SAM: Optimizing Multithreaded Cores for Speculative Parallelism

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Executive Summary

Analyzes the interplay between hardware multithreading and speculative parallelism

(eg: Thread Level Speculation and Transactional Memory)

Conventional multithreading causes performance pathologies on speculative workloads

- Increase in aborted work
- Inefficient use of speculation resources

    Why? All threads are treated equally

Speculation Aware Multithreading (SAM)

- Prioritize threads running tasks more likely to commit

SAM makes multithreading more useful

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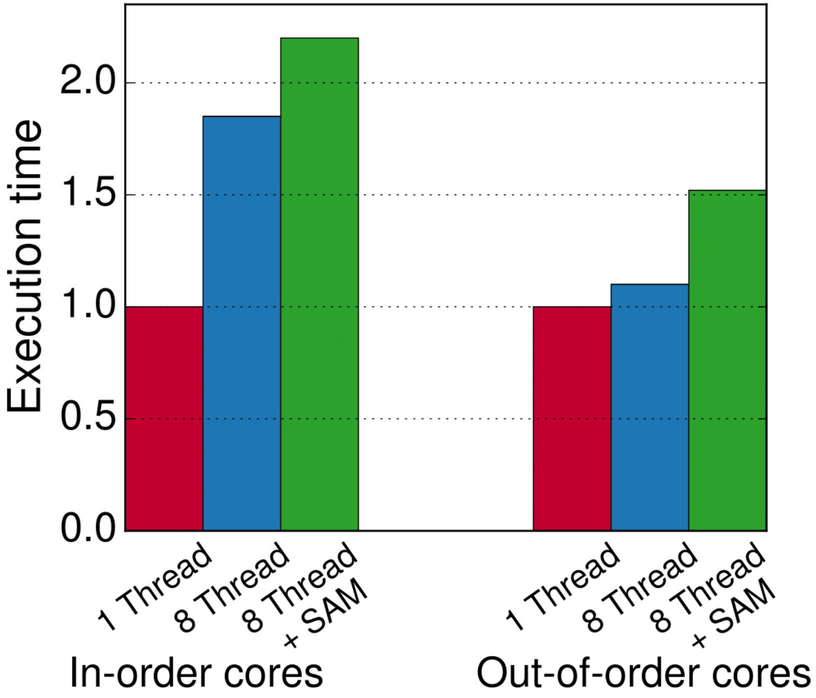

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Outline

Background on speculative parallelism

Pitfalls of speculative parallelism with conventional multithreading

SAM on in-order cores

SAM on out-of-order cores

Background on Speculative Parallelism

Parallelize tasks when the dependences are not known in advance

Hardware executes all tasks in parallel, aborting upon conflicts

Which task to abort? Conflict resolution policy

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Speculative Parallelism

Ordered
e.g. Thread-Level Speculation (TLS)
(Program order dictates the conflict resolution order)

Unordered
e.g. Hardware Transactional Memory
(Any execution order is valid, but high-performance conflict resolution policies define an order)

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Implicit order among all tasks in any speculative system

Baseline System - Swarm [Jeffrey, MICRO' 15]

```
void desTask(Timestamp ts , GateInput* input) {
     Gate* g = input ->gate ();
     bool toggledOutput = g.simulateToggle(input);
     if ( toggledOutput ) {
         for (GateInput* i : g-> connectedInputs ()) {
             swarm::enqueue(desTask , ts+delay(g,i), i);
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Tasks create children tasks
(function ptr, timestamp, args)

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Tasks create children tasks (function ptr, timestamp, args)

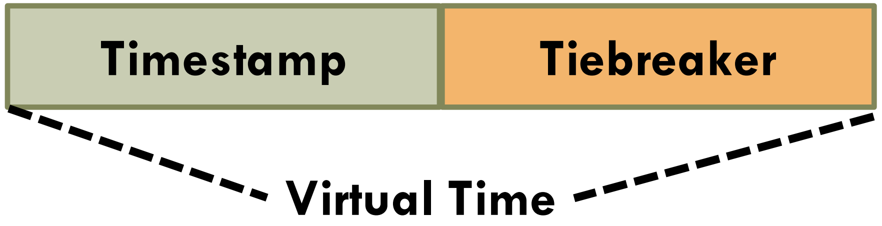
Tasks appear to execute in timestamp order

Unordered execution via equal timestamps

Swarm Microarchitecture

Equal timestamps:

global order via Virtual Time (VT)



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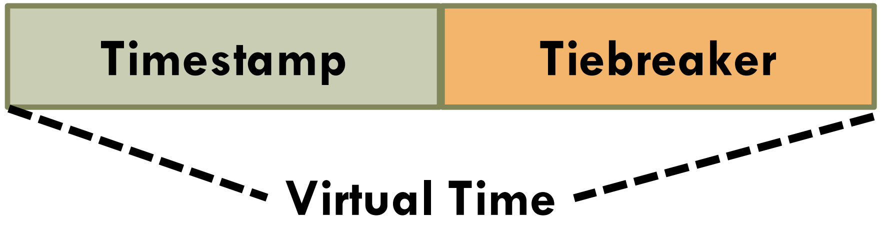

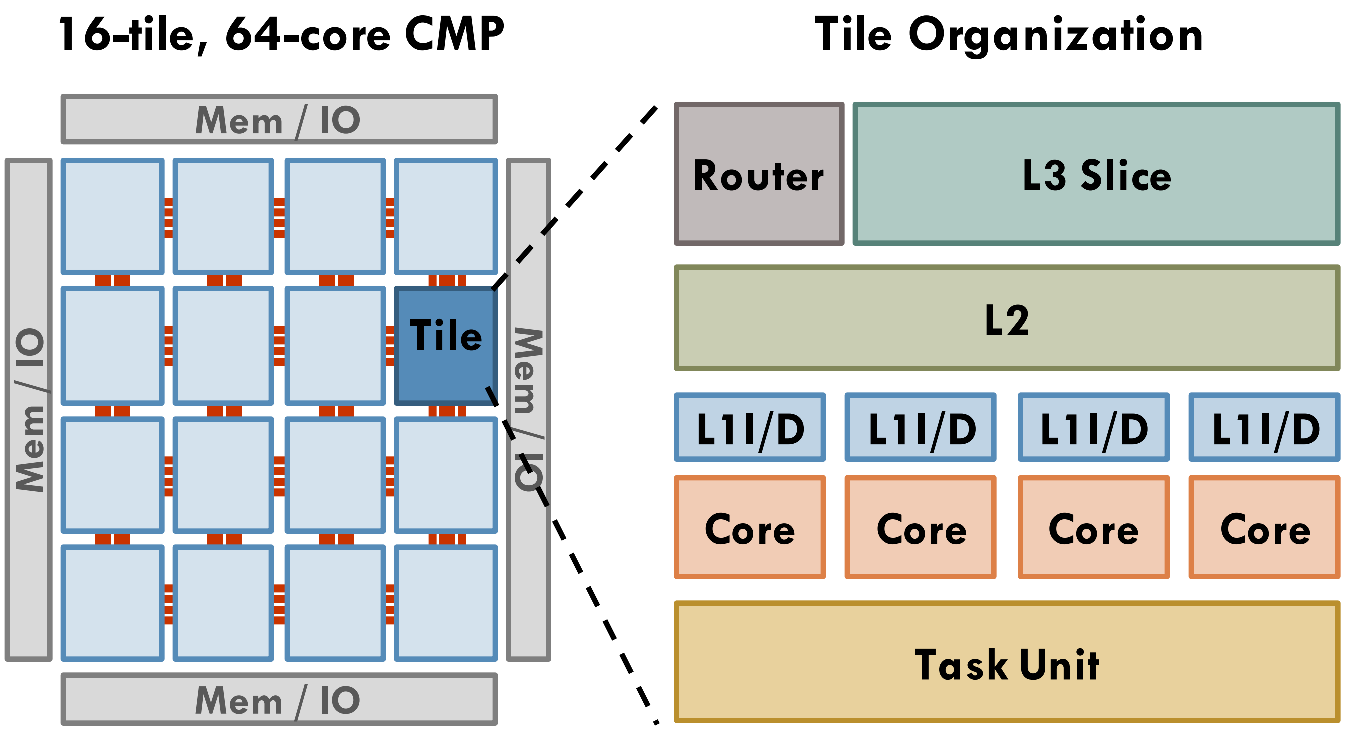

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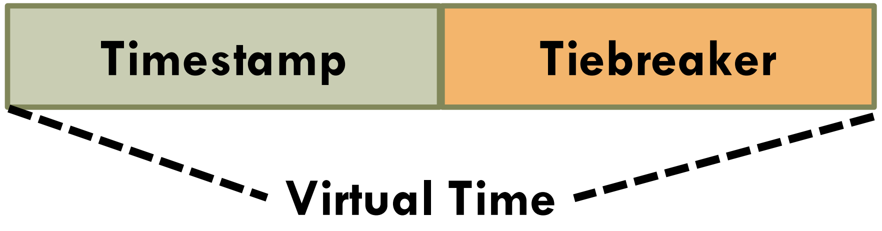

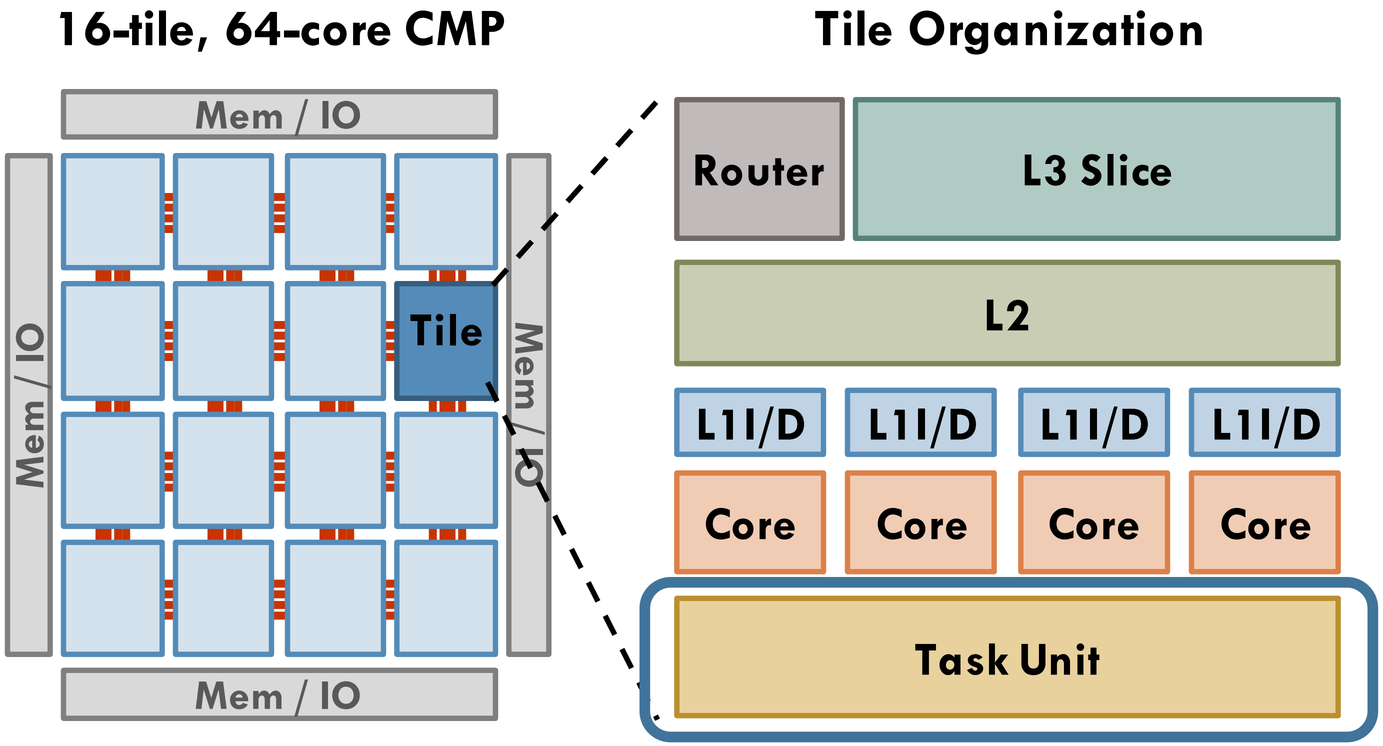

Tasks execute out-of-order,
but commit in VT order

Commit queue: state of tasks waiting to commit

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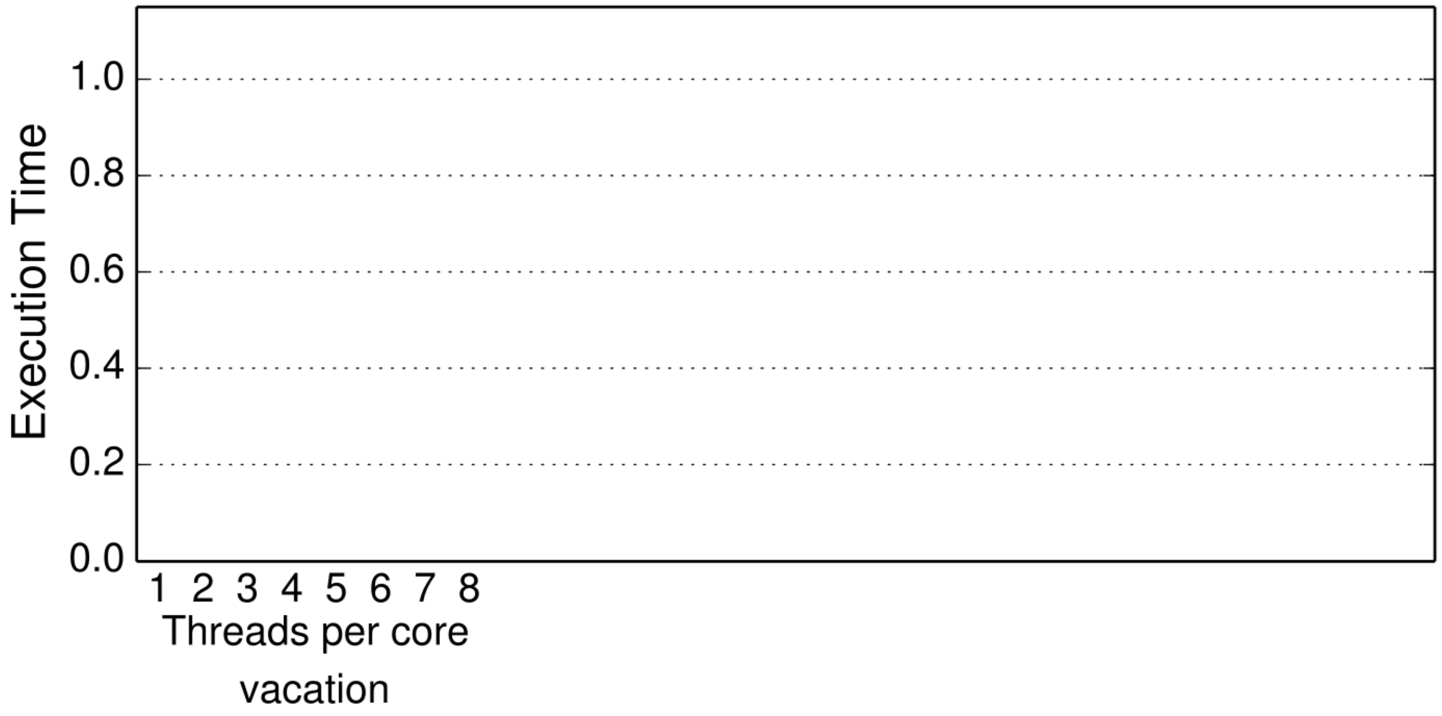
Pitfalls of Speculation-Oblivious Multithreading



System configuration:
64-core SMT system
In-order core with 2-wide issue
Speculation-oblivious round-robin order

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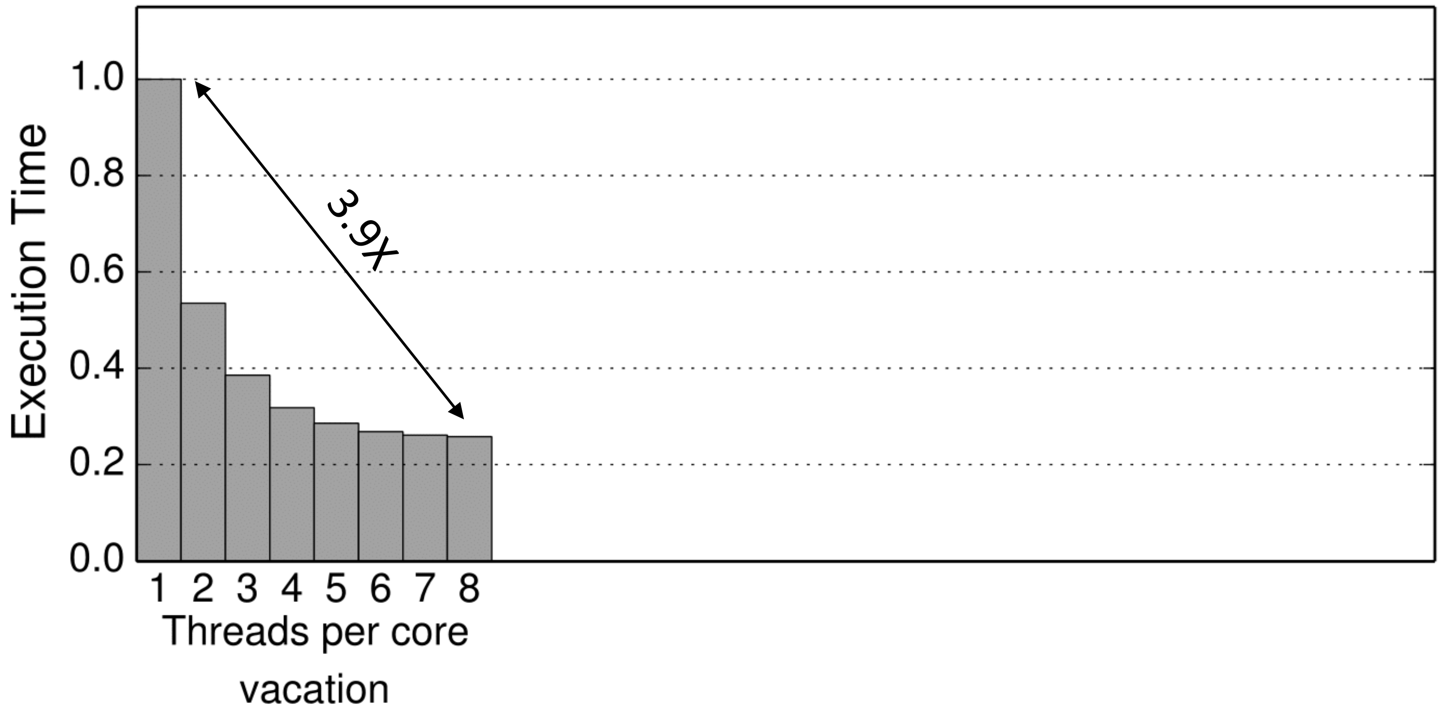

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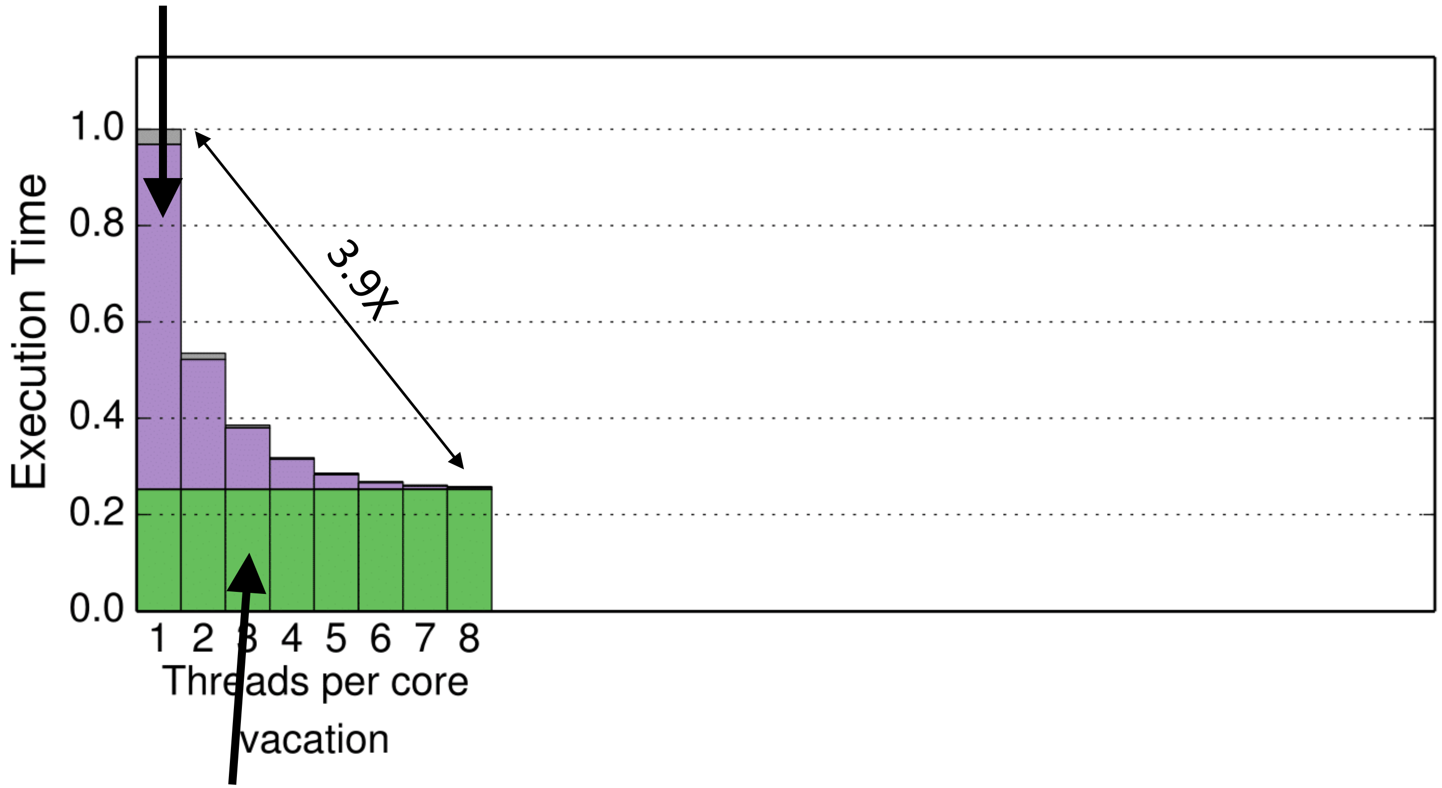

Micro-ops issued from **committed** tasks

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Insights:

1. Multithreading can be highly beneficial

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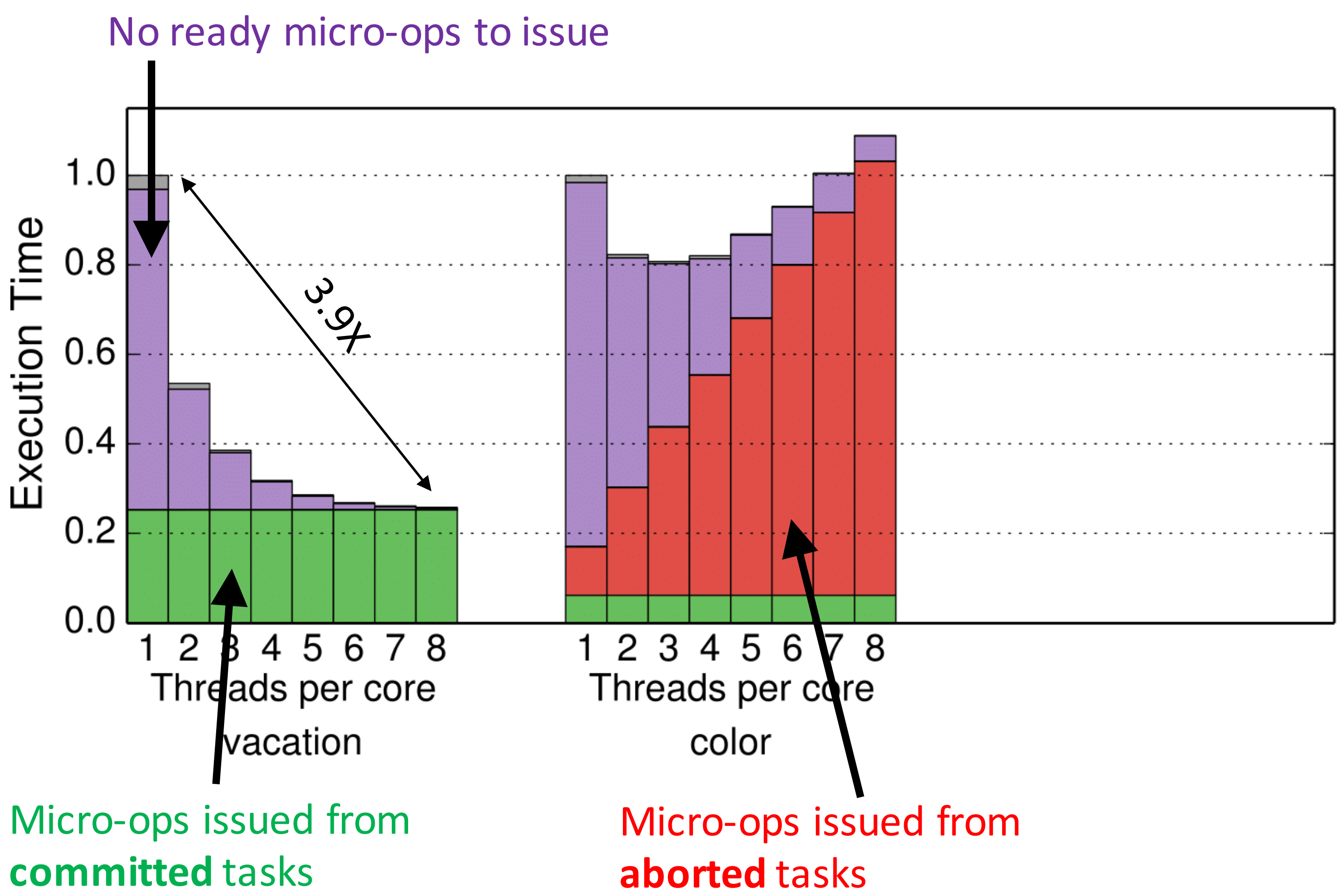

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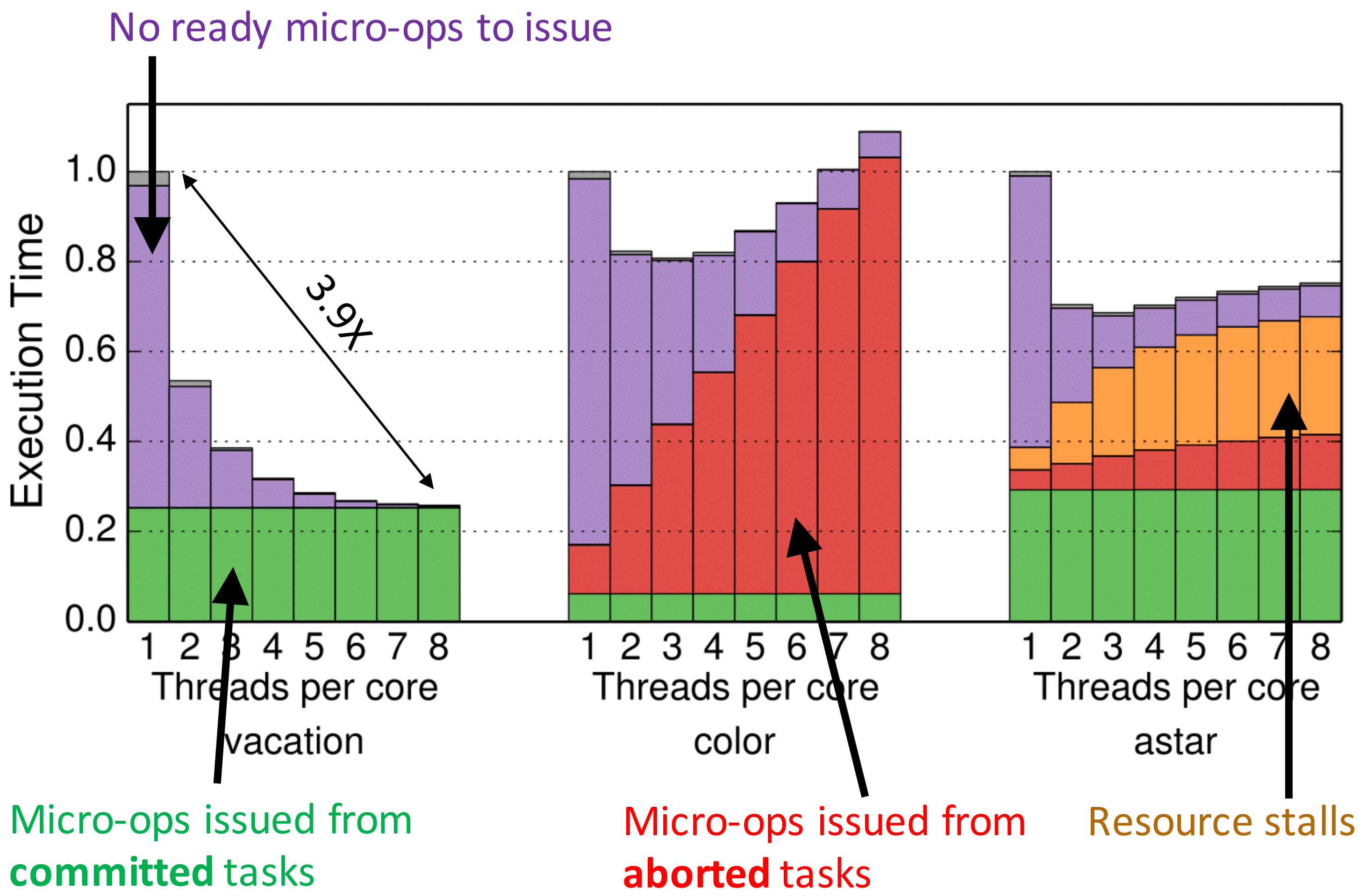

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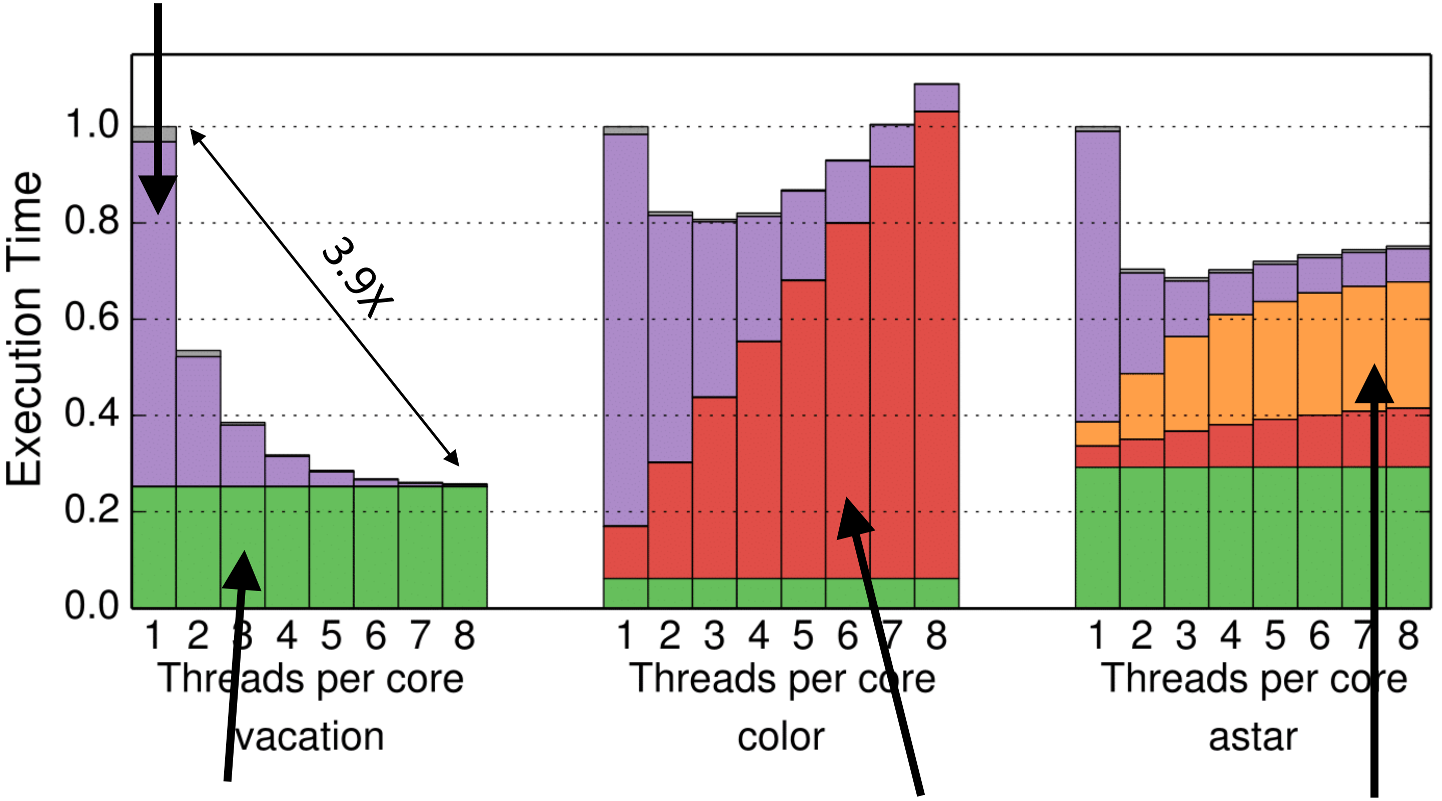

Micro-ops issued from **committed** tasks

Micro-ops issued from **aborted** tasks

Resource stalls

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1. Multithreading can be highly beneficial

However, multithreading can also lead to:

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3. Inefficient use of speculation resources

Unlikely-to-commit tasks hurt the throughput of likely-to-commit ones

Speculation-Aware Multithreading

Prioritize threads according to their conflict resolution priorities

Reduce Aborts
(focus resources on tasks likely to commit)

Reduce Speculation Resource Stalls
(tasks commit early)

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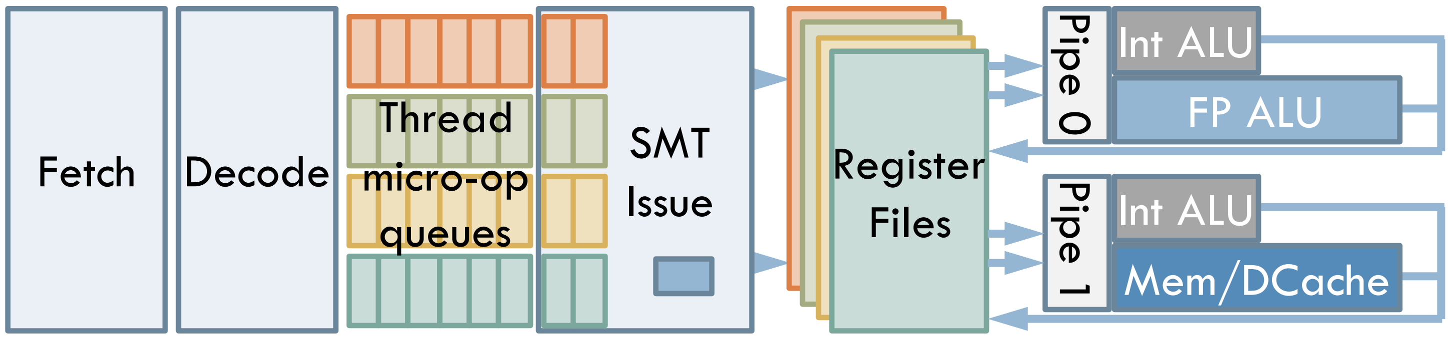

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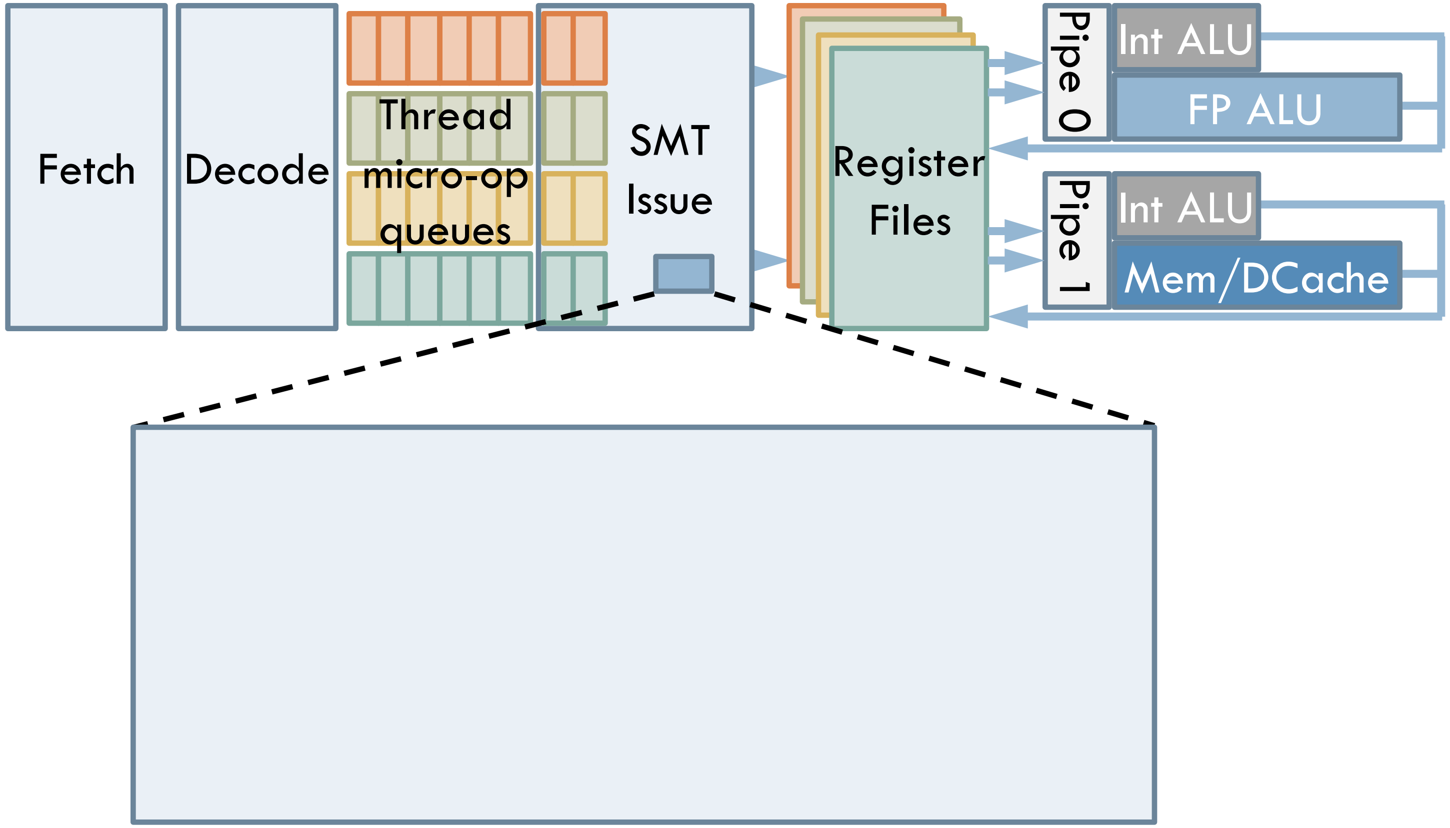

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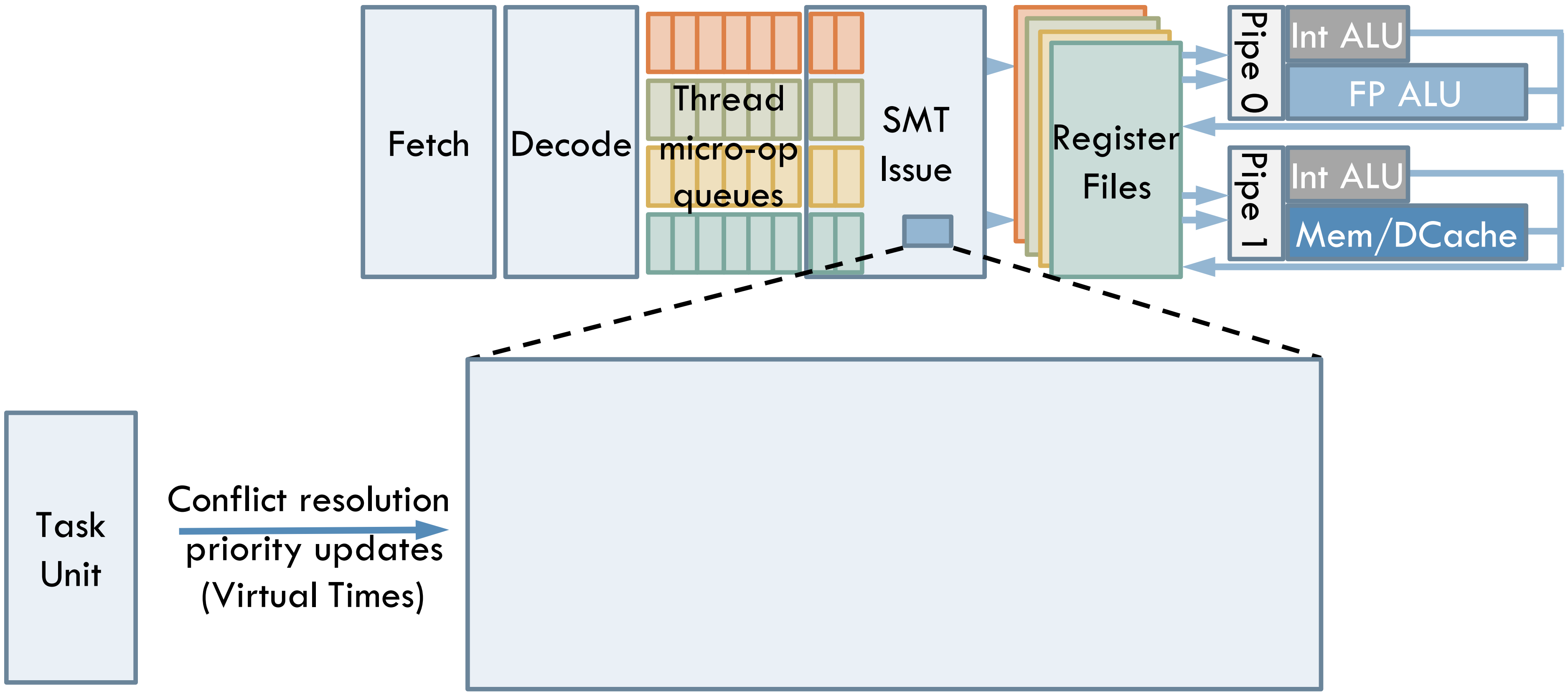

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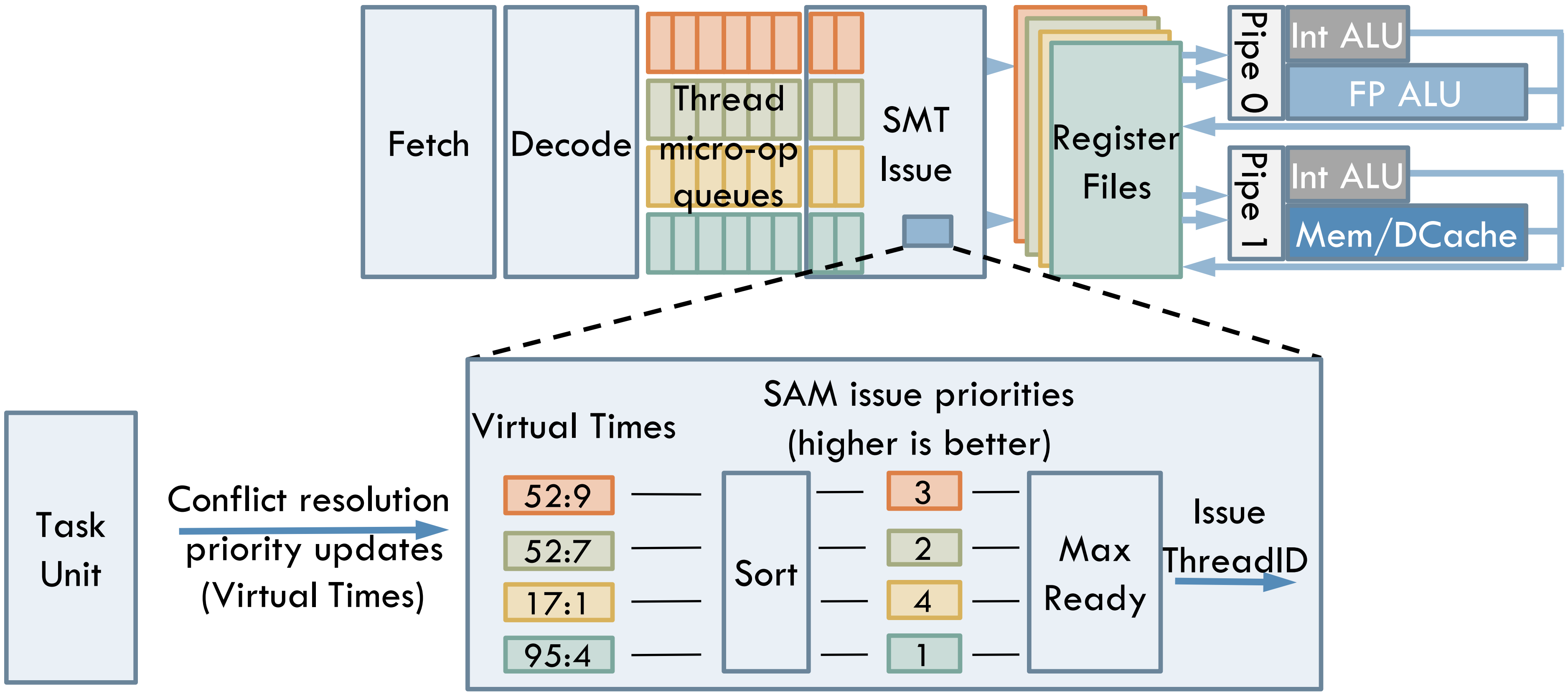


Experimental Methodology

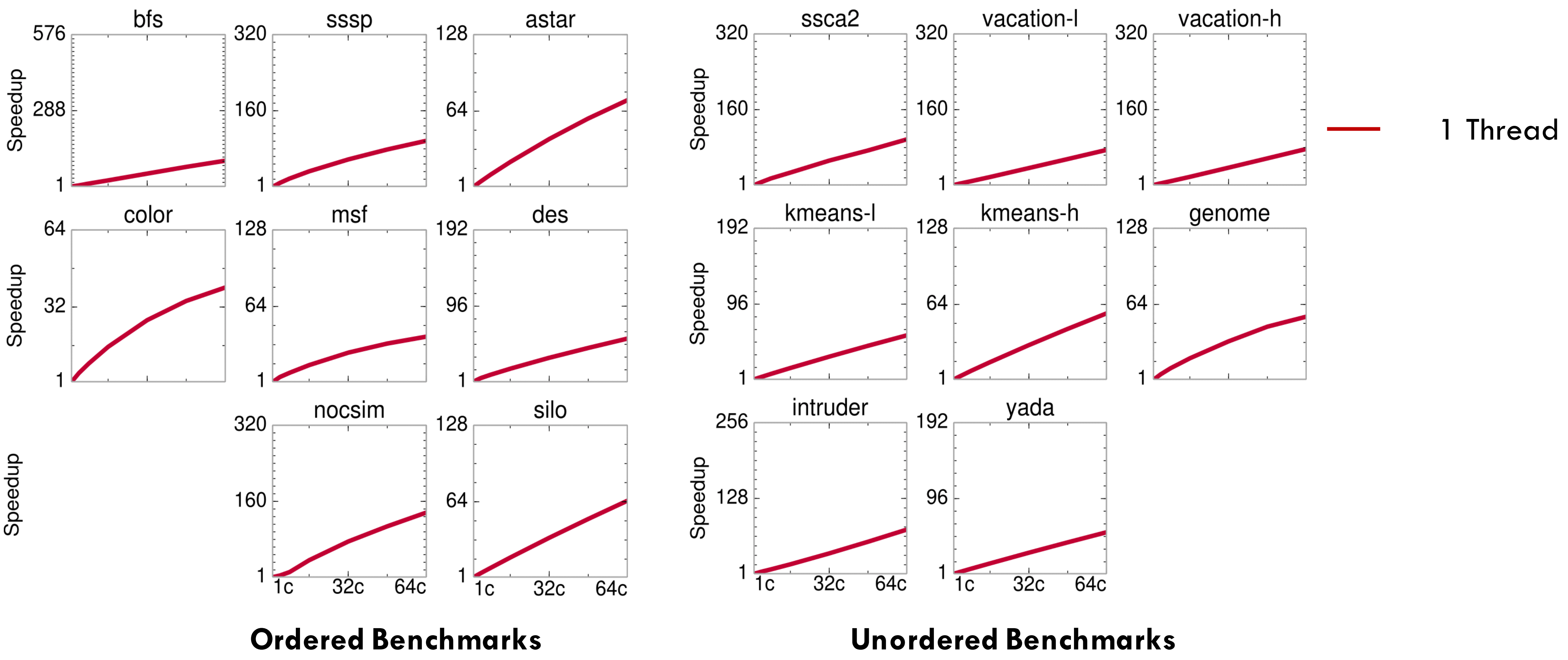
Baseline System

- Swarm + Wait-N-GoTM [Jafri et al. ASPLOS'13] conflict resolution techniques
- Cycle-accurate, event-driven, Pin-based simulator
- Model systems up to 64 cores
- Cores: 2 wide issue, up to 8 threads per core

Benchmarks

- Ordered : Swarm [Jeffrey et al. MICRO'15, MICRO'16] – 8 benchmarks
- Unordered : STAMP [Minh et al. IISWC' 08] – 8 benchmarks

SAM makes multithreading more effective



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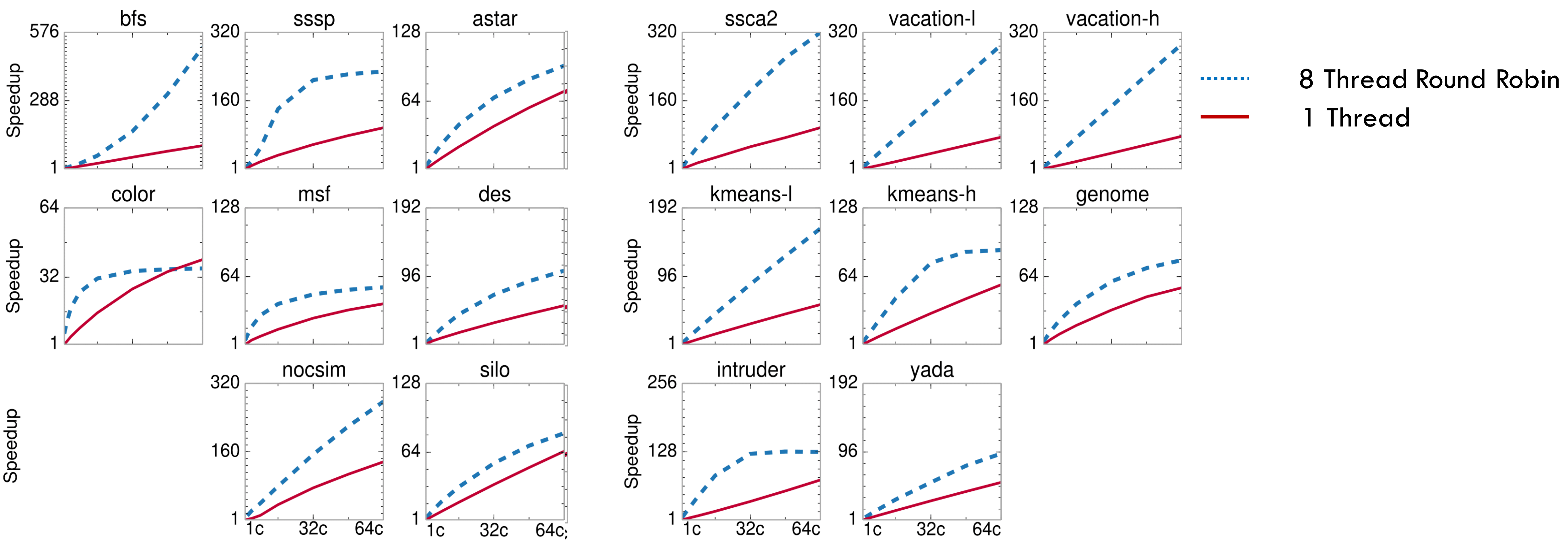

Ordered Benchmarks

Unordered Benchmarks

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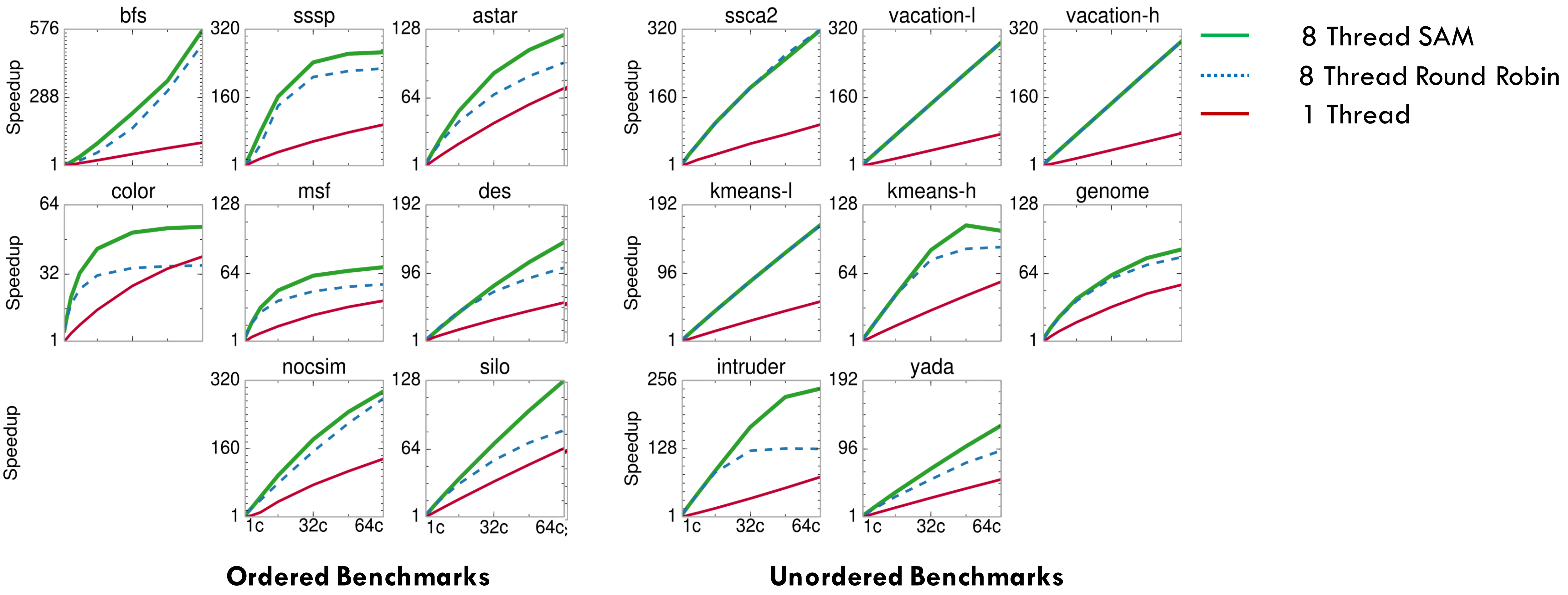

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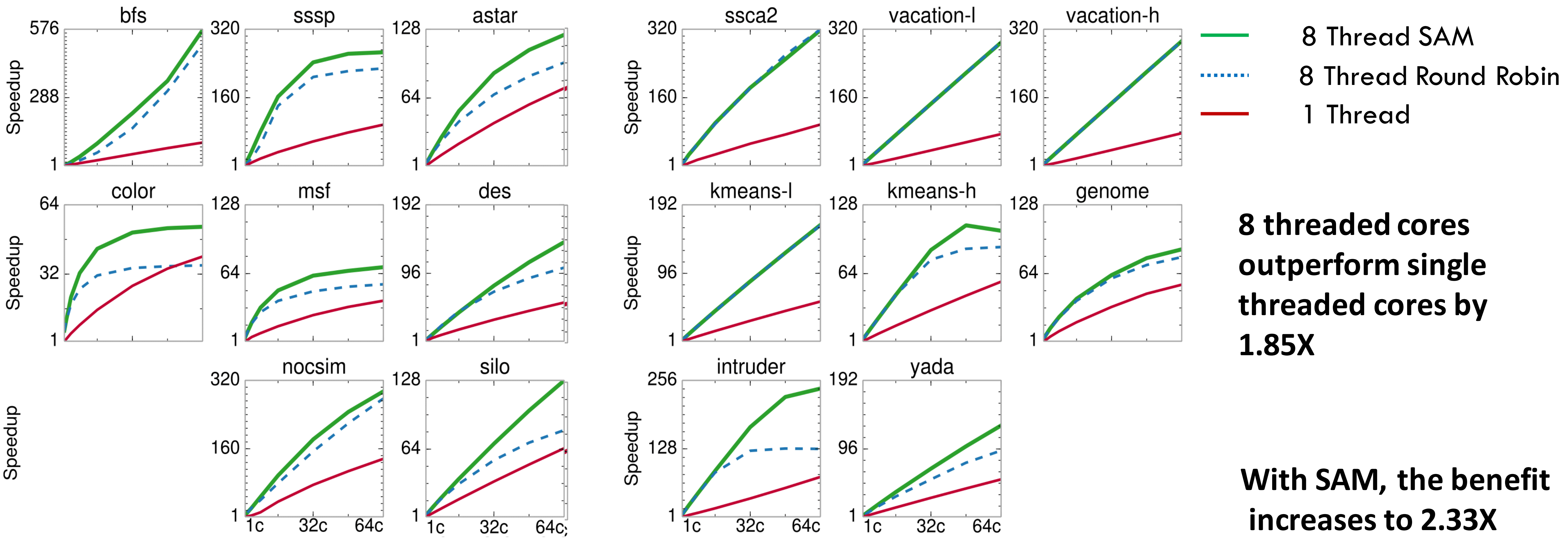

Ordered Benchmarks **Unordered Benchmarks**

8 threaded cores outperform single threaded cores by 1.85X

With SAM, the benefit increases to 2.33X

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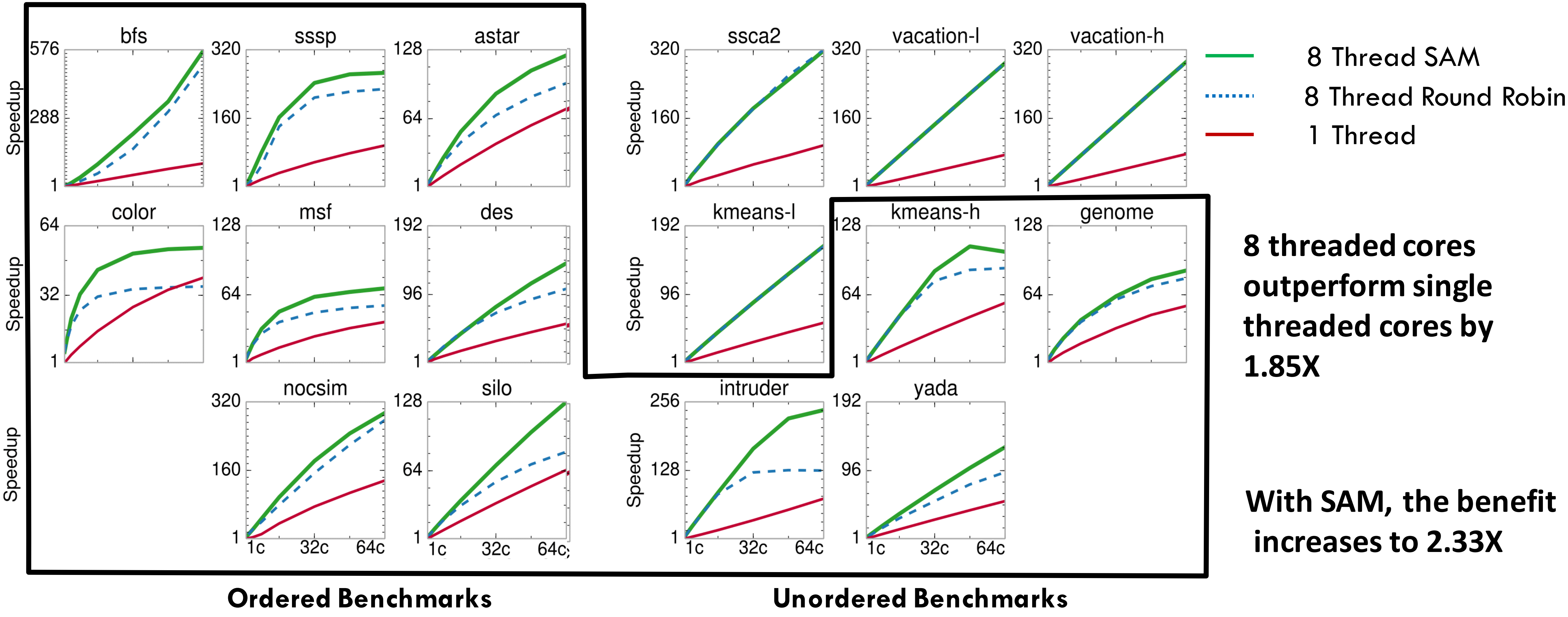

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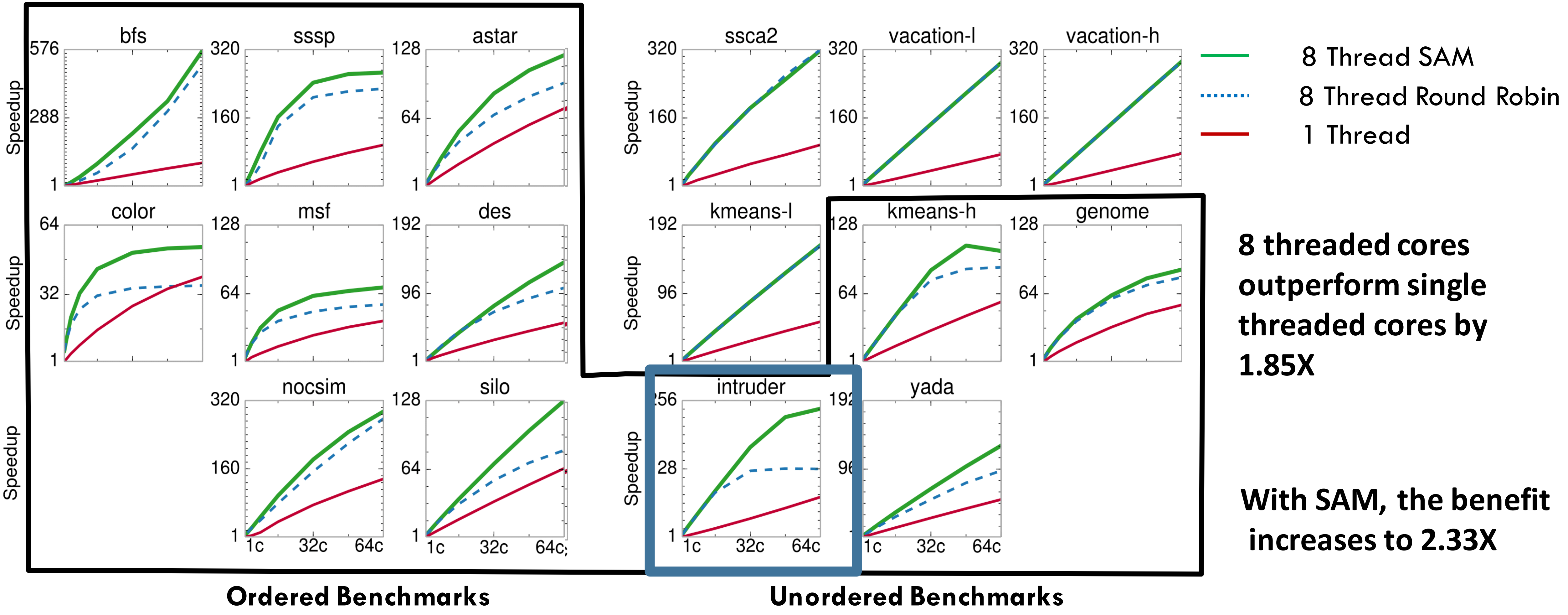

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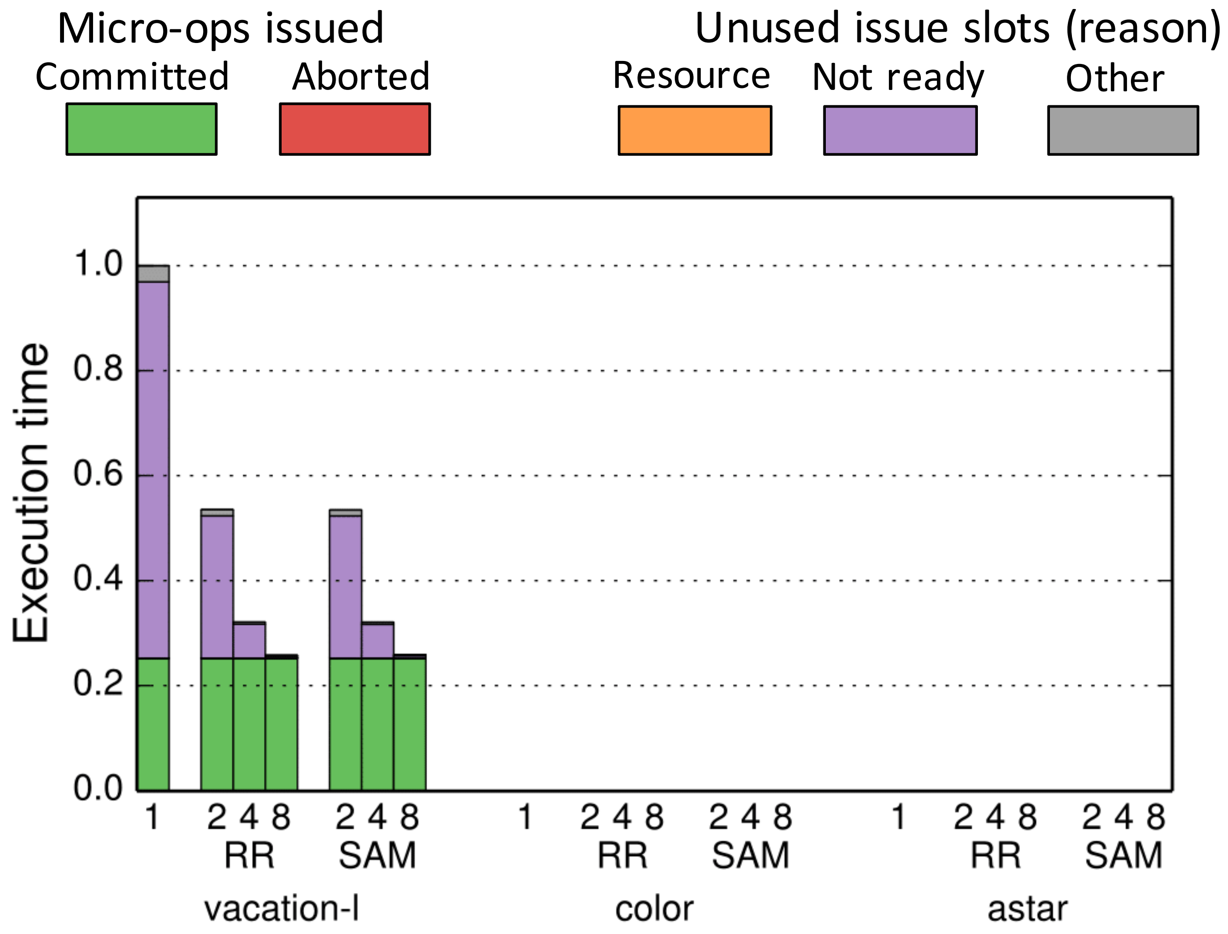

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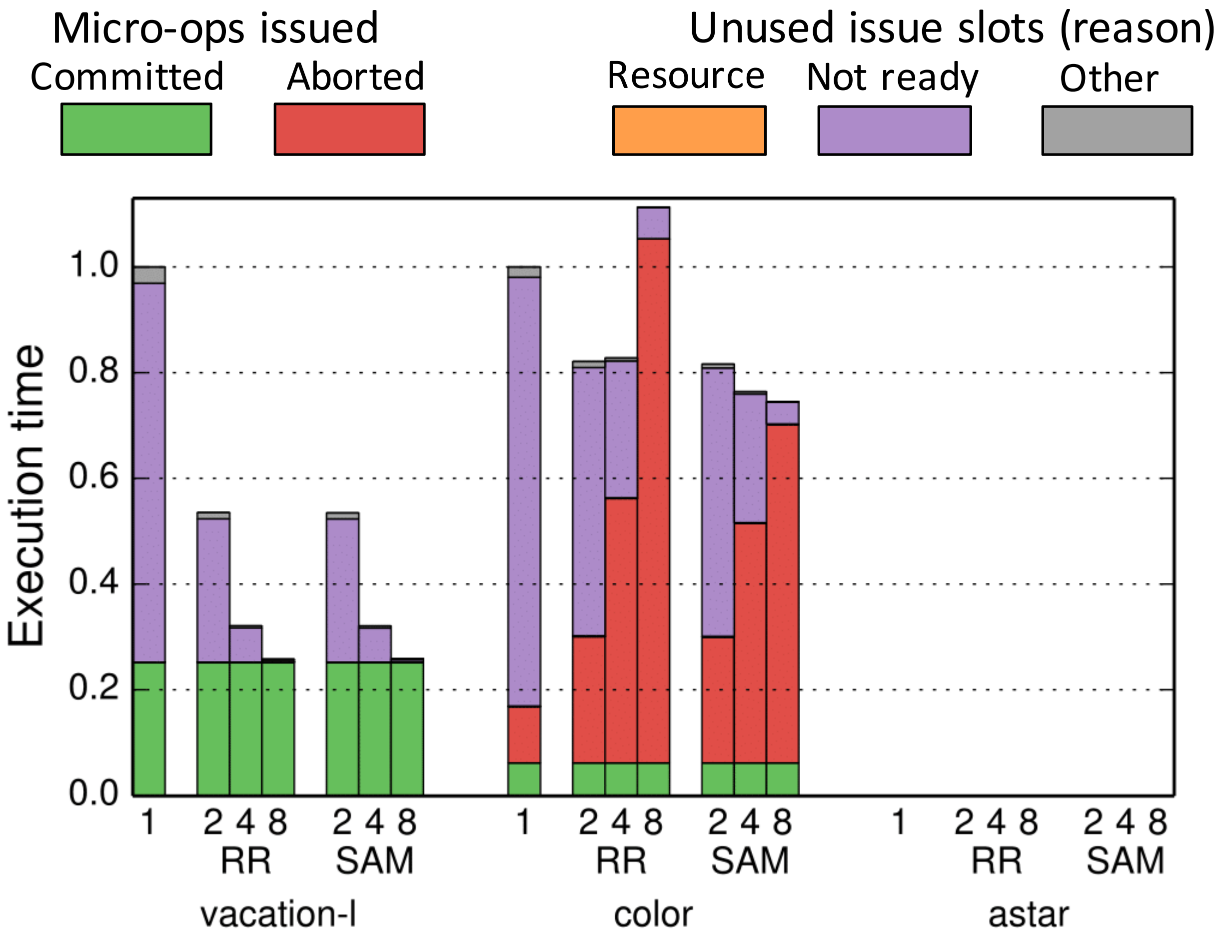

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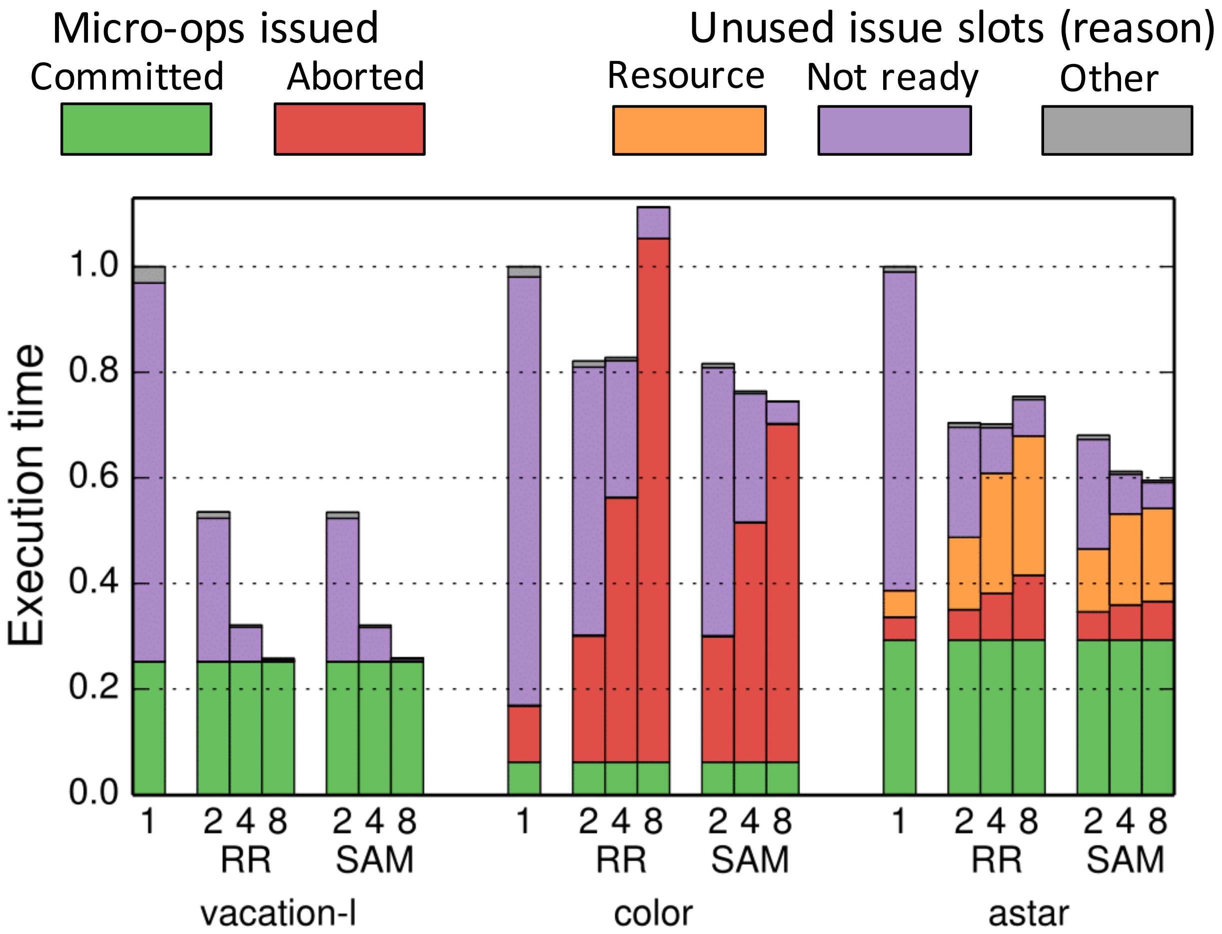

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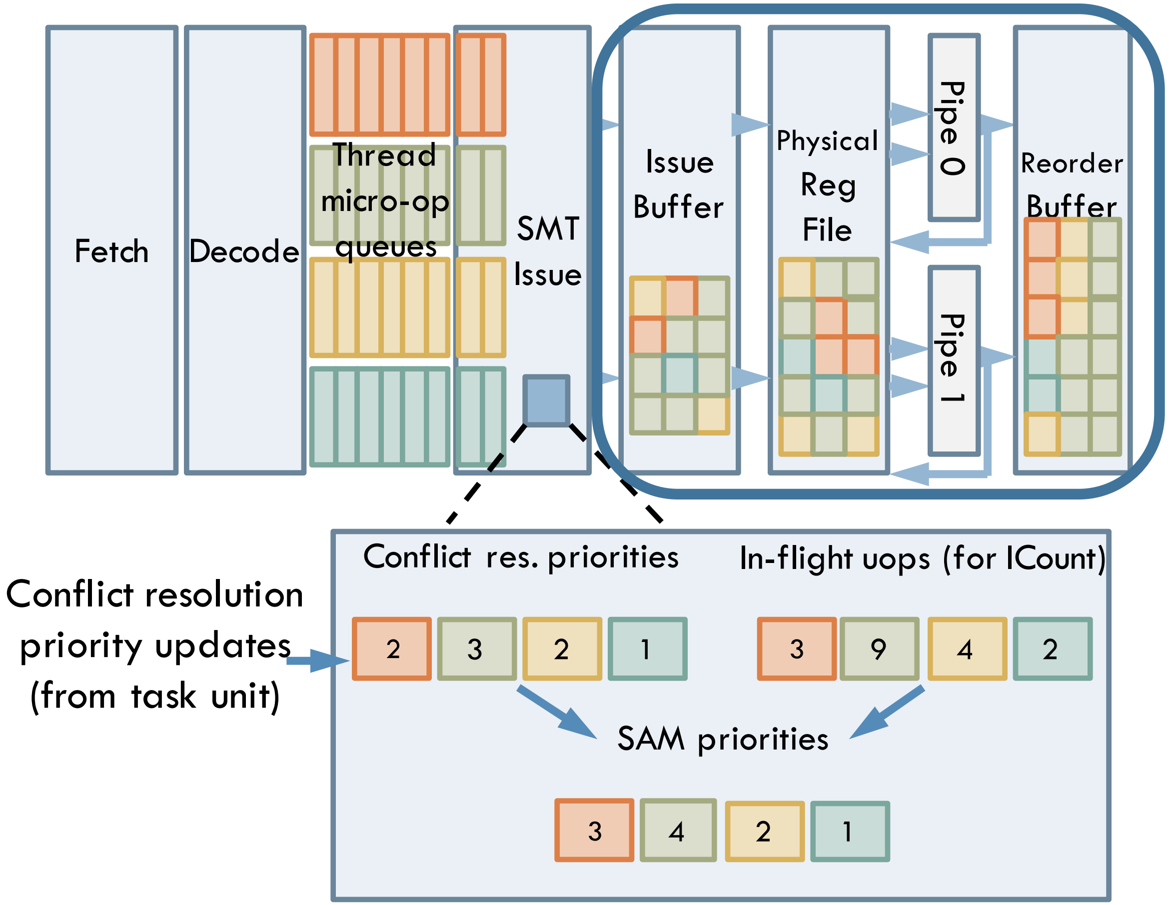
Unlike in-order cores, priorities affect pipeline efficiency

- A single thread can clog core resources
- Increased wrong path execution

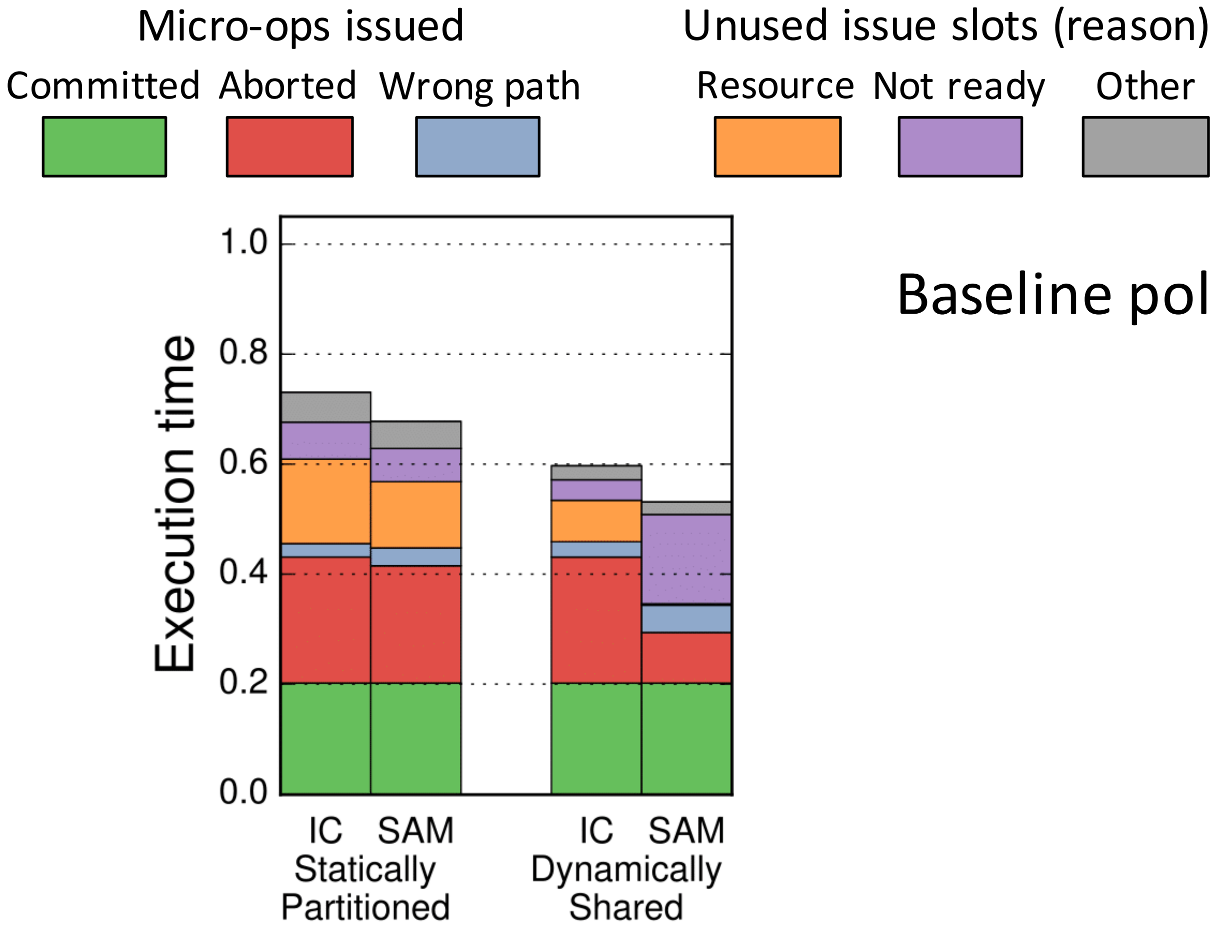
Despite these, prioritizing tasks is better

Need for aggressive prioritization affects core design

- Shared, not partitioned ROBs



SAM tradeoffs with out-of-order cores



sssp – 8 threads

Baseline policy - ICount (IC)

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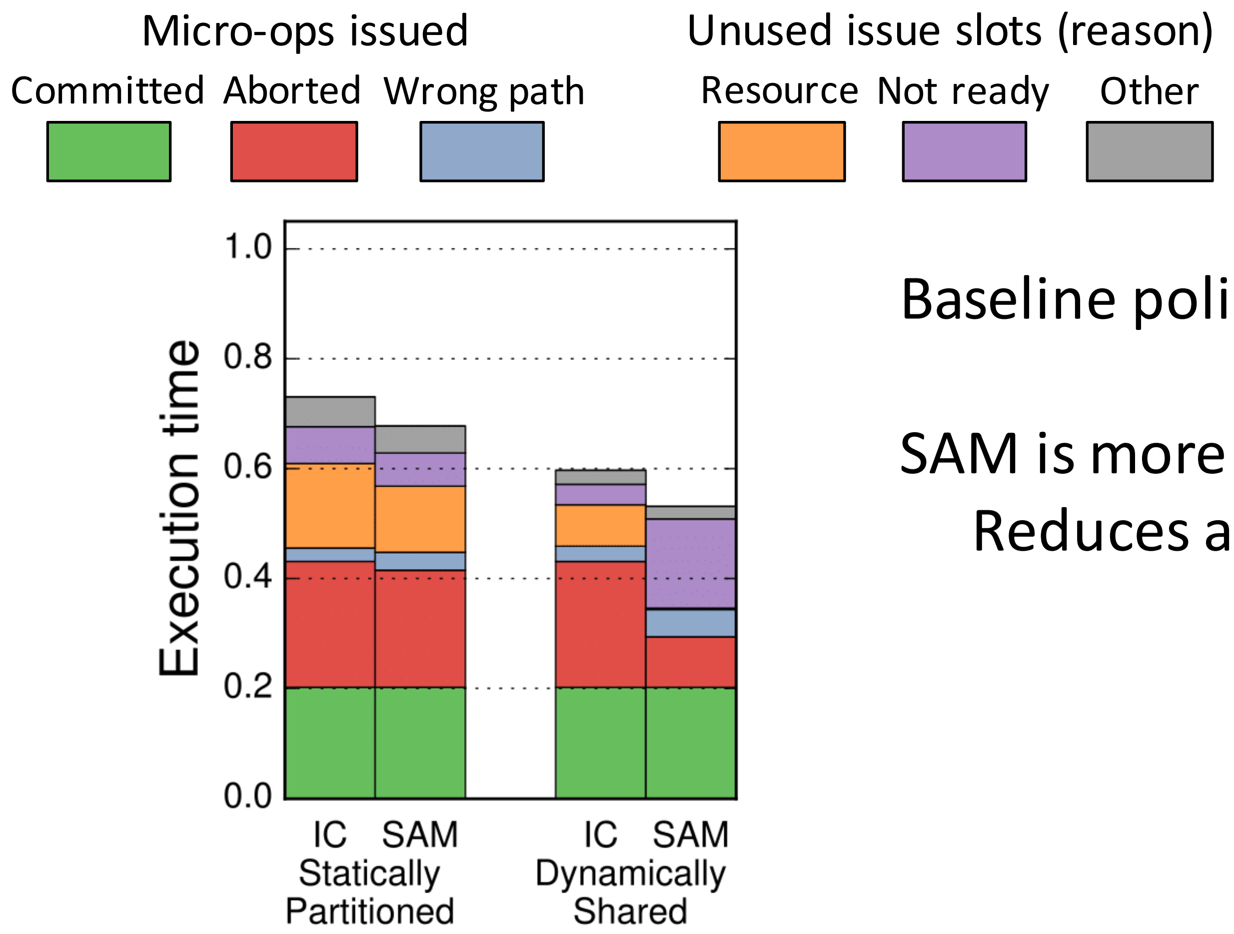

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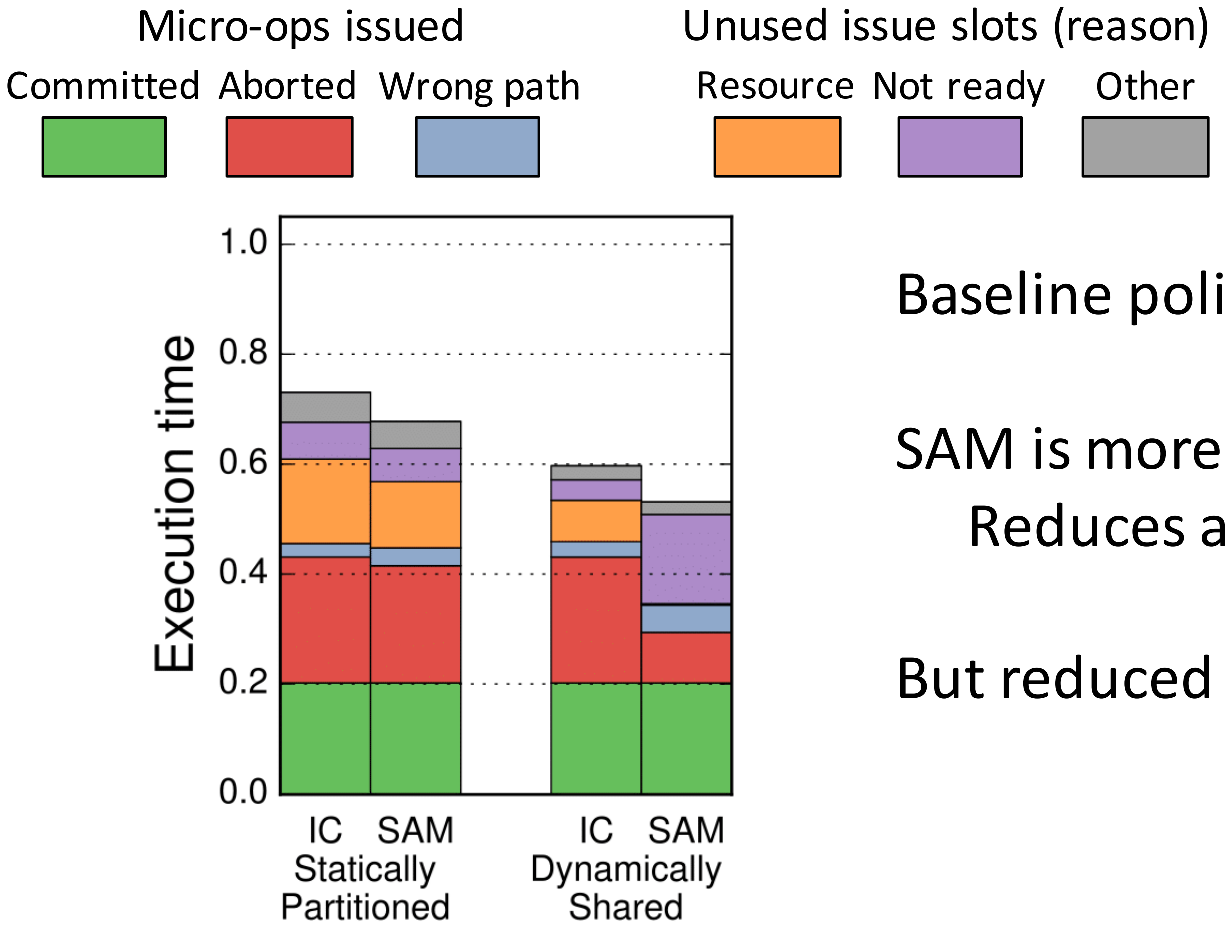

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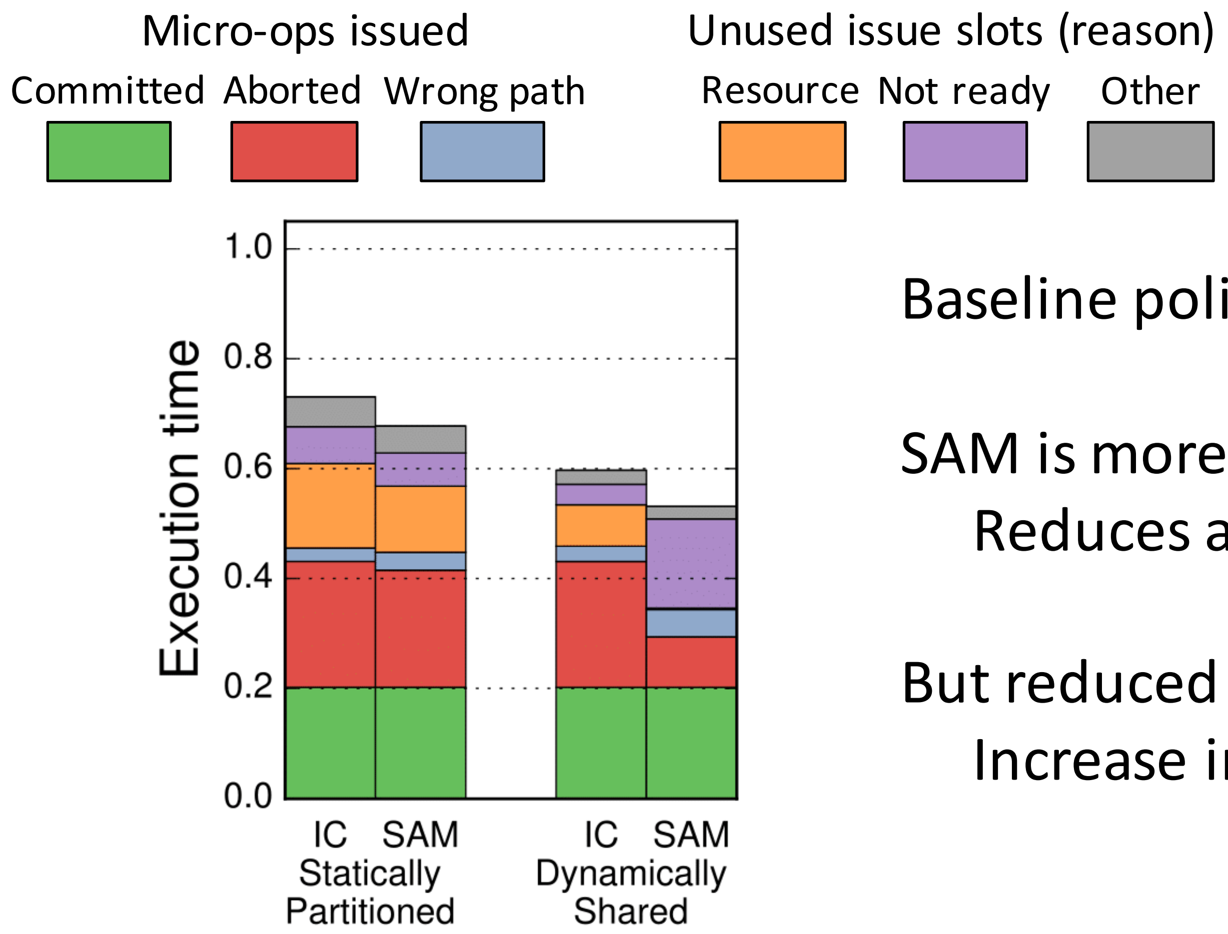

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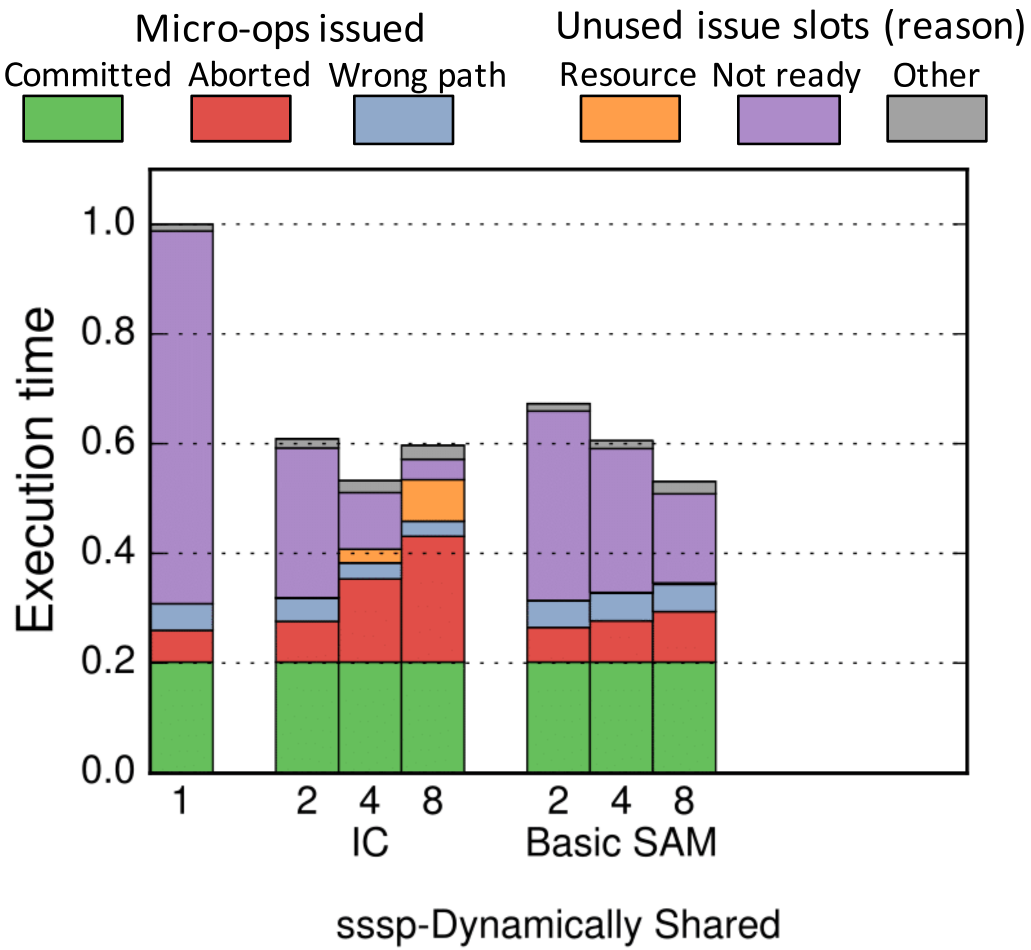
But reduced pipeline efficiency

Increase in wrong-path issues + not-ready stalls

Adaptive SAM policy



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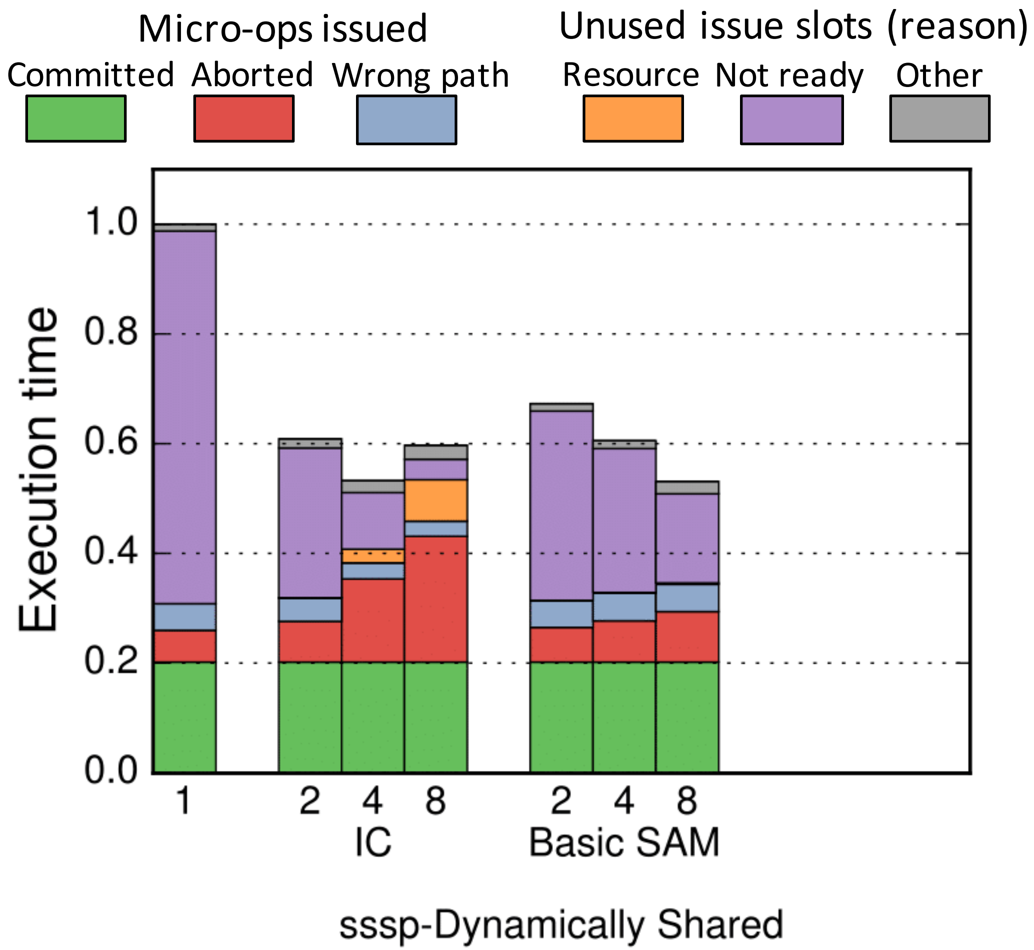
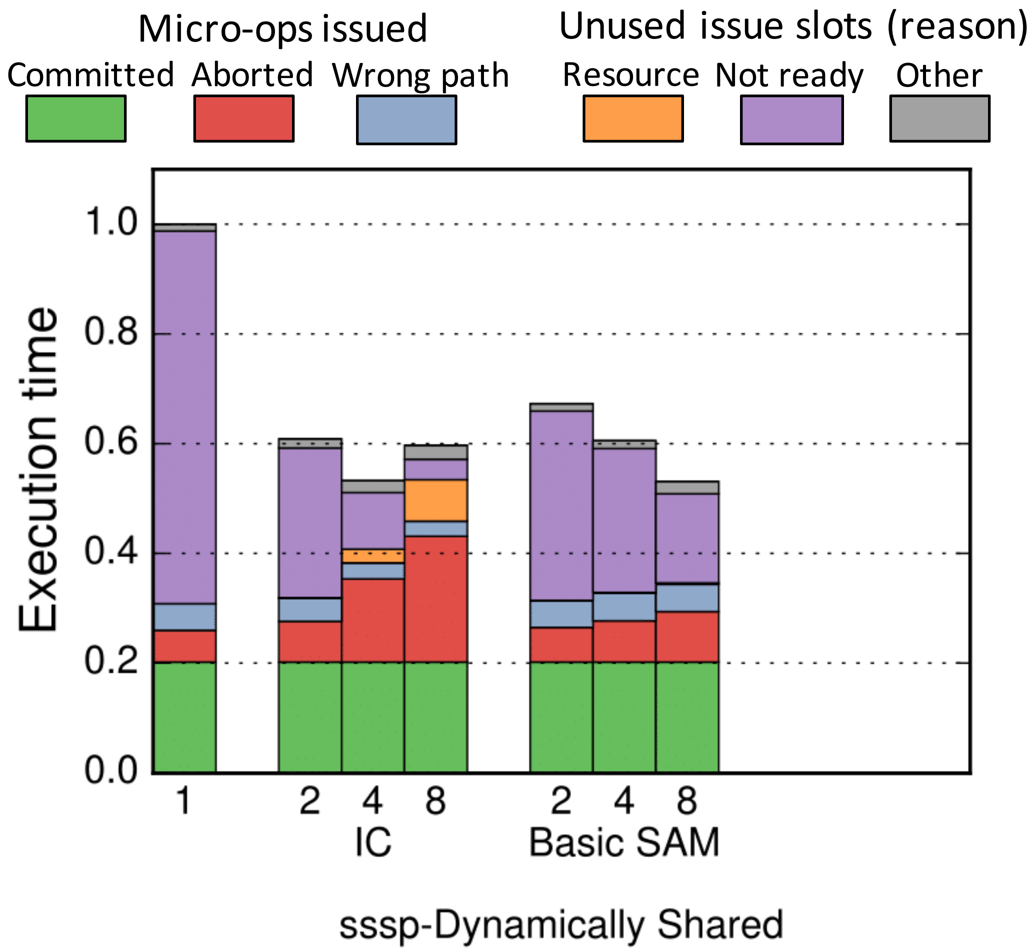


Hardware counters to track cycles

Adaptive SAM policy



Hardware counters to track cycles

Aborted Resource Wrong path Not ready

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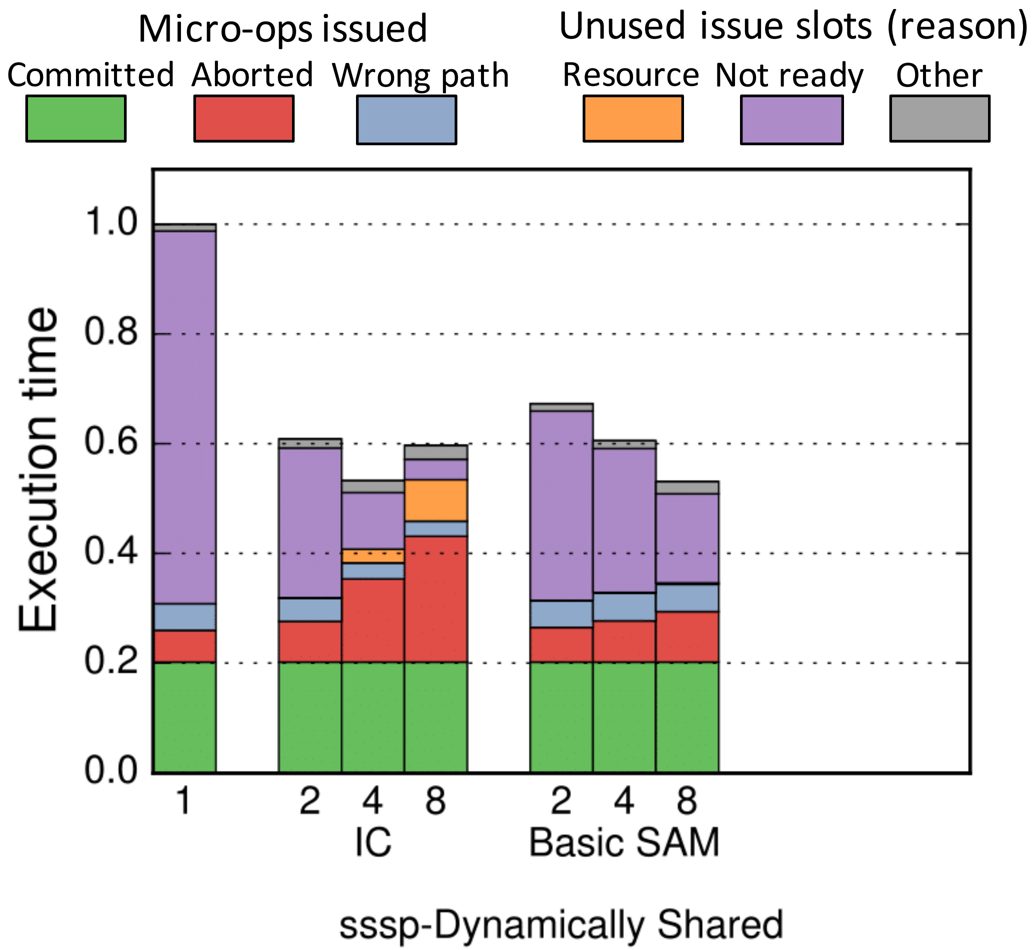

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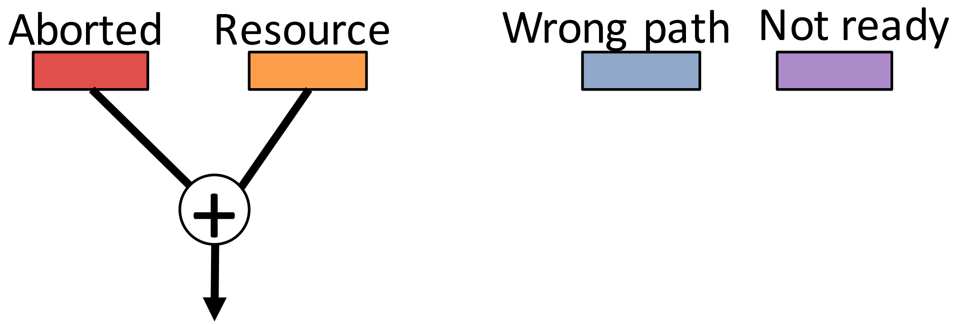

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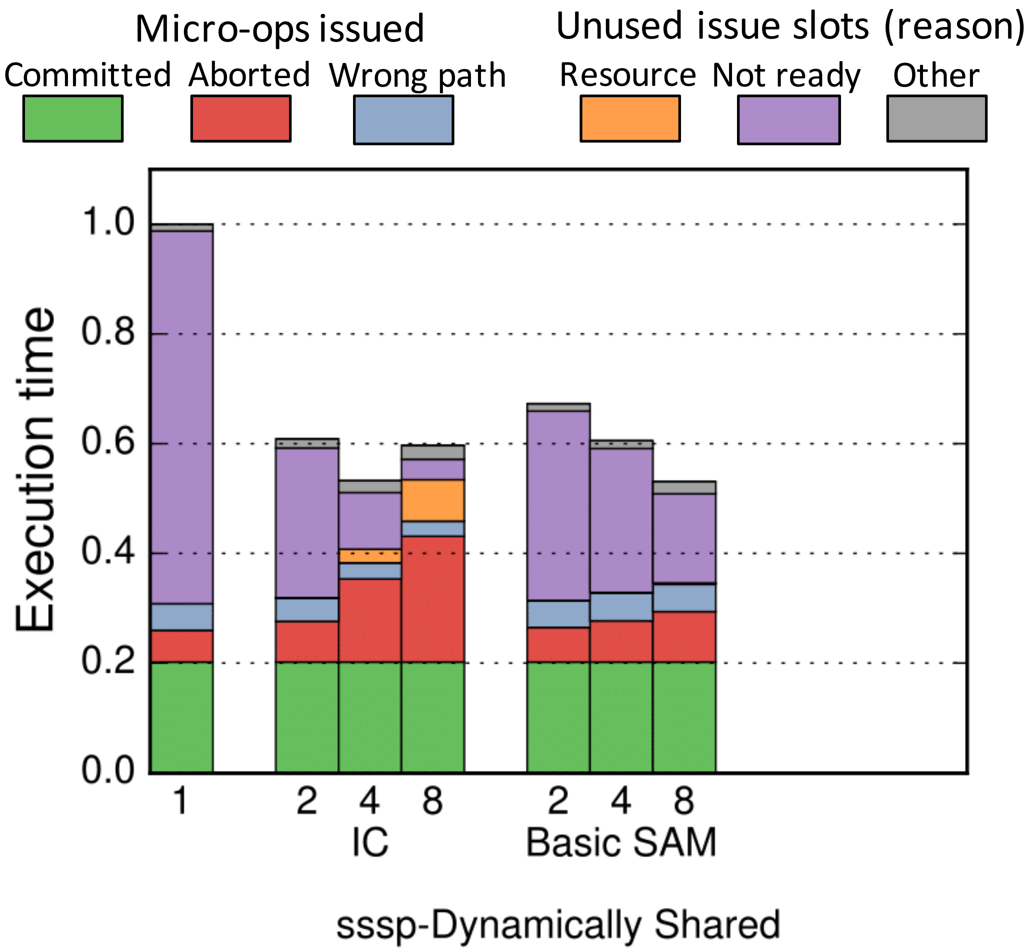

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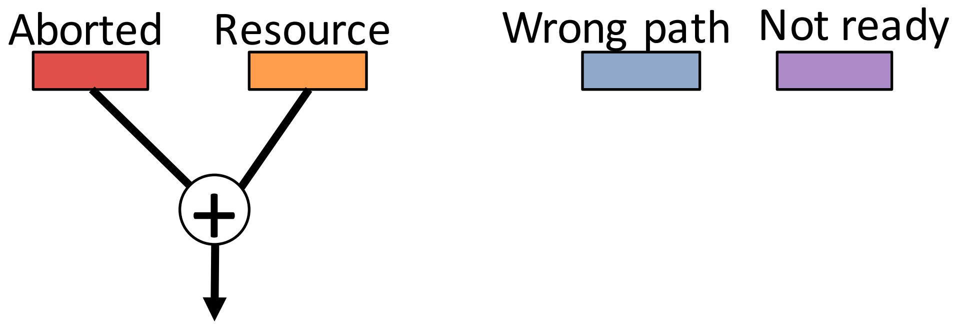
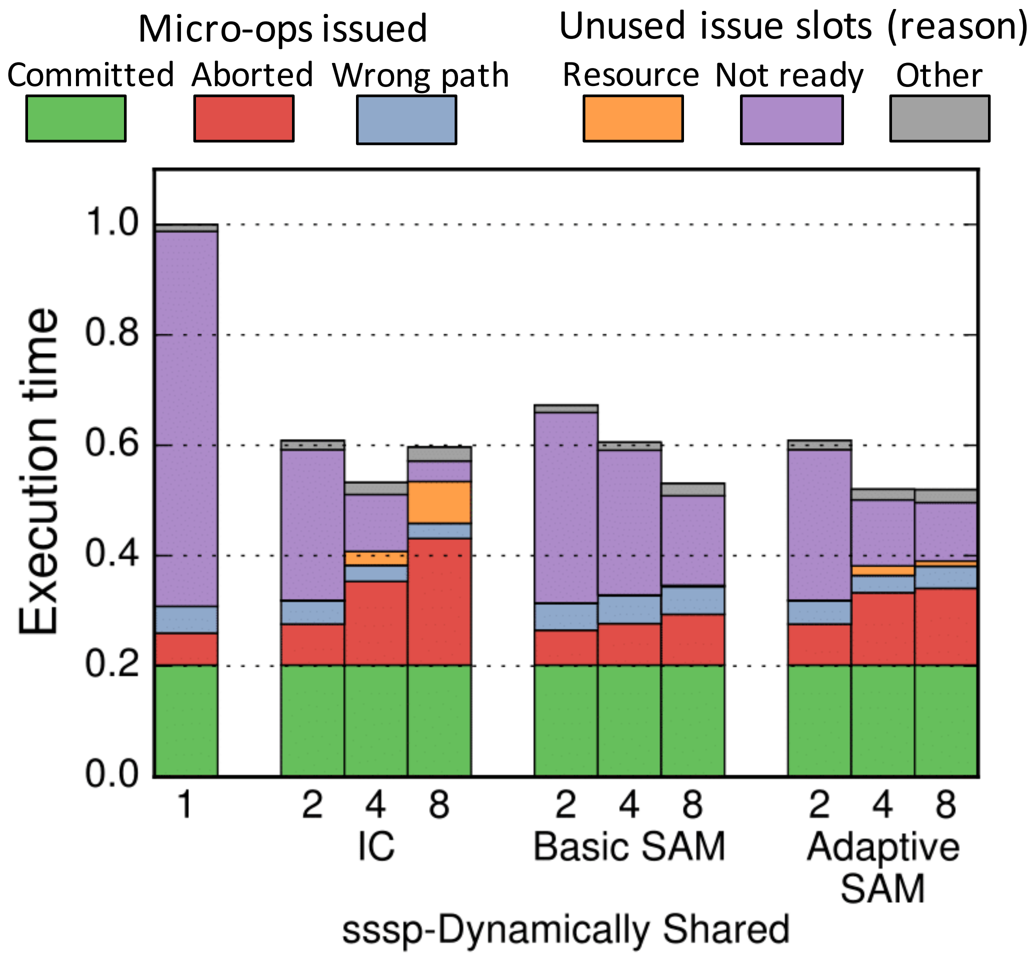
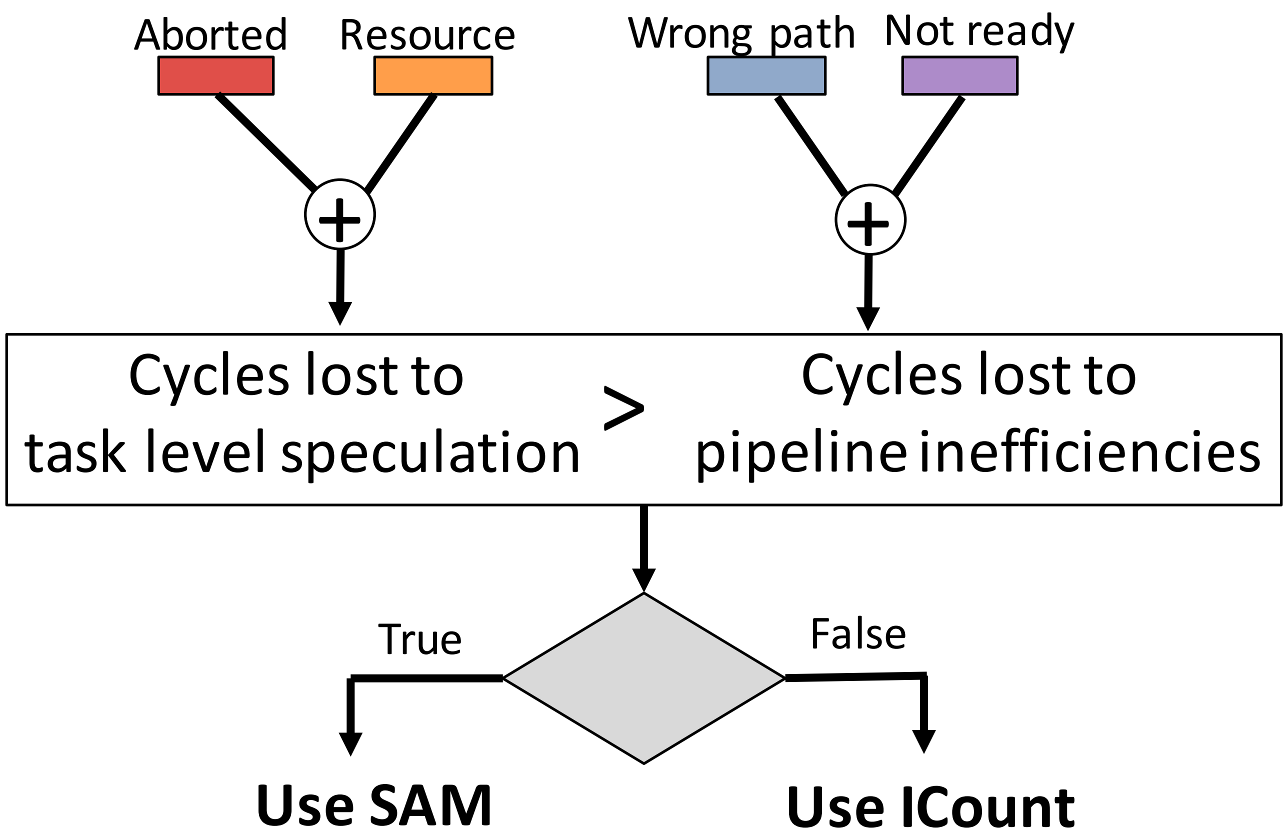


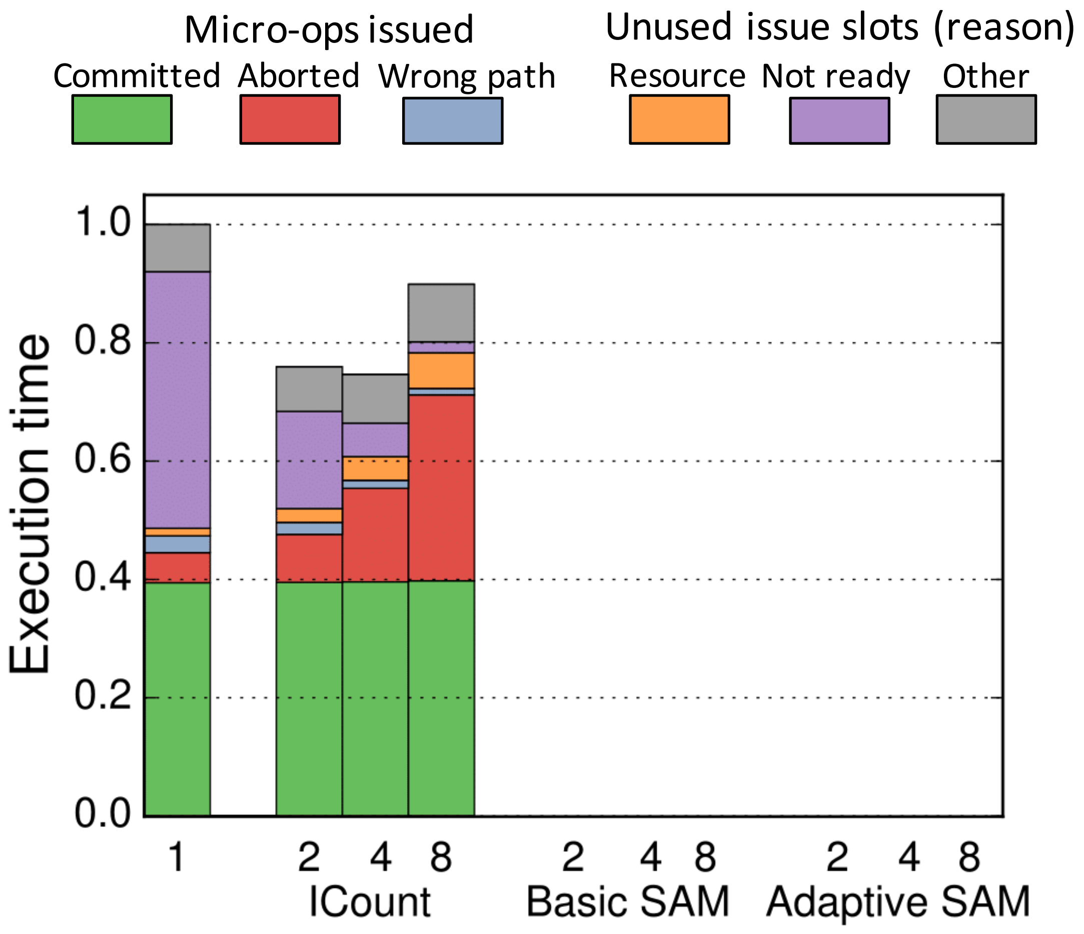
Cycles lost to
task level speculation

Adaptive SAM policy





SAM on OoO cores (all benchmarks)



Average over all benchmarks

At 8 threads / core:

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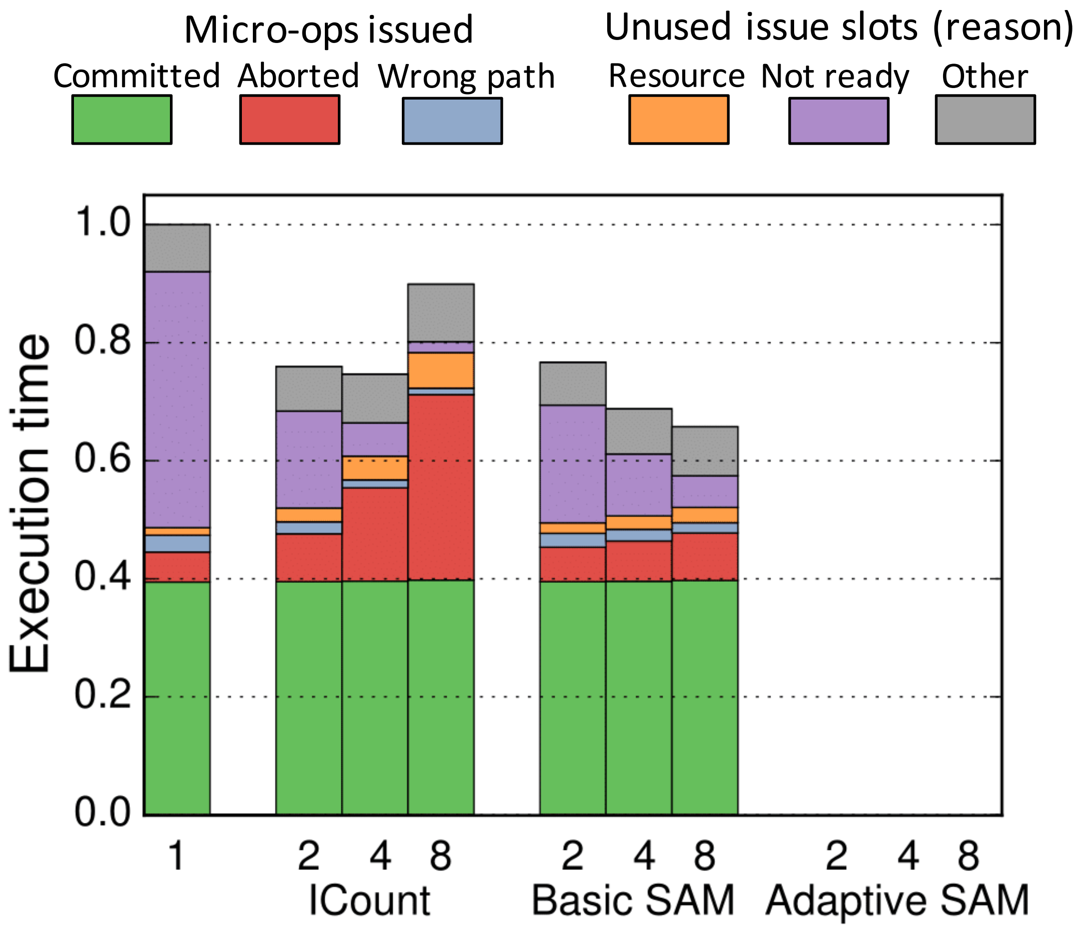

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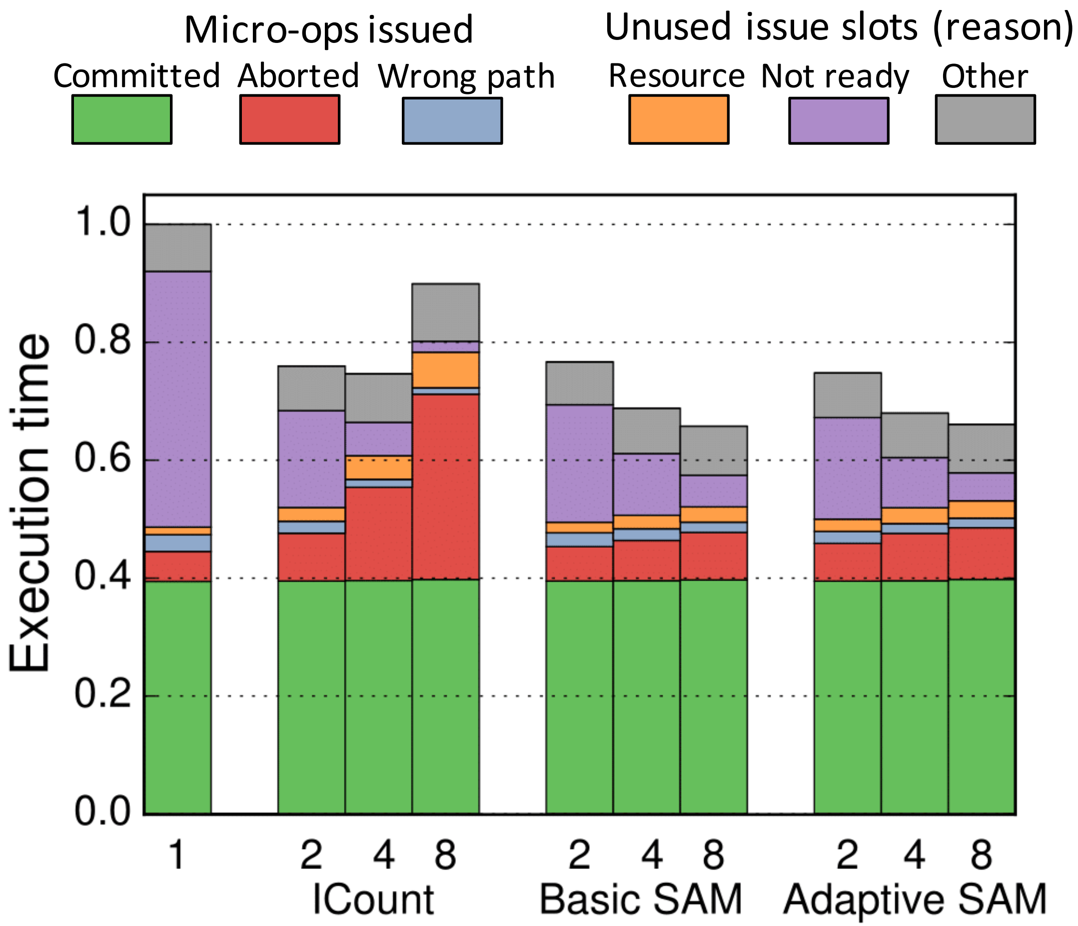

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Adaptive policy slightly increases performance at 2 and 4 threads

Conclusion

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- Inefficient use of speculation resources

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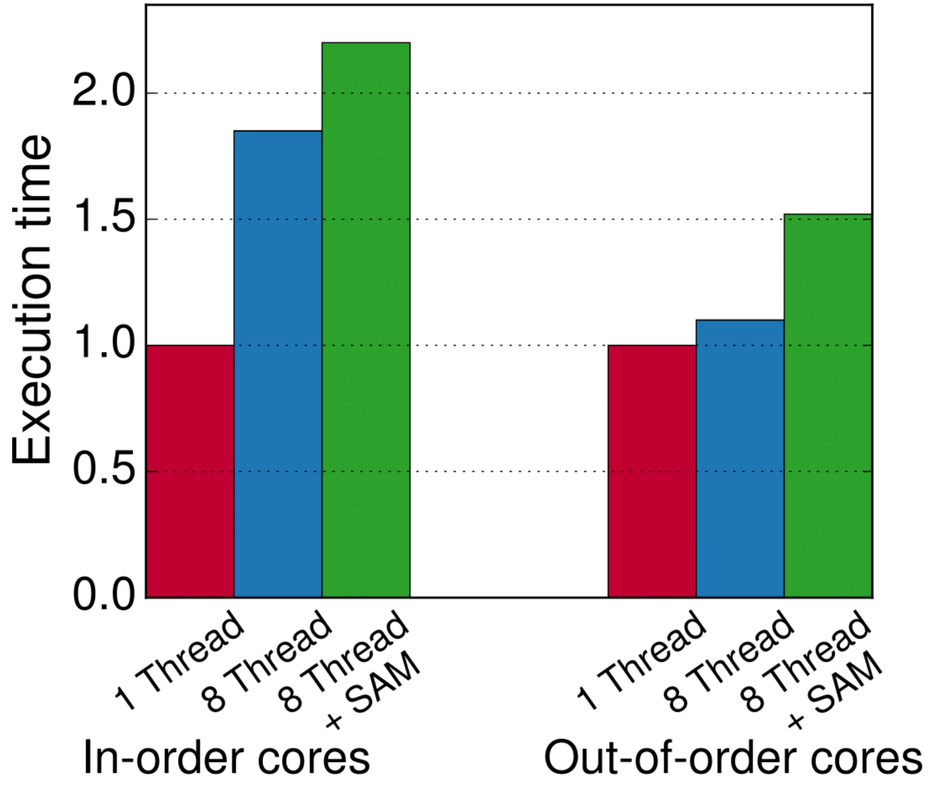
SAM makes multithreading more useful



Questions?

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