Thread-Level Speculation with Kernel Support

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International Conference on Compiler Construction
March 17th, 2016, Barcelona

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Thread-Level Speculation (TLS)

- *unsafe / optimistic* parallel execution
- data or control dependences might exist
- runtime system checks for violations
- rollback & re-execute in case of conflict

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Thread-Level Speculation (TLS)

- *unsafe / c*
- data or c
- runtime s
- rollback &

```
for (auto &task : tasks[today]) {
    task.compute();
    if (!task.success()) {
      fatalError(“task failed: ” + task.id());
    }
}
```

```
for (auto id : taskIds[today]) {
    tasks[id].compute();
}
```

Thread-Level Speculation (TLS)

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- data or c
- runtime s
- rollback &

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```

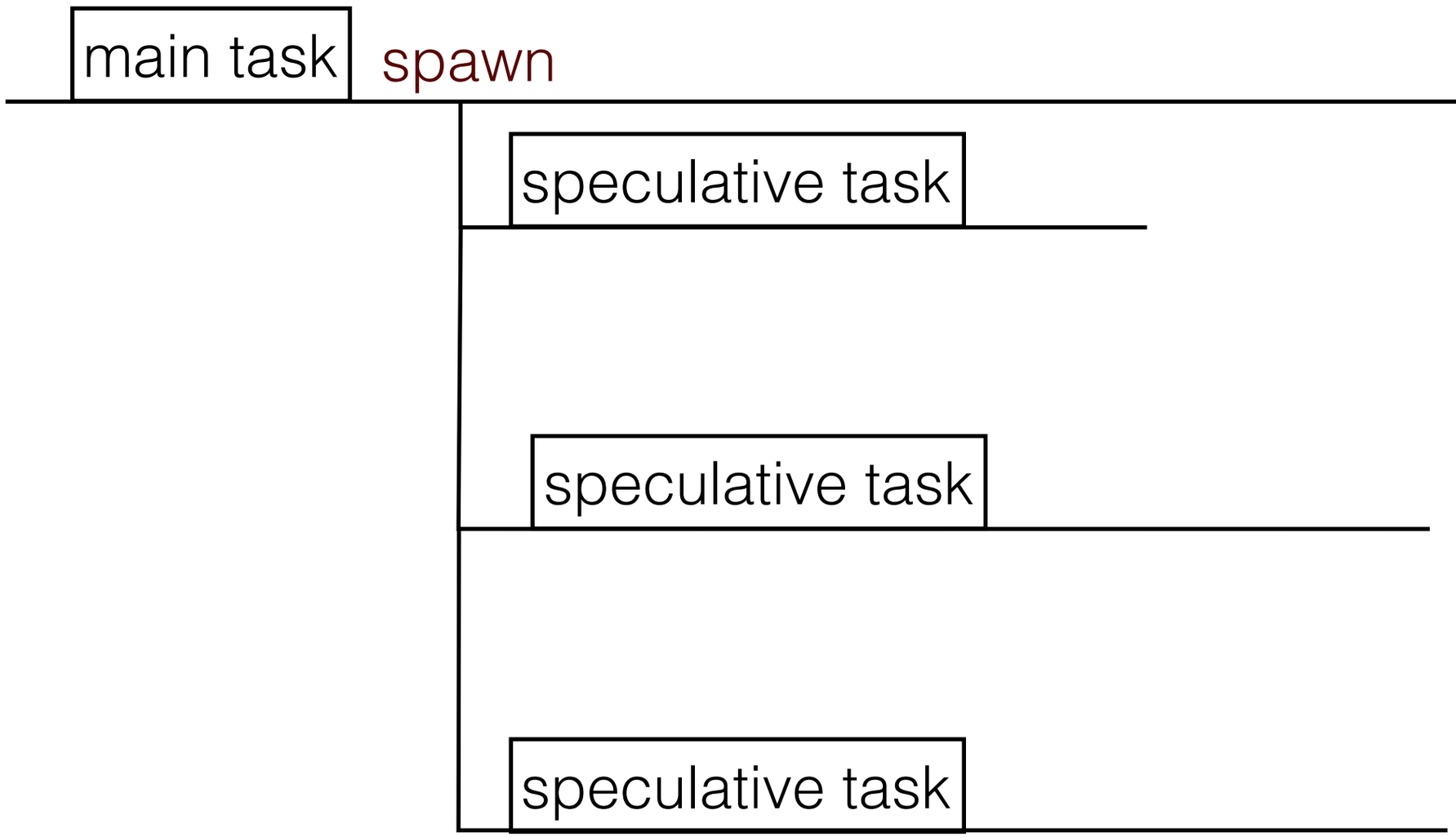
→ manual / guided parallelization

→ automatic parallelization

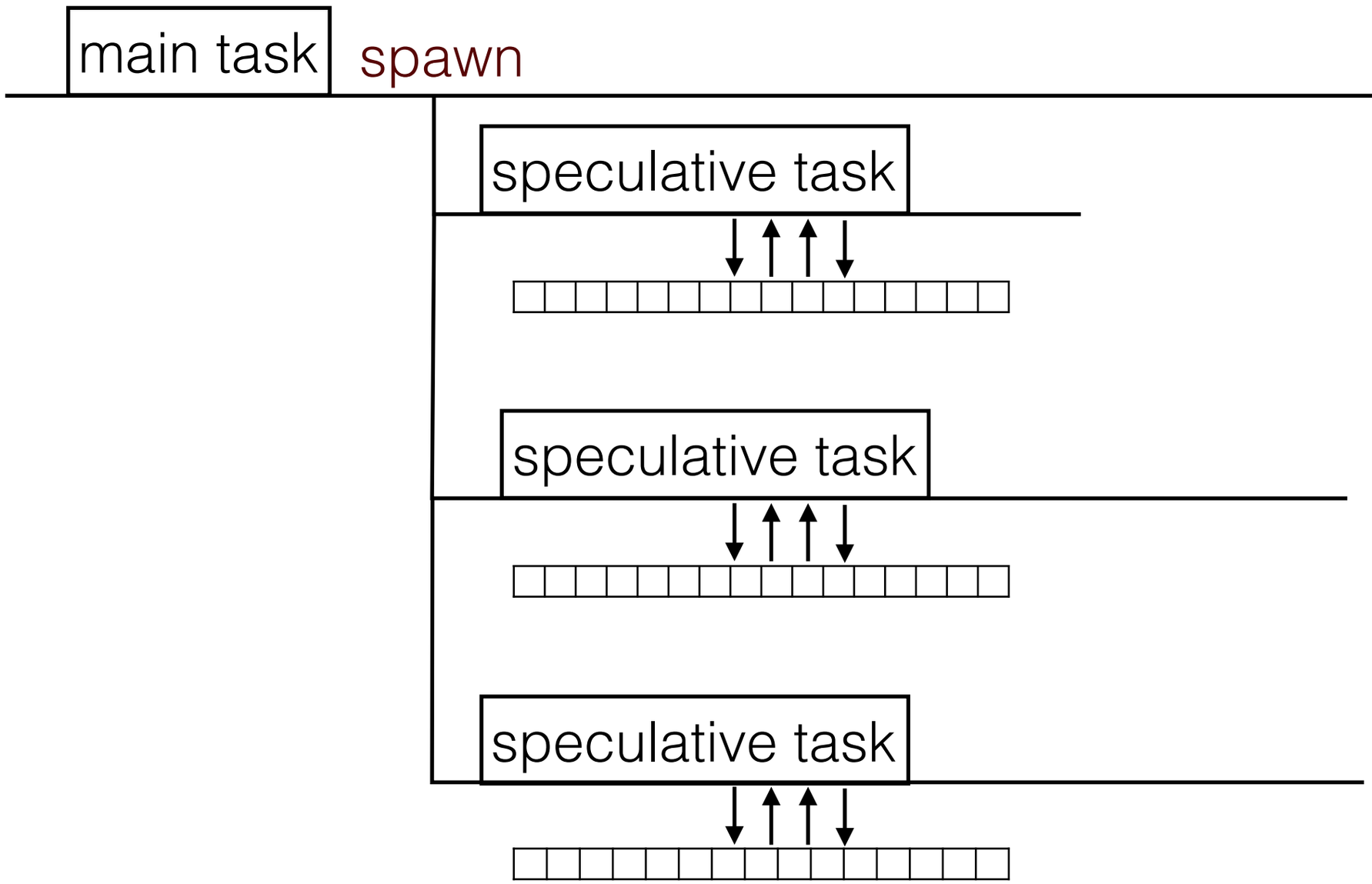
Execution in TLS

main task

Execution in TLS



Execution in TLS



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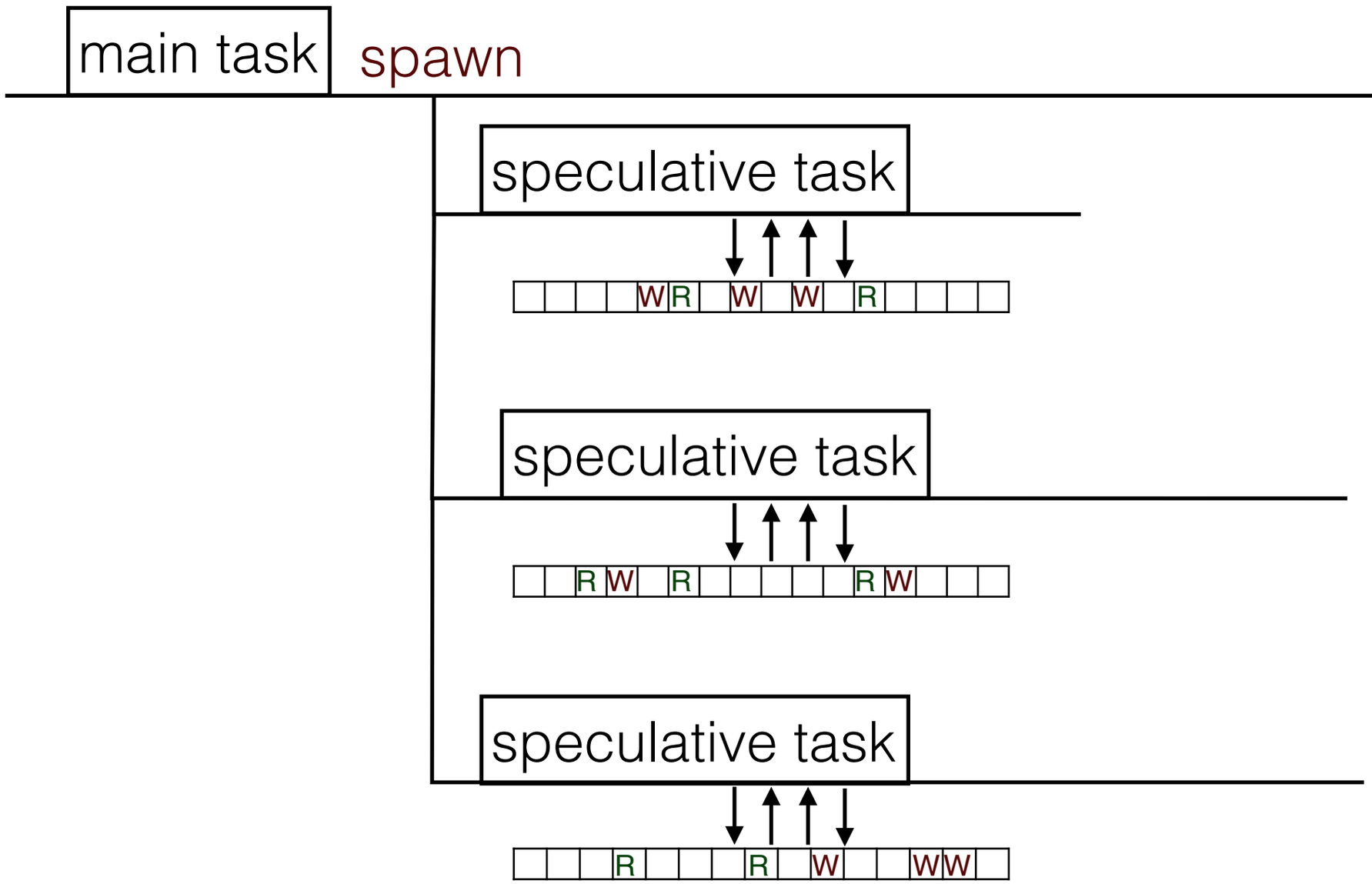

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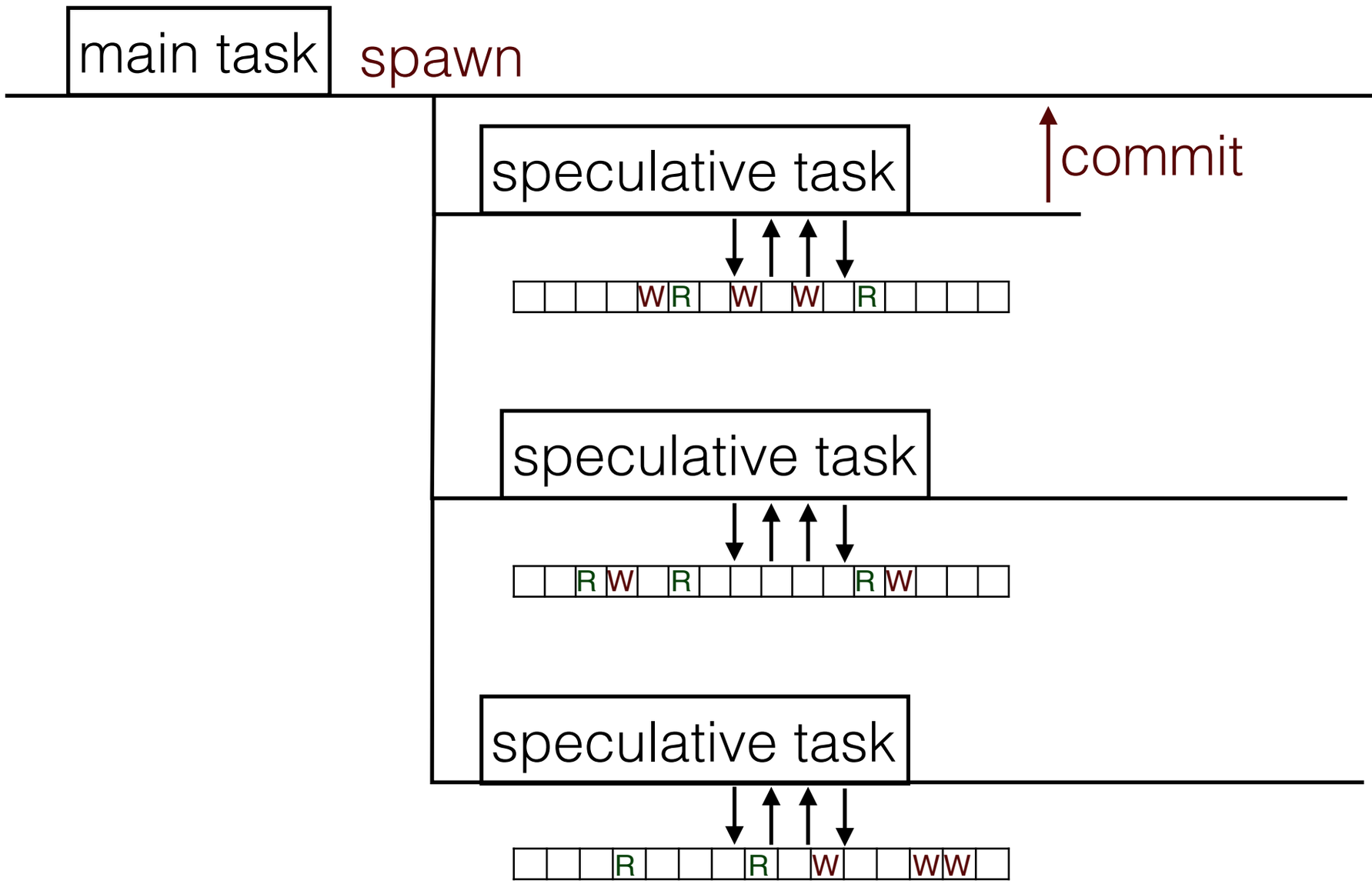

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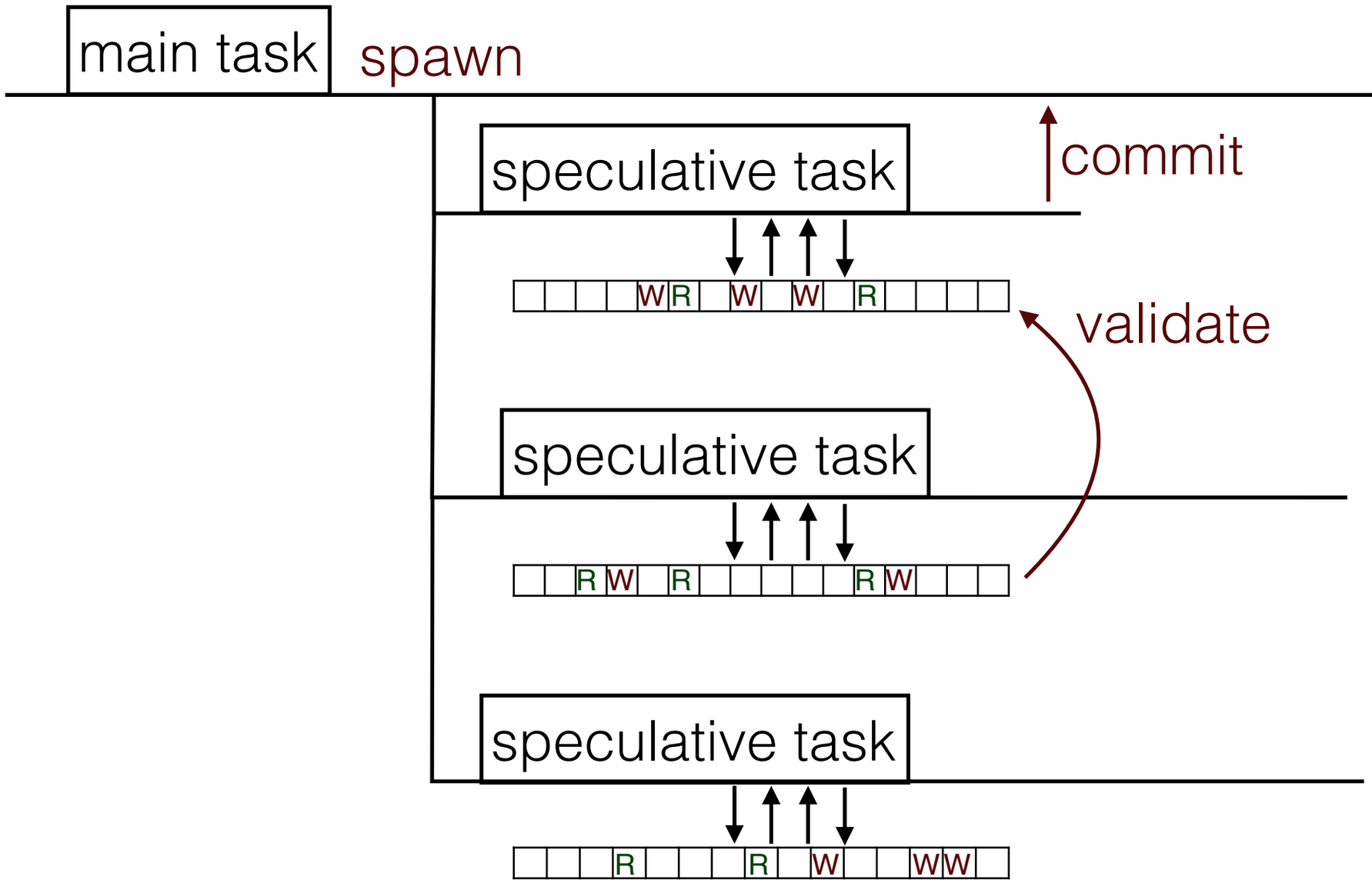

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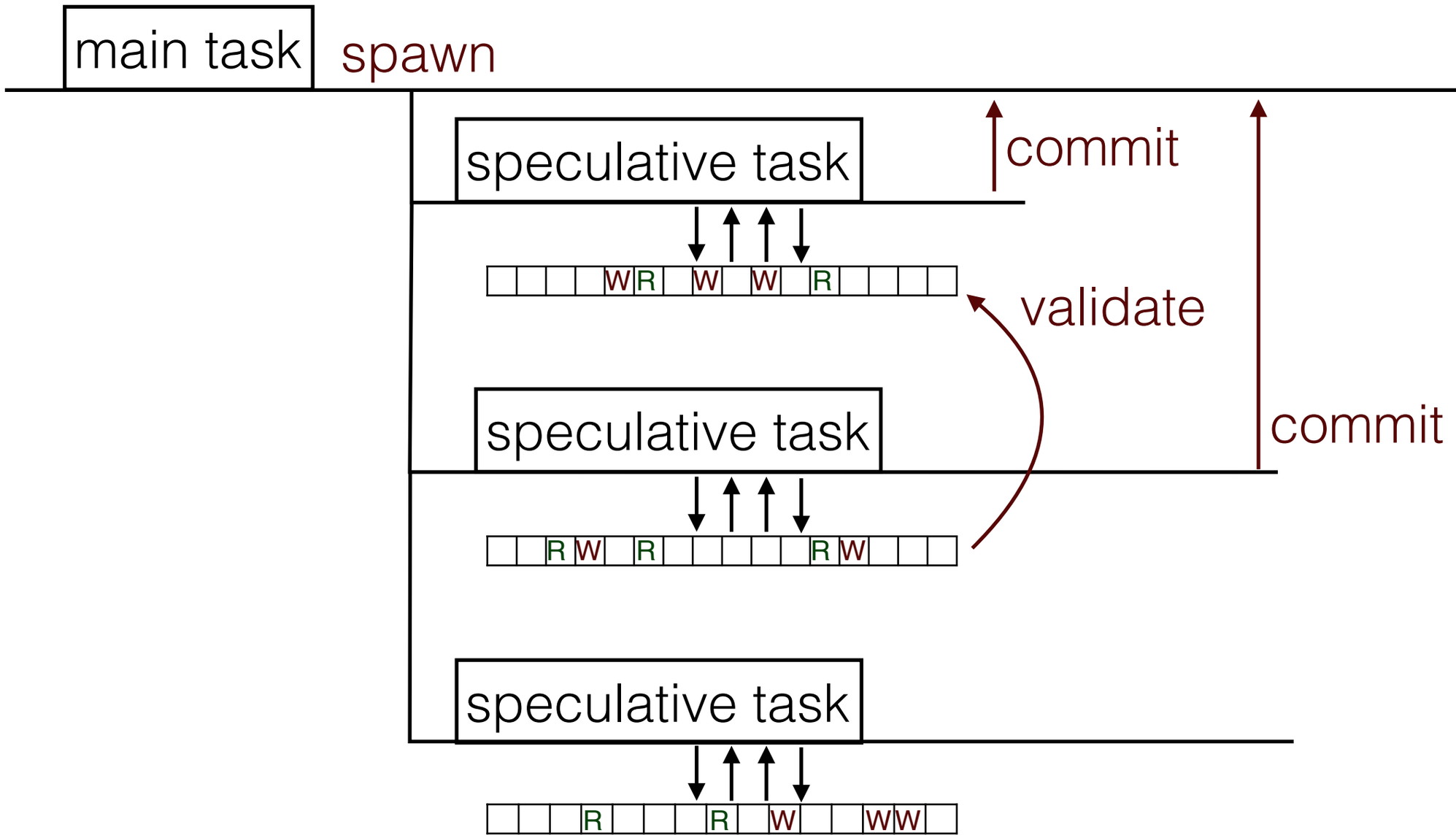

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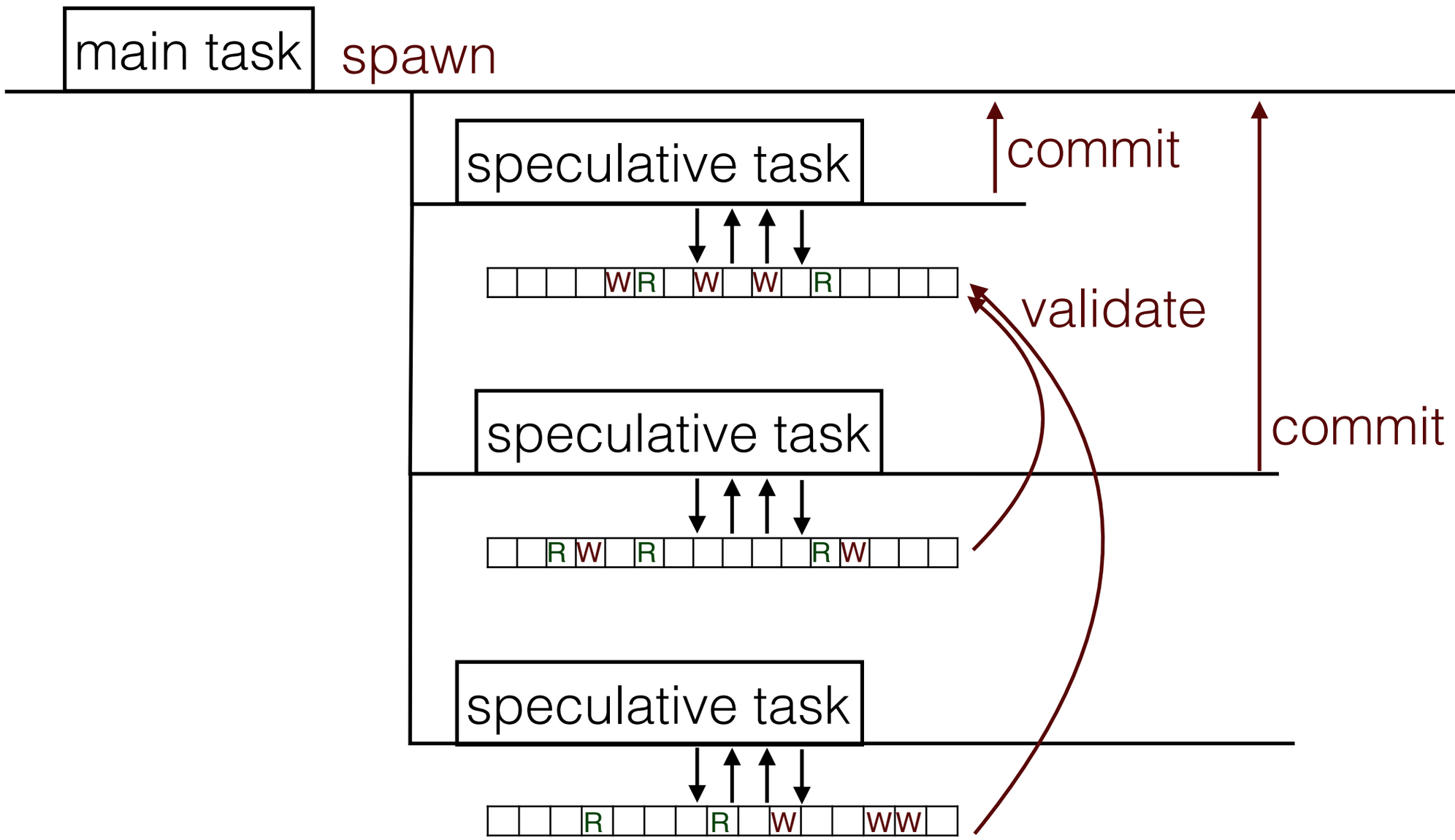

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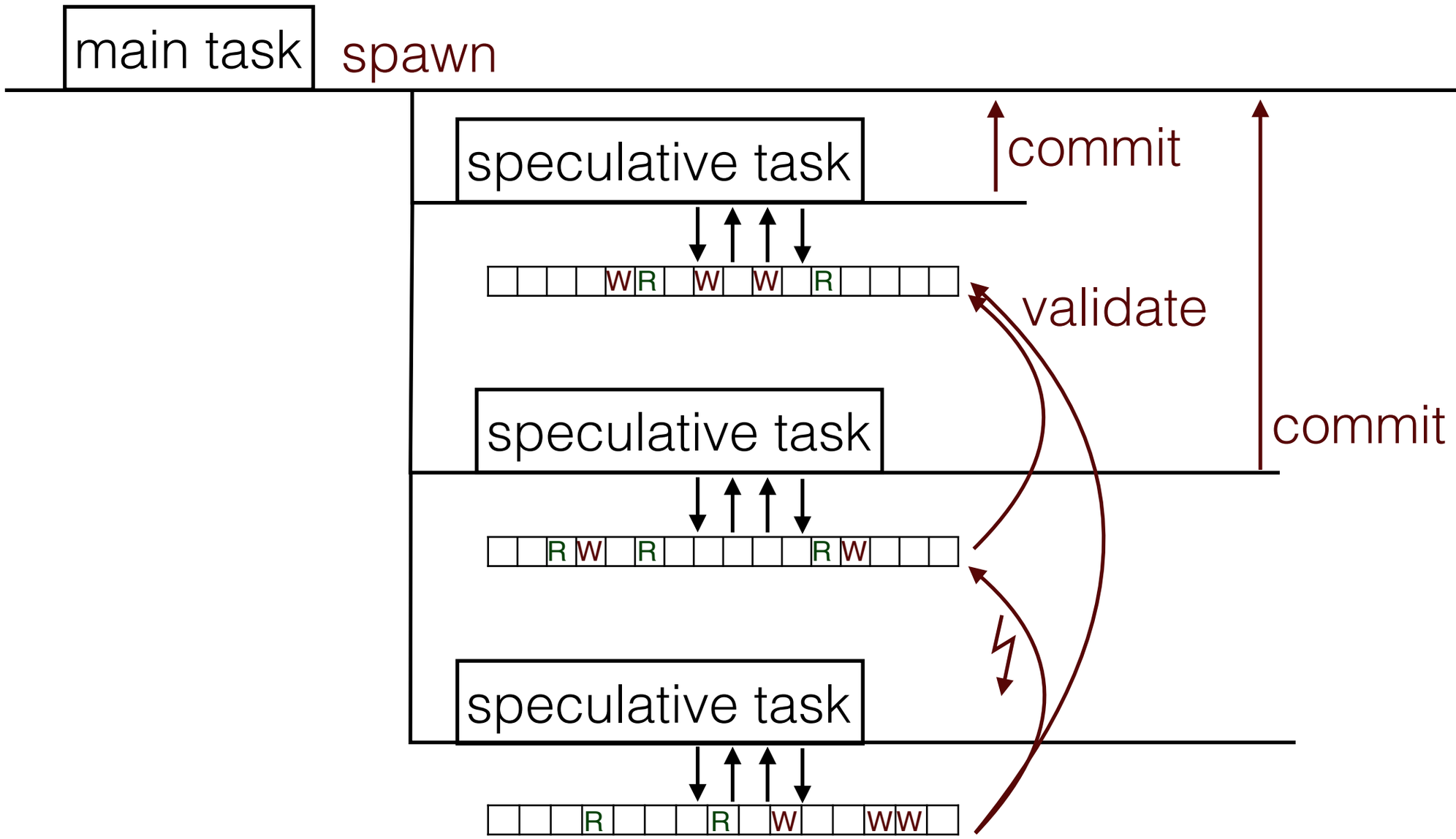

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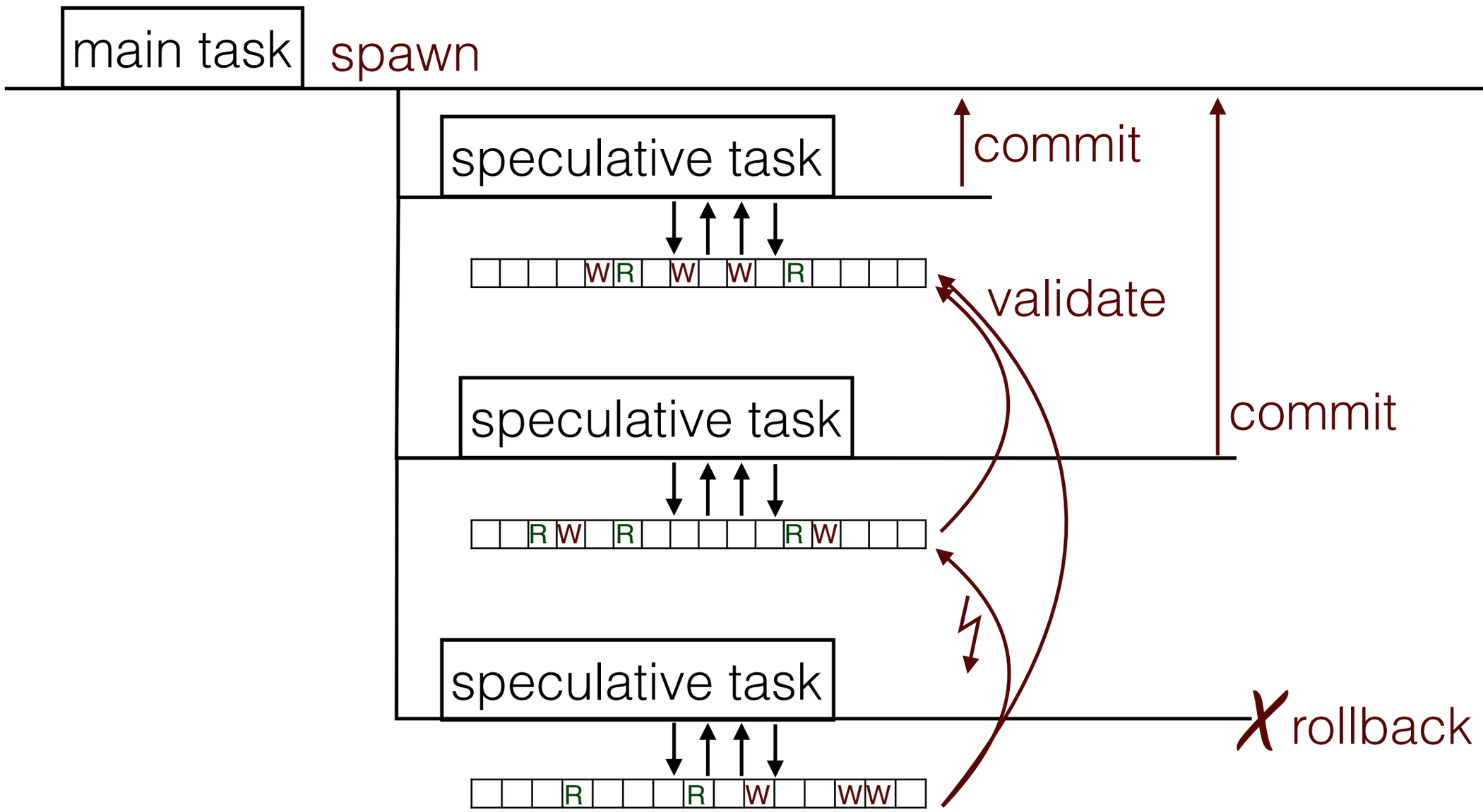

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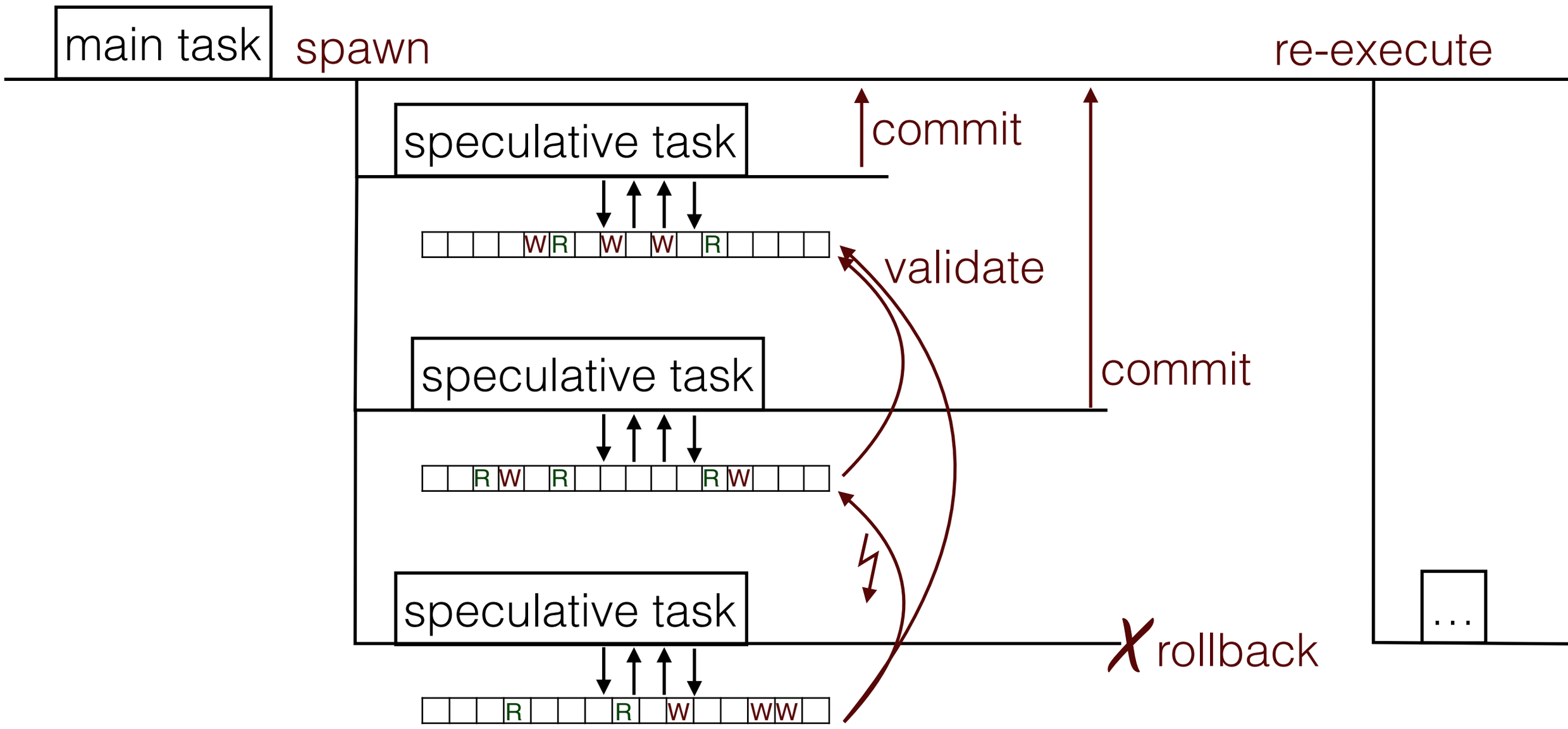


TLS Implementations

S-TLS VM-TLS

- Thread-Level Speculation in pure software
- similar to software transactional memory (STM)
- *explicit* tracking of memory accesses
- code *instrumentation*
- *multithreaded* in same address space
- first described in 1993 by Herlihy and Moss

TLS Implementations

S-TLS

VM-TLS

performance on STM benchmarks
(lots of small transactions)

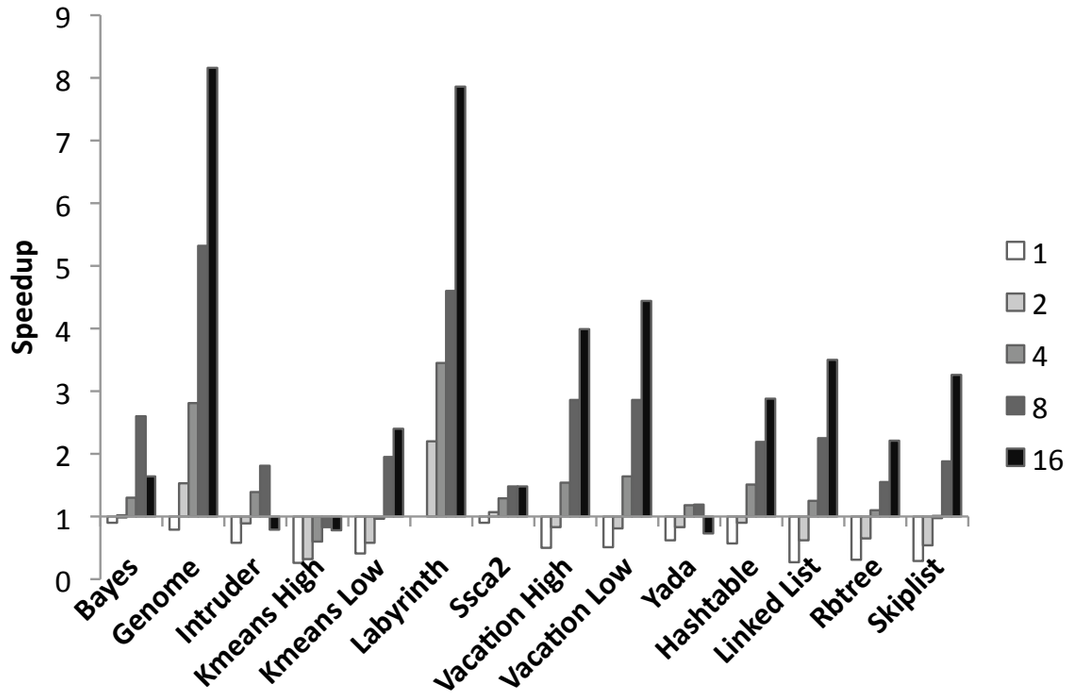
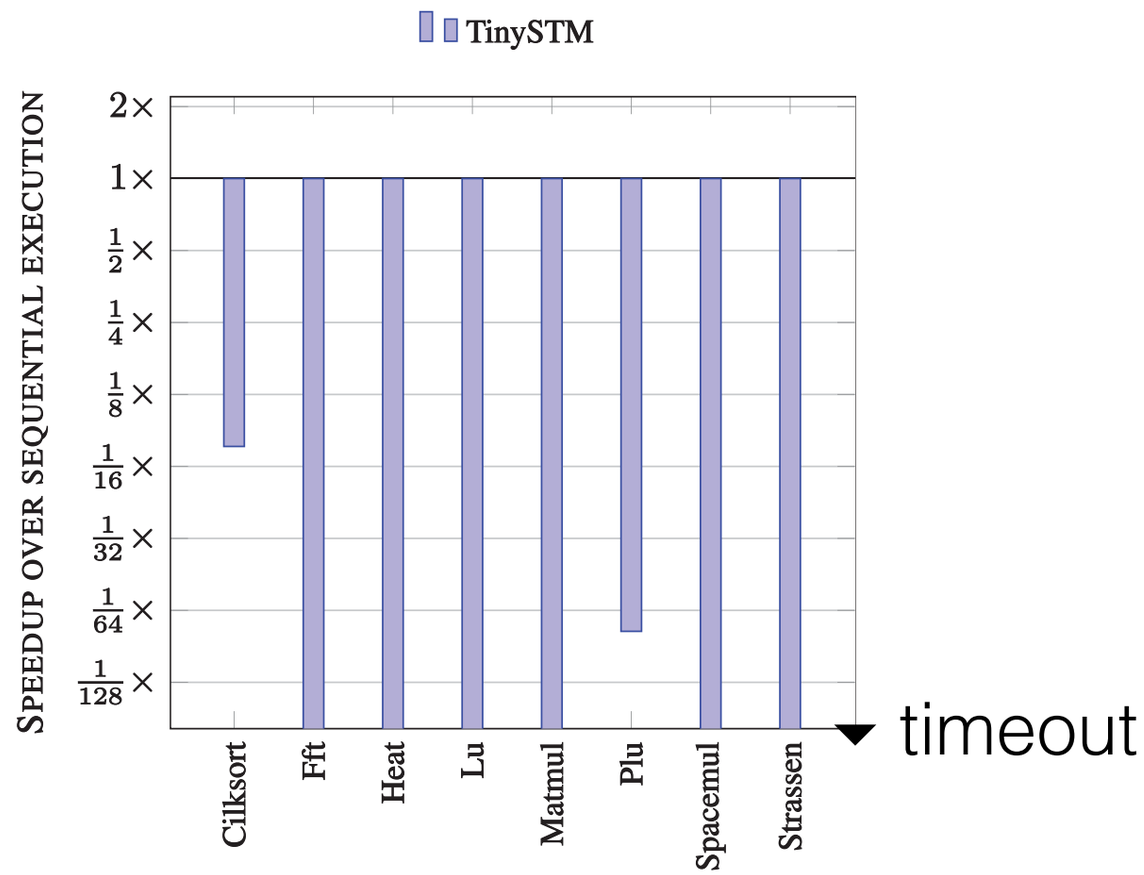


Figure 11. TinySTM performance with 16 core x86
source: Dragojevic et al., 2011, *Communications of the ACM*.

performance on TLS benchmarks
(few large transactions)



TLS Implementations

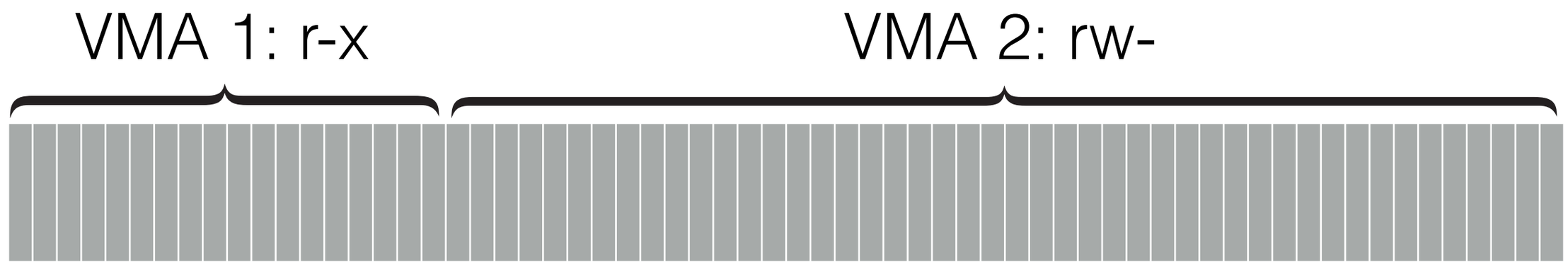
S-TLS

VM-TLS

- Virtual-memory based approaches
  - *implicit* tracking by protecting memory pages
  - segfault handler logs access & unprotects the page
  - can execute *arbitrary code*, even from compiled libraries
  - *multi-process execution* for separate address spaces
  - introduces in 2001 by Papadimitriou and Mowry

Memory Protection
In Virtual-Memory Based TLS

main process:



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Memory Protection
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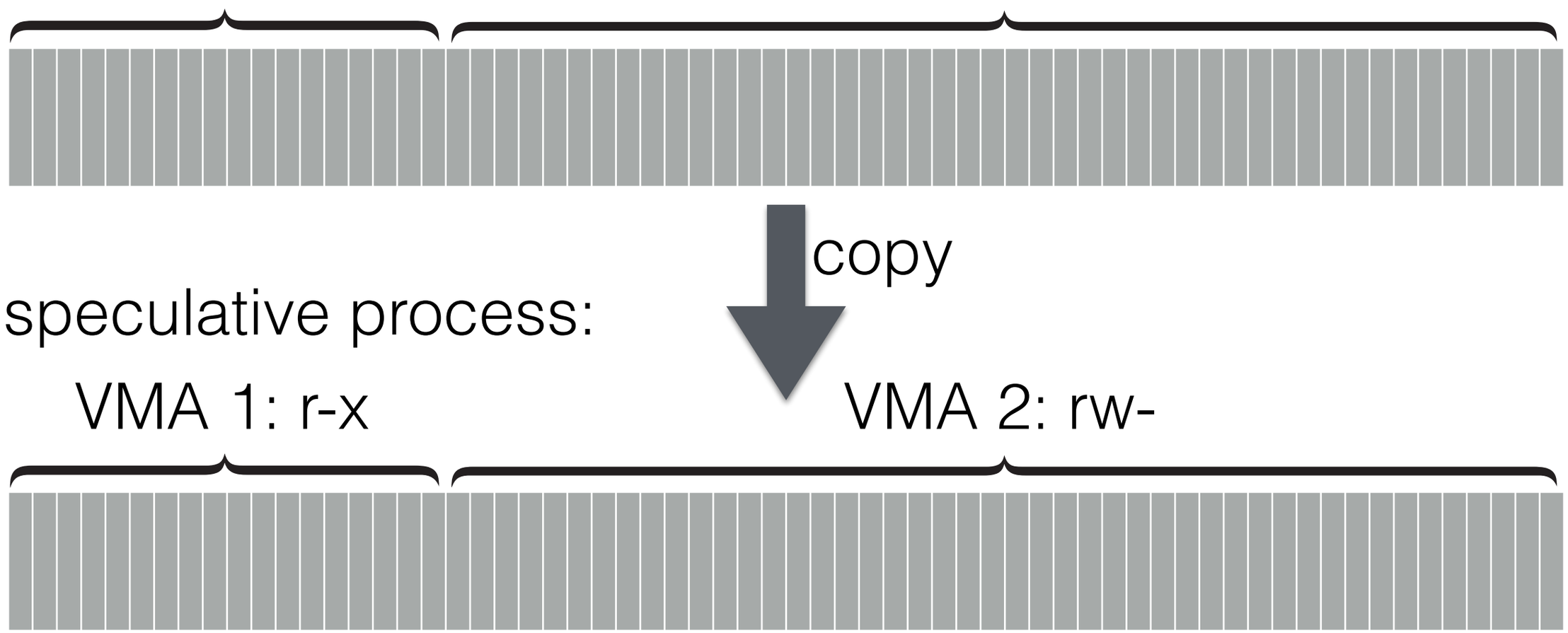

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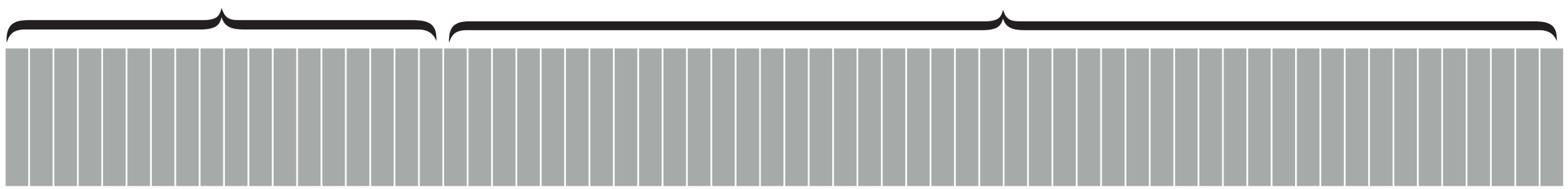
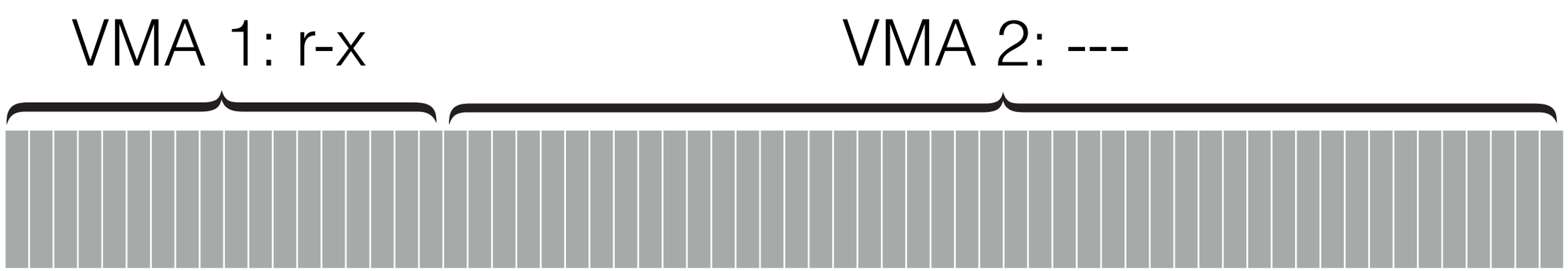


speculative process:



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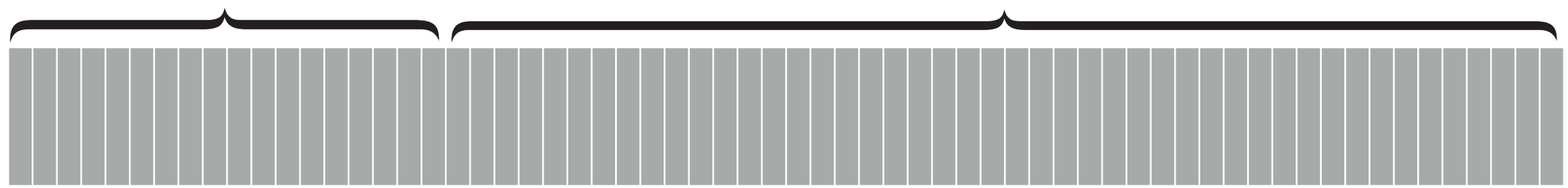

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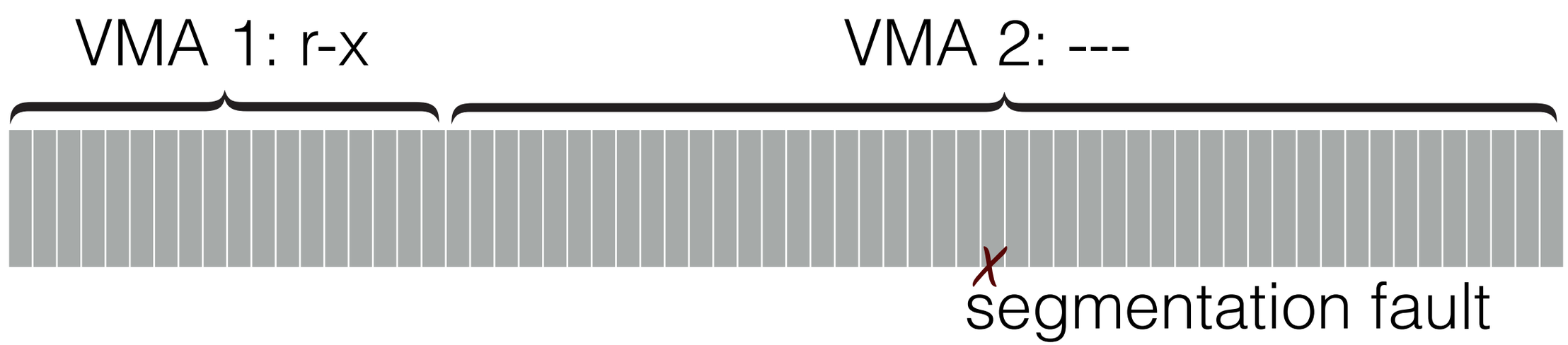

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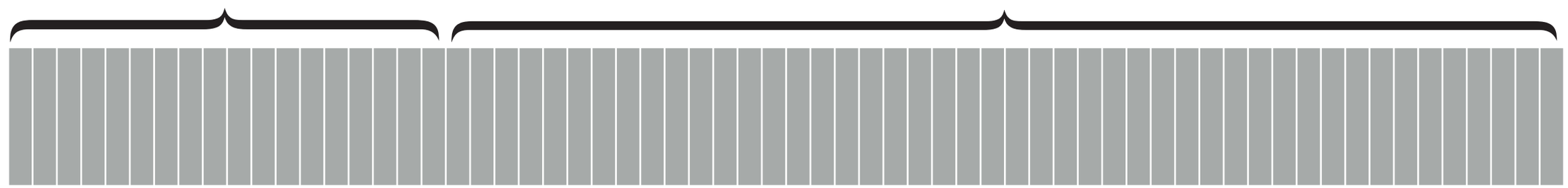

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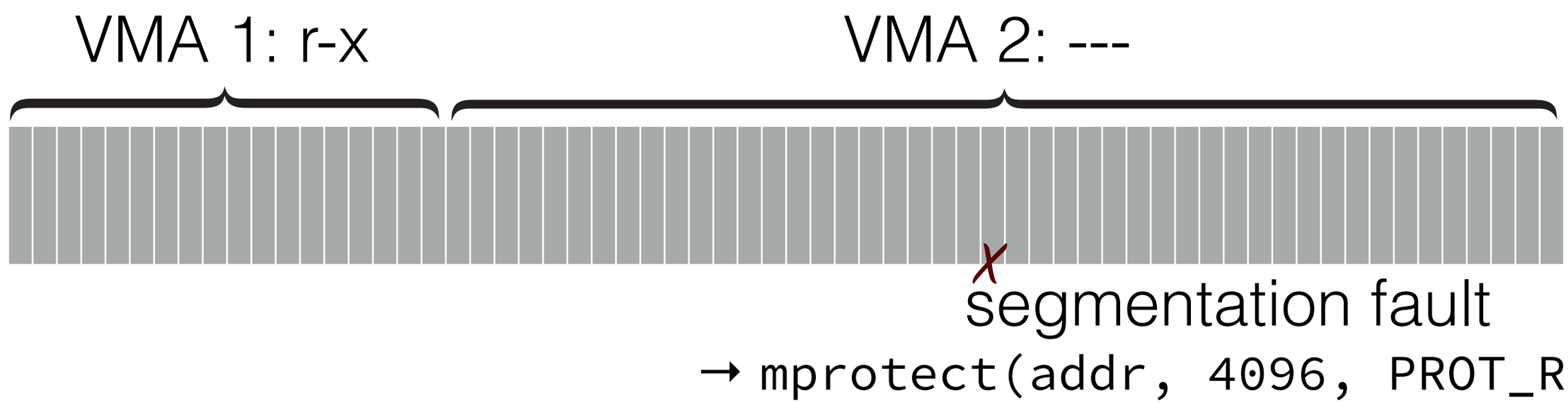

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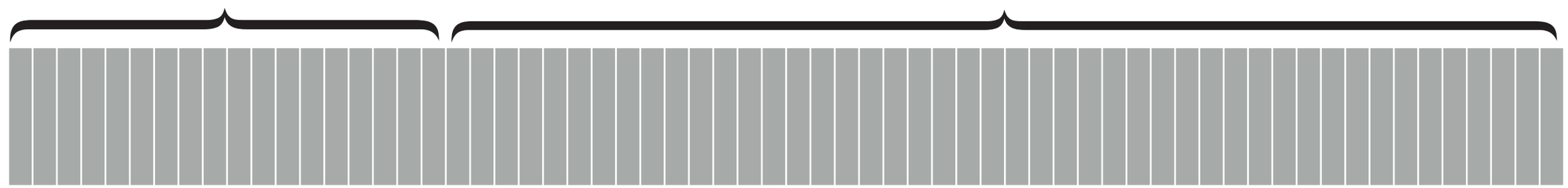

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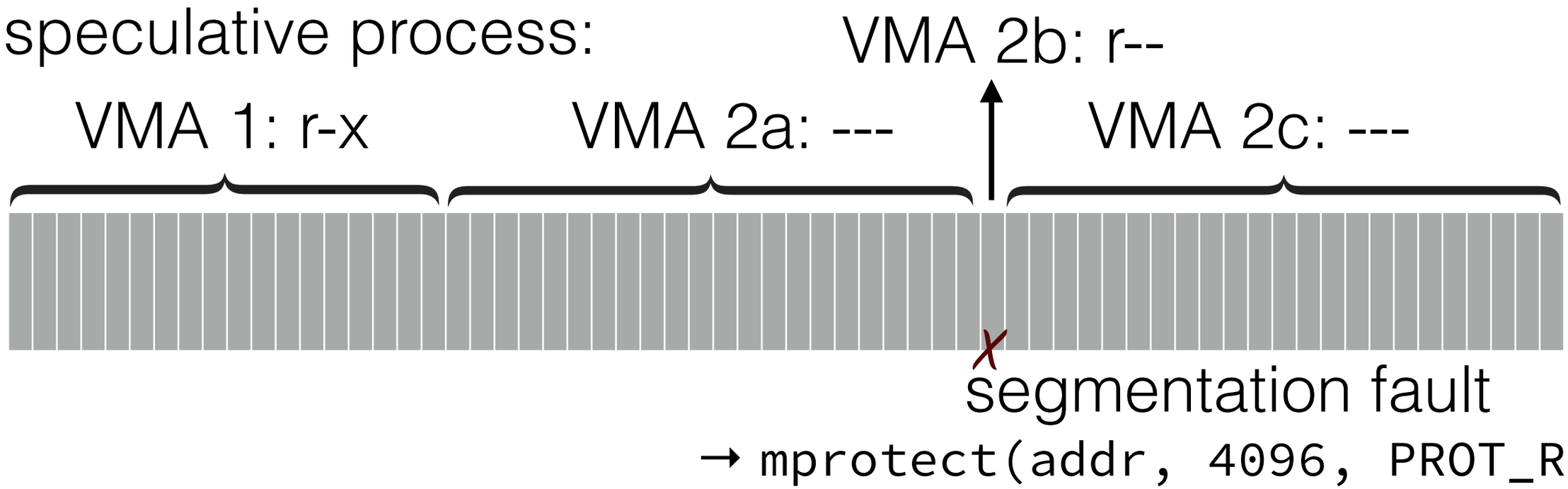
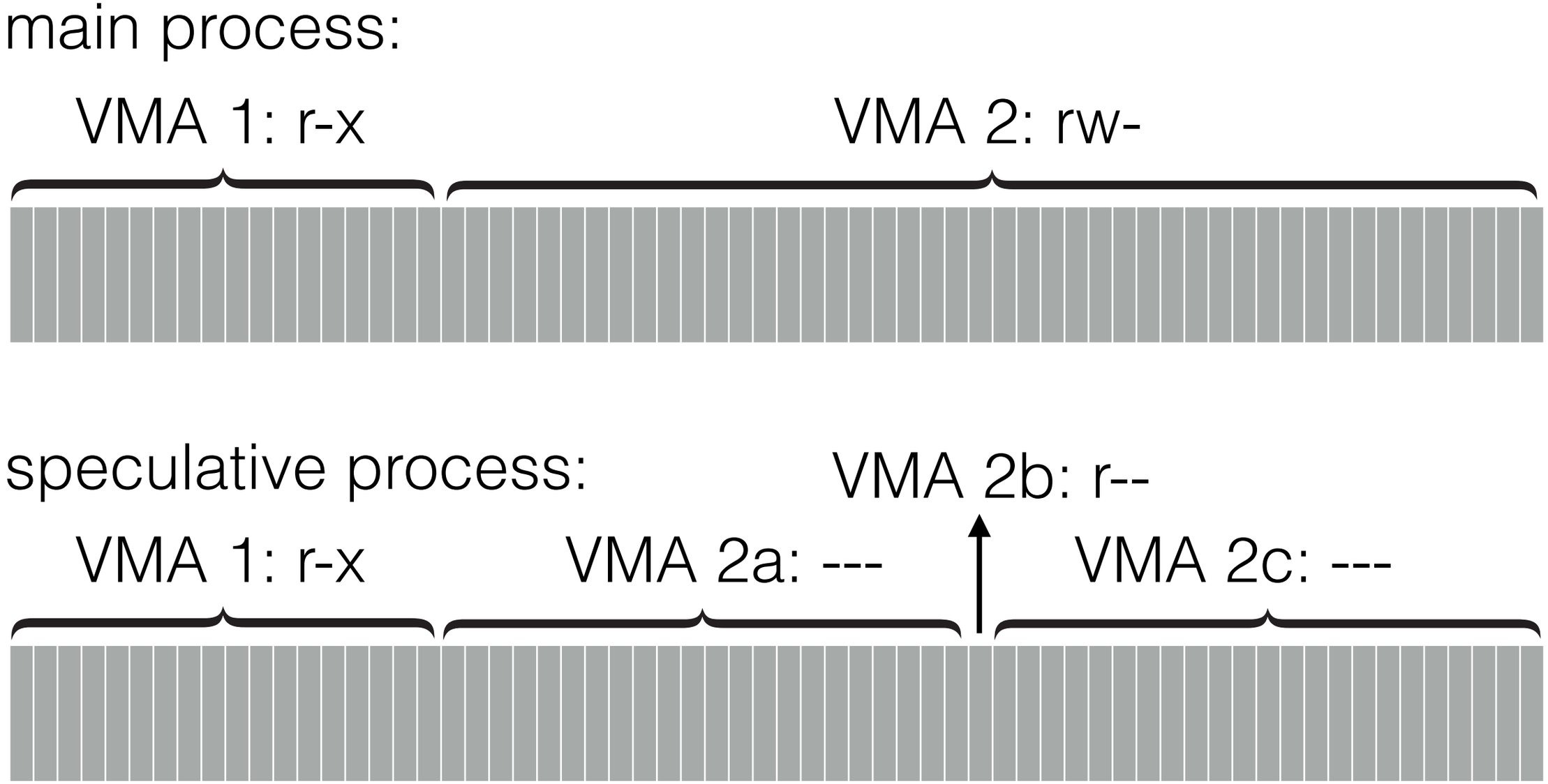


→ `mprotect(addr, 4096, PROT_READ)`

Memory Protection
In Virtual-Memory Based TLS



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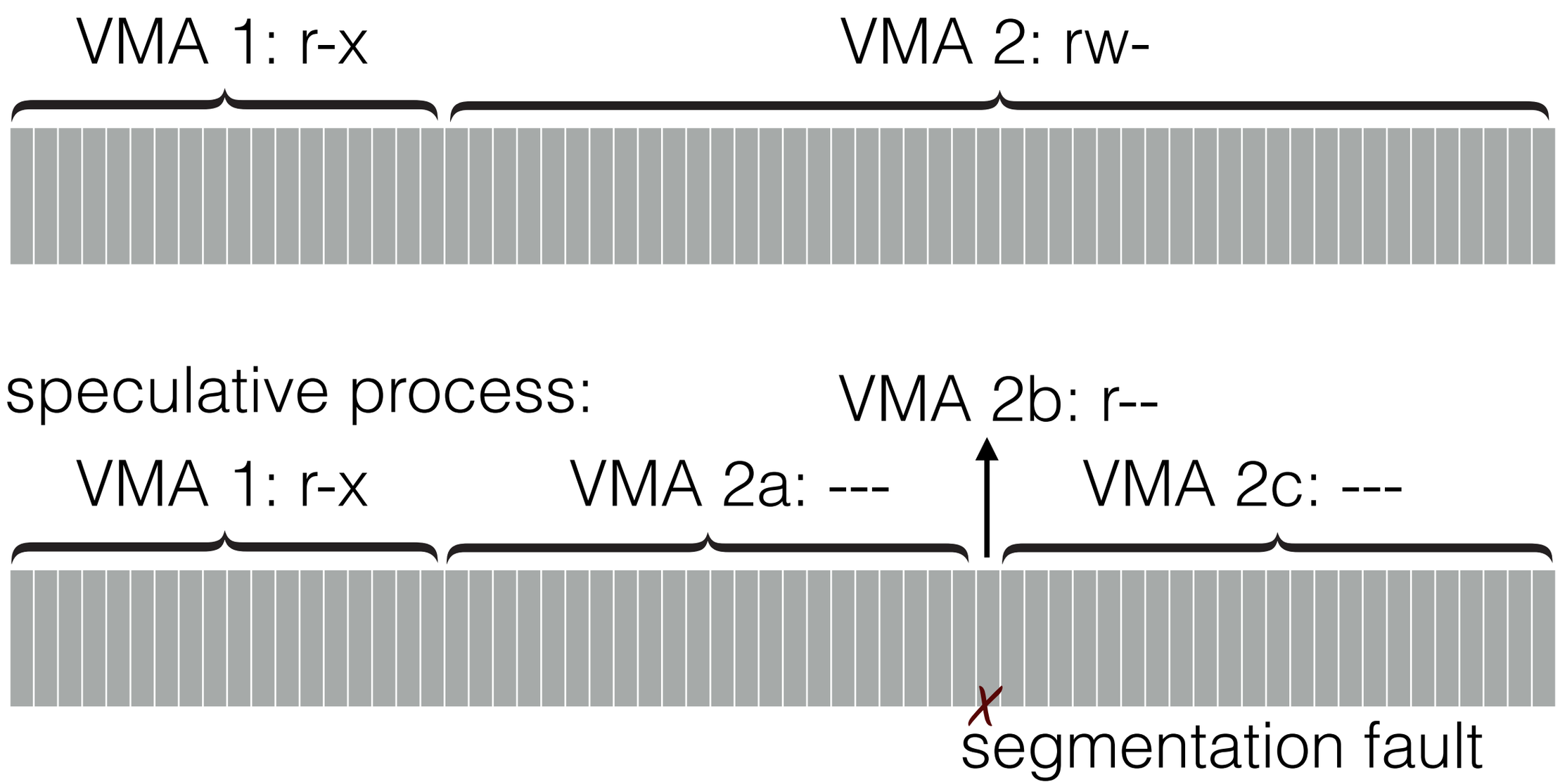

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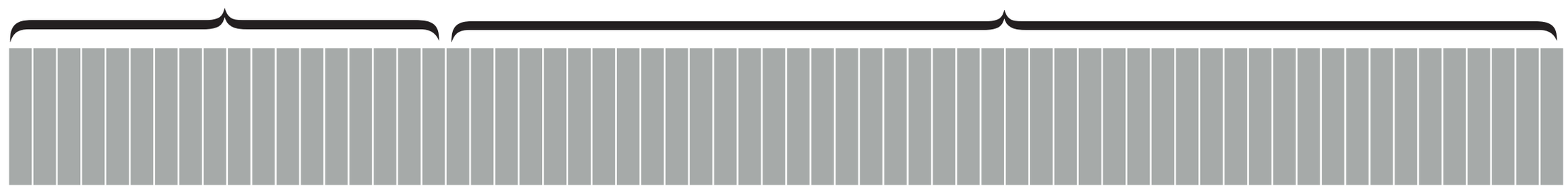

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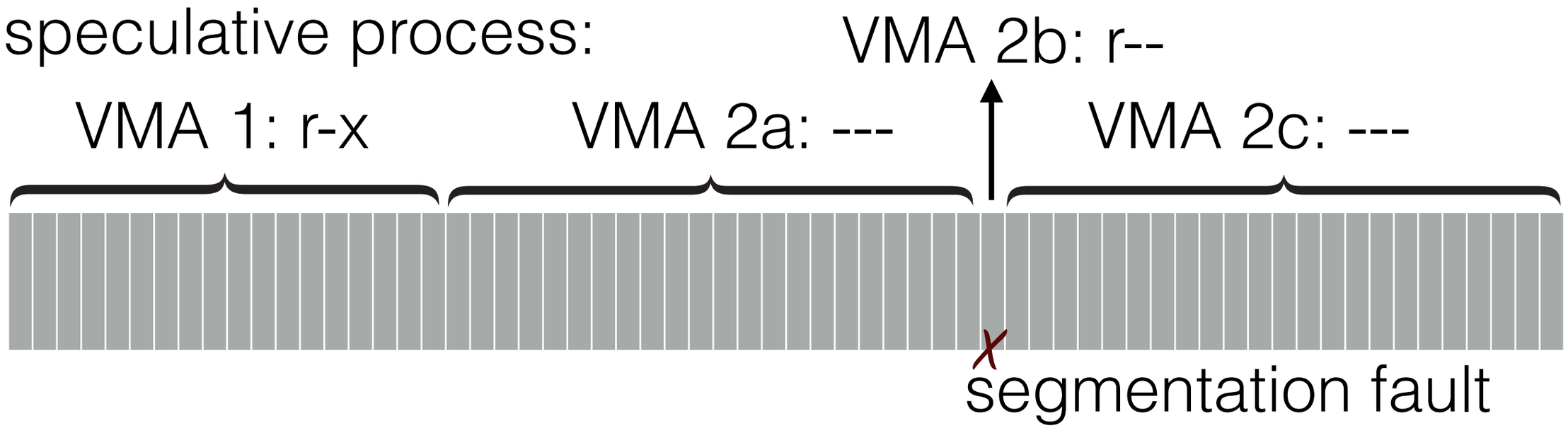

→ `mprotect(addr, 4096, PROT_READ|PROT_WRITE)`

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Memory Protection
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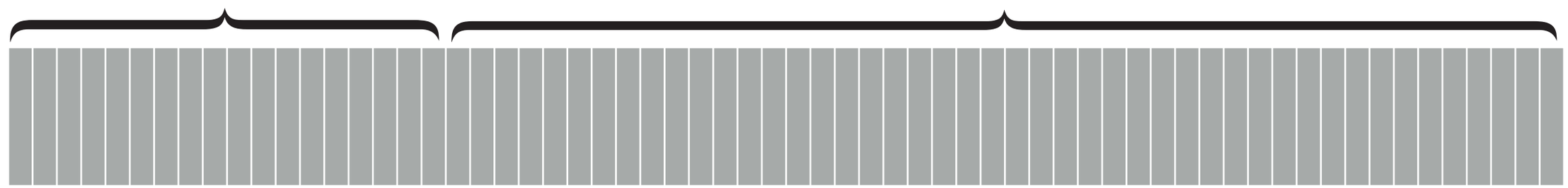

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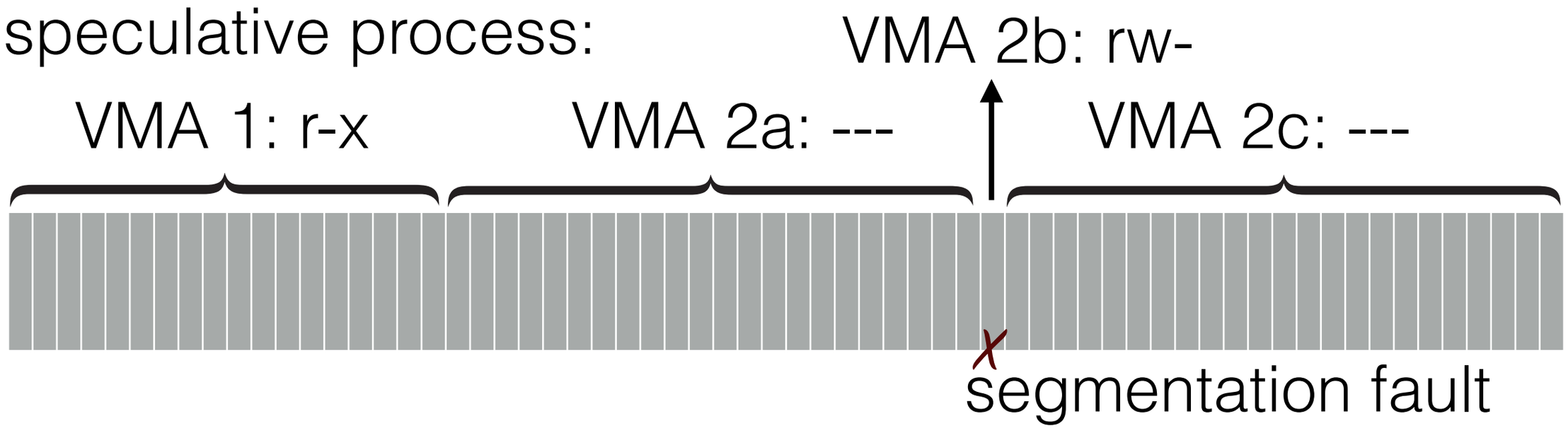

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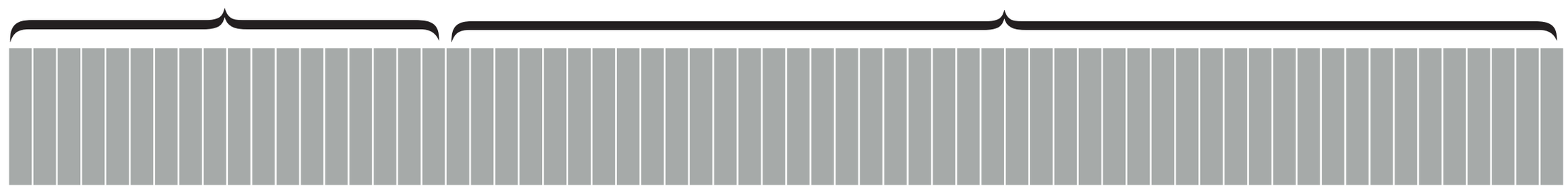

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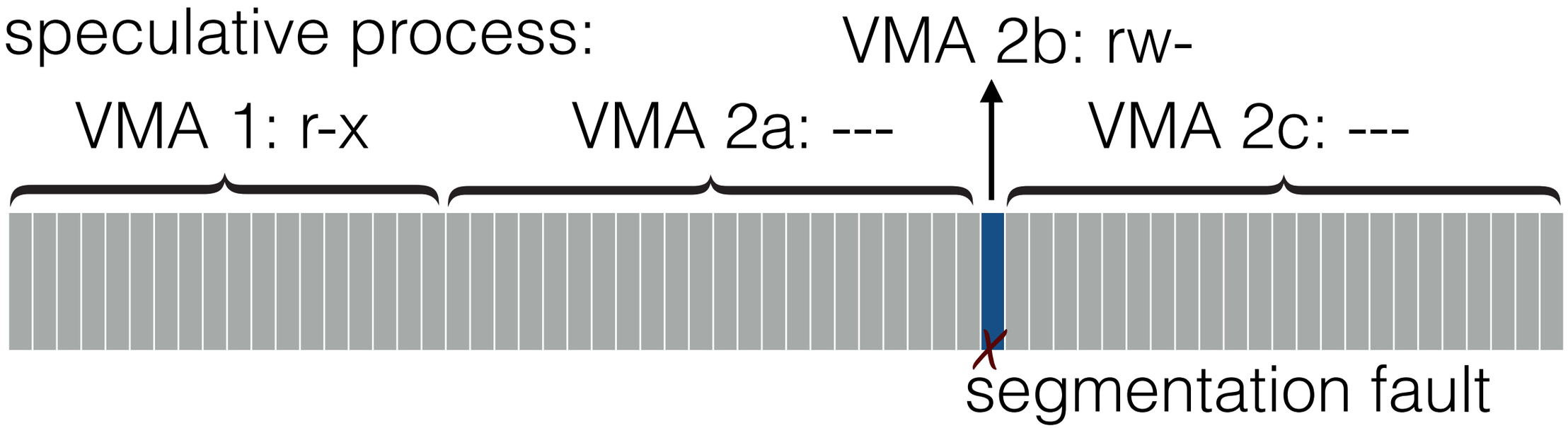

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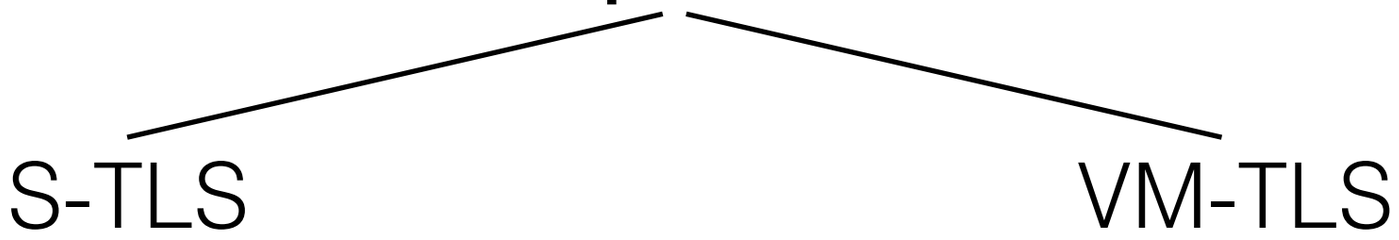
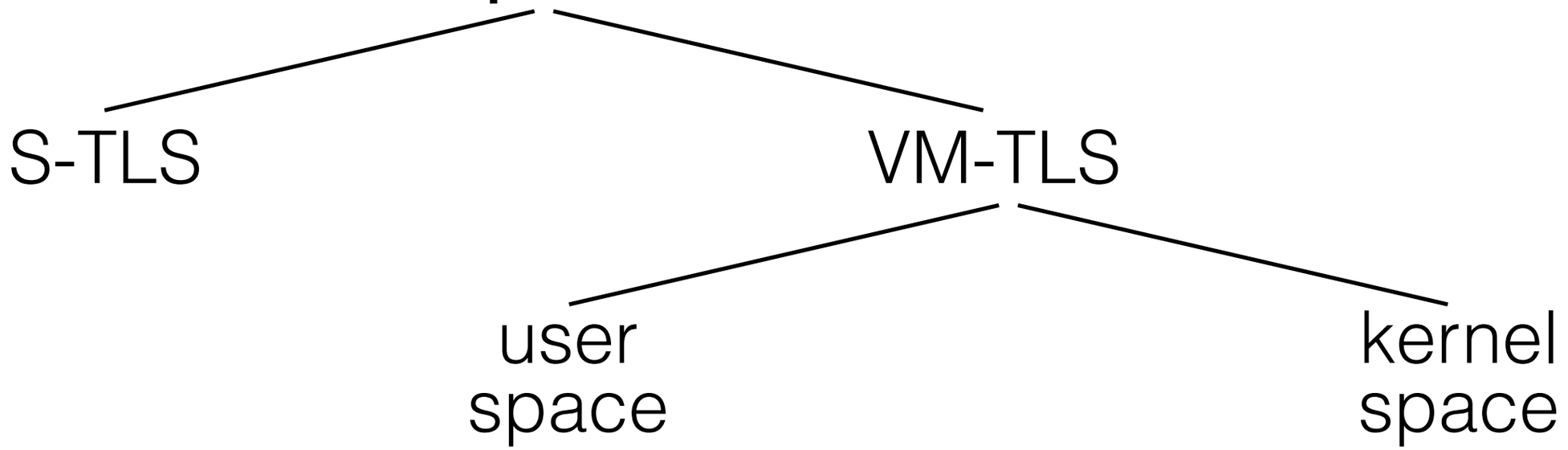
TLS Implementations



	user space library	instrumentation	setup cost	execution overhead	commit cost	granularity	I/O isolation
S-TLS	✓	✓	$	$$$ (per access)	$$$	✓ (arbitrary)	—
VM-TLS	✓	—	$$$	$$ (per page)	$$	✗ (memory page)	—

TLS Implementations



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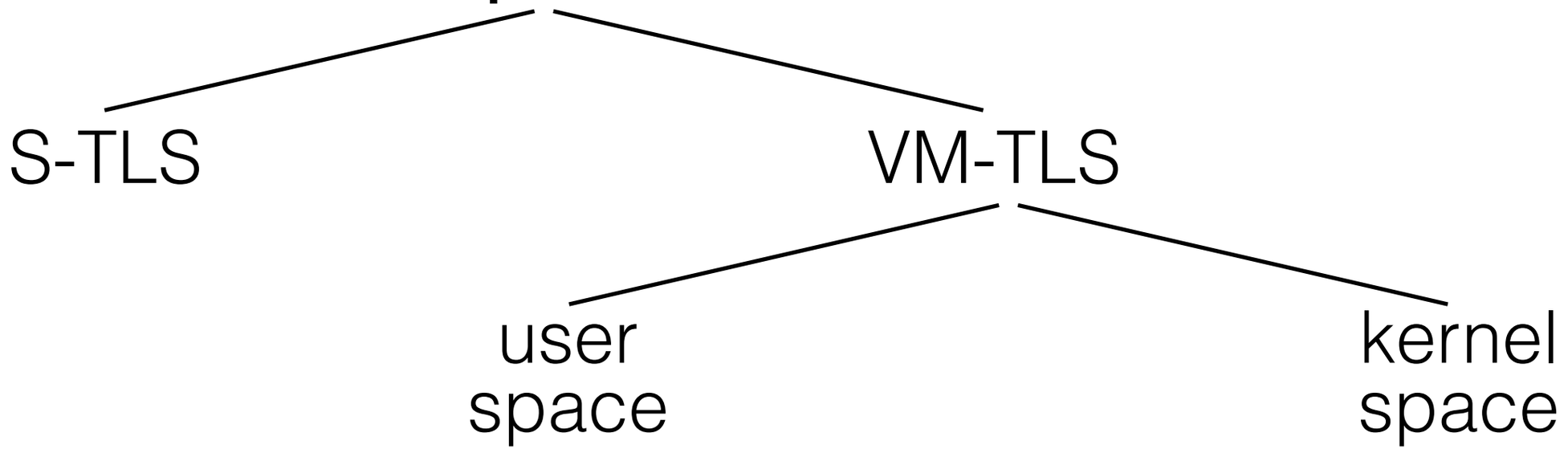

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S-TLS	✓	✓	$	$$$ (per access)	$$$	✓ (arbitrary)	—
U-TLS	✓	—	$$$	$$ (per page)	$$	✗ (memory page)	—
K-TLS	—	—	$$	$ (per page)	$	✗ (memory page)	✓

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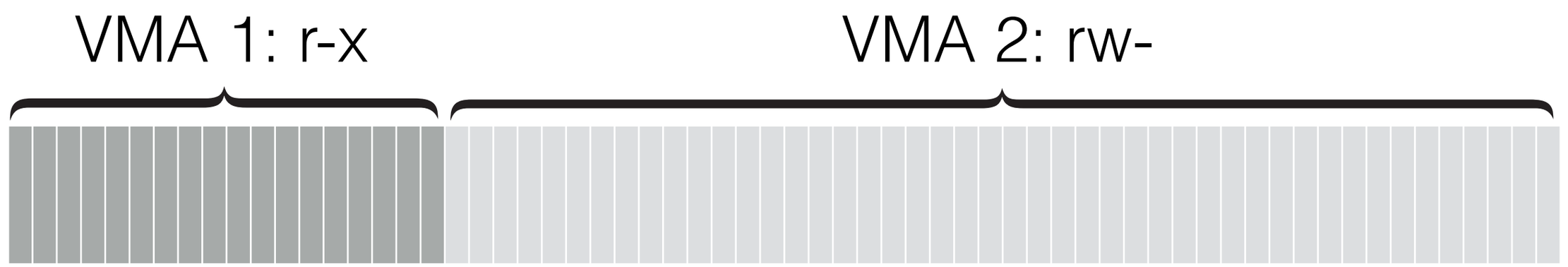
Memory Protection
In Kernel Space

main process:

speculative process:



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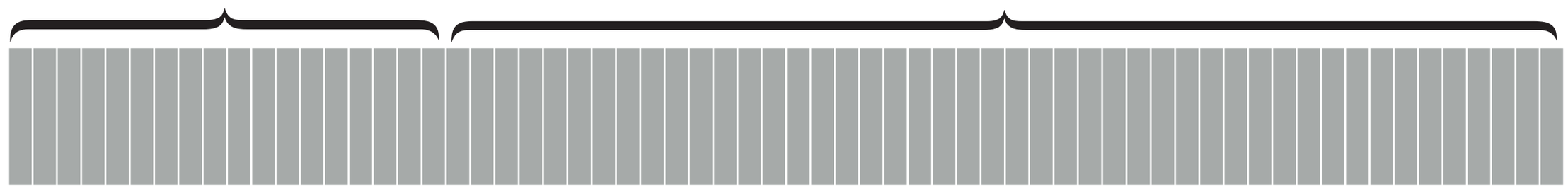

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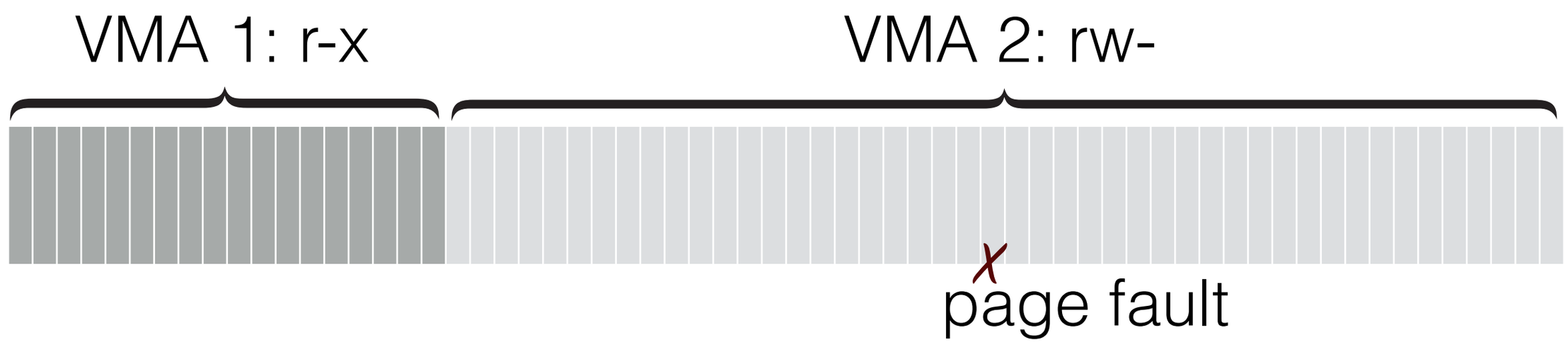

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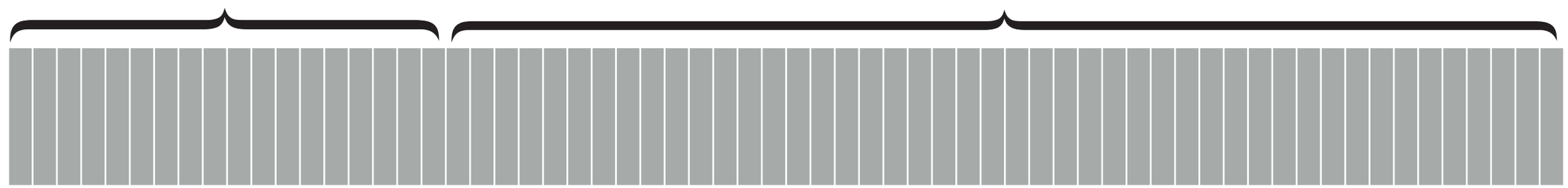

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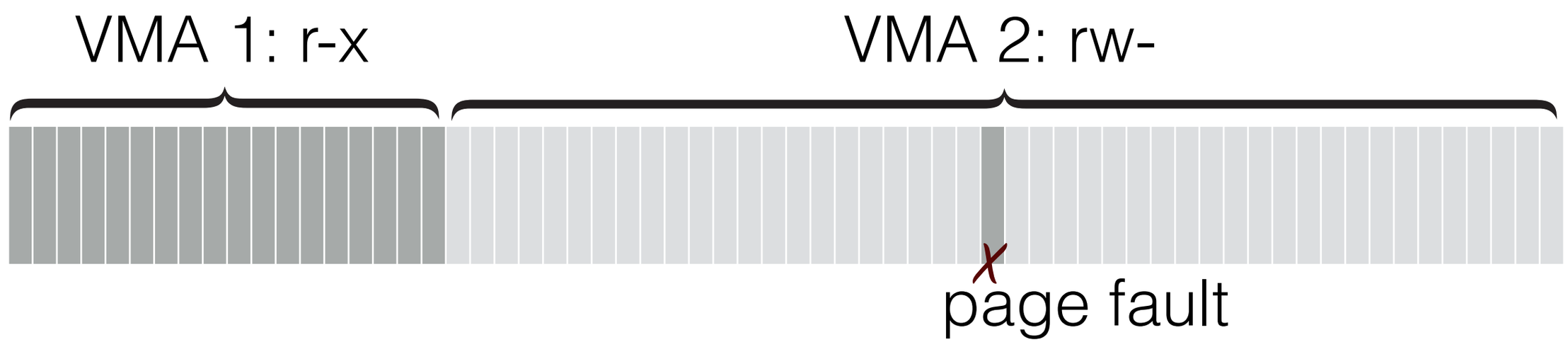
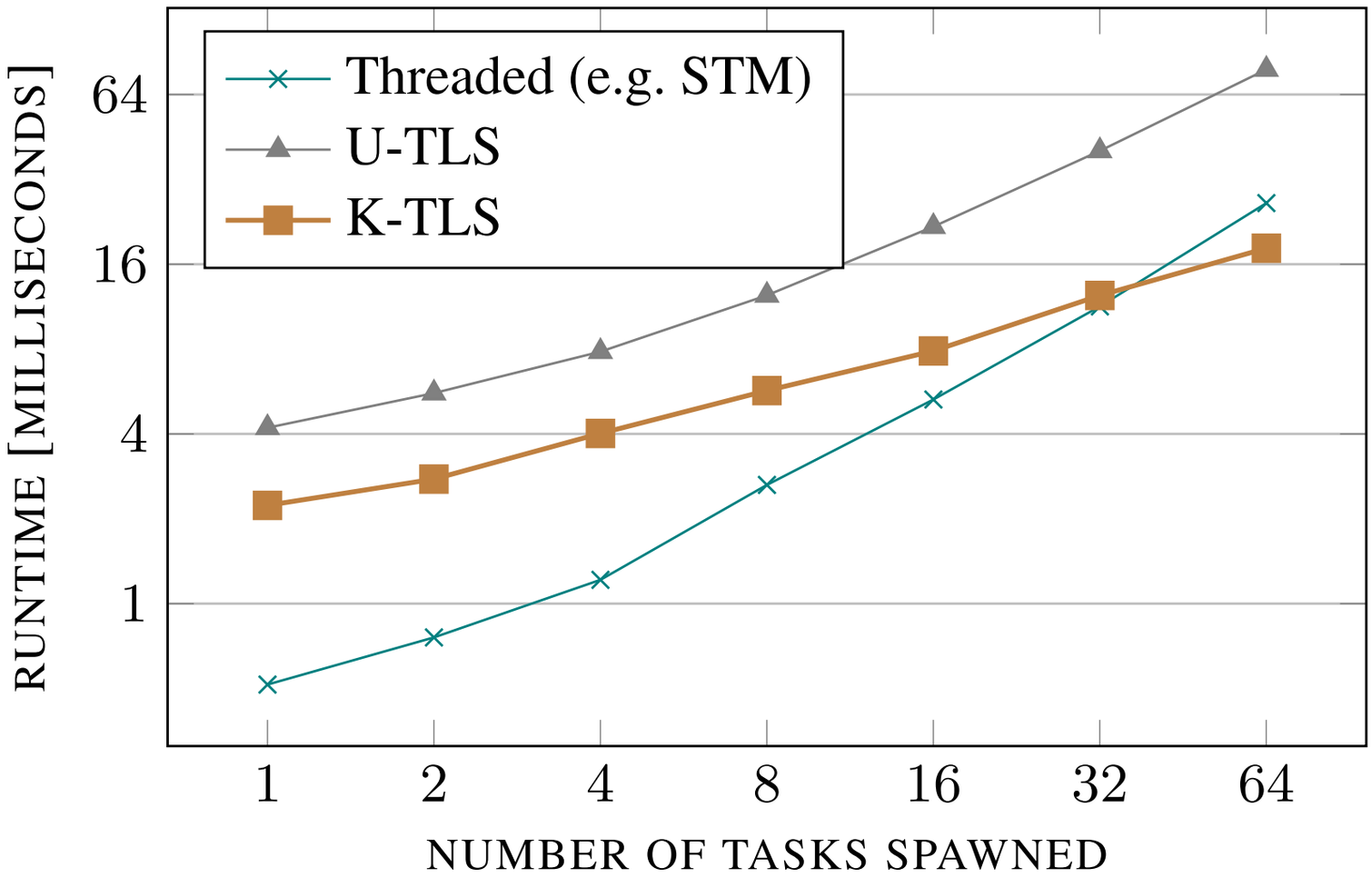


Evaluation
Spawn Time



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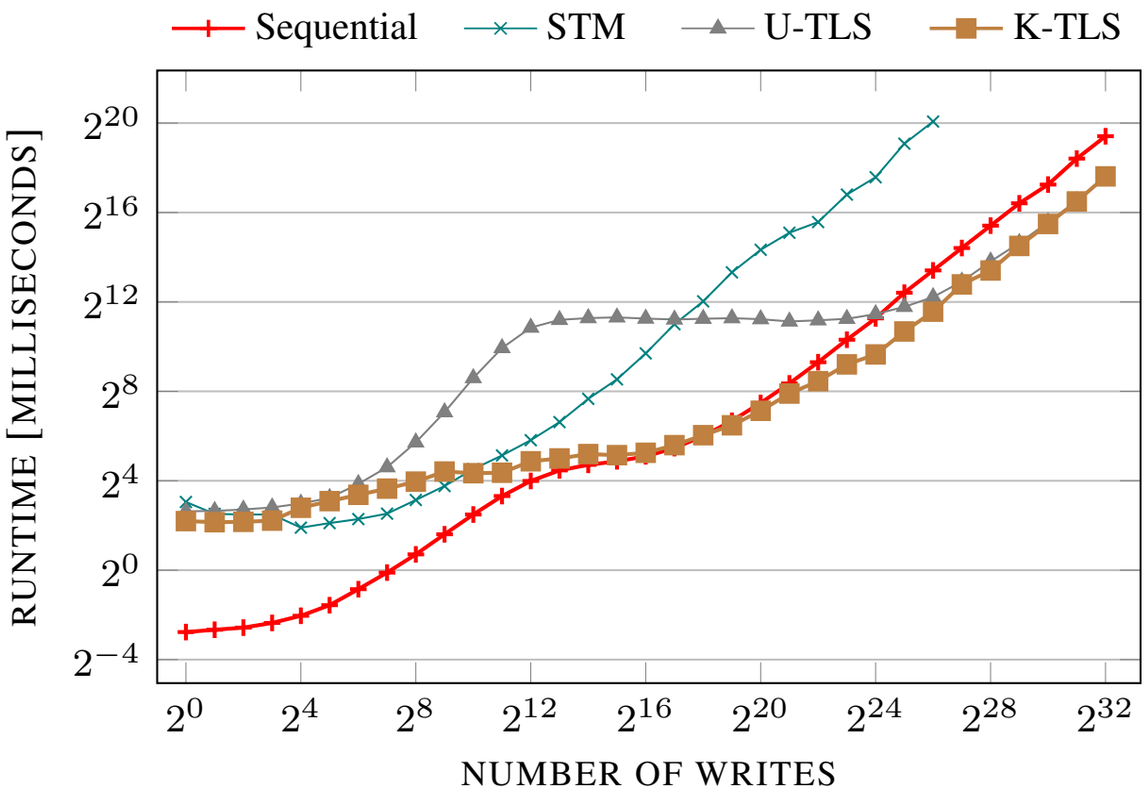
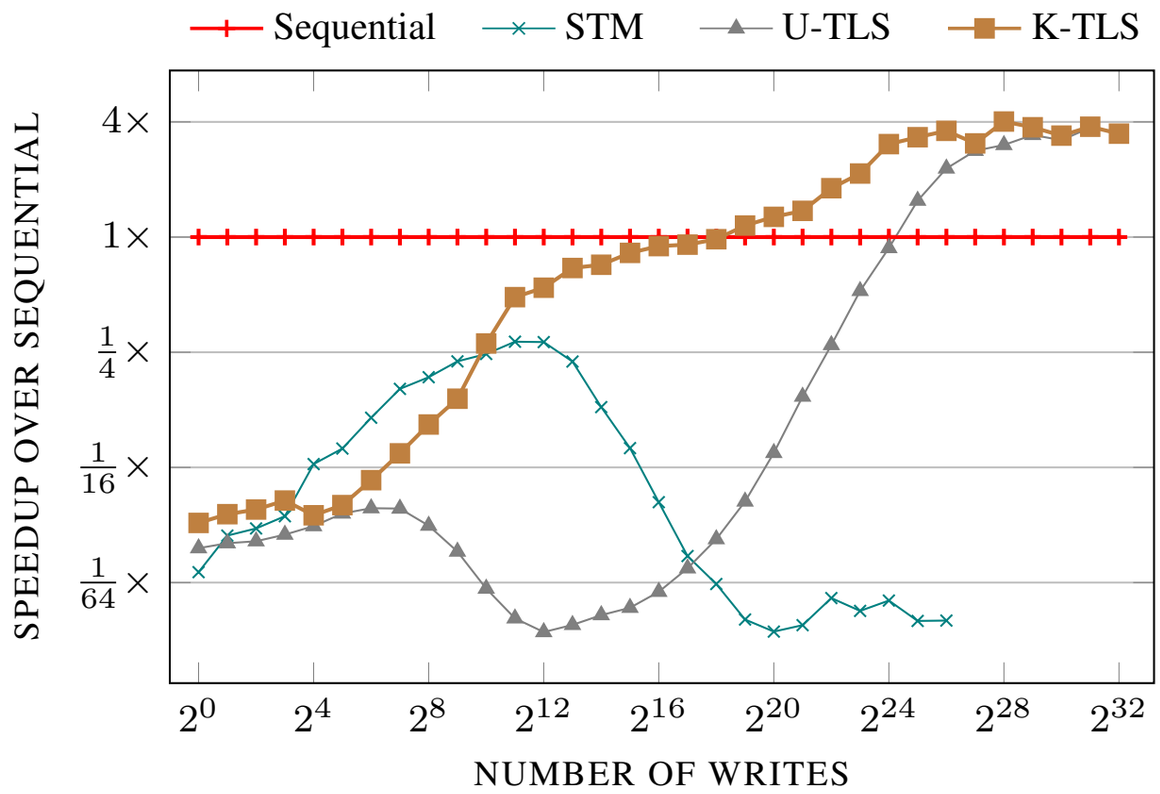
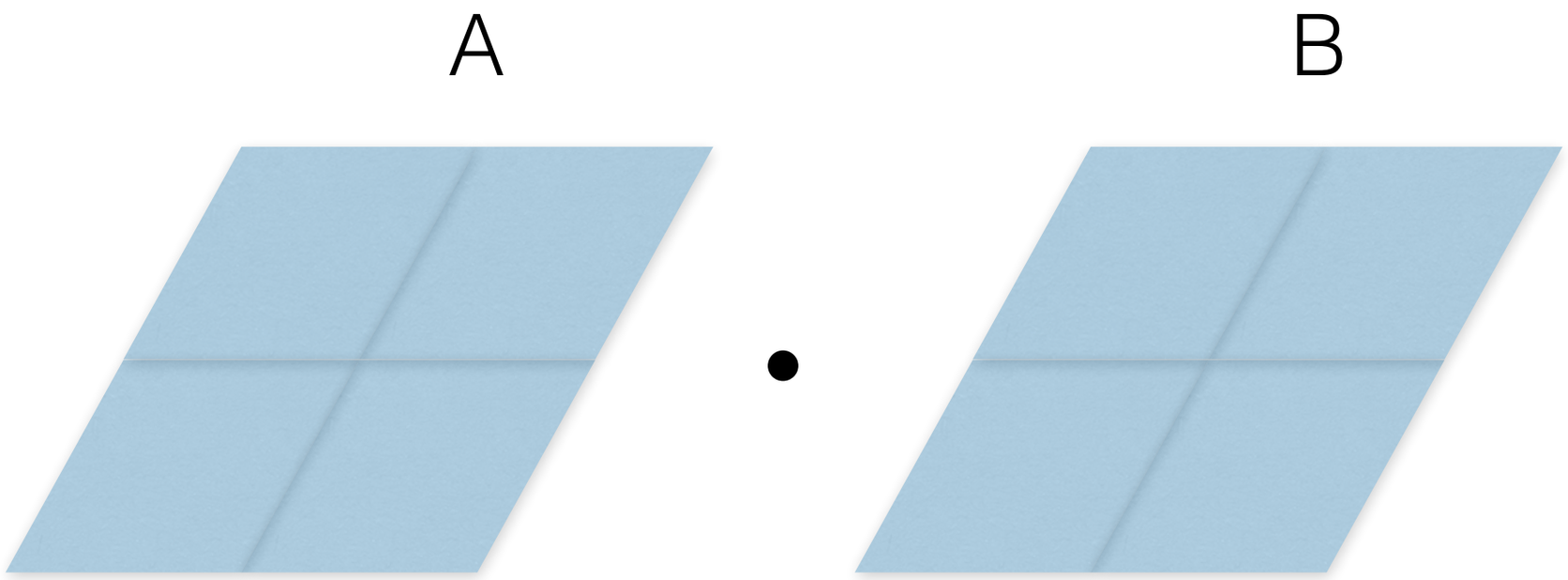
Evaluation
Random Memory Writes

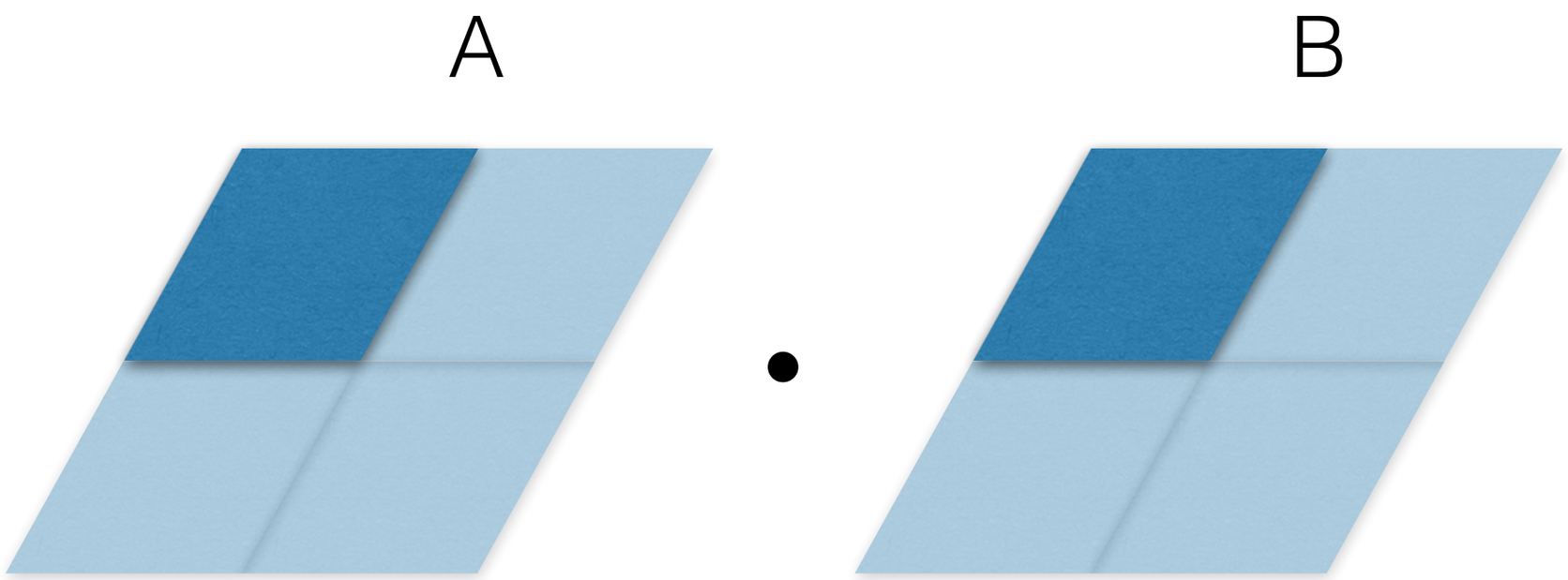




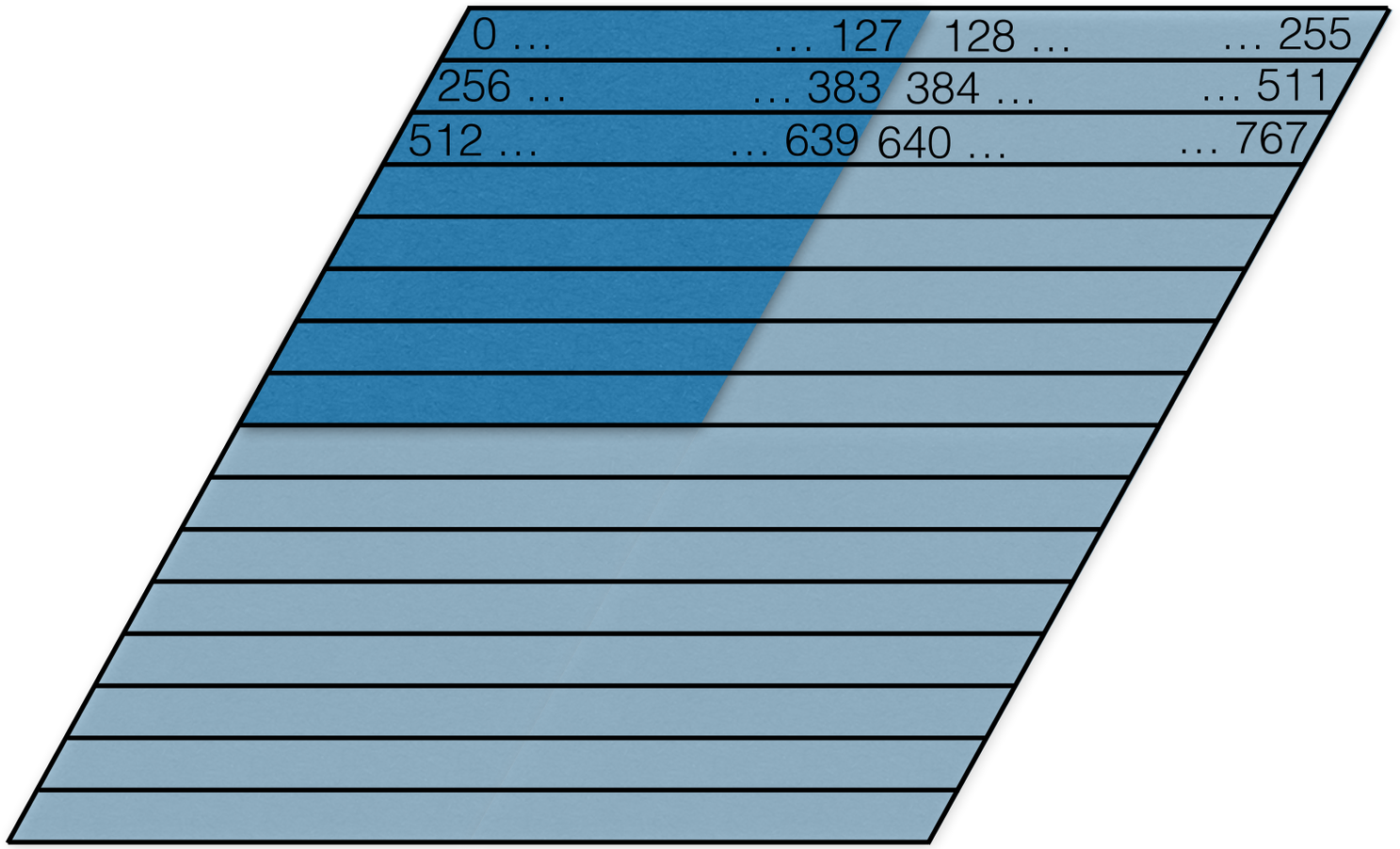
Evaluation
Strassen Matrix Multiplication



Evaluation
Strassen Matrix Multiplication



Evaluation
Strassen Matrix Multiplication



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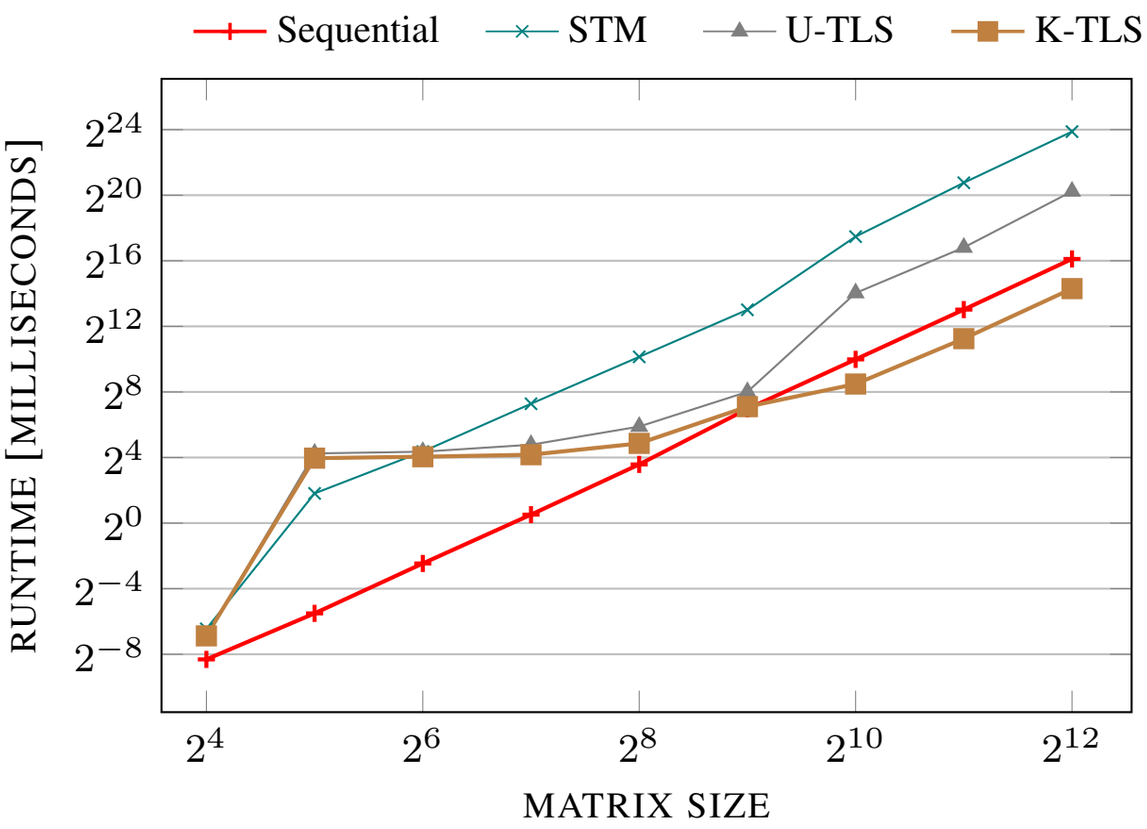
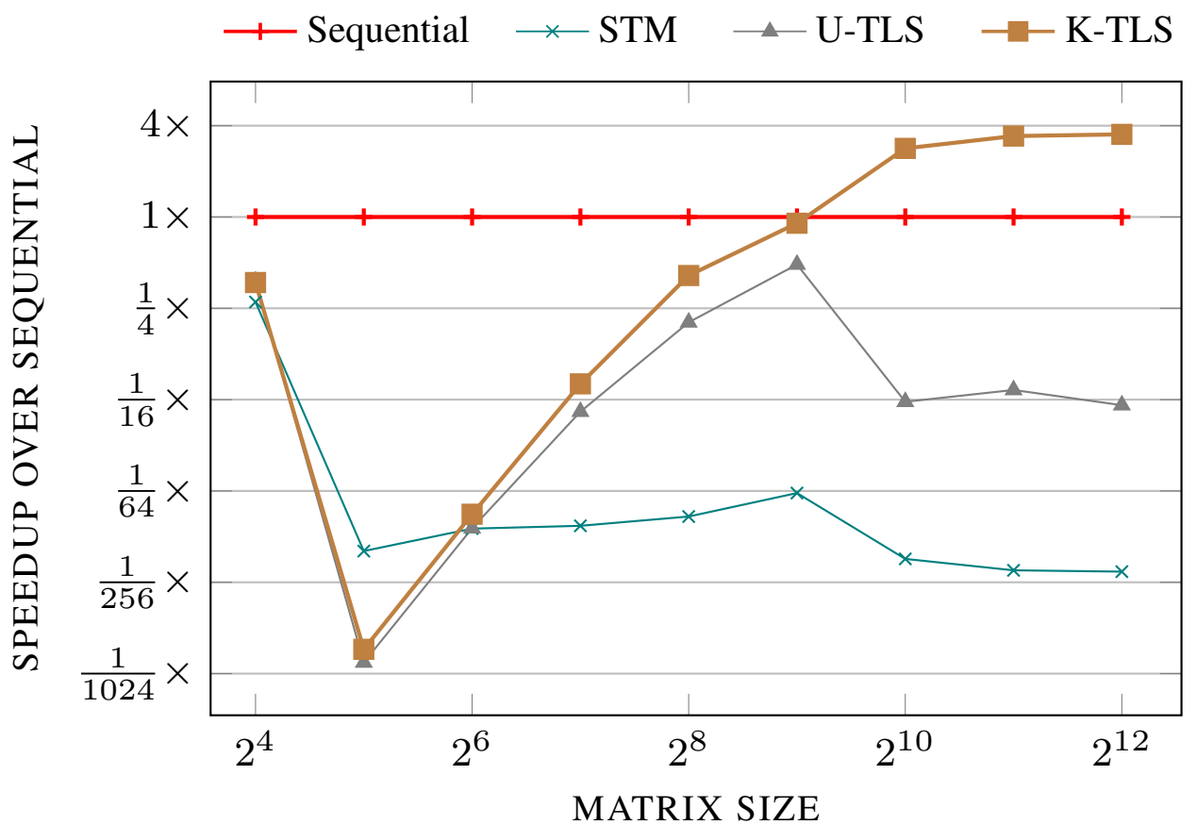
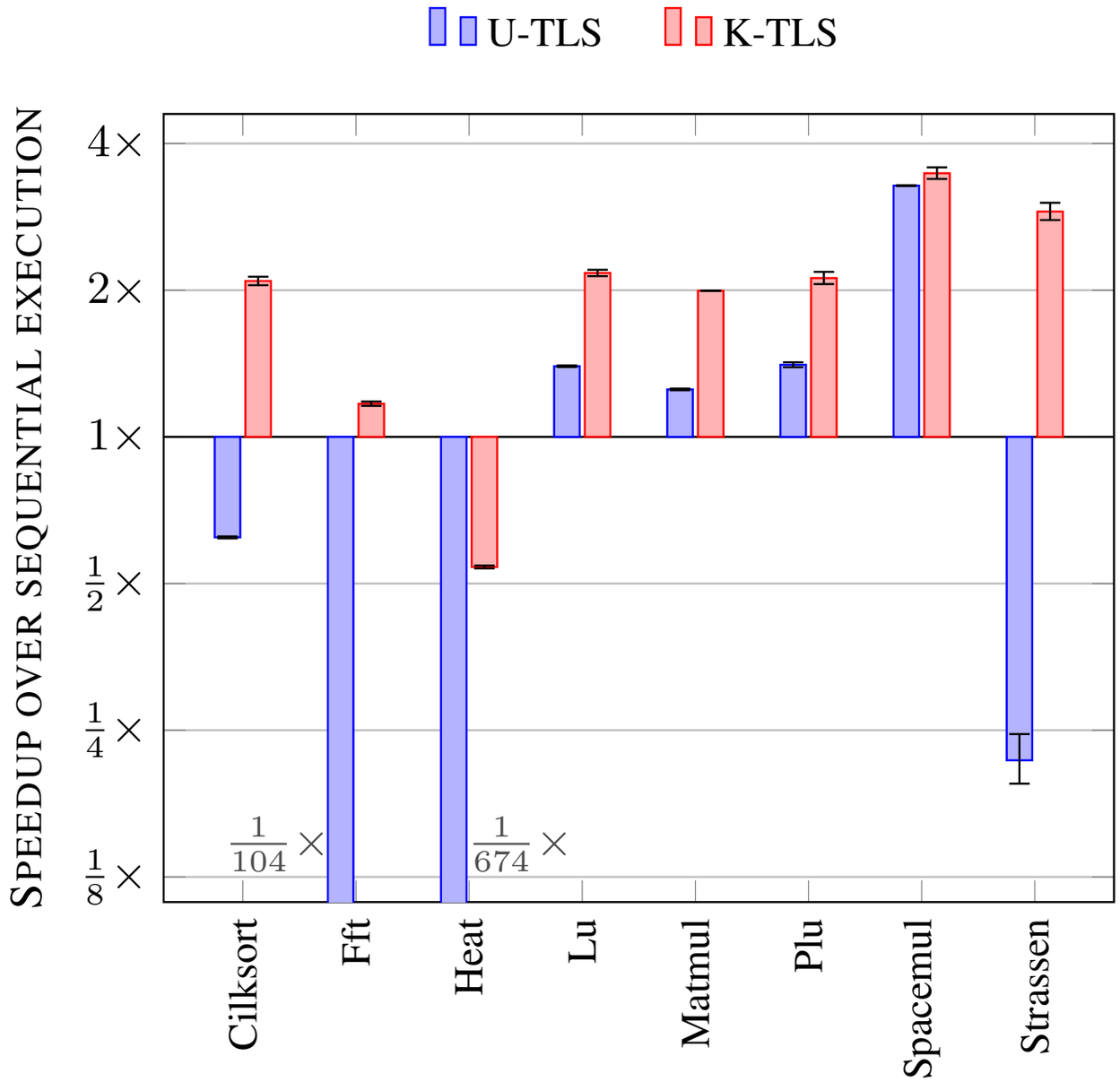
Evaluation
Strassen Matrix Multiplication





Evaluation
Cilk Suite



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Summary

- K-TLS: Thread-Level Speculation with Kernel Support
  - superior to software-only approaches like STM
  - superior to virtual-memory based method in user space
  - full isolation even for system calls
  - no instrumentation → easy to integrate
  - open source: https://github.com/hammacher/k-tls