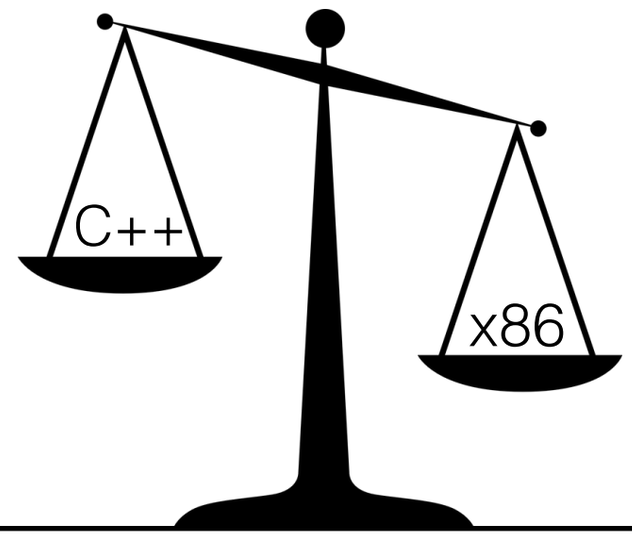

Automatically Comparing Memory Consistency Models

John Wickerson Imperial
Mark Batty U Kent
Tyler Sorensen Imperial
George A. Constantinides Imperial

S-REPLS @ Imperial
Tuesday 27 September 2016

Contents

- Context: memory consistency models (MCMs)
- Where our work fits in
- Key Ideas
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Relaxed-memory behaviours

```
          x = y = 0;
x = 1;    ||  y = 1;
r0 = y;   ||  r1 = x;
```

Relaxed-memory behaviours

```
          x = y = 0;
x = 1;    ||
r0 = y;   ||
          ||  y = 1;
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```

r0 = 0, r1 = 1

Relaxed-memory behaviours

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                x = y = 0;
x = 1;      ||
            ||  y = 1;
r0 = y;     ||
            ||  r1 = x;
```

r0 = 0, r1 = 1

r0 = 1, r1 = 1

Relaxed-memory behaviours

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x = y = 0;
                ||  y = 1;
                ||  r1 = x;
x = 1;          ||
r0 = y;         ||
```

r0 = 0, r1 = 1

r0 = 1, r1 = 1

r0 = 1, r1 = 0

Relaxed-memory behaviours

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        x = y = 0;
x = 1;     ||  y = 1;
r0 = y;    ||  r1 = x;
```

```
r0 = 0, r1 = 0
r0 = 0, r1 = 1
r0 = 1, r1 = 1
r0 = 1, r1 = 0
```

Much confusion!

Subtleties related to relaxed memory have led to bugs in...

- **programming language specifications** [Batty+ POPL'11, Batty+ ESOP'13],
- **deployed processors** [Alglave+ CAV'10];
- **compilers** [Morisset+ PLDI'13, Sevcik+ ECOOP'08], and
- **vendor-endorsed programming guides** [Alglave+ ASPLOS'15].

Axiomatic models

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r0 = y;  ||  r1 = x;
```
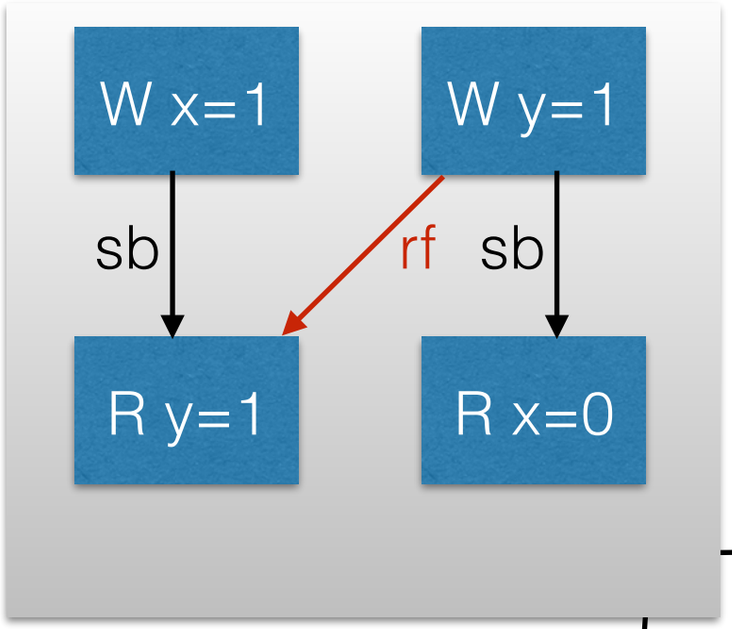

Axiomatic models

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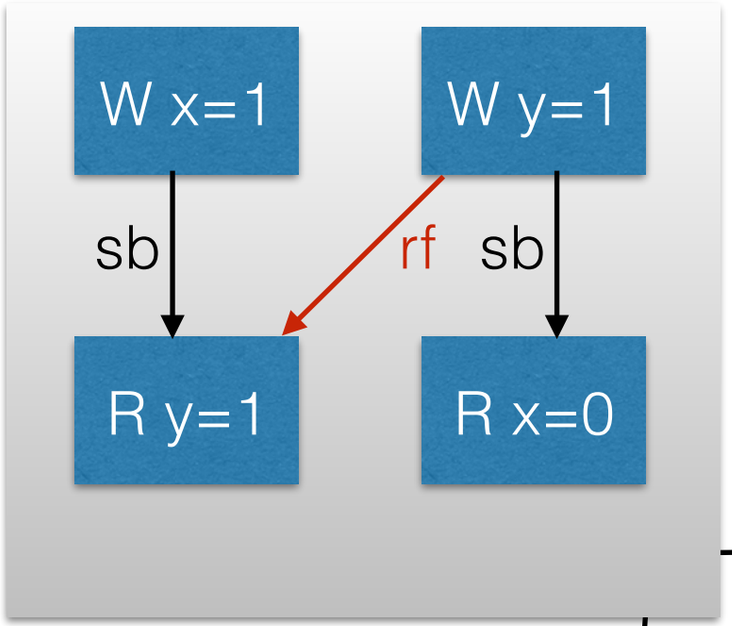

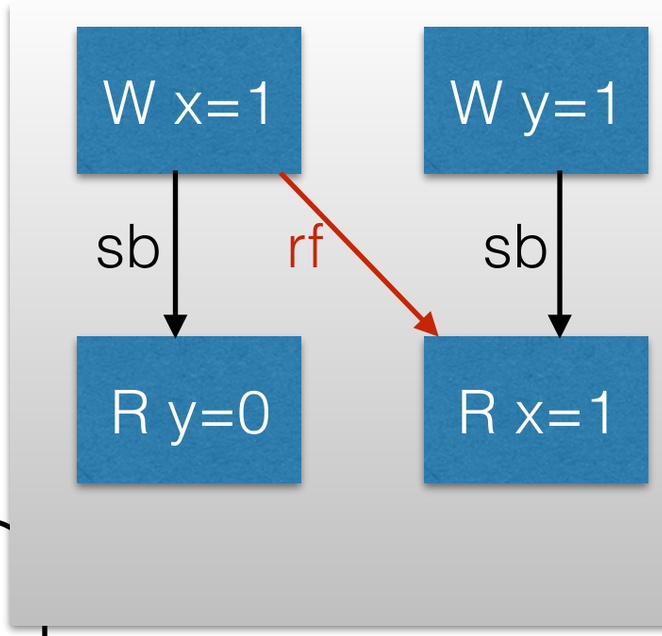


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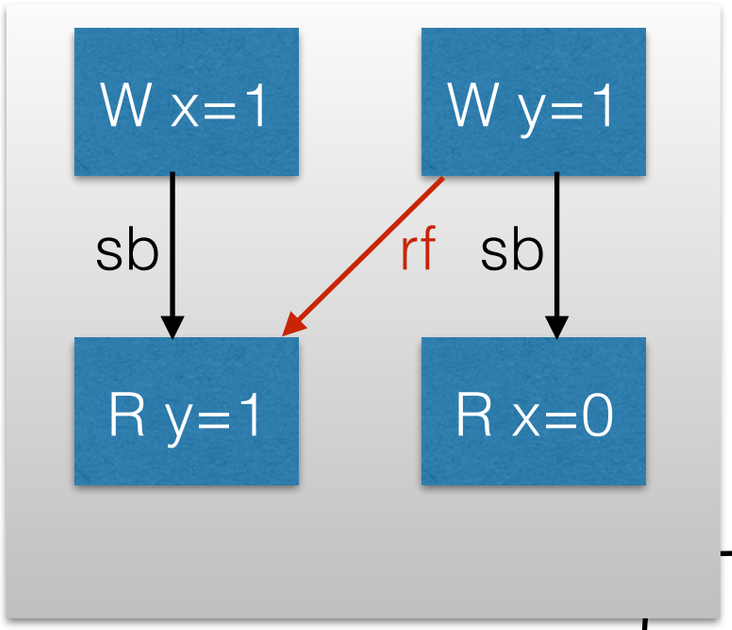

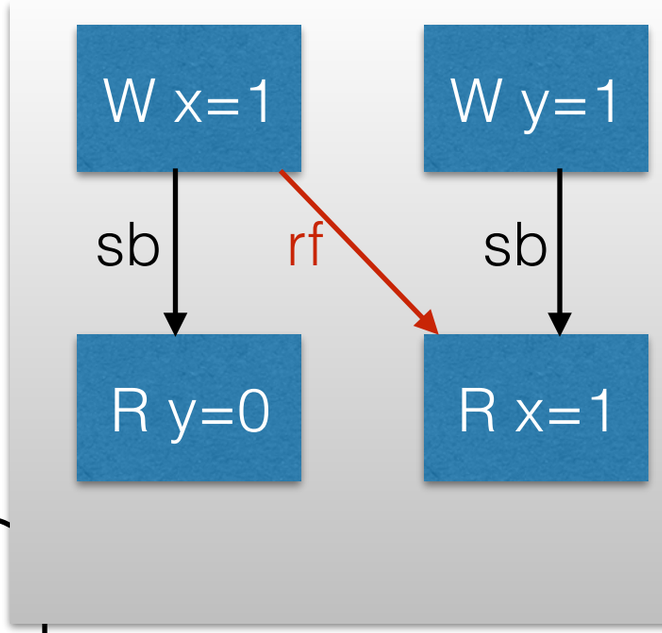


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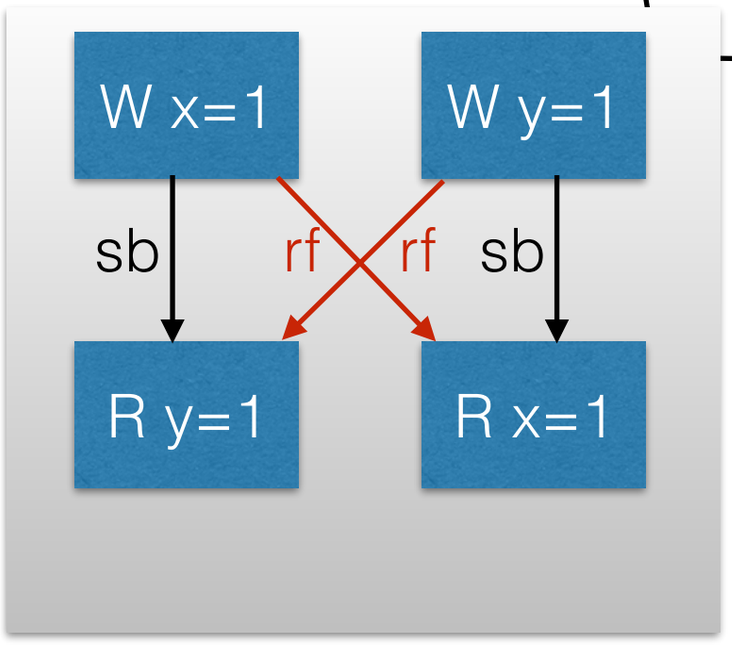

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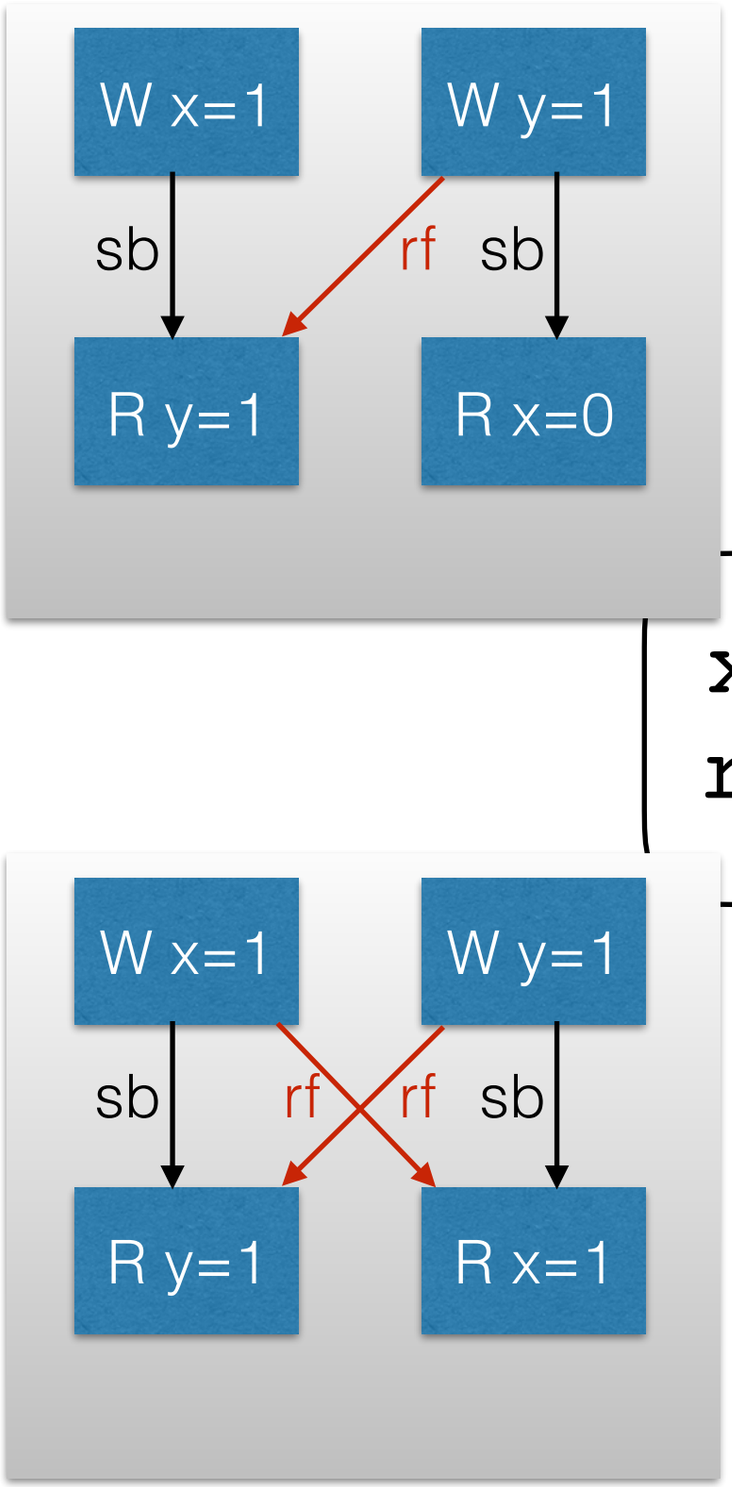

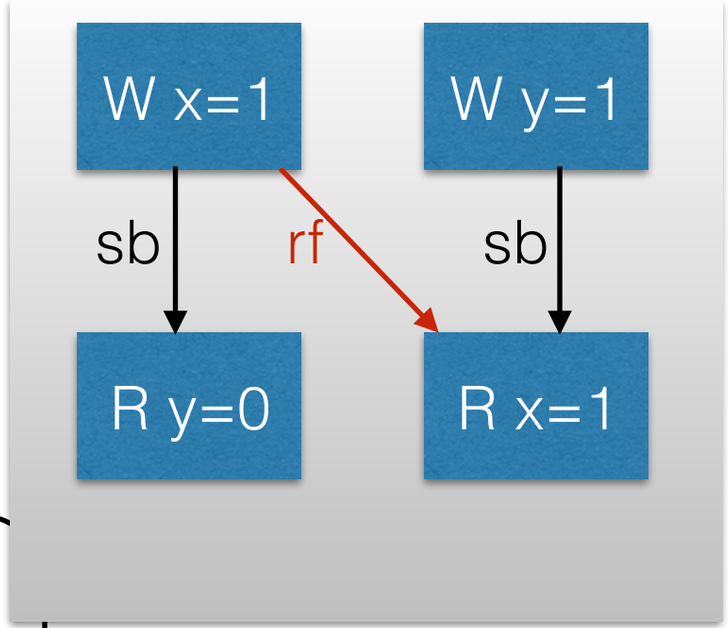


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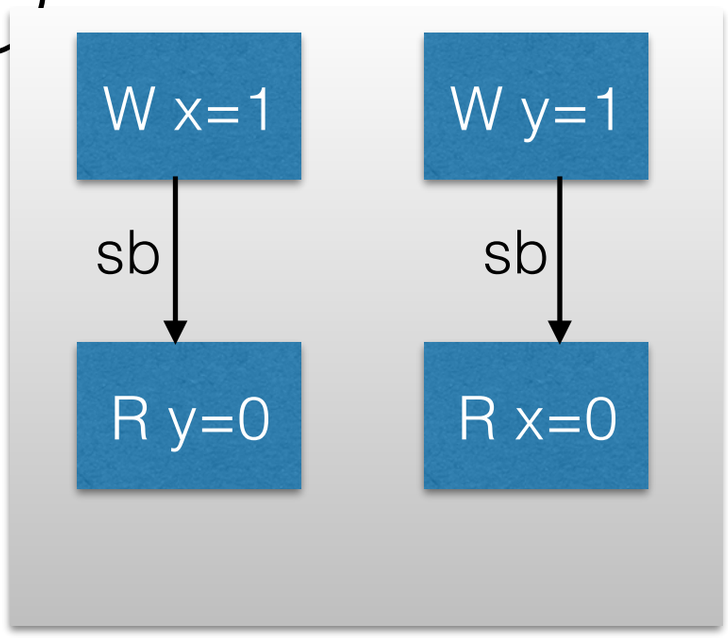

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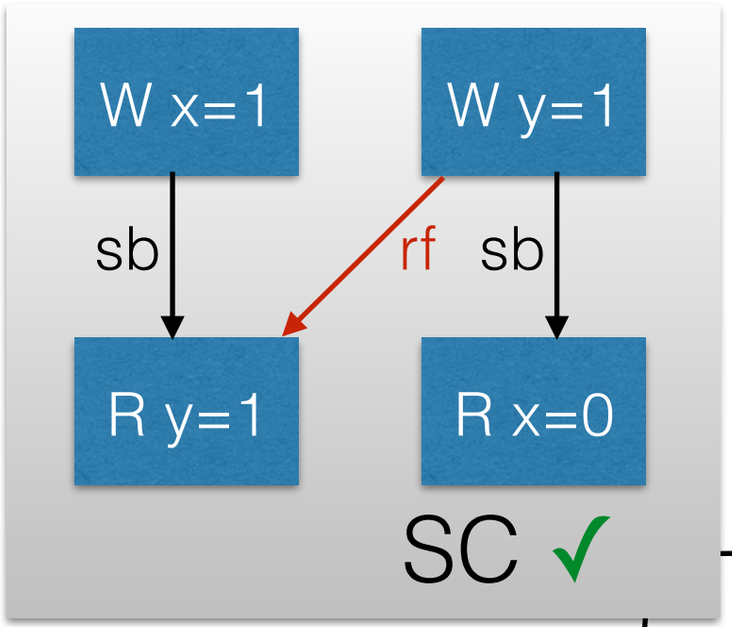

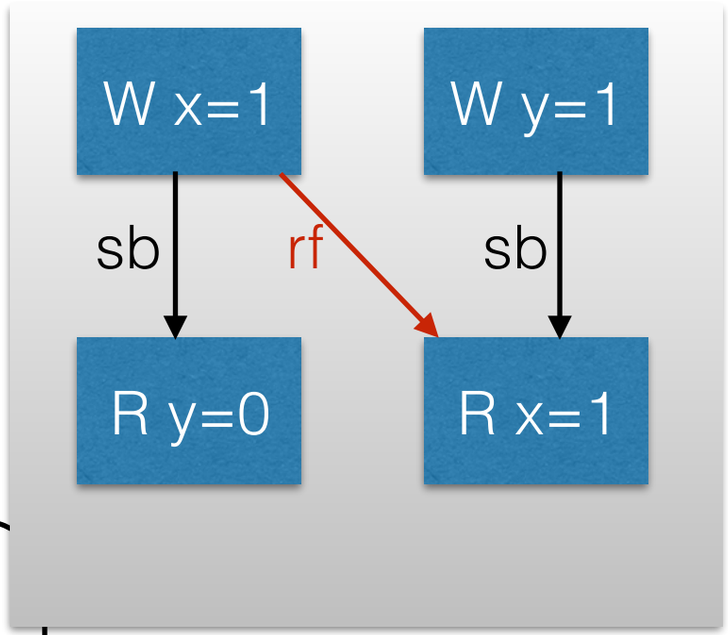


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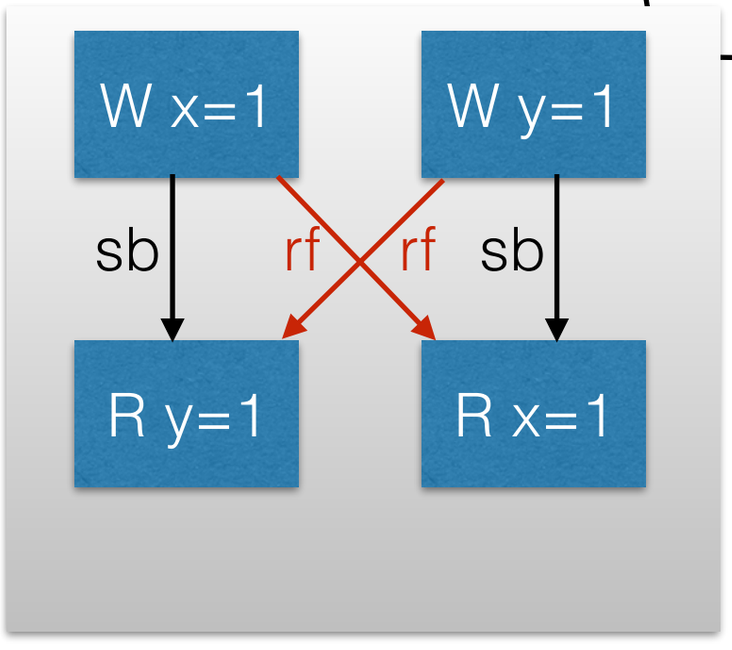

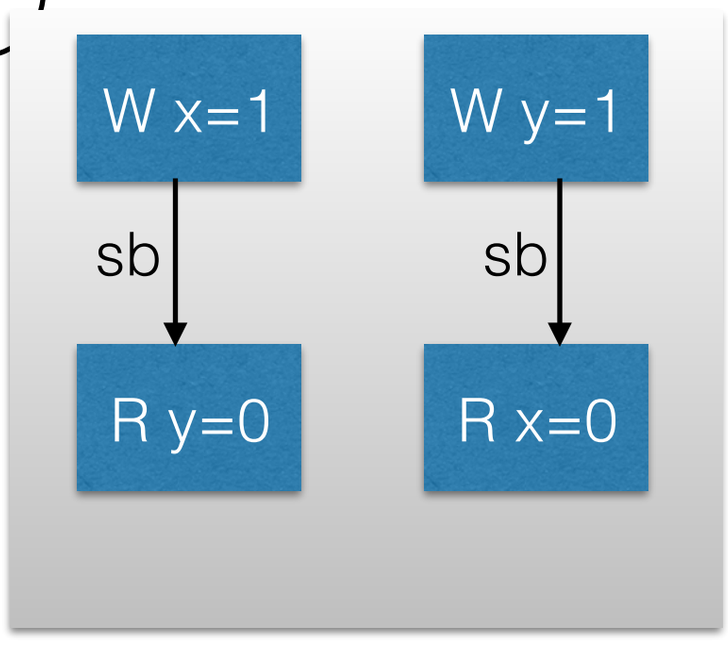

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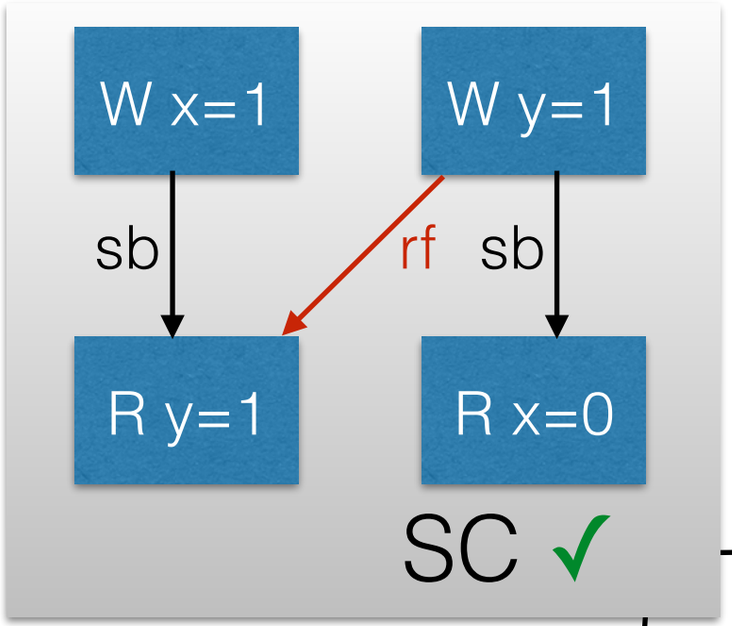

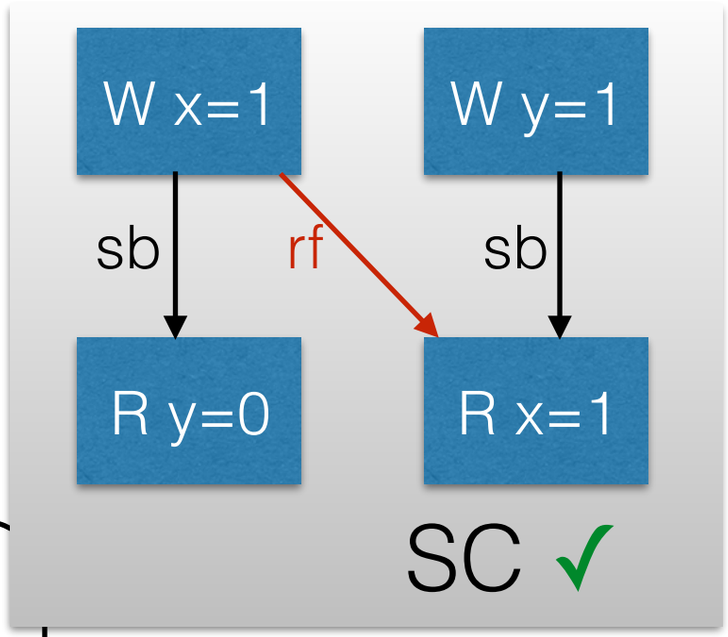


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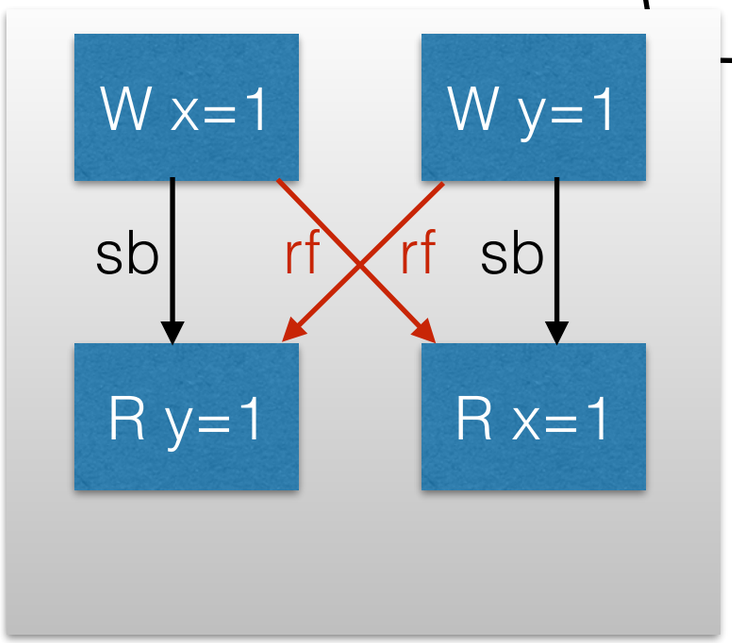

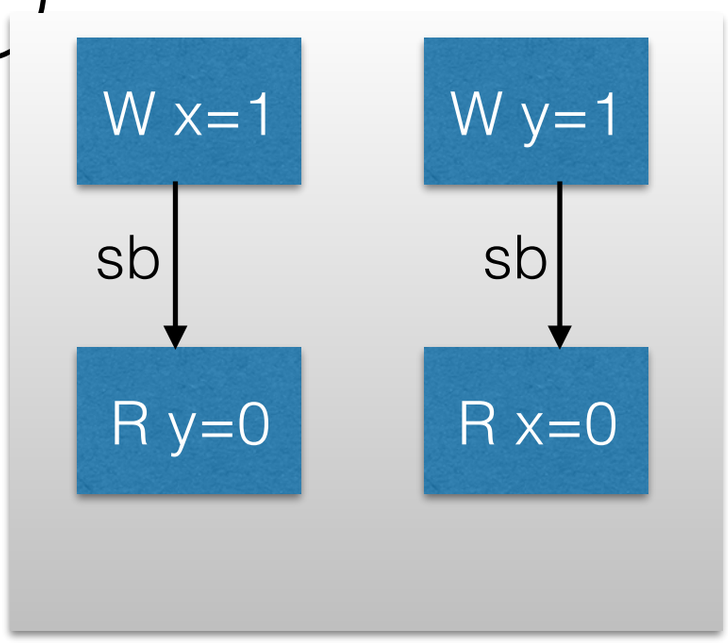

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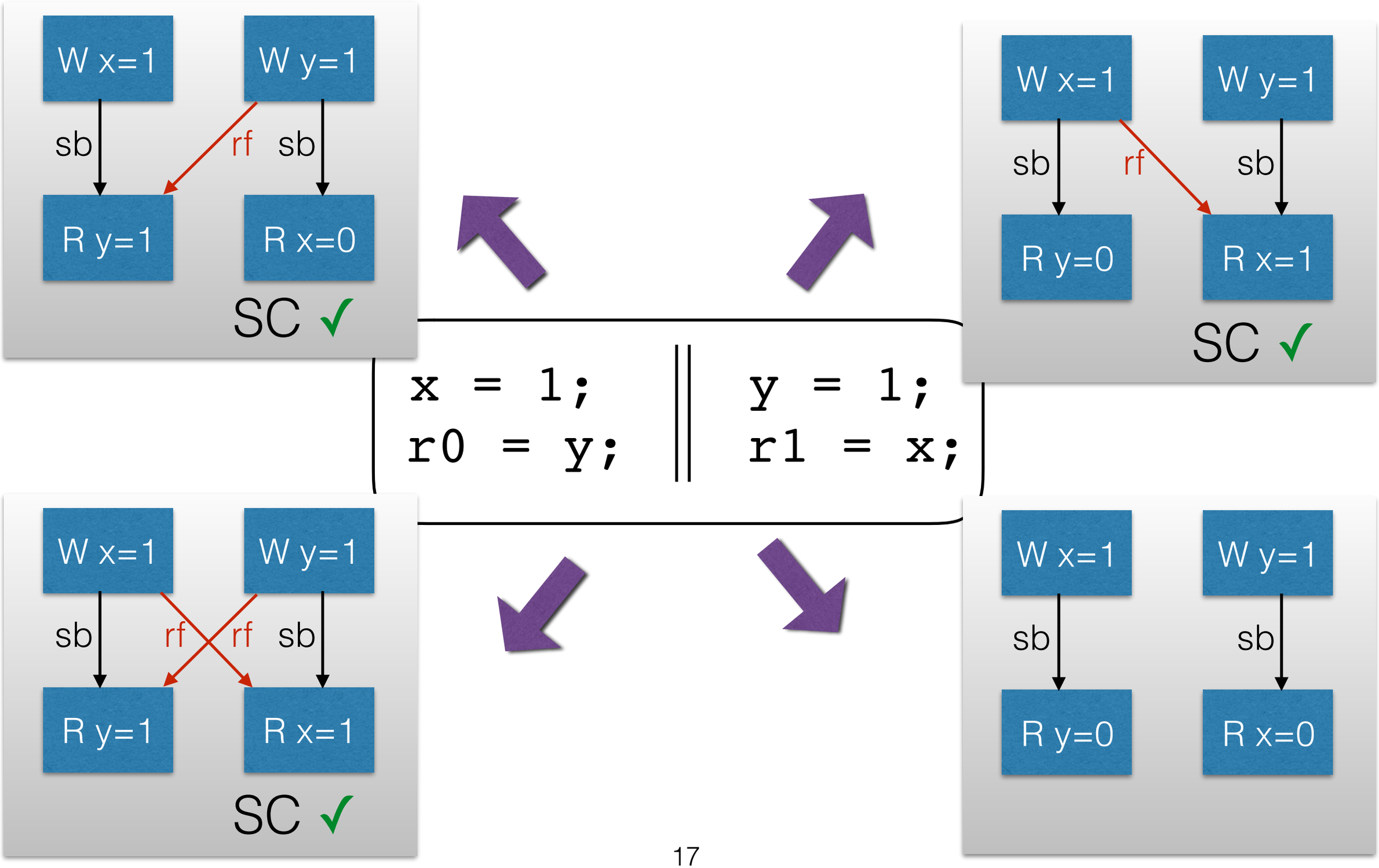

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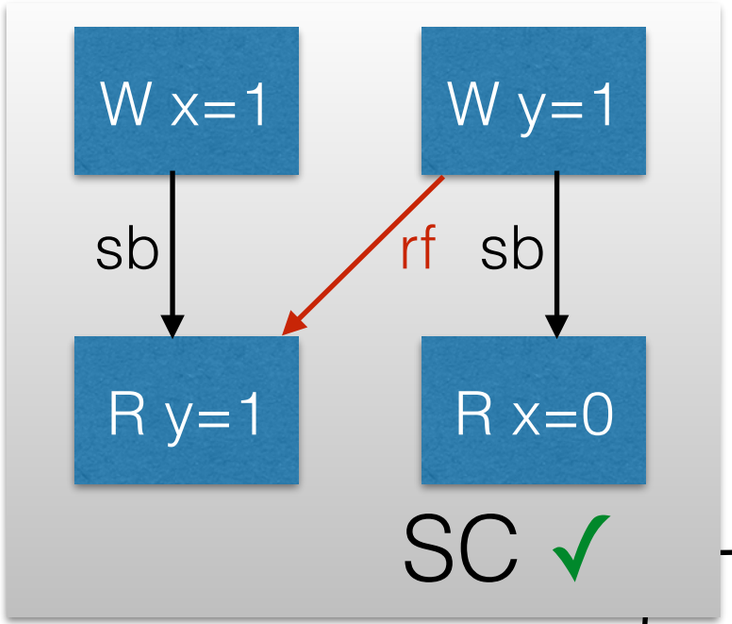

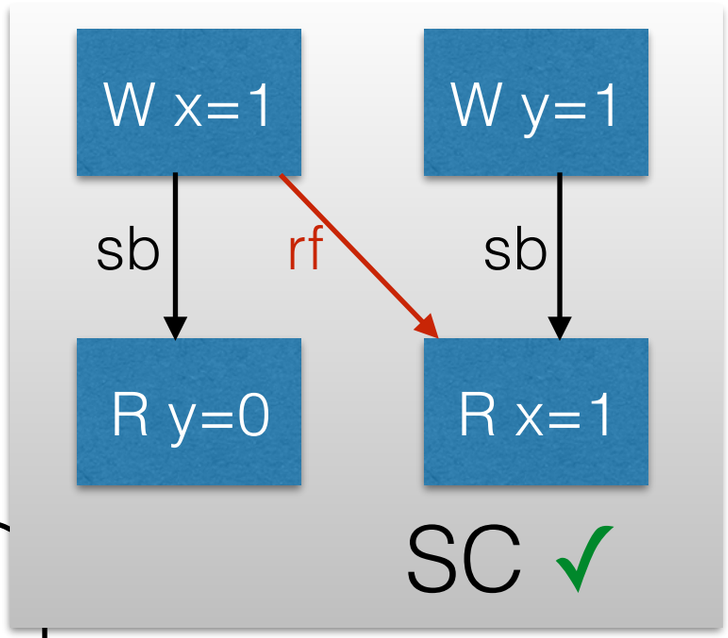


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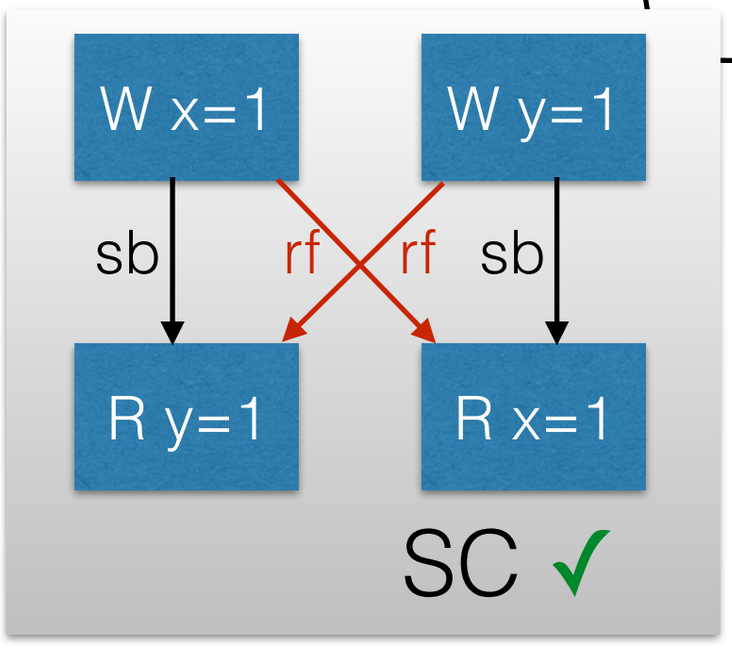

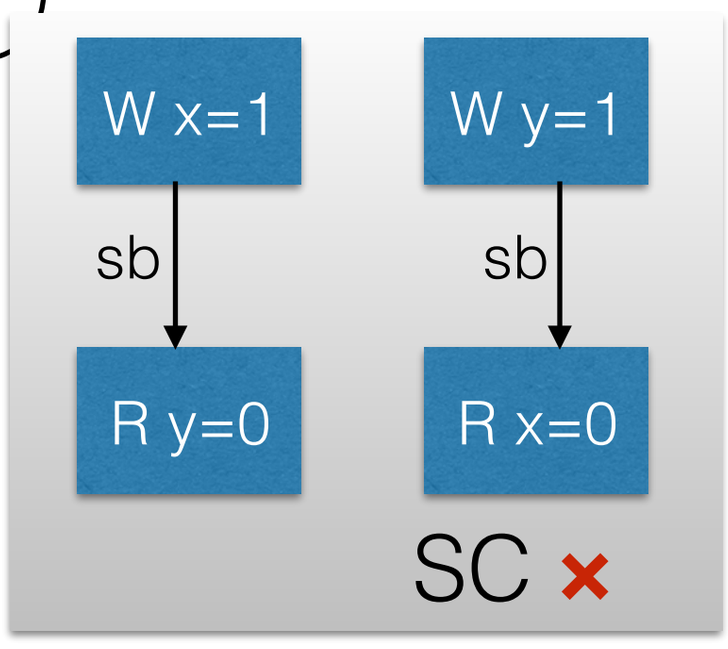

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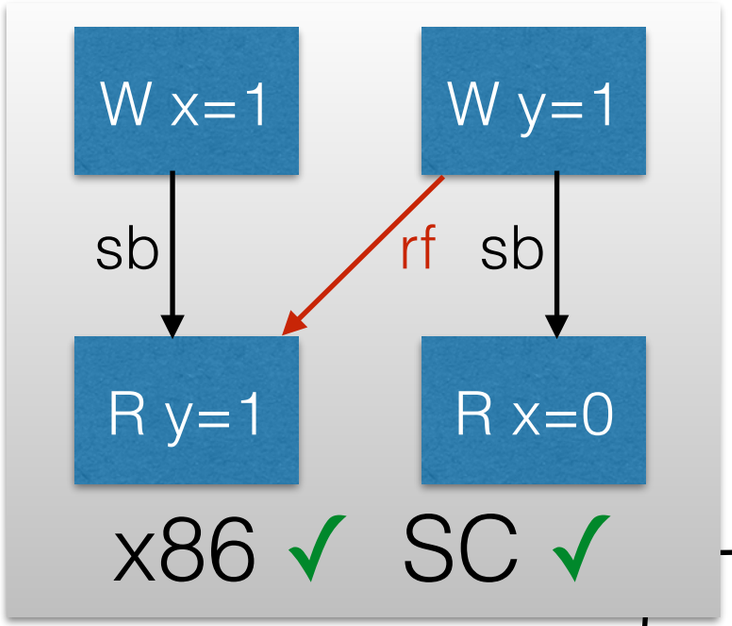

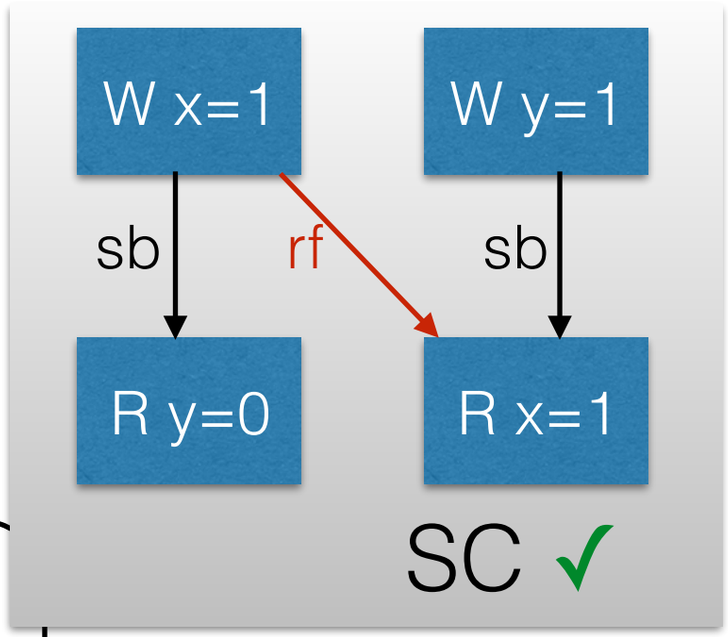


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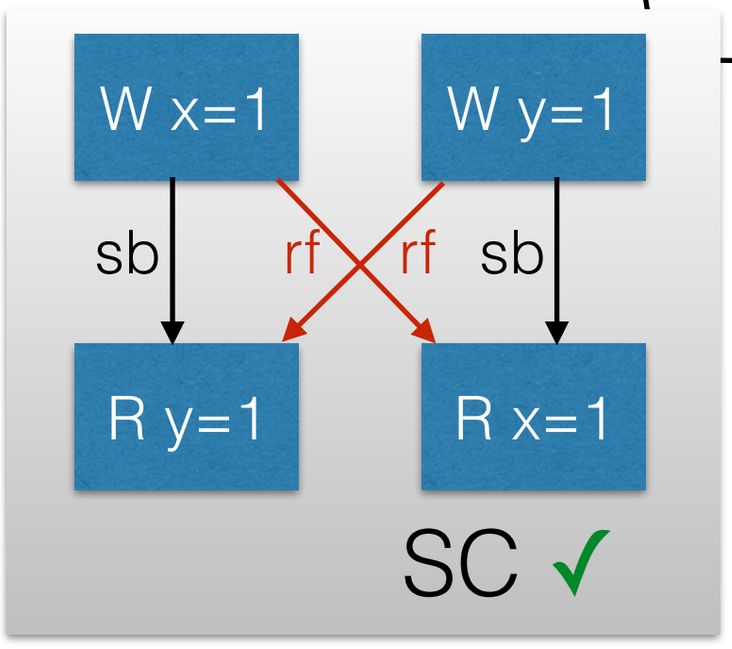

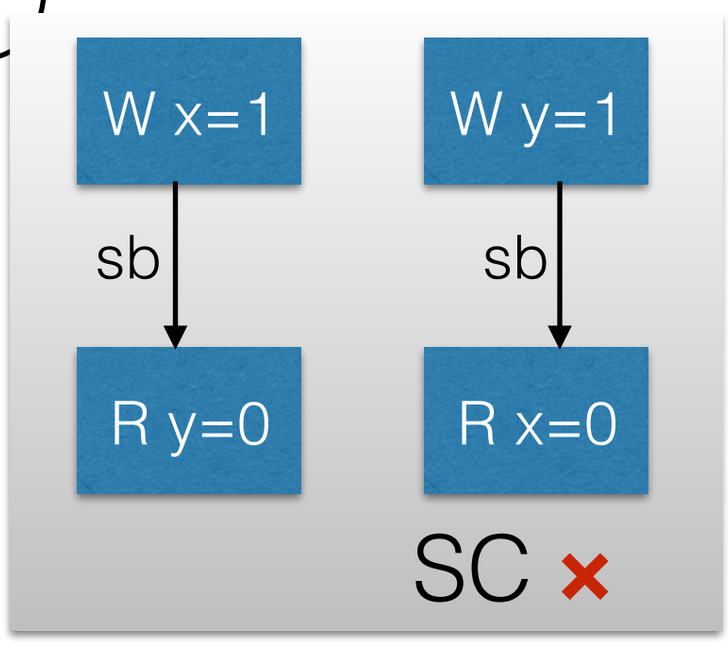

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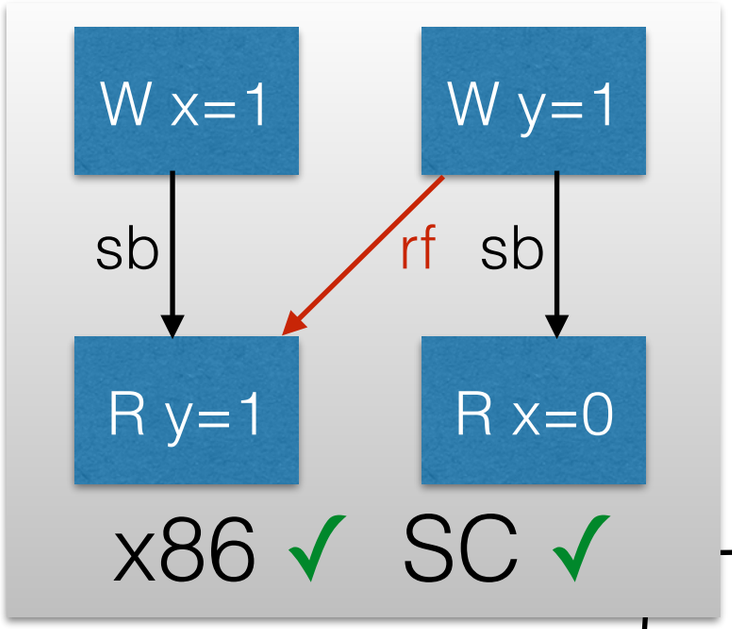

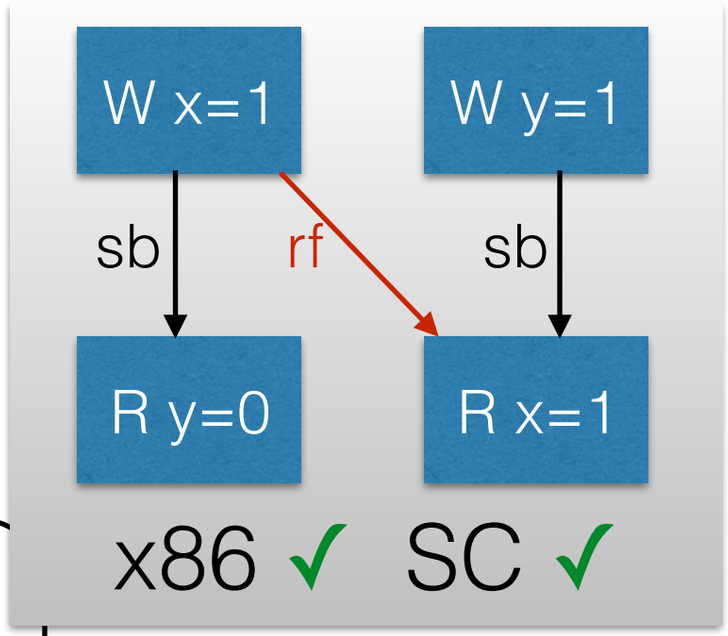


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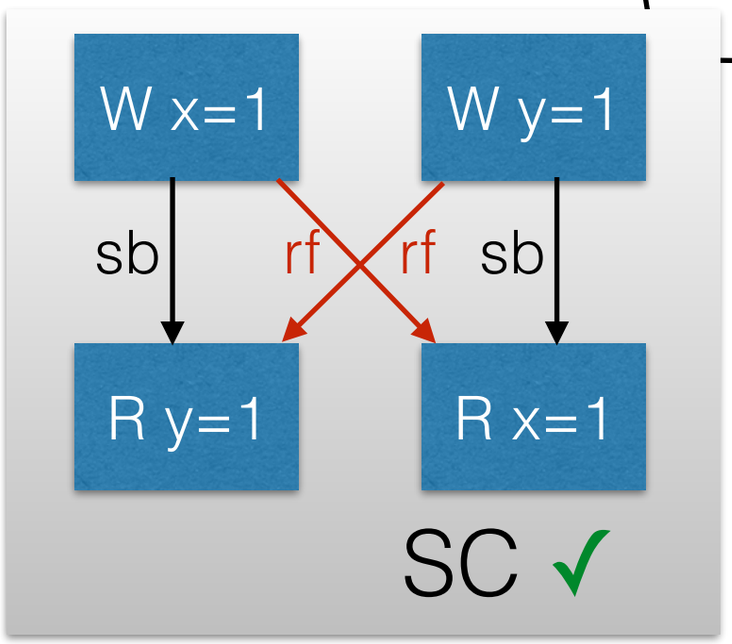

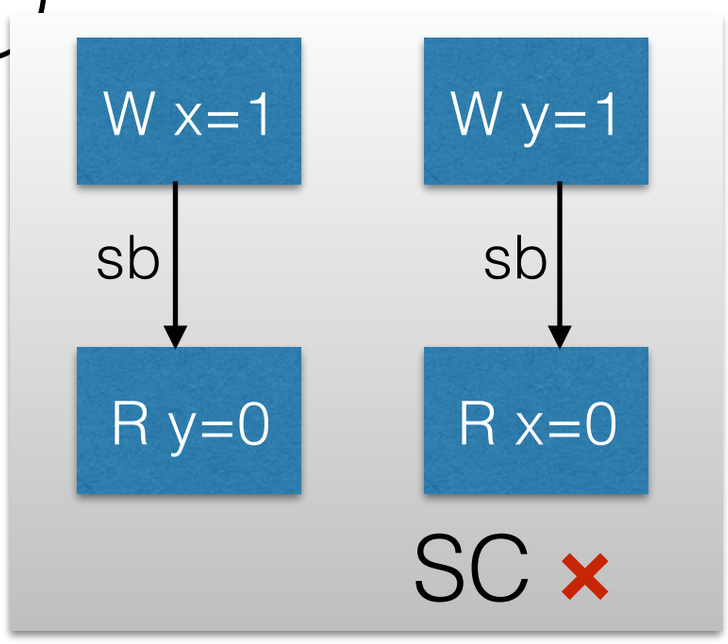

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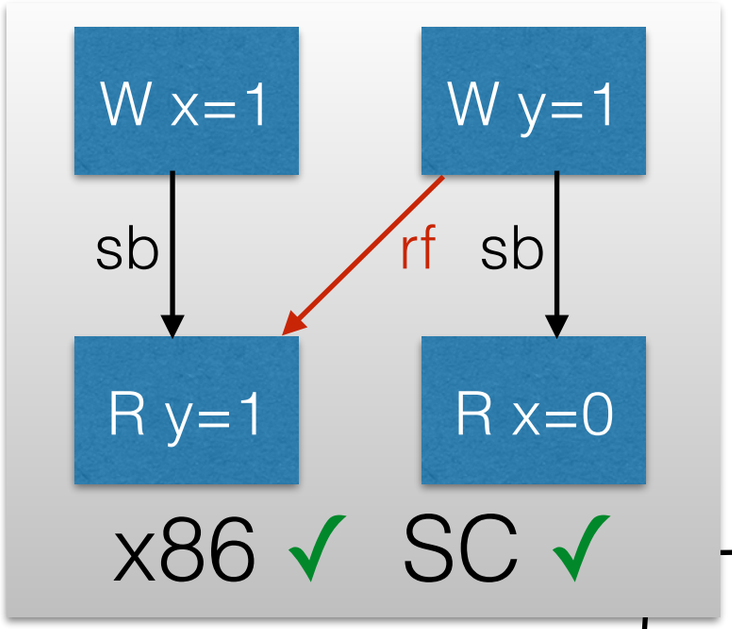

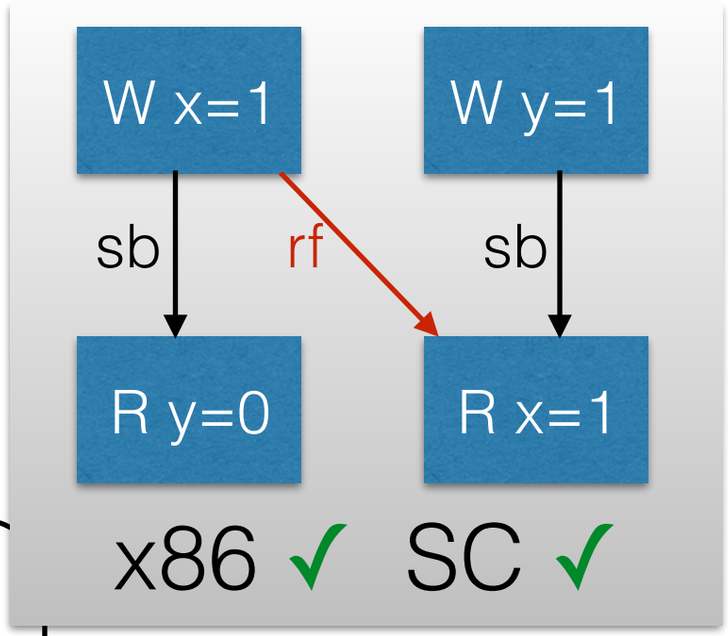


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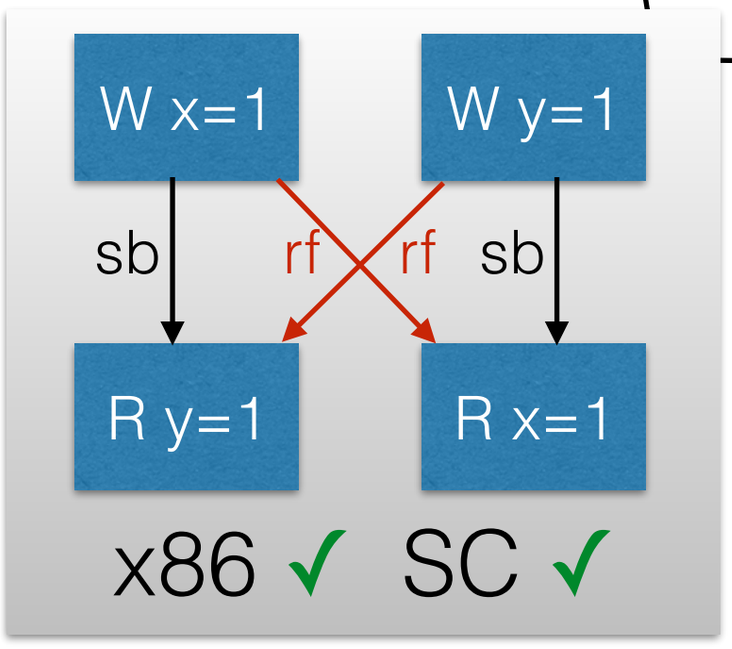

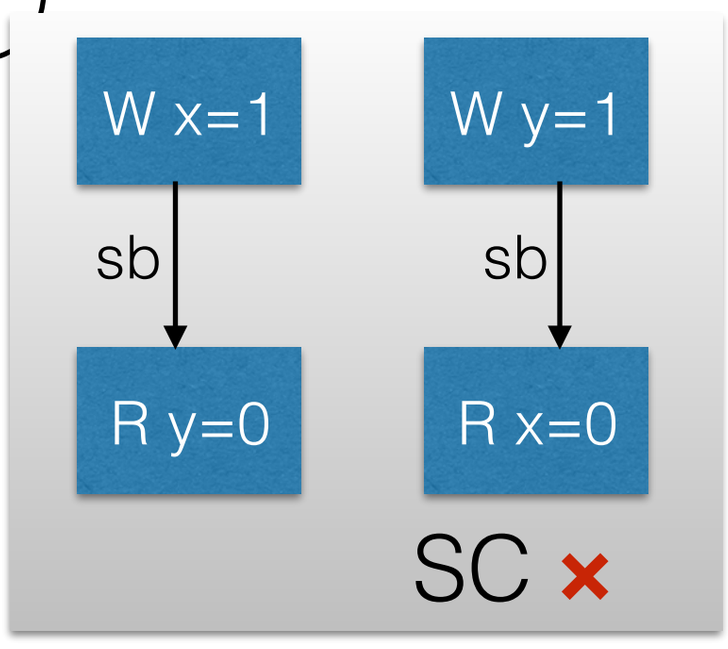

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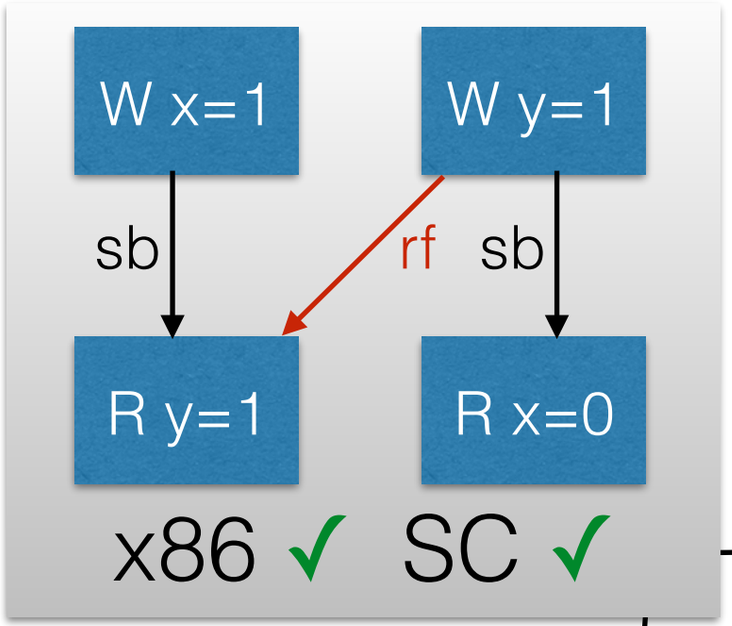

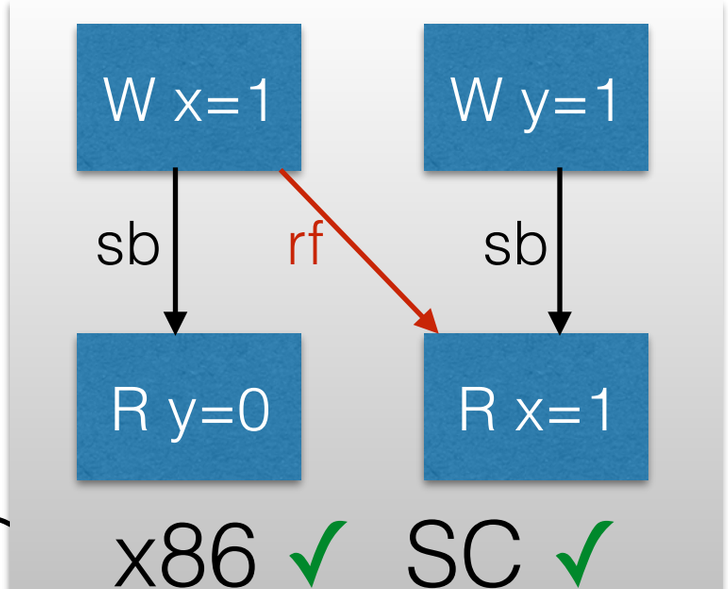


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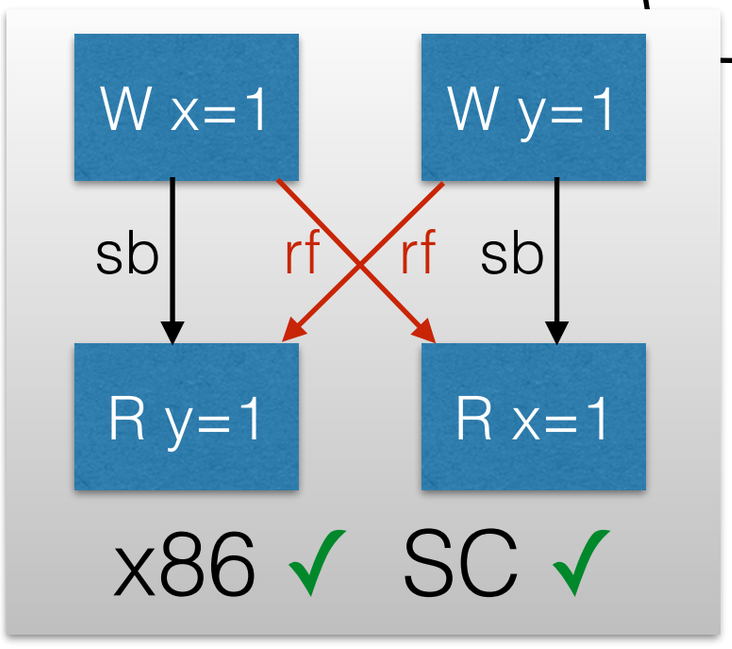

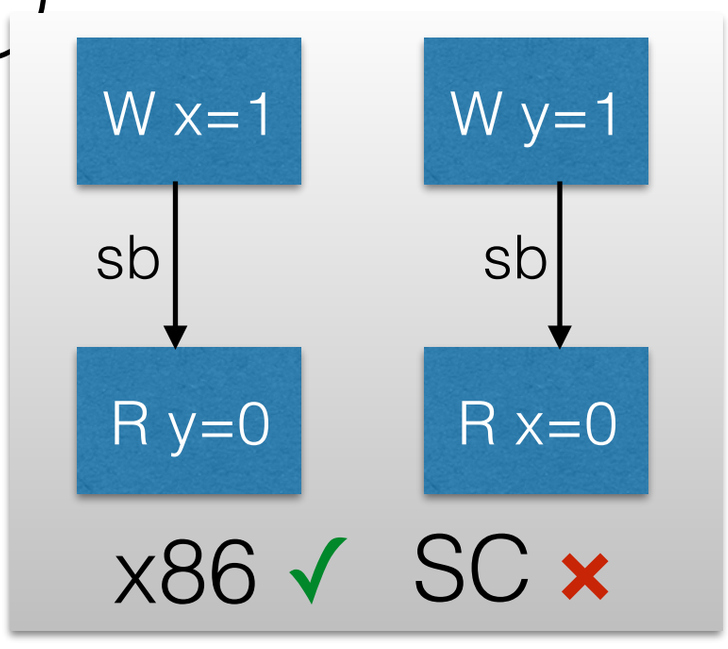

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Does my MCM allow a given compiler mapping?	manual c'examples [Wickerson+ OOPSLA'15]; manual proof [Batty+ POPL'11, Batty+ POPL'12];

Our contributions

Question	Existing work
Can a given litmus test pass under a given MCM?	CppMem, Herd, MemSAT, Nemos, ...
Which litmus tests can be run to check whether a machine conforms to a given MCM?	semi-automatic generation with DIY [Alglave+ CAV'10]; **automatic generation**
Is one MCM more permissive than another?	manual proof; manual examples [Batty+ POPL'16]; semi-automatic checking with DIY+Herd; **automatic checking**
Does my MCM allow a given compiler optimisation?	manual c'examples [Vafeiaidis+ POPL'15]; manual proof [Sevcik PLDI'11]; **automatic checking**
Does my MCM allow a given compiler mapping?	manual c'examples [Wickerson+ OOPSLA'15]; manual proof [Batty+ POPL'11, Batty+ POPL'12]; **automatic checking**

Contents

- Context: memory consistency models (MCMs)
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Key Idea 1

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  Find (P,σ) where $\sigma \notin obs_{\mathbf{M}}(P)$ and $\sigma \in obs_{\mathbf{0}}(P)$.

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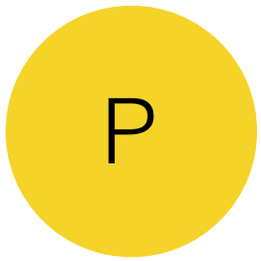

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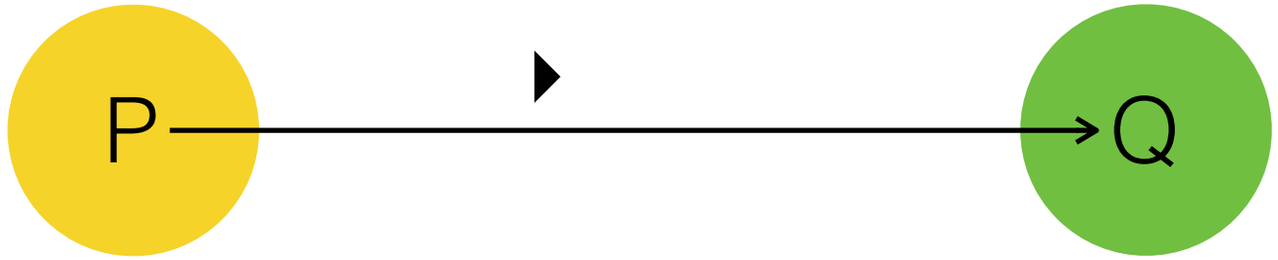

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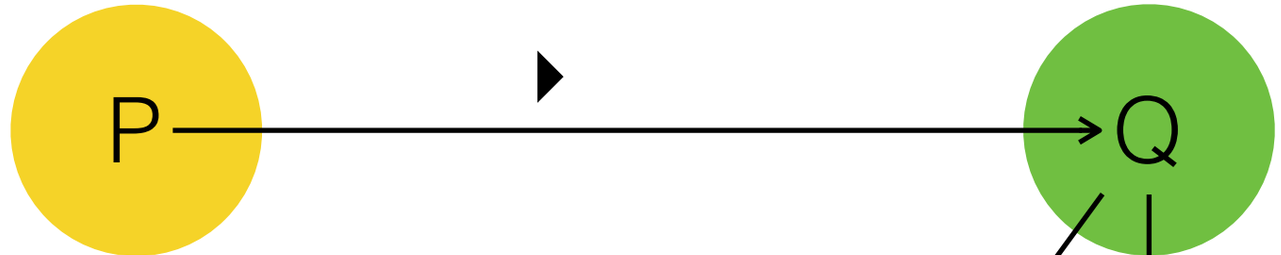

some (consistent) execution must reach σ

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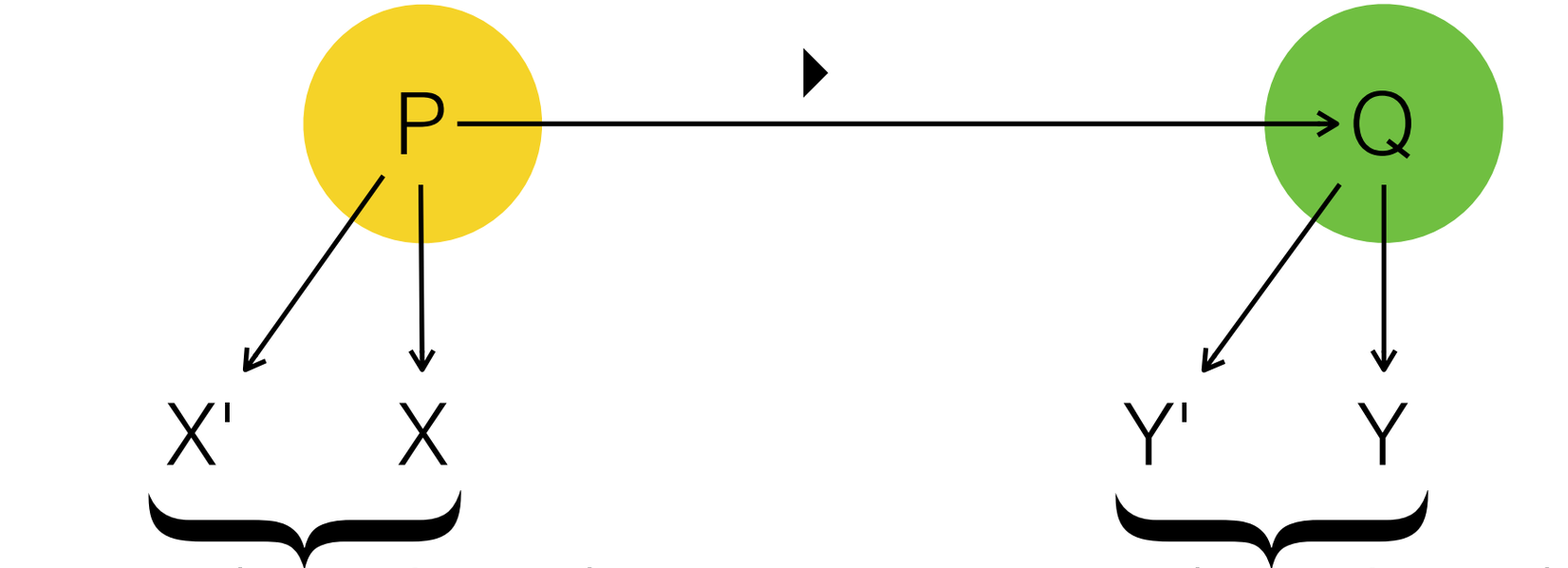

every (consistent) execution must not reach σ

some (consistent) execution must reach σ

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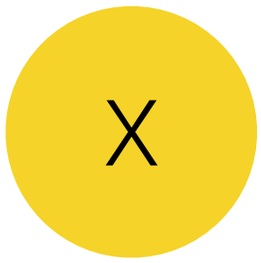

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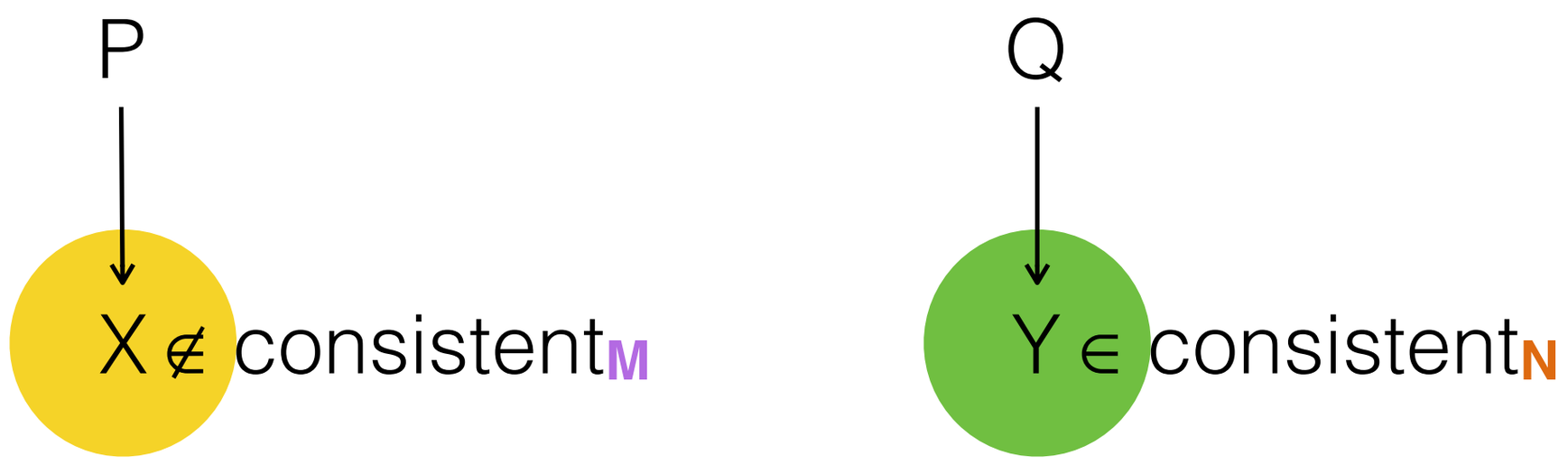

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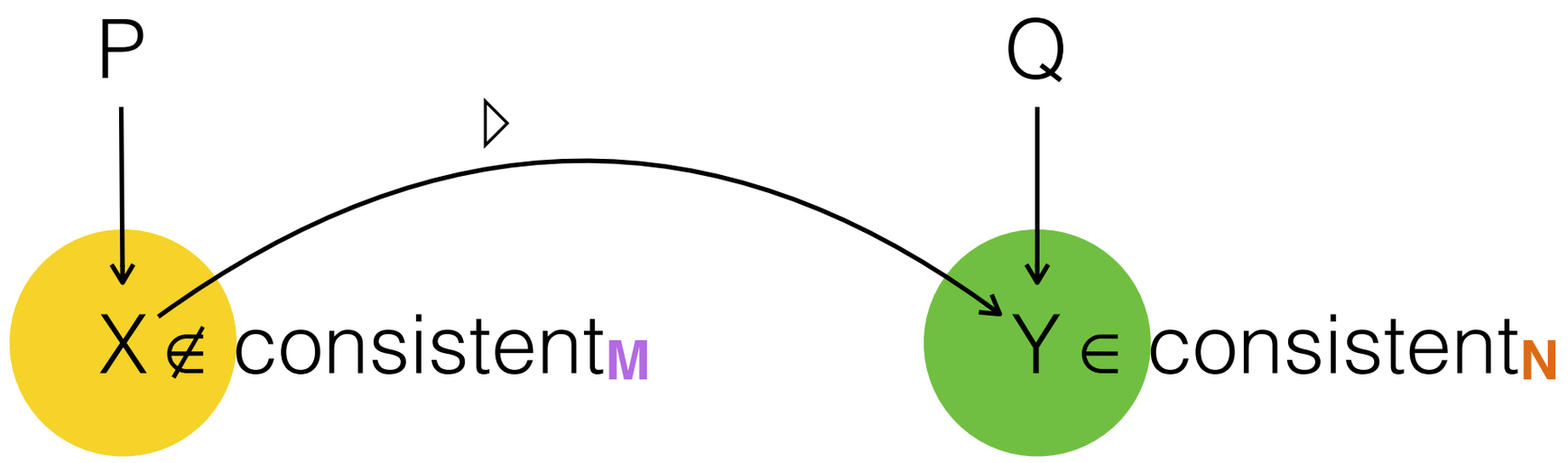

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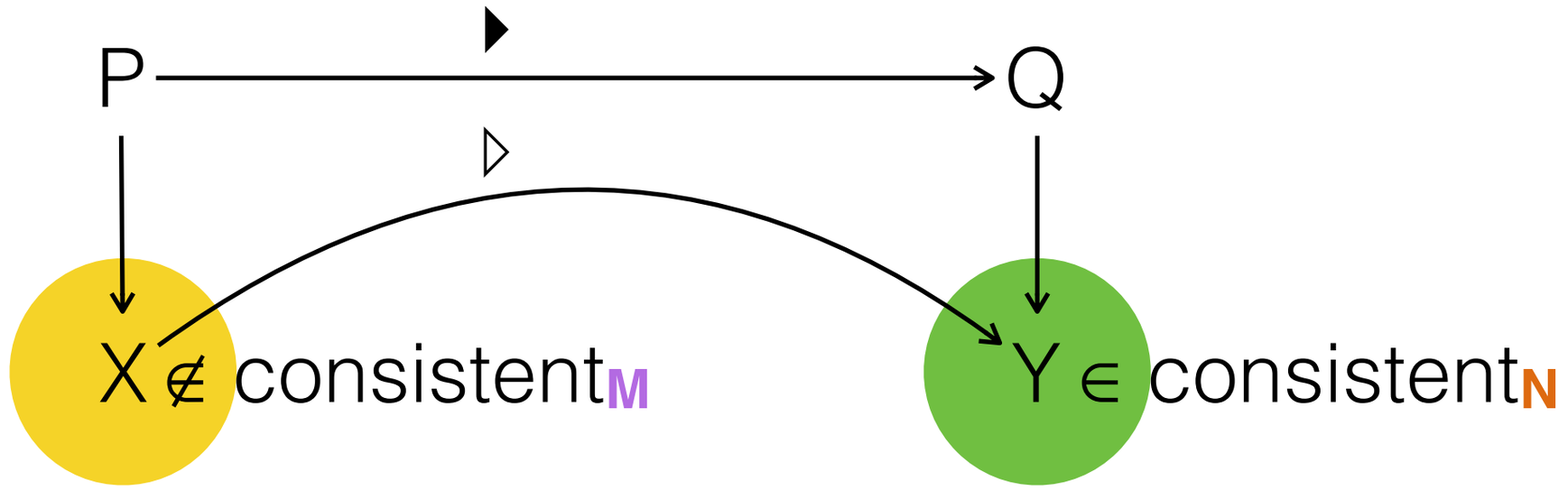

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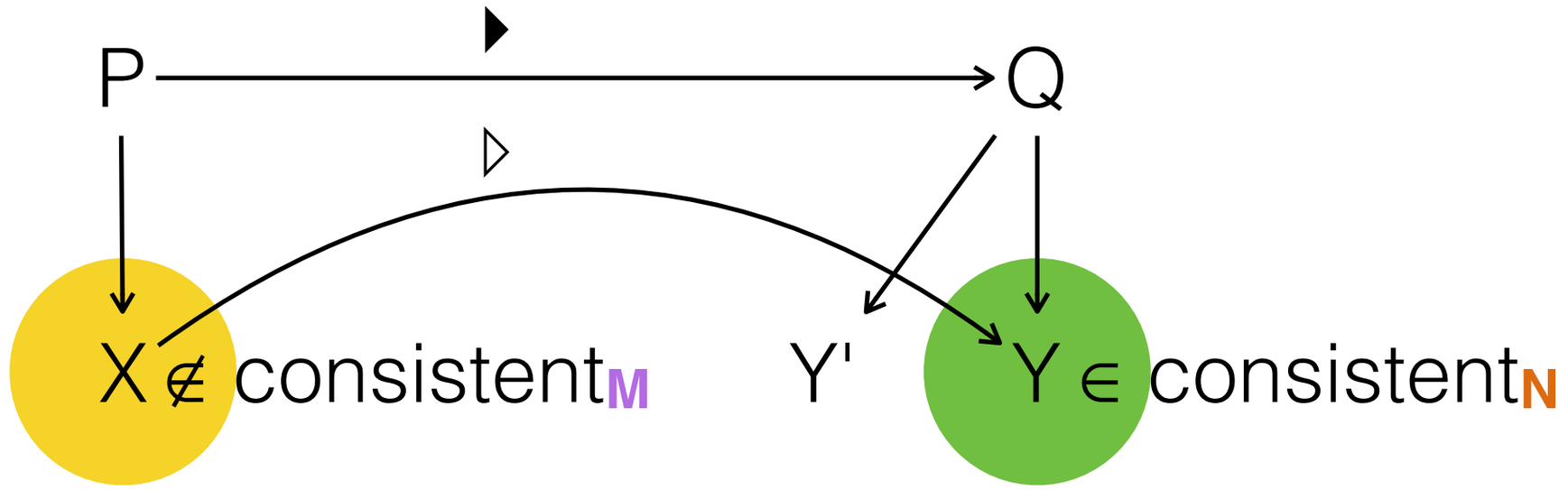

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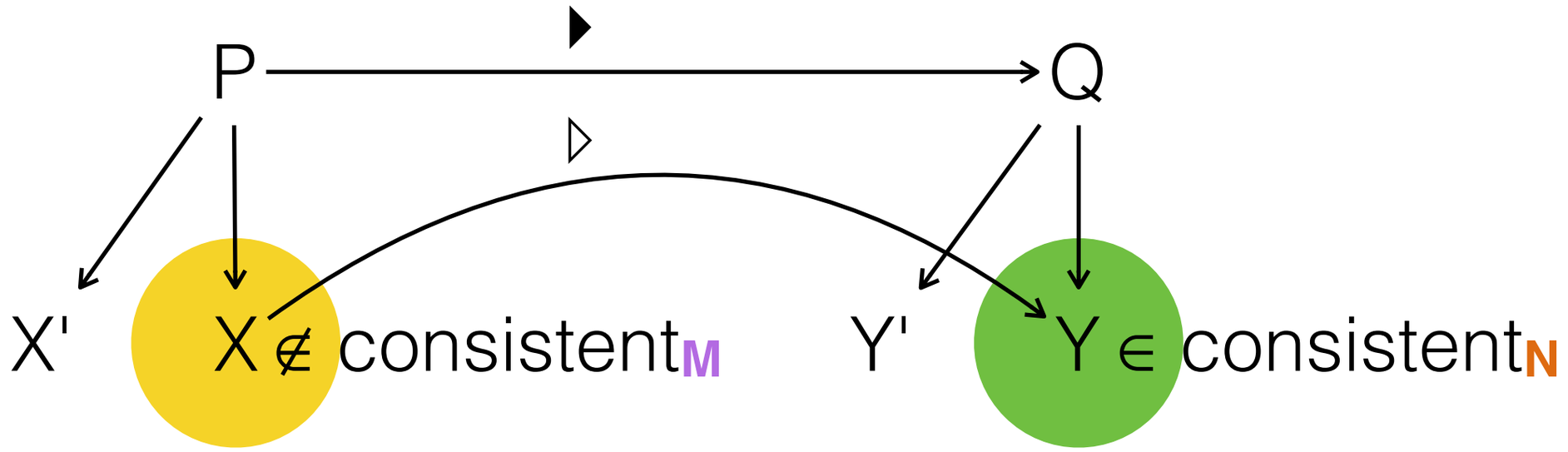

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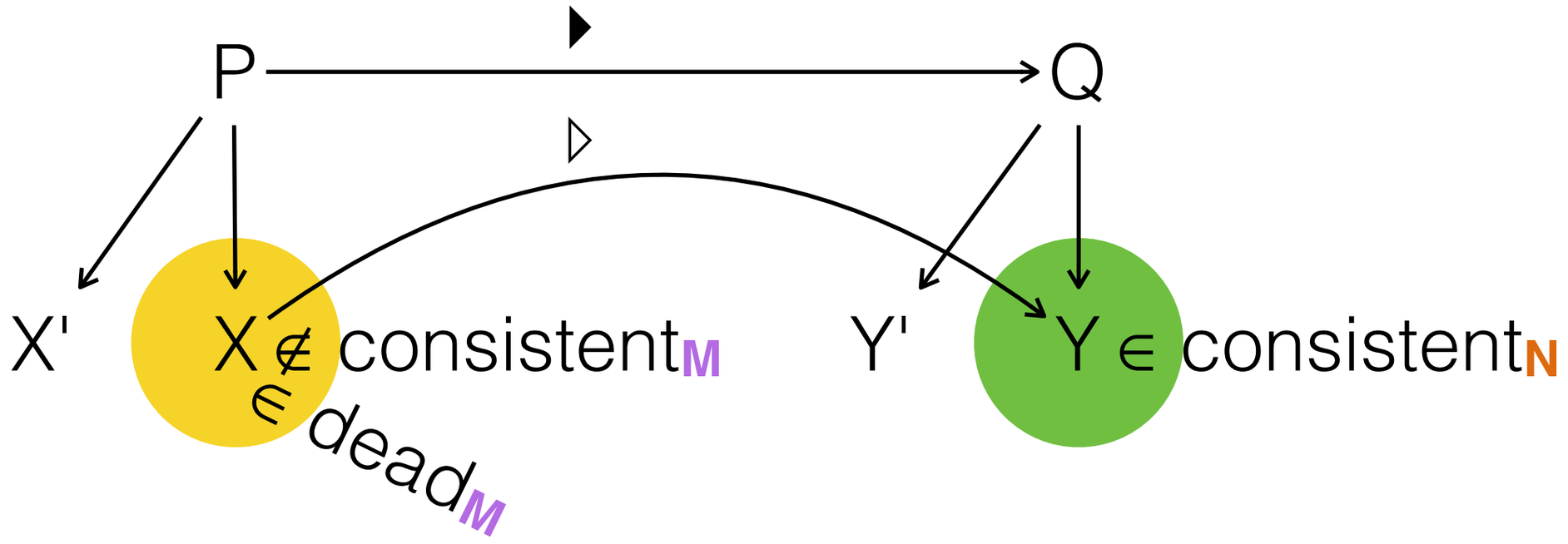


The Alloy Constraint Solver

/Users/jpw48/git/memalloy/models/tests/Q2_c11_sra_simp/question.als

New Open Reload Save Execute Show

```
open ../../sw/c11_nafence[E] as M1
open ../../sw/c11_simp[E] as M2

sig E {}

pred gp [X : Exec_C] {

  // Prefer solutions with total sb per thread
  total_sb[X]

  // ignore RMWs
  no_RMWs[X]

  // The execution is forbidden in M1
  not(M1/consistent[X])
  //M1/dead[X]

  // The execution is allowed (and not faulty)
  M2/consistent[X]

}

run gp for 1 Exec, 5 E, 3 Int
```

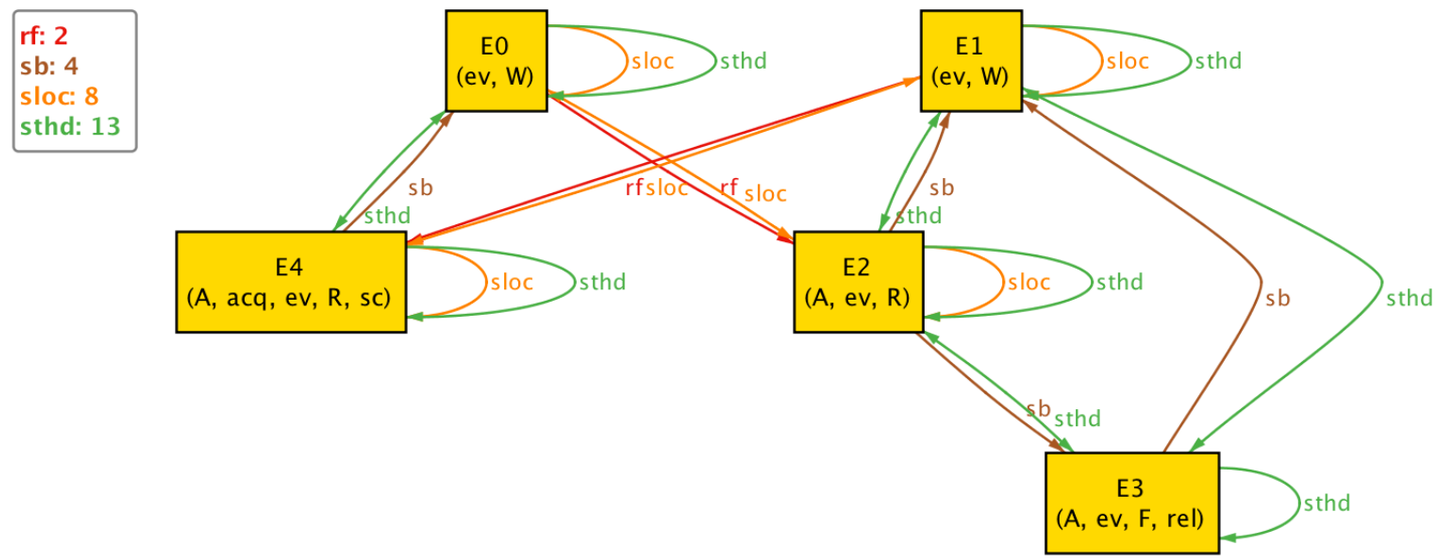
```
Alloy Analyzer 4.2.? (build date: unknown)

Executing "Run gp for 3 int, 1 Exec, 5 E"
   Solver=glucose(jni) Bitwidth=3 MaxSeq=3 Symmetry=20
   13526 vars. 258 primary vars. 43898 clauses. 1466ms.
   Instance found. Predicate is consistent. 756ms.
```

(question) Run gp for 3 int, 1 Exec, 5 E

Viz Txt Tree Theme Magic Layout Evaluator Next

Projected over M1/c11_nafence_base/exec_C/exec/Exec



<< M1/c11_nafence_base/exec_C/Exec_C$0 >>

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Comparing "strong release-acquire" to original release-acquire

Taming Release-Acquire Consistency

Ori Lahav Nick Giannarakis Viktor Vafeiadis

for Software Systems (MPI-SWS), Germany

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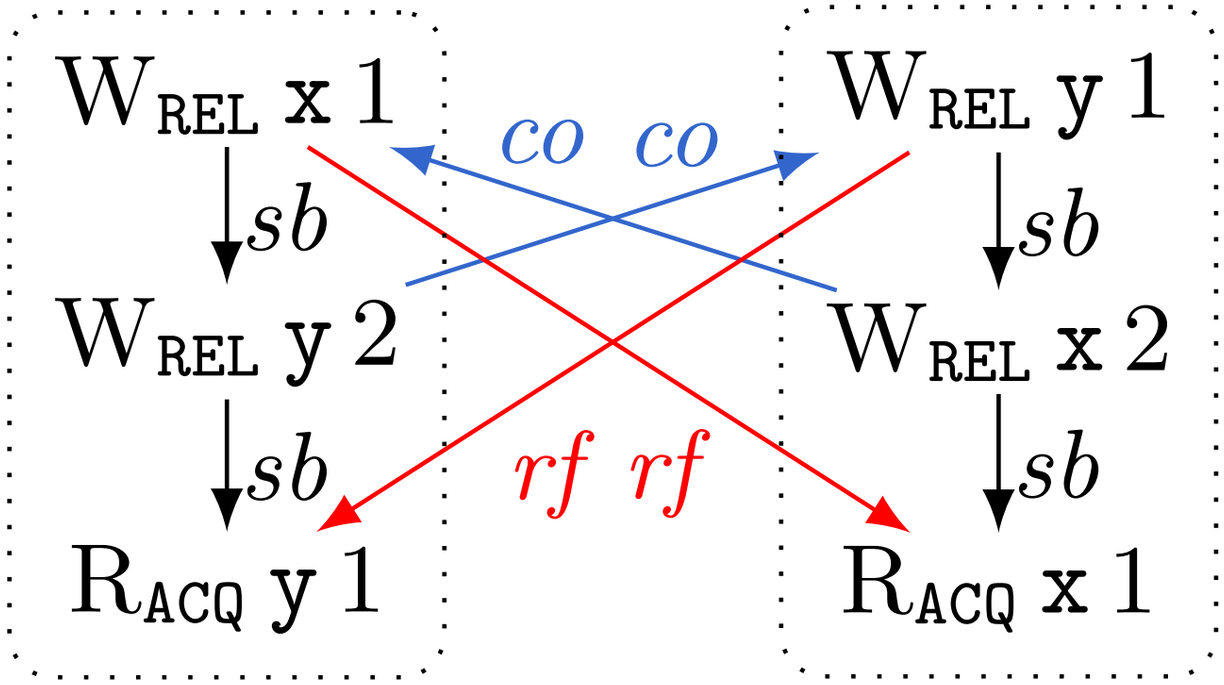


```
atomic_int x=0,y=0;
  x.store(1,REL);
  y.store(2,REL);
  r0=y.load(ACQ);
  ||
  y.store(1,REL);
  x.store(2,REL);
  r1=x.load(ACQ);
r0==1 && r1==1
```

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Comparing Nienhuis et al.'s C++ variant to the original

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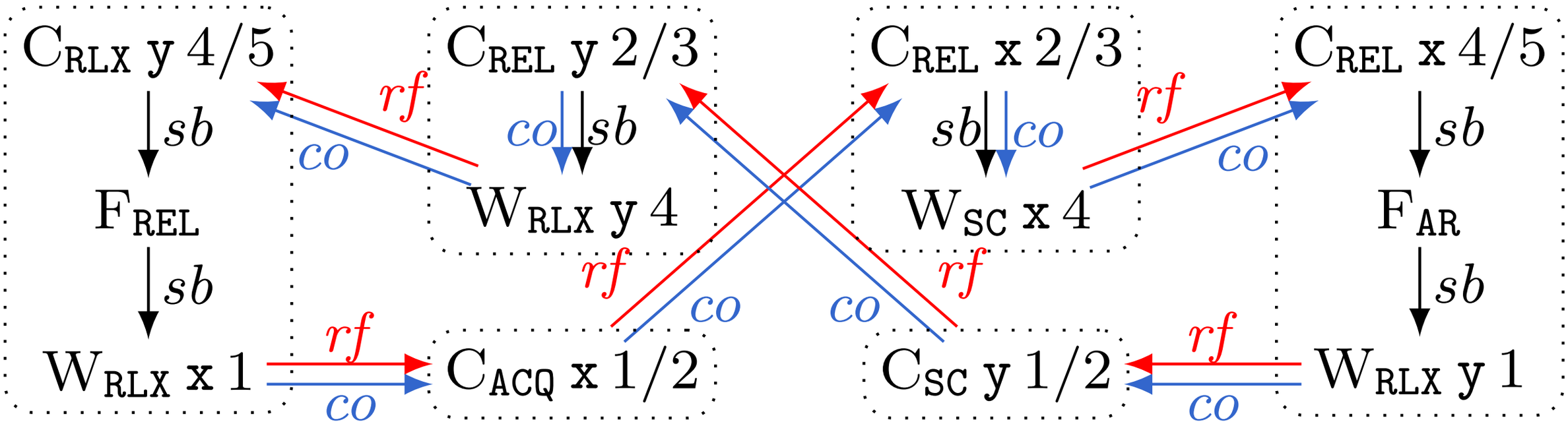

Comparing Batty et al.'s C++ variant to the original

Overhauling SC Atomics in C11 and OpenCL

Mark Batty
University of Kent, UK
m.j.batty@kent.ac.uk

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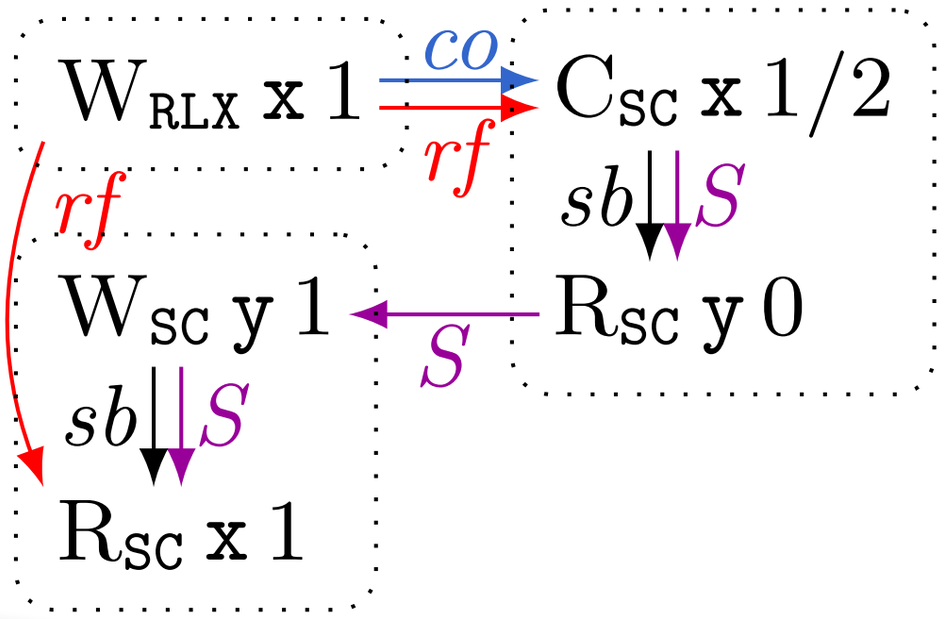


```
atomic_int x=0,y=0;
  x.store(1,RLX);
  ||
  r0=x.cas(1,2,SC,RLX);
  r1=y.load(SC);
  ||
  y.store(1,SC);
  r2=x.load(SC);
r0==true && r1==0 && r2==1
```

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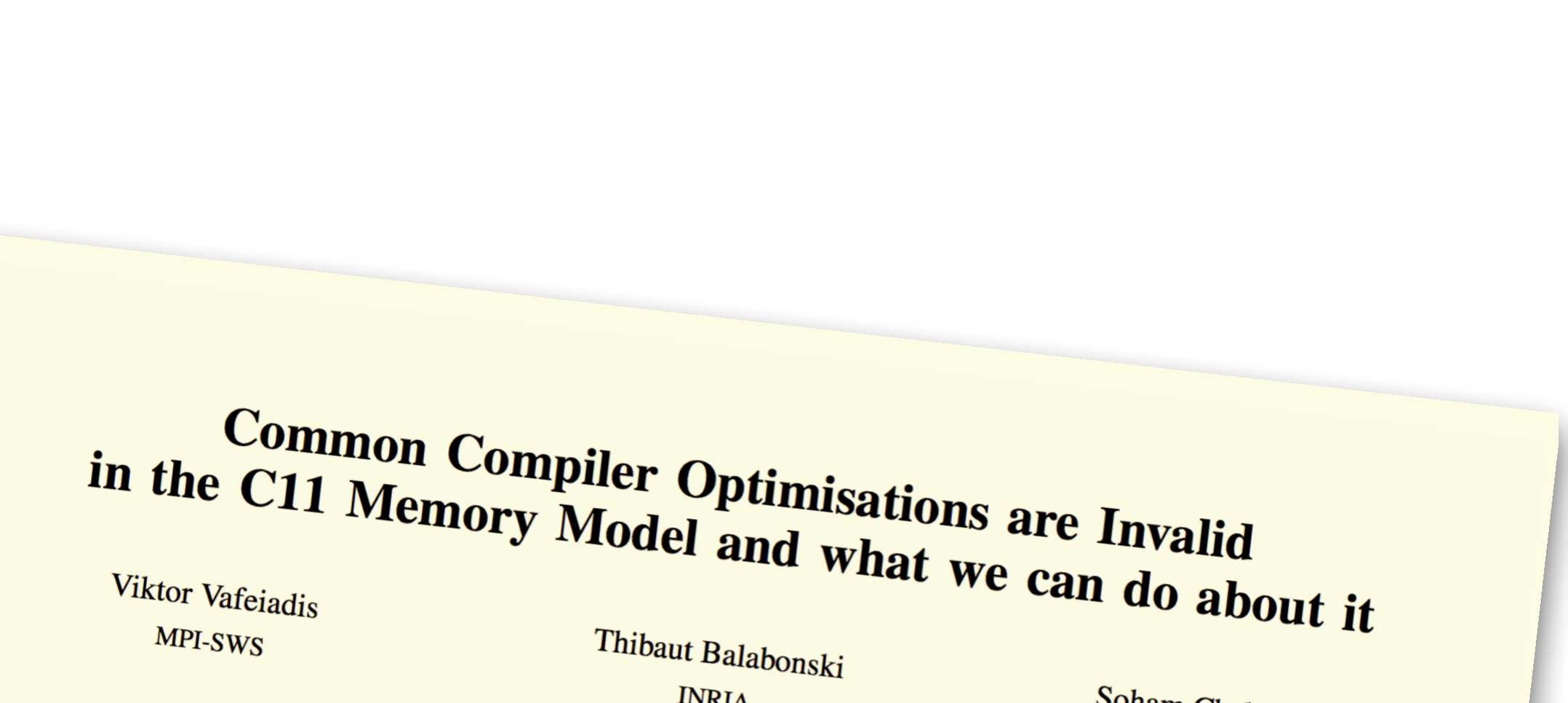
Does C++ allow "linearisation"?



Common Compiler Optimisations are Invalid in the C11 Memory Model and what we can do about it

Viktor Vafeiadis
MPI-SWS

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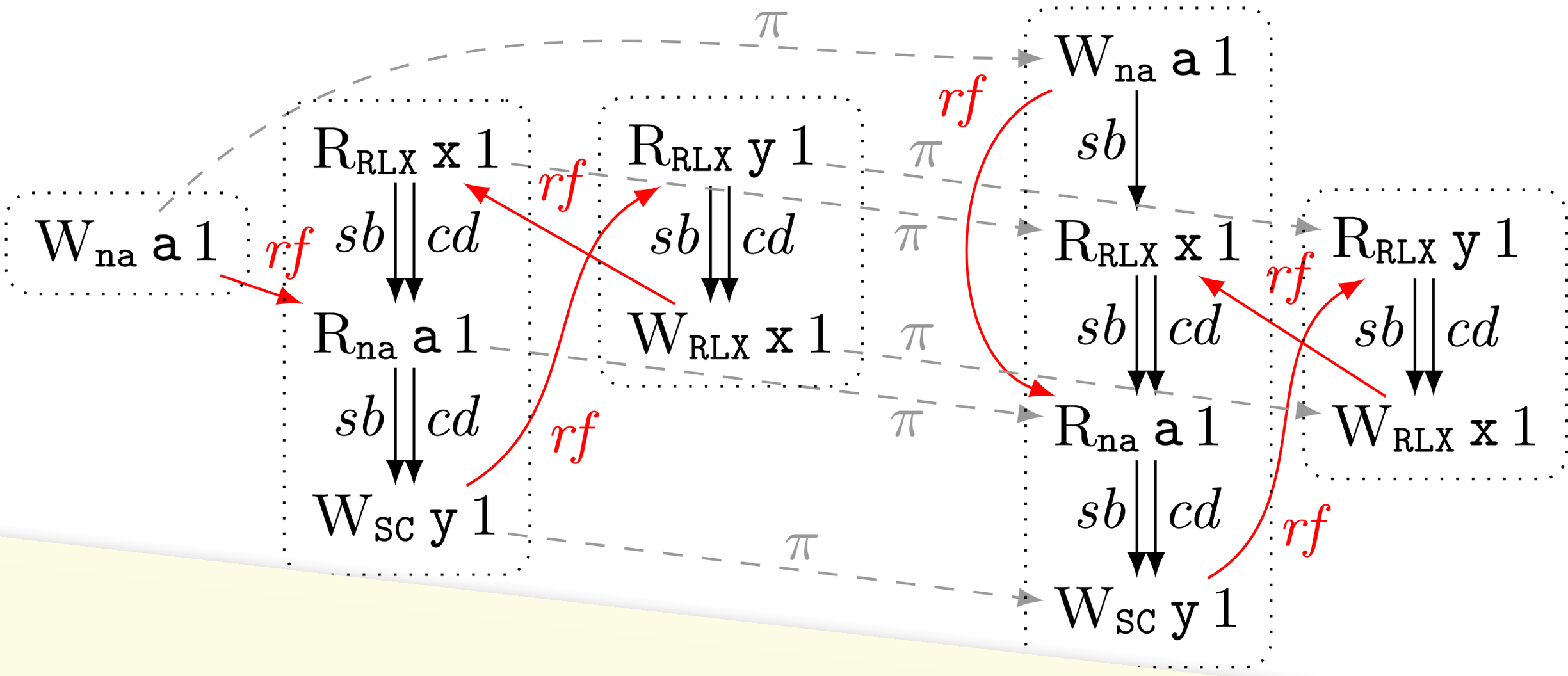

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Is AMD's OpenCL compiler mapping sound?

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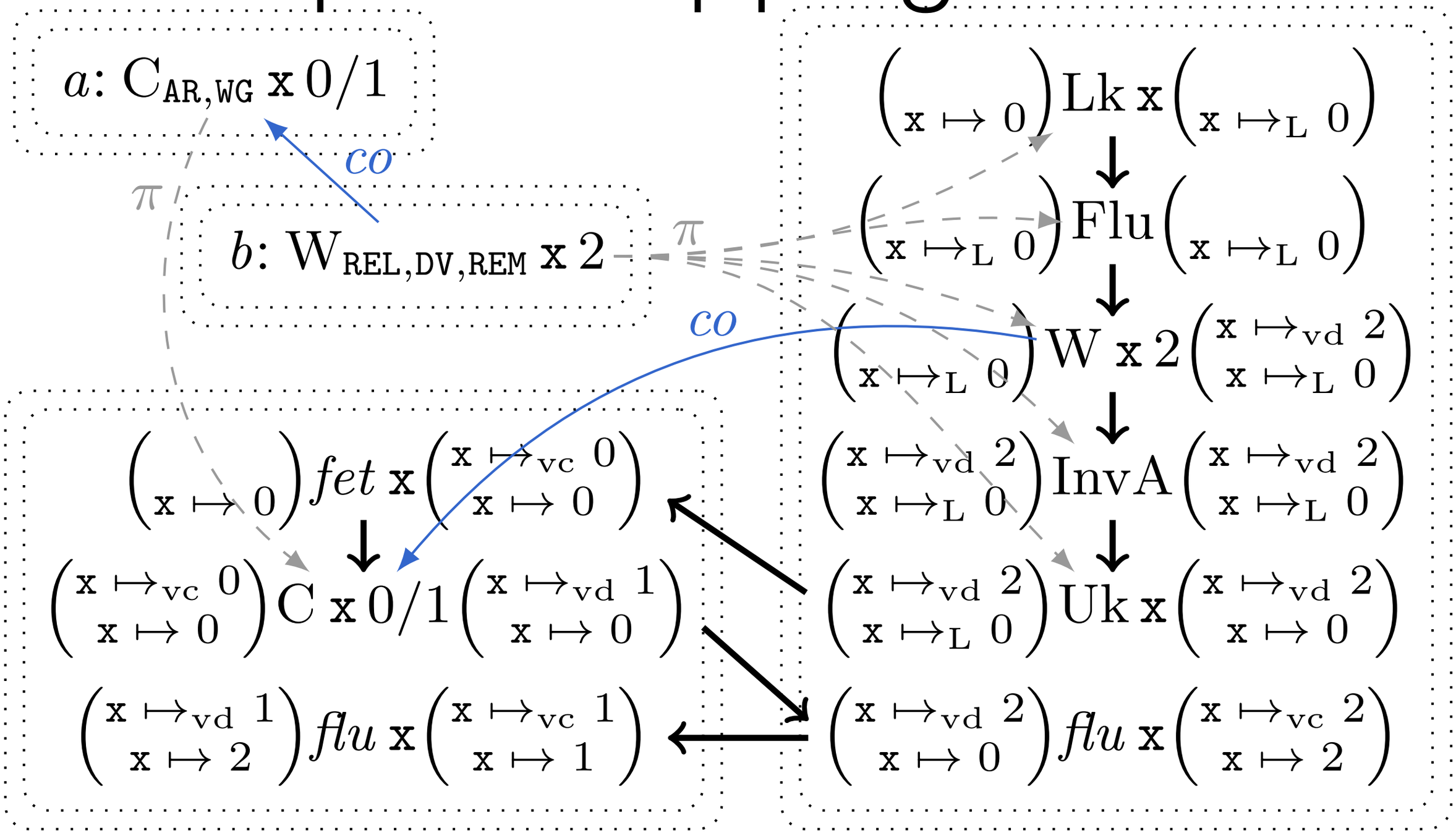

Checking and fixing an OpenCL/PTX compiler mapping

- PTX MCM proposed by Alglave et al. (ASPLOS '15)
- "Obvious" OpenCL/PTX mapping is invalid
- Manually revise PTX MCM (to obtain "PTX2")
- Now mapping is valid
- Run litmus tests that distinguish PTX/PTX2 against GPU hardware to validate PTX2

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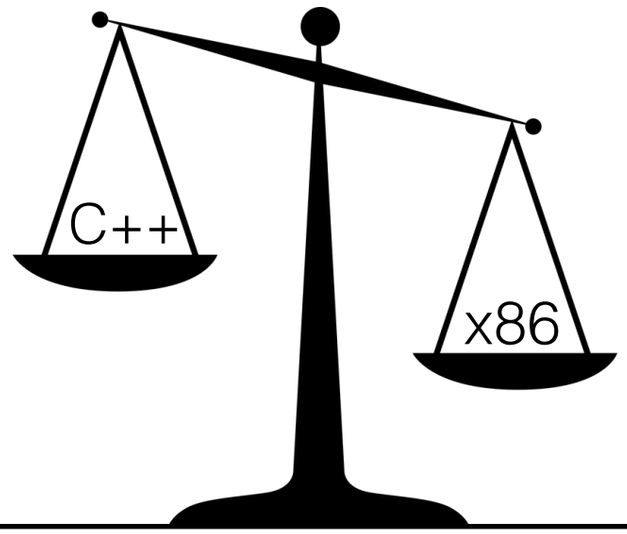

Automatically Comparing Memory Consistency Models

John Wickerson (Imperial)
Mark Batty (U Kent)
Tyler Sorensen (Imperial)
George A. Constantinides (Imperial)

Newcastle University
Wednesday 31 August 2016