# Multi-Queue Fair Queueing

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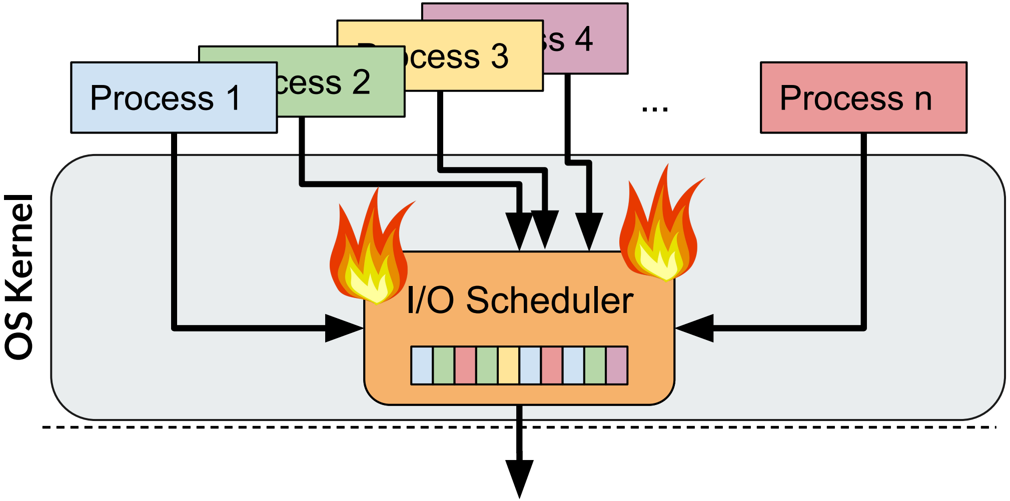
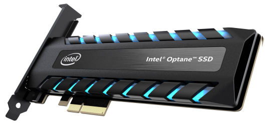
# Conventional I/O Design

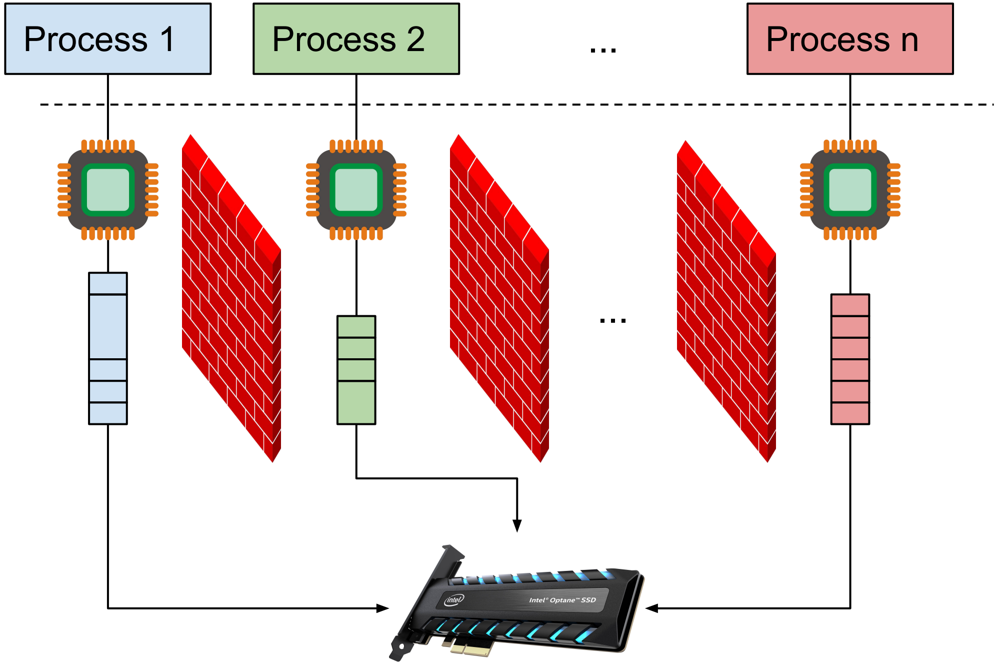


**O(1M IOP/s): less than 1µs per IOP**

**What can be done in less than 1µs?**

# Multi-Queue I/O Design



# Multi-Queue I/O Design

## Pros:

- Better scalability
- Better throughput

## Cons:

- Challenges in preserving system-wide properties
  - e.g., Fairness

# Overview

- Motivation
- Multi-Queue Fair Queueing
- Scalable Implementation of MQFQ
- Evaluation
- Conclusion

# Fair Queueing

- Supports proportional sharing (weights)
- Work-conserving
- Handling of under-utilizing tasks
- Provable fairness bounds

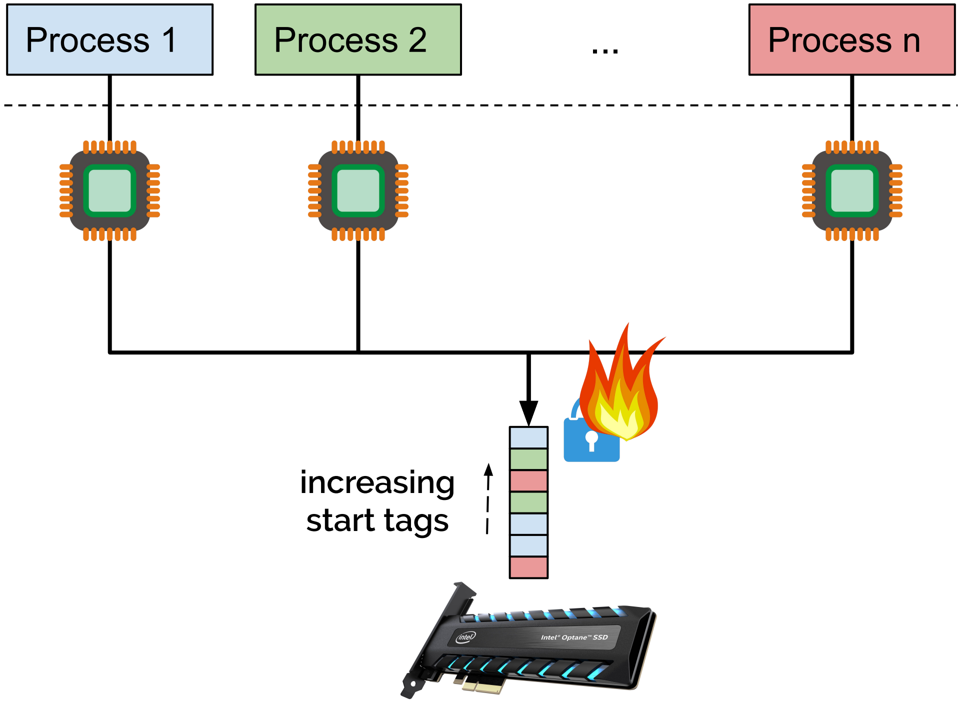
- Additionally, we need to support **Parallel Dispatch**

# Multi-Queue Fair Queueing

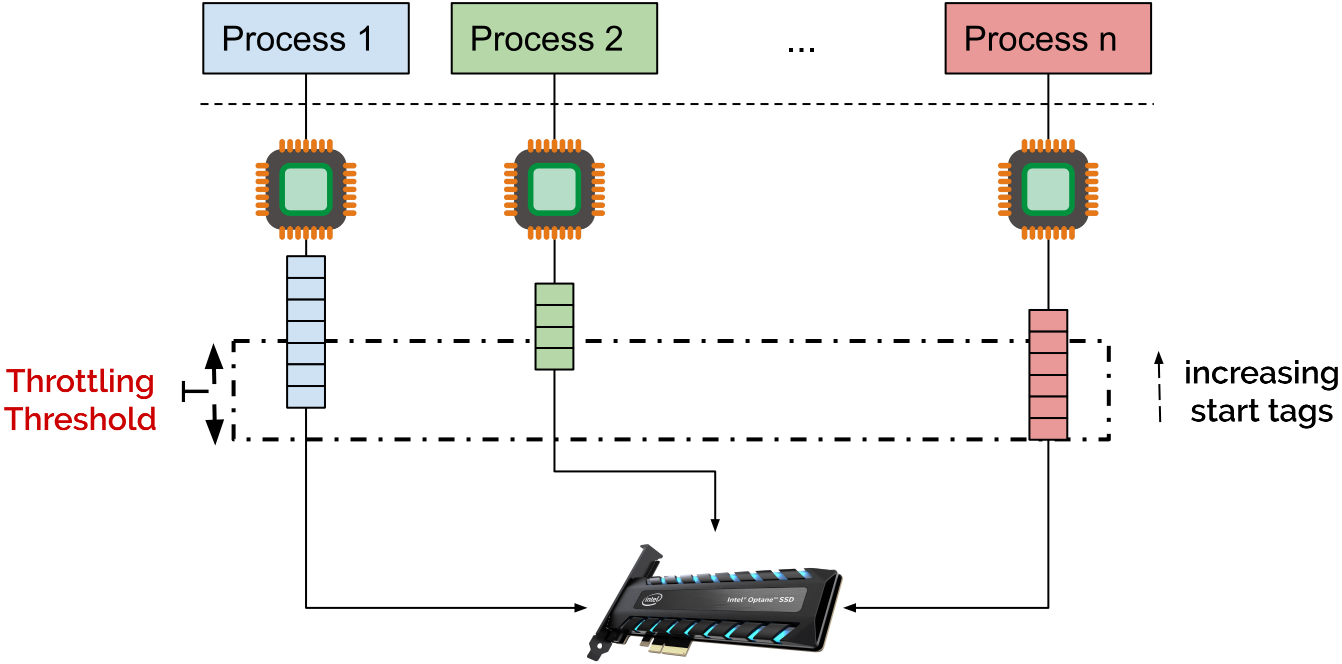
- MQFQ builds on SFQ(D) [Jin et al. '04]
  - **Start tag:** roughly, the task's accumulated resource usage at request dispatch
  - Orders requests based on their start tags for fairness
  - Allows up to D parallel dispatches
- Challenges:
  - Strict ordering hampers scalability
  - Tracking global statistics requires cross-CPU communication

# Multi-Queue Fair Queueing

- SFQ(D)



# Multi-Queue Fair Queueing



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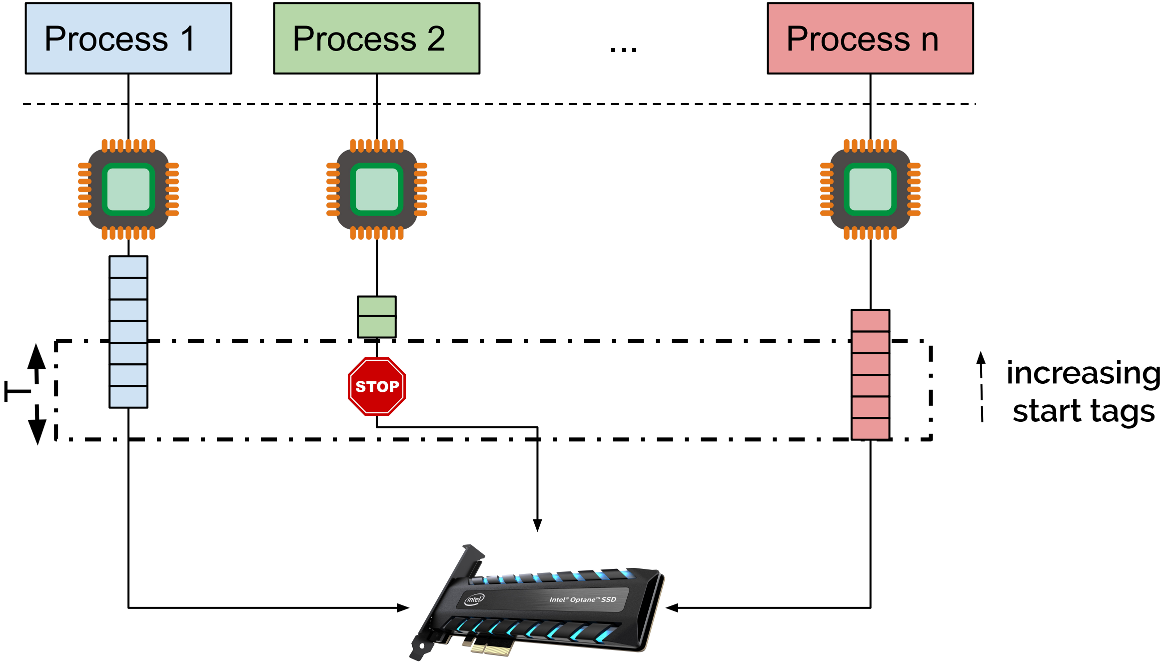
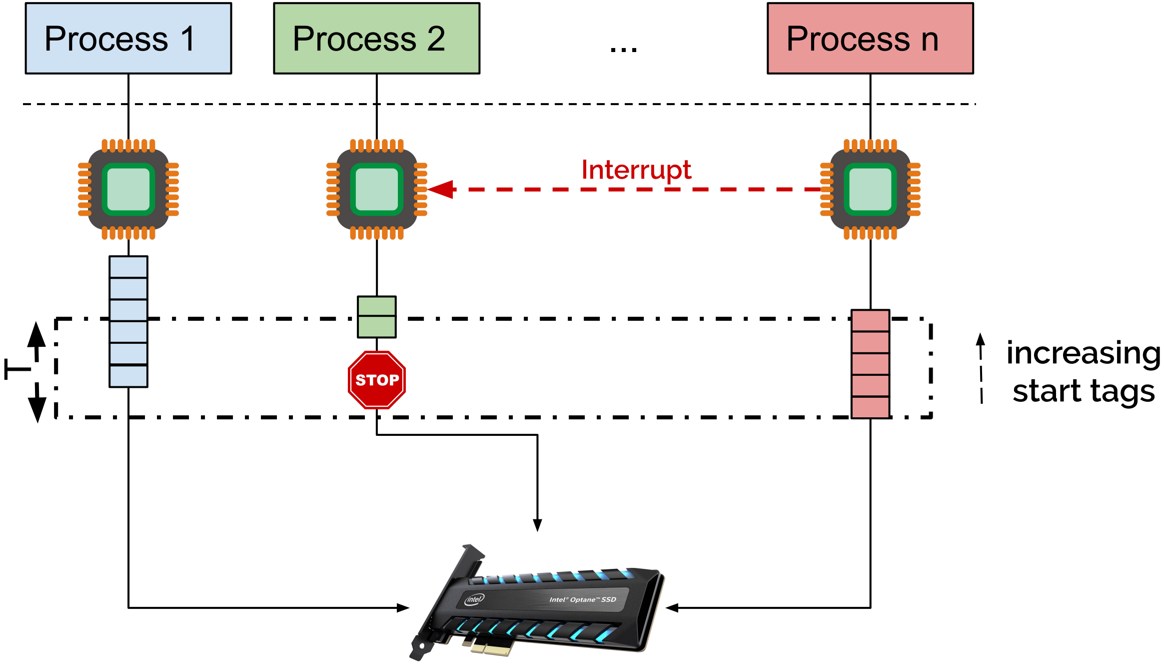


# Multi-Queue Fair Queueing



# Bounded Unfairness

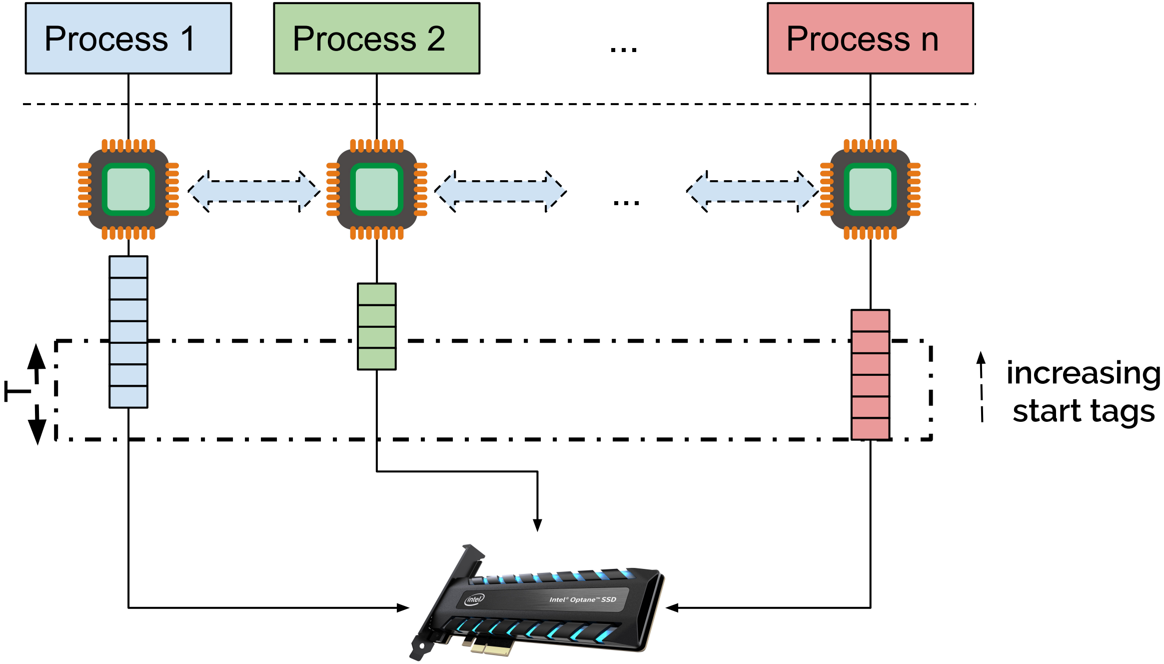
- For throttling threshold T and D-parallel dispatch:

| | | |
|---|---|---|
| Difference in service received by any two flows, tasks, etc. | **is less than** | (D+1) (2T+c) |

(c is a function of maximum request length and flow weights)

- See paper for proof and assumptions

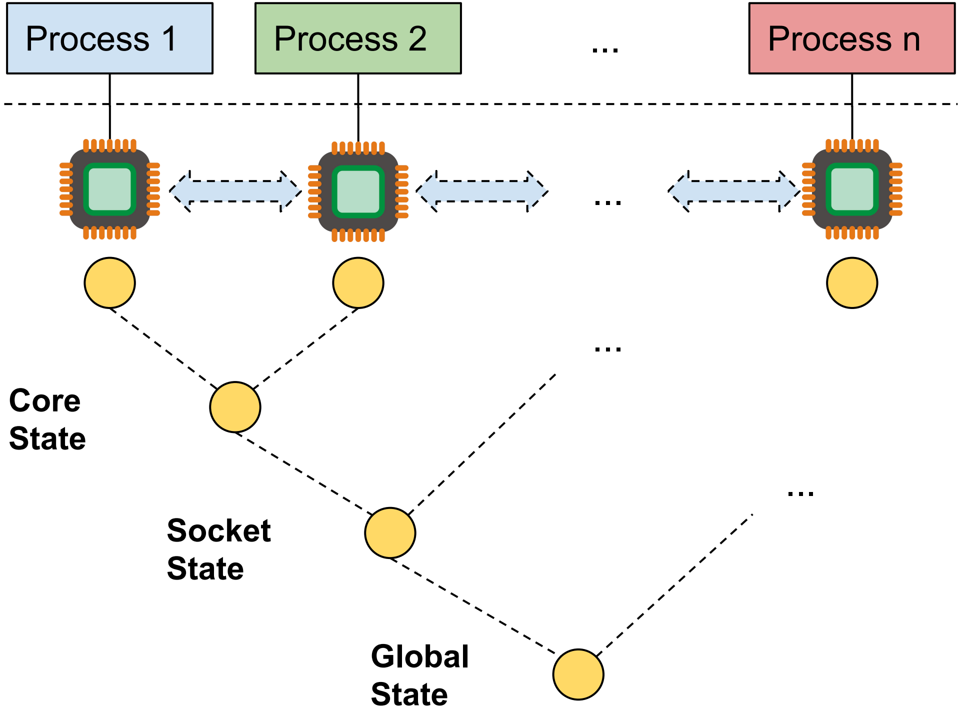
# Multi-Queue Fair Queueing



# Scalable Implementation

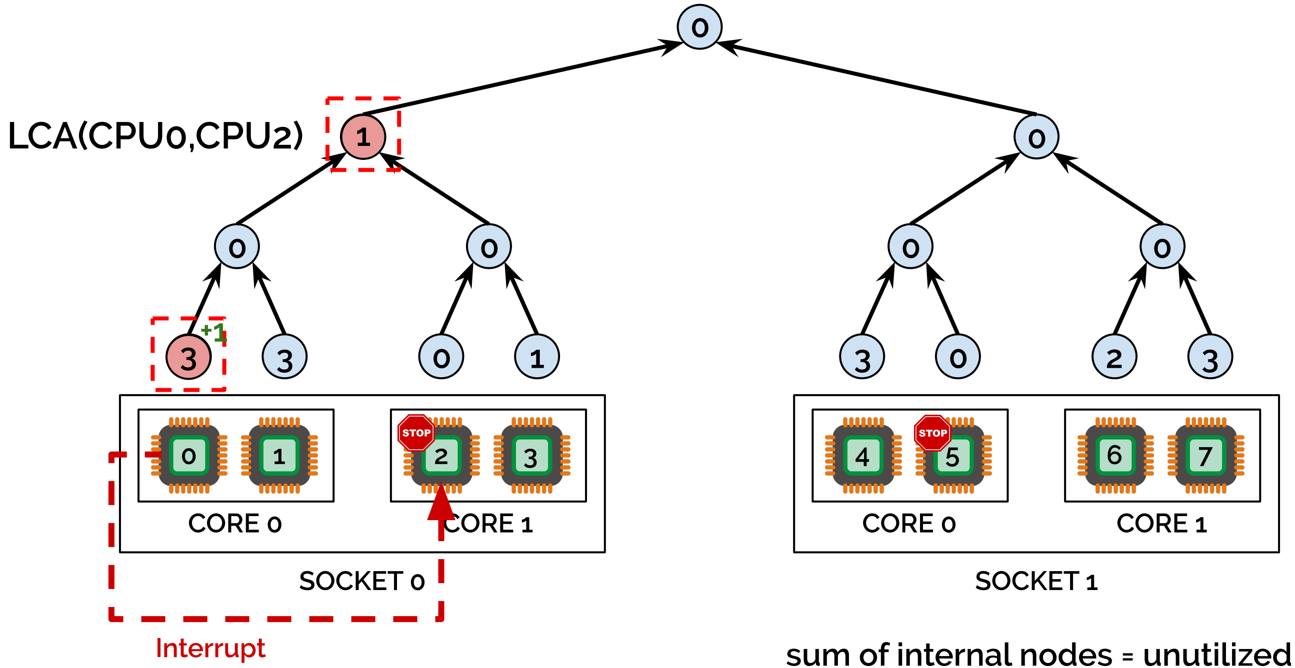
- Fairness is inherently global
- MQFQ needs to maintain:
  - Smallest start tag (i.e., slowest queue) -- *Mindicator* (see paper)
  - Parallelism utilization (i.e., # of in-flight requests) -- *Token-Tree*
  - Throttling meta-data (see paper)

# Scalable Implementation



# Example: Parallelism Utilization

- Token-Tree




sum of internal nodes = unutilized parallelism

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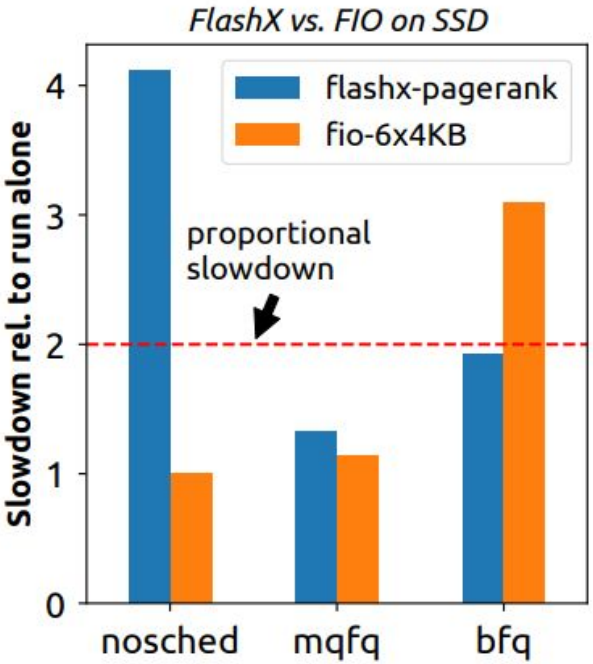
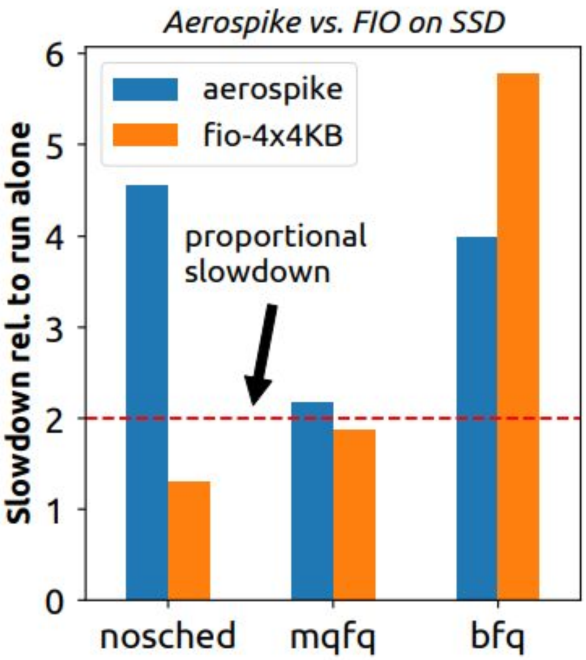
# Evaluation

- Implemented as Linux IO-Scheduler
- Benchmarked over:
  - NVMe SSD (up to 0.5M IOP/s)
  - NVMe over RDMA (up to 4M IOP/s)
- Tested applications:
  - Flexible IO (FIO): benchmarking tool
  - Aerospike: key-value store
  - FlashX: graph processing
- Compared against Linux's Budget Fair Queueing (BFQ)

# MQFQ is Fair


FlashX vs. FIO on SSD
Slowdown rel. to run alone
0
1
2
3
4
flashx-pagerank
fio-6x4KB
proportional
slowdown
nosched
mqfq
bfq


Aerospike vs. FIO on SSD
Slowdown rel. to run alone
0
1
2
3
4
5
6
aerospike
fio-4x4KB
proportional
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mqfq
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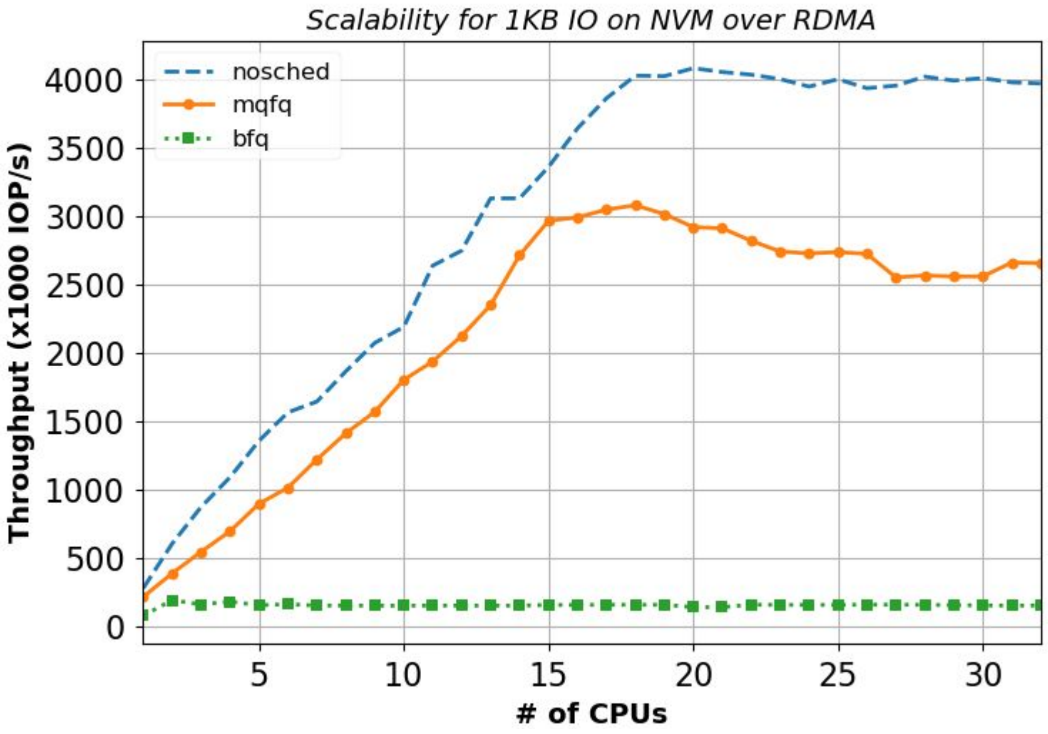
# MQFQ is Scalable



# Conclusion

- We discussed:
  - Scalability vs. fairness in multi-queue I/O
- We introduced:
  - *Multi-Queue Fair Queueing (MQFQ)*
- We presented:
  - Scalable implementation
    - Up to **3.1 M IOP/s**
    - All while guaranteeing fairness