Schism: Fragmentation-Tolerant Real-Time Garbage Collection

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- minimizes external **fragmentation** *proven space bounds (see appendix)*

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We want something as fast as Metronome, but fragmentation-tolerant like Java RTS.

Previous Approaches to Minimizing Fragmentation in RTGC

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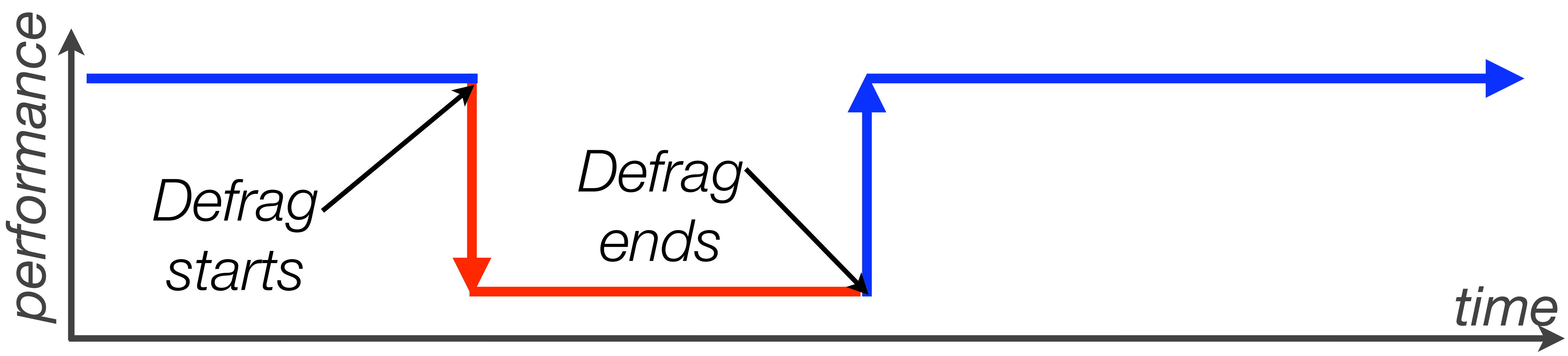

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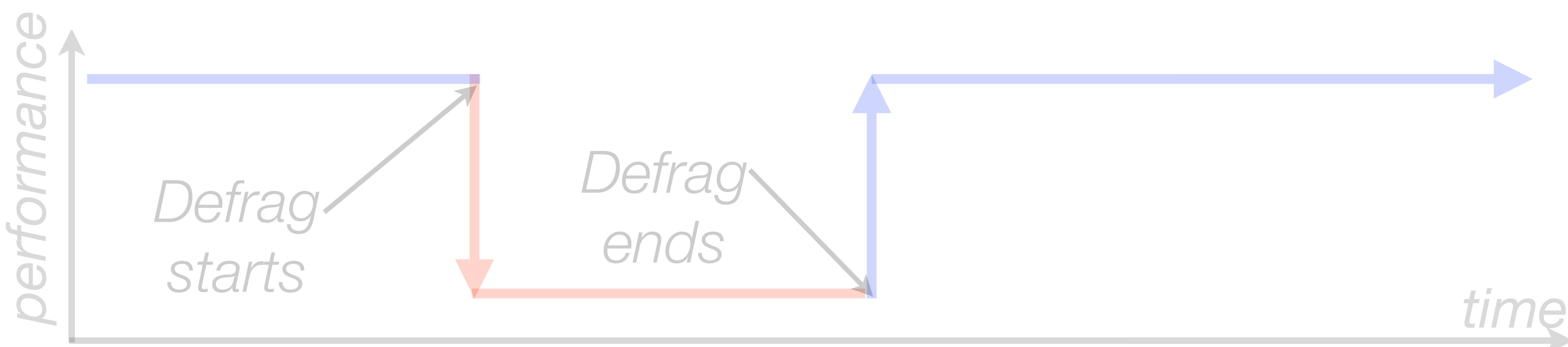
Worst-case throughput penalty is too large.



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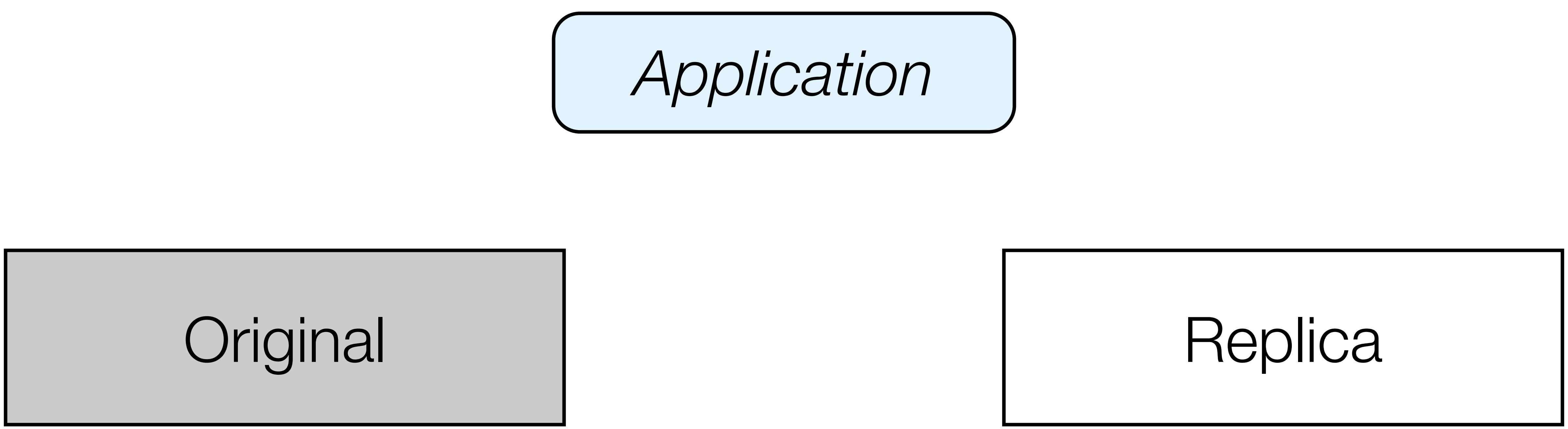

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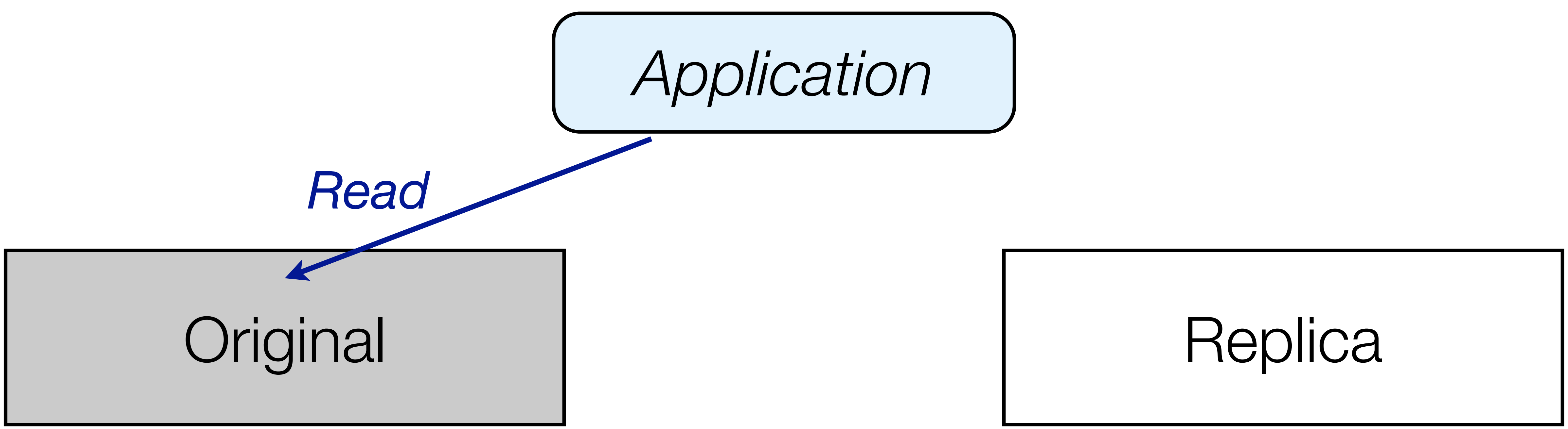

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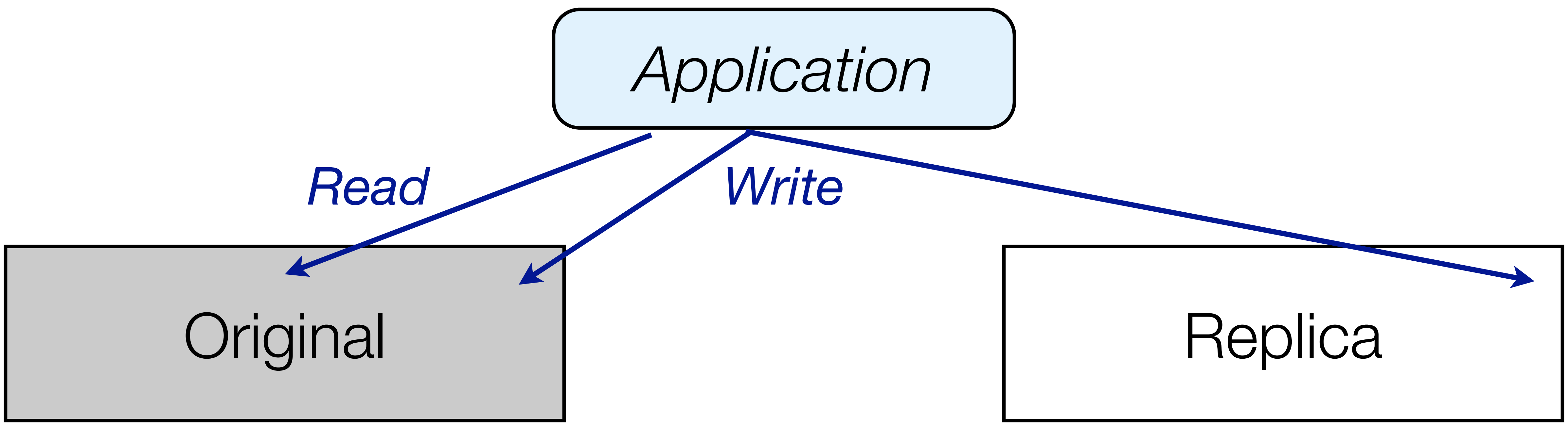

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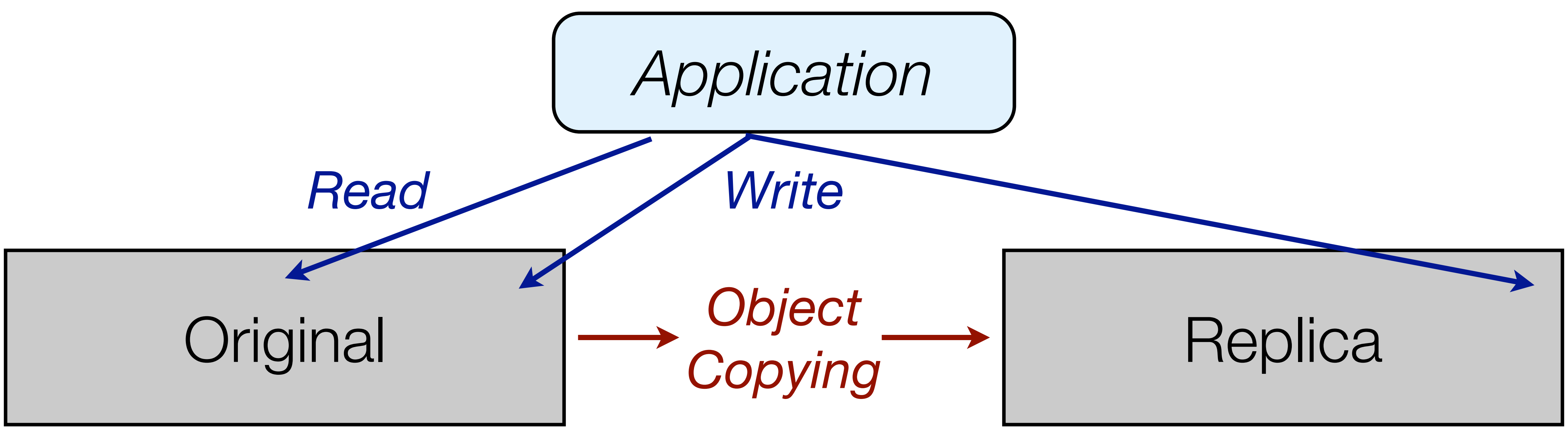

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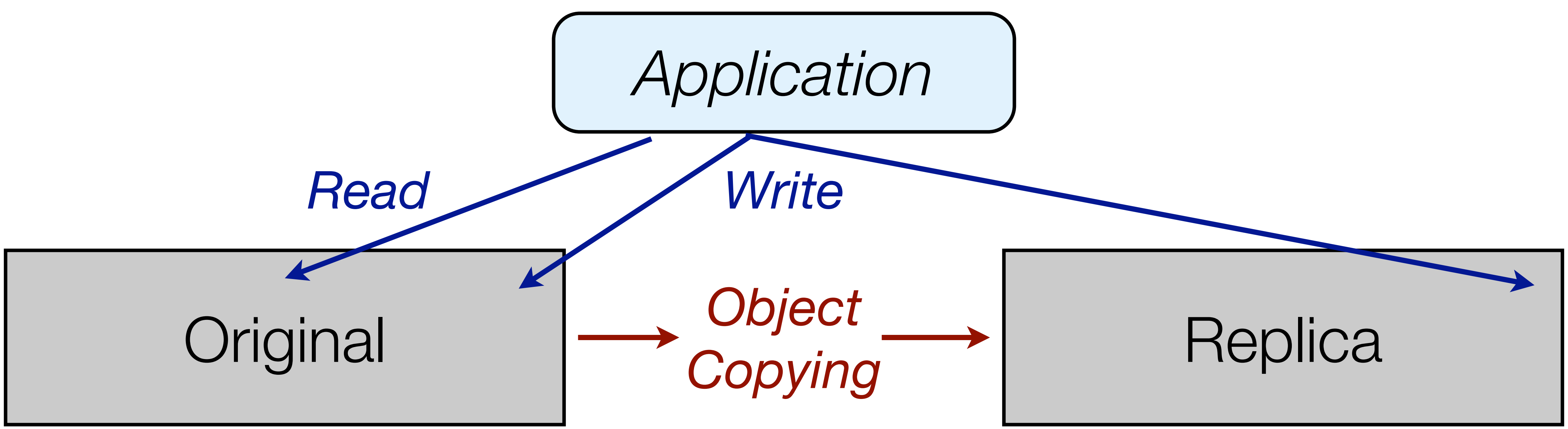

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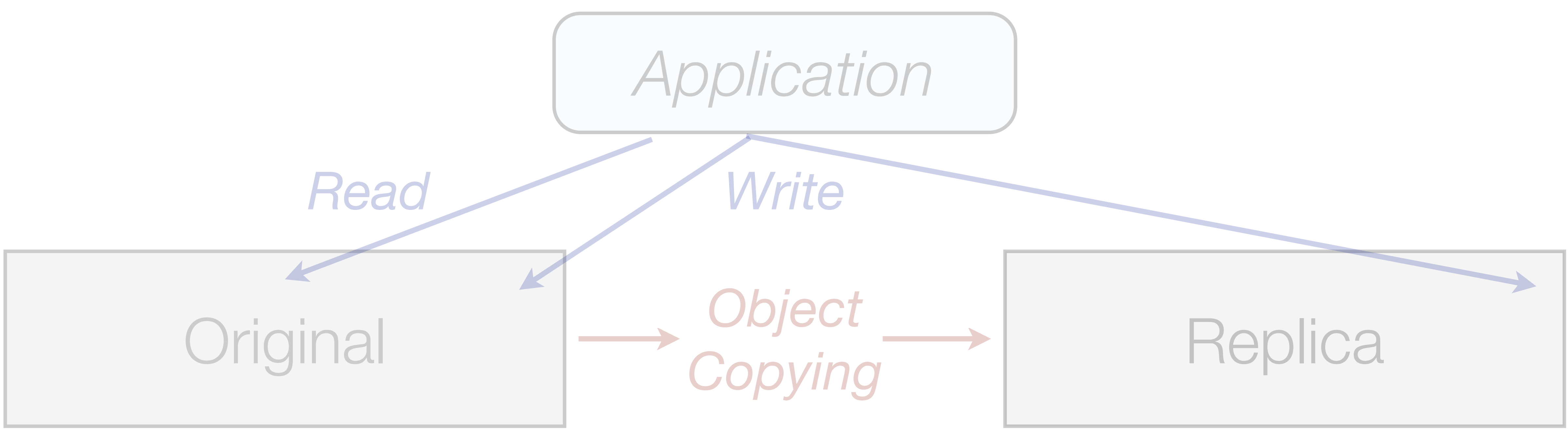
Works best for immutable objects.



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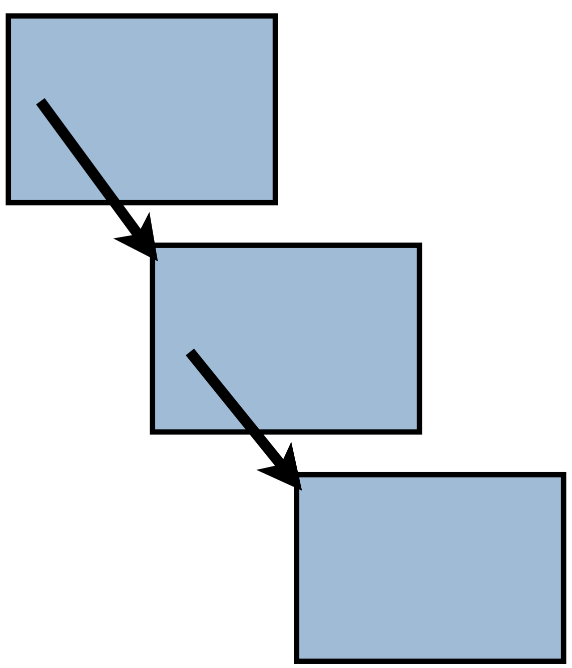

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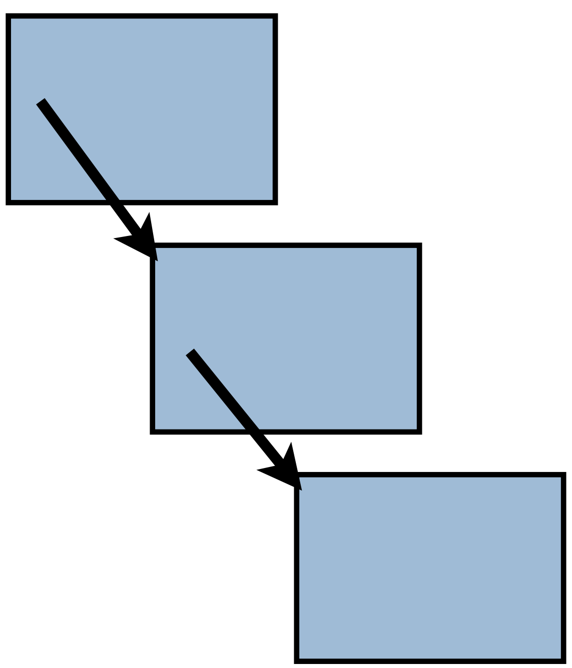

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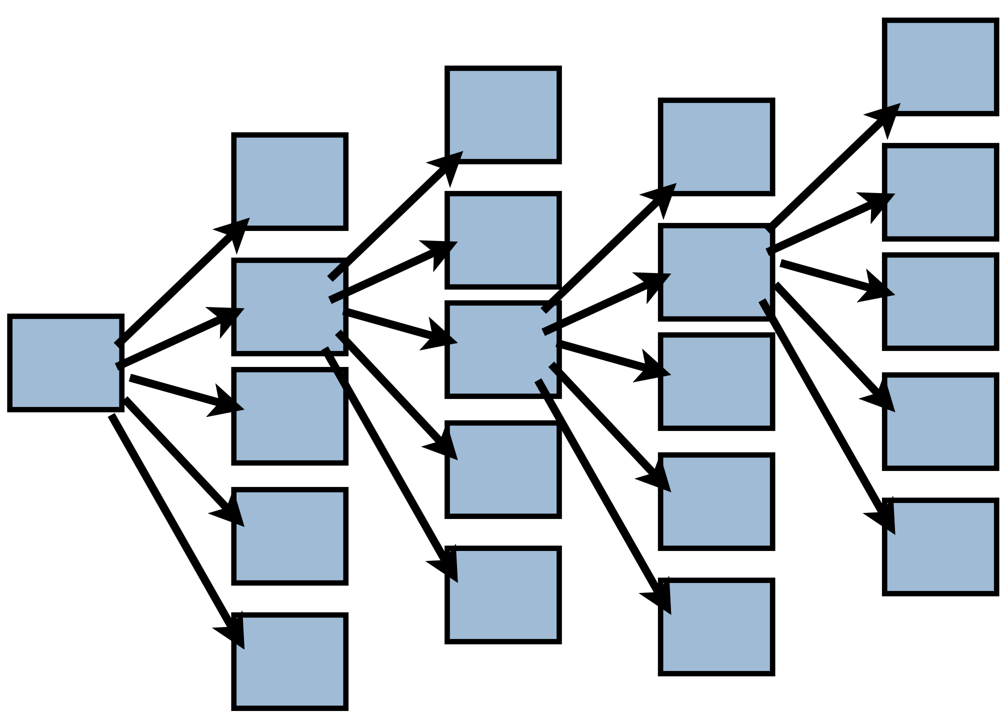

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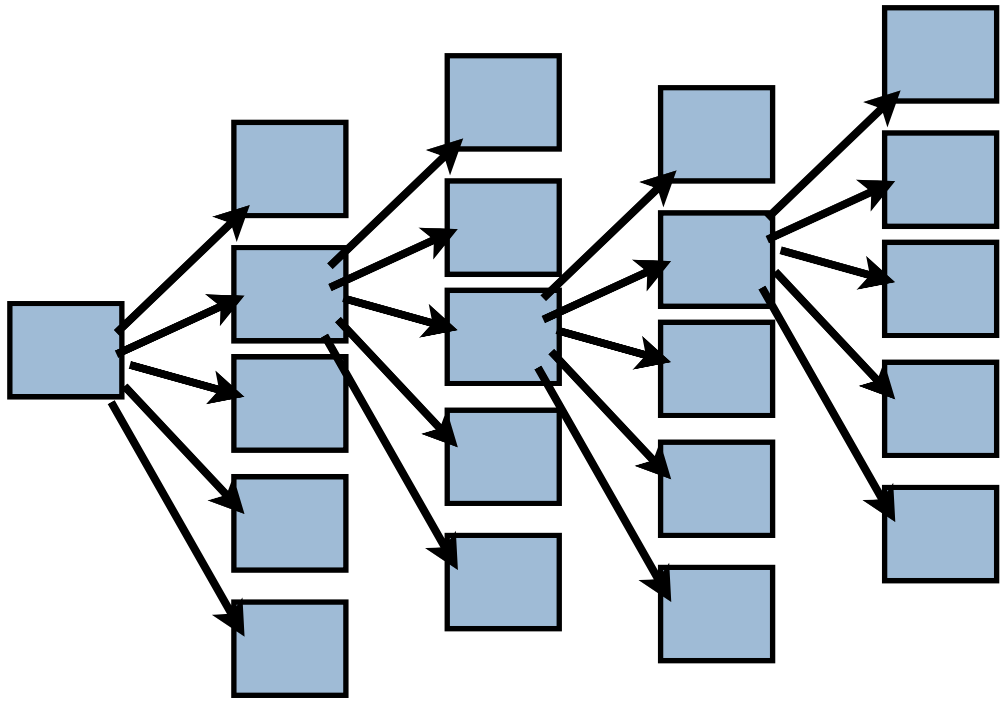

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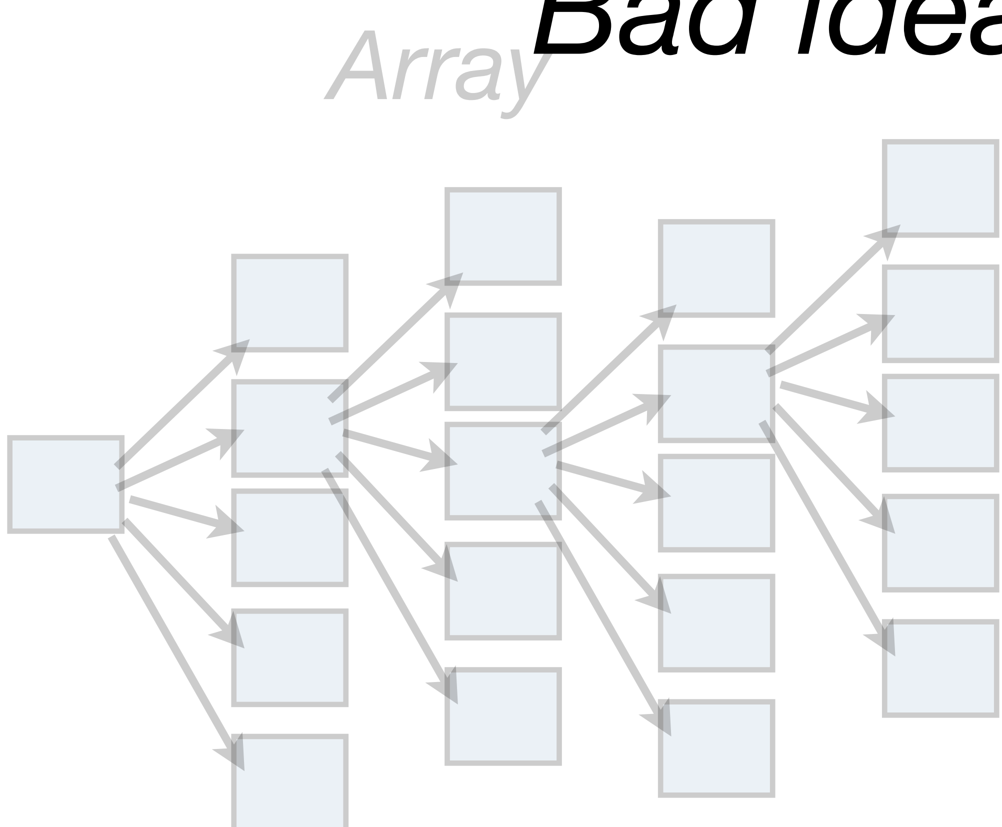
Bad idea for large arrays.



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Can we combine the two?

Idea:

combine *Fragmented Allocation*
with *Replication-Copying*
using *Arraylets*

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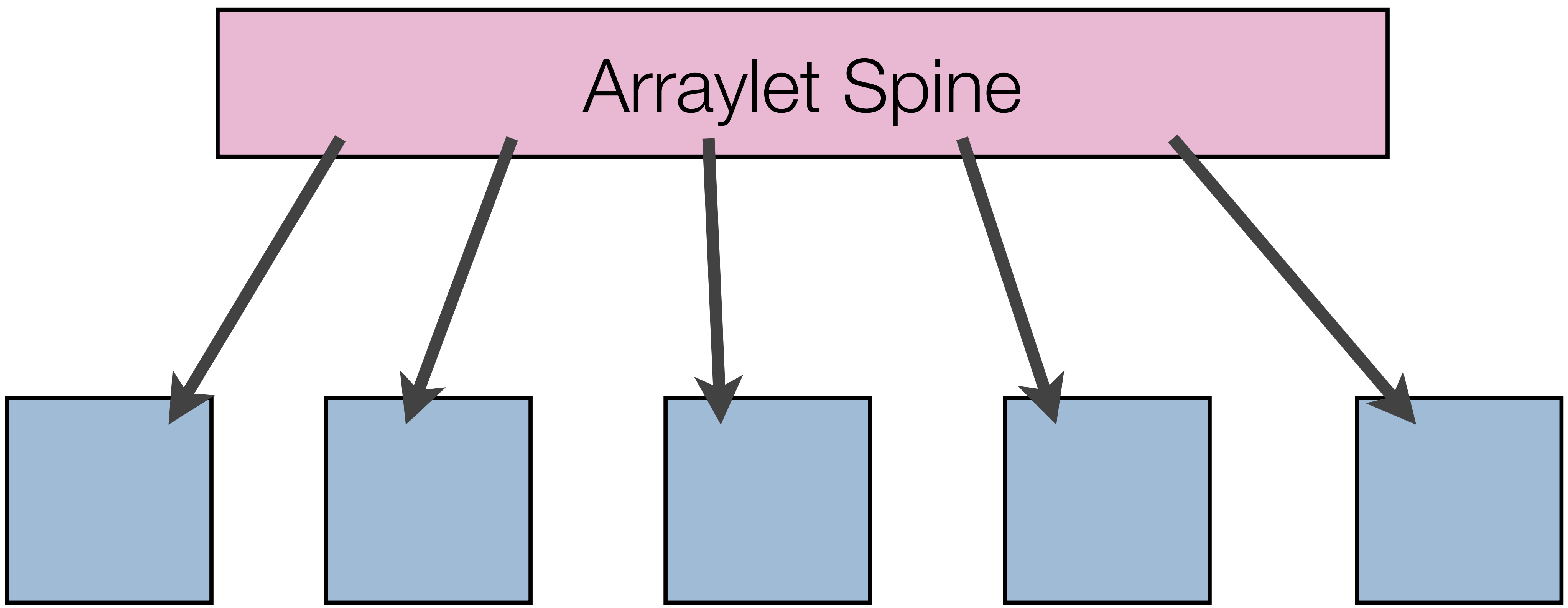

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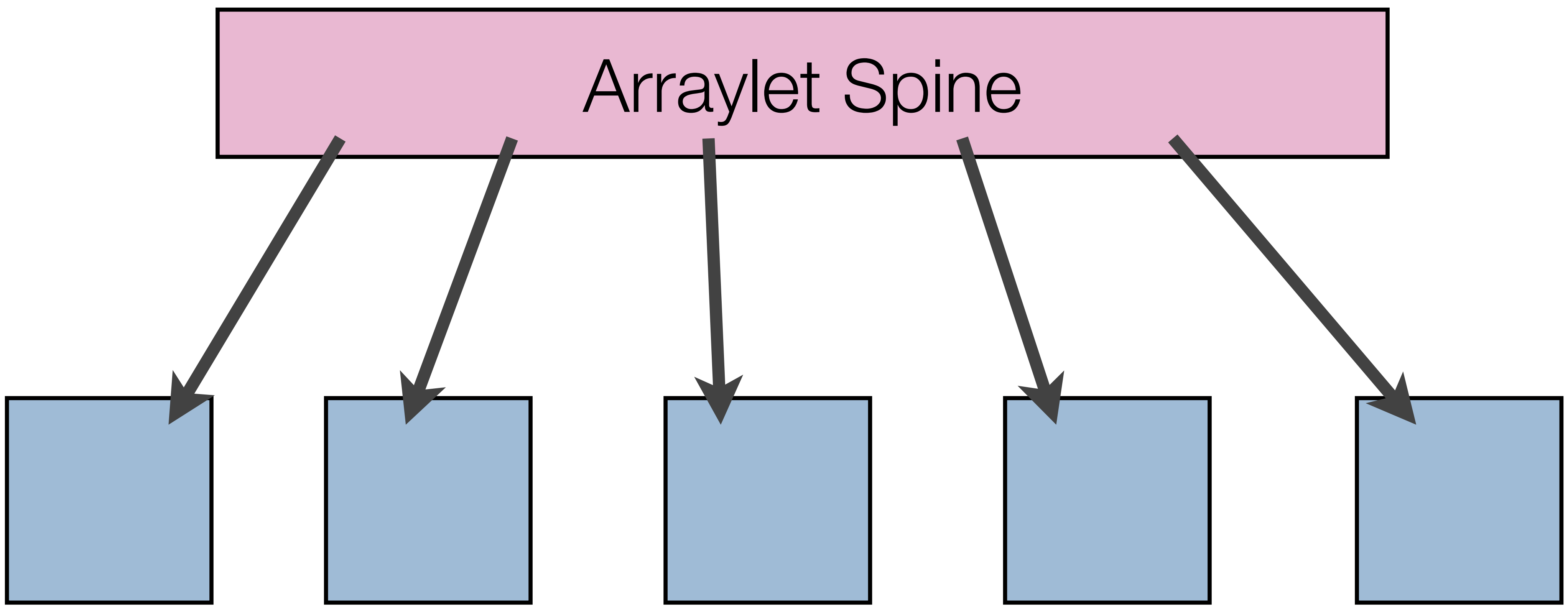

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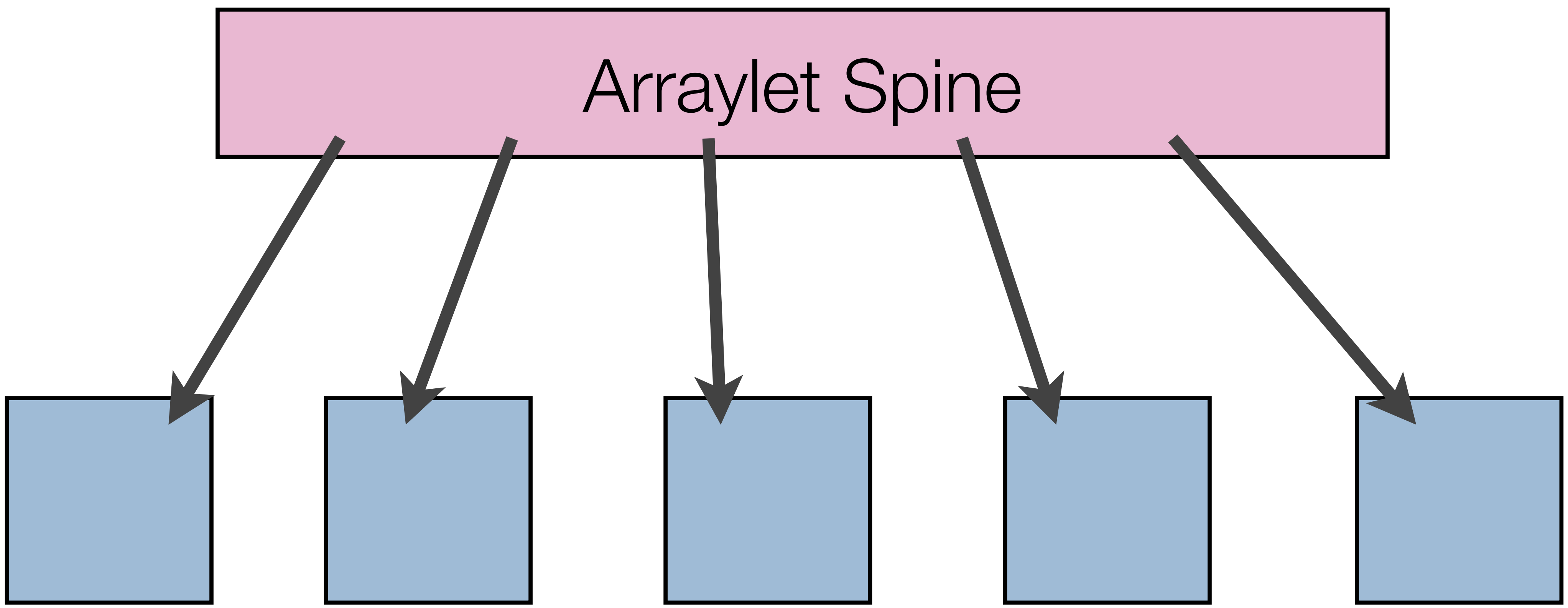
A new way of exploiting Arraylets

The Arraylet Spine has variable size, which can lead to fragmentation!



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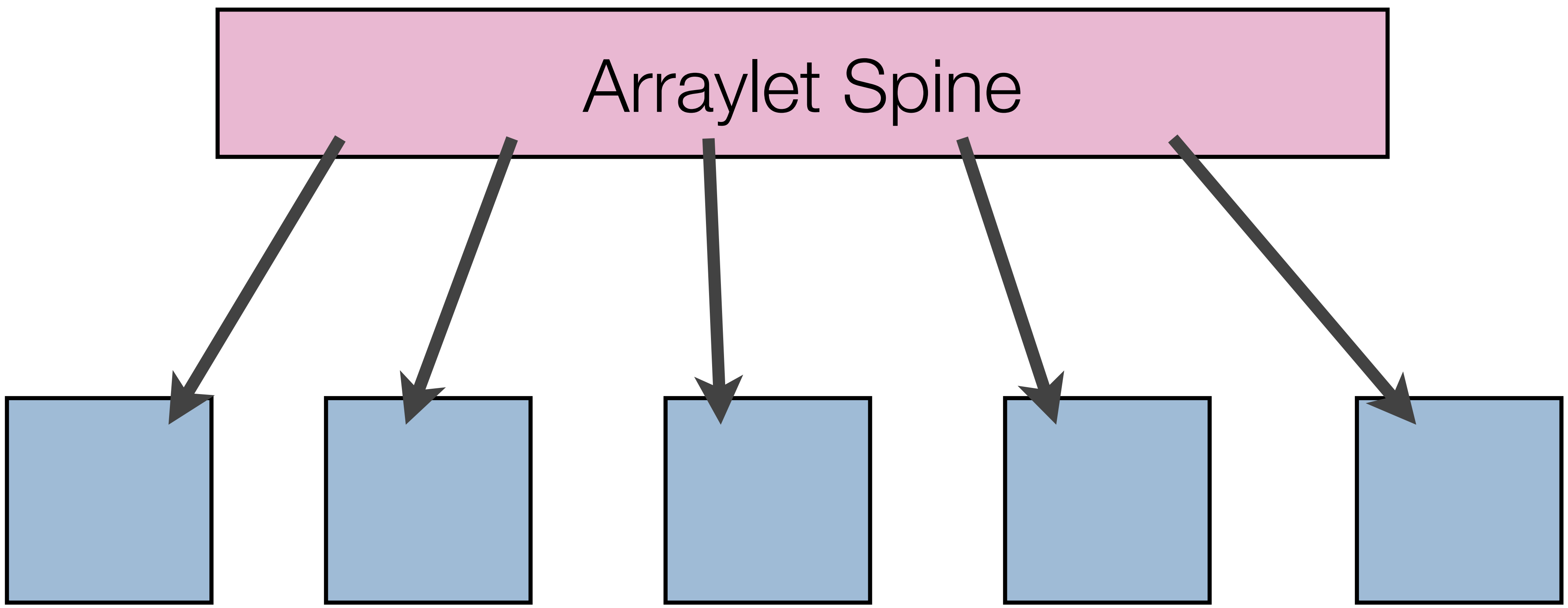

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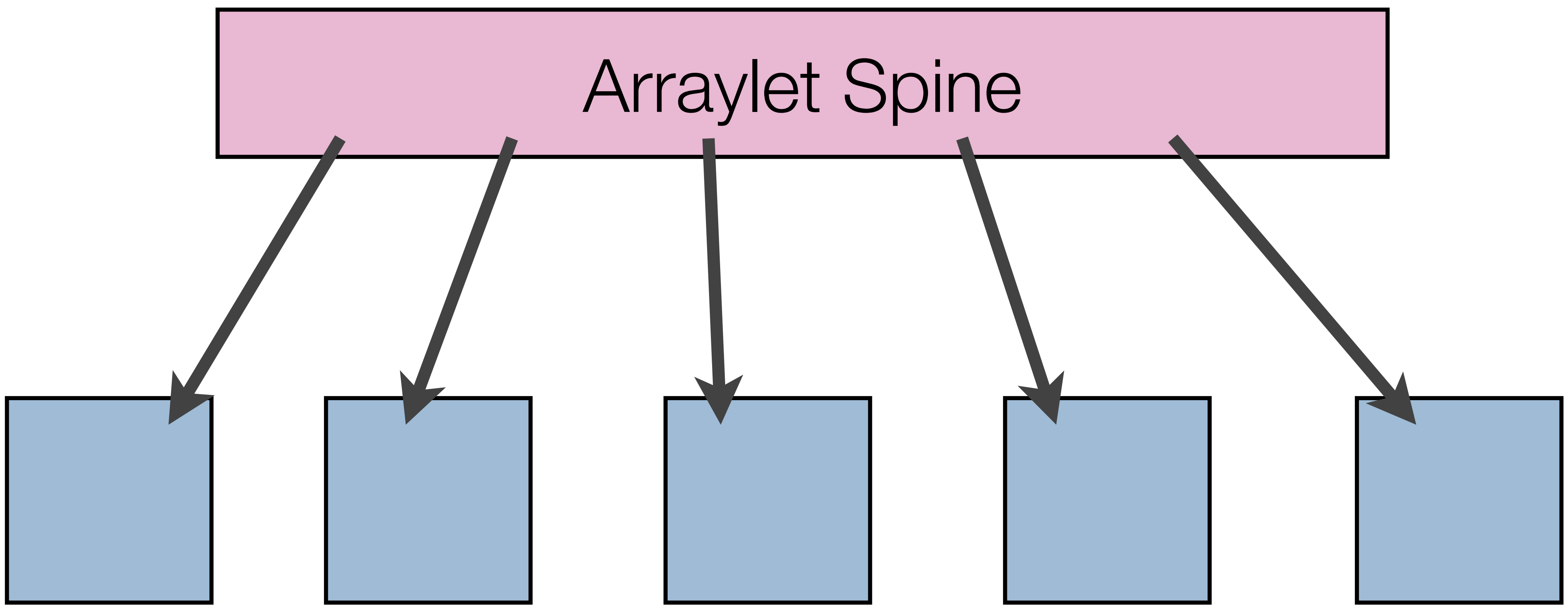
... and <u>replication</u> is ideal for immutable objects



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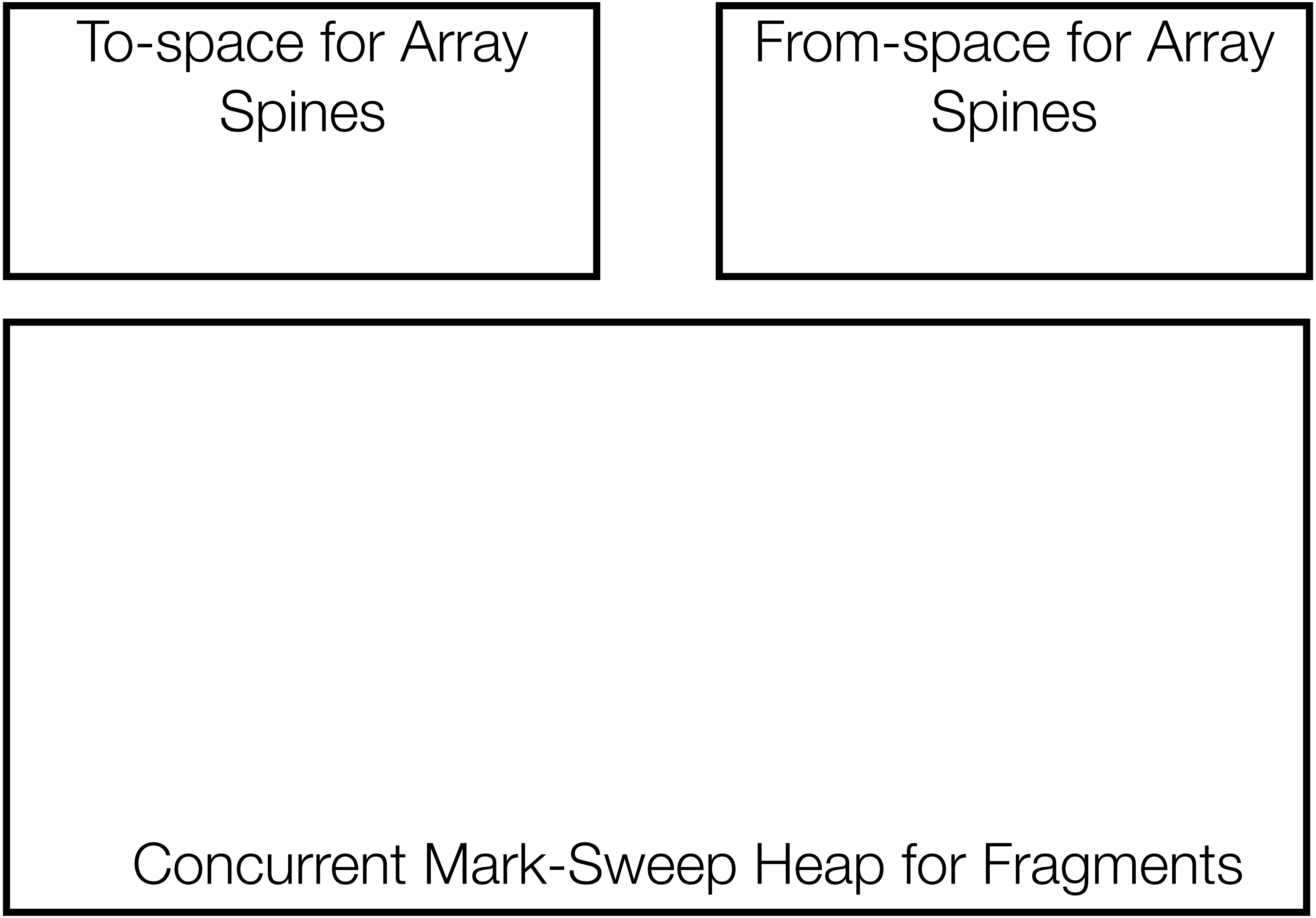
Schism = arraylets + replication + fragments

- Combination:
  - Concurrent **mark-sweep GC** for fixed-size **fragments**
  - **Replication copying** for variable-size **arraylet** spines
- *No external fragmentation for either fragments or spines*
- *Heap access is O(1), wait-free, and coherent.*

Concurrent Replication Heap for Spines



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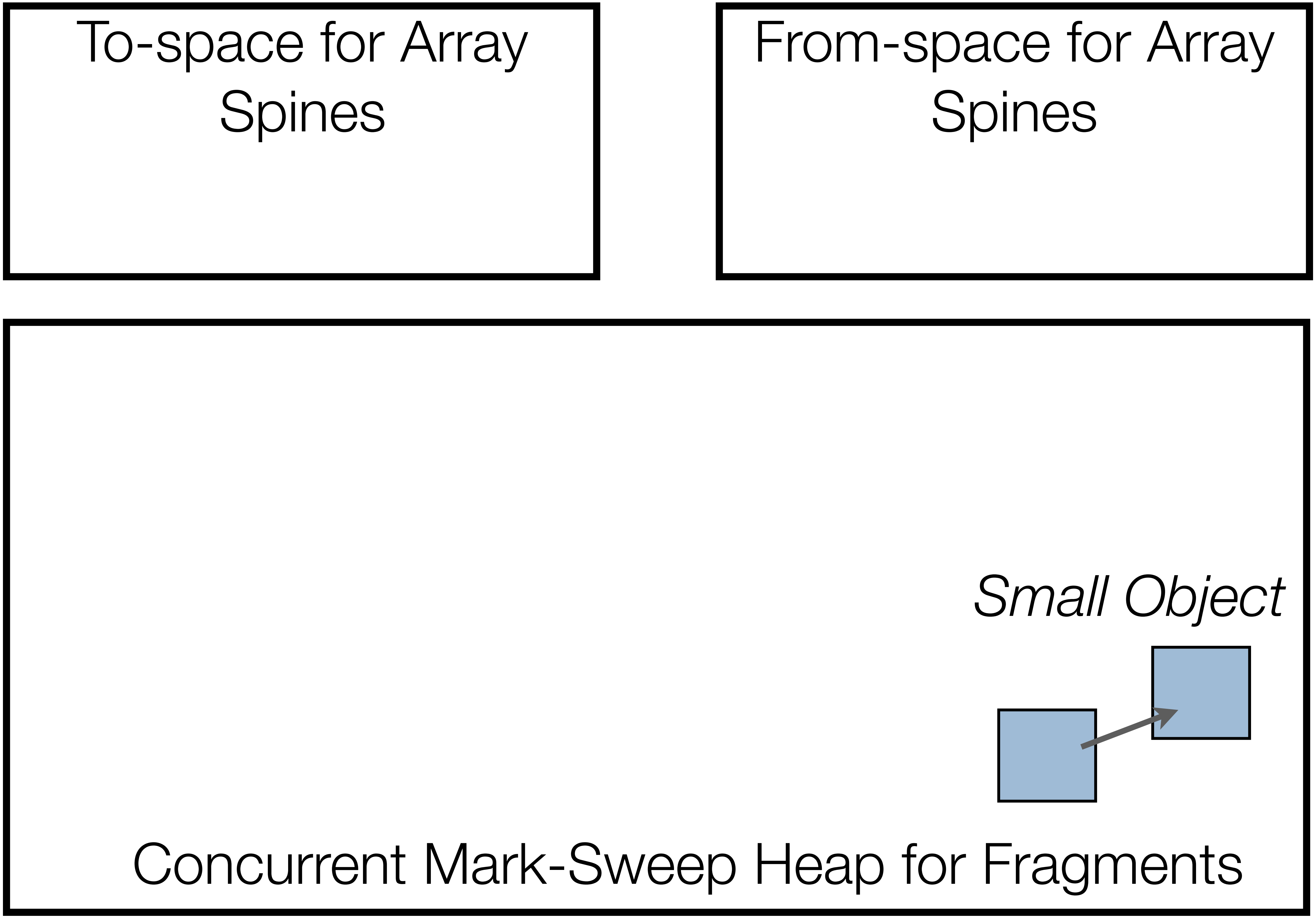

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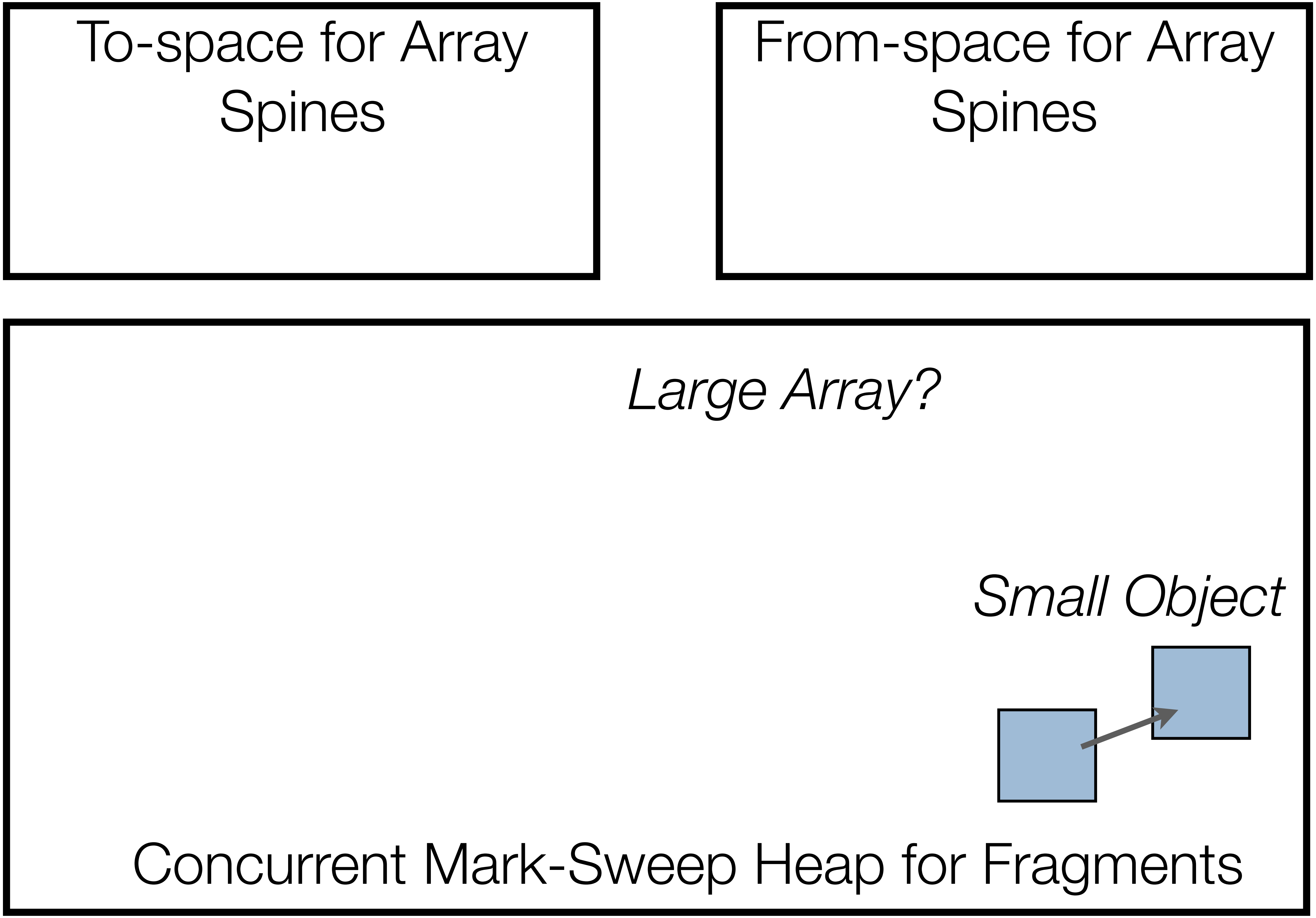

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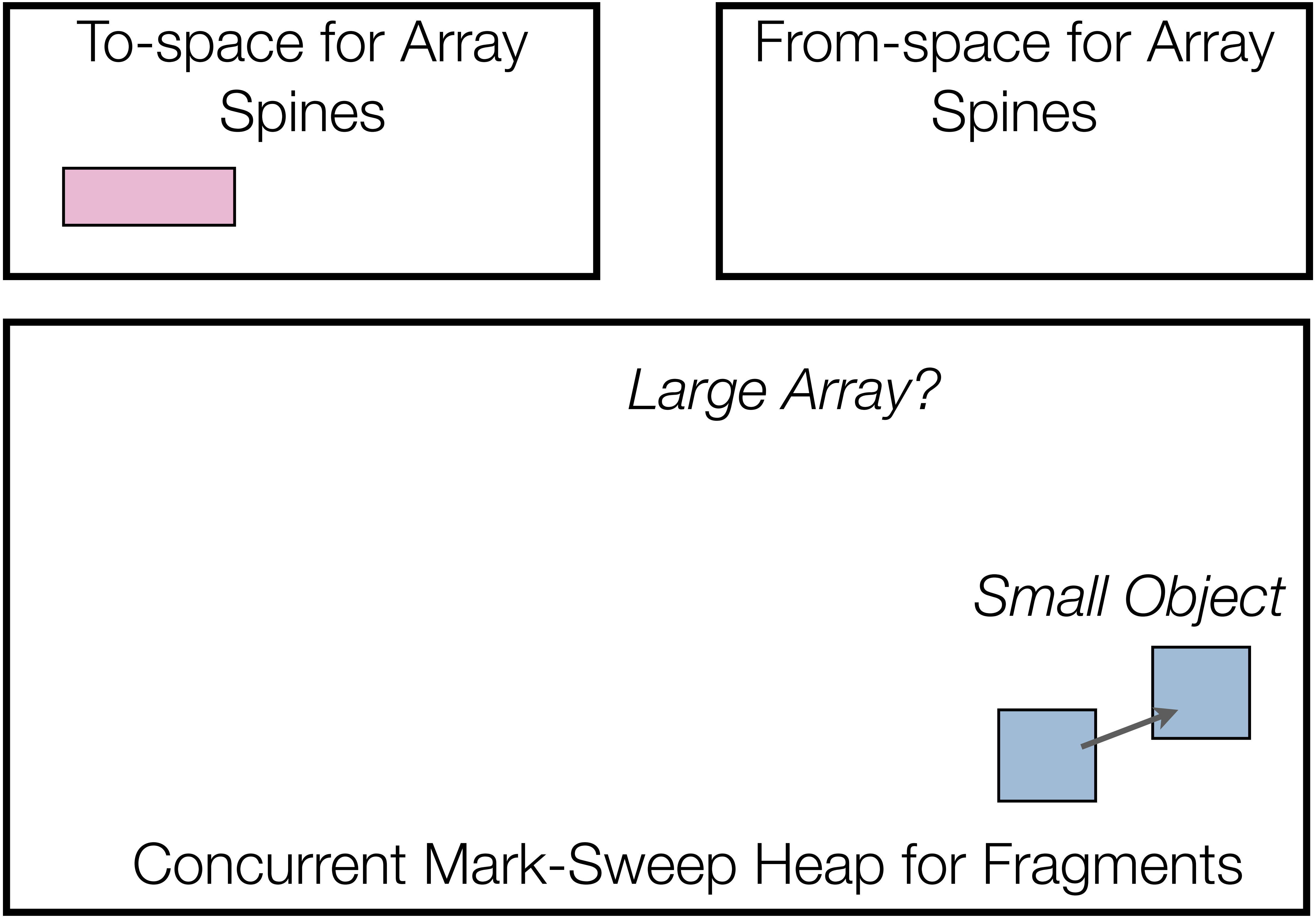

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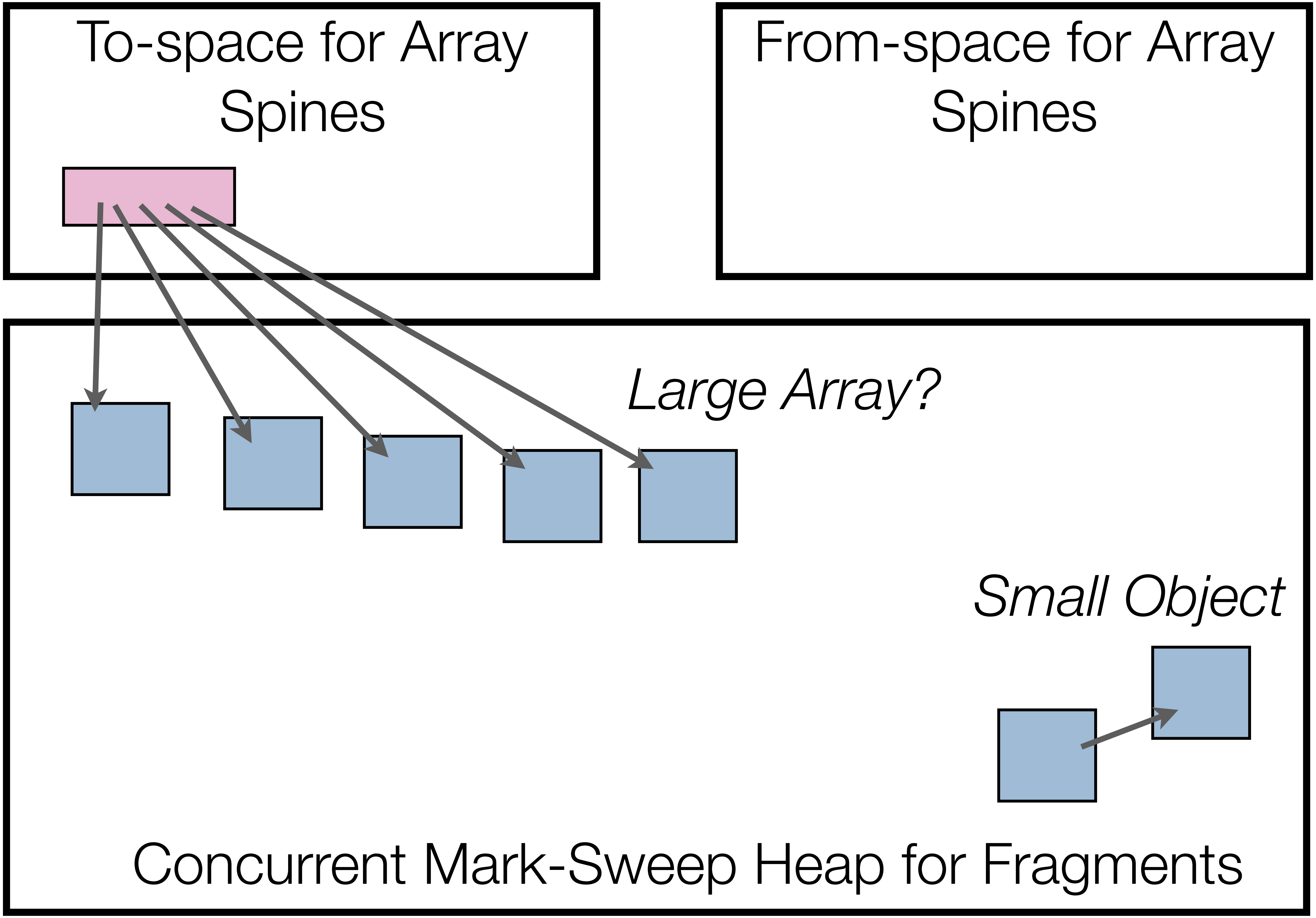

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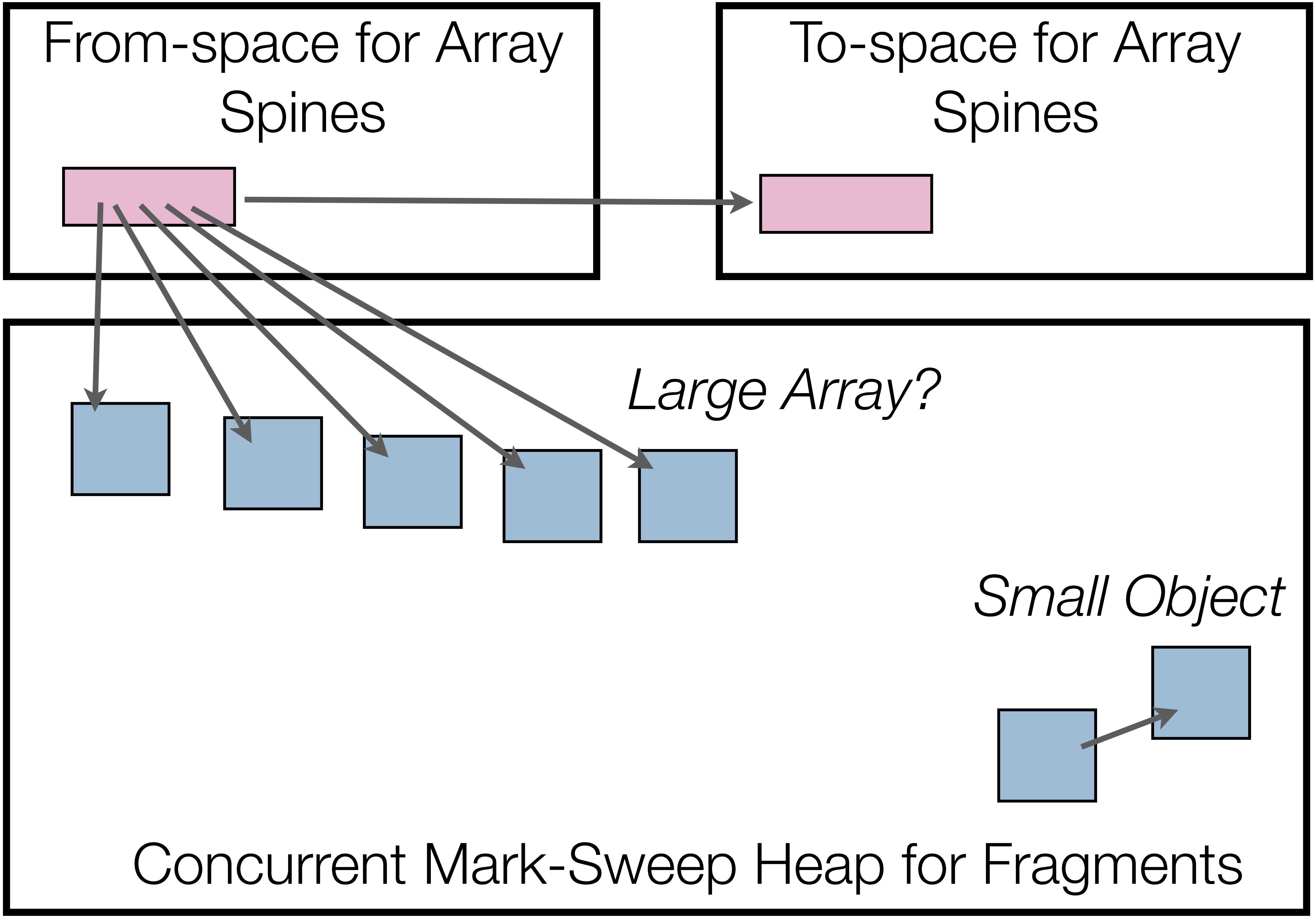

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how to make a complete RTGC

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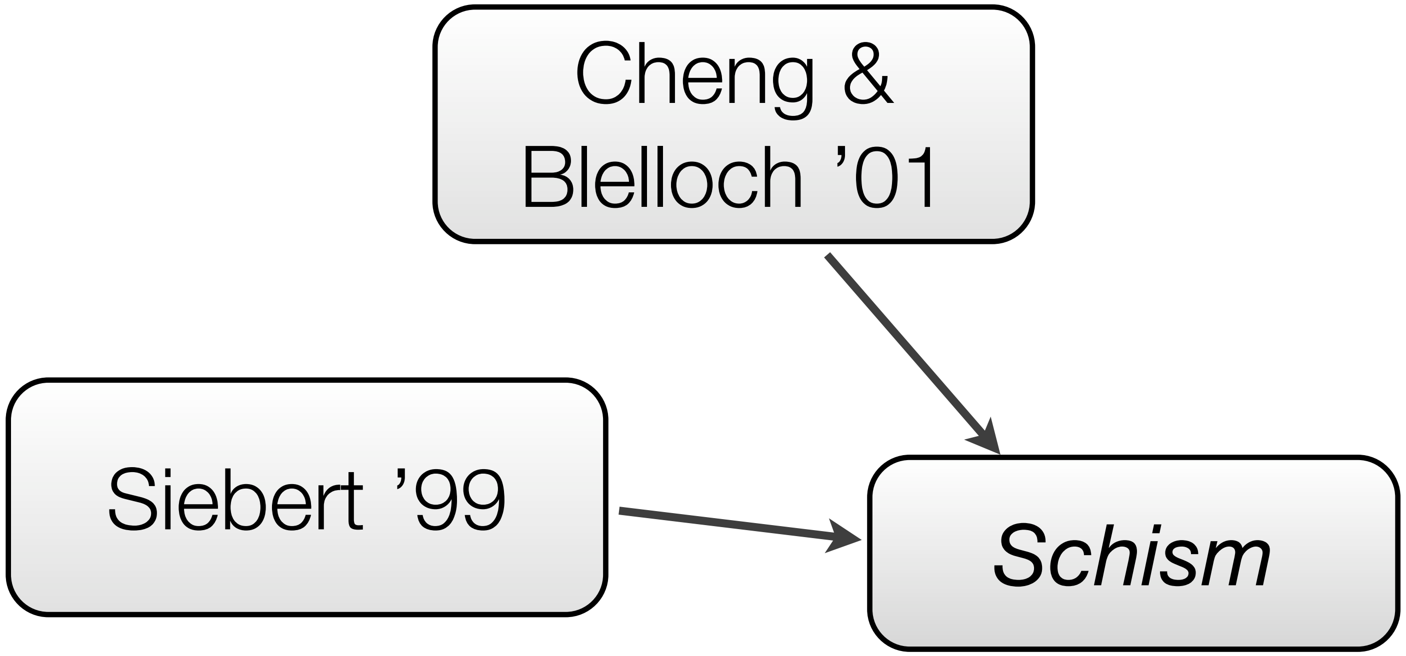

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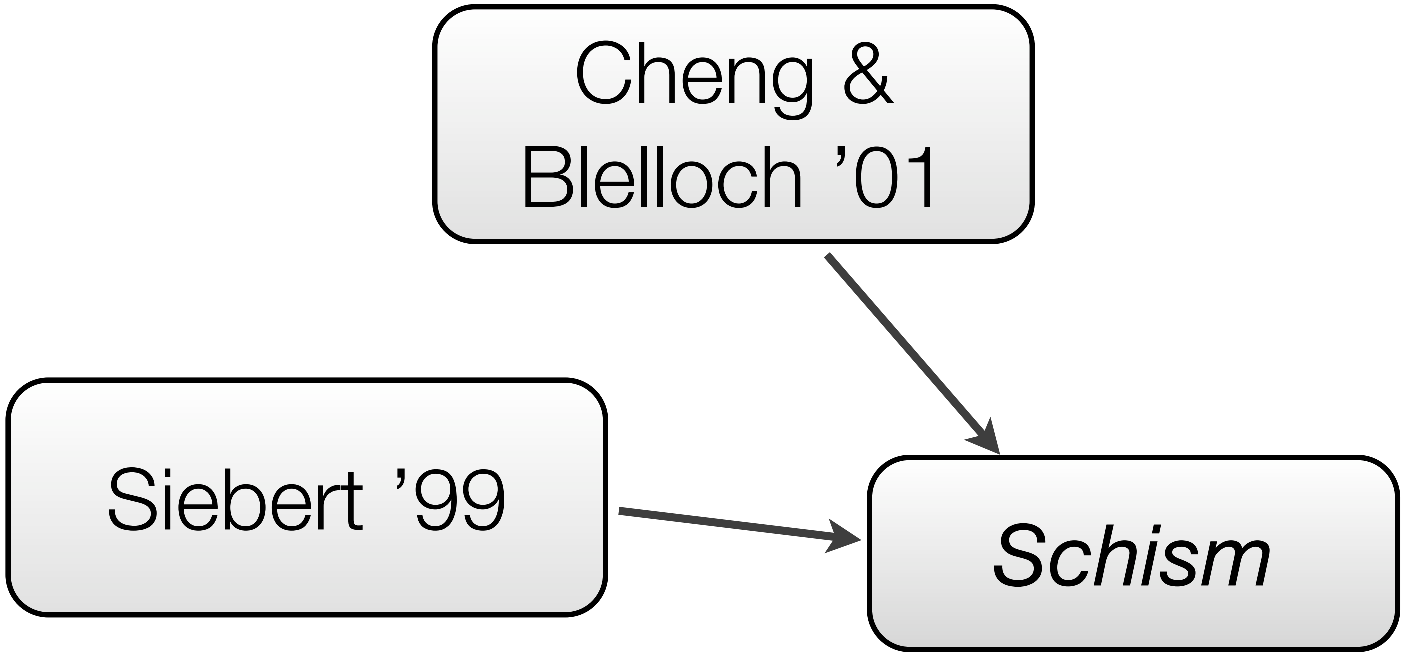

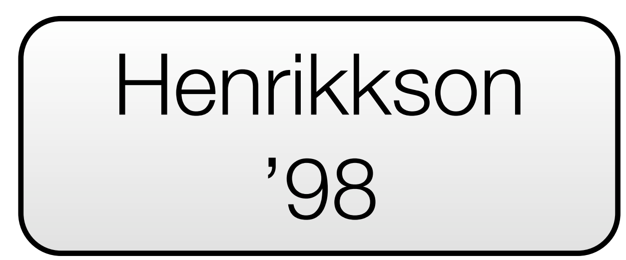

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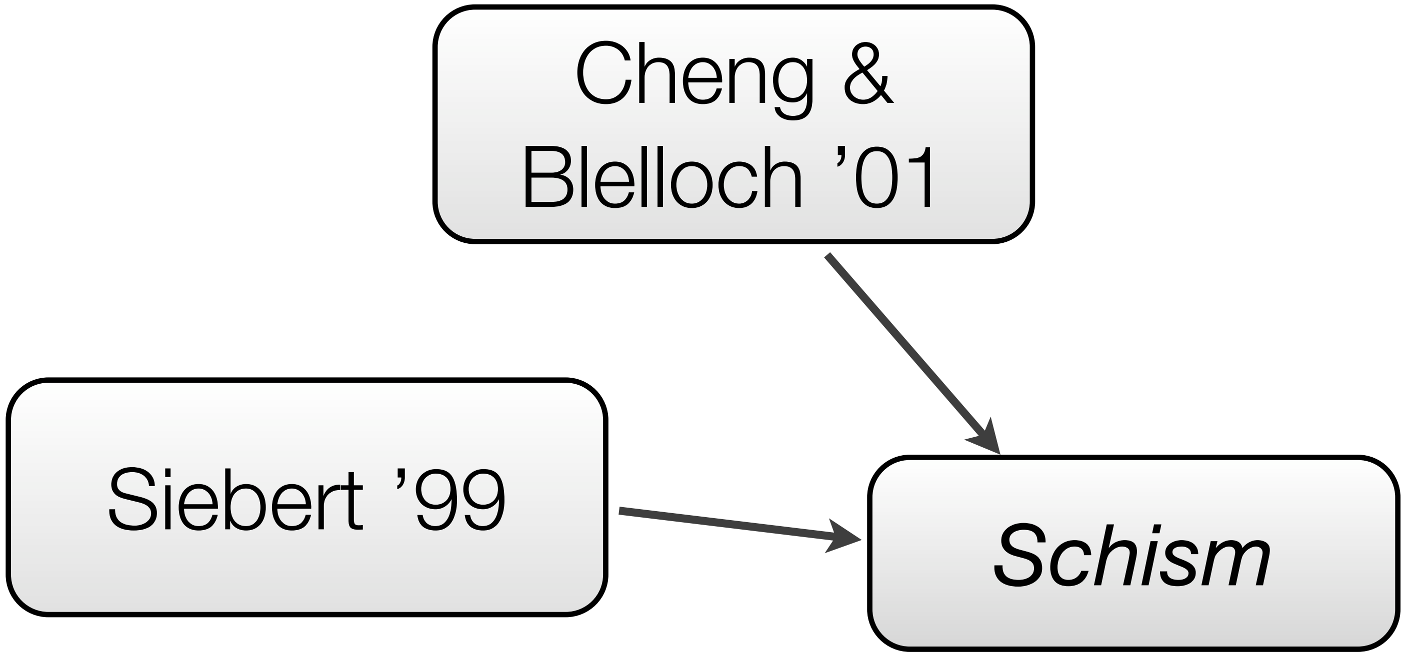

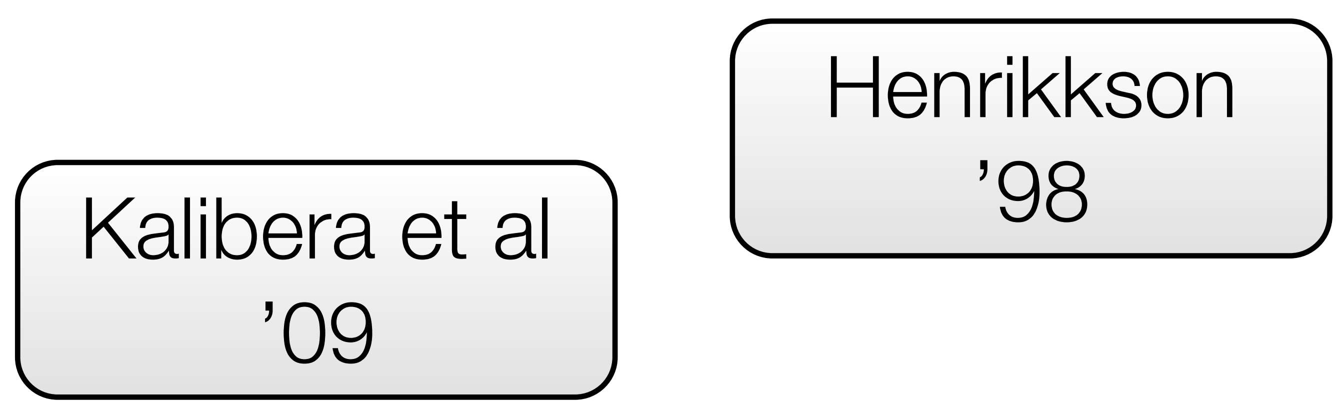

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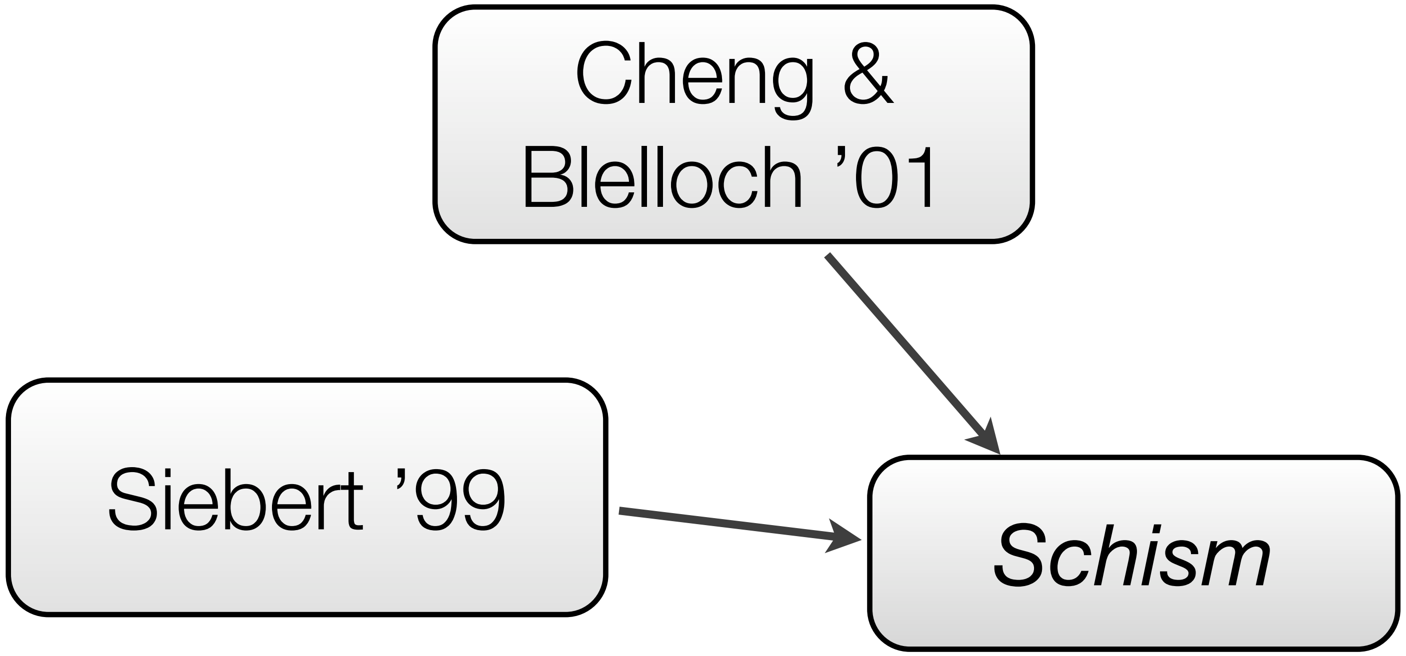

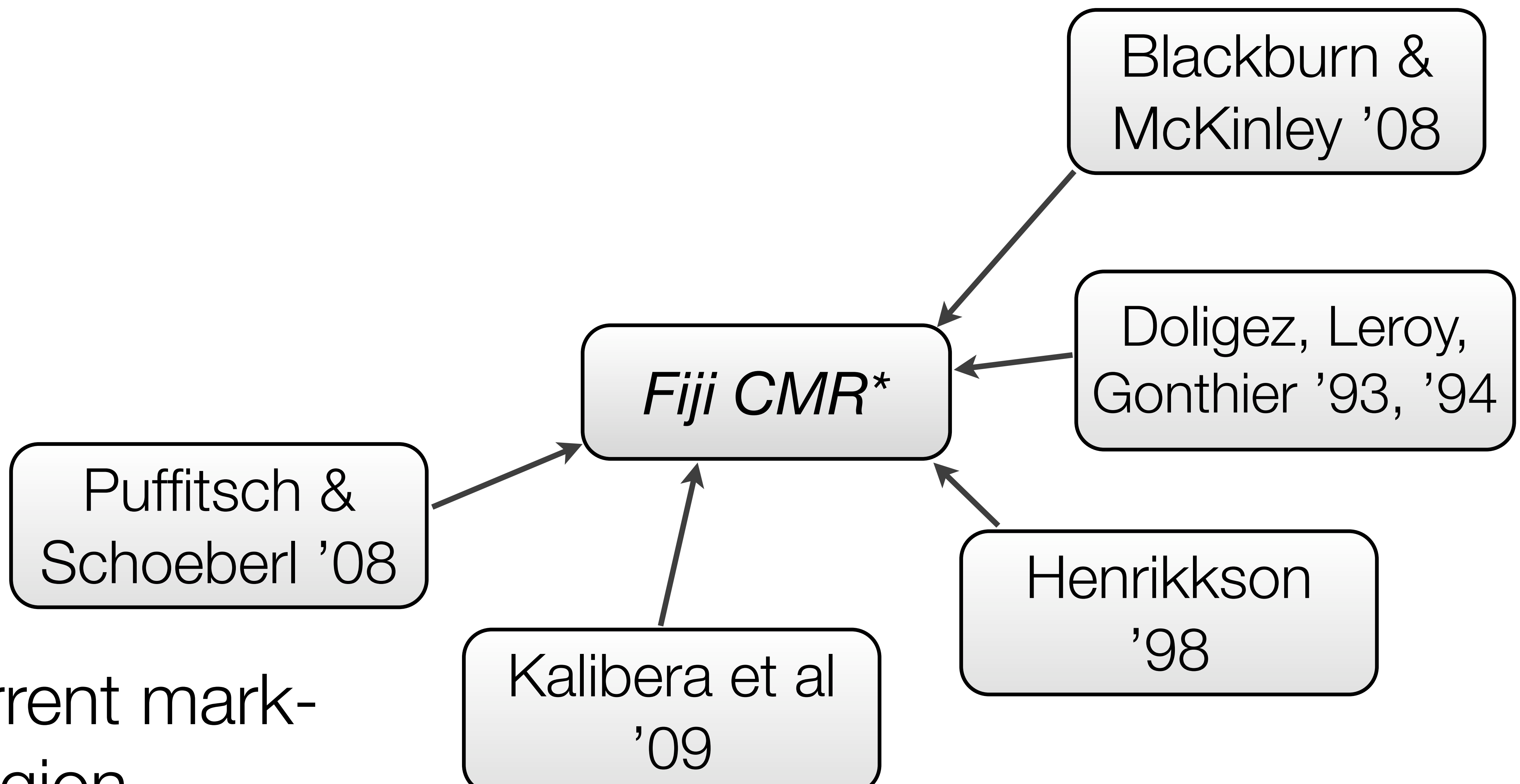

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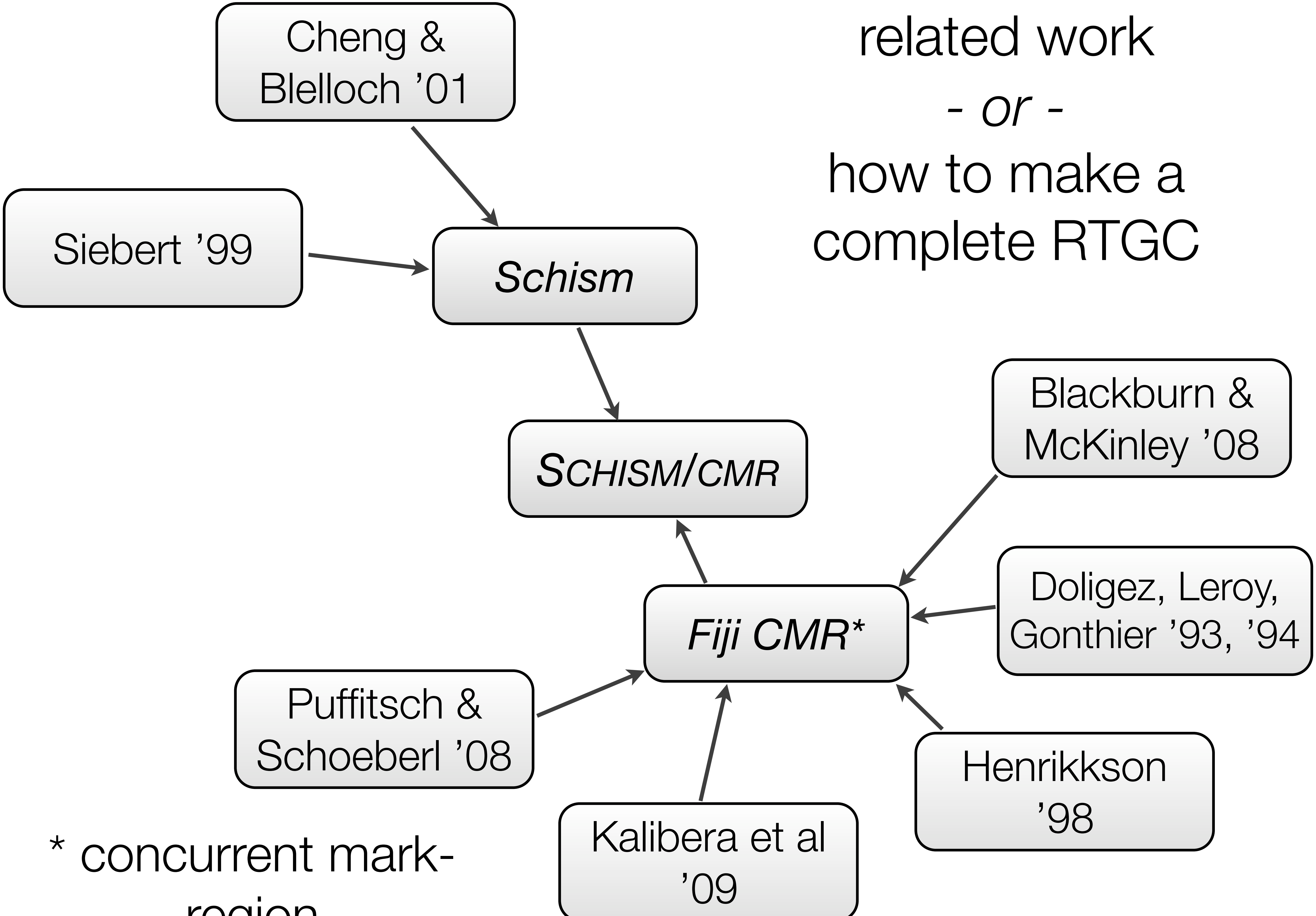

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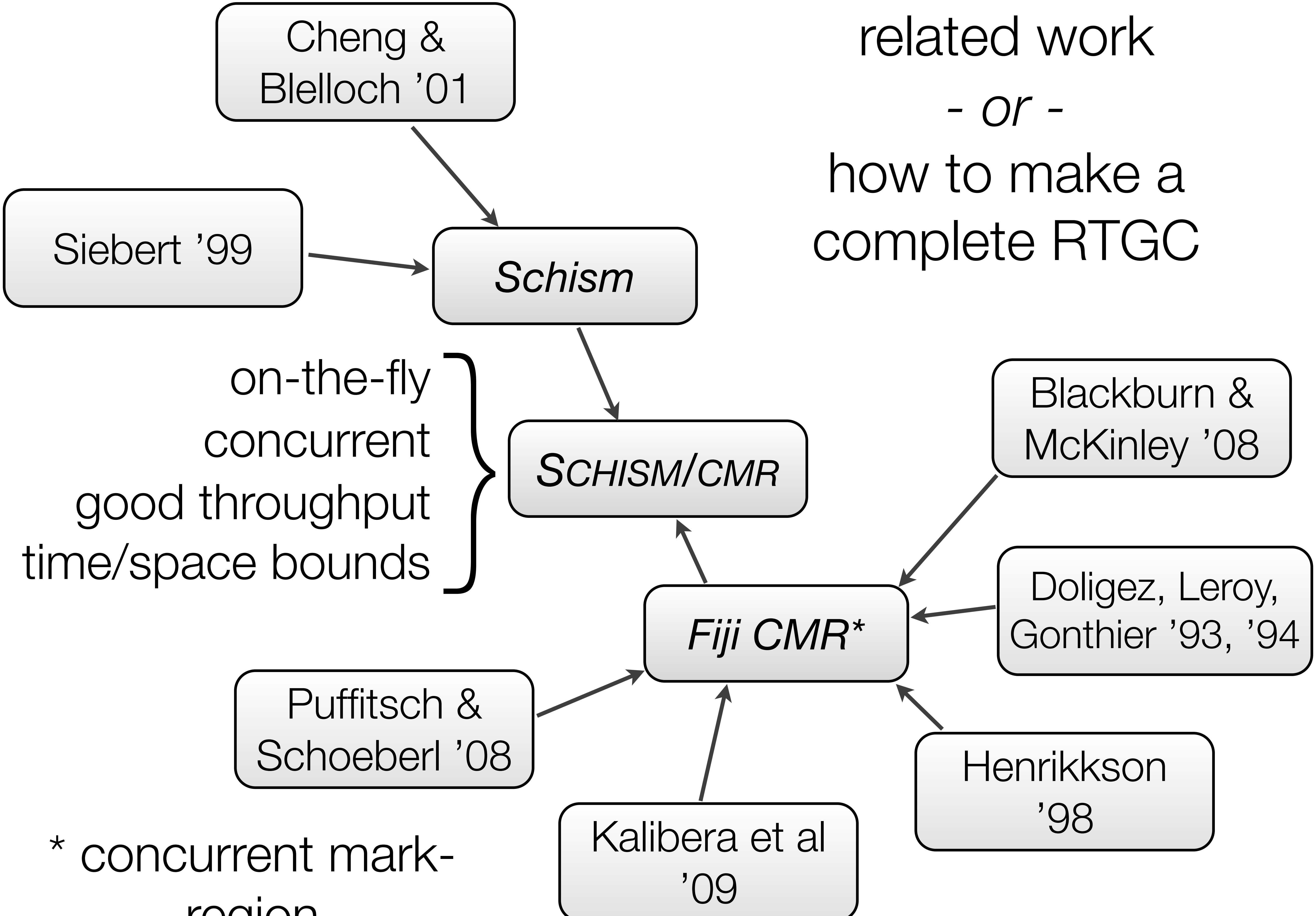

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Tunable throughput-predictability trade-off.

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- **Schism A**: *completely deterministic*:
  - arrays allocated fragmented
- **Schism C**: optimize throughput:
  - allocate contiguously if possible
- **Schism CW**: simulate worst-case execution of Schism C:
  - poison all fast-paths (array accesses, write barriers, allocations)

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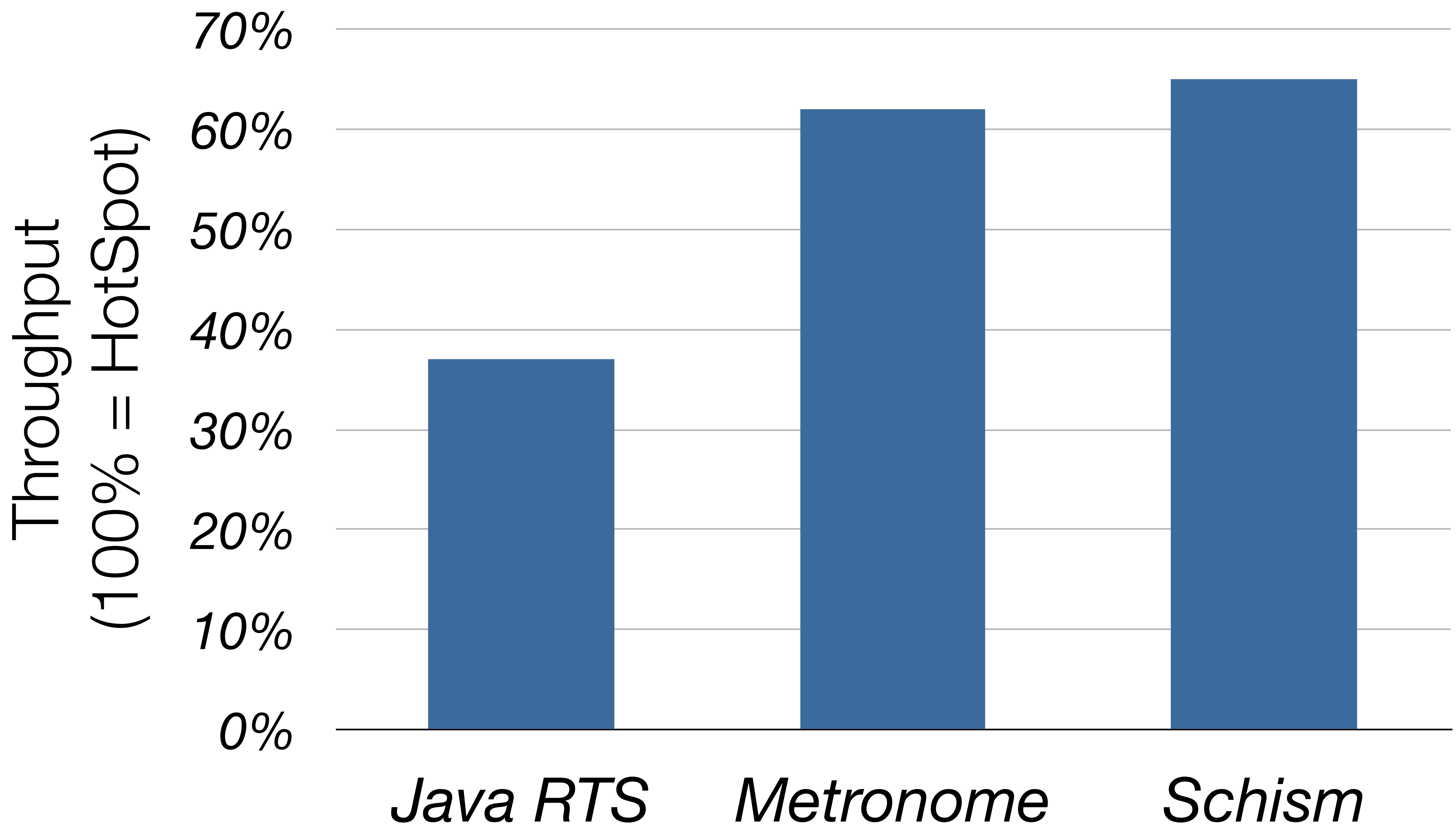
SPECjvm98 throughput summary



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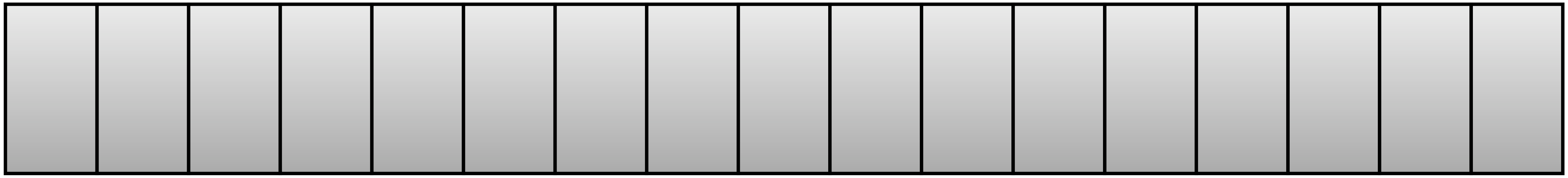

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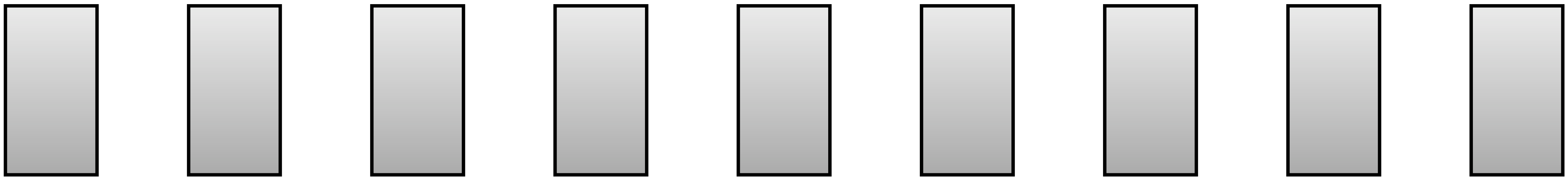

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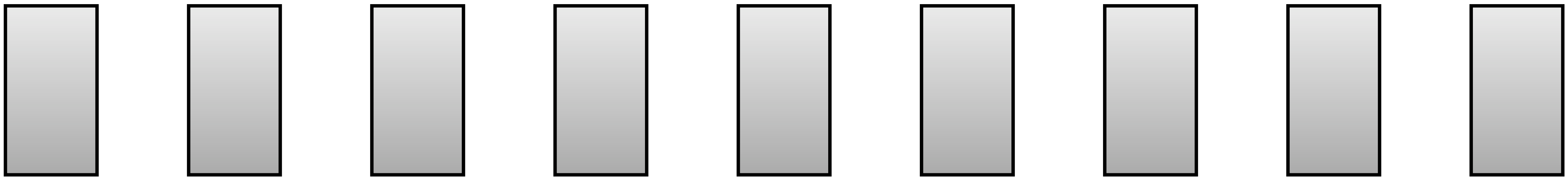

- Amount of free memory successfully allocated under fragmentation:
  - *HotSpot*: ~**100%**
  - *Java RTS*: ~**80%**
  - *Metronome*: ~**1%**, unless using >10KB objects
  - *Schism*: ~**100%** (all objects)

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(very short) Summary of Results

- Goal: as fast as Metronome ✓
- Goal: fragmentation tolerant like Java RTS ✓
- **Goal: deterministic**

Schism predictability:
RTEMS* on 40MHz LEON3

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* Real Time Executive for Missile Systems

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The OS/hardware platform used for NASA & ESA space missions.

* Real Time Executive for Missile Systems

Performance baseline: C code.

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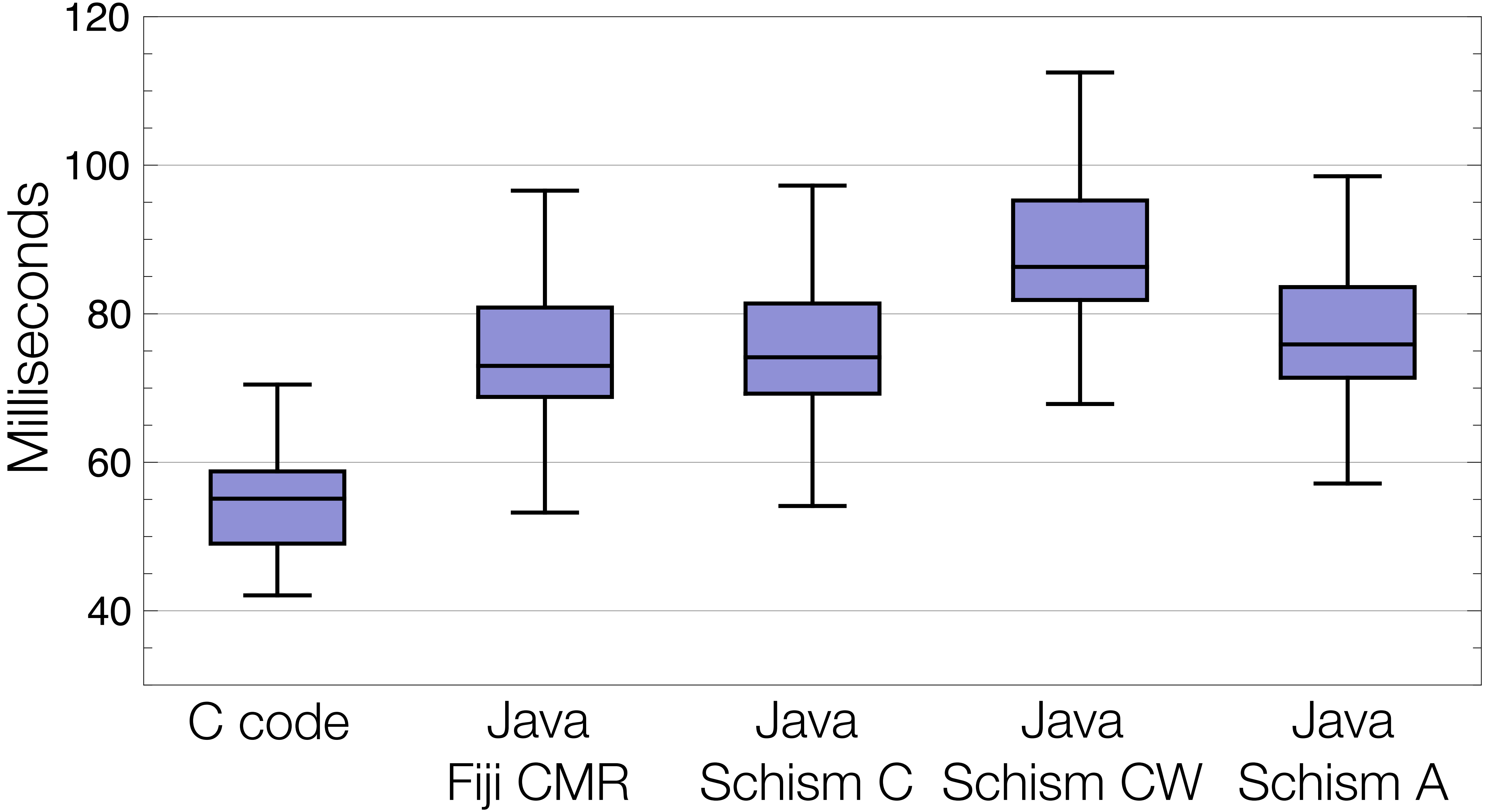
Using both C and Java implementations of the ***CDx*** *real-time air traffic collision detection benchmark [Kalibera et al '09].*

Java (CMR, Schism) versus C on **CDx** real-time benchmark



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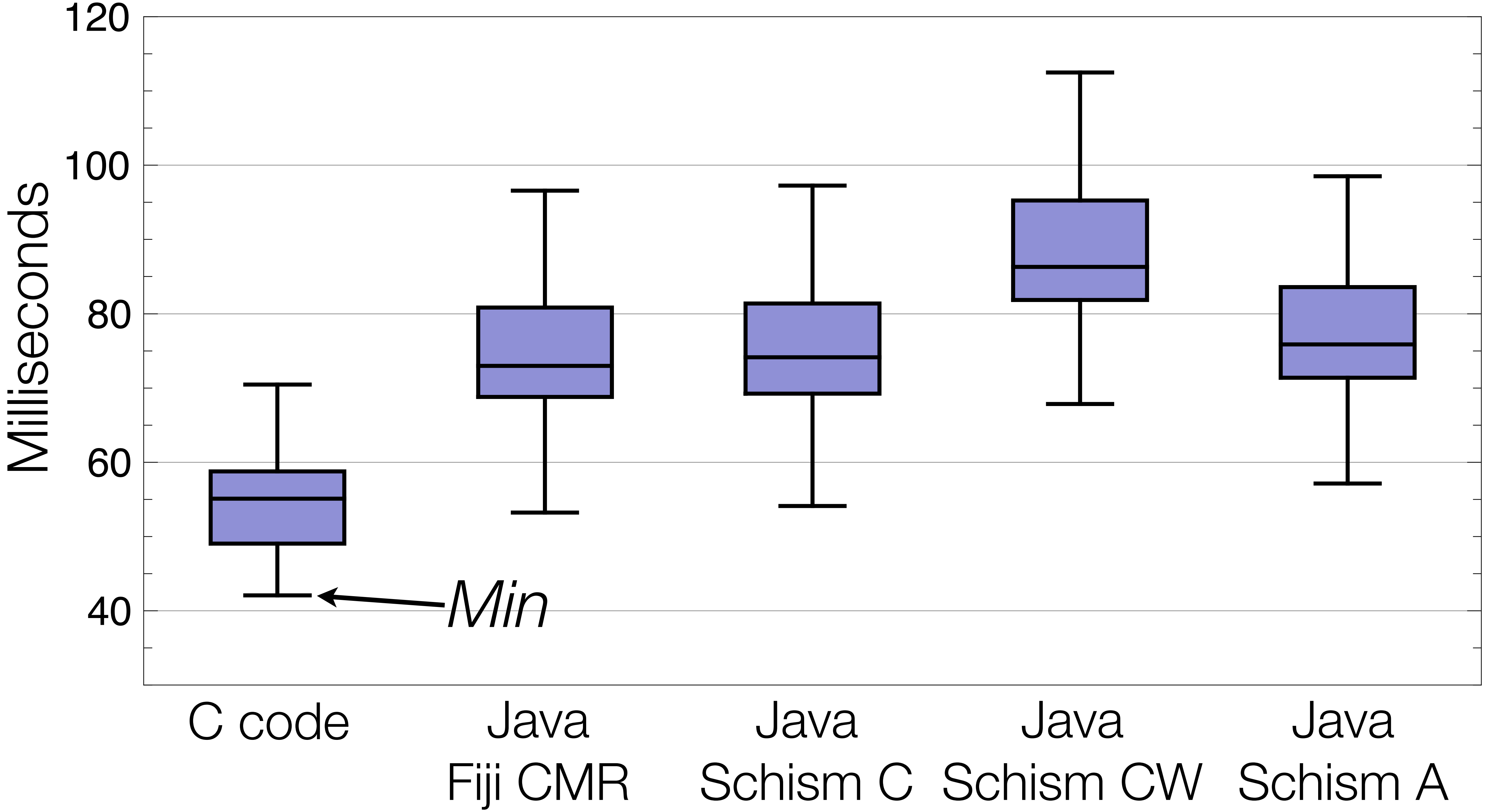

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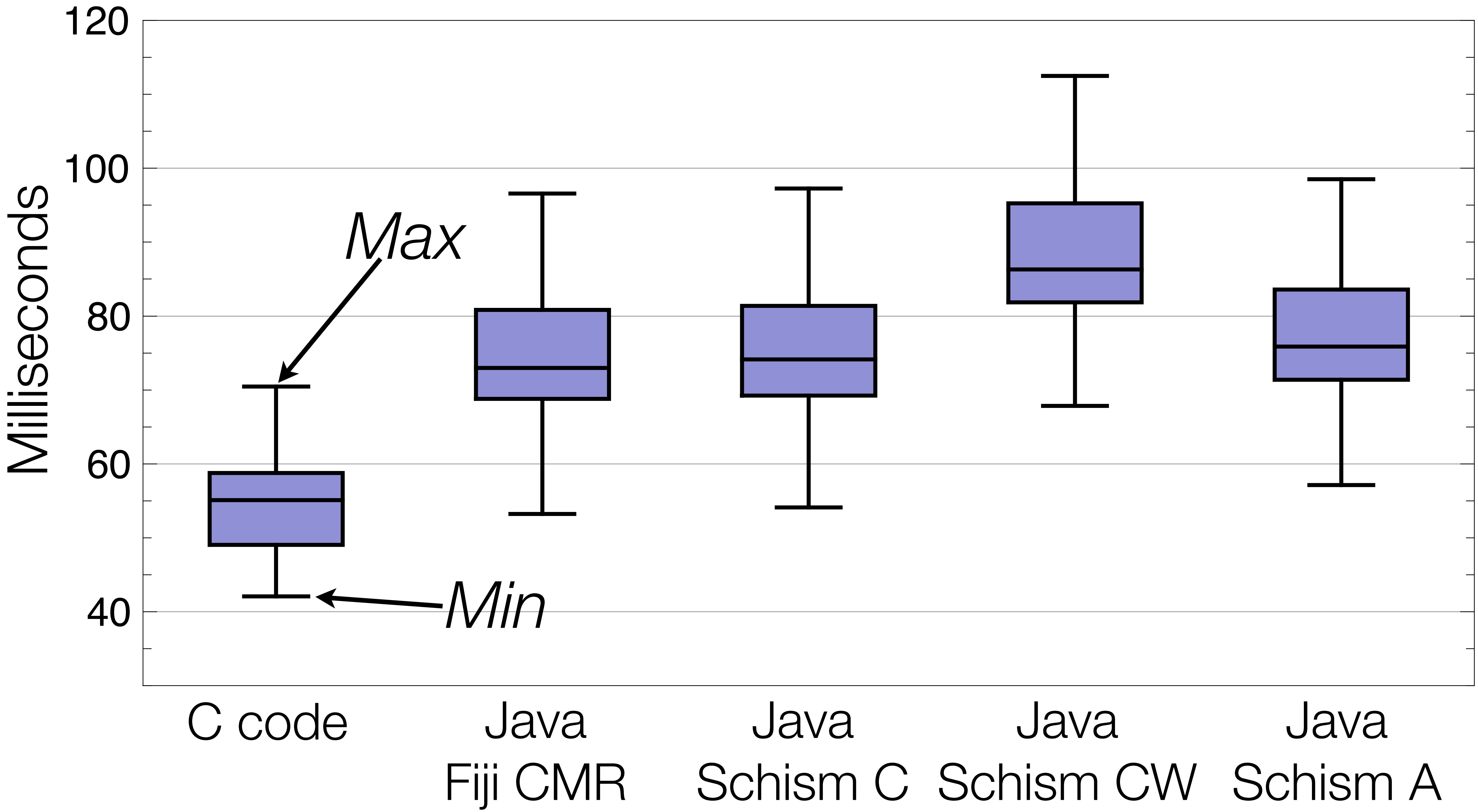

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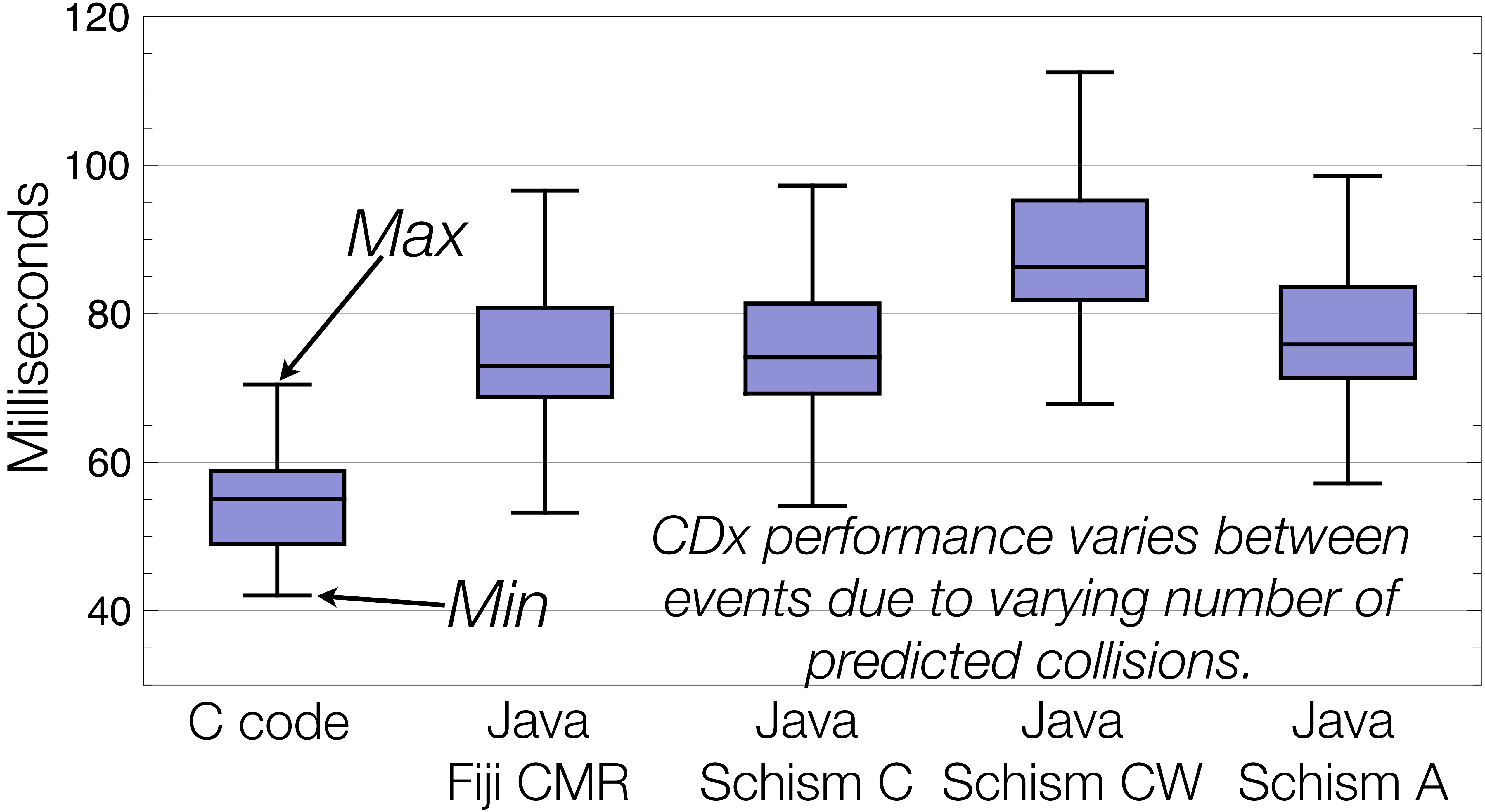

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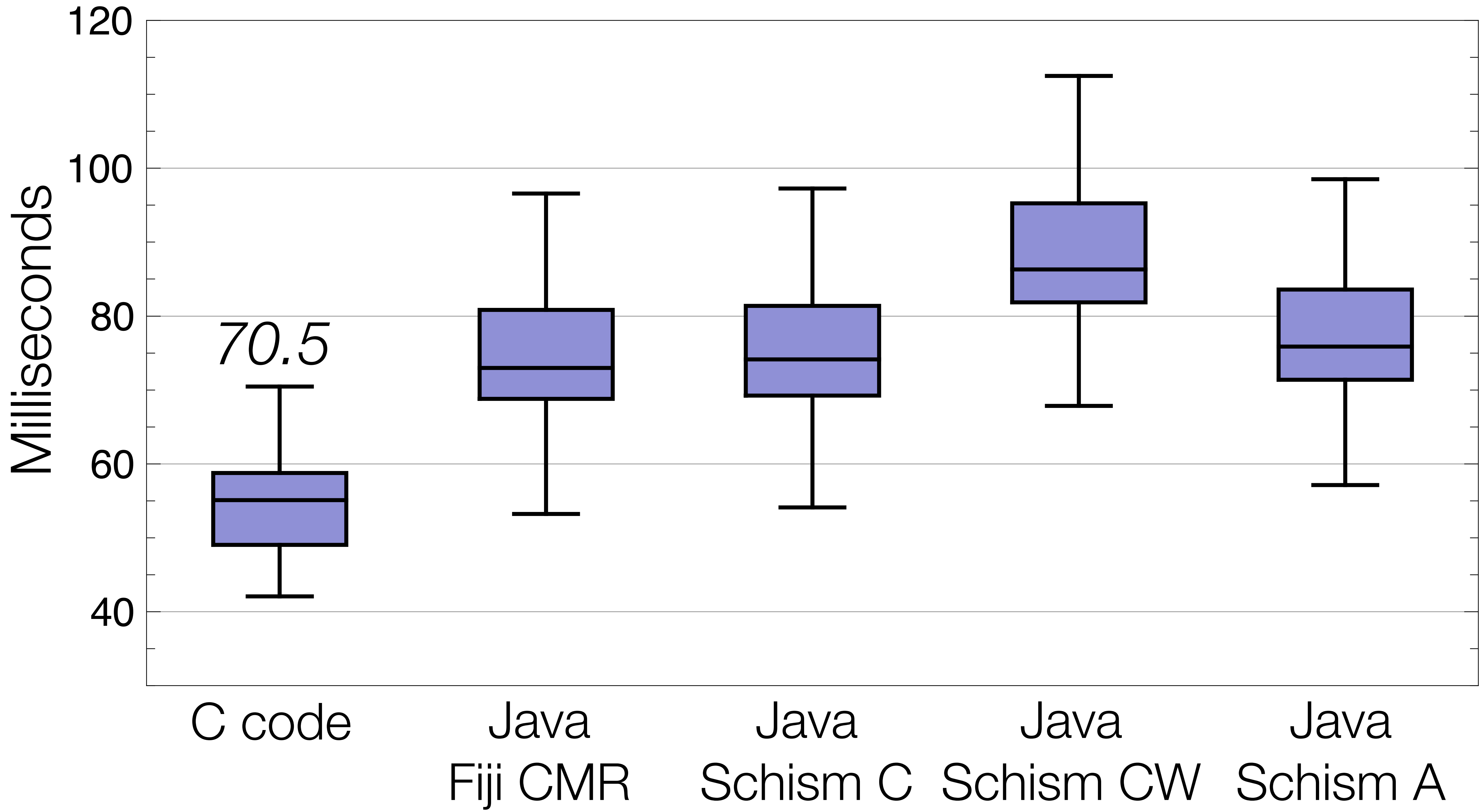

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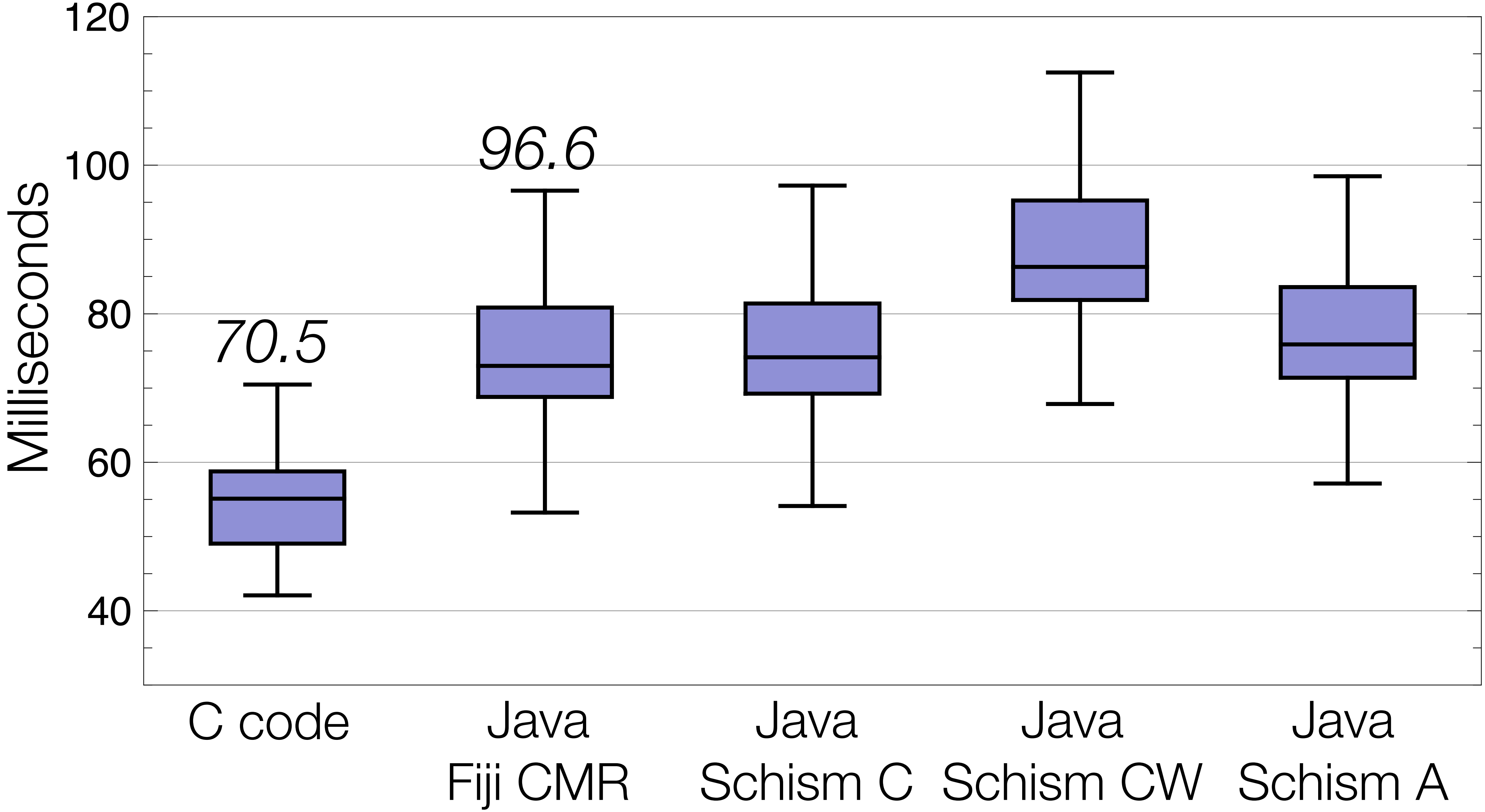

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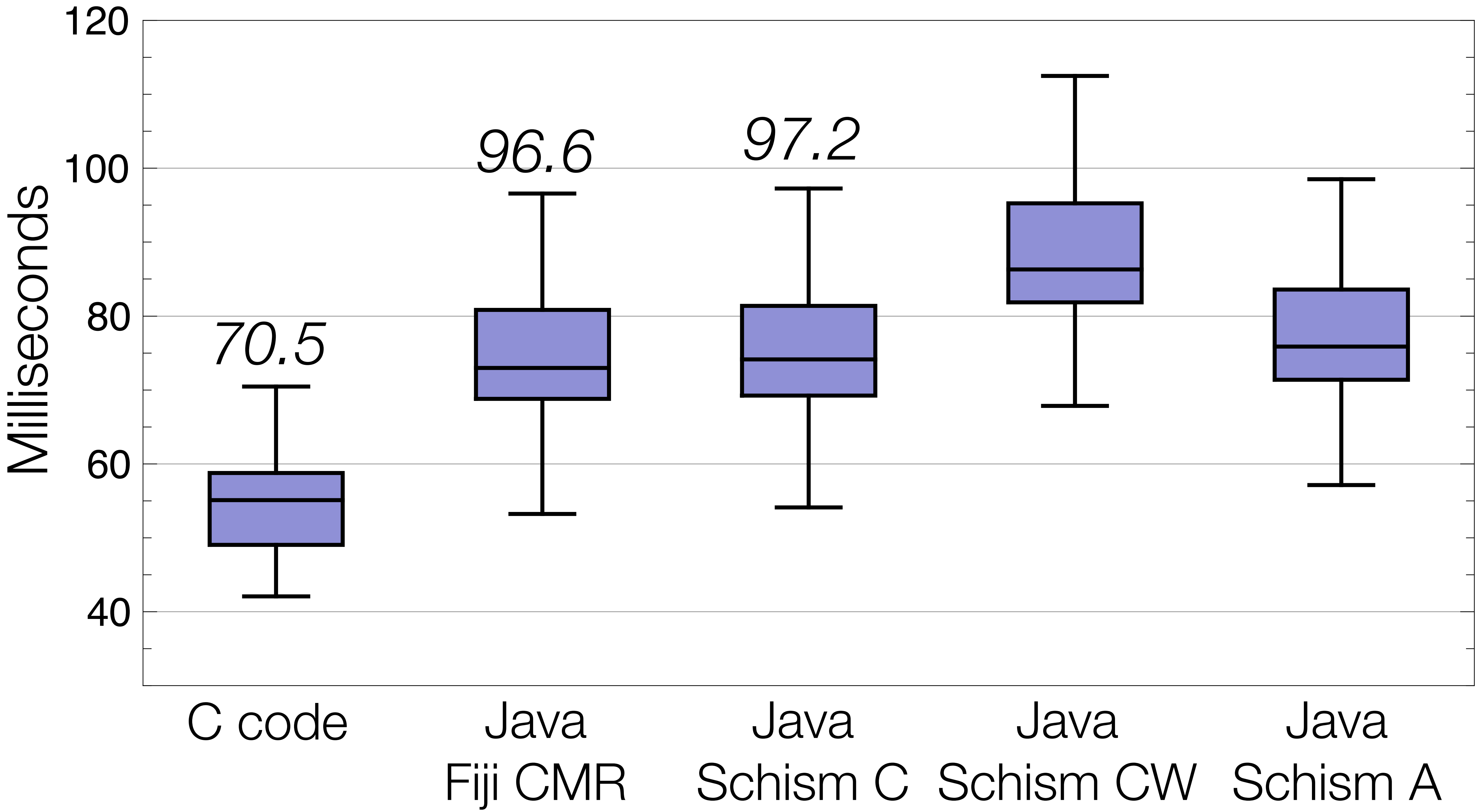

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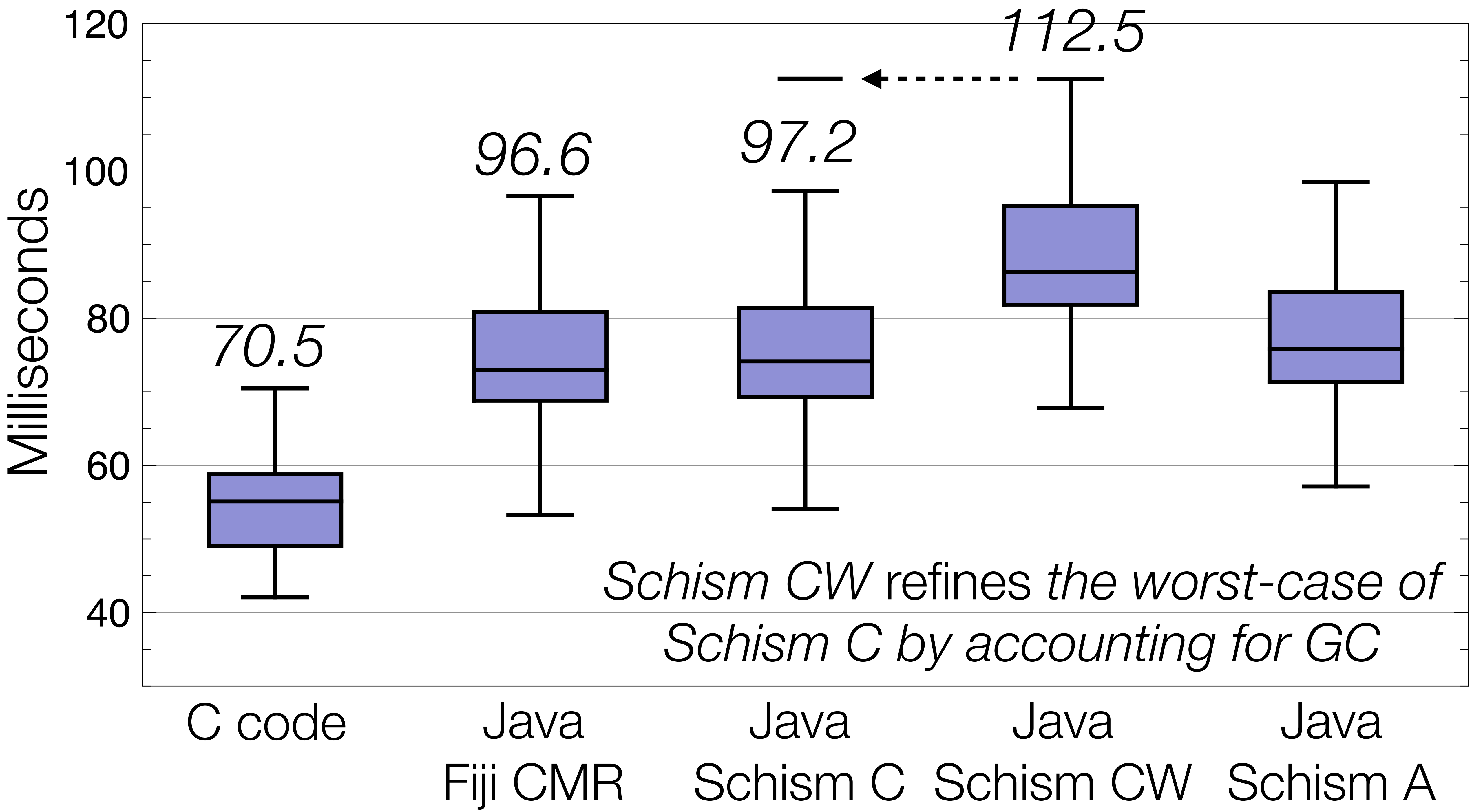

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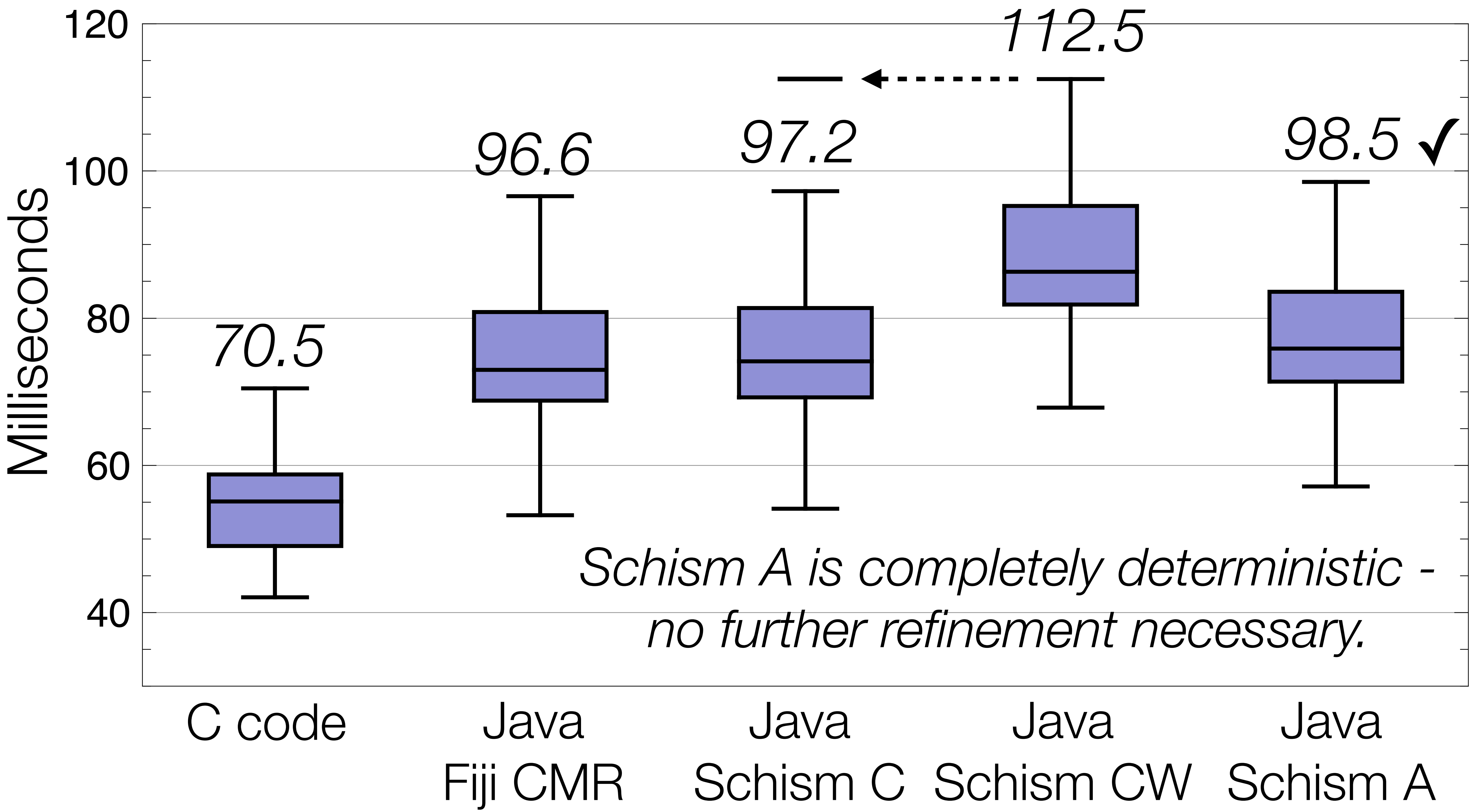

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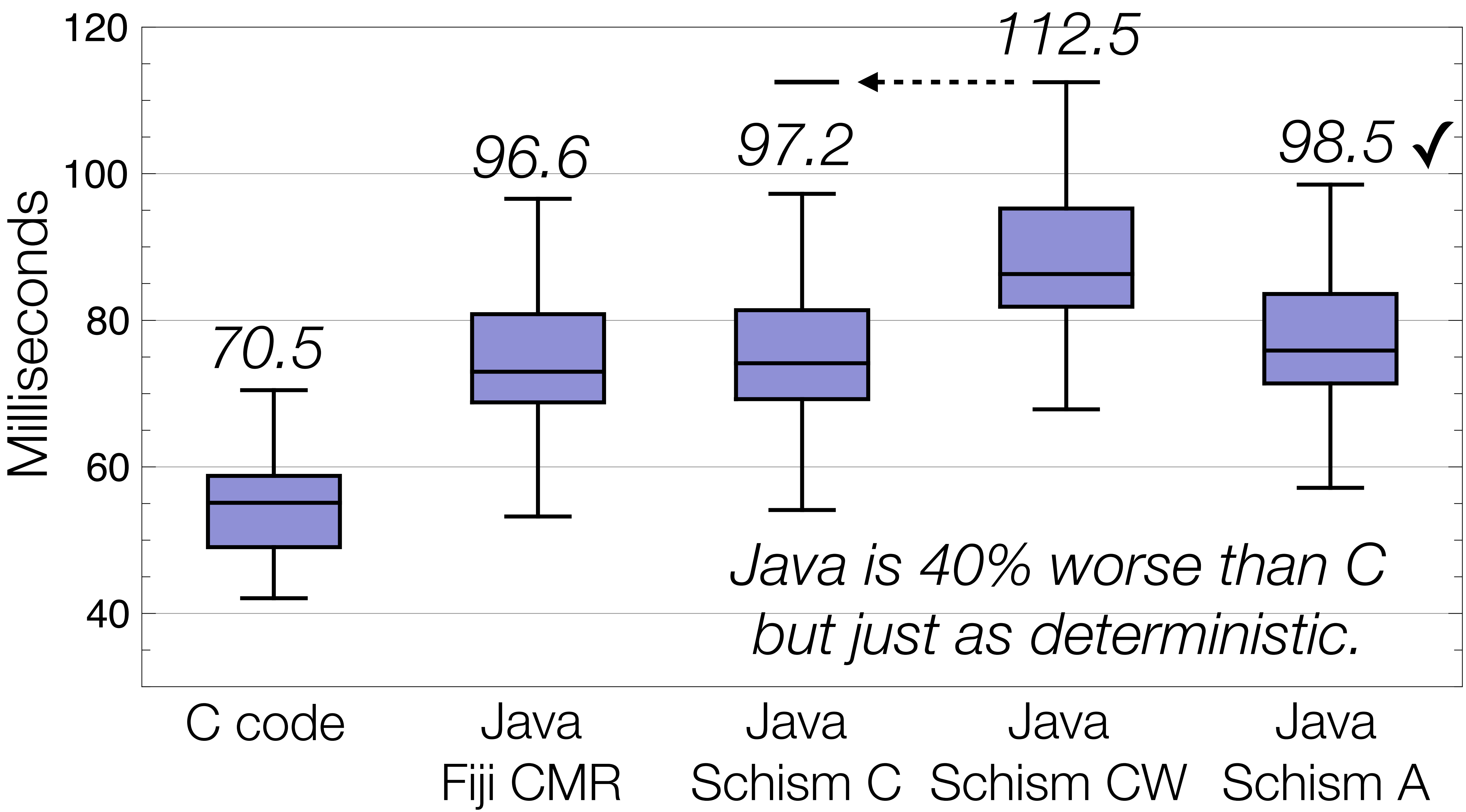
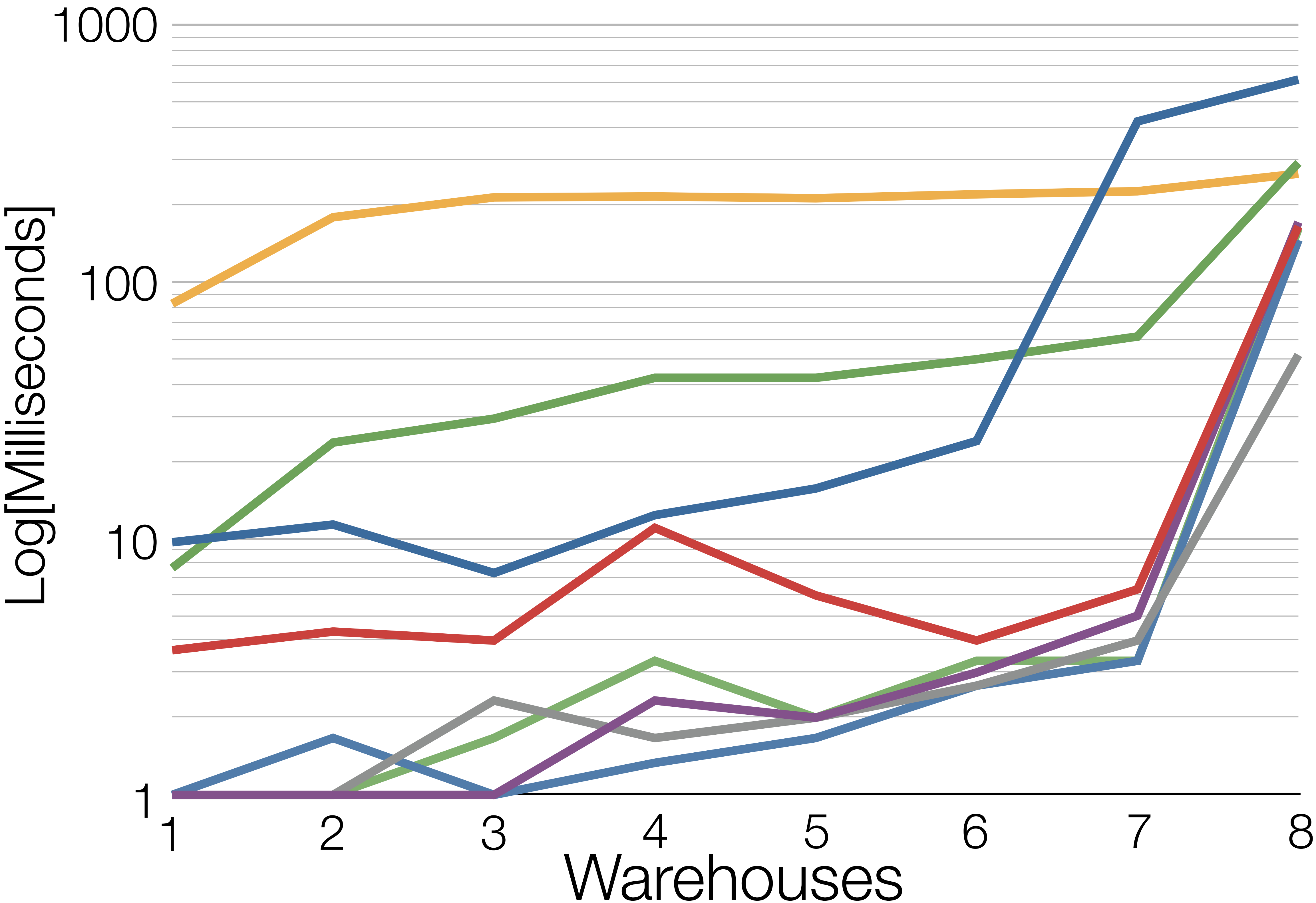
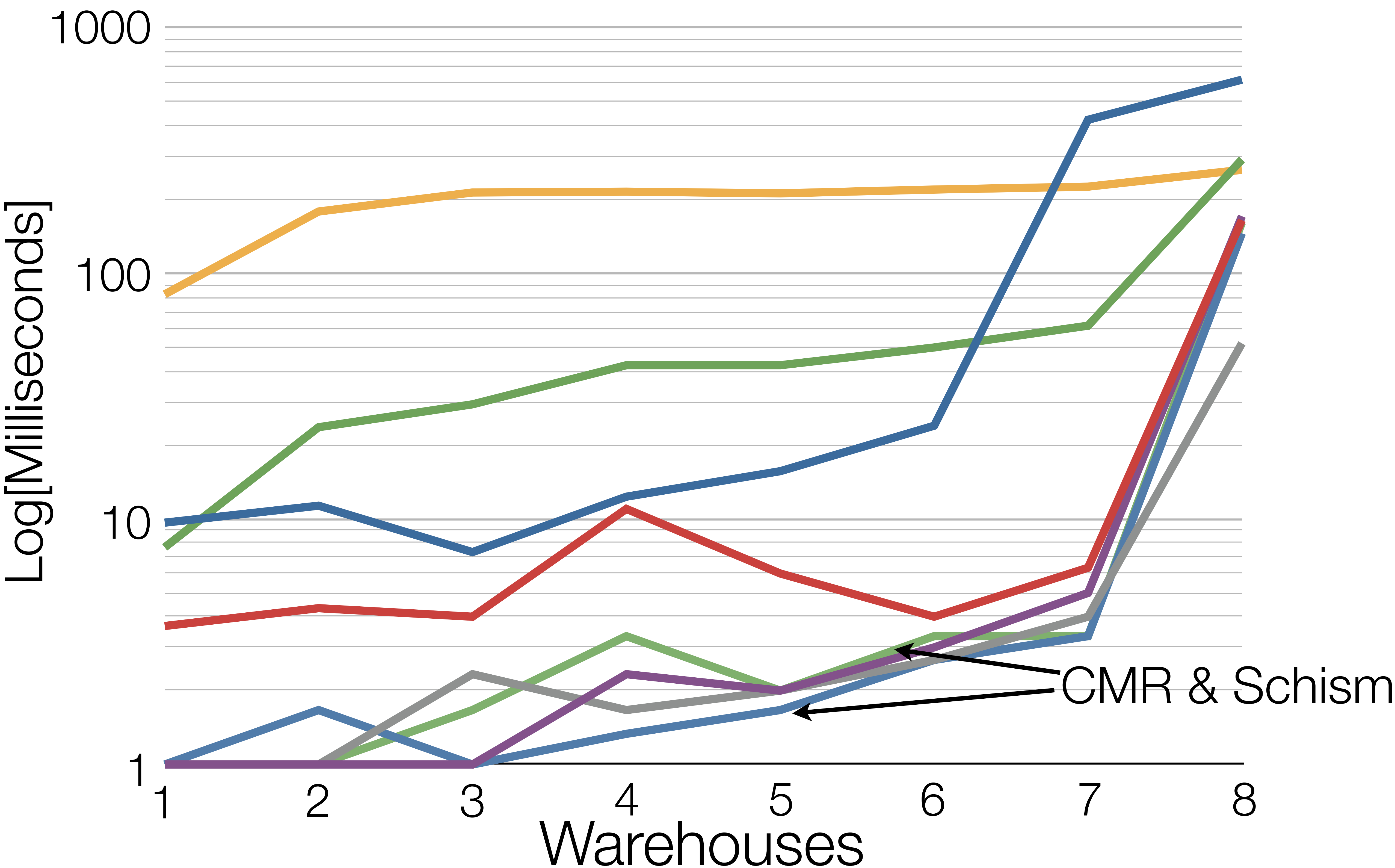


Schism Predictability:
SPECjbb2000 on Linux Xeon

SPECjbb2000 Worst-case Transaction Times



SPECjbb2000 Worst-case Transaction Times



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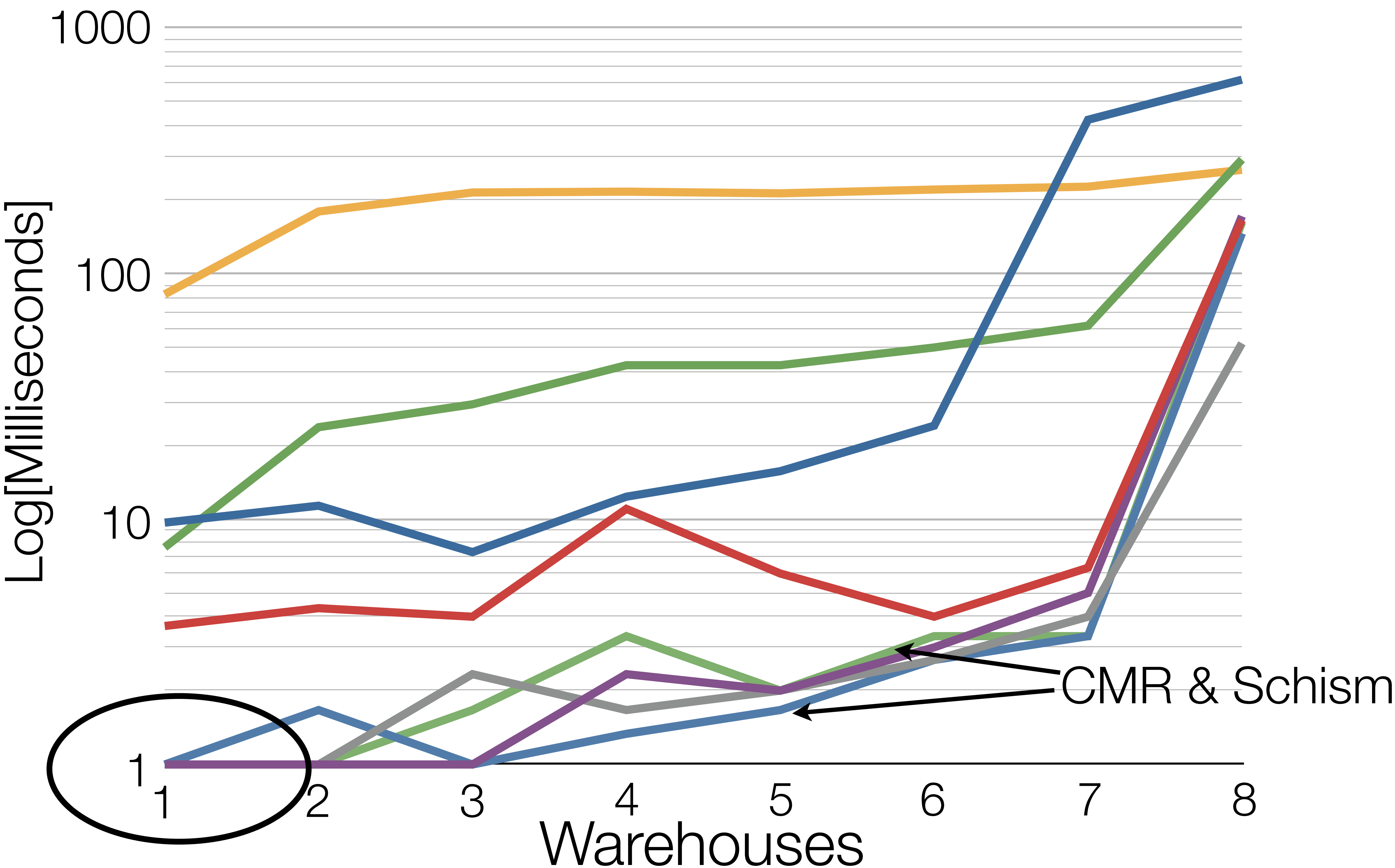

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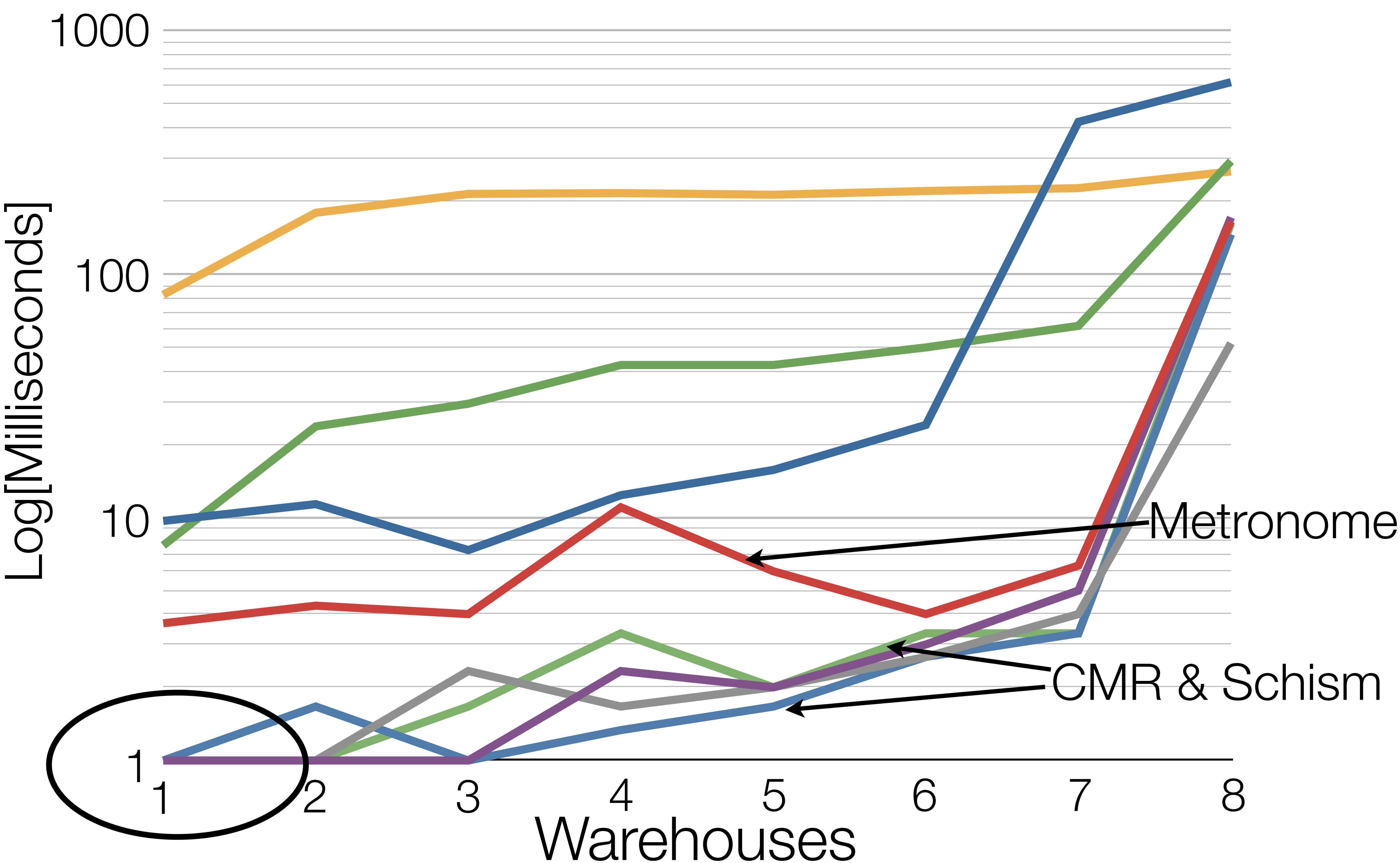

- Additional experiments in the paper:
  - SPECjvm98 in detail
  - Worst-case-time v. memory for CDx on RTEMS/LEON3
  - MMU for CDx on RTEMS/LEON3
  - Detailed fragmentation numbers with Fragger
  - Array access performance under fragmentation
  - Scalability with SPECjbb2000
  - Analytical proof of space bounds
  - Experimental validation of analytical proof of space bounds

Read the paper for the most awesomely epic RTGC evaluation, ever.

Conclusion: A good Real-Time GC...

- executes concurrently with mutator threads
- guarantees progress for heap accesses
  - wait-free (per-thread progress)
- minimizes heap access overhead
  - few instructions
- gives uniformly good throughput
- is space efficient (minimizes external fragmentation)

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