Promising Compilation to ARMv8.3

Anton Podkopaev[1] Ori Lahav[2] Viktor Vafeiadis[3]

[1]St. Petersburg University, JetBrains Research, Russia

[2]Tel Aviv University, Israel

[3]Max Planck Institute for Software Systems, Germany

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Modern Compilers and CPUs are **Optimizing**

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Features

- reorderings
- cache
- buffers
- read-after-write elimination
- speculative execution
- fake dependency elimination
- ...

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Lead to strange concurrent behaviors

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Lead to **weak** concurrent behaviors

Weak Behavior: Load Buffering

$$\begin{array}{l} a := [x]; \\ [y] := 1; \end{array} \;\Big\|\; \begin{array}{l} b := [y]; \\ [x] := 1; \end{array}$$

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Final values $a = 1$, $b = 1$

Memory Model (MM) is semantics of concurrent system

Weak memory model allows weak behaviors

Most PLs and CPUs have weak MMs

Most PLs and CPUs have weak MMs, but only **racy** programs have weak behaviors

Most PLs and CPUs have

When to **care** about Weak MMs?

Most PLs and CPUs have

When to **care** about Weak MMs?
Writing/verifing lock-free code
(i.e., locks themselves)

(Weak) Memory Models in the Wild

For hardware

For programming languages

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For hardware

- x86-TSO, [Owens et al., 2009]
- Power, [Alglave et al., 2014]
- $\mathrm{ARMv8\ POP}$, [Flur et al., 2016]
- $\mathrm{ARMv8.3}$, [Pulte et al., 2018]

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Have flaws:
out-of-thin-air values, unsoundness of optimizations, ...

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Same ideas don't work for ARMv8.3!

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Result

Proved compilation correctness from Promise subset to ARMv8.3

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relaxed loads and stores,
release and acquire fences,
no certification

Load Buffering

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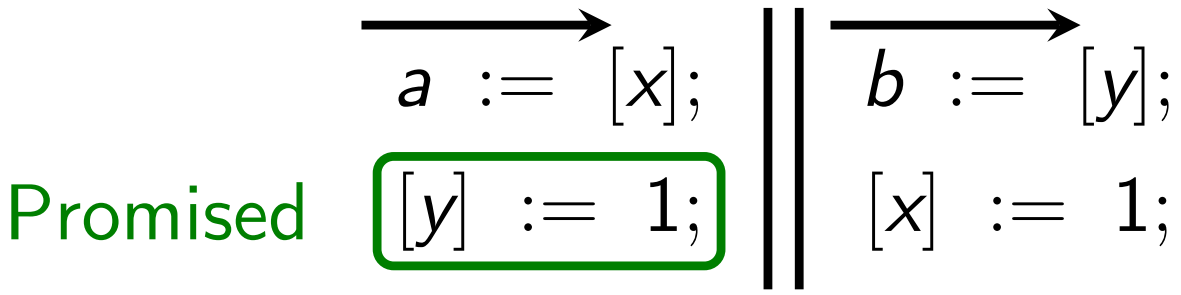

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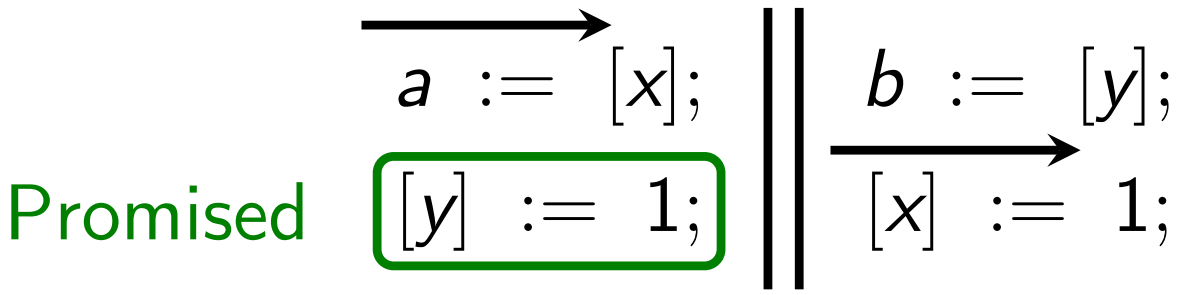

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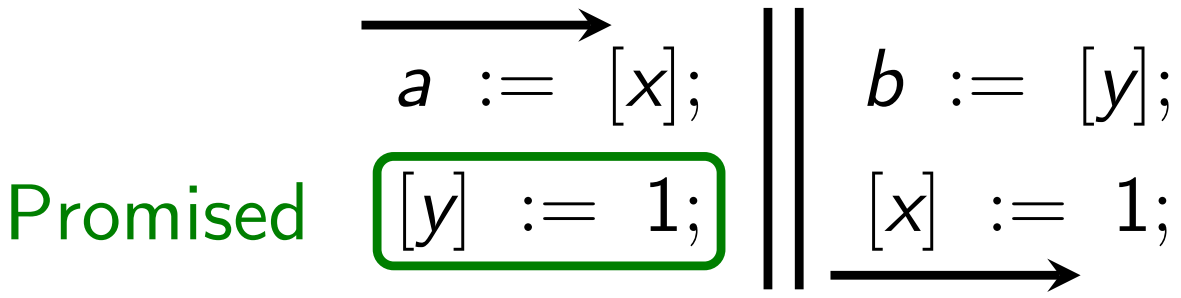

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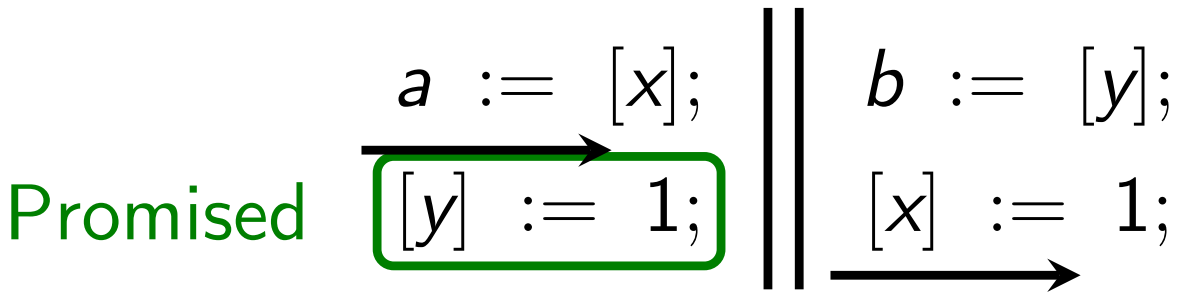

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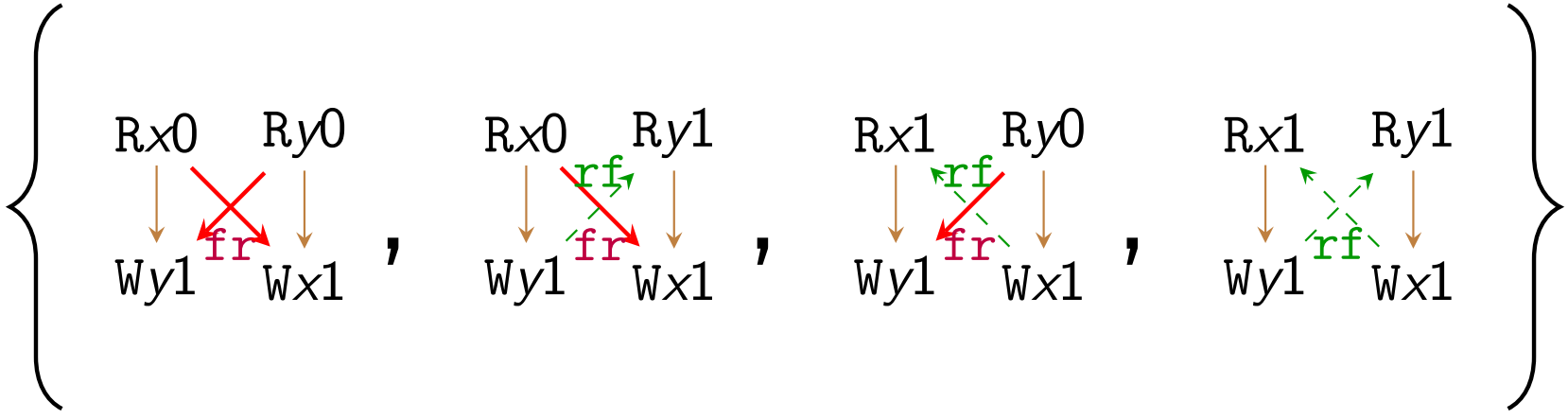

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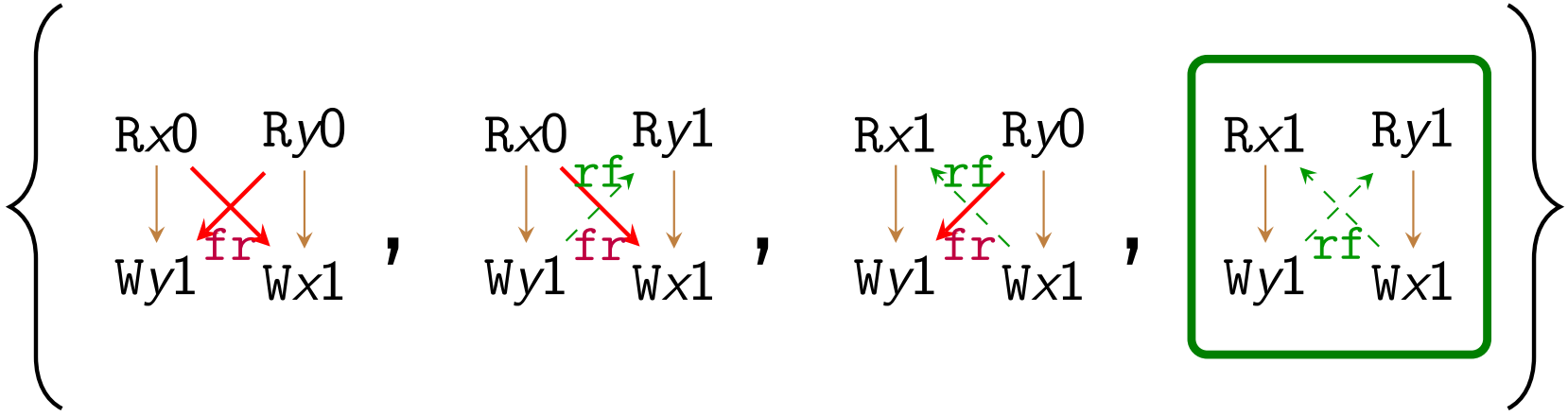

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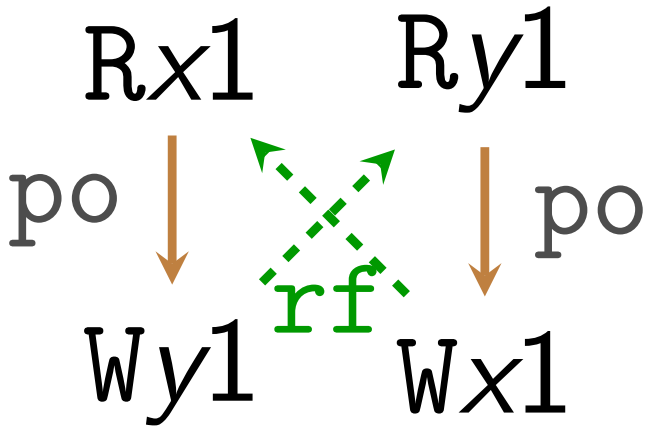

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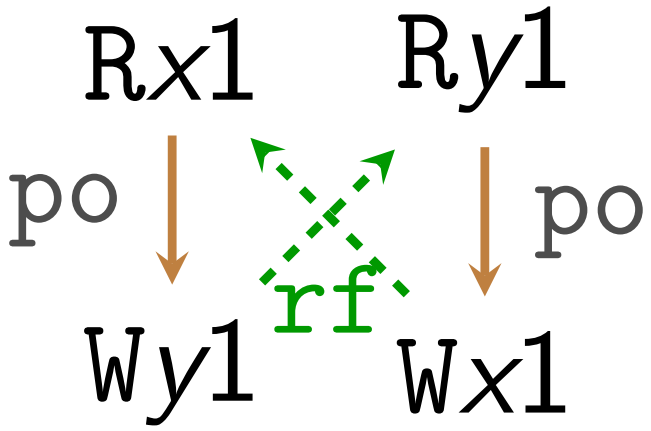
Axioms:

1. $\mathtt{po}\restriction_{\mathtt{loc}} \cup \mathtt{rf}$ is acyclic

...



How to prove correctness of compilation?

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Standard technique:
Simulation

Simulation works for operational semantics

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How to **simulate graphs**?

Simulation works for operational semantics

How to **simulate graphs**?

Traverse in proper order!

Traverse of ARMv8.3 execution

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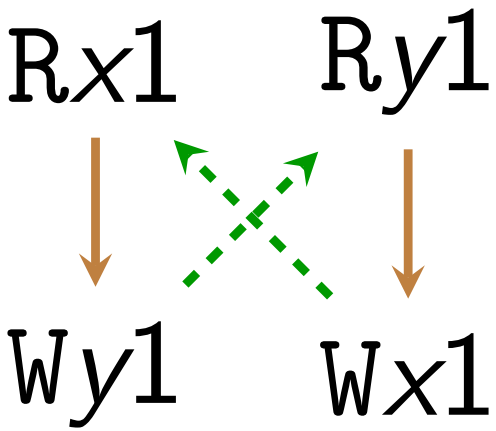

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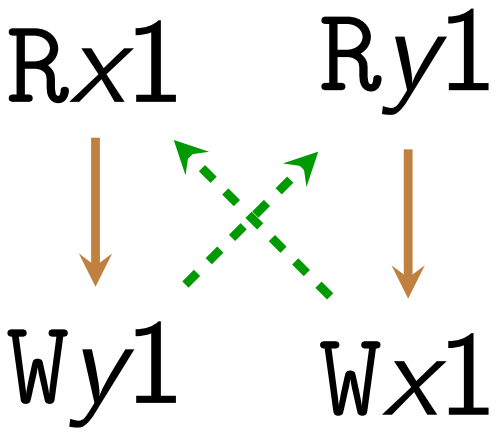

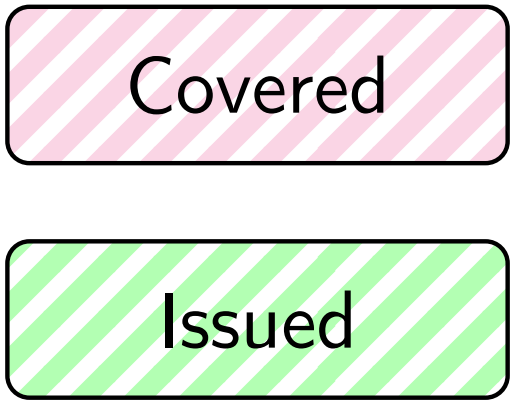

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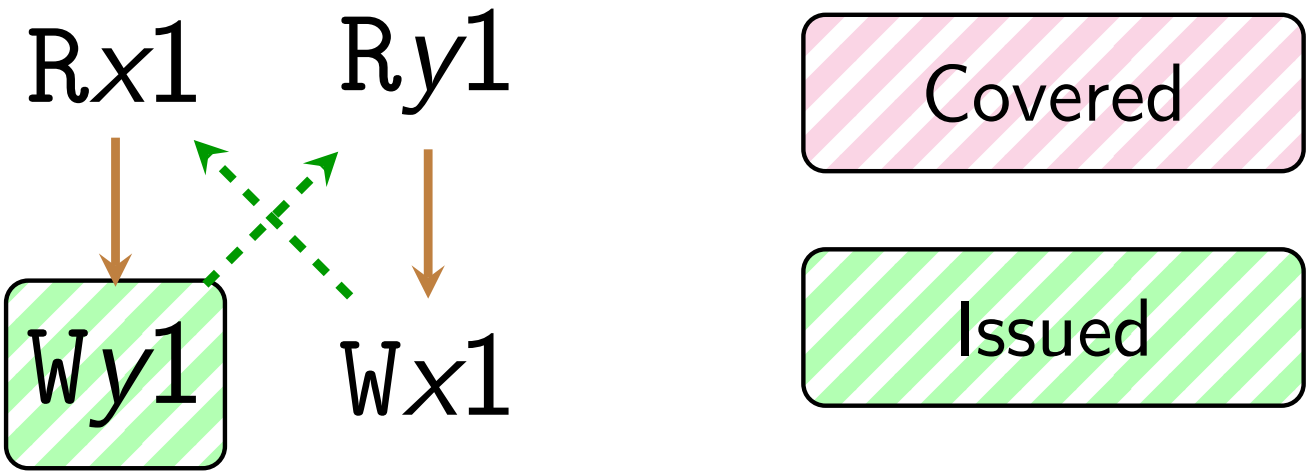

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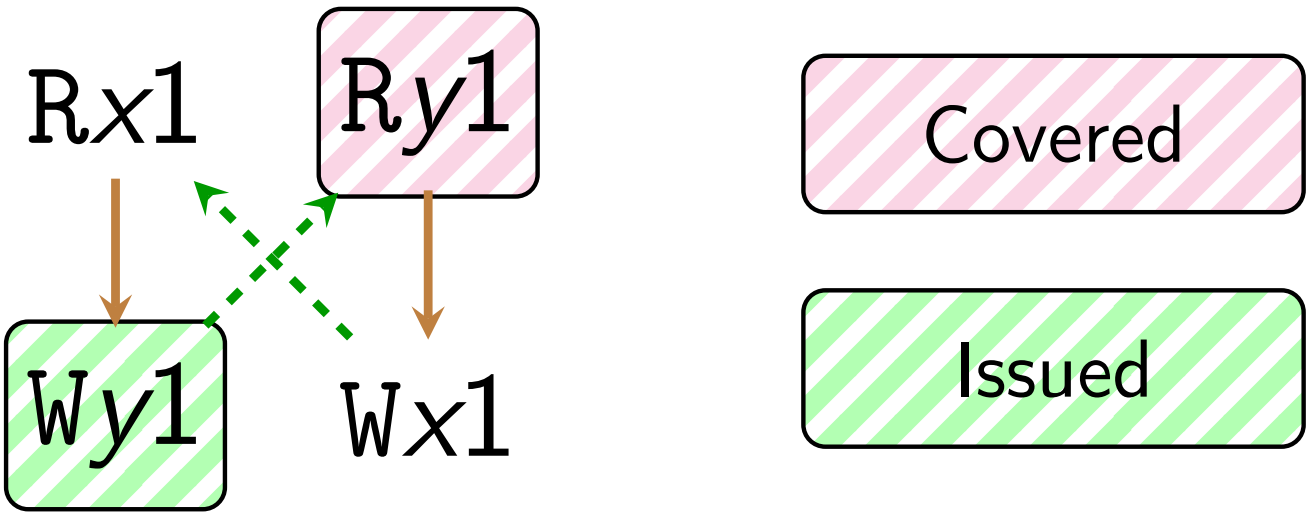

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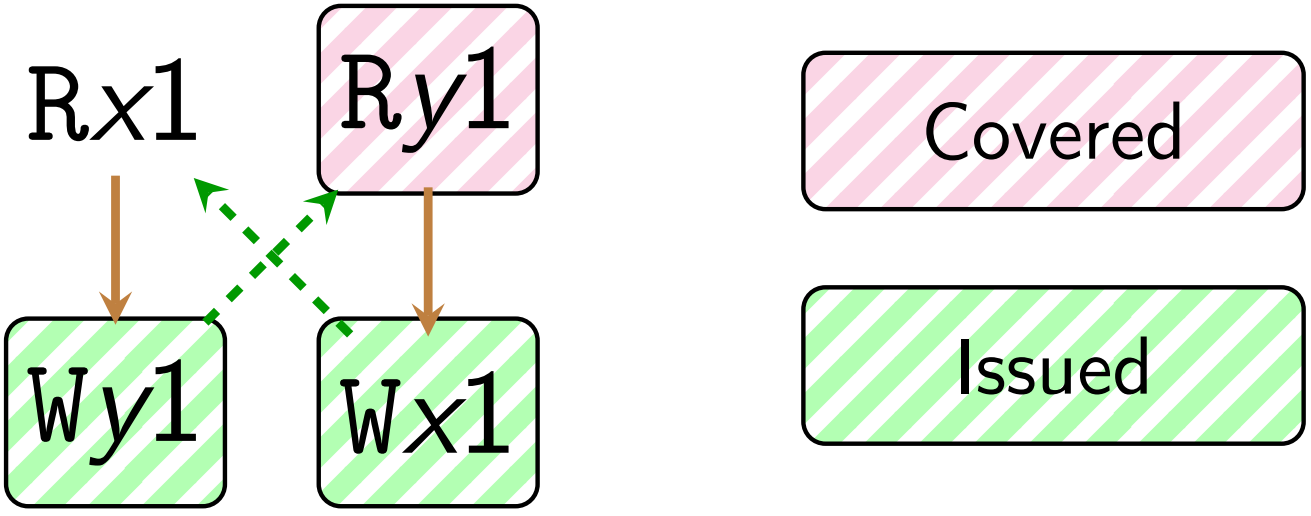

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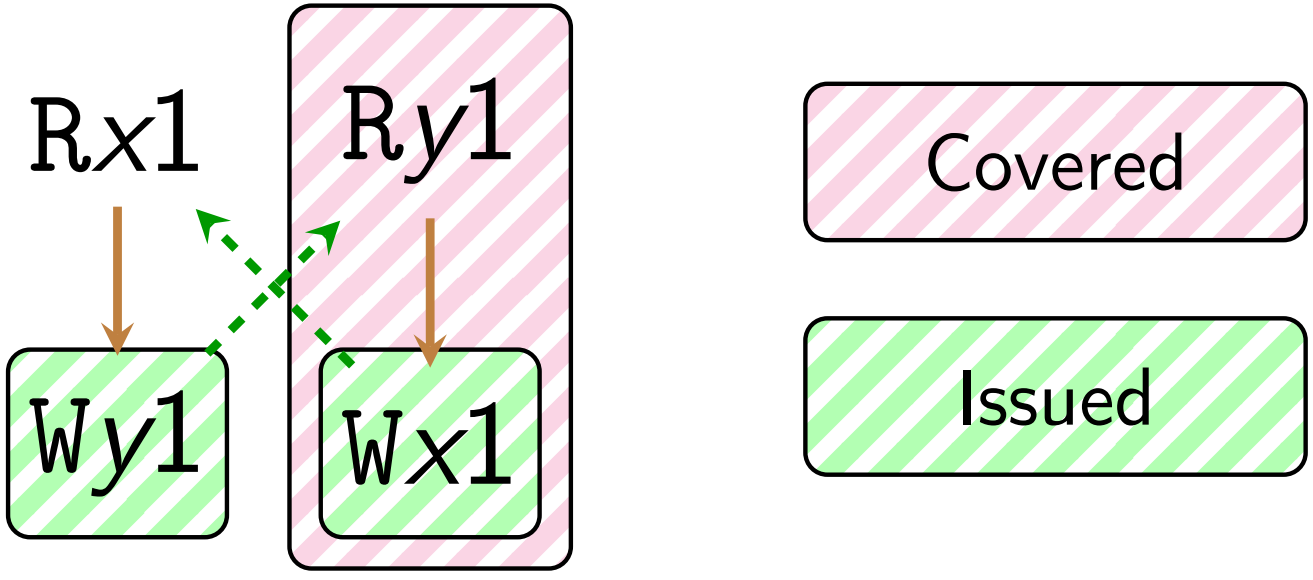

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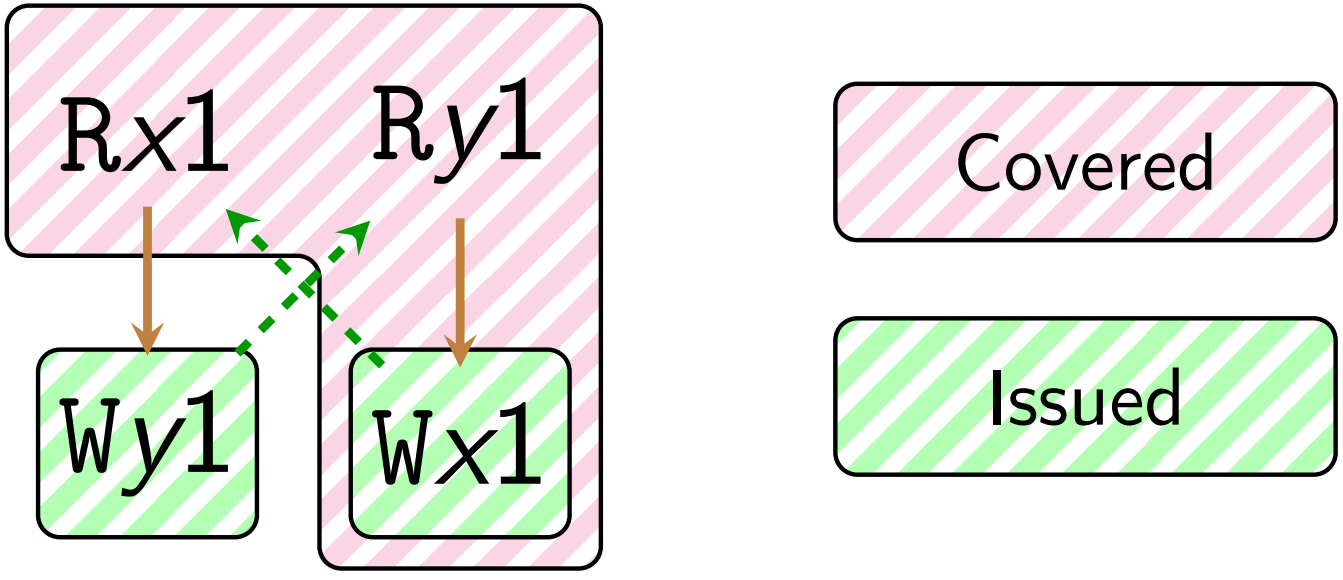

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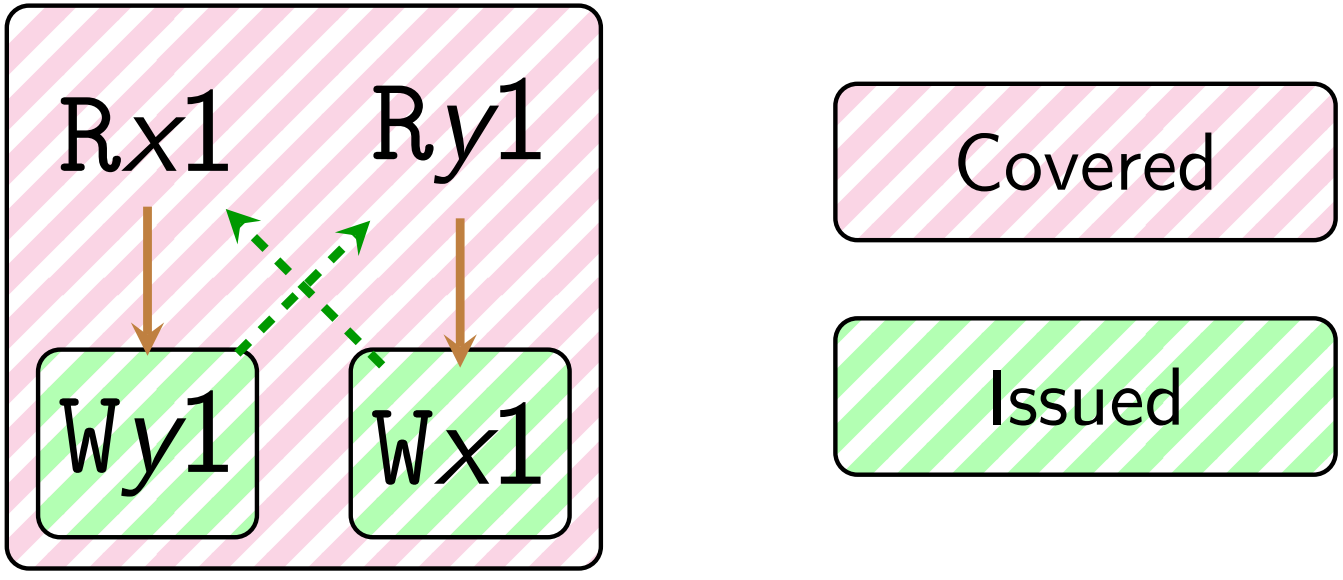

Traversal formally

Cover step:

$$\frac{\ldots}{G \vdash \langle C, I \rangle \to \langle C \cup \{a\}, I \rangle}$$

Issue step:

$$\frac{\ldots}{G \vdash \langle C, I \rangle \to \langle C, I \cup \{w\} \rangle}$$

Traversal formally

Cover step:

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Mimics Promise requirements!

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Proof Structure

1. Prove $\mathrm{Promise}$ simulates traversal

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2. Show completeness of traversal

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2. Show completeness of traversal

$$\forall G.\ G \in \mathsf{Consistent}(\mathrm{ARMv8.3}) \Rightarrow \langle \emptyset, \emptyset \rangle \rightarrow^* \langle G.\mathsf{Events}, G.\mathsf{Writes} \rangle$$

Future Work

- Cover other features of Promise

  (Read-Modify-Writes, Release/Acquire accesses, SC fences)

- Proof mechanization in Coq

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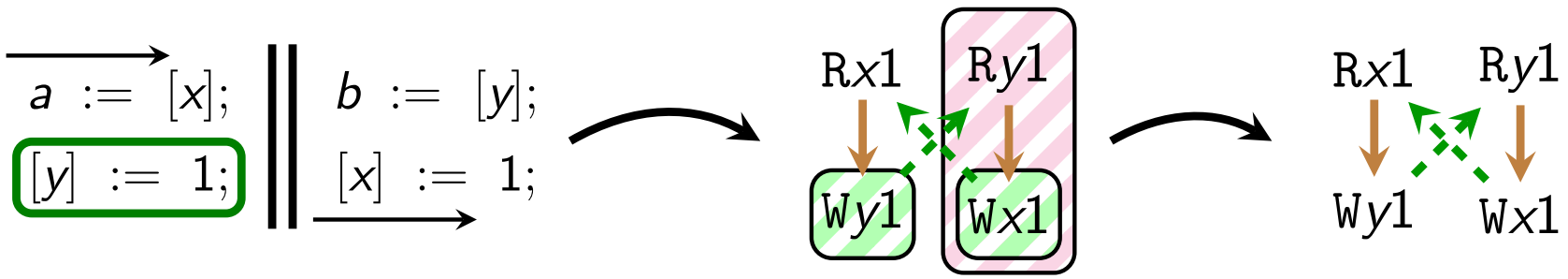

`http://podkopaev.net/armpromise`

Thank you!

Links I


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Links II

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Promising compilation to ARMv8 POP.
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Compilation Correctness

$$compile : S \rightarrow T$$
$$\forall Prog \in S.$$
$$[\![compile(Prog)]\!]_T \subseteq [\![Prog]\!]_S.$$