Non-Speculative Load→Load Reordering in TSO[1]

Alberto Ros

Universidad de Murcia

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[1] A. Ros, T. E. Carlson, M. Alipour, and S. Kaxiras, "Non-Speculative Load-Load Reordering in TSO". ISCA, 2017.

Outline

Program order

- Programmer intuition: instructions execute in the order they appear in the program

Thread 1

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$r0 = X;   // load
$r1 = Y;   // load
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Y = 1;   // store
X = 1;   // store
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- store→store
- load→store

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TSO RULES

- load→load
- store→store[2]
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- This talk focus on the load→load order

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POSSIBLE RESULTS UNDER LOAD→LOAD (E.G. TSO)

INITIALLY X=0, Y=0

lx: $r0 = X;	sy: Y = 1;
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SIX POSSIBLE INTERLEAVINGS AND VALUES FOR ($R0, $R1)

lx	lx	lx	sy	sy	sy
ly	sy	sy	lx	lx	sx
sy	ly	sx	ly	sx	lx
sx	sx	ly	sx	ly	ly
(0,0)	(0,1)	(0,1)	(0,1)	(0,1)	(1,1)

- (1,0) is not possible if load→load & store→store

RELAXING LOAD→LOAD

INITIALLY X=0, Y=0

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- (1,0) is possible by relaxing load→load

LOAD→LOAD REORDERING

- Waiting for a load to finish to start the execution of the next load is very inefficient

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- Waiting for a load to finish to start the execution of the next load is very inefficient
- High-performance processors execute multiple load operations simultaneously
  - Memory level parallelism
- Load operations can execute out of order
- This is correct for single-core processors

LOAD→LOAD REORDERING

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Program

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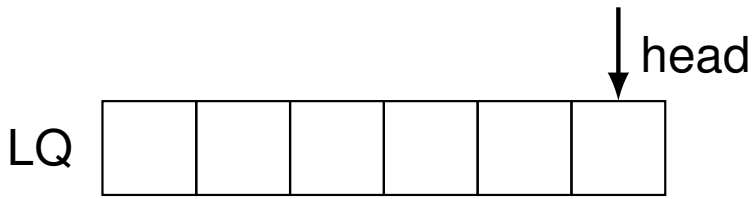
ld_2
ld_3
ld_4
ld_5
ld_6



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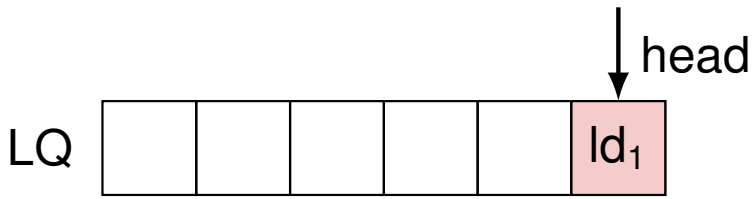

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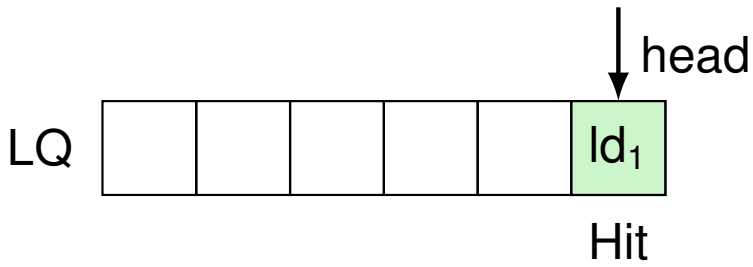

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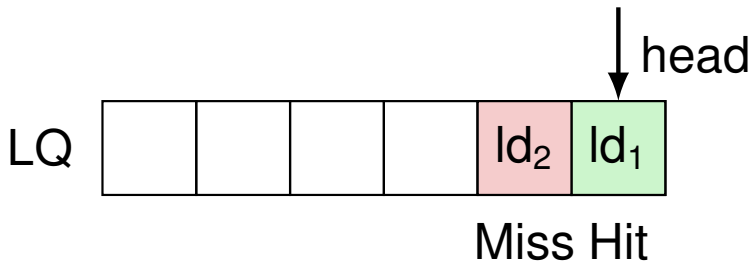

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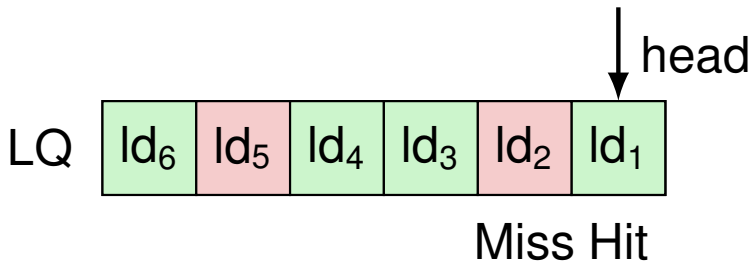

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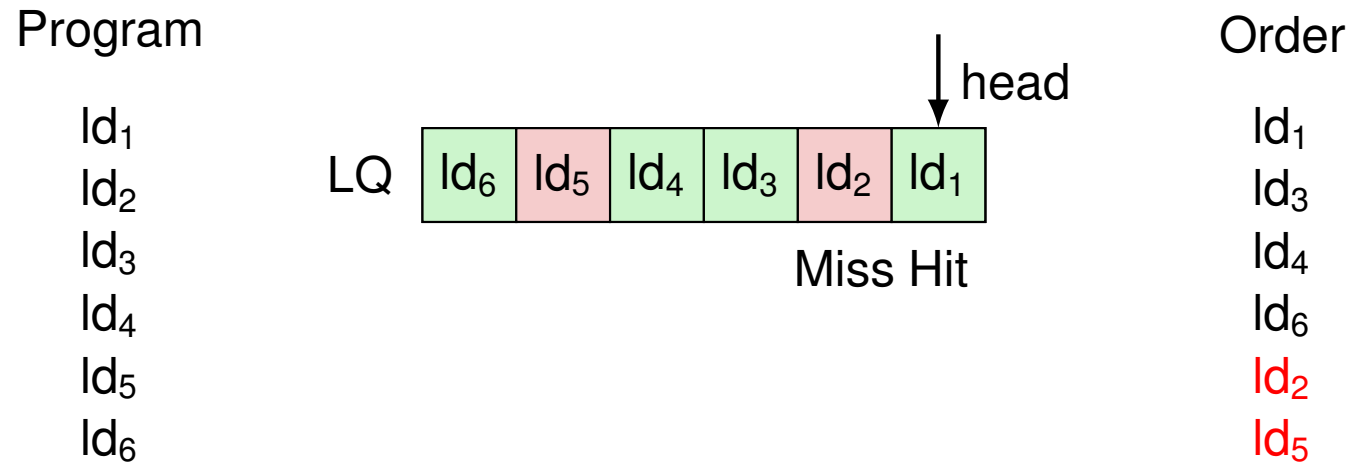

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$r1 = X;  |
          |  Y = 1;
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           |  Y = 1;
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- No, if the other cores do not see the reordering

RELAXING LOAD→LOAD

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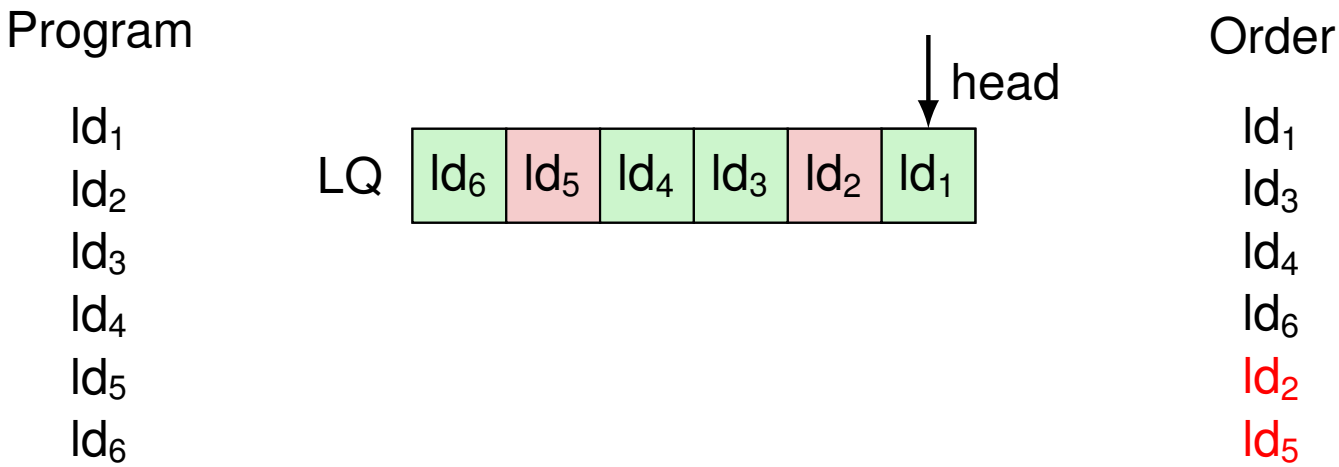

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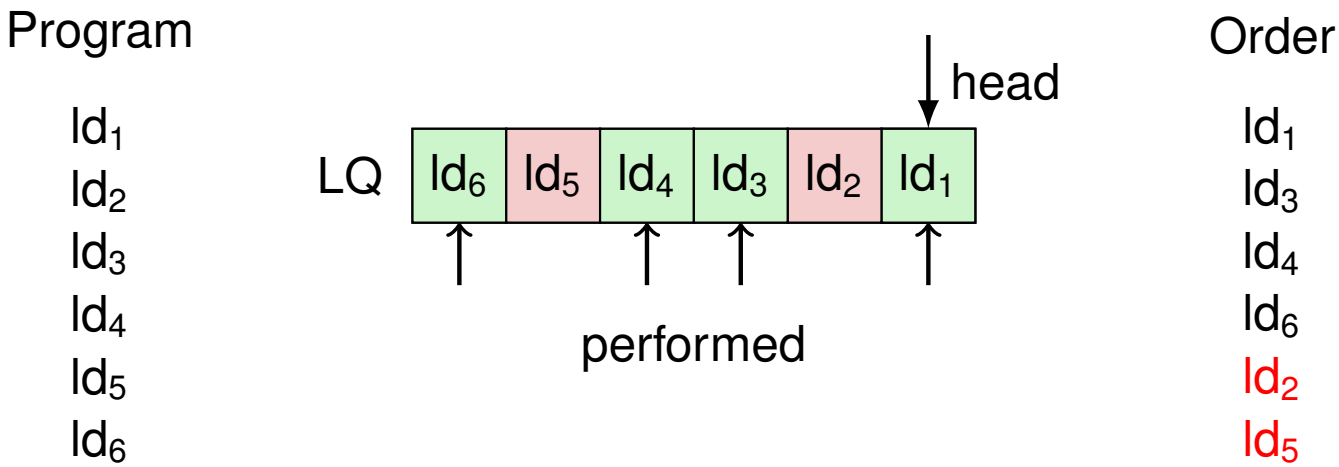

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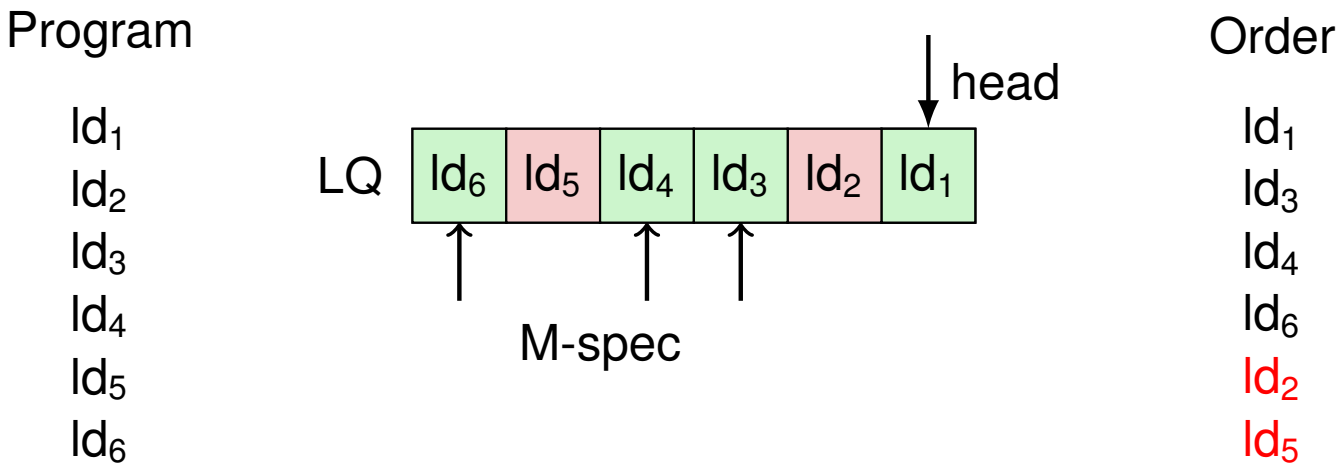

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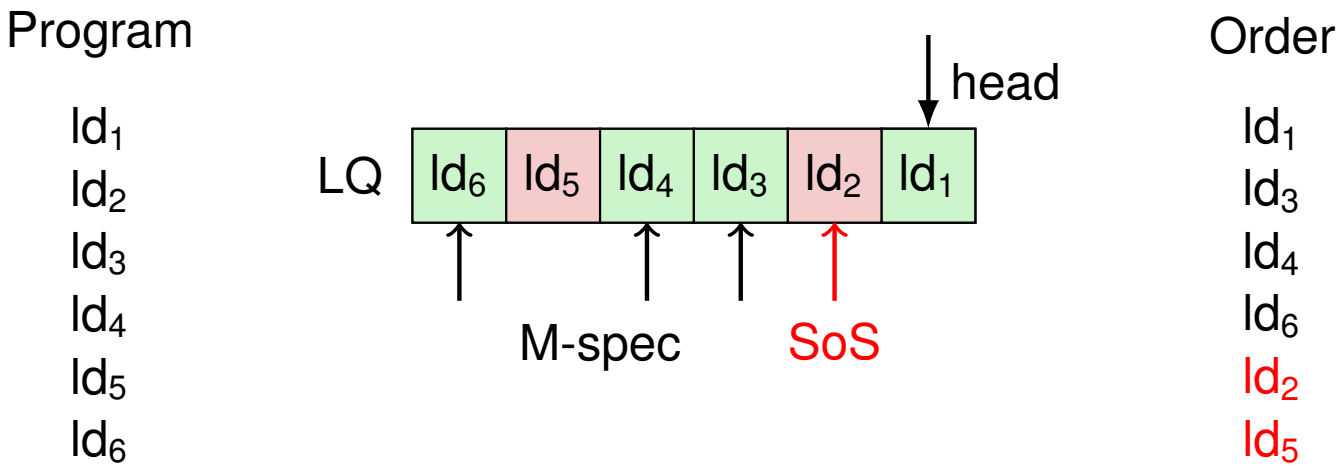

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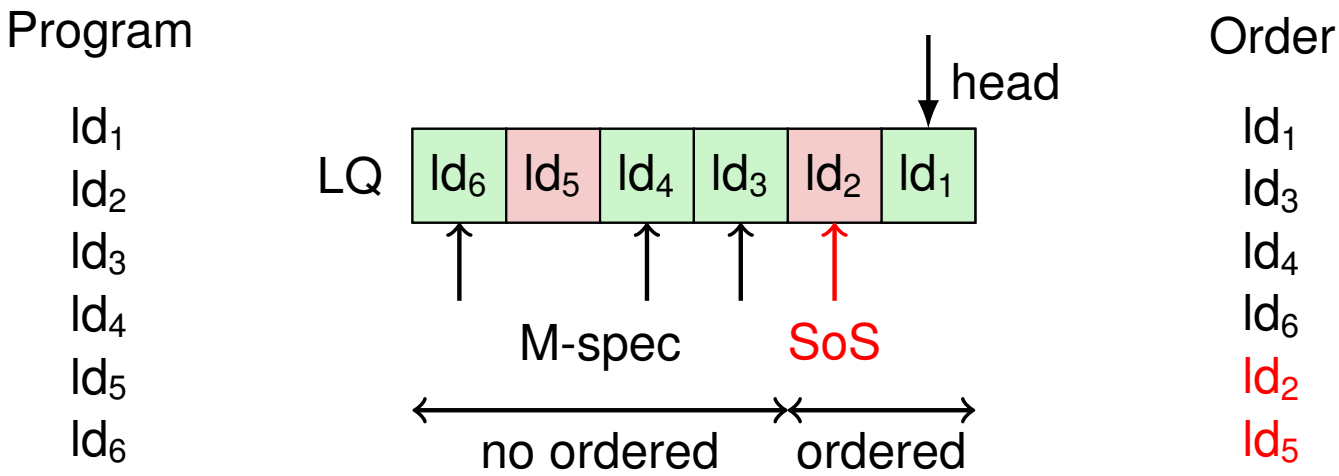

SQUASH AND RE-EXECUTE UPON INVALIDATION

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  - With the help of the cache coherence protocol

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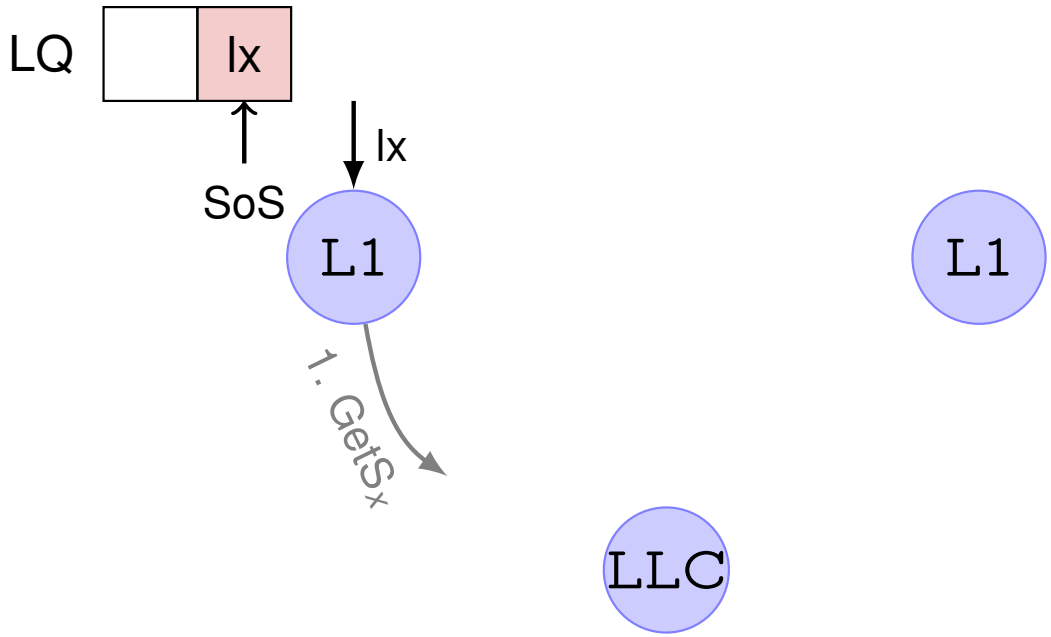

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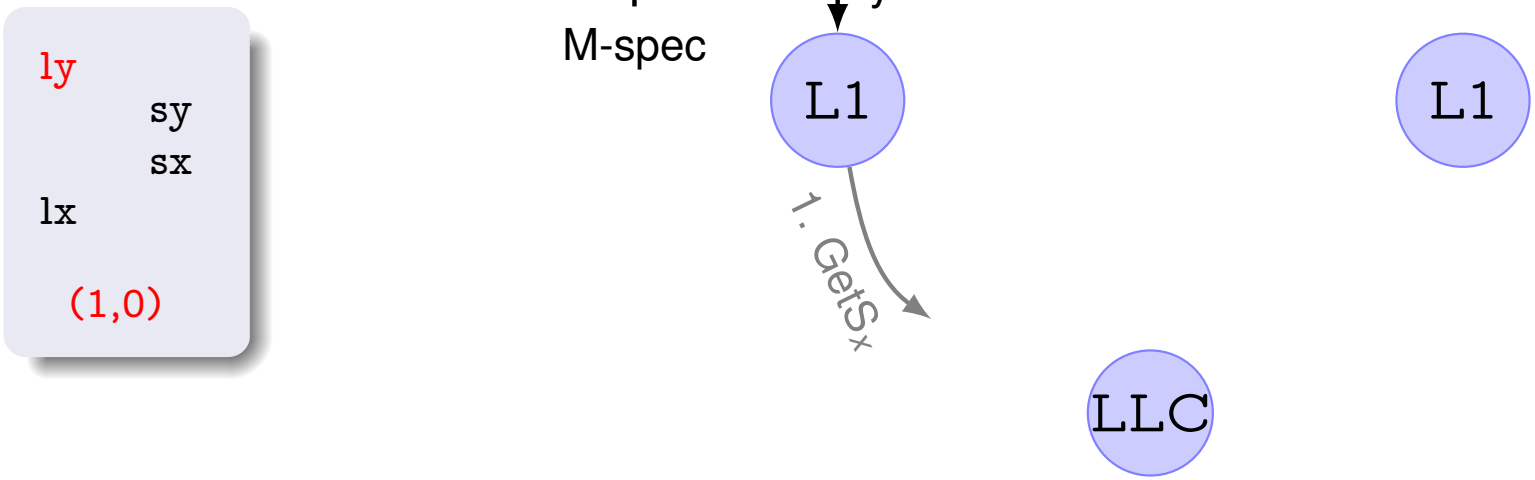

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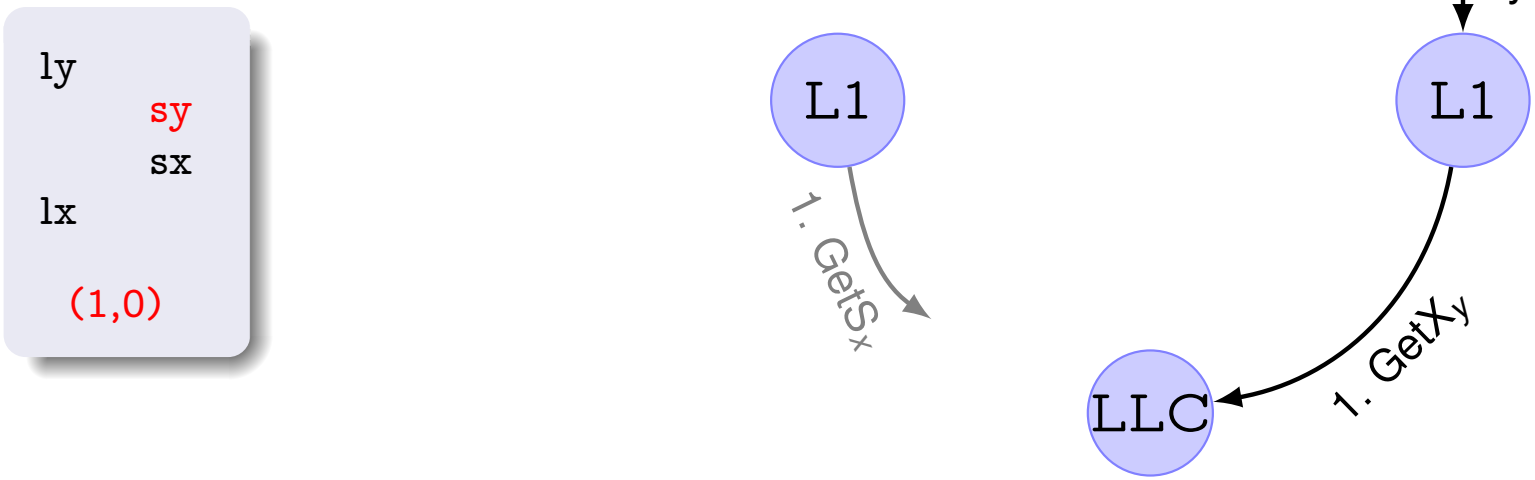

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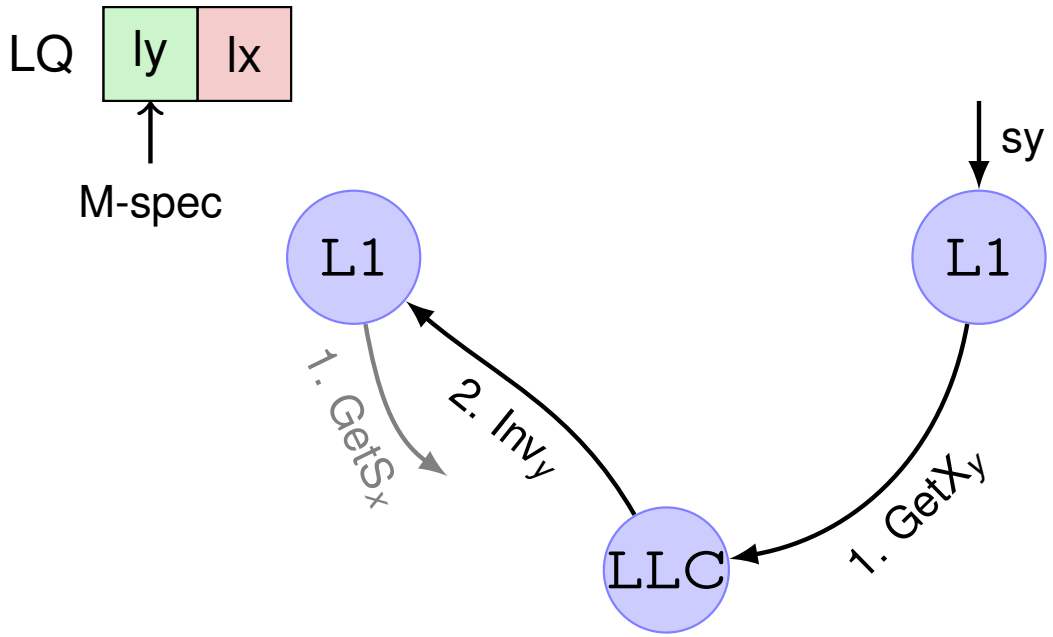

SQUASH AND RE-EXECUTE UPON INVALIDATION

- Current multicore avoid incorrect results
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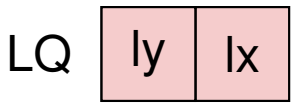
  - Squashing and re-executing on remote writes

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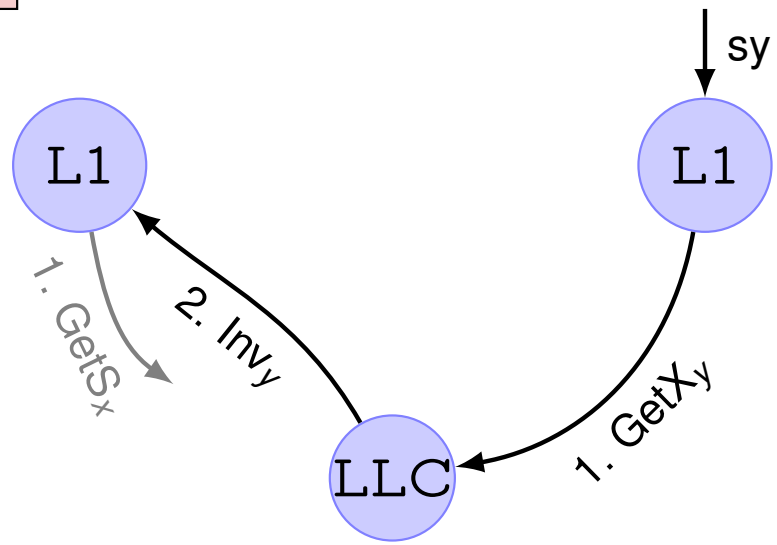

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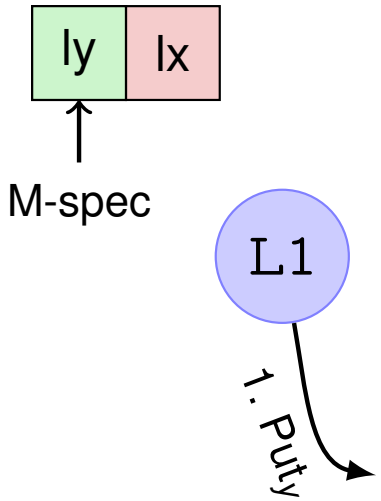

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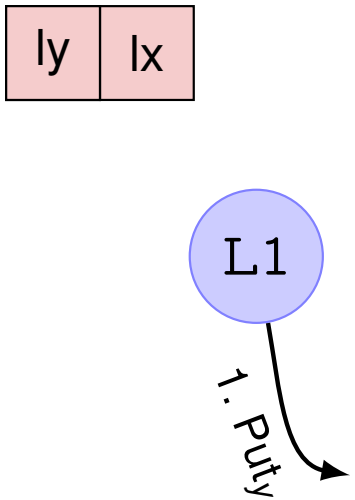

SQUASH AND RE-EXECUTE UPON EVICTIONS

- What happens when a cache block loaded by an M-spec load is evicted?
  - If the directory stops tracking the block, the M-spec load will not receive an invalidation
- Solution: Squash and re-execute upon evictions
  - This impacts the performance of sequential applications!!!

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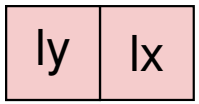

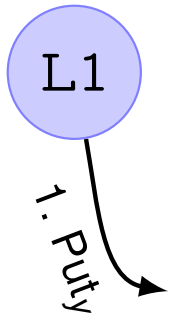

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Question

Can we execute loads out of order without speculation and guaranteeing load→load?

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WritersBlock achievement

- Current multicore processors speculatively execute loads out of order
- If a conflict happens, loads are squashed and re-executed

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WritersBlock

Makes possible removing this speculation, executing loads out of order, and making that an executed load is never squashed because of the consistency model

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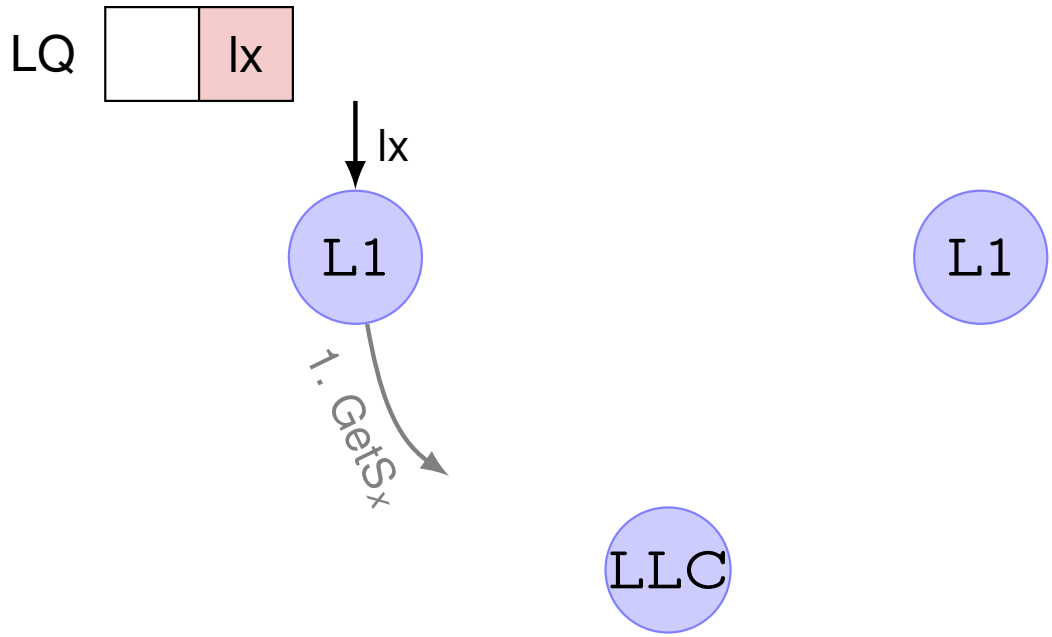

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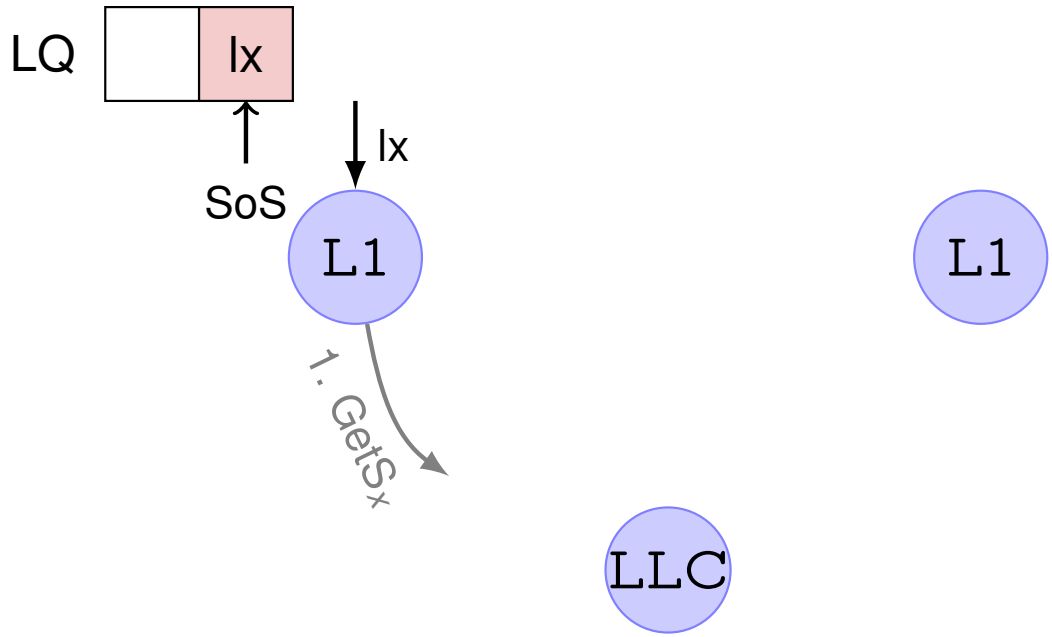

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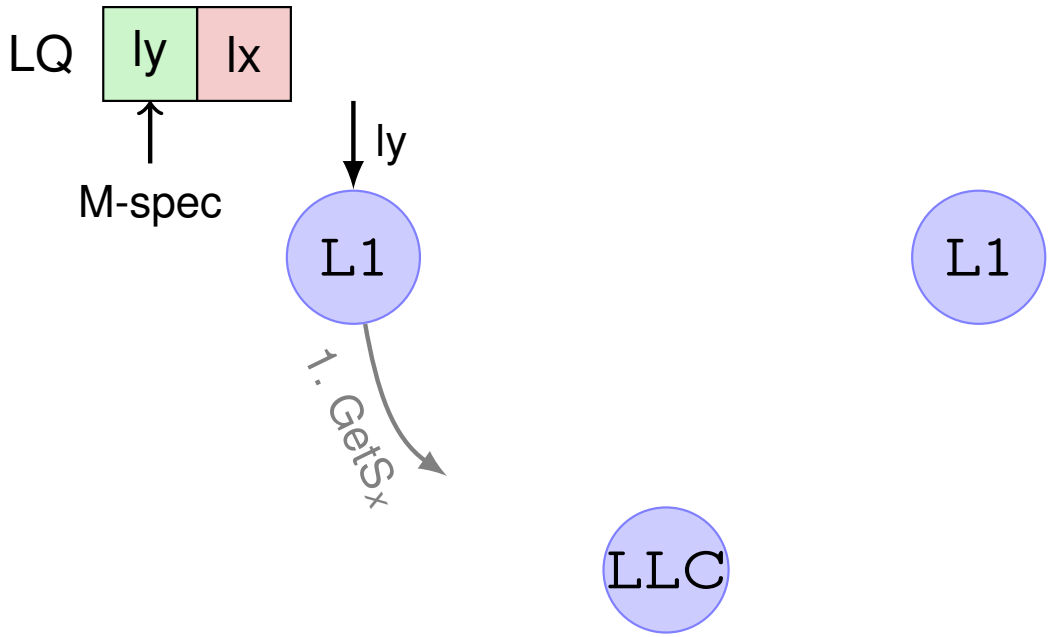

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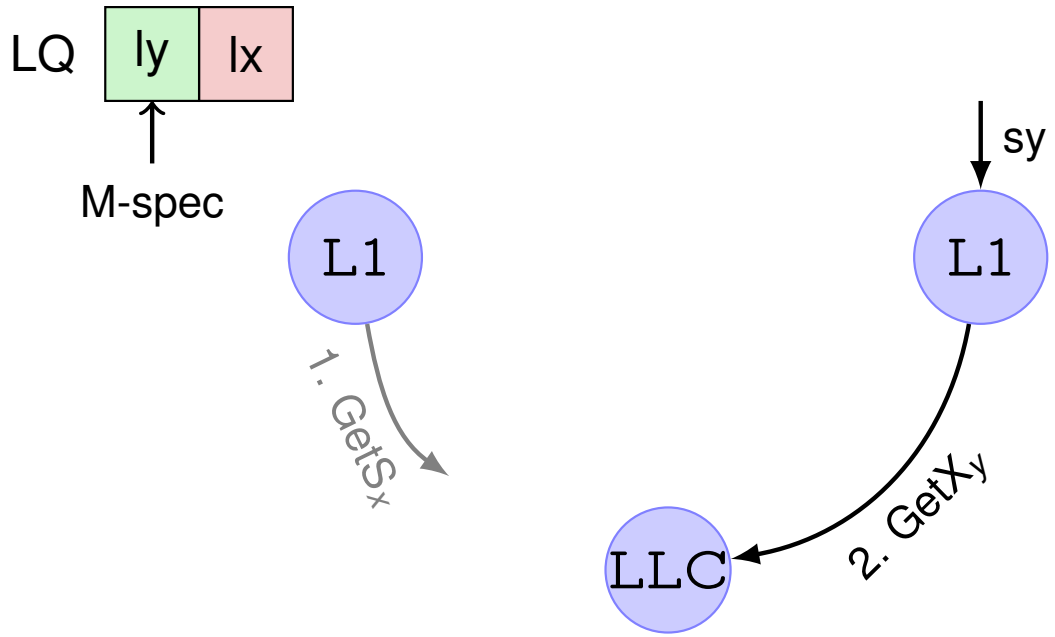

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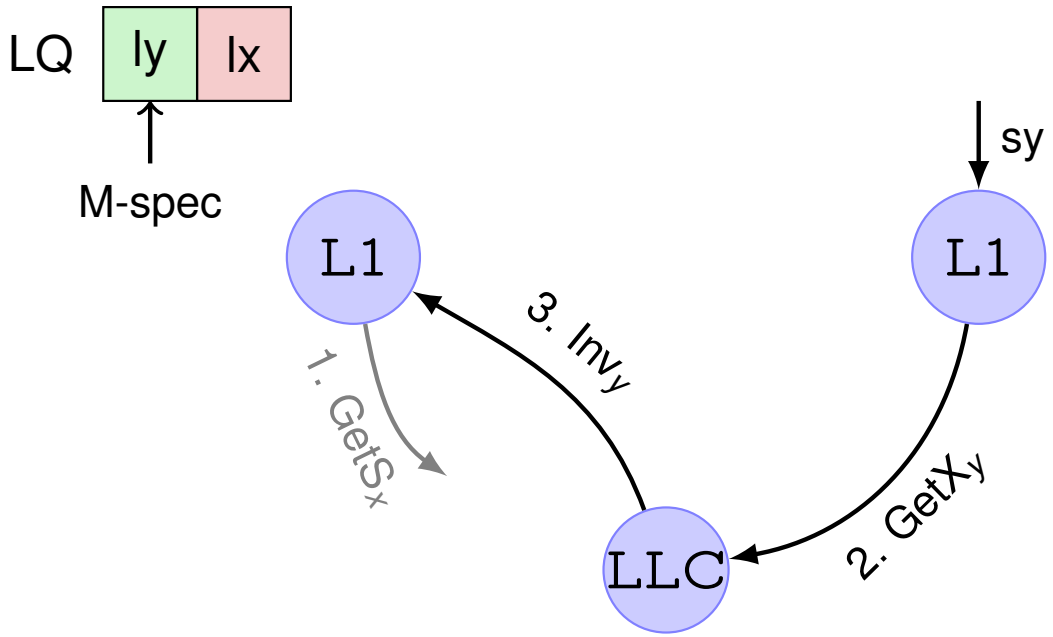

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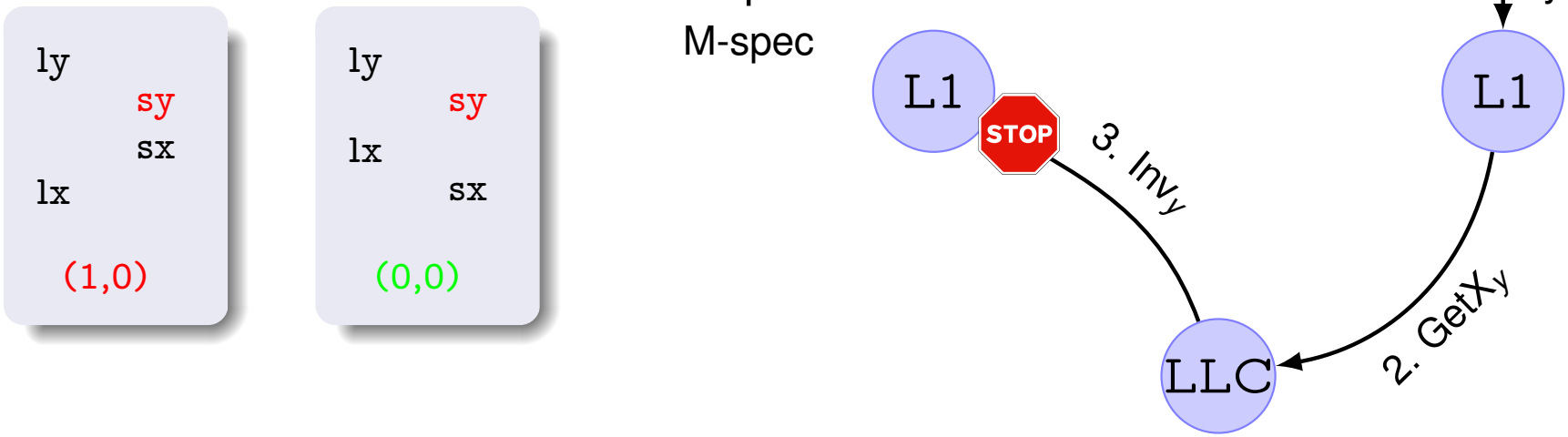

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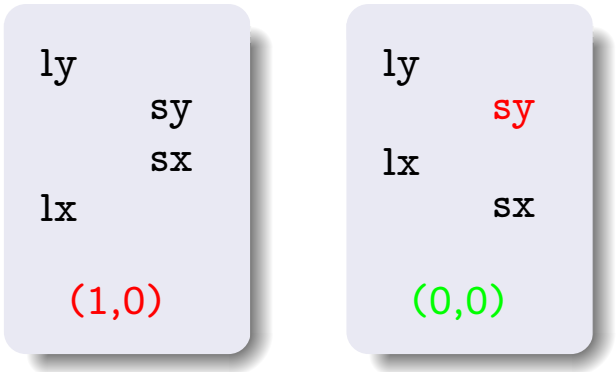

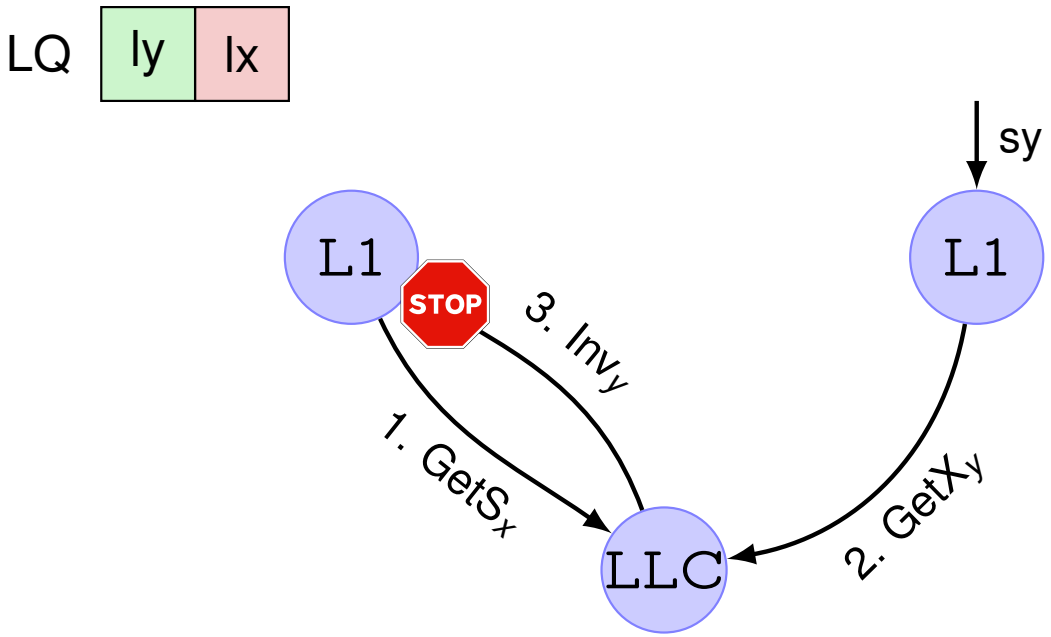

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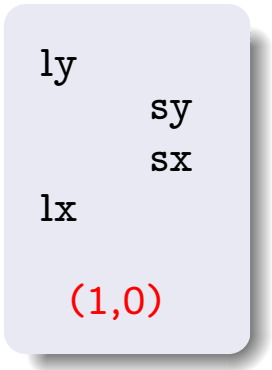
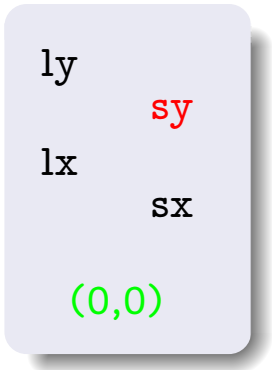
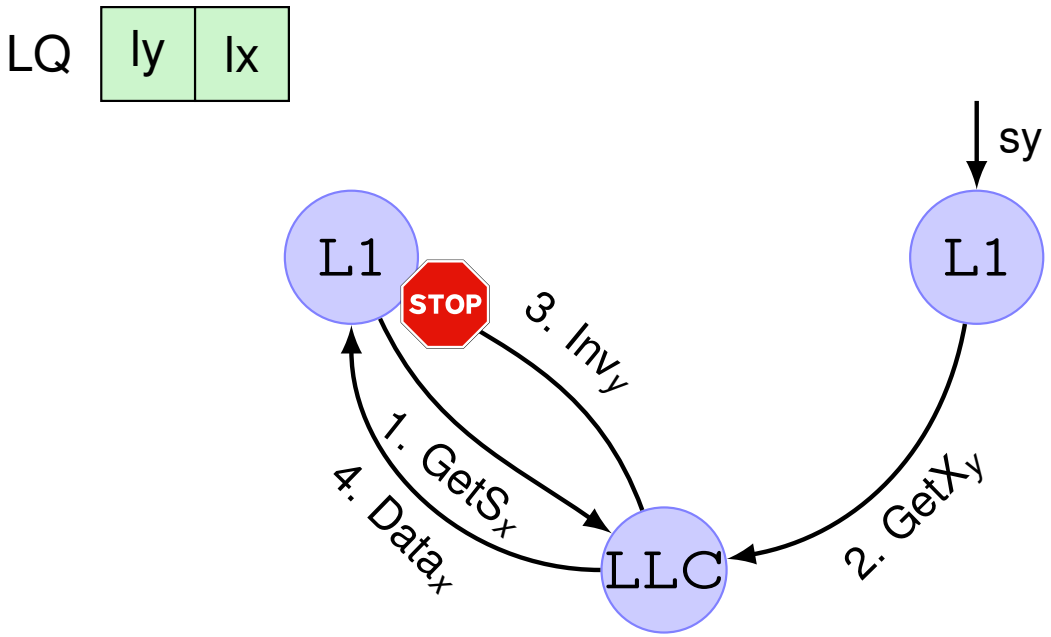
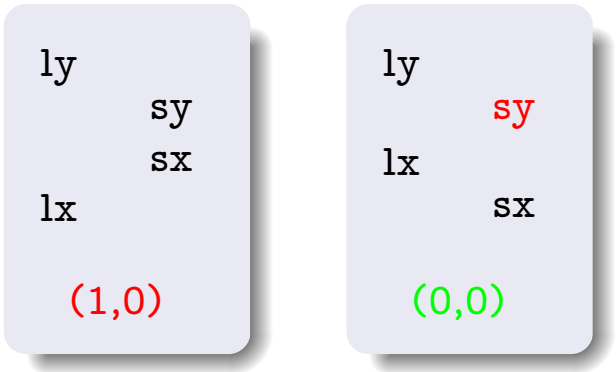


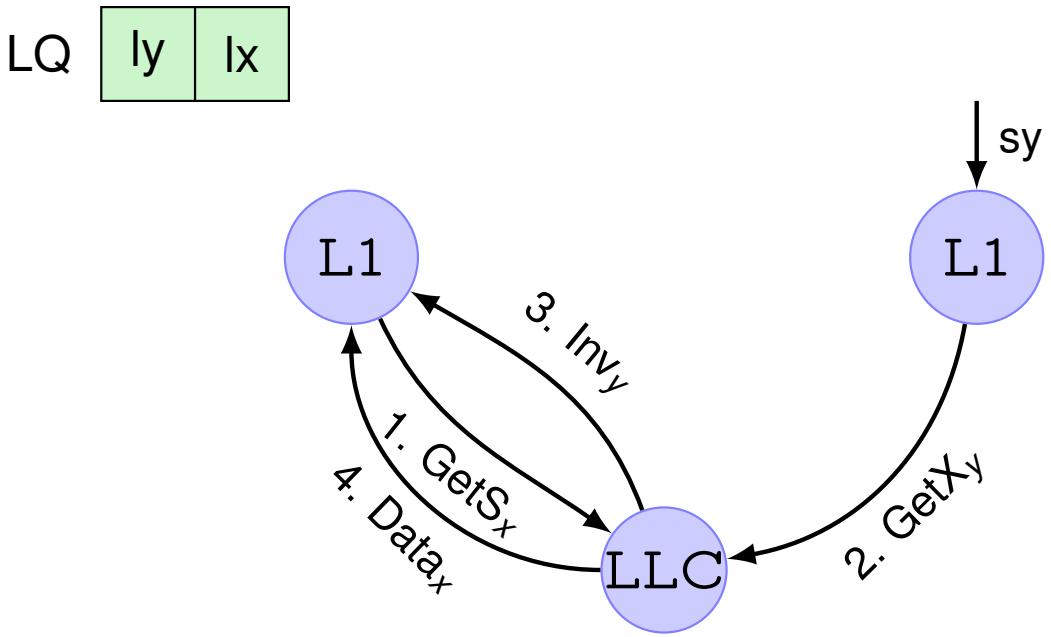




How?

- With the help of the cache coherence protocol
  - Blocking and delaying the remote write (WritersBlock)
  - Until when? Until the load stop being M-spec





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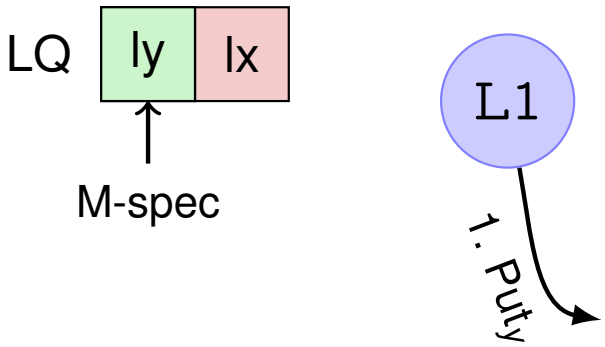

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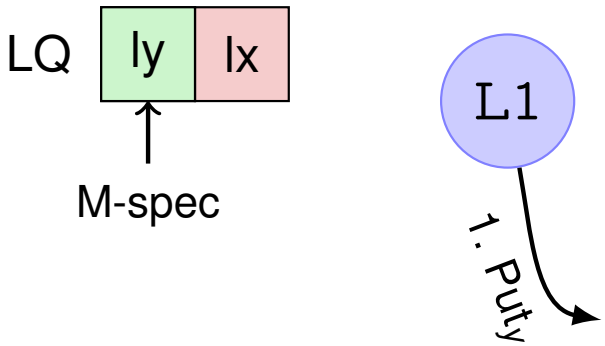

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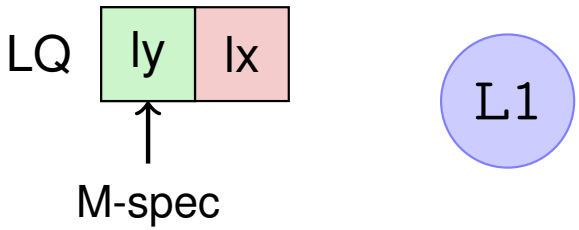

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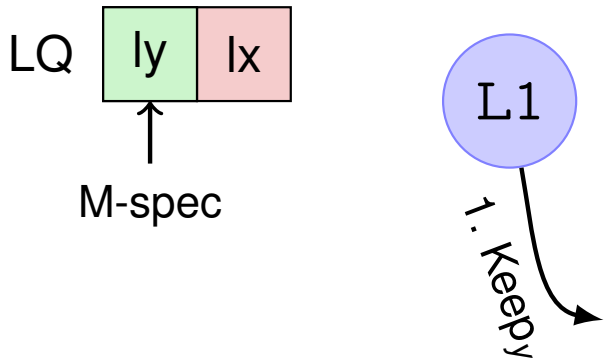

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Deadlock

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        sy
        sx
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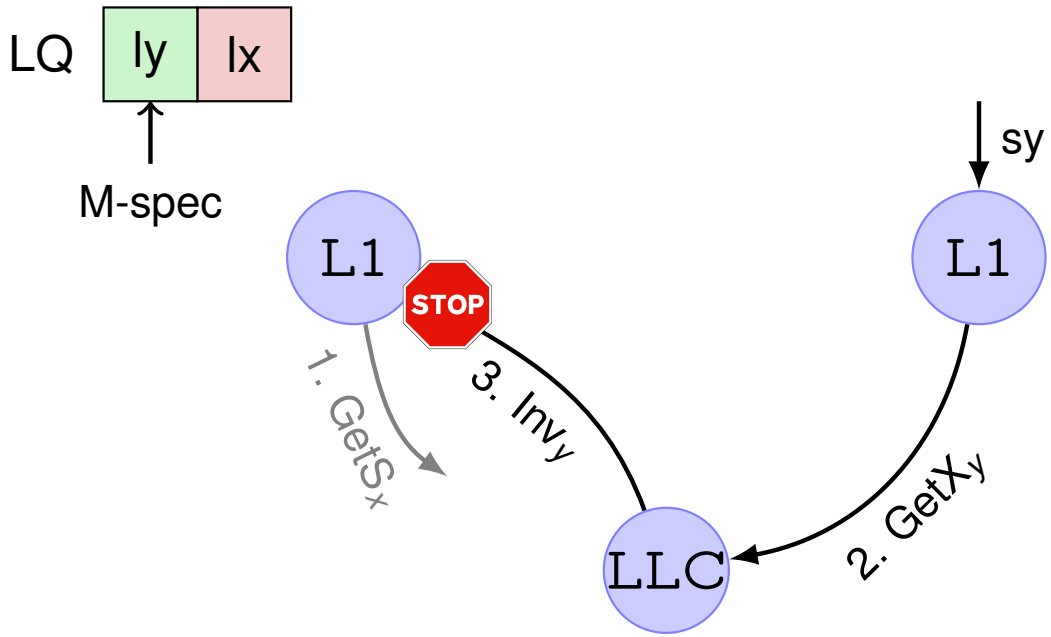

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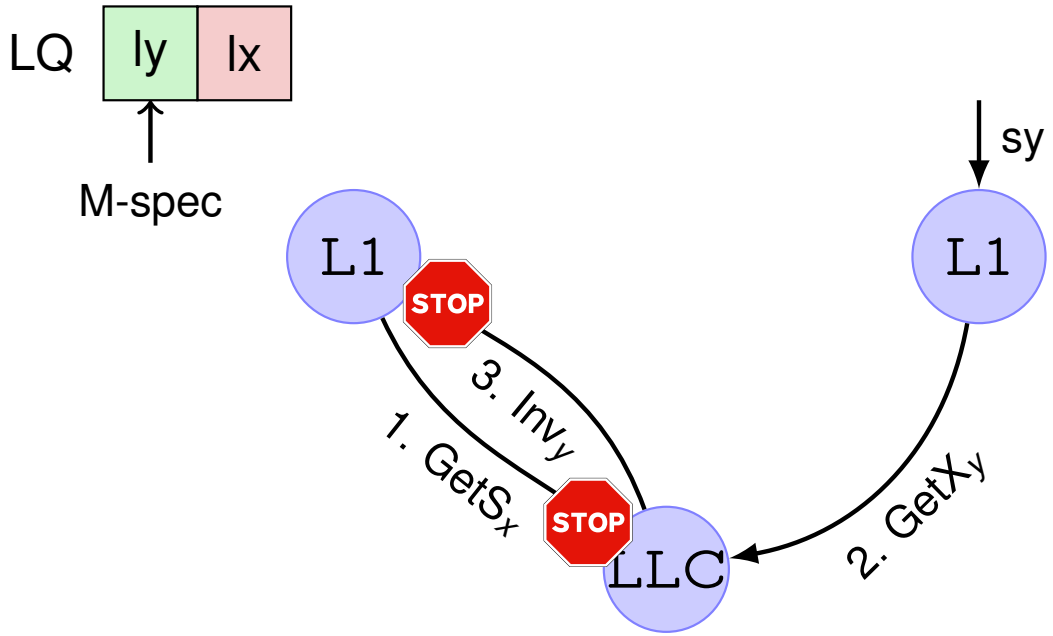

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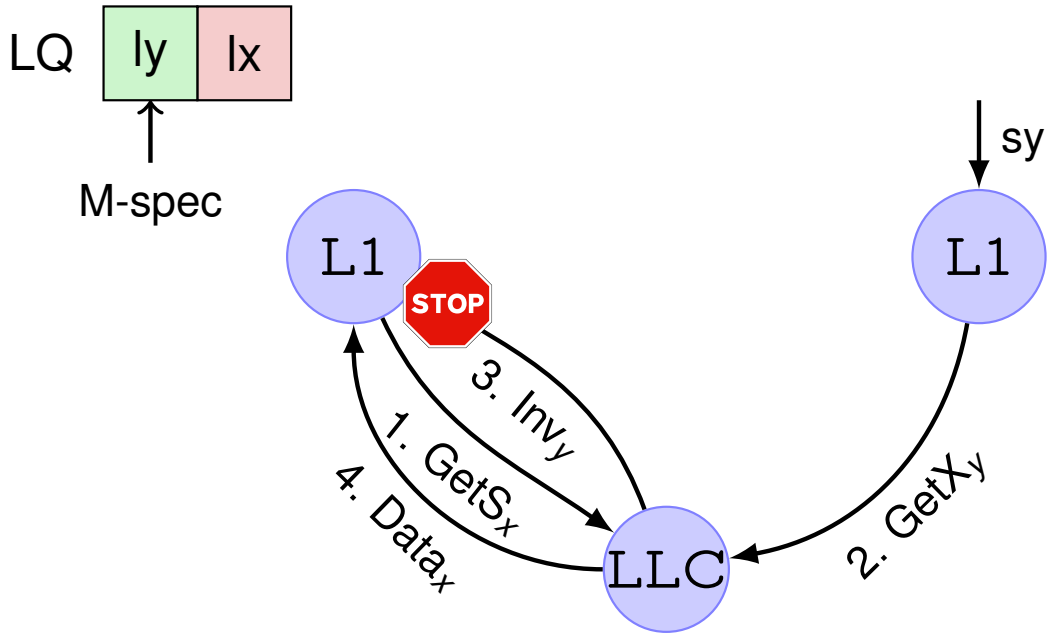

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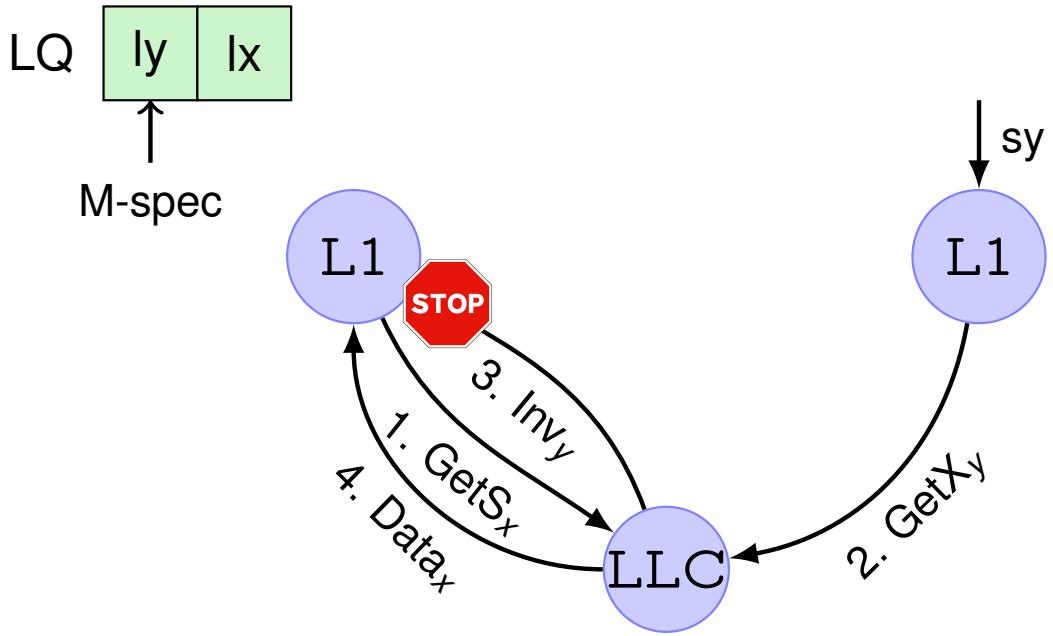

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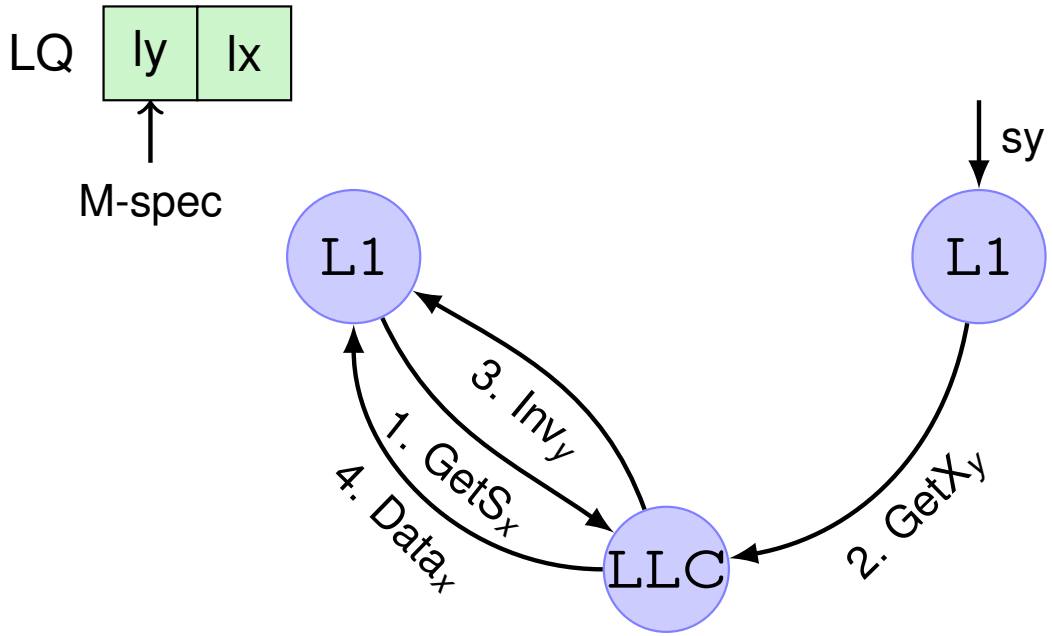

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- Solution
  - Reads resolved through WritersBlock must be non-cacheable
  - and cannot resolve M-spec loads (no invalidation will be received)

DEADLOCK AVOIDANCE

- WRITERSBLOCK cause writes to be blocked
  - Until a load stop being M-speculative
- Deadlocks will not happen if loads cannot be stopped by a pending write miss
- Other blocking causes:
  - MSHR address occupied by write miss $\Rightarrow$ Duplicate read-write MSHR allocation
  - Full directory/LLC $\Rightarrow$ Non-cacheable loads
  - Atomic Read-Modify-Write $\Rightarrow$ Non-speculative

Case of use: Out-of-order commit

- Out-of-order commit[4] allows the processor to retire instructions from the reorder buffer (RoB) even if they are not at the head
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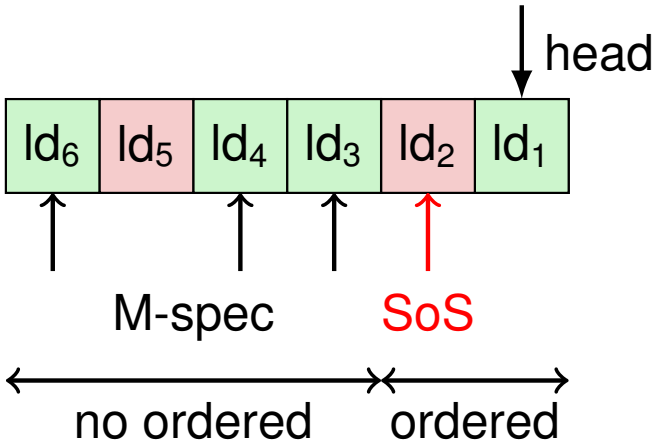

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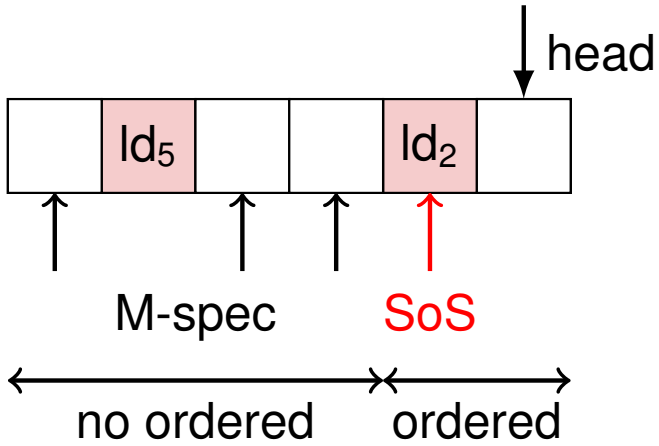

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WritersBlock: Blocked writes

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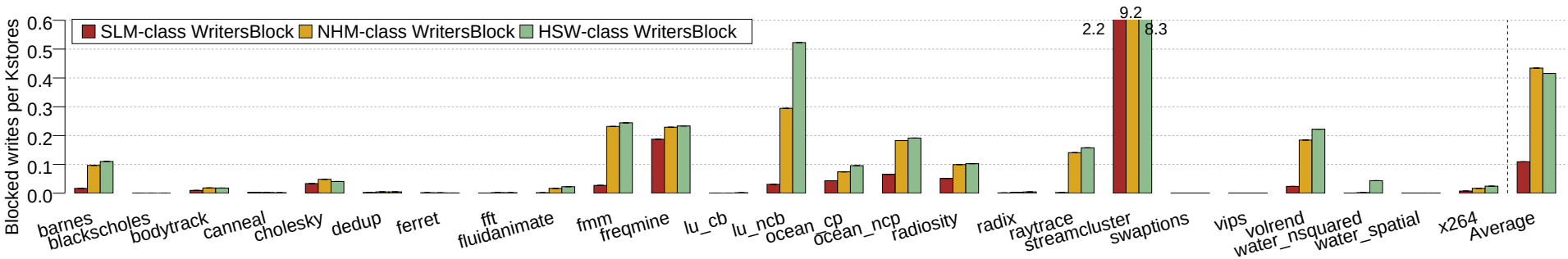

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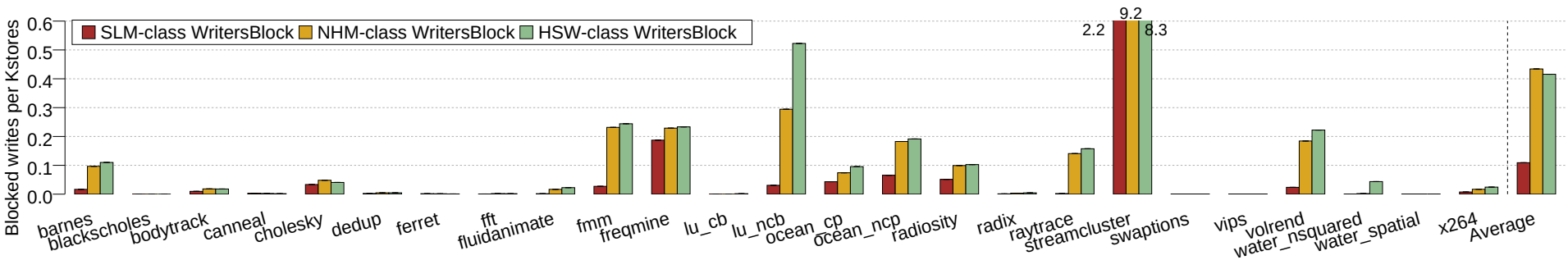

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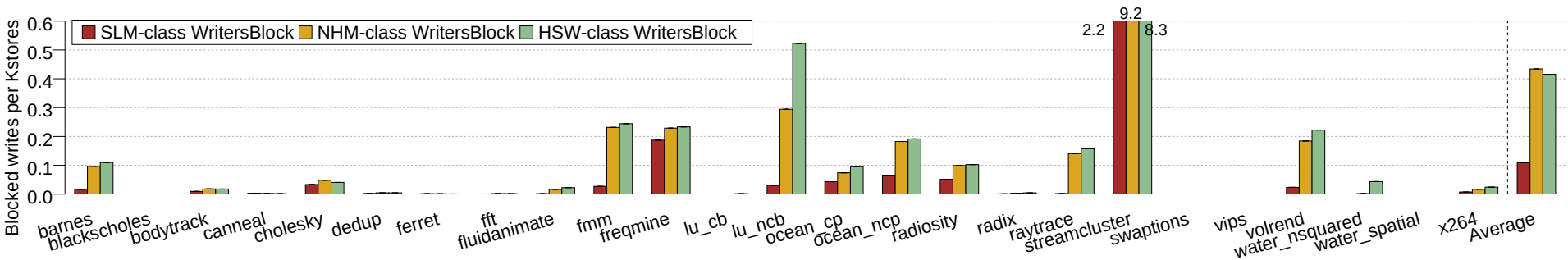

WritersBlock: Non-cacheable data

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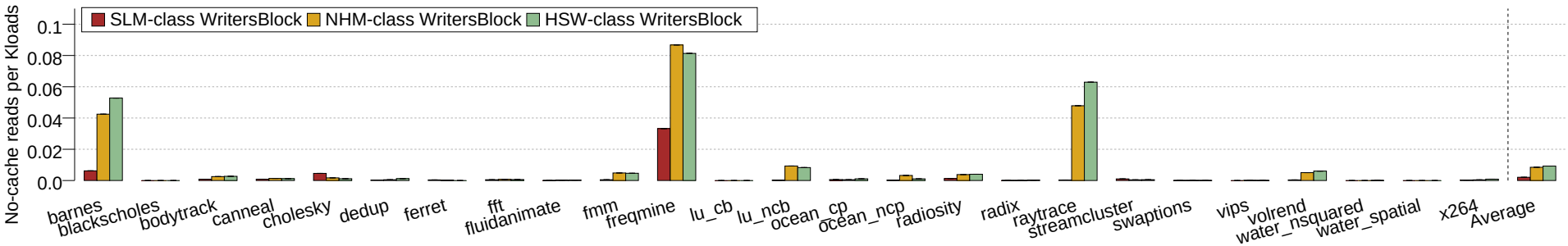

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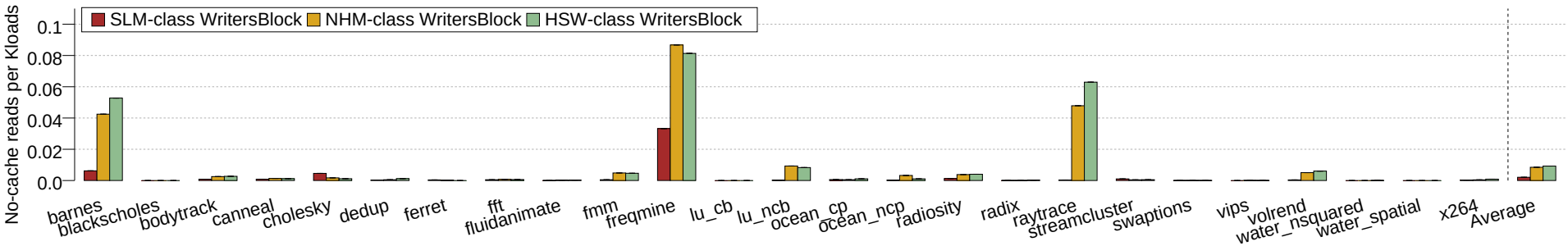

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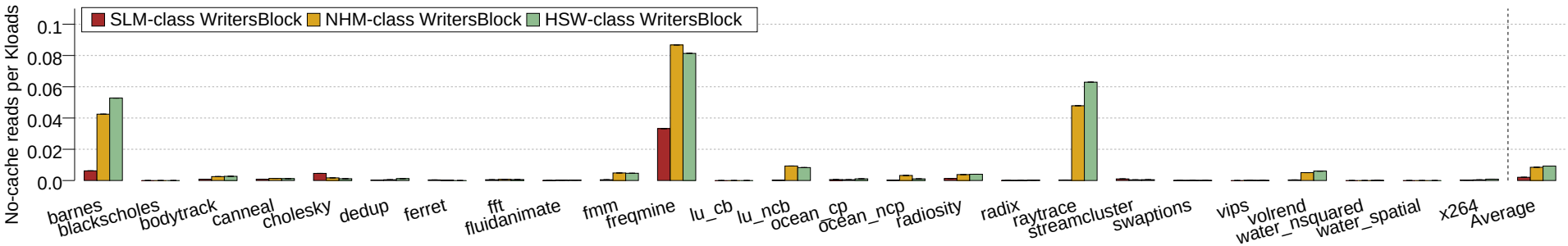

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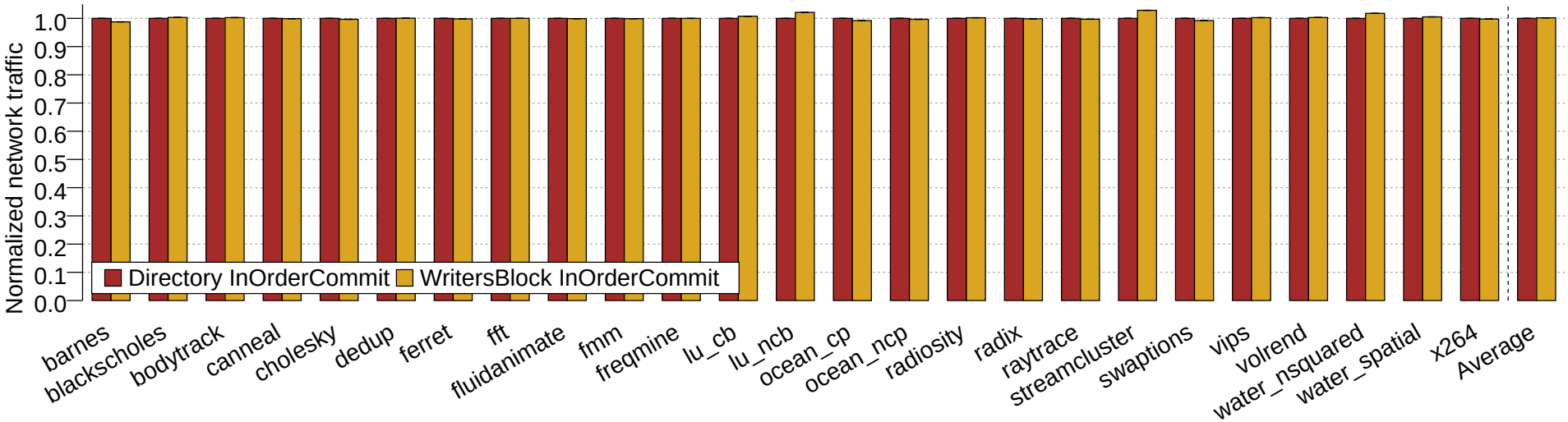

WritersBlock: Network traffic

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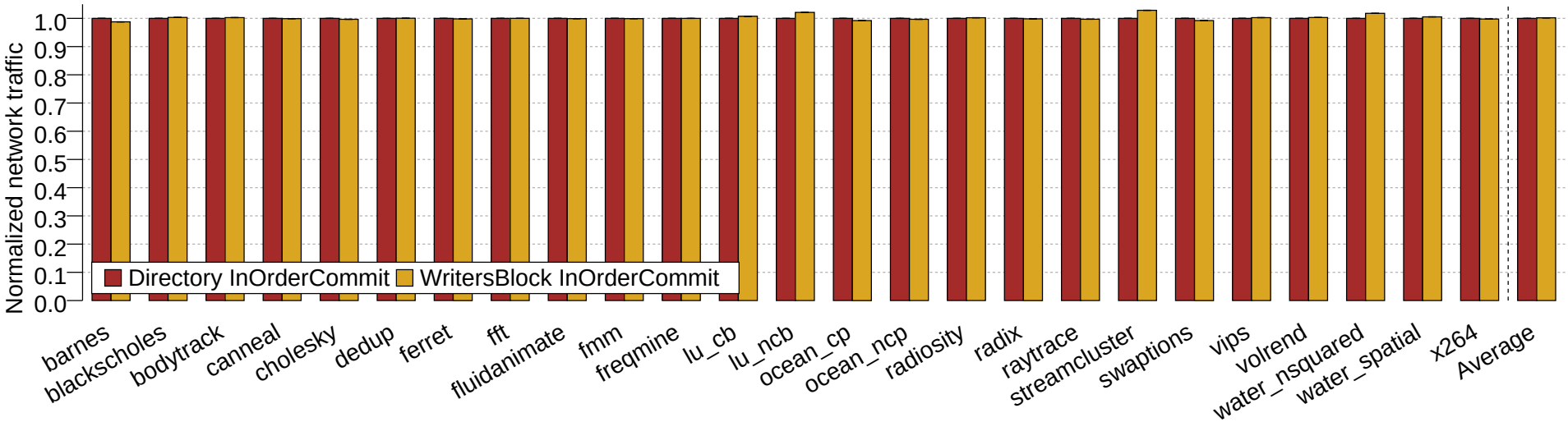
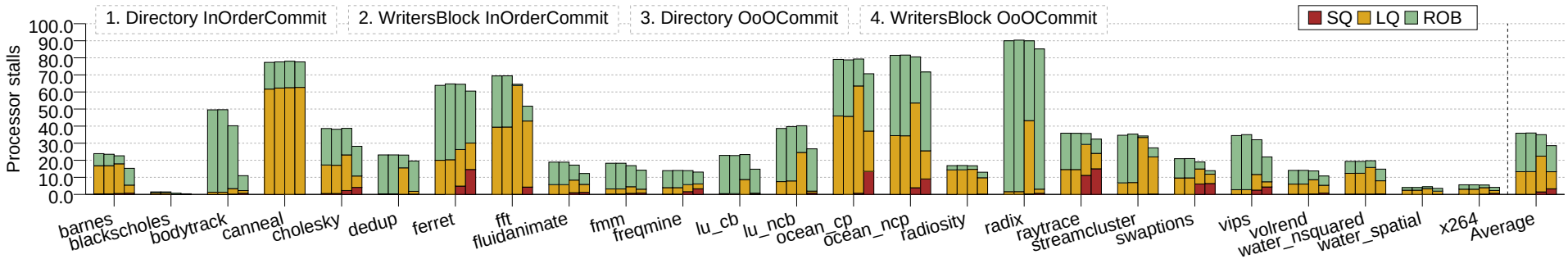


Out-of-order Commit: Processor stalls

- Normalized to DIRECTORY + INORDERCOMMIT



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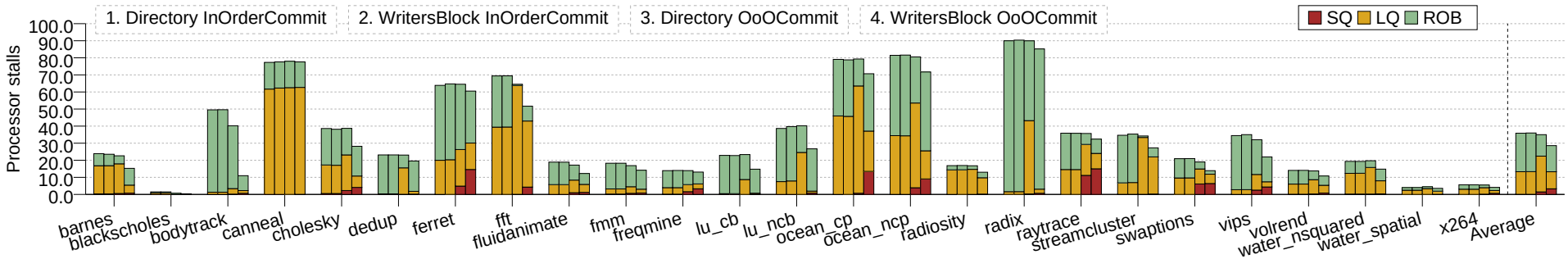

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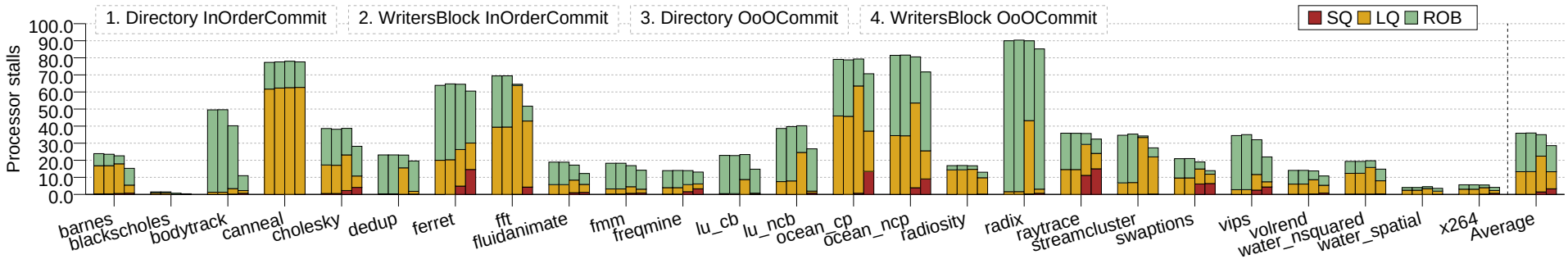

Out-of-order Commit: Execution time

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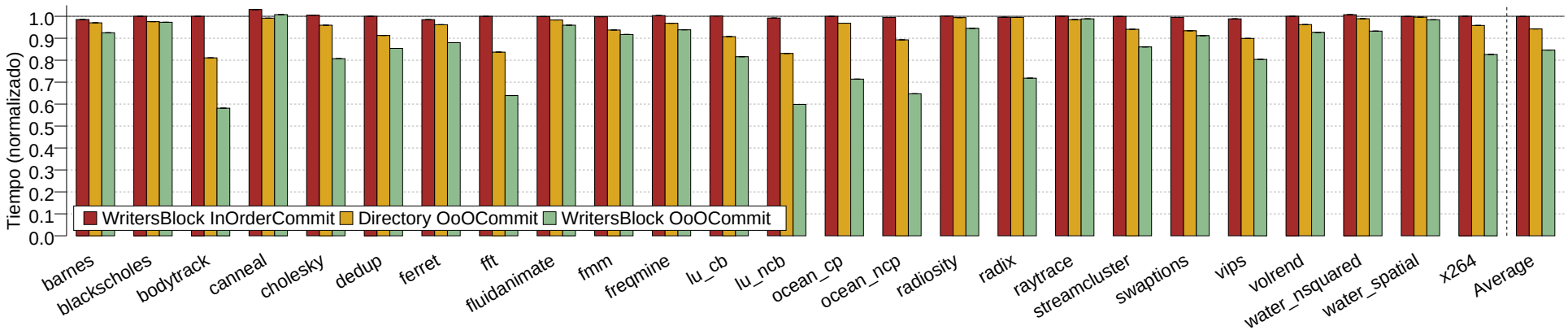

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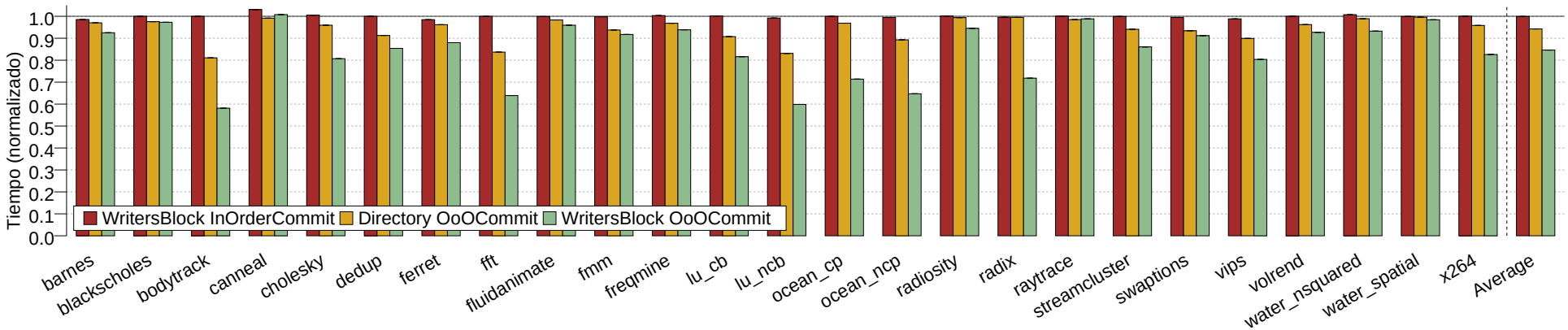

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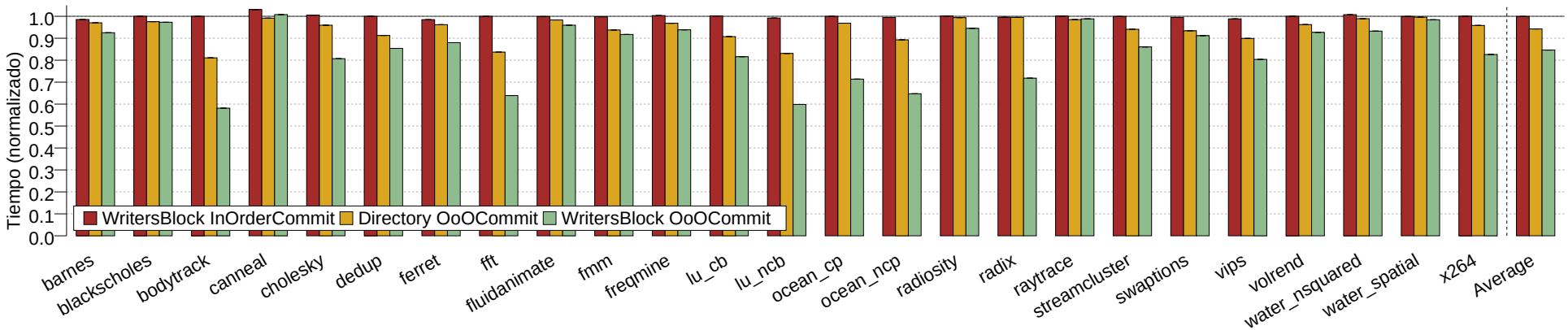
  - WritersBlock does not harm performance on average respect to Directory
- OoOCommit
  - WritersBlock improves performance by 11% on average respect to Directory



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Non-speculative loads can increase performance of
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Non-Speculative Load→Load Reordering in TSO[1]

Alberto Ros

Universidad de Murcia

October 17th, 2017

[1] A. Ros, T. E. Carlson, M. Alipour, and S. Kaxiras, "Non-Speculative Load-Load Reordering in TSO". ISCA, 2017.