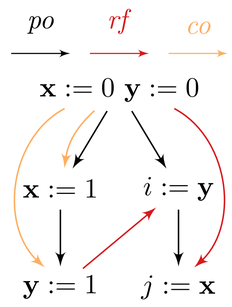
Software Verification Witnesses for Weak Memory

Levente Bajczi
https://leventebajczi.com

EXAMPLE

$$\mathbf{x} := 0, \mathbf{y} := 0$$
$$\begin{array}{l|l} \mathbf{x} := 1 & i := \mathbf{y} \\ \mathbf{y} := 1 & j := \mathbf{x} \end{array}$$
$$\neg(i = 1 \wedge j = 0)$$

Program with property



CEx. candidate

Bold variables are global, *italicized* variables are local. The program is safe under SC and TSO but not PSO.

Memory Models Overview

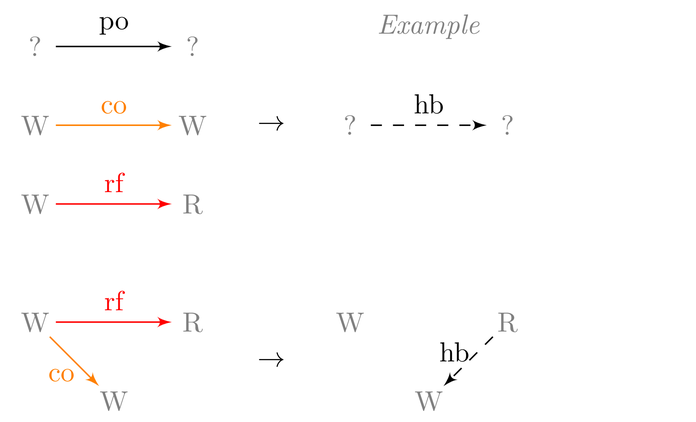
$$\mathbf{x} := 0$$
$$\begin{array}{l|l} \mathbf{x} := 1 & a := \mathbf{x} \\ \mathbf{x} := 2 & b := \mathbf{x} \end{array}$$

po — Instruction order

co — Memory update order (W -> W)

rf — Dataflow (W -> R)

$$\forall r^{\mathbf{x}} \exists w^{\mathbf{x}} : w^{\mathbf{x}} \xrightarrow{rf} r^{\mathbf{x}}$$
$$\forall w_1^{\mathbf{x}}, w_2^{\mathbf{x}} : w_1^{\mathbf{x}} \xrightarrow{co} w_2^{\mathbf{x}} \vee w_2^{\mathbf{x}} \xrightarrow{co} w_1^{\mathbf{x}}$$
$$\dots$$



Find *co* and *rf* for a given *po* such that ***hb*** is acyclic.

Tools for Weak Memory

Exhaustive Enumeration

Generate execution candidates, and check their consistency

Herd7 [2]
(memory model simulator)
Litmus tests CAT
memory model

Stateless Model Checking

Generate increasingly larger, always consistent executions (traces)

GenMC [5], **Nidhugg [1]**, ...
(Subset of) C11
Custom library

Bounded Model Checking

Encode constraints of the memory model in the SMT query

Dartagnan [4]
(SV-COMP flavored) C
Subset of CAT

Violation Witness Example

Thread 0	waypoint type	value	line	column
	assume	$\backslash at(\mathbf{x}, 0) = 0$	0	*middle*
	assume	$\backslash at(\mathbf{y}, 0) = 0$	0	*end*
	thread_start	1, 2	1	0
Thread 1				
	assume	$\backslash at(\mathbf{x}, 1) = 1$	1	*end*
	assume	$\backslash at(\mathbf{y}, 1) = 1$	2	*end*
Thread 2				
	assume	$i = \backslash at(\mathbf{x}, 1)$	1	*end*
	assume	$j = \backslash at(\mathbf{y}, 1)$	2	*end*
	target	-	2	*end*

A violation witness, encoding a violation under PSO

Correctness Witness Example

invariant type	value	line	column
location	$\backslash at(\mathbf{x}, 0) = 0$	0	*middle*
location	$\backslash at(\mathbf{y}, 0) = 0$	0	*end*
location	$\backslash at(\mathbf{x}, 1) = 1$	1 *(left)*	*end*
location	$\backslash at(\mathbf{y}, 1) = 1$	2 *(left)*	*end*
location	$\exists a : a \in \{0, 1\}$ $i = \backslash at(\mathbf{x}, a)$	1 *(right)*	*end*
location	$\exists a, b : a, b \in \{0, 1\}$ $j = \backslash at(\mathbf{y}, a)$ $i = \backslash at(\mathbf{x}, b)$ $b = 1 \implies a = 1$	2 *(right)*	*end*
location	$\neg(i = 1 \wedge j = 0)$	2 *(right)*	*end*

A correctness witness, encoding a proof over SC

Mapping Verdicts to Witnesses

$\backslash at(\mathbf{e}, \mathbf{id})$: Built-in ACSL construct *(abused a bit)*

- referring to the value of the expression **e** in the state at label **id** [3]
- Our *state labels* are integers, and denote ordering of memory events.
- Correctness: *state labels* are **symbolic** integers, and denote ordering of memory events.

Future Plans

- Implement witness serialization (Theta, CPAchecker)
- Implement violation witness checking (Theta)
- Implement correctness witness checking (Theta)

References

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[3] Baudin, P., Cuoq, P., Filliatre, J.C., Marché, C., Monate, B., Moy, Y., Prevosto, V.: ACSL: ANSI/ISO C Specification Language v1.20. Tech. rep., Frama-C (2024)
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[5] Kokologiannakis, M., Vafeiadis, V.: GenMC: A Model Checker for Weak Memory Models. In: Computer Aided Verification: 33rd International Conference, CAV 2021, Virtual Event, July 2023, 2021, Proceedings, Part I. p. 427440. Springer-Verlag, Berlin, Heidelberg (2021). https://doi.org/10.1007/978-3-030-81685-8_20

Report

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