Model Checking of C++ Programs under the x86-TSO Memory Model

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Relaxed Memory

- caches and inter-core communication in modern CPUs
- out-of-order execution
- has observable effects in multithreaded environments
- can cause nasty and hard to detect bugs

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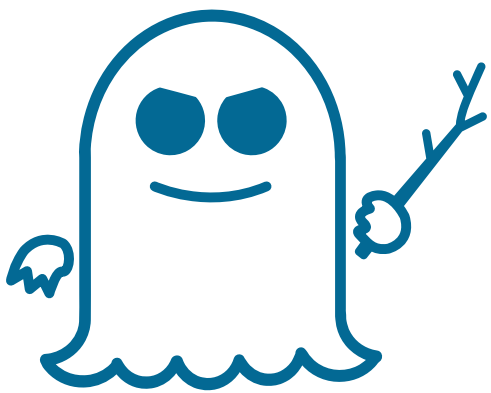
- out-of-order execution
- has observable effects in multithreaded environments
- can cause nasty and hard to detect bugs
- relaxed memory will probably be here to haunt us for a long time



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Current Approaches

- many different ways of finding errors
  - stateless model checking (Nidhugg, RCMC, ...)
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Our Focus

- x86-TSO memory model of the Intel and AMD CPUs (x86-TSO)
- C and C++
- based on explicit-state model checking

The x86-TSO Memory Model

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- writes are not reordered with each other but a CPU will not see writes done by other CPUs instantly

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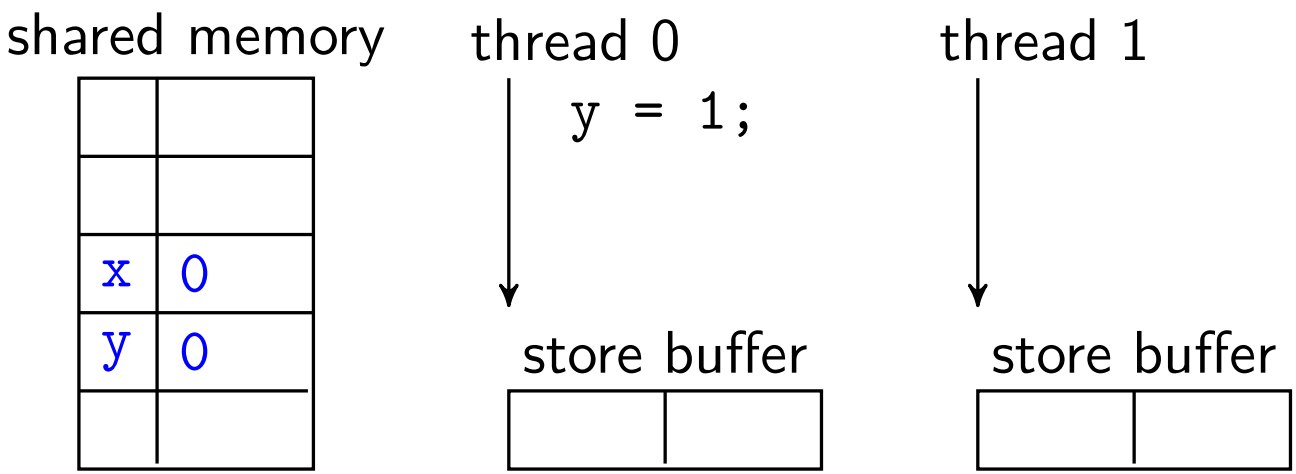

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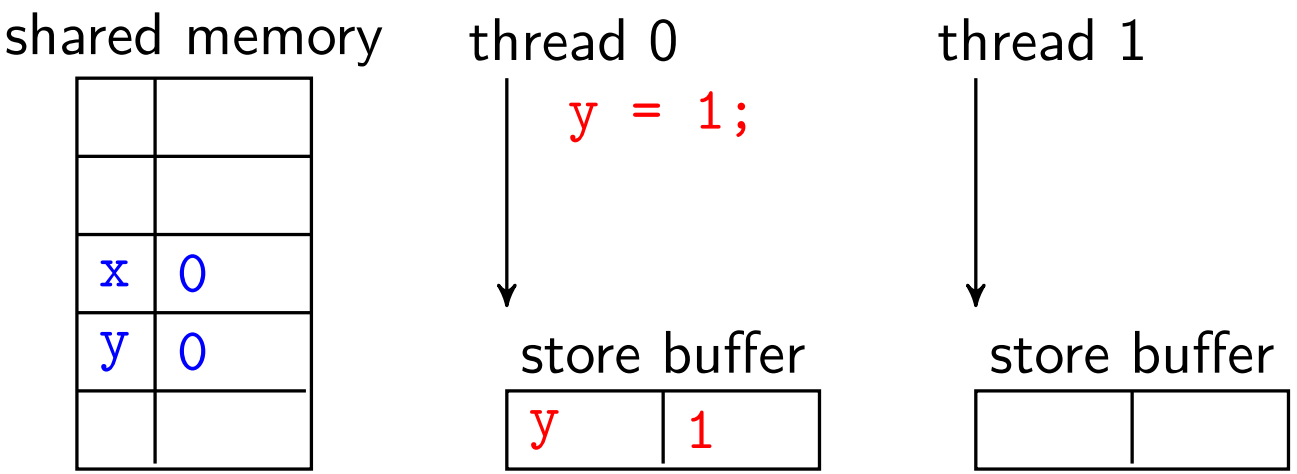

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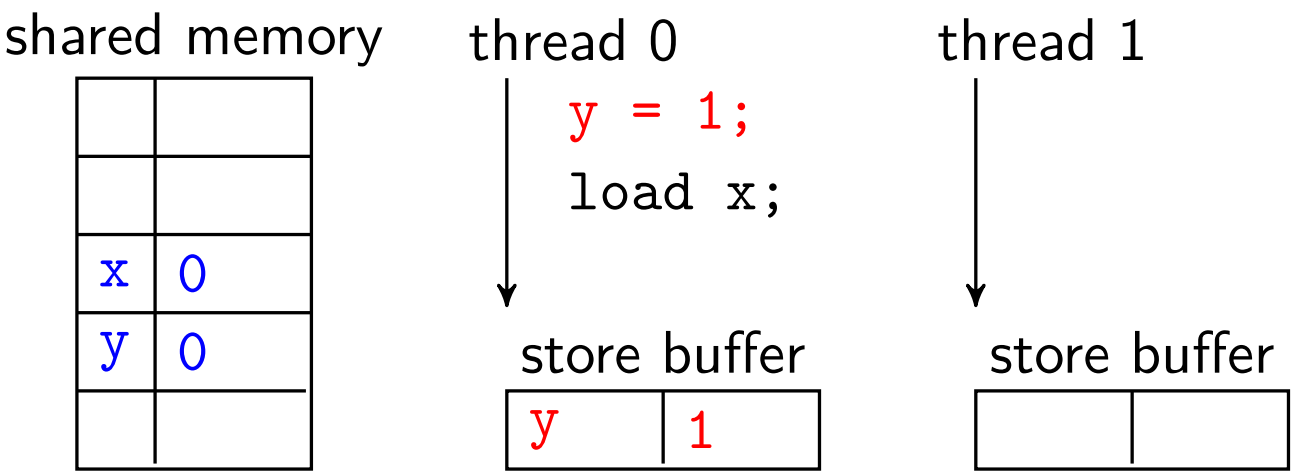

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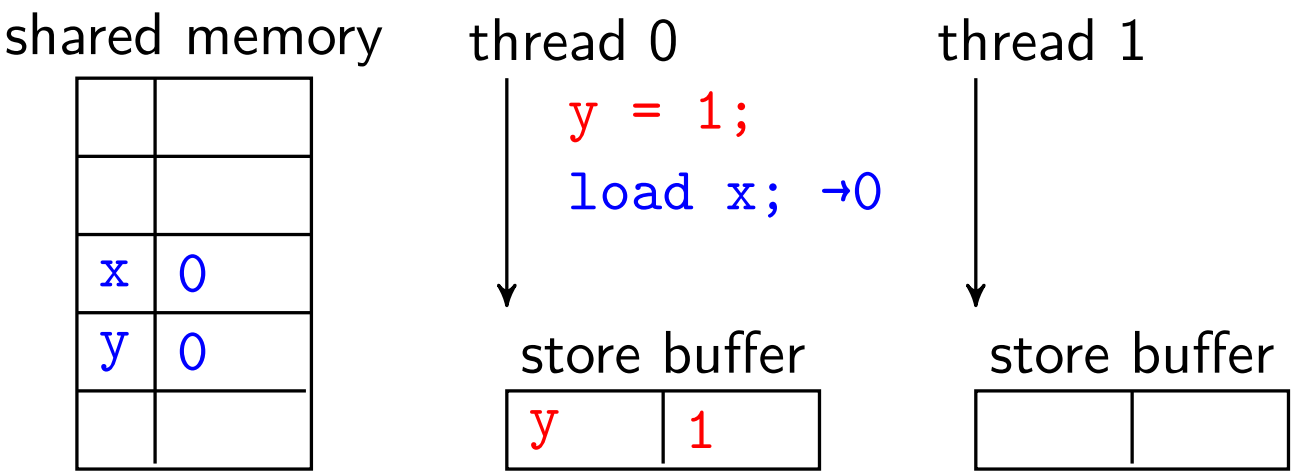

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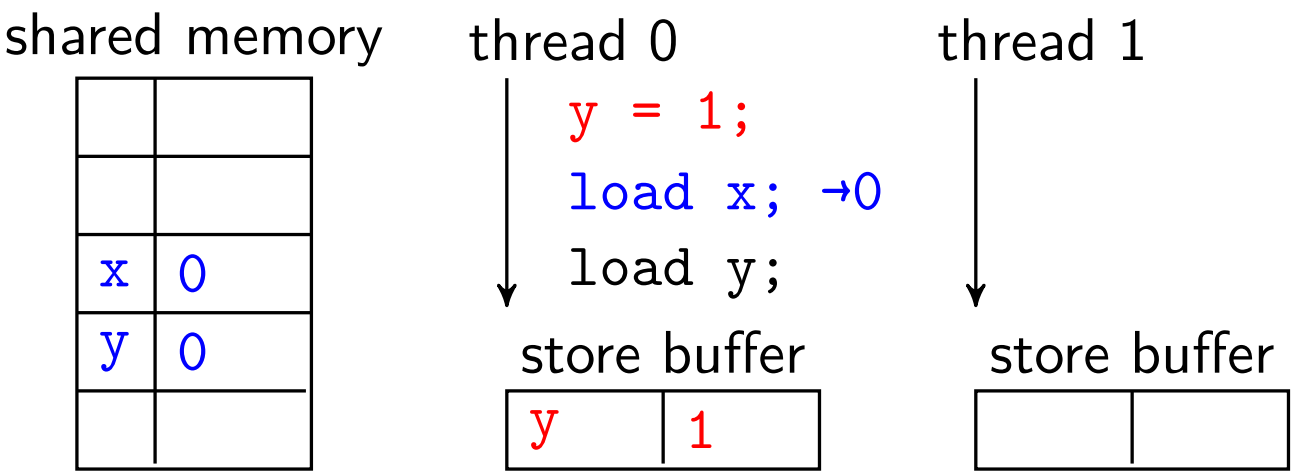

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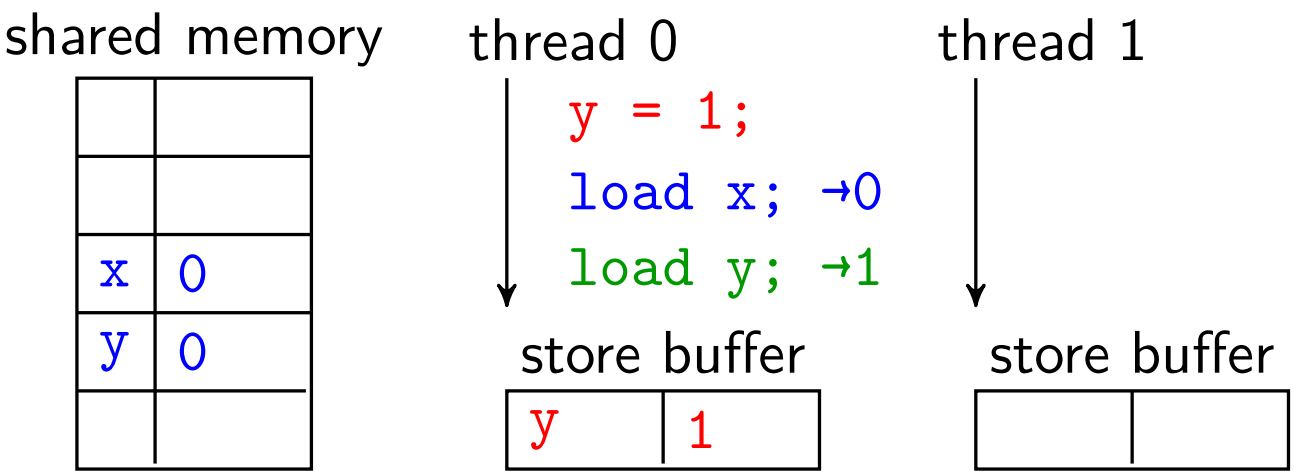

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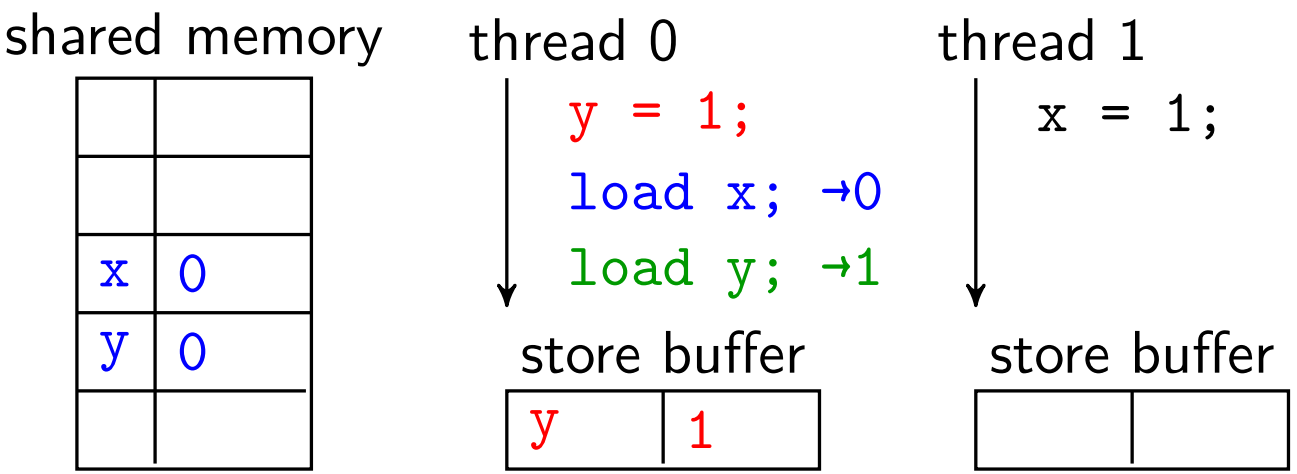

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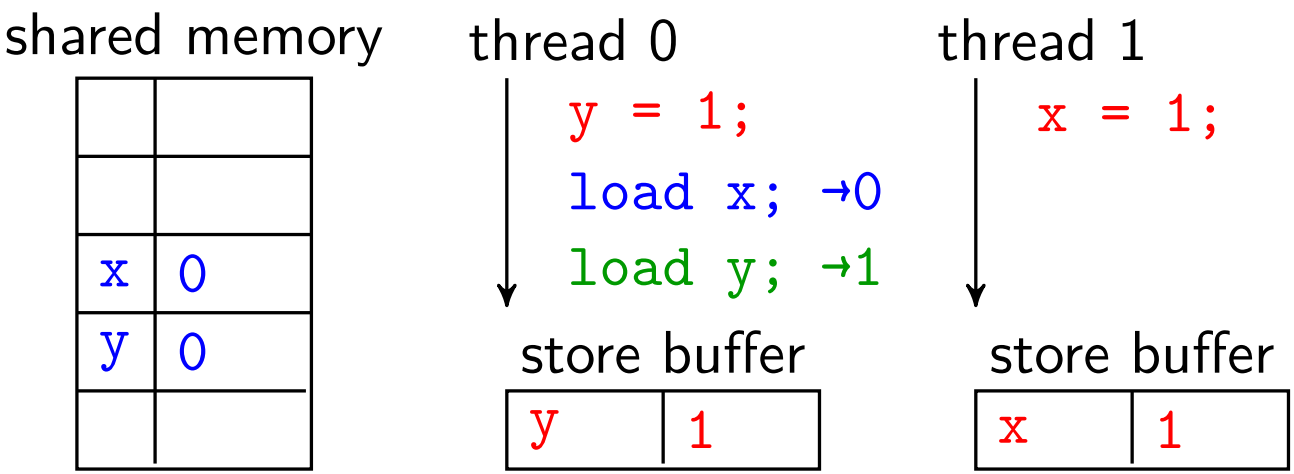

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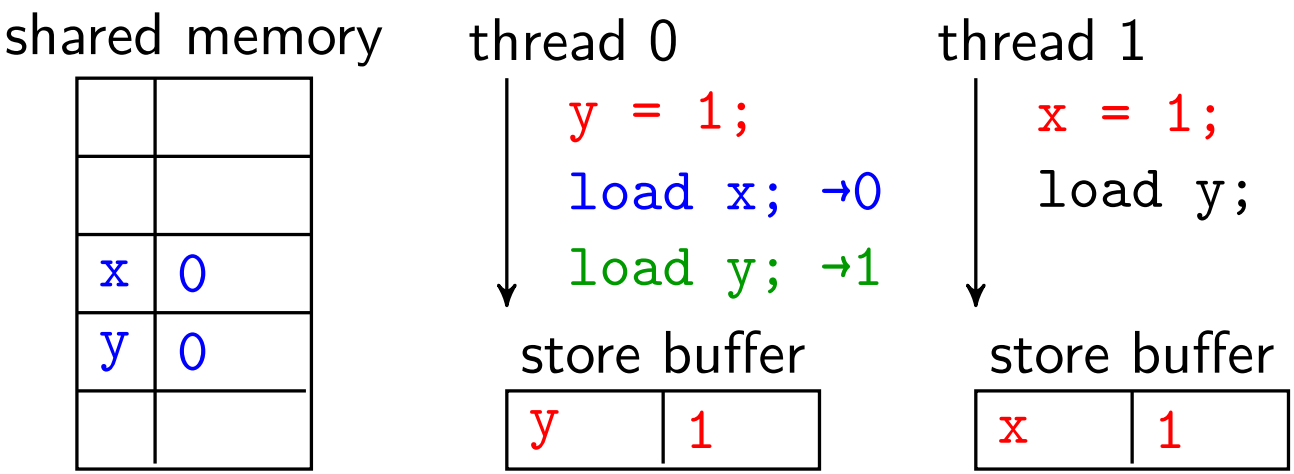

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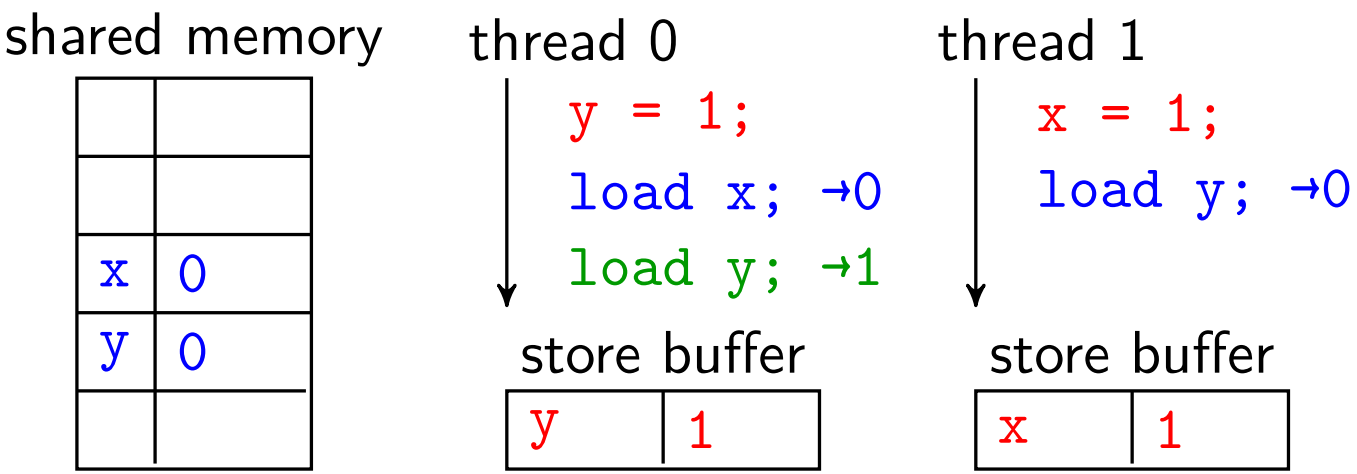

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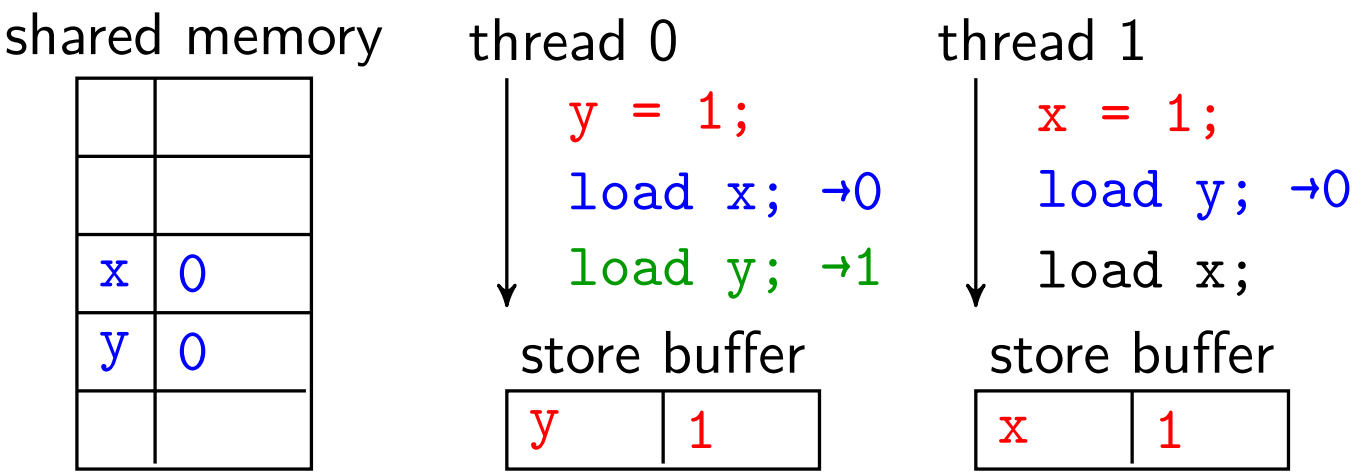

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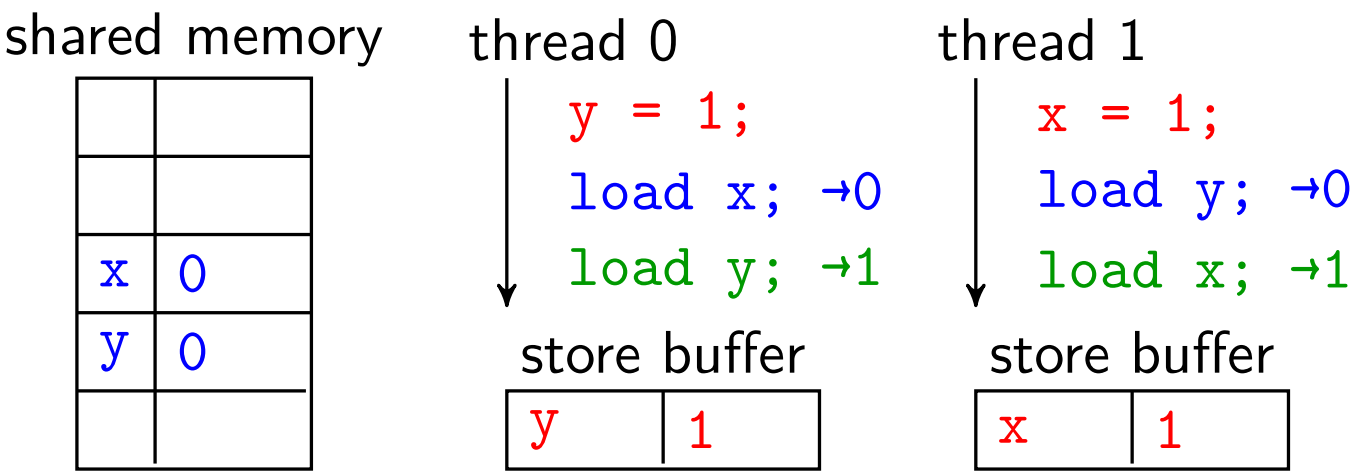

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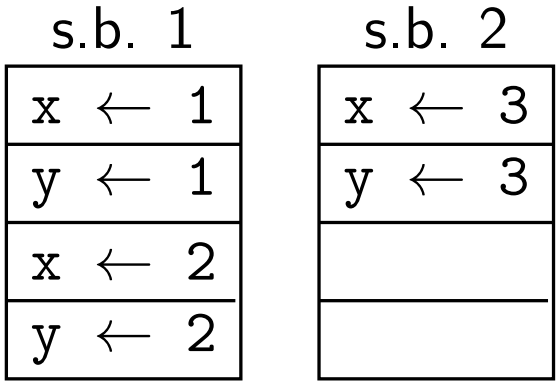
- but only some possibilities are meaningful and observable
- consider flushing the store buffer only if someone reads buffered values
- still, store buffer can be large $\rightarrow$ many ways to flush it
- problem: store buffer keeps order
- solution: *delayed flushing* – some values can behave as flushed, but their order respective to other buffered values can be undetermined

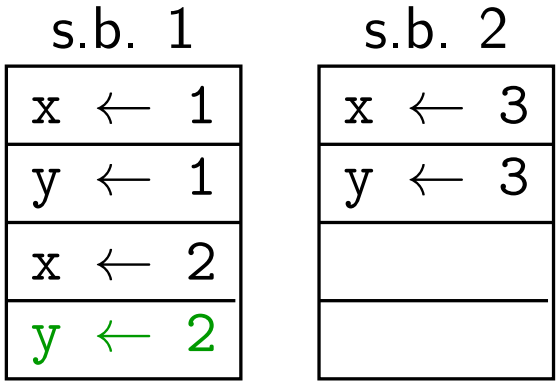
Delayed Flushing




```
void thread0() {
  int a = y;
  int b = x;
}
```

- three threads, thread 0 executing

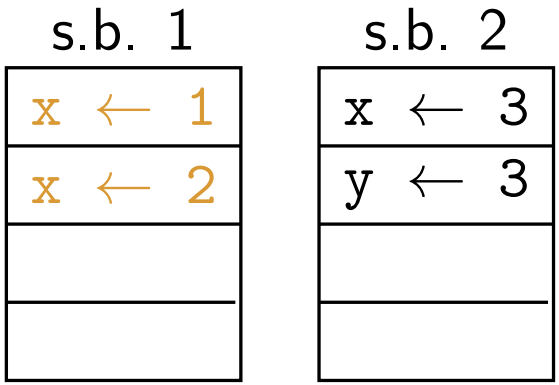
Delayed Flushing




```
void thread0() {
  int a = y; // →2
  int b = x;
}
```

- nondeterministically choose which value to load from the store buffers

Delayed Flushing

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void thread0() {
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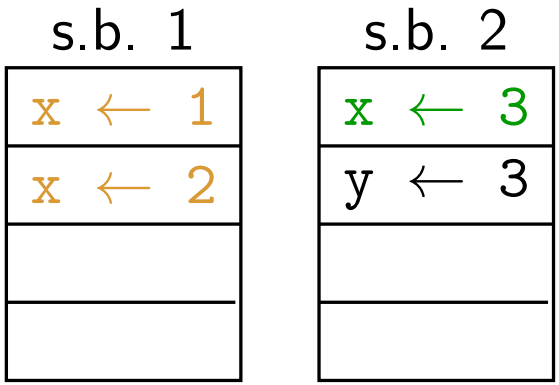
- older values for y in s.b. 1 removed
- other older values in s.b. 1 marked as flushed

Delayed Flushing




```
void thread0() {
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  int b = x; // →3
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- nondeterministically choose to load value from s.b. 2

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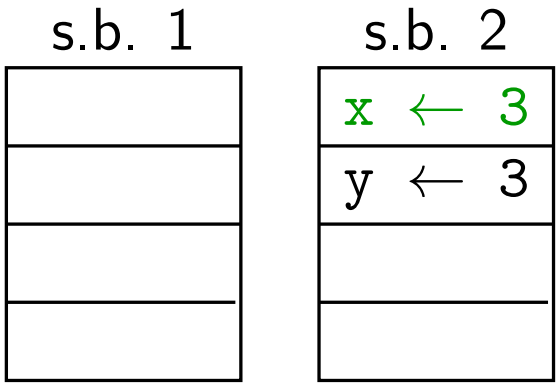


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- flushed values for `x` has to be removed (overwritten)

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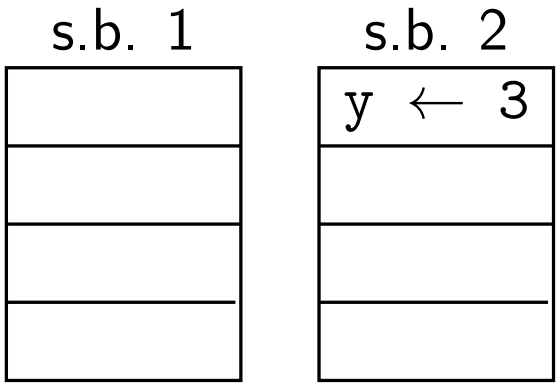


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- `x` is propagated to the memory

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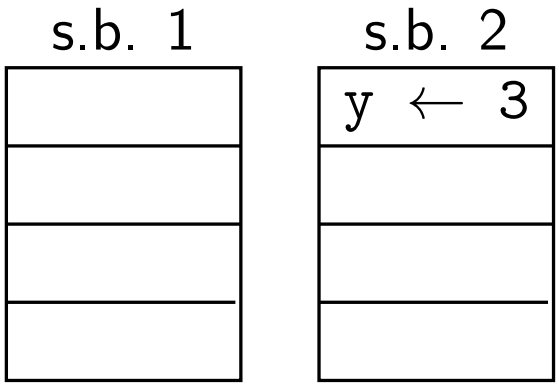


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- $y \leftarrow 3$ stays in buffer unless y is read again

Results

- evaluation on nonsymbolic SV-COMP concurrency benchmarks
- compared with CBMC and Nidhugg

(total = 54)	CBMC	**DIVINE**	Nidhugg
finished	20	23	24
TSO errors	3	10	3
uniqly solved	5	6	8

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