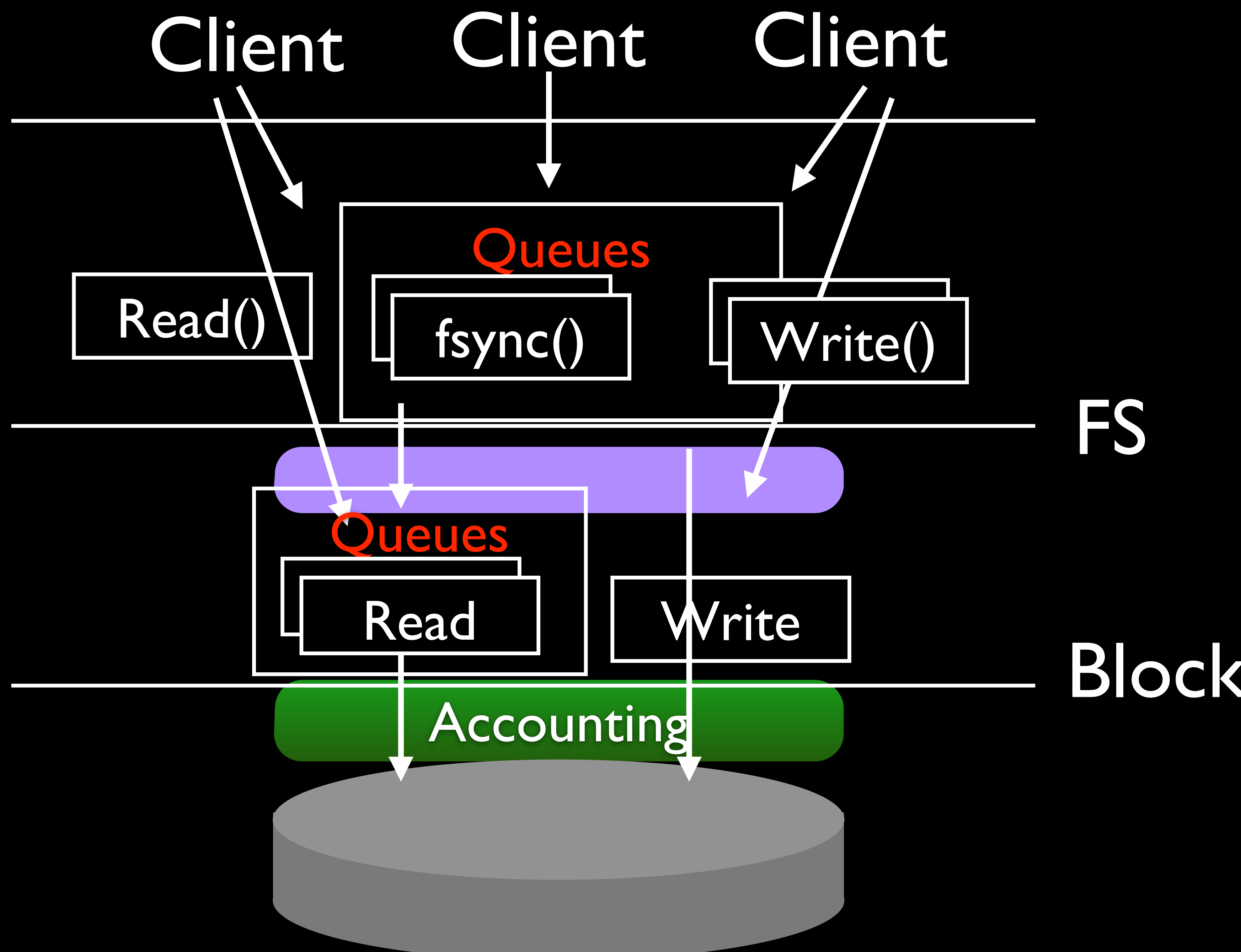
New Cross Layer Scheduler Framework

- File system view *and* block level view: both high level ordering and low level optimization
- Ability to control important *file system* behavior and memory state.
- io-tag enables correct *and accurate (low level)* accounting.

Things We Enable

- Correct priority-based I/O scheduling.
- I/O isolation based on cache partitioning.
- Real end-to-end latency control.
- and others…

Split Level *Actual* Fair Queuing



Outline

Intro: disk scheduling basics

CFQ isn't fair!

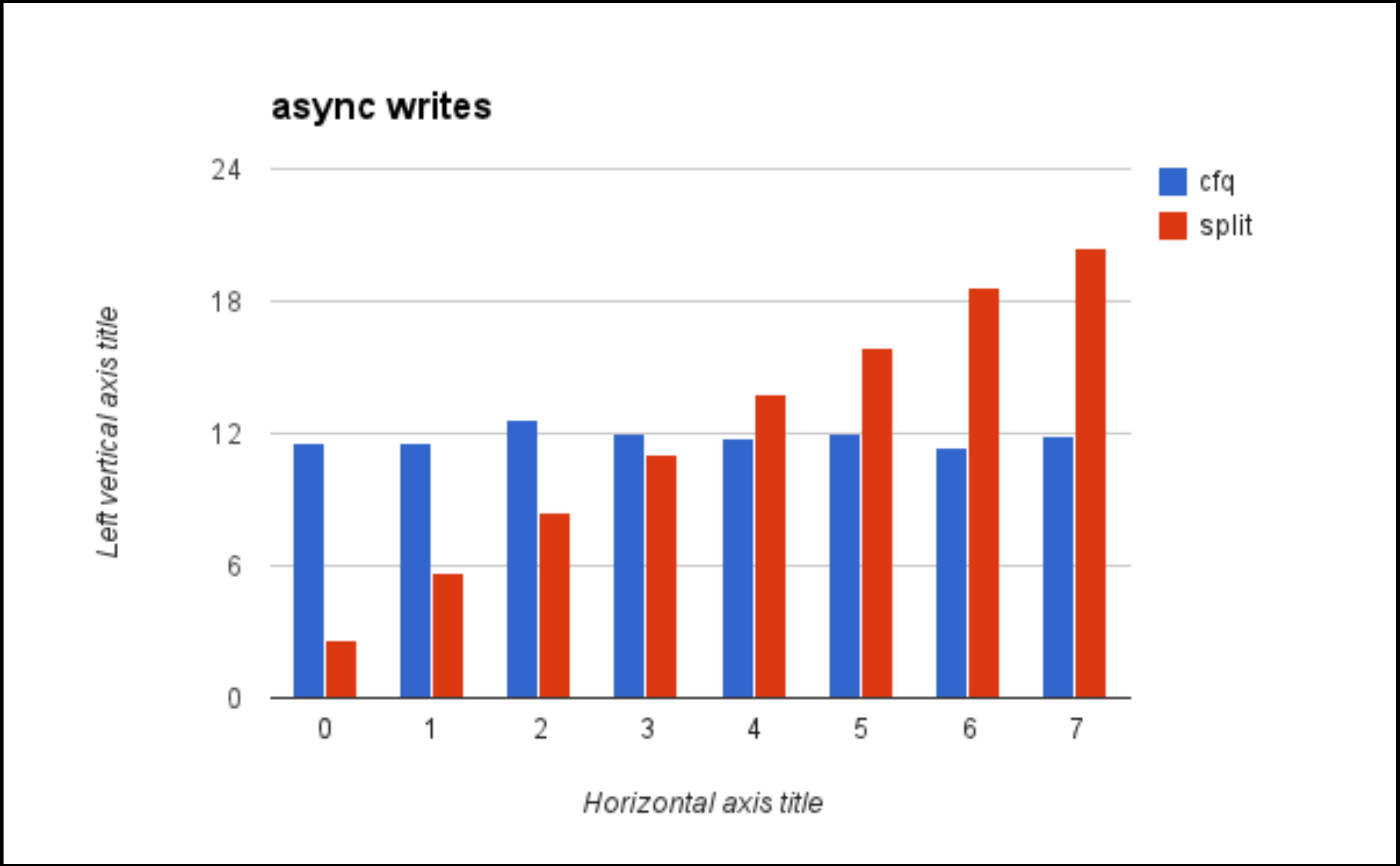
FS Scheduling Challenges (ext4 case study)

Naive approach (not our idea)

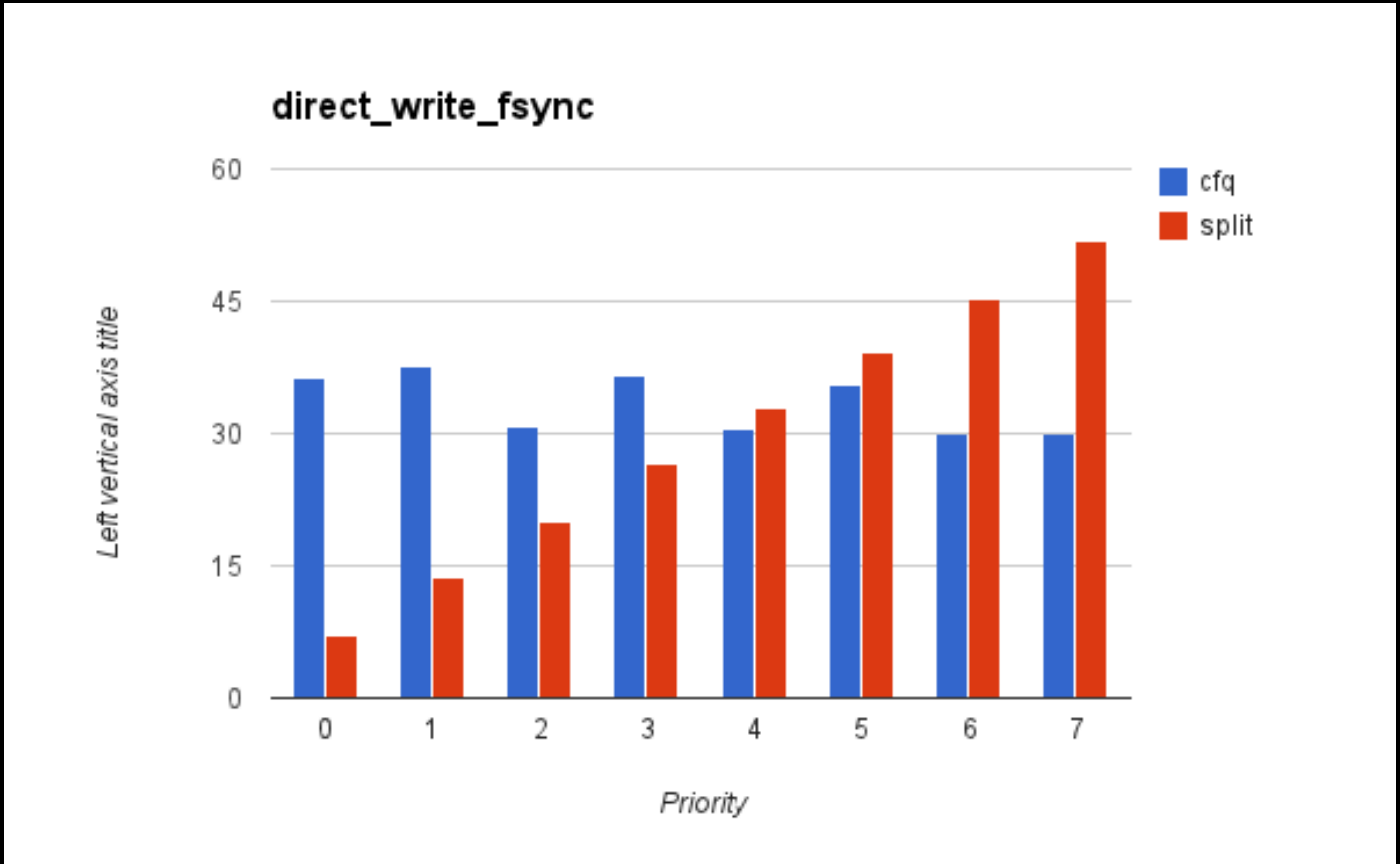
Split-Level Scheduling (Preliminary Results)

Conclusions

Asynchronous Writes now work!



Write+Fsync works too!



Outline

Intro: disk scheduling basics

CFQ isn't fair!

FS Scheduling Challenges (ext4 case study)

Naive approach (not our idea)

Split-Level Scheduling (Implementation)

Conclusions

Conclusions

Life's not fair, but file systems should be

Reads are easy, writes are hard

Simple layer stacking makes some problems impossible to solve - have to work cross-layer

New Cross Layer Scheduler Framework

- New notification to scheduler: add_block_req, *add_write_call, add_fsync_call,* req_complete, *write_complete, fsync_complete* *writeback_happened,* disk_need_work

- New action available: issue_block_req, *issue_write_call, issue_fsync_call, flush_file_cache*

- New info of accou*nting: io-tag* for client *identification*