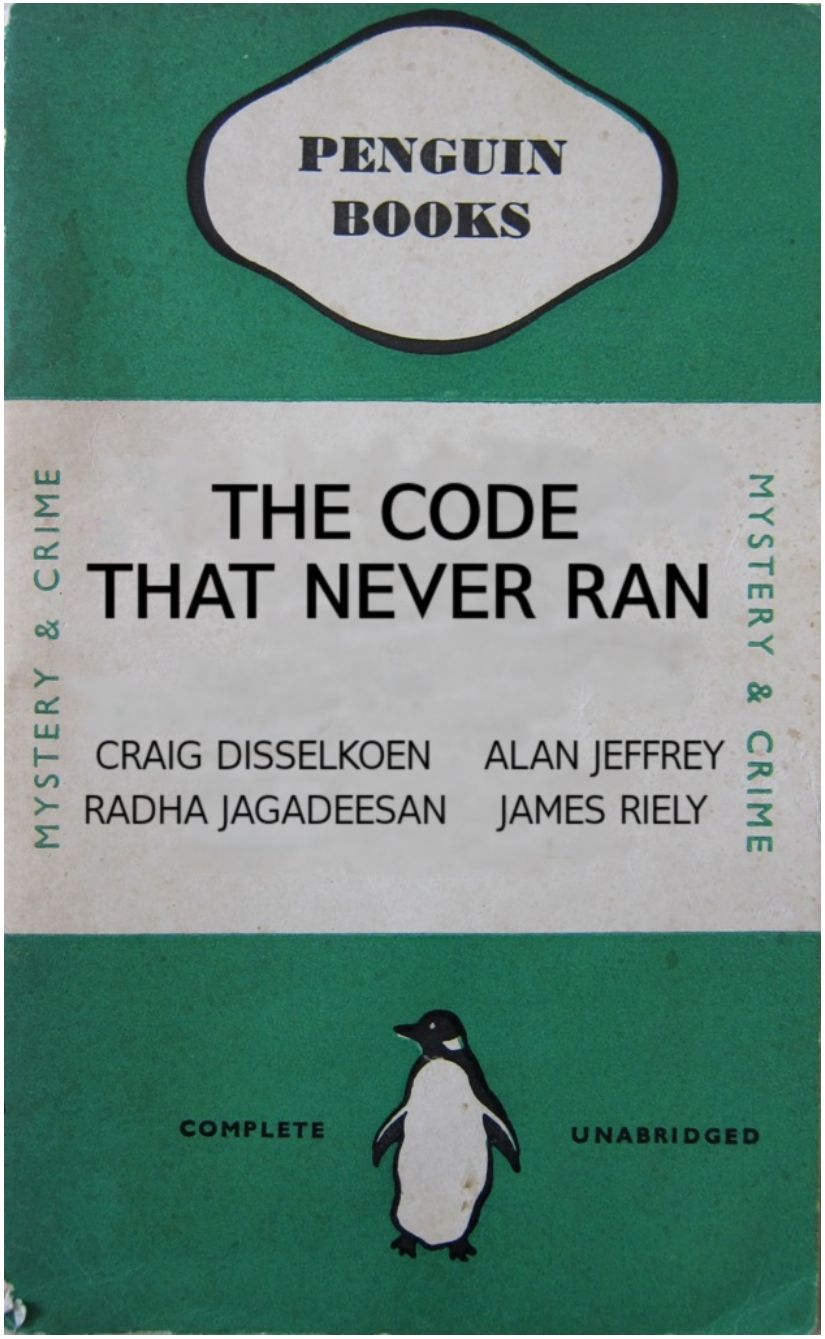


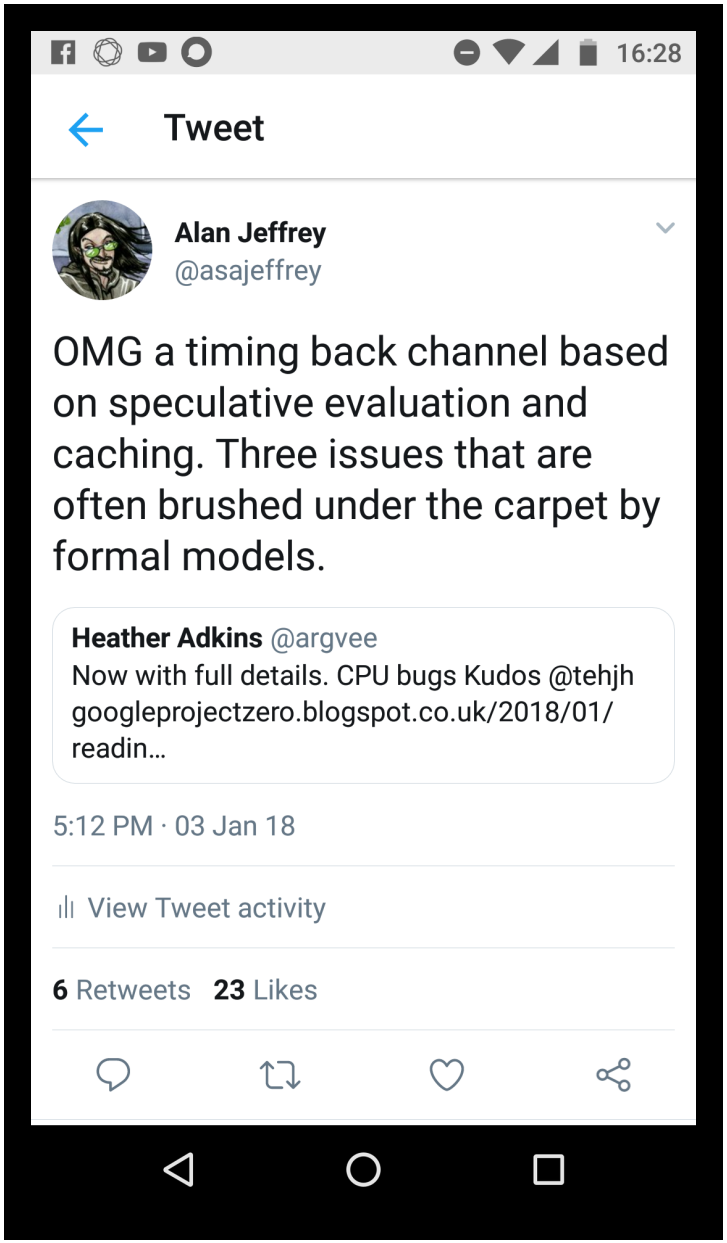
A classic locked-room mystery.
Eve was in the false branch of a conditional the whole time,
how could she do it?

Mozilla Research | DePaul University | U. California San Diego

Overview

Introduction
Model
Attacks
Experiments
Conclusions

Why? Spectre!



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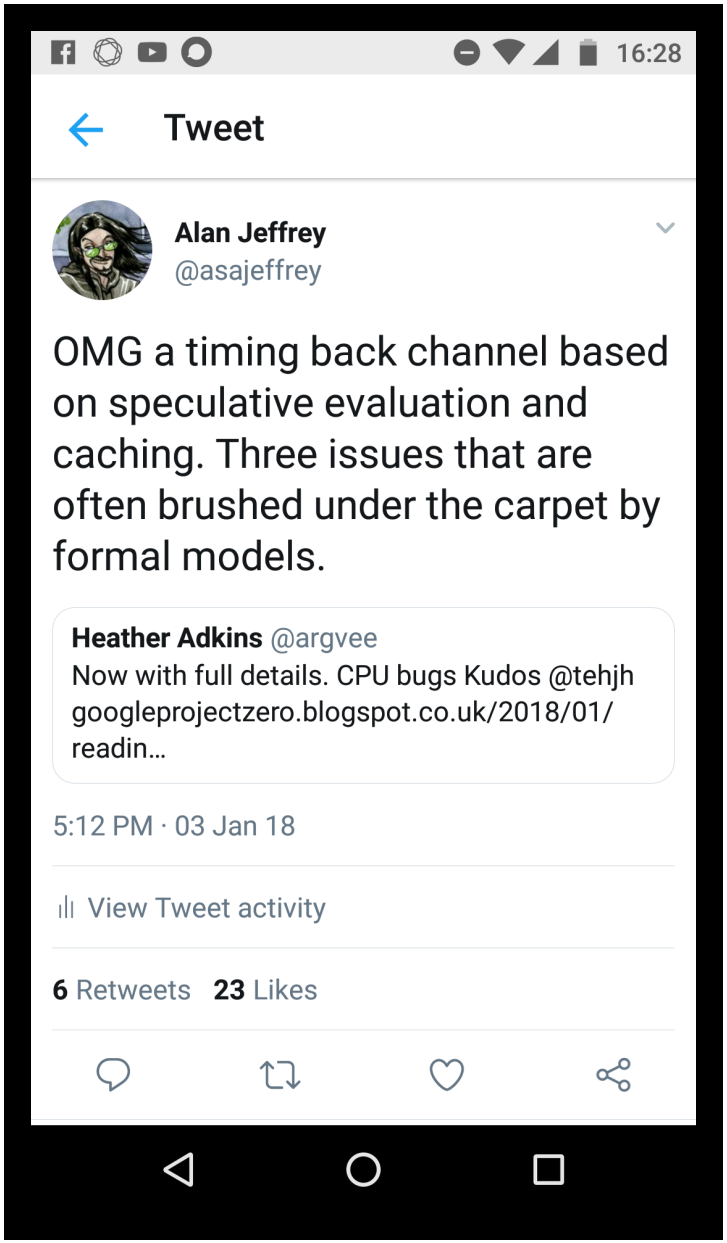
Why? Spectre!



Attacks bypass dynamic security checks:

```
if (canReadSecret) {
  doStuffWith(SECRET);
}
```

Information flow from `SECRET` even though `canReadSecret` is false.

Most formal models ignore code in branches that aren't taken.

Models that include speculation?

There are some models that include speculation *relaxed memory models*:

- *The Java Memory Model*
  Manson, Pugh and Adve, 2005.
- *Generative Operational Semantics for Relaxed Memory Models*
  Jagadeesan, Pitcher and Riely, 2010.
- *A promising semantics for relaxed-memory concurrency*
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Question: is there a simple model similar to those of relaxed memory, that can model speculation?

Information flow attacks on speculation

Speculation happens in many places:

- *Speculation in hardware* (branch prediction,. . .)
- *Transactions* (transactional memory,. . .)
- *Relaxed memory* (compiler optimizations,. . .)

Information flow attacks on speculation

Speculation happens in many places:

- *Speculation in hardware* (branch prediction,. . .)
  Attacked by Spectre (Kocher *et al.* 2019).
- *Transactions* (transactional memory,. . .)
  Attacked by Prime+Abort (Disselokoen *et al.* 2017).
- *Relaxed memory* (compiler optimizations,. . .)
  No known attacks.

Question: are there information flow attacks against compiler optimizations?

Contributions

- A simple compositional model.
- Examples.
- Attacks (including a new attack on relaxed memory).
- Experiments (testing practicality of new attacks).

Pomsets

C11-style models are based on *events*
with *labels* (e.g. $(\mathrm{R}\, x\, 3)$ or $(\mathrm{W}\, x\, 3)$)
and *relations* (e.g. happens-before or reads-from).

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Simplest such is *partially ordered multisets* (Gisher, 1988).

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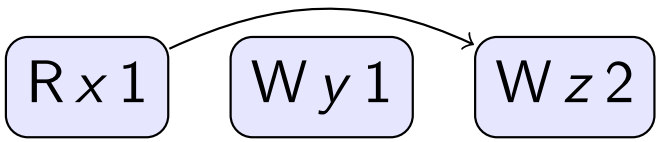

is an execution of $(r := x\,;\; y := 1\,;\; z := r + 1)$.

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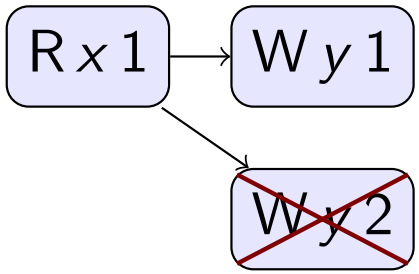

is an execution of (`if` $(x)\,\{\,y := 1\,\}$ `else` $\{\,y := 2\,\}$).

Compositional pomset model

First off, straight-line code.

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New idea: put preconditions on events

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$$r = 1 \mid \mathrm{W}\, z\, 2$$

is an execution of ($z := r + 1$).

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New idea: put preconditions on events, e.g.

$$\boxed{\mathrm{W}\, y\, 1} \quad \boxed{r = 1 \mid \mathrm{W}\, z\, 2}$$

is an execution of ($y := 1 ; z := r + 1$).

Note: no dependency because r does not depend on $y := 1$.

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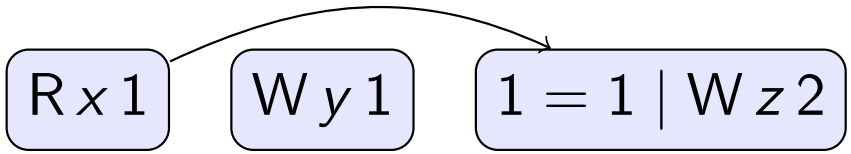

is an execution of $(r := x\,;\ y := 1\,;\ z := r + 1)$.

Note: dependency because r depends on $r := x$.
Also note: performing a substitution $[1/r]$.

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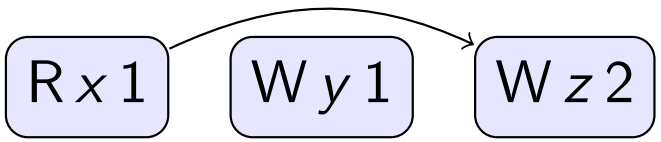

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Visualize: elide tautologies

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Next, conditionals.

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$$r \neq 0 \mid \mathrm{W}\, y\, 1$$

is an execution of ($y := 1$)
when $r \neq 0$

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comes from an execution of C *and* an execution of D, e.g.

$$r = 0 \mid \mathrm{W}\, y\, 2$$

is an execution of ($y := 2$)
when $r = 0$

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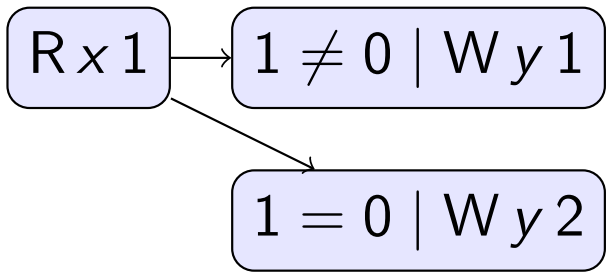

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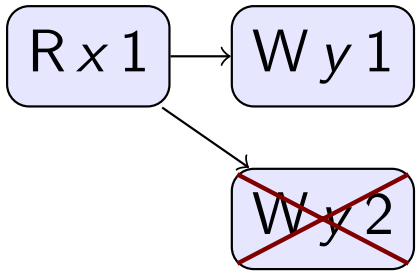

is an execution of $(r := x\,;\ \texttt{if}\,(r)\,\{\,y := 1\,\}\,\texttt{else}\,\{\,y := 2\,\})$

Visualize: elide tautologies and cross out unsatisfiables

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But. . .

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But. . . any execution of C should be an execution of $\texttt{if}\ M \{ C \} \texttt{else} \{ C \}$

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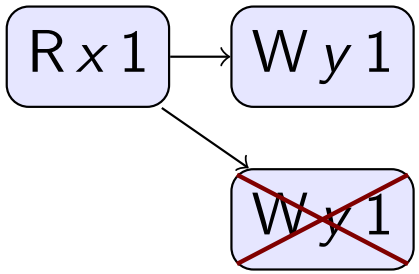

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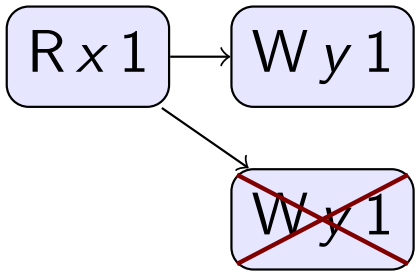

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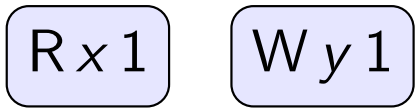

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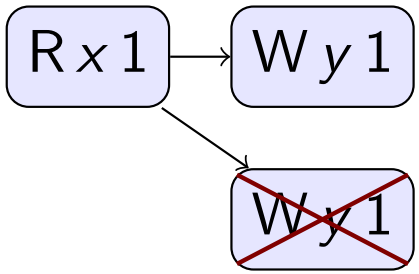

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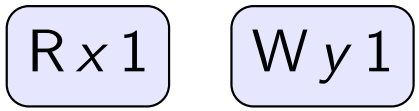

New idea: events from different branches can merge.

Compositional pomset model

Lastly, concurrency.

Compositional pomset model

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Old idea: match reads with matching writes (à la C11)

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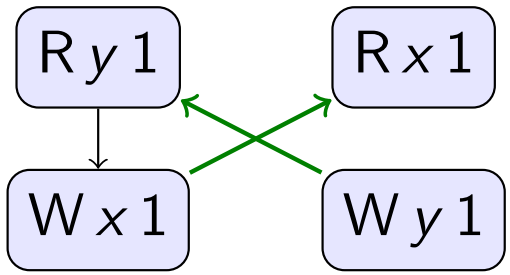

is an execution of $(x := y \;||\; r := x;\; y := 1)$.

Compositional pomset model

Glossed over some details:

- 3-valued pomsets for negative constraints $d \not< e$,
- sanity conditions on reads-from,
- precise rules for dependency,
- variable declaration,
- ...

All in the paper!

Information flow attacks go here

Implementing the new attacks

Outro goes here