Software Transactional Memory for Large Scale Clusters

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Cray Inc.

Transactional Memory (TM)

Can simplify parallel programming

Well studied for small-scale, cache-coherent platforms

No prior work on TM for *large scale platforms*

- Potentially thousands of processors
- Distributed memory, no cache coherence
- Slow communication between nodes

Why STM On Clusters?

TM is a natural fit for *PGAS Languages*

- UPC, CAF, Titanium, Chapel, Fortress, X10, ...
- Address space is *global* (unlike message passing)
- But *data distribution is explicit* (unlike cc-NUMA, DSM)

Commodity clusters are in widespread use

Software transactional memory (STM) is natural choice

- Communication done in software anyway
- Could leverage hardware TM support if it exists

What's New About STM on Clusters?

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Heap address space	Uniform	Partitioned
STM metadata	Uniform	Distributed
Distributing computation for data locality	N/A	*on p { ... }*

Research Contributions

First STM designed for high performance on large clusters

- Block data movement
- Computation migration
- Distributed metadata

Experimental evaluation of prototype

- Performance vs. locks
- New design tradeoffs

Decomposition of STM design space into eight axes

Outline

Interface Design

Algorithm Design

Evaluation

- Cluster STM vs. Manual Locking
- Read Locks vs. Read Validation

Conclusion

Interface Design

Compiler target, not primarily for programmers

Correct use guarantees *serializability of transactions*

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Chapel

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atomic {
   // Array assignment
   cache = A;
   compute(cache);
   A = cache;
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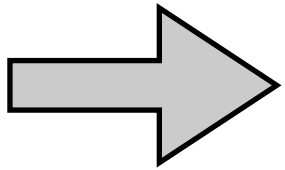


compiler

Cluster STM API

```
stm_start(...)
stm_get(&cache, &A,...)
compute(&cache);
stm_put(&A, &cache, ...);
stm_commit(...);
```

Interface Summary

Transaction start and commit

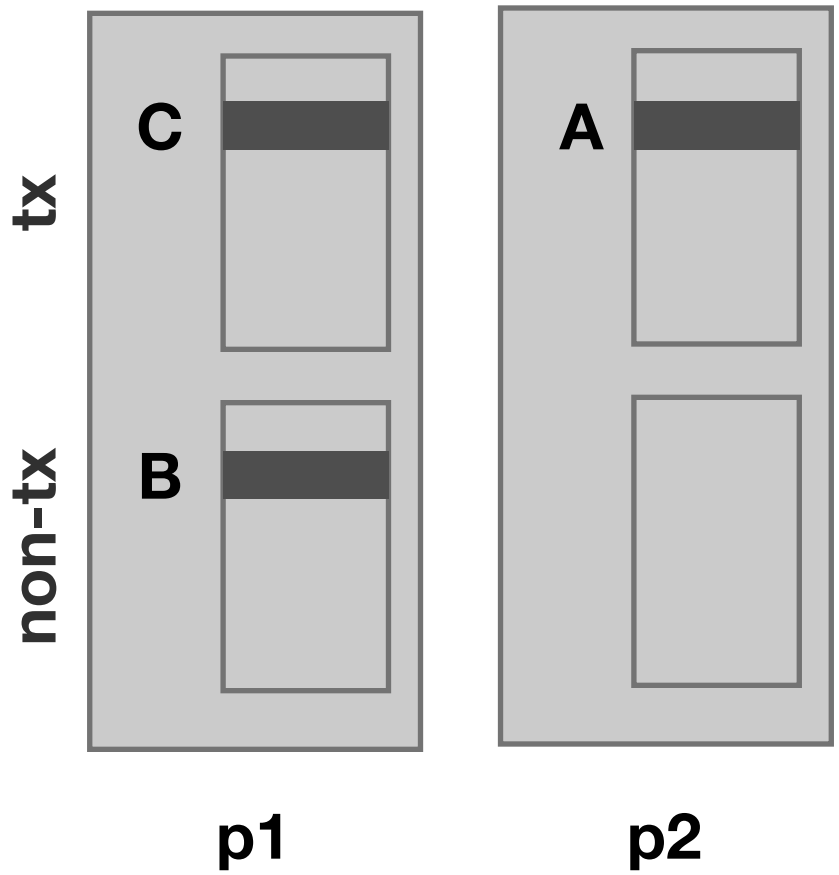
Transactional memory allocation

Block data movement to and from transactional store

Remote execution of transactional computations

Block Data Movement

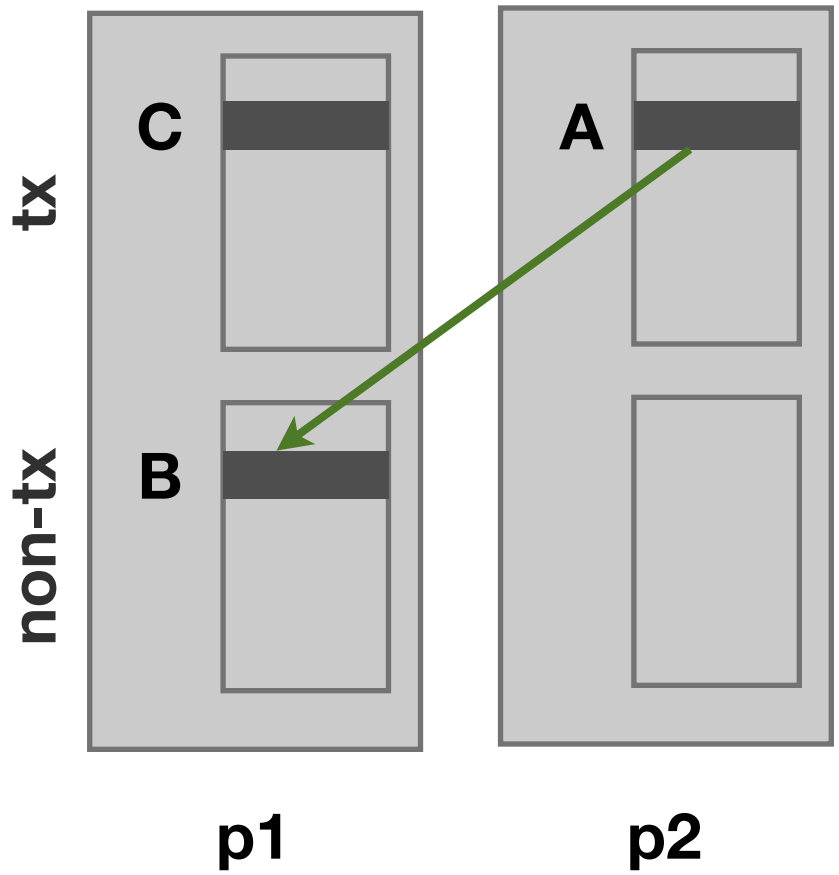
All ops occur on p1



Block Data Movement

All ops occur on p1

stm_get(work_proc=p2, src=A, dest=B, size=n, ...)



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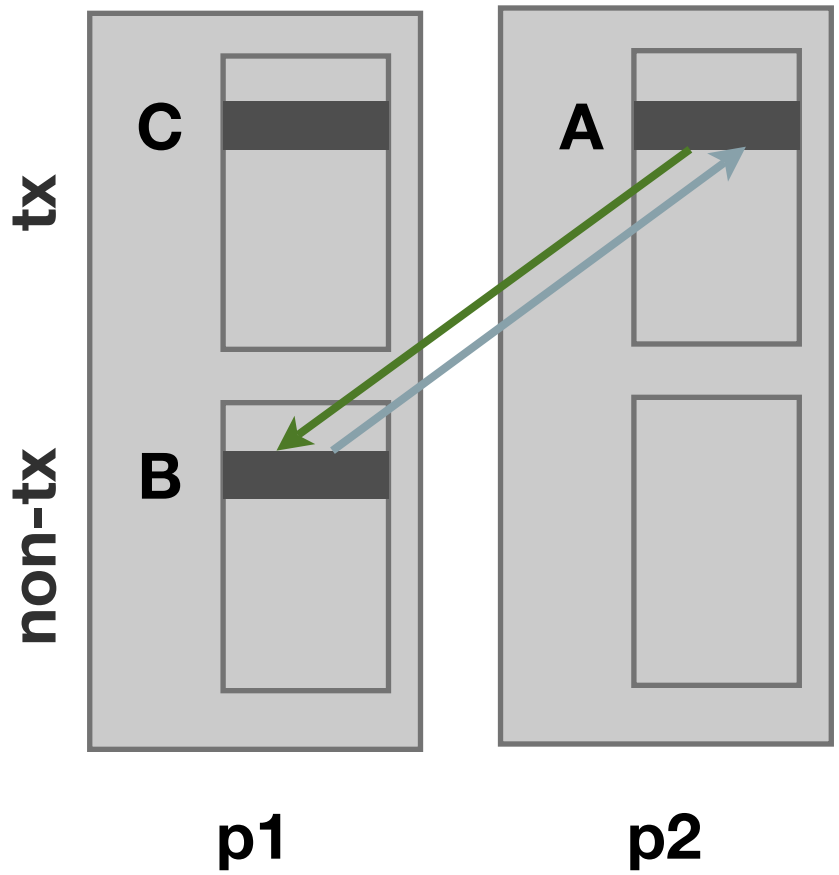

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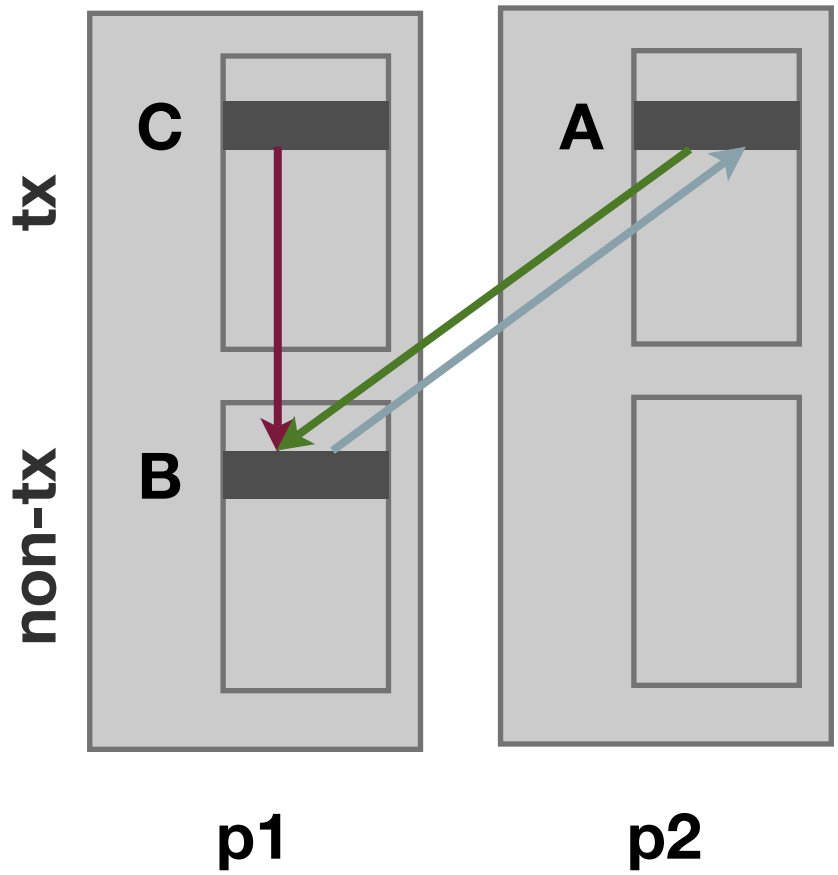
stm_read(src=C, dest=B, size=n, ...)



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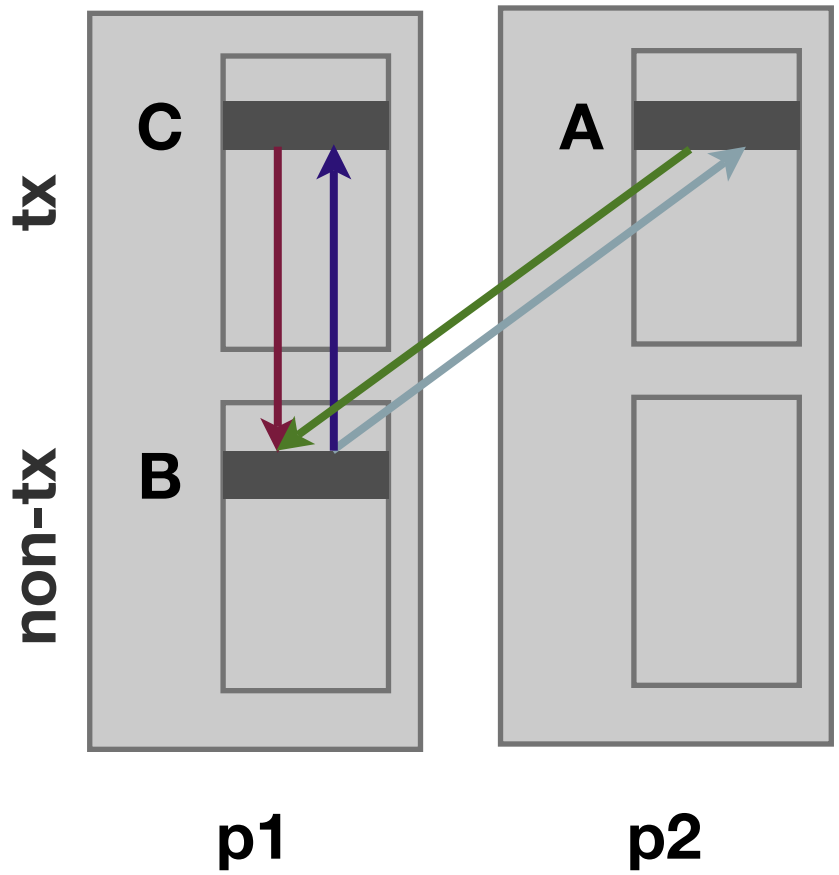
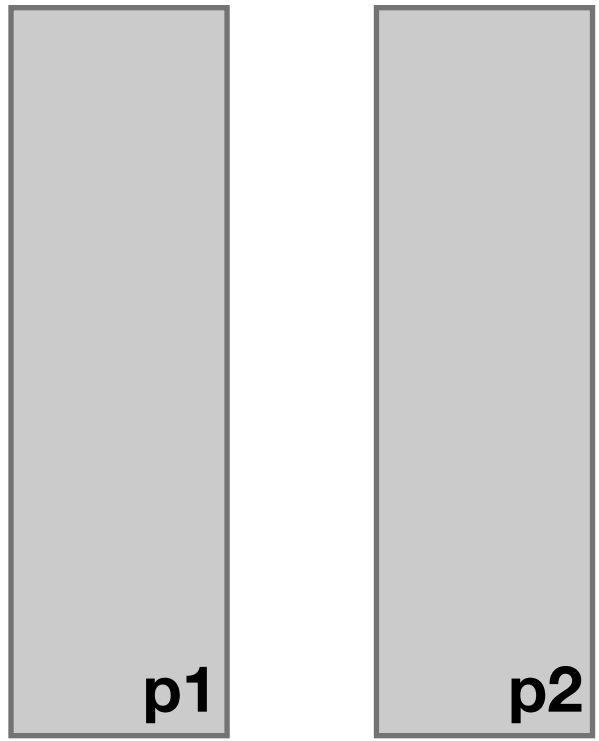
stm_write(src=B, dest=C, size=n, ...)



Remote Work for Exploiting Locality



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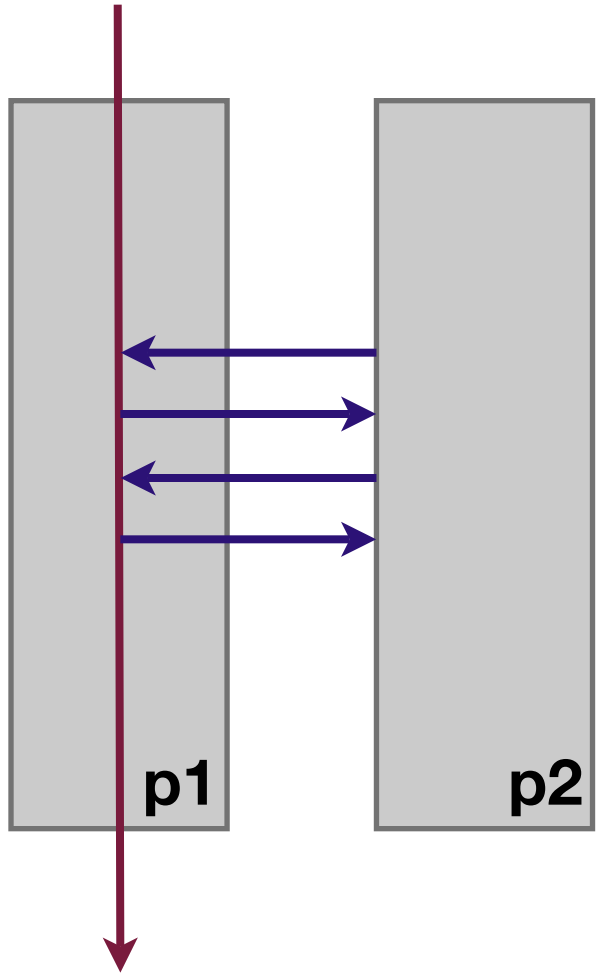

remote puts & gets

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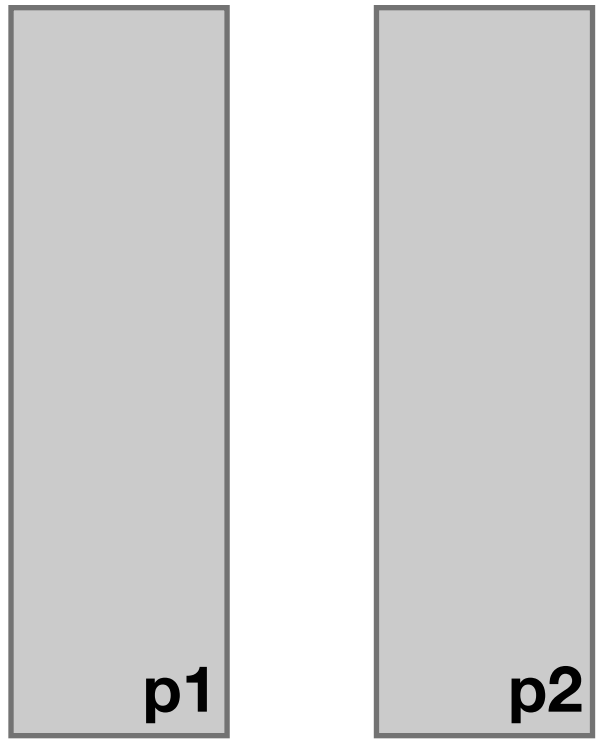

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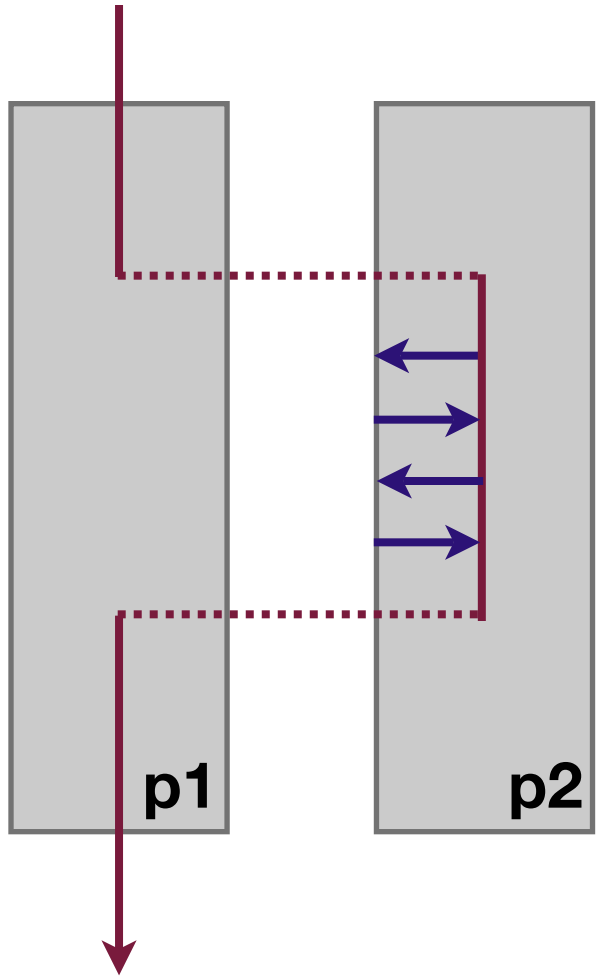
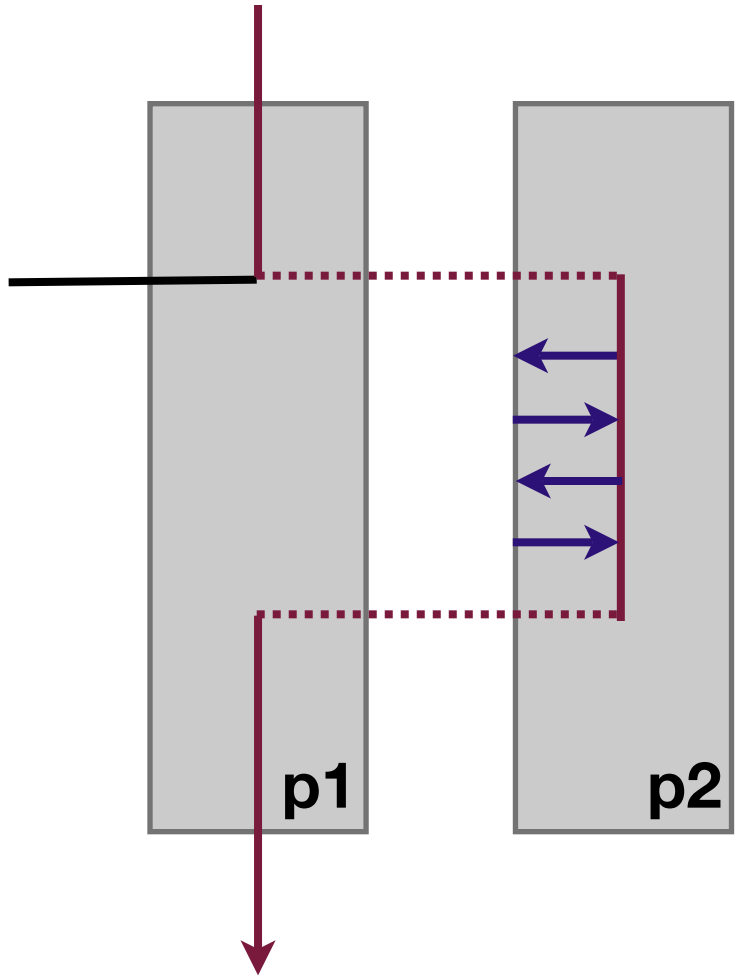


local reads & writes

Remote Work for Exploiting Locality

stm_on(work_proc=p2,
function=f, ...)



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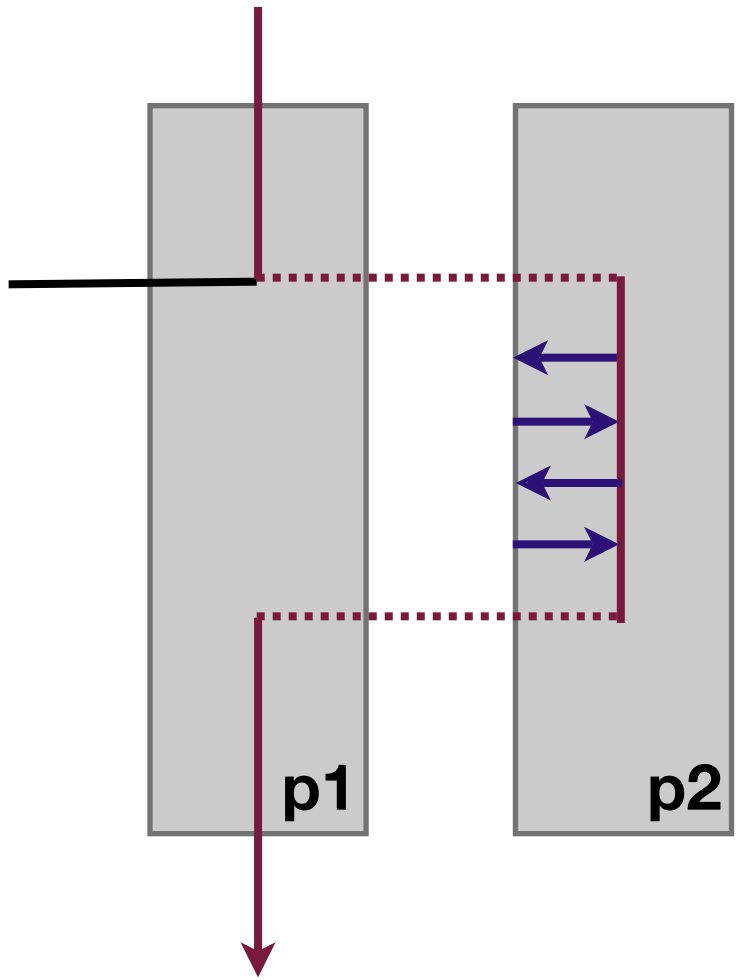
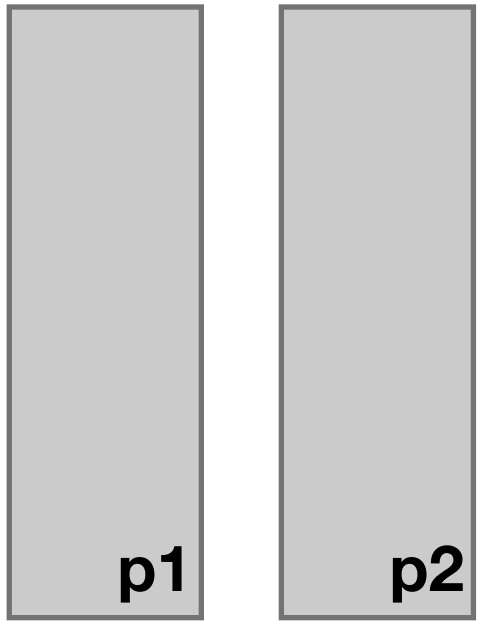
Chapel: on p2 { f(...); }



local reads & writes

Remote Work Inside Transaction

atomic { on p2 { f(...); } }



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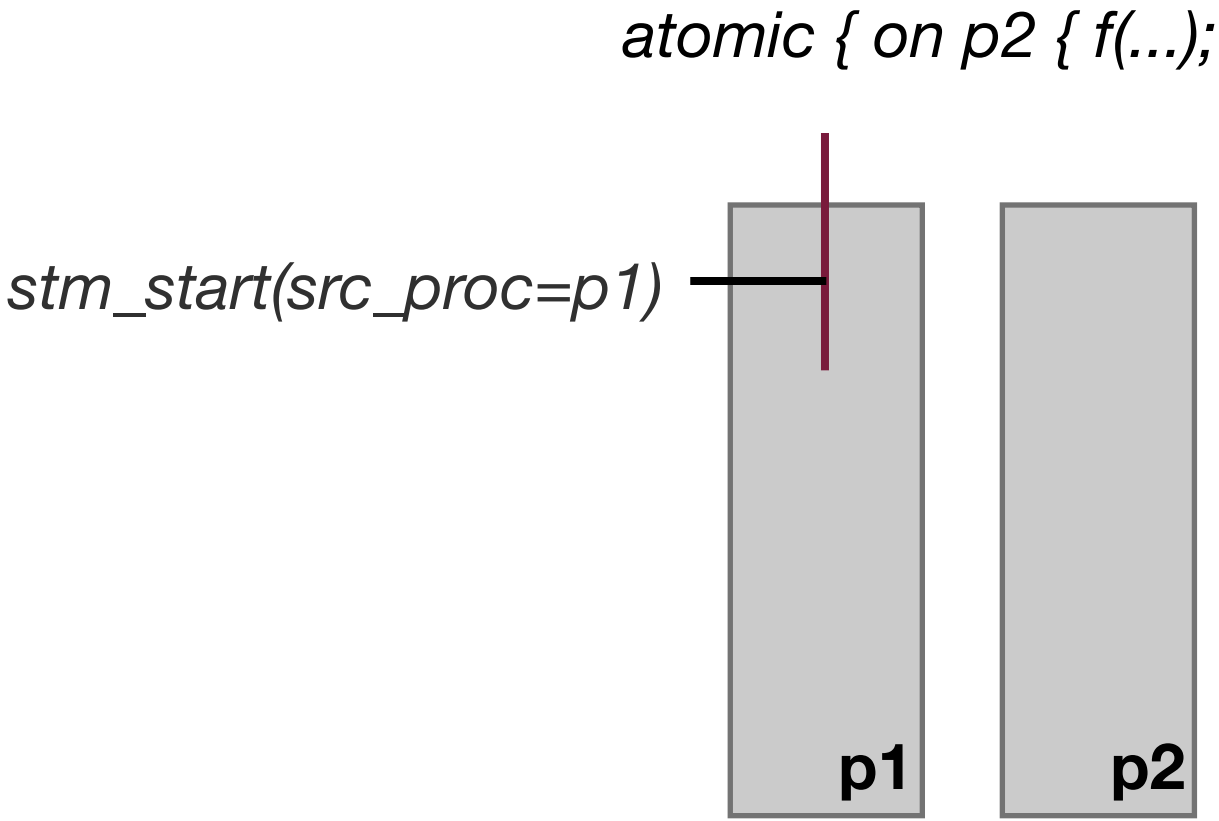
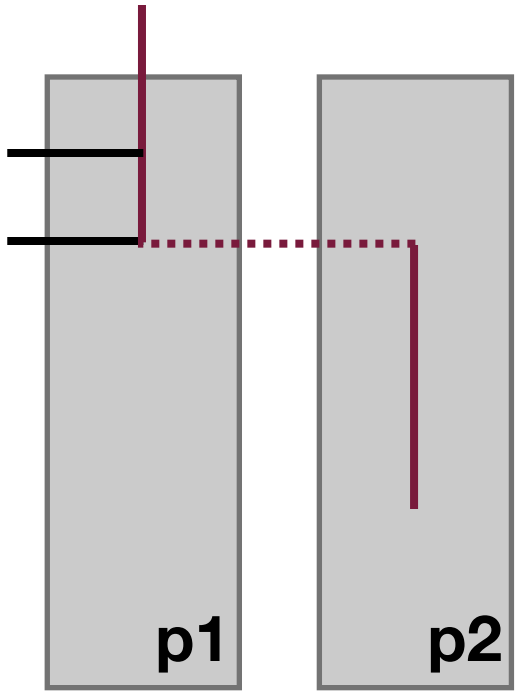


Remote Work Inside Transaction

atomic { on p2 { f(...); } }

stm_start(src_proc=p1)

stm_on(src_proc=p1, work_proc=p2, function=f, ...)



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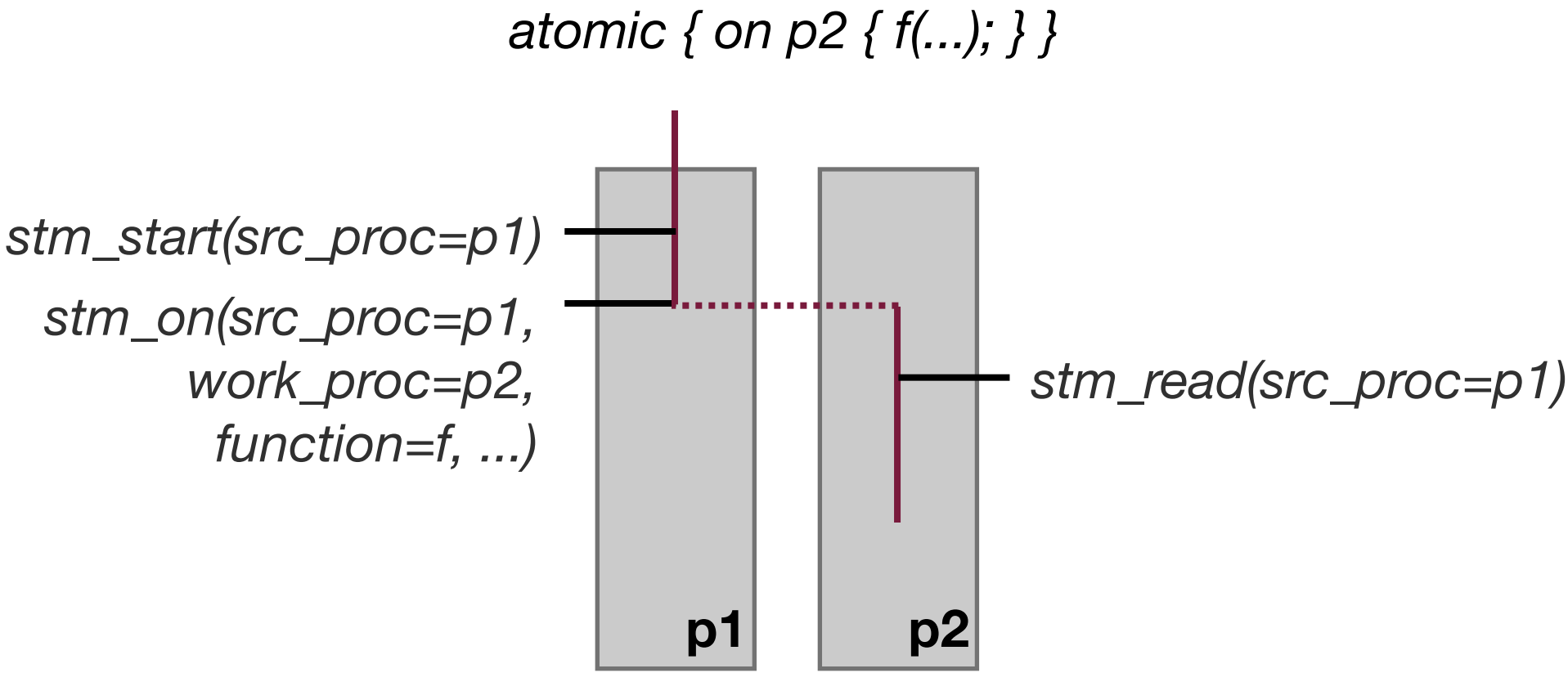

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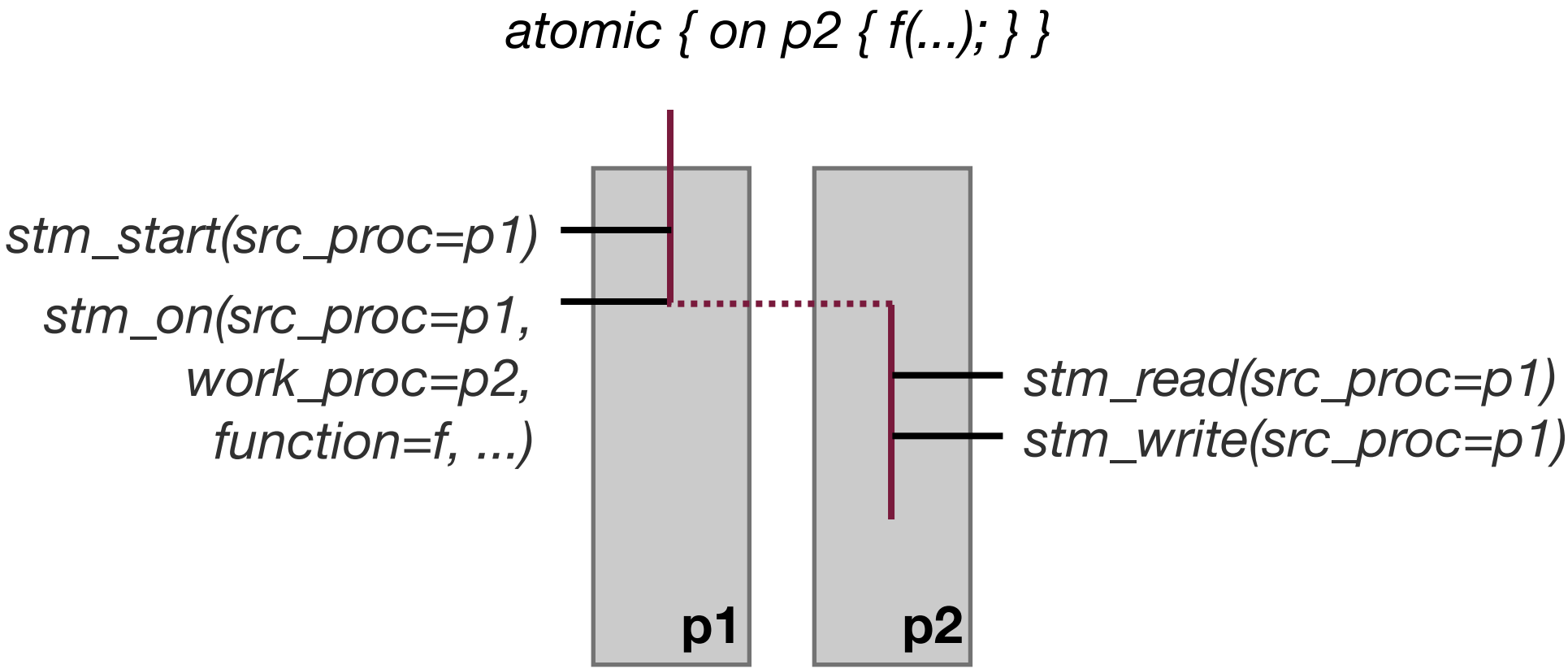

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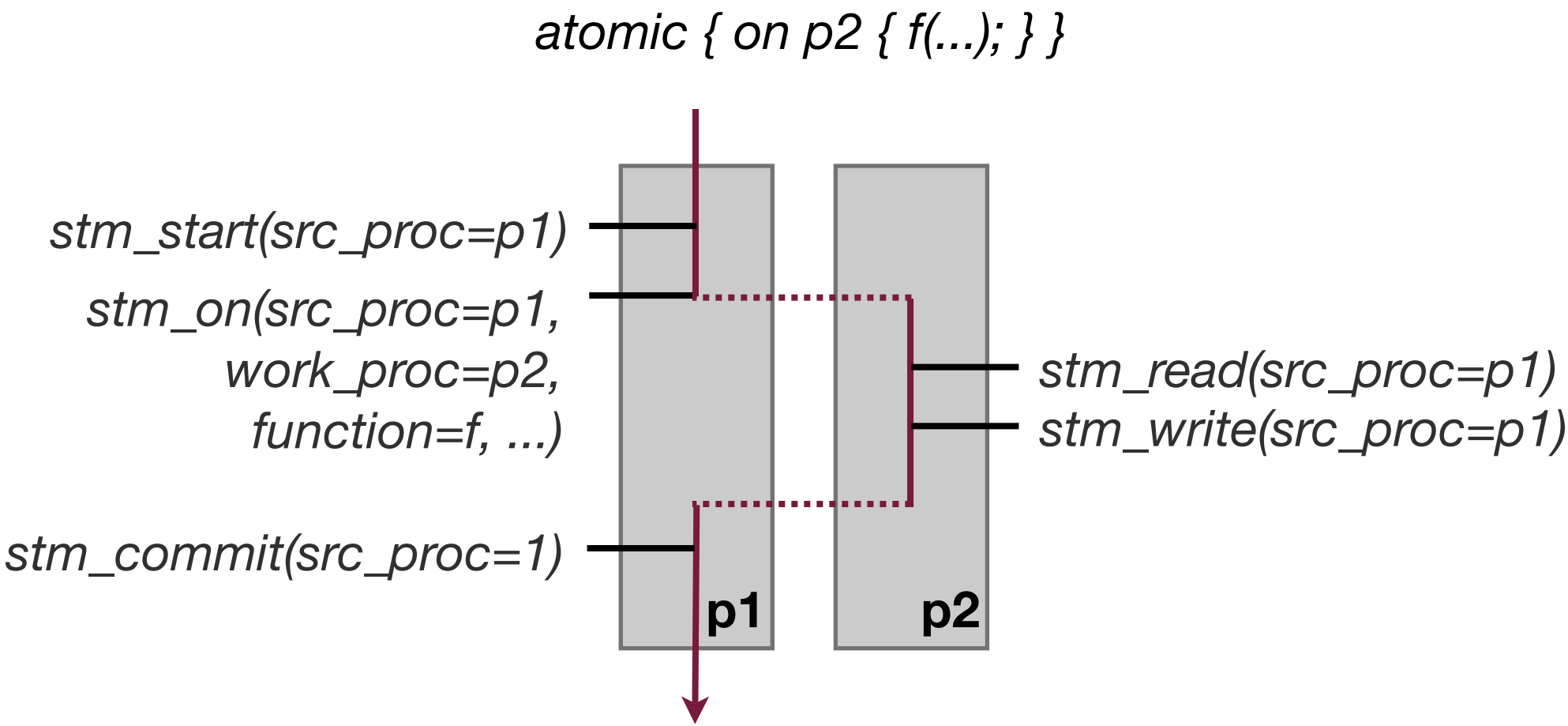

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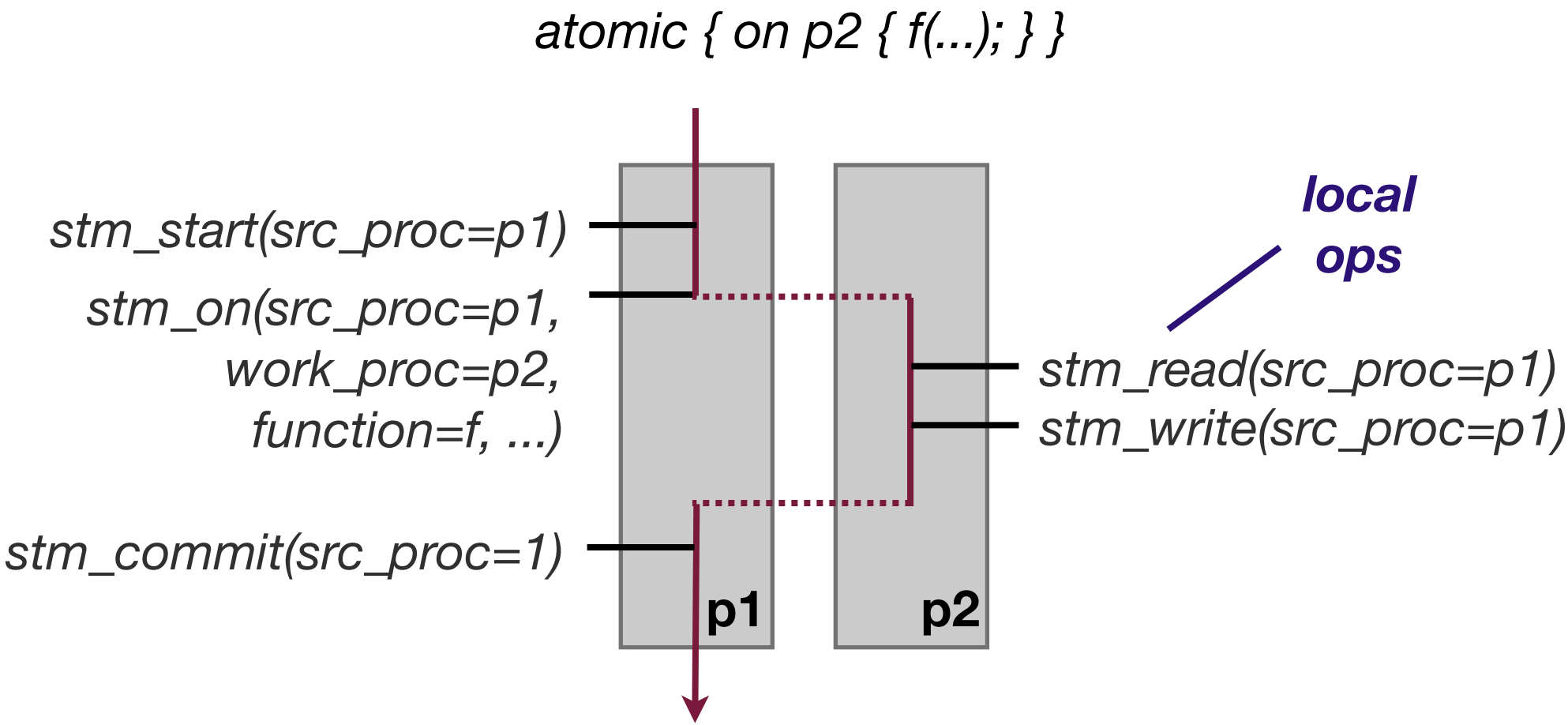

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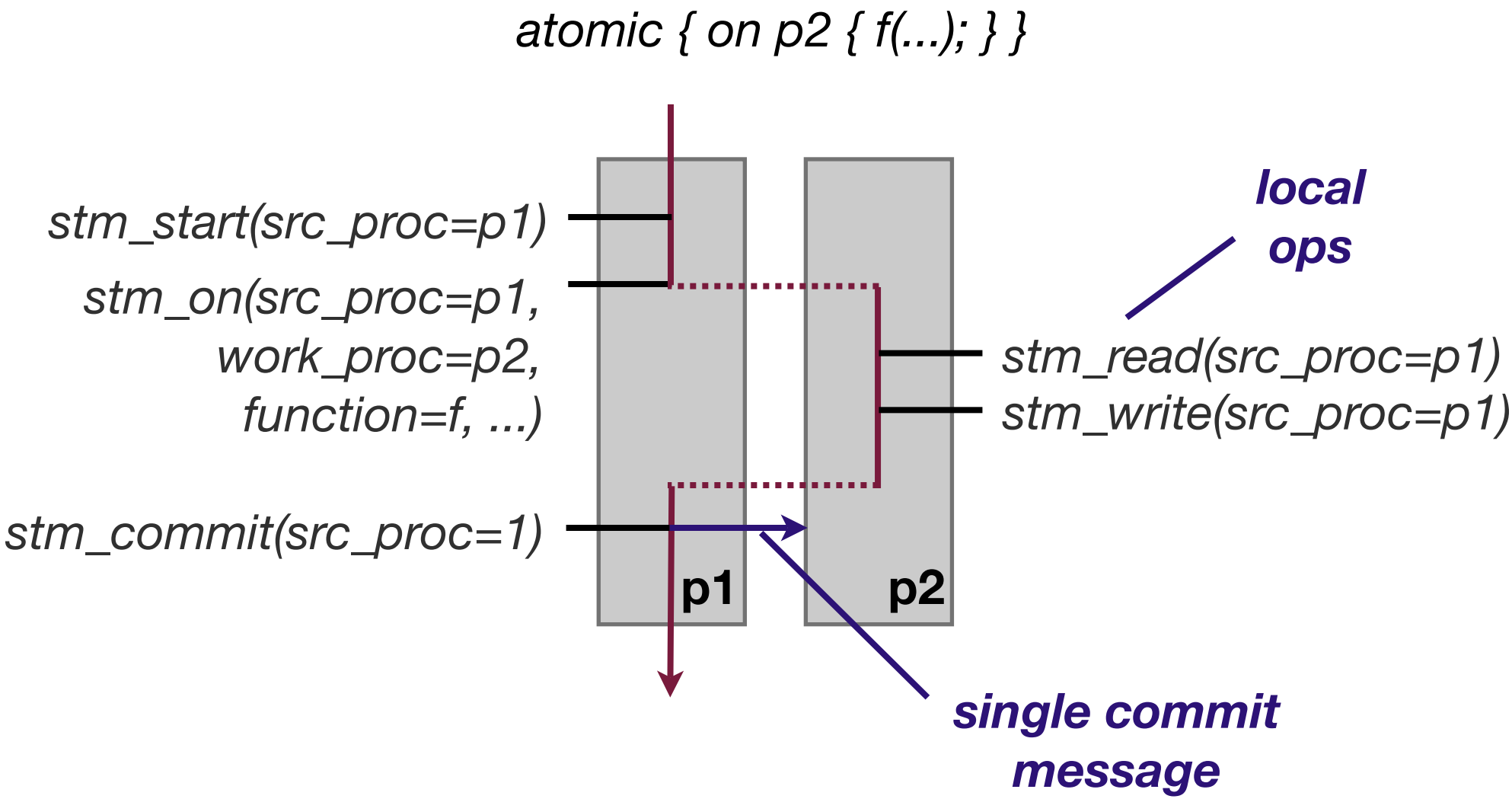

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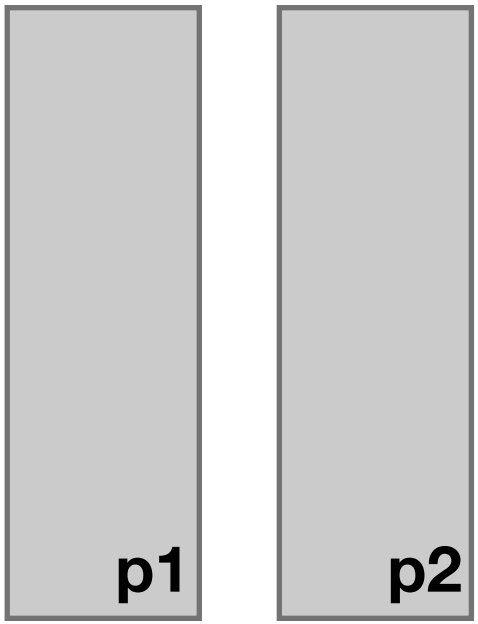

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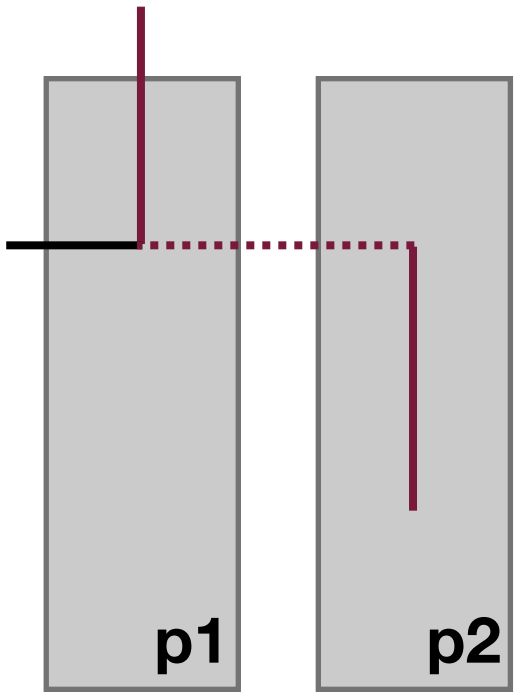

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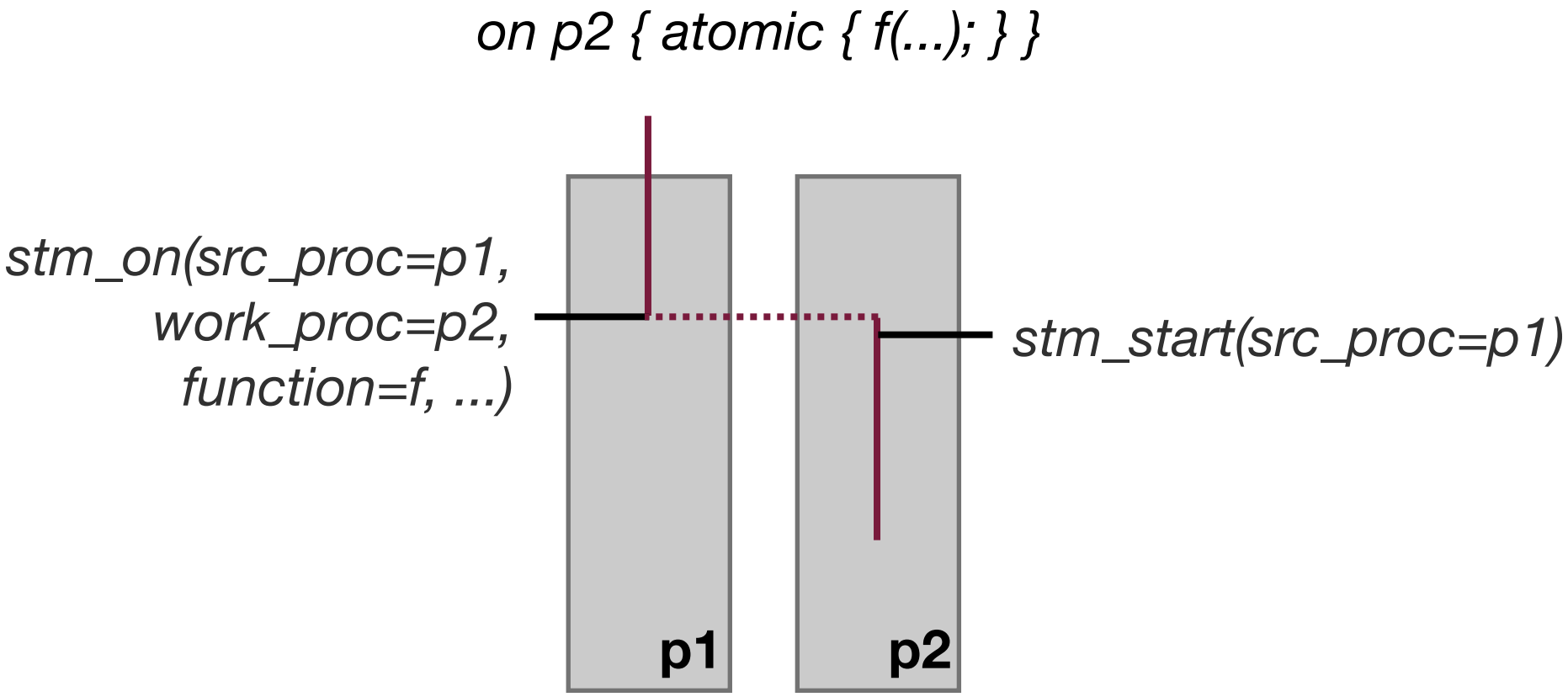

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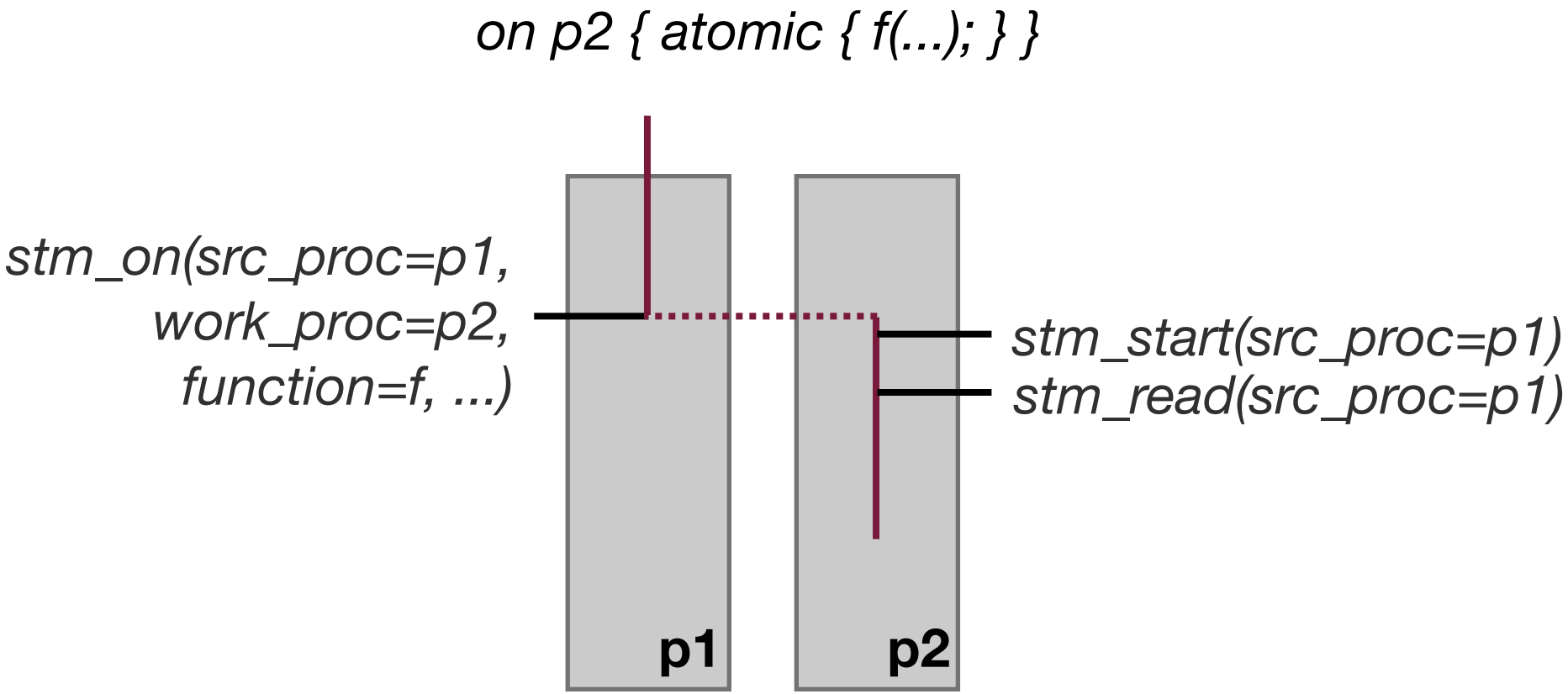

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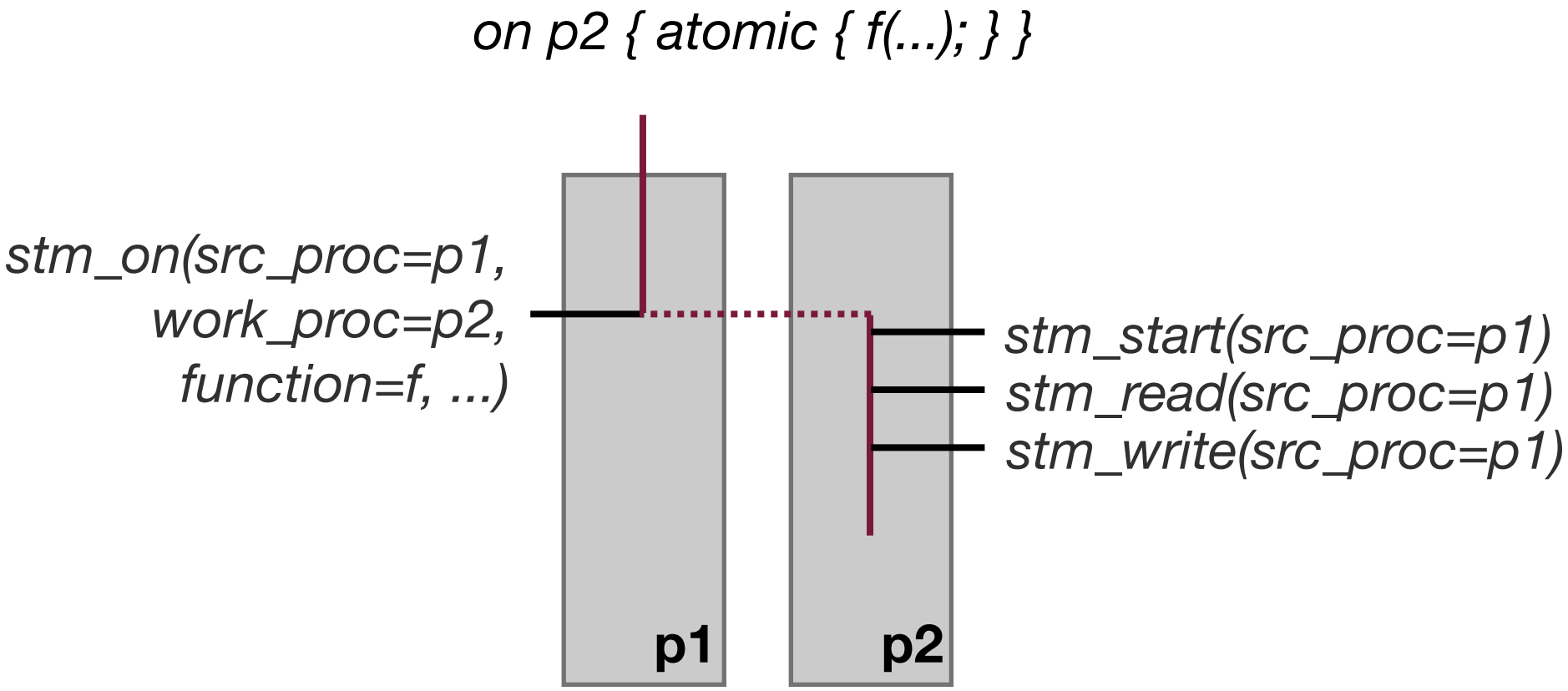

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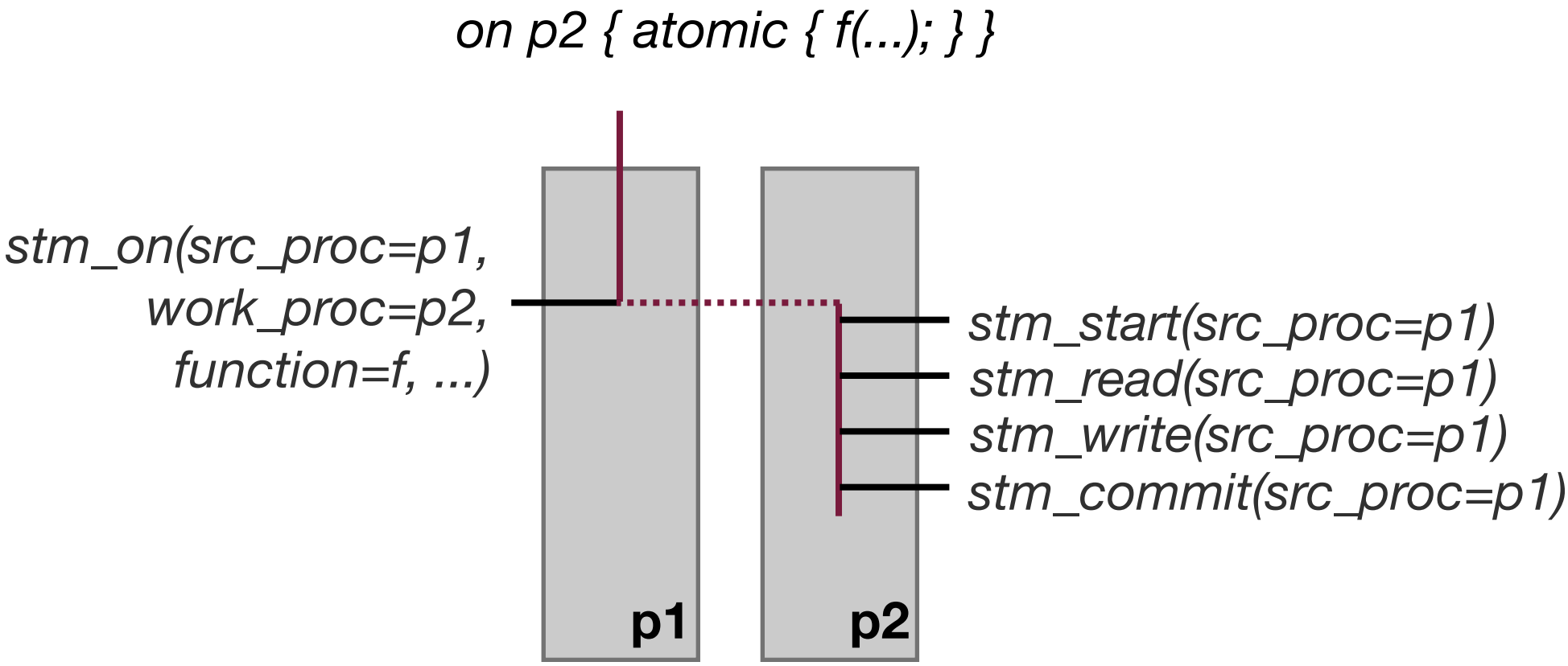

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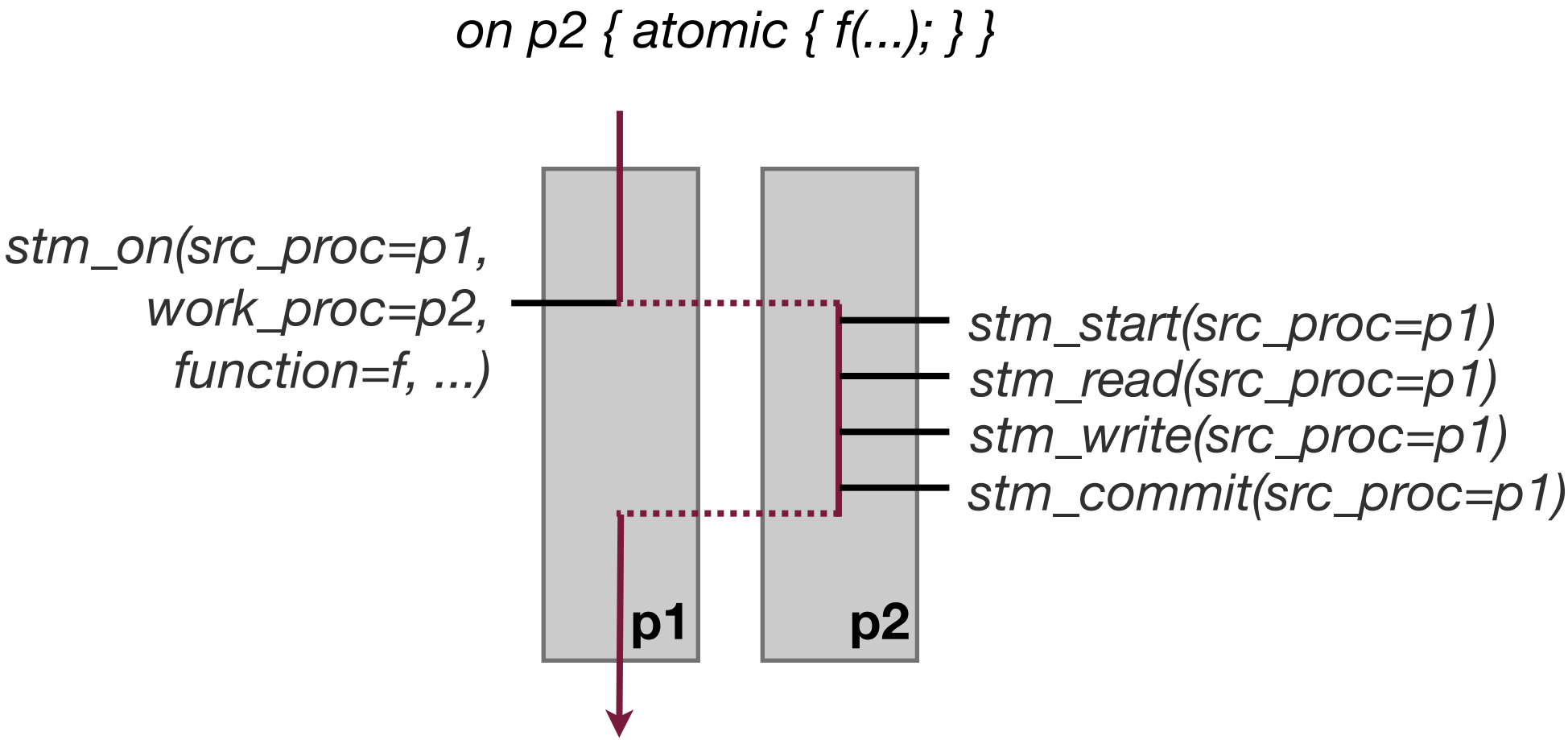

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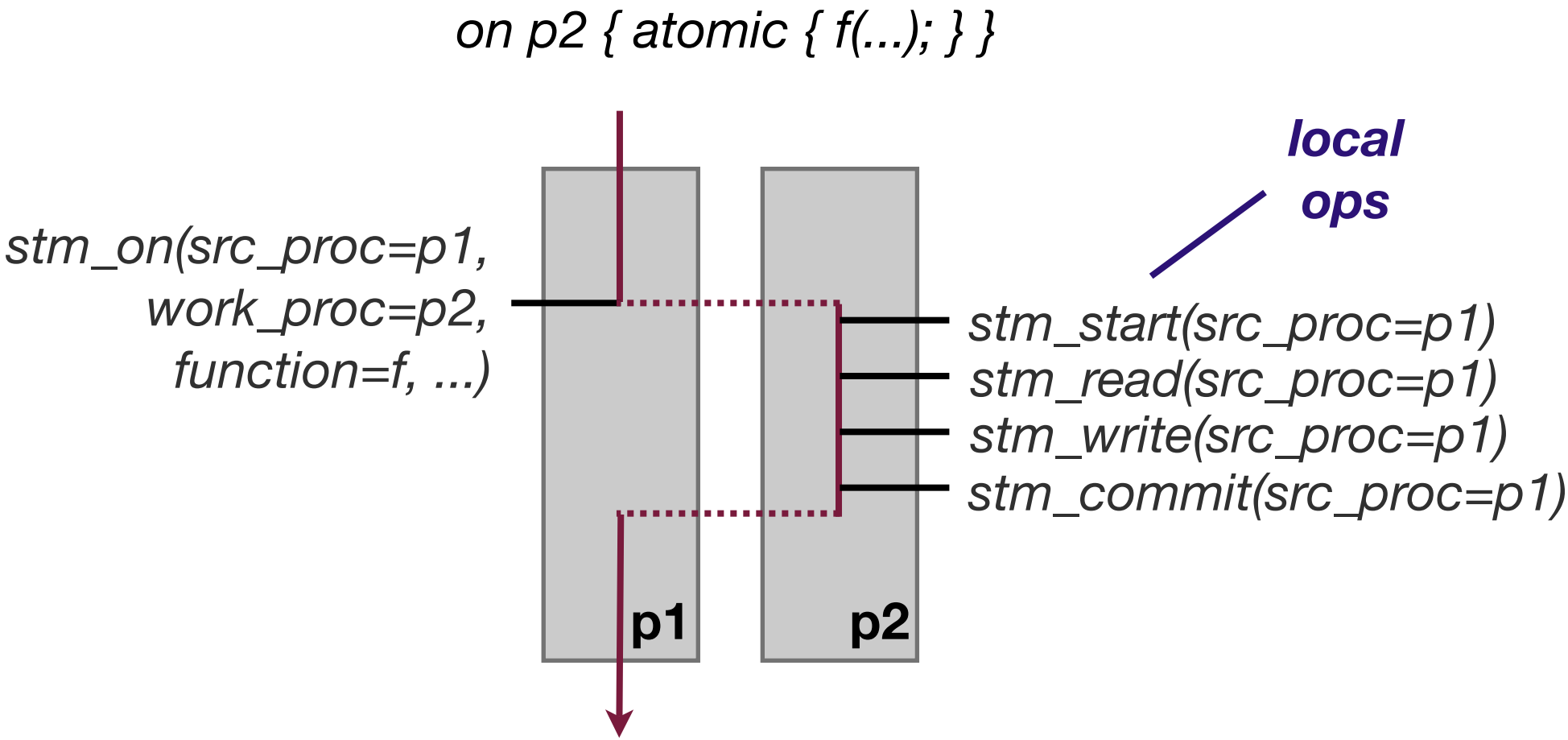

Outline

Interface Design

Algorithm Design

Evaluation

- Cluster STM vs. Manual Locking
- Read Locks vs. Read Validation

Conclusion

Algorithm Design

Shared metadata

Transaction-local metadata

STM design choices

Shared Metadata

Some metadata must be visible to all transactions

- Read and write locks
- Validation ID

Memory overhead compromise

- Each metadata word guards one *conflict detection unit (CDU)*
- CDU size is $s \geq 1$ words
- $s > 1$ may introduce false sharing

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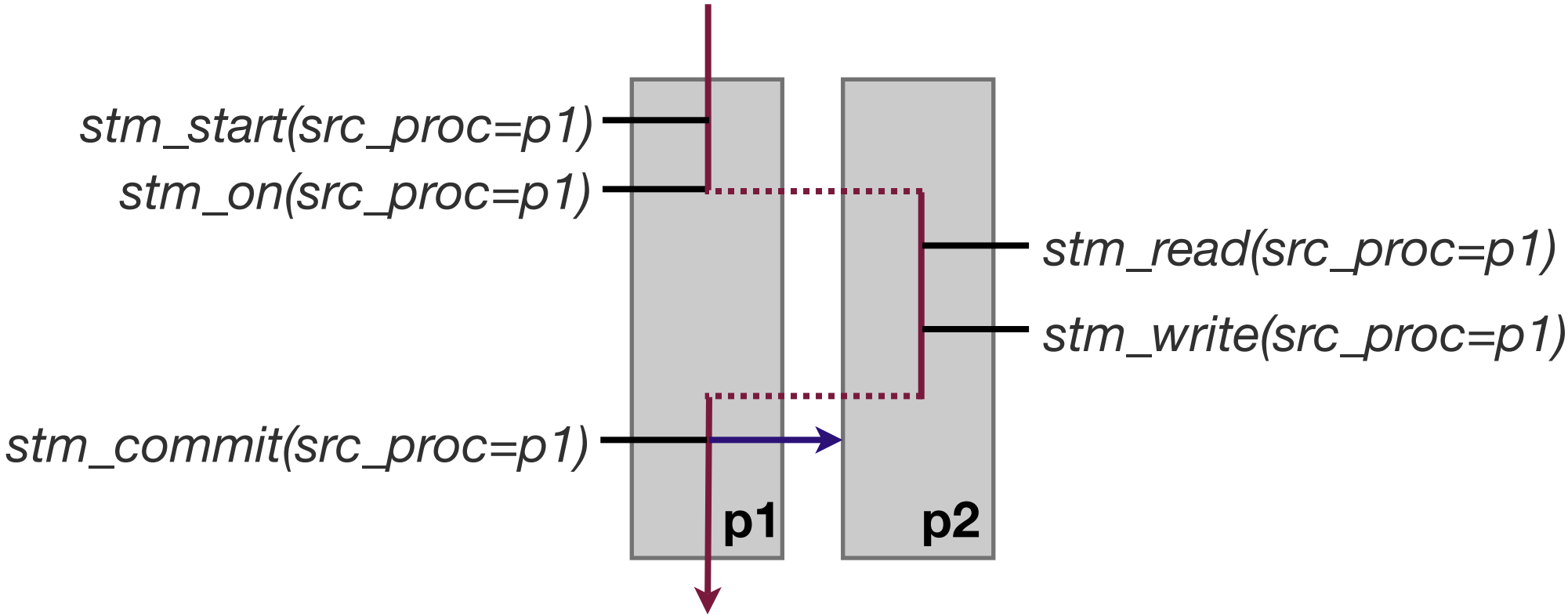
Keep metadata on same processor as corresponding CDU

Transaction-Local Metadata



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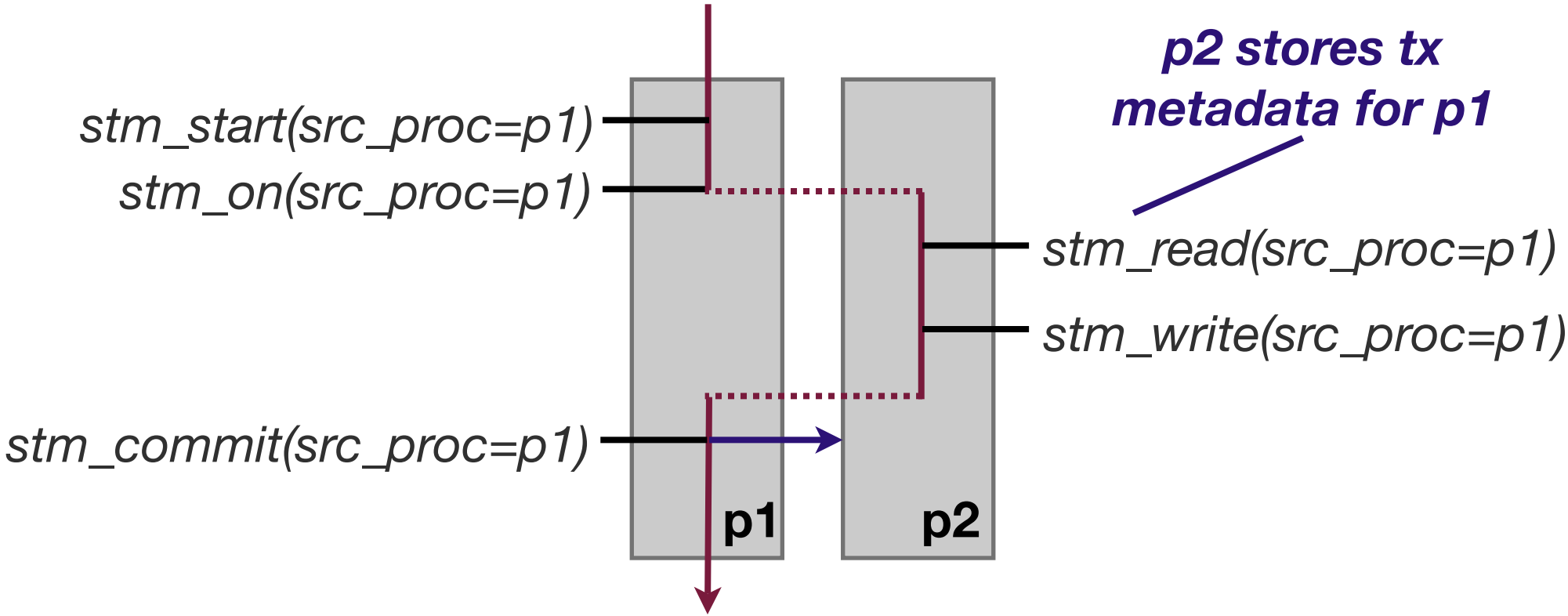

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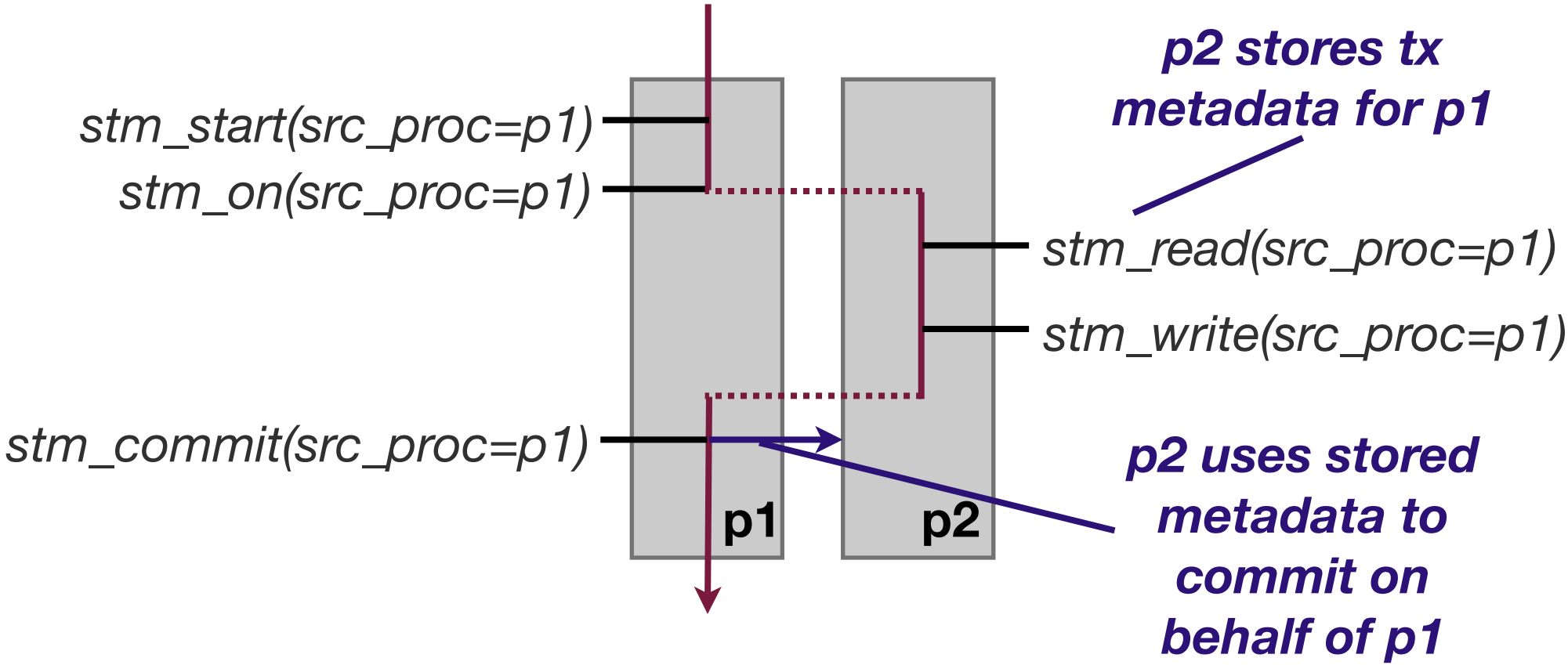

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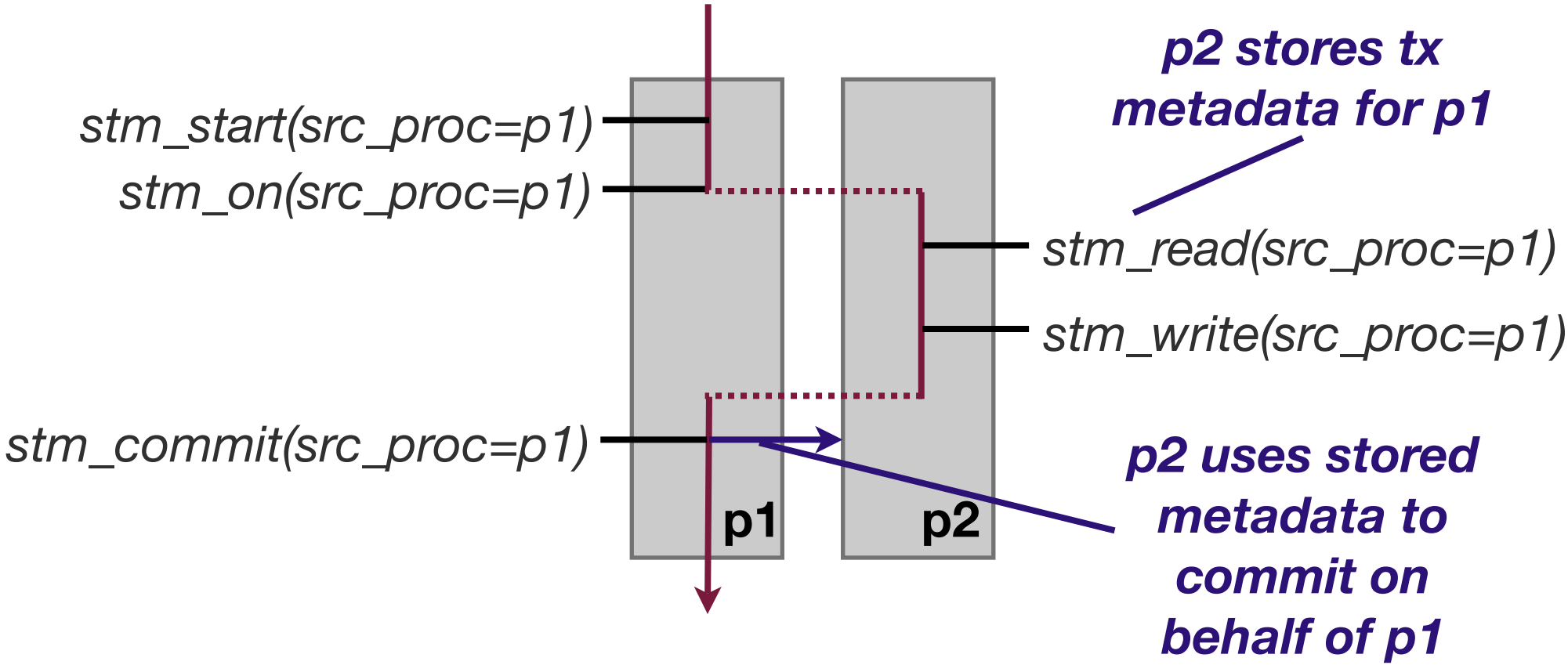

Keep metadata local to processor where access occurred

STM Design Choices

Eight-axis design space (see paper)

Choose four axes to explore

- CDU size
- Read locks (RL) vs. read validation (RV)
- Undo log (UL) vs. write buffer (WB)
- Early acquire (EA) vs. late acquire (LA)

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See paper for additional results

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Benchmarks

- Micro Benchmarks: Intset, Hashmap Swap
- Graph clustering: SSCA 2 Kernel 4

Machine

- Intel Xeon cluster
- Two cores per node
- Myrinet

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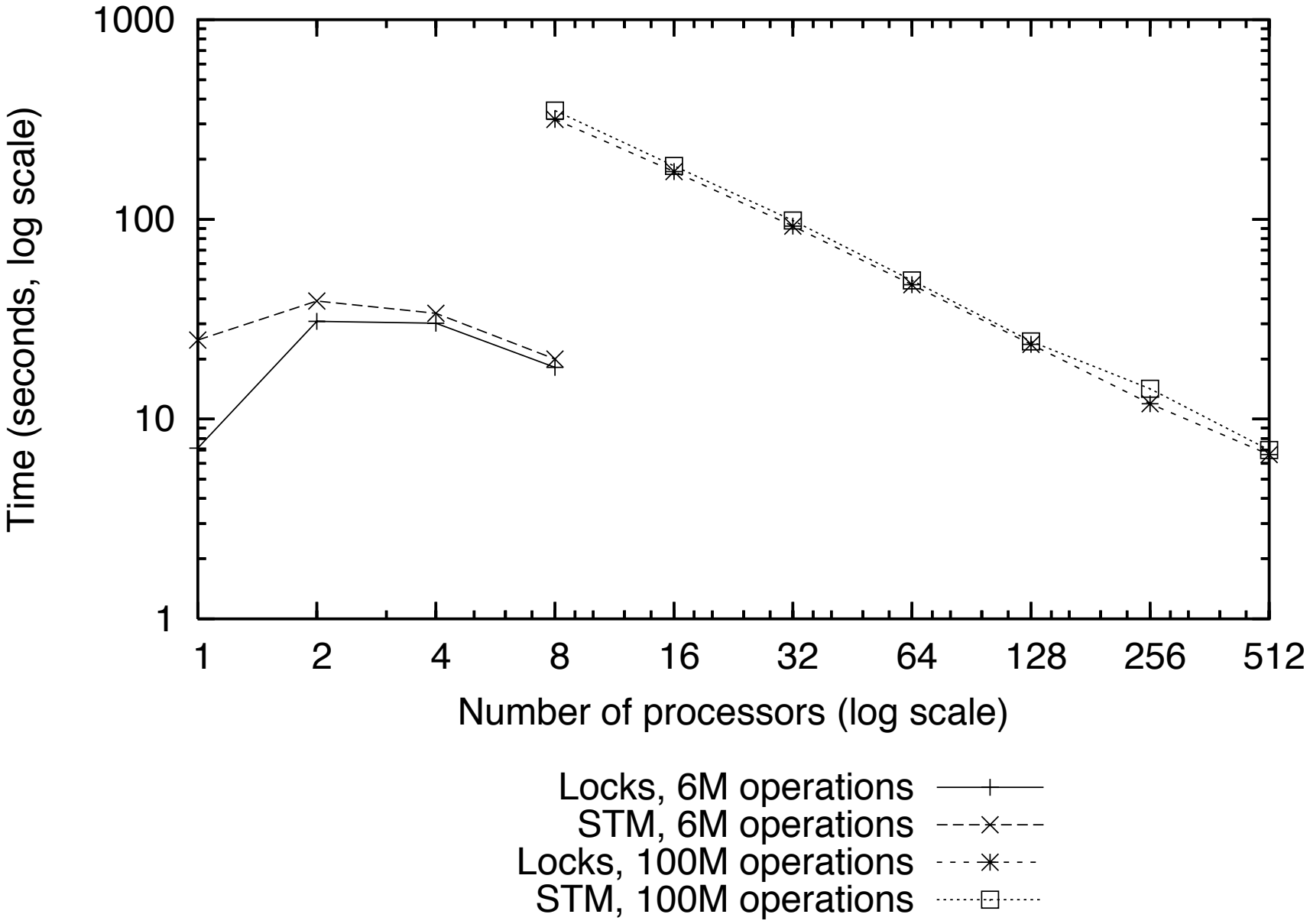
Intset Results



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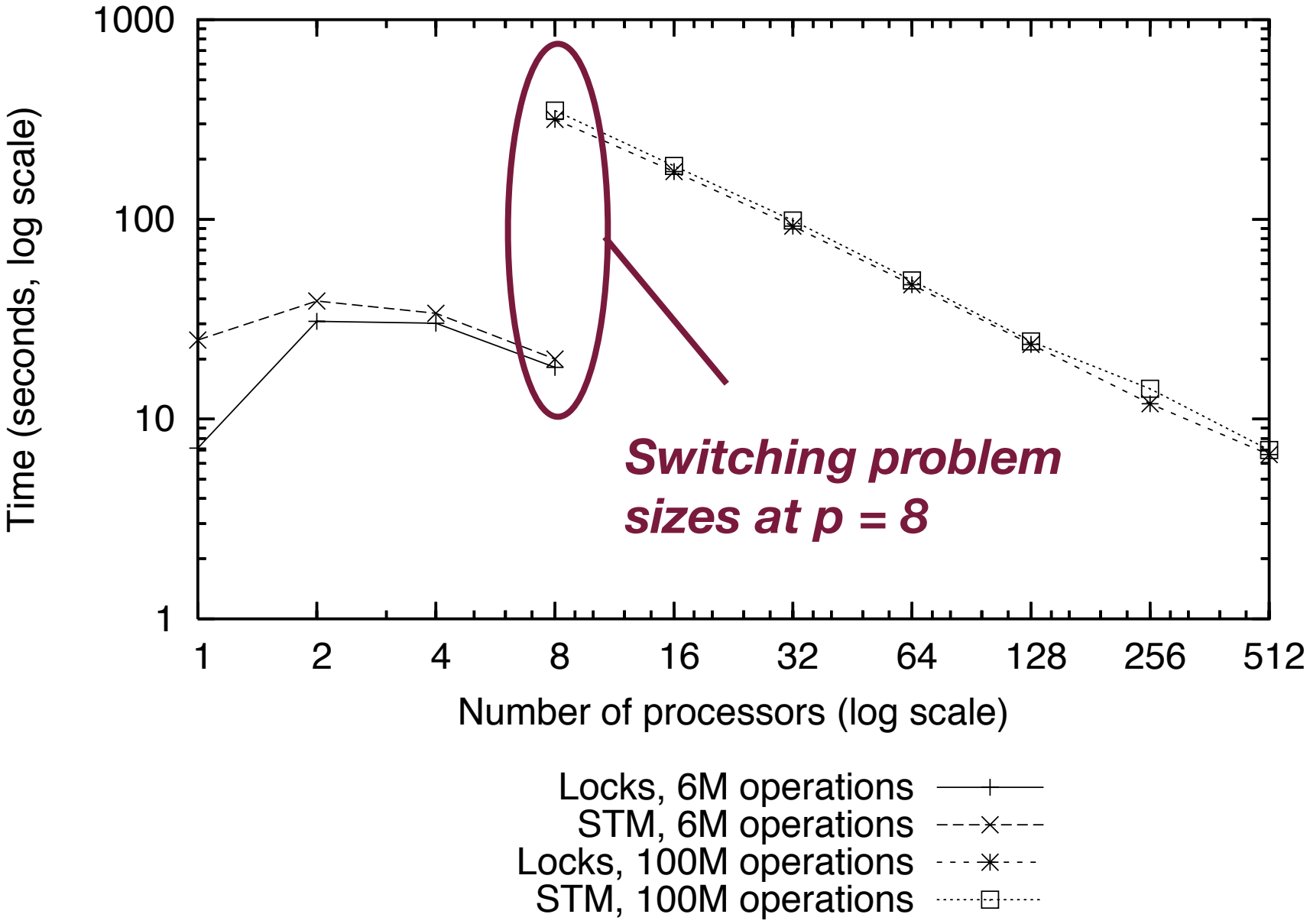

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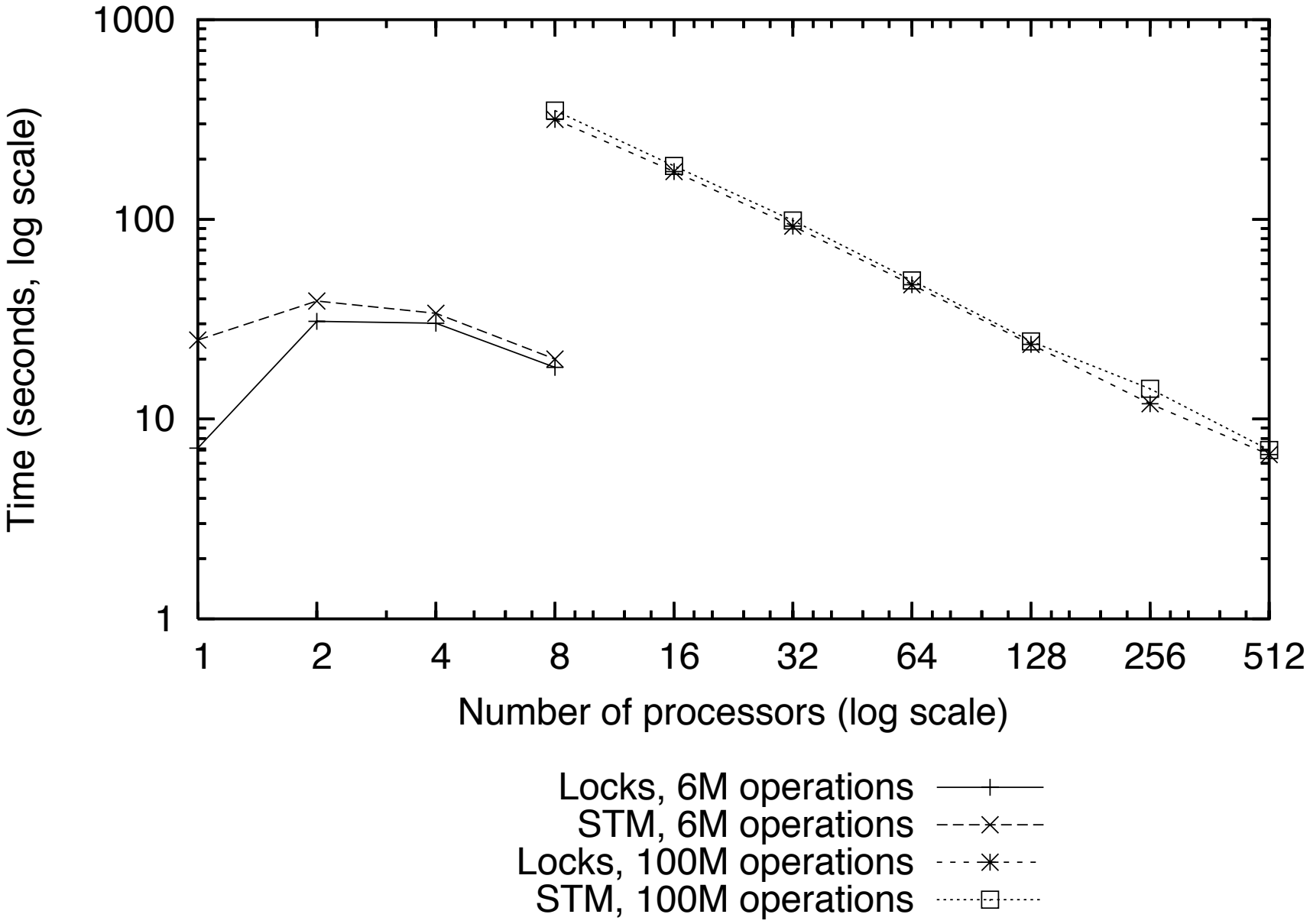

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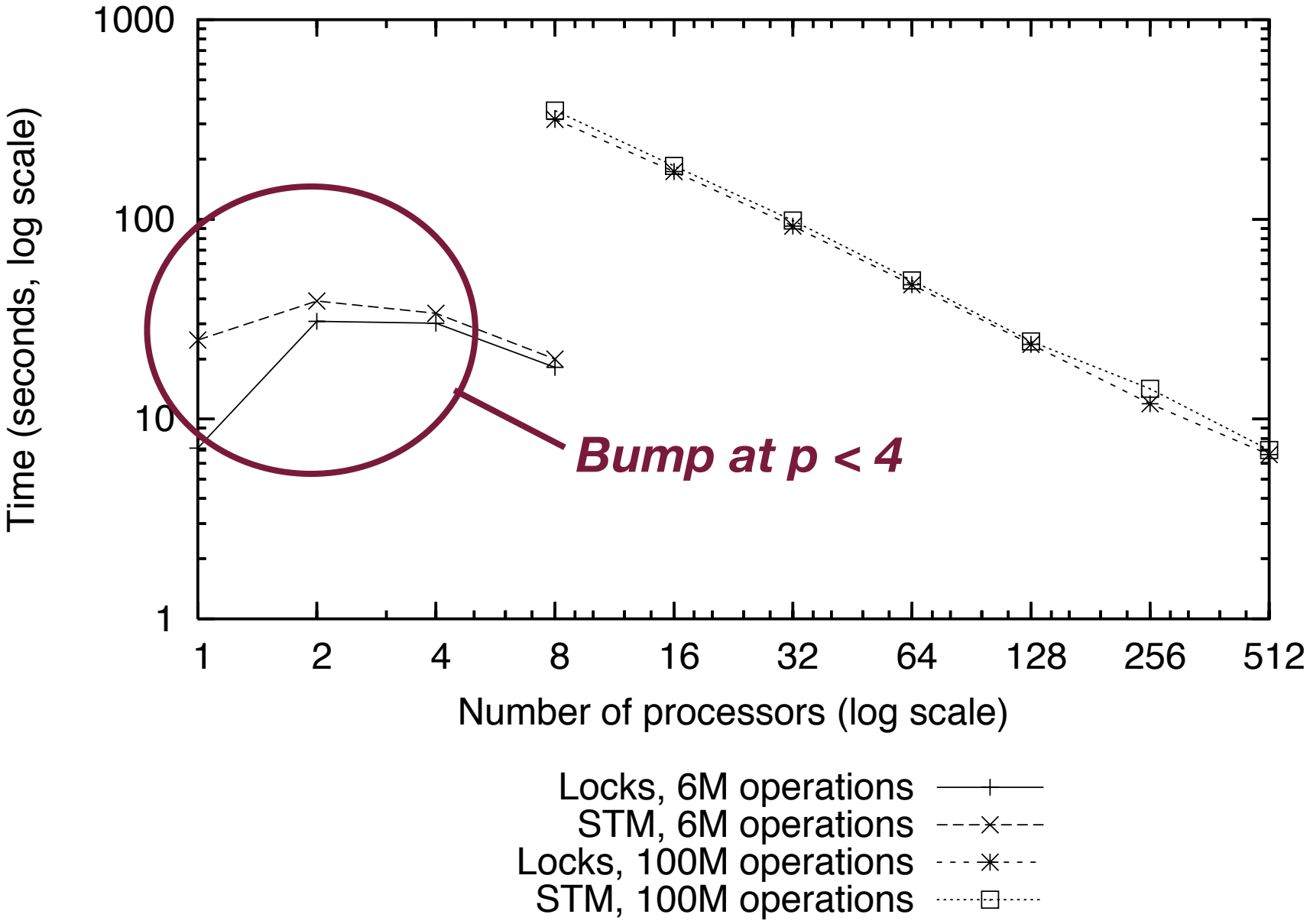

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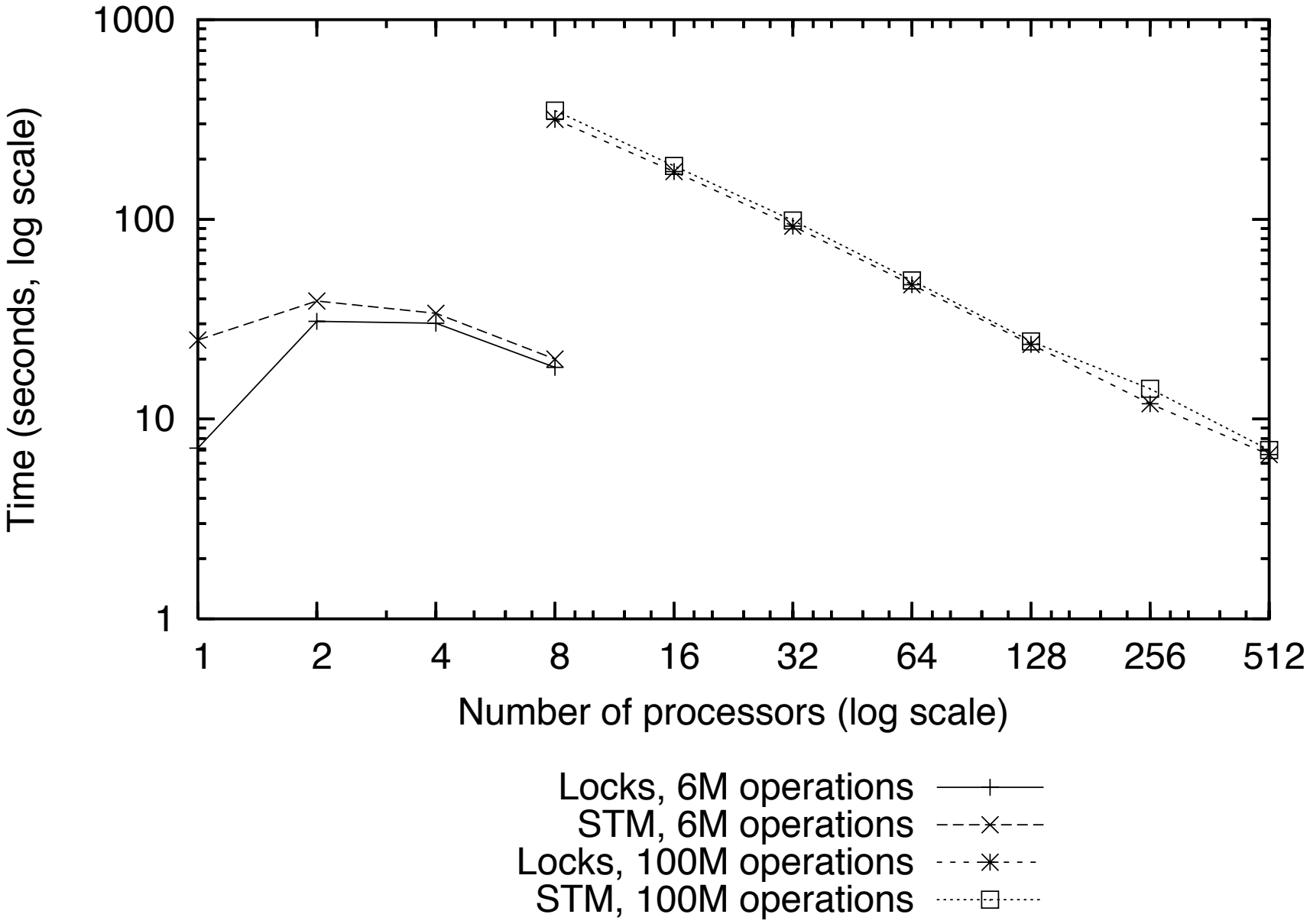

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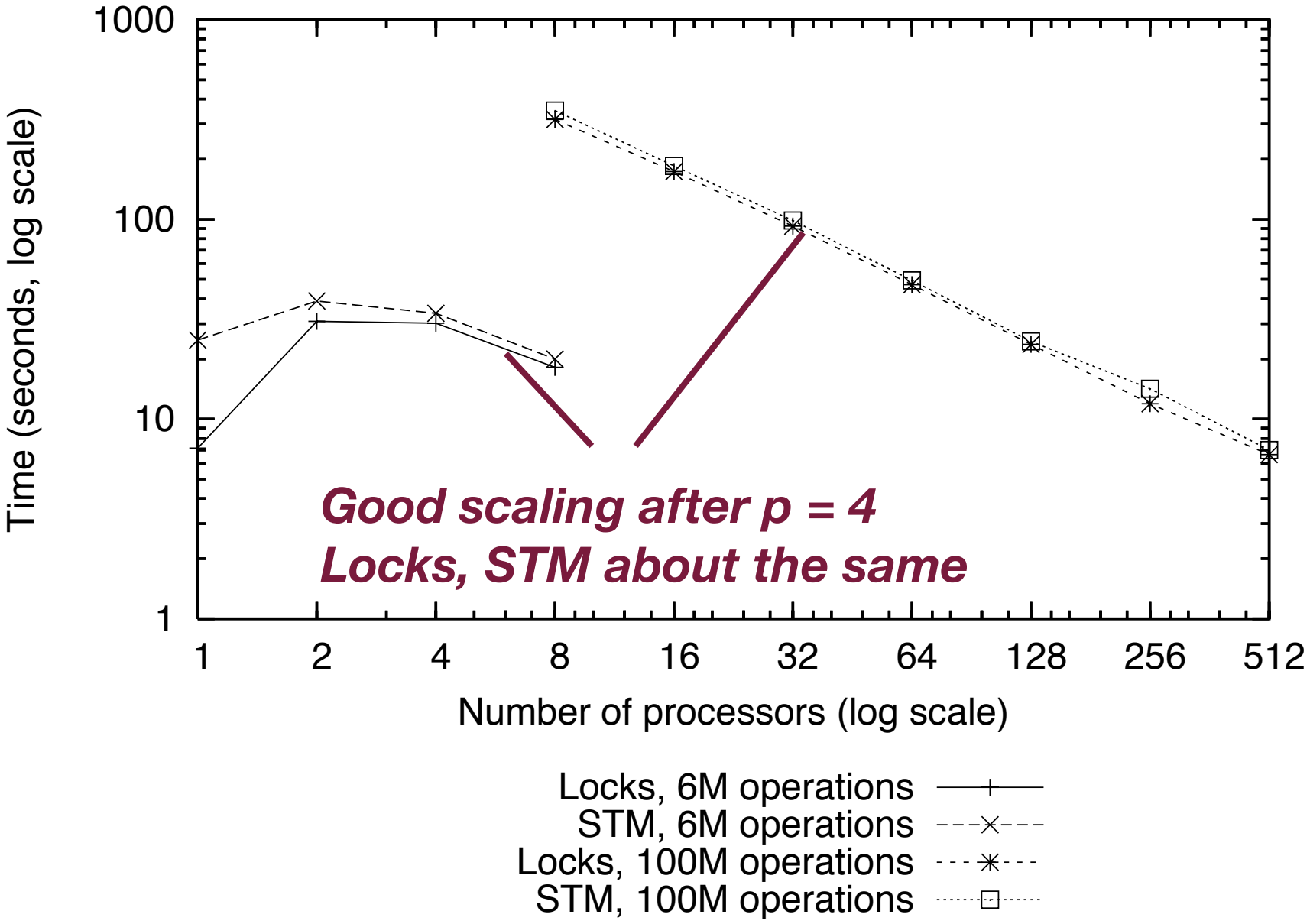

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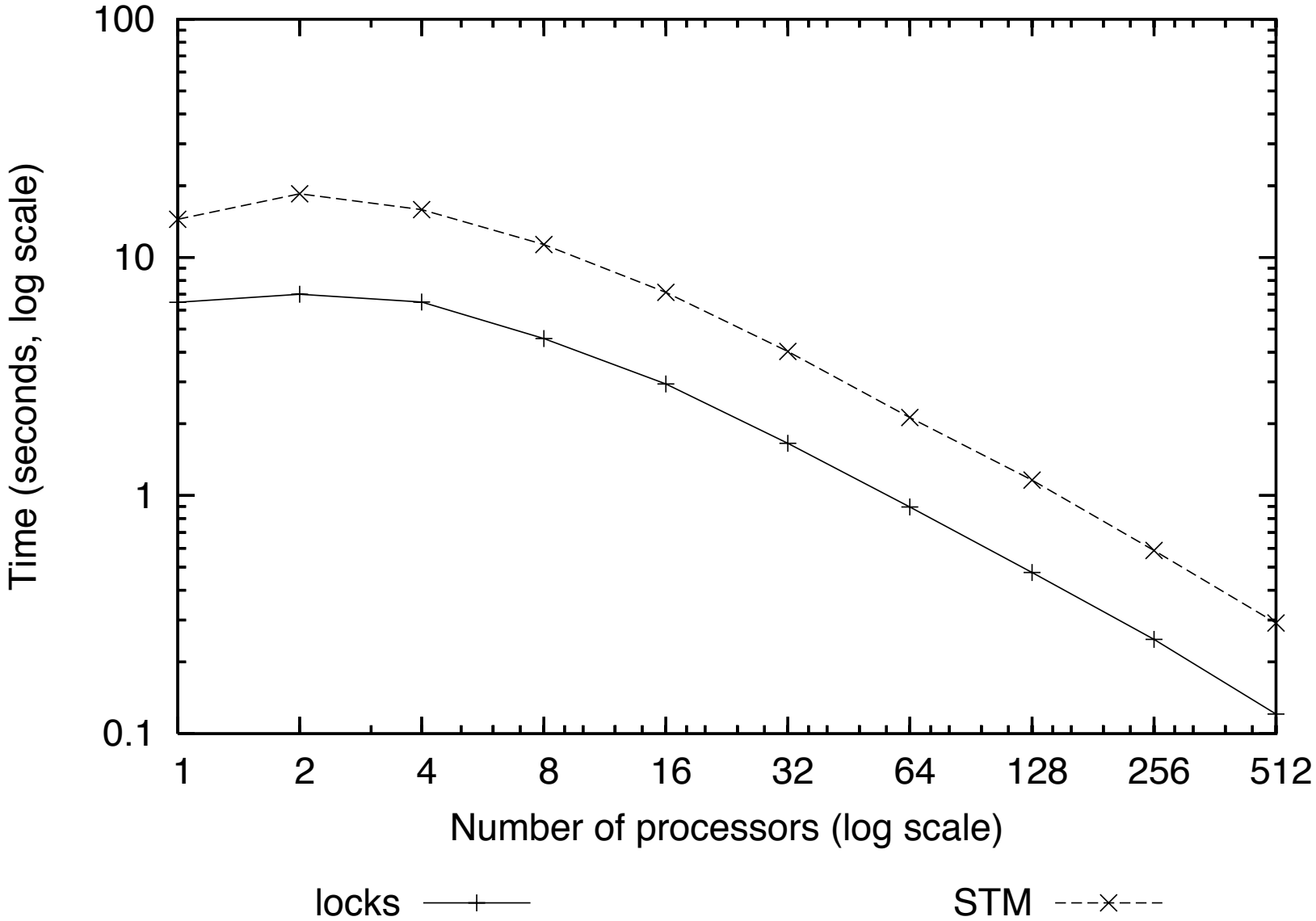

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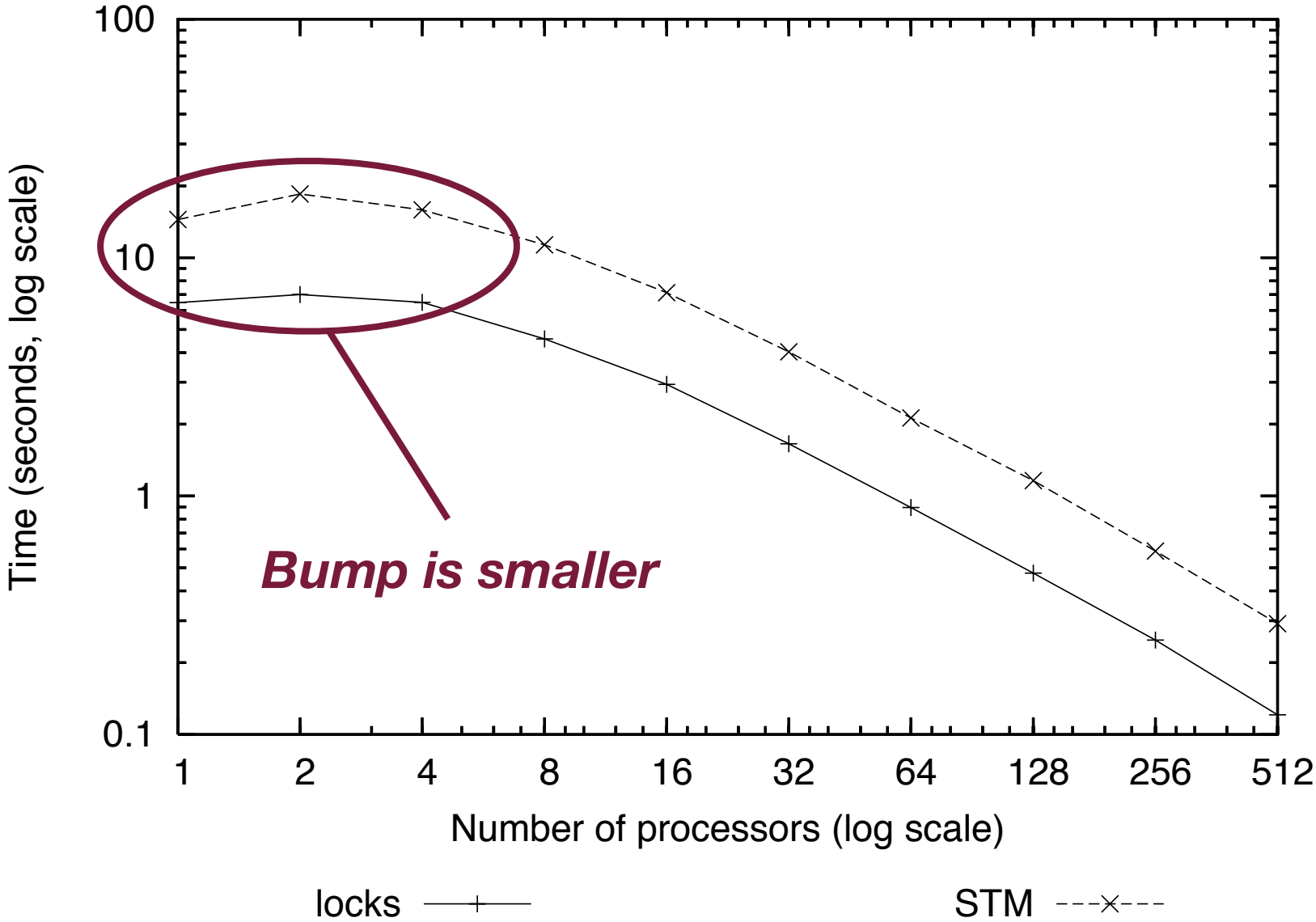

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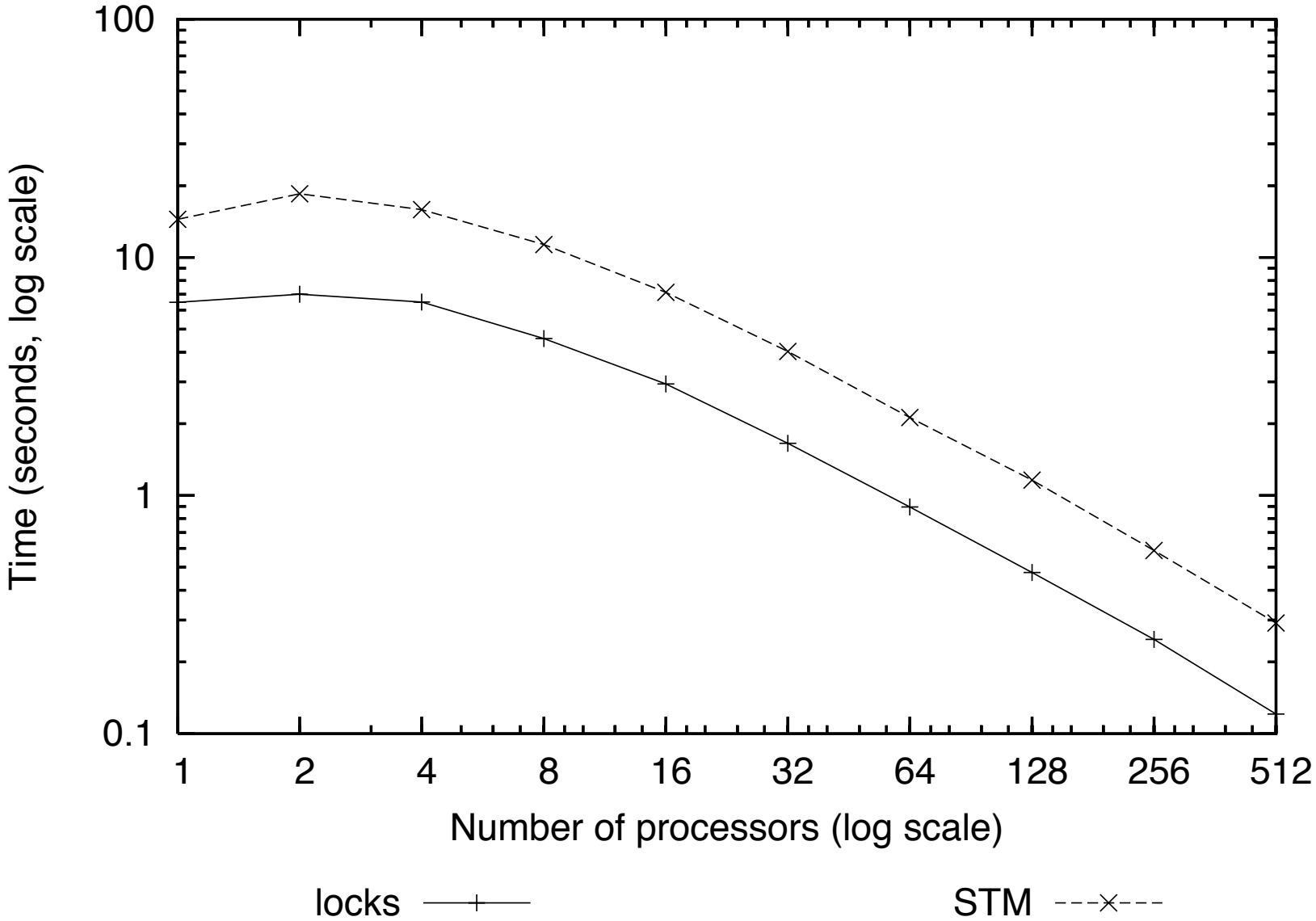

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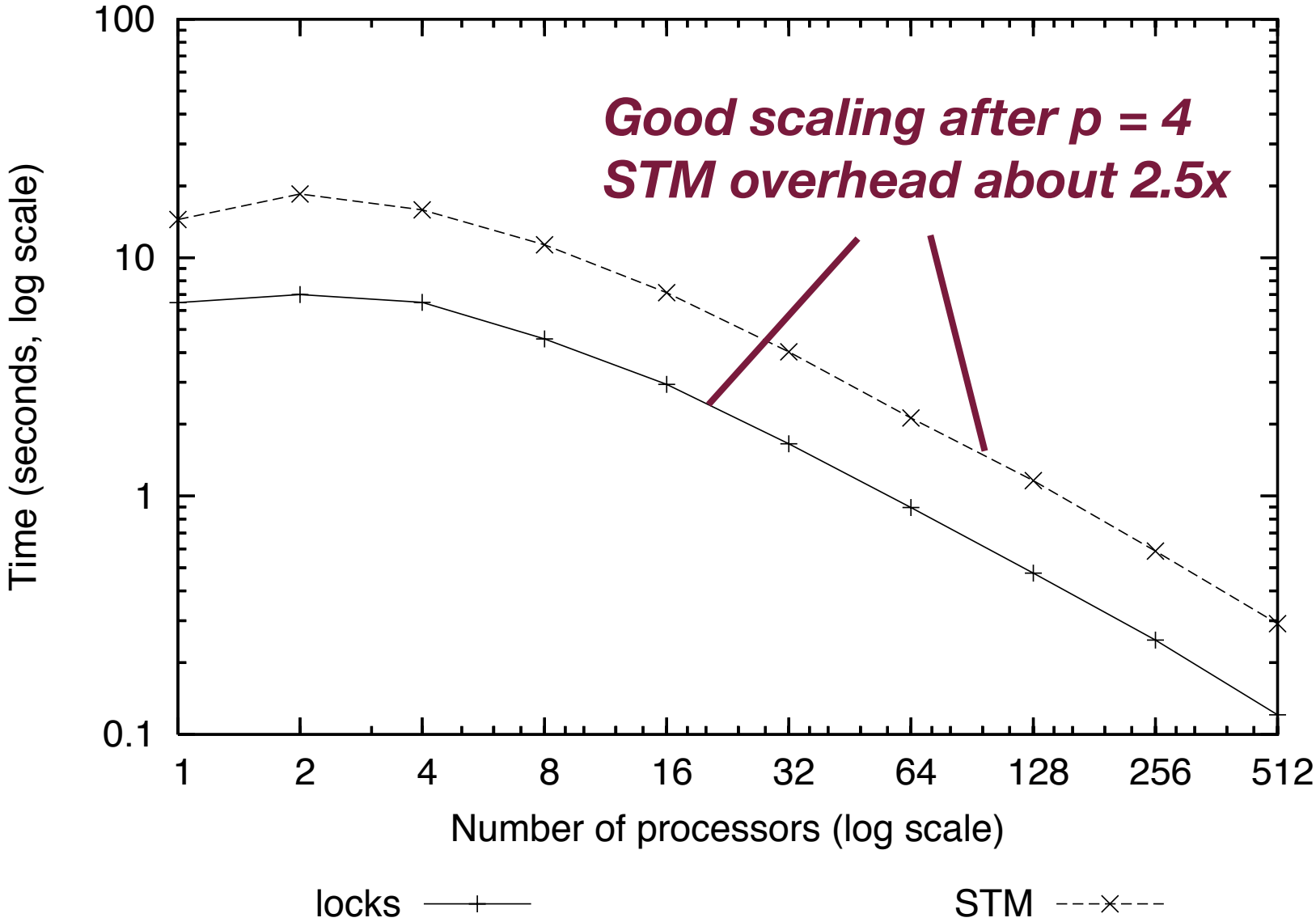

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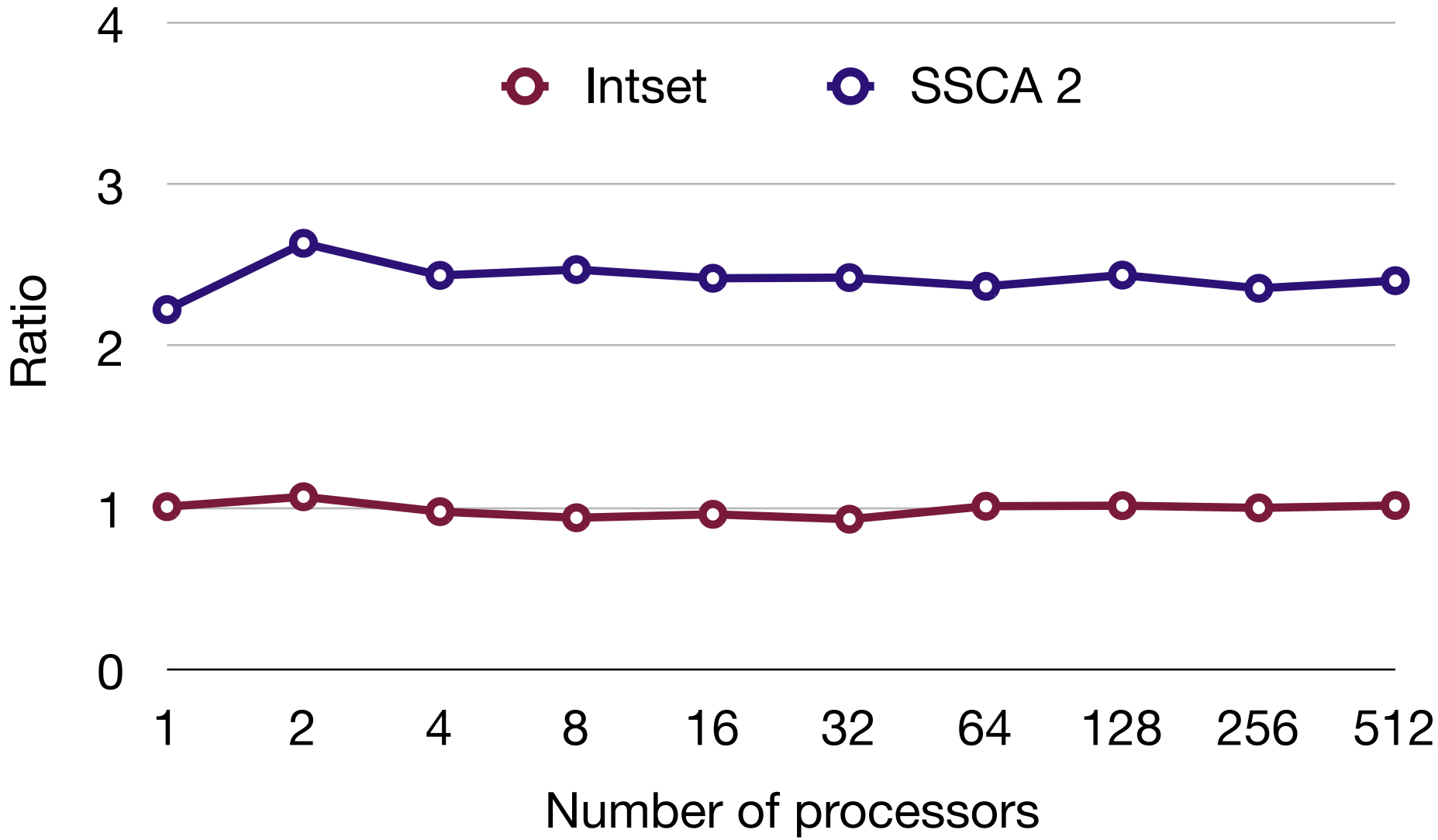
Validation requires extra remote op at commit

No global cache ⇒ no helpful cache effects

Ratio of RV to RL Runtimes



Results Summary

Good scalability to $p = 512$

Good performance

- Nearly identical to locks on micro benchmarks
- Some STM overhead for SSCA2

Different design tradeoffs

- RL outperforms RV
- EA outperforms LA (see paper)
- Minimal penalty for WB (see paper)

Outline

Interface Design

Algorithm Design

Evaluation

Conclusion

Conclusion

Presented design and evaluation of Cluster STM

- First STM for high performance on large scale clusters
- Good performance, scaling to $p = 512$
- New evaluation of design tradeoffs

Future work

- Exploiting shared memory within a node
- Nested parallelism in a transaction
- Dynamic spawning of threads

Thank You