A Case for Unlimited Watchpoints

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Goal of This Work

MAKE

SOFTWARE

FAST

Goal of This Work

MAKE

dynamic

SOFTWARE

analysis

FAST

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MAKE

dynamic

SOFTWARE

analysis

FASTer

Dynamic Software Analysis

Bounds Checking

Data Race Detection

Taint Analysis

Deterministic Execution

Transactional Memory

Speculative Parallelization

Dynamic Software Analysis

Bounds Checking

10-80x

Data Race Detection

2-300x

Taint Analysis

2-30x

Deterministic Execution

2-10x

Transactional Memory

2-50x

Speculative Parallelization

2-4x

Real Goal of This Work

Generic Hardware to Accelerate Many Dynamic Software Analyses

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Generic Hardware to Accelerate Many Dynamic Software Analyses

WATCHPOINTS

Hardware-Assisted Watchpoints

- HW Interrupt when touching watched data

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0	1	2	3	4	5	6	7
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**

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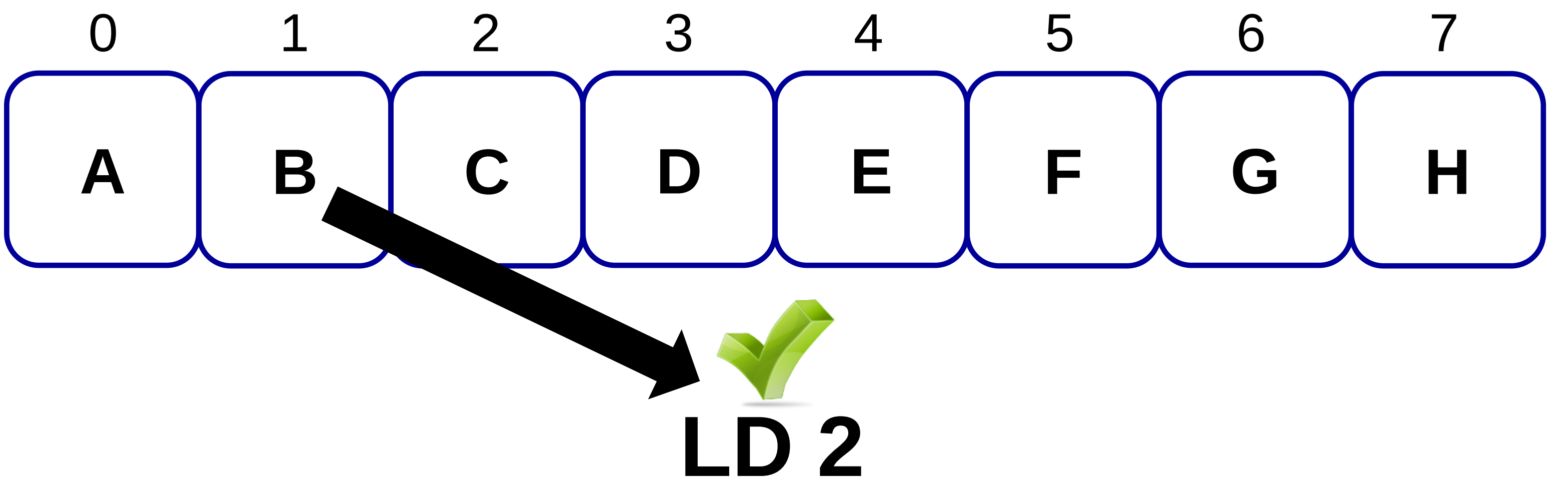

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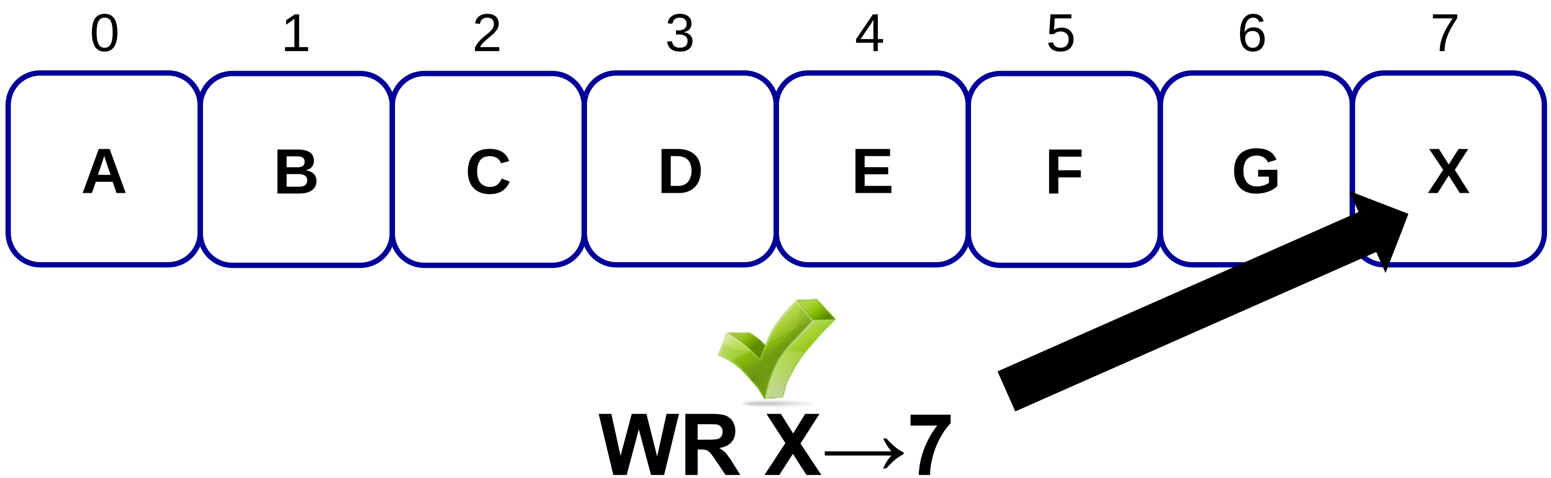

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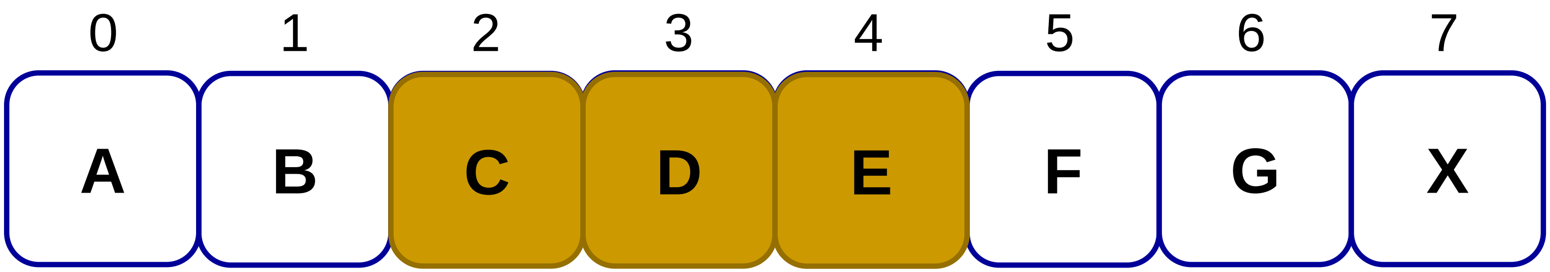

R-Watch 2-4

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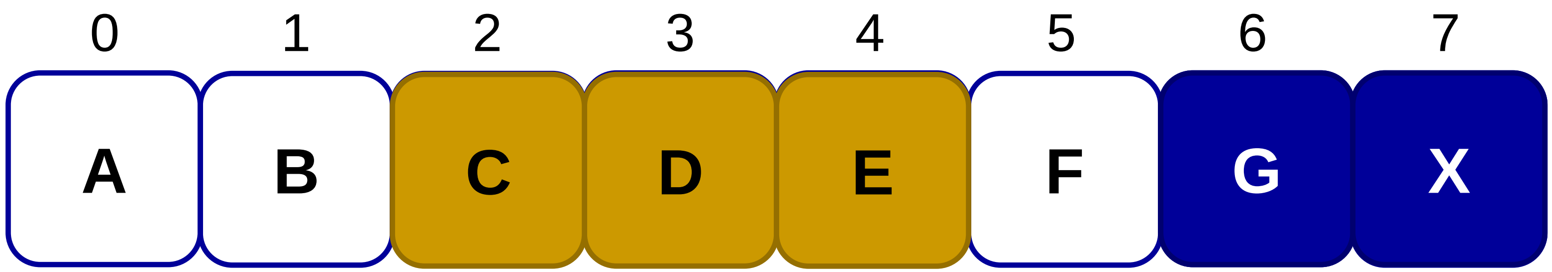

W-Watch 6-7

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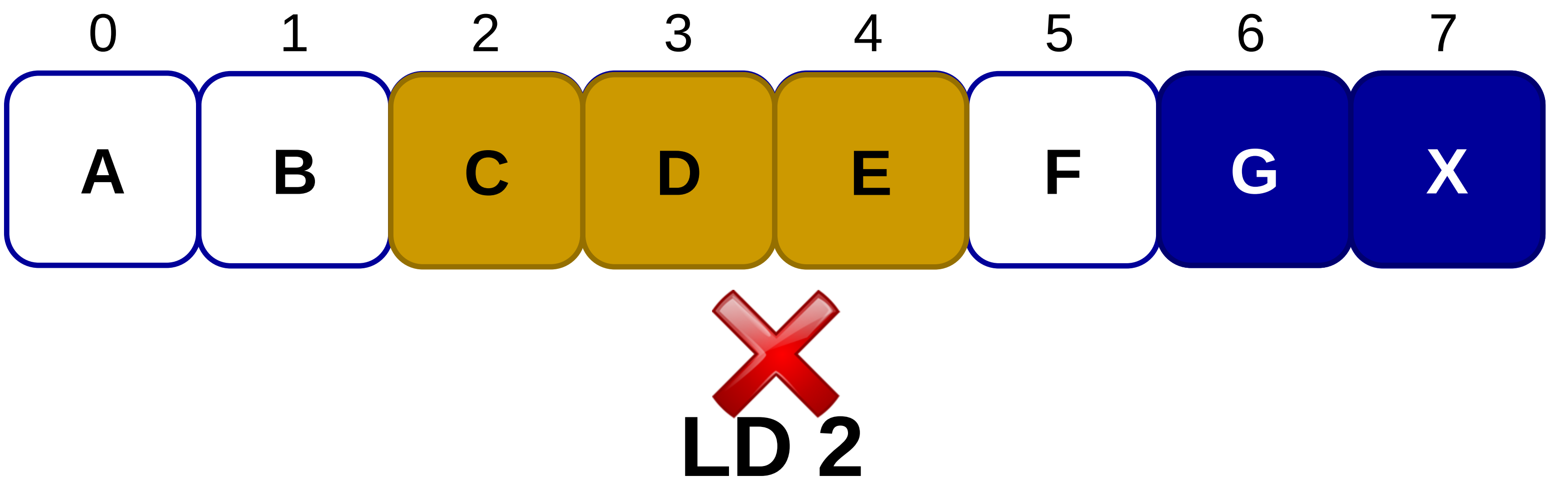

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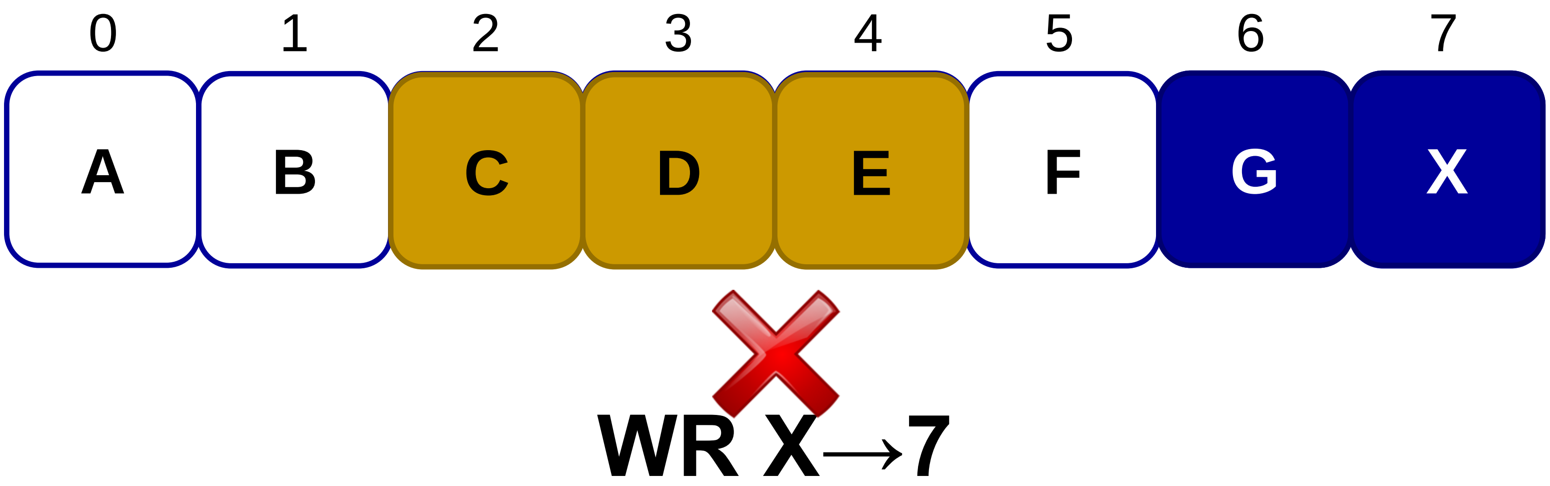

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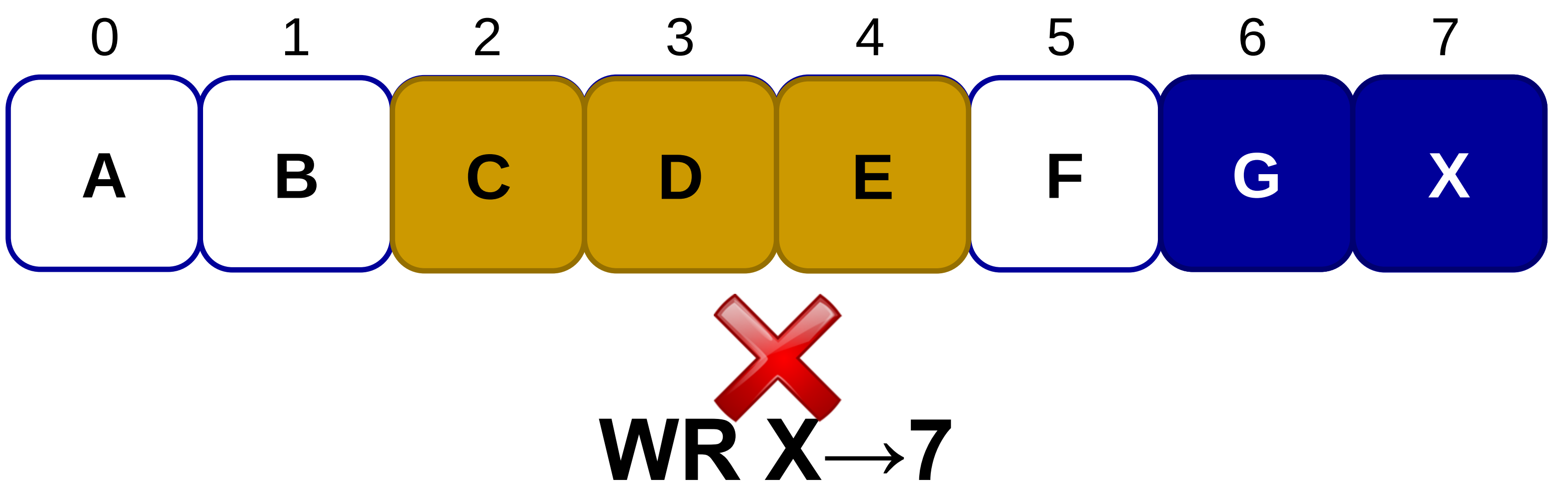

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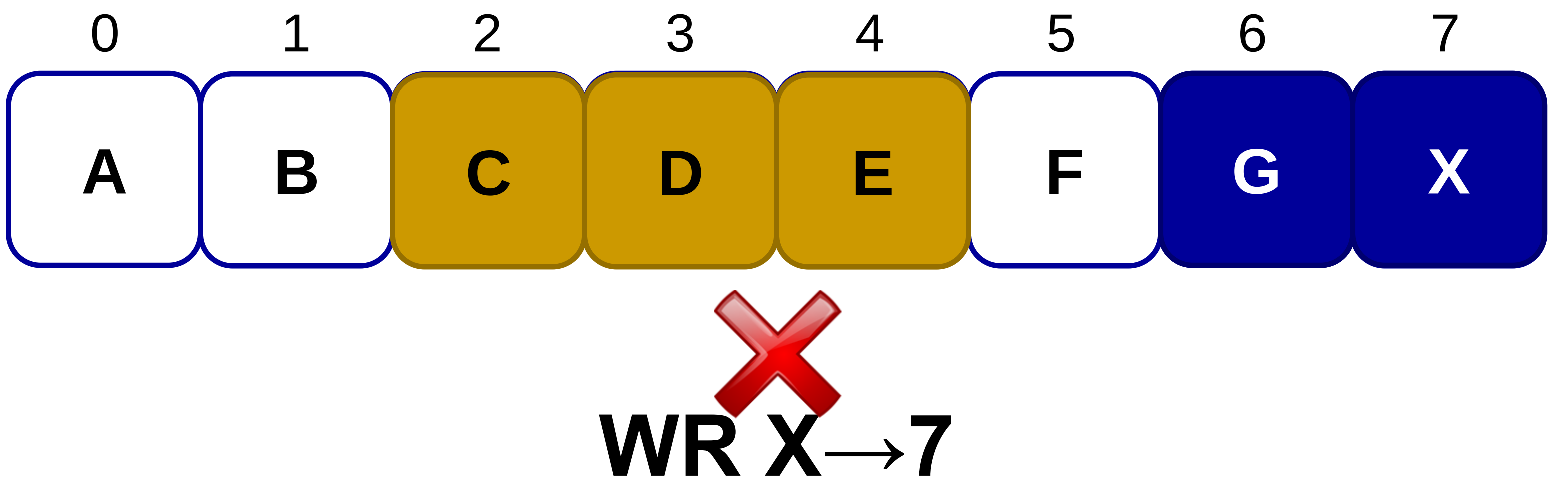

- SW knows it's touching important data
  - AT NO OVERHEAD

Dynamic Software Analysis

Bounds Checking

Data Race Detection

Taint Analysis

Deterministic Execution

Transactional Memory

Speculative Parallelization

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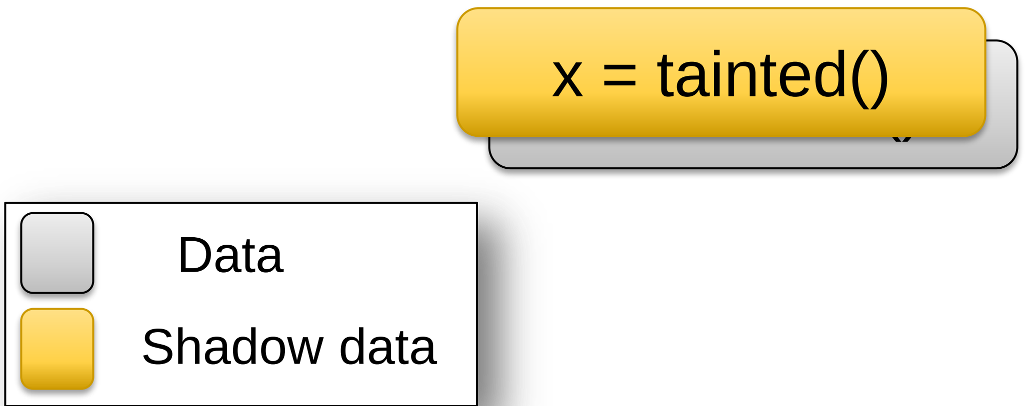
- Taint analysis works on shadow values



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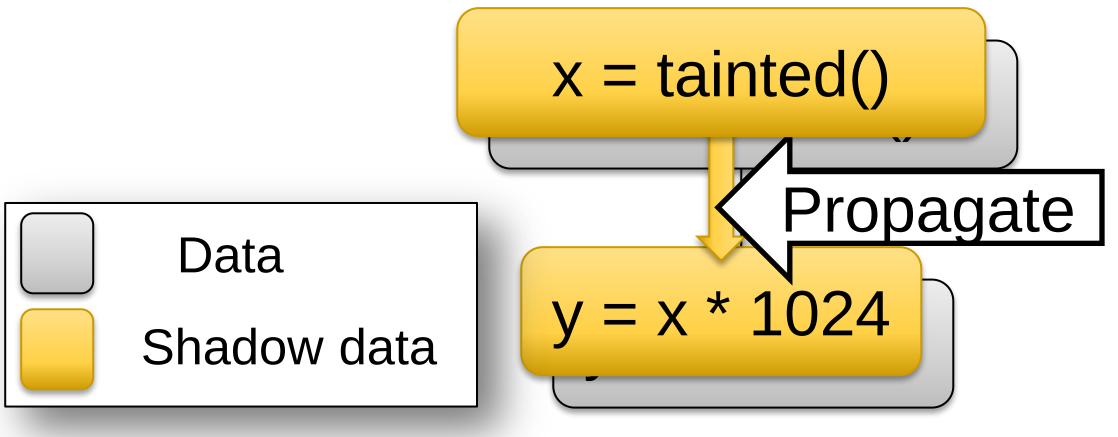

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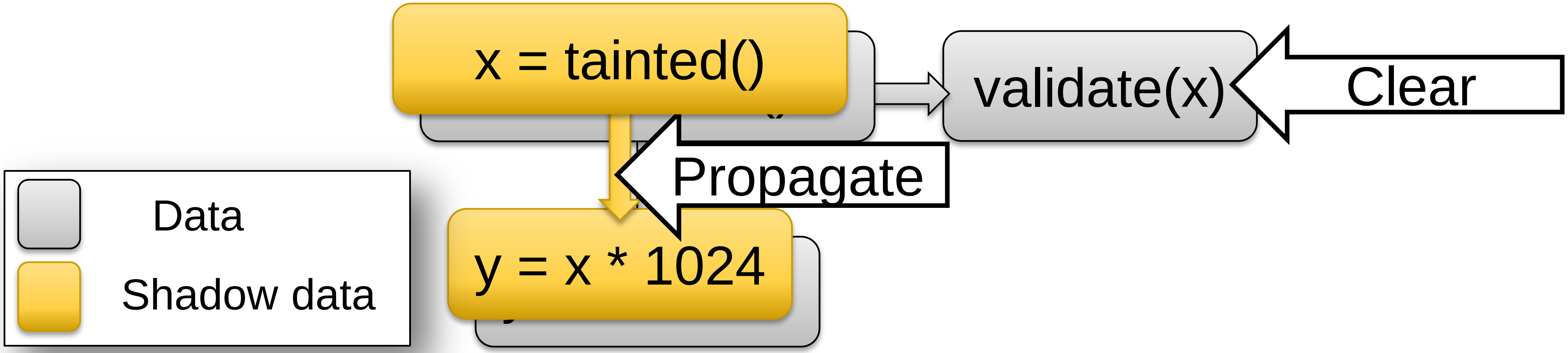

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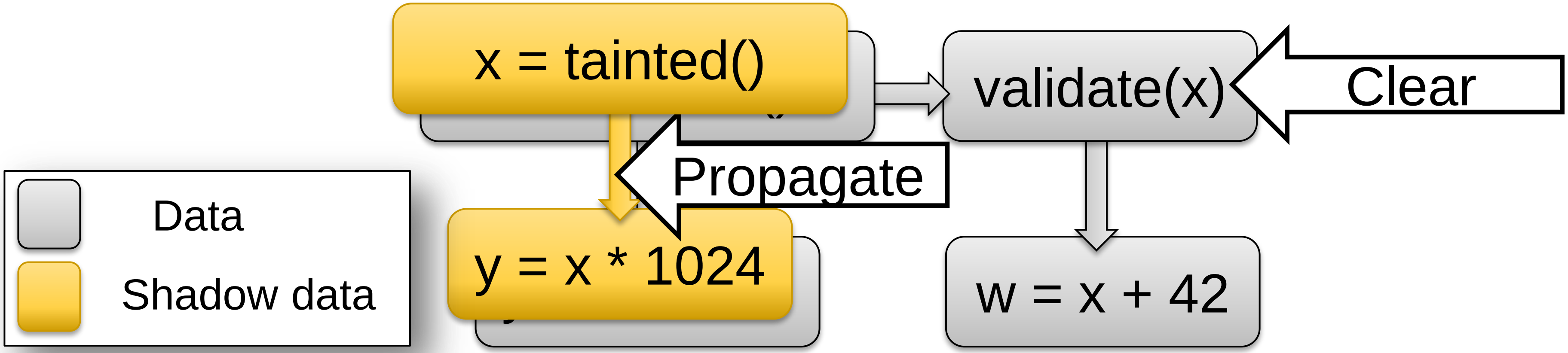

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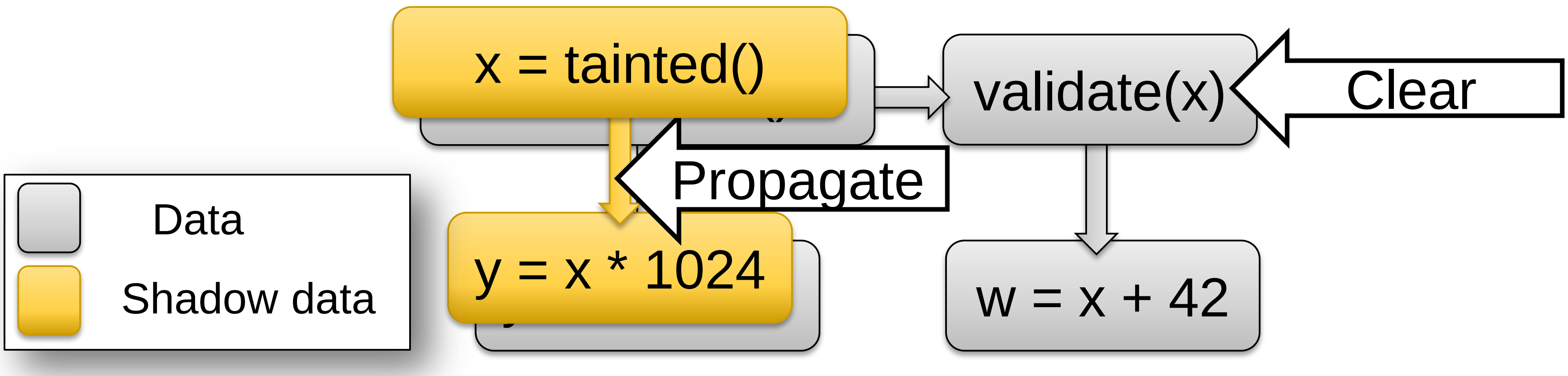

- Set R/W watchpoints on tainted values
- No tainted data? → **Run at full speed**

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- Find inter-thread data sharing, check locks
  - No sharing, no possible data race
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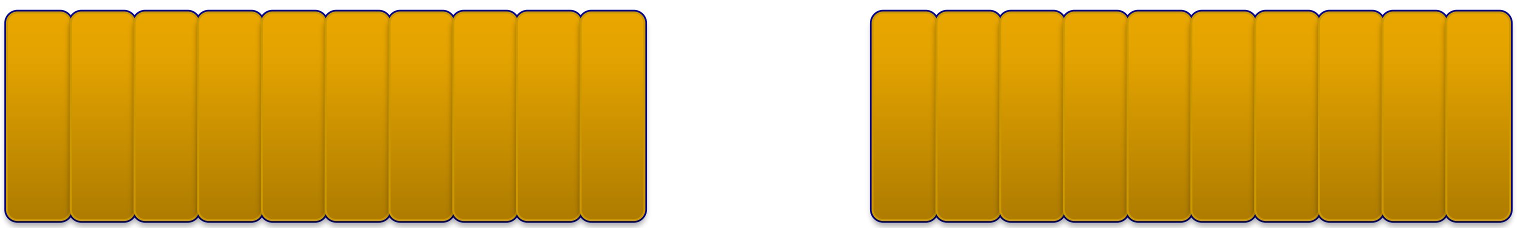

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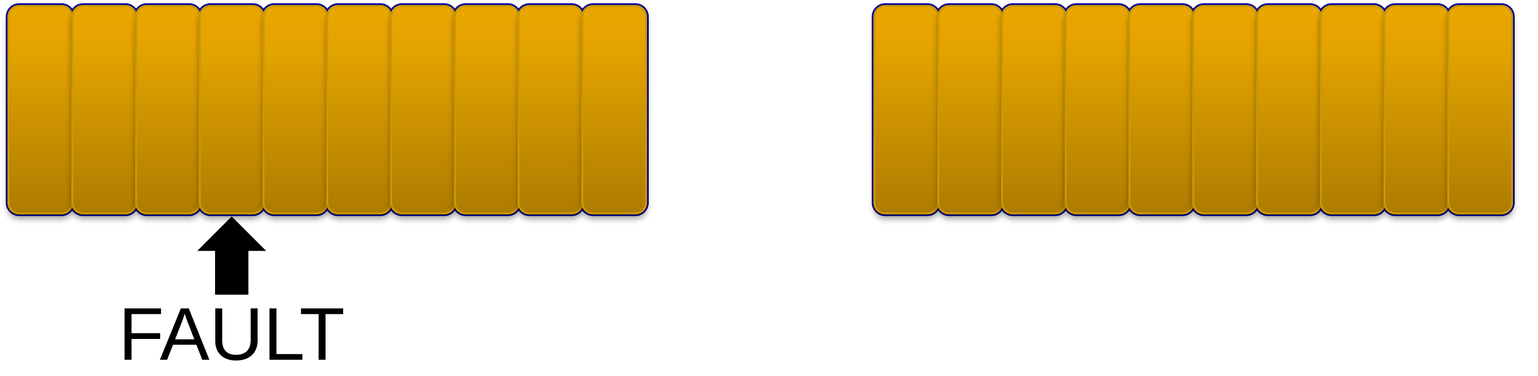

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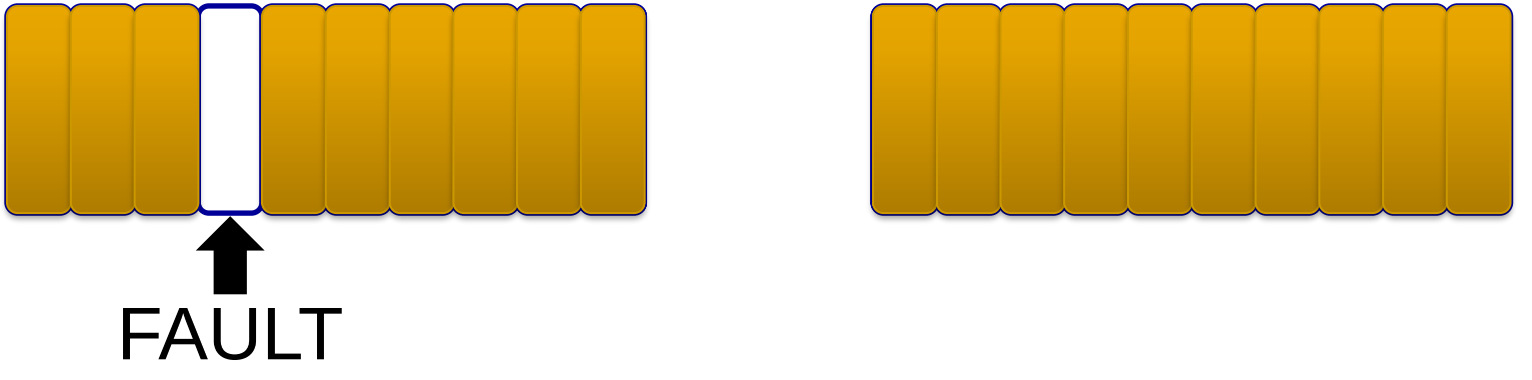

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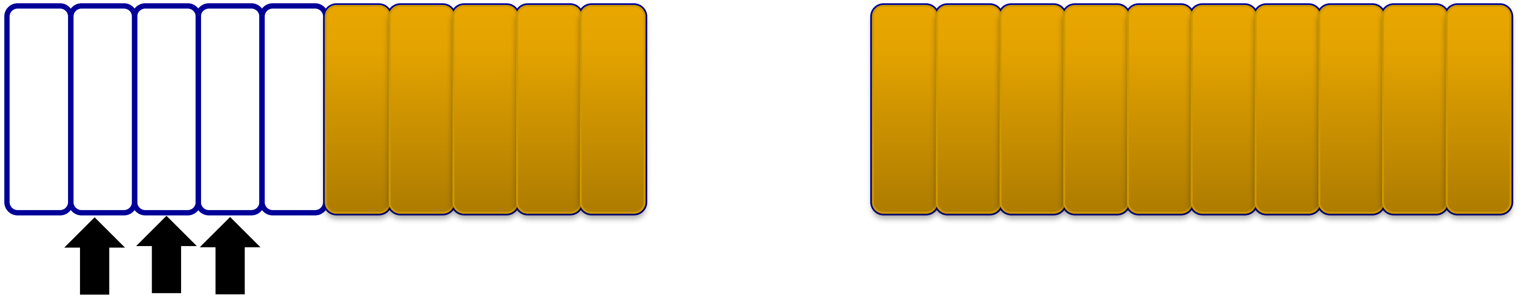

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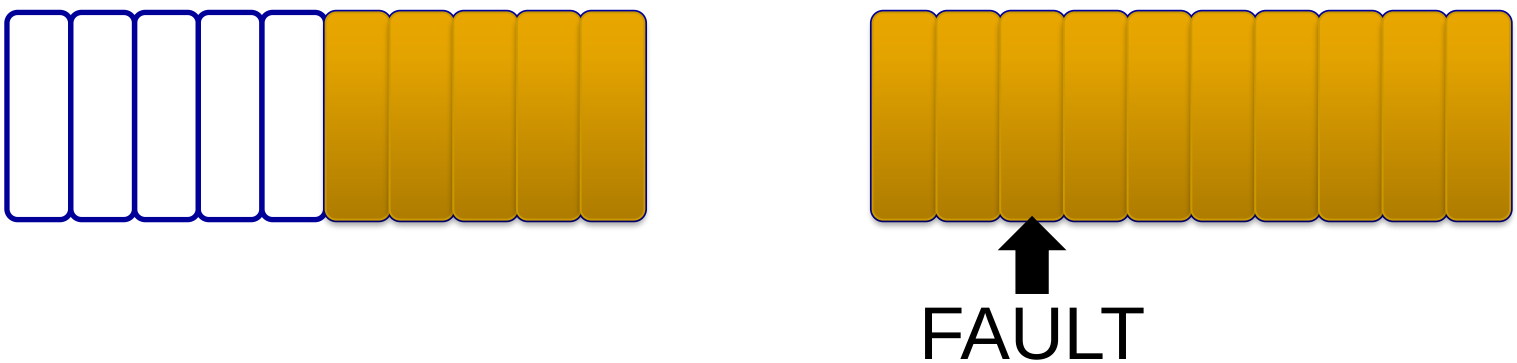

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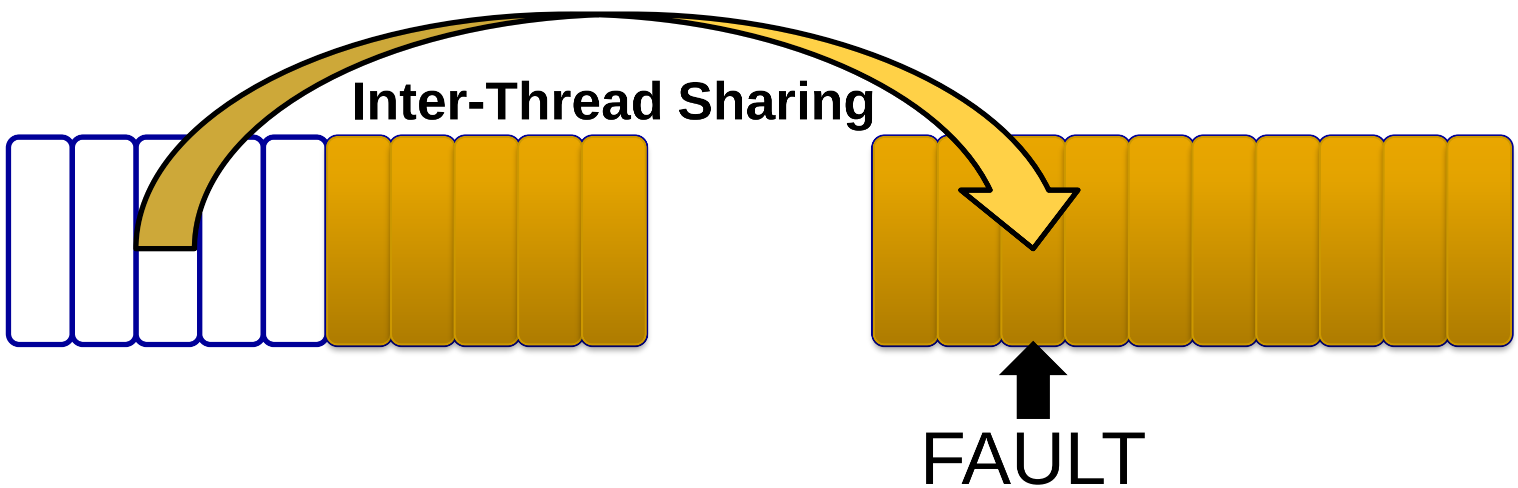
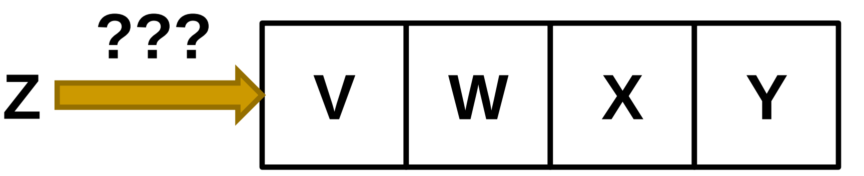


Needed Watchpoint Capabilities

- Large Number



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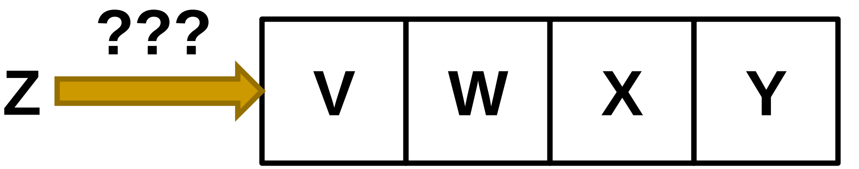
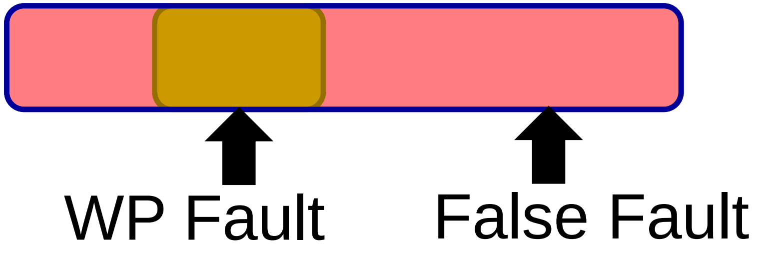
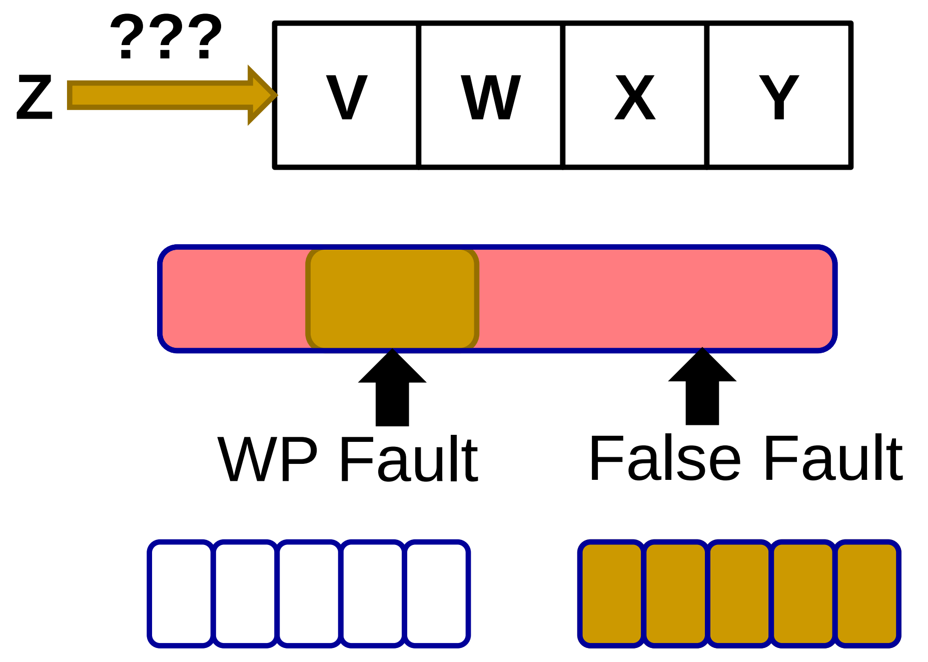


- Fine-grained



Needed Watchpoint Capabilities

- Large Number
- Fine-grained
- Per Thread



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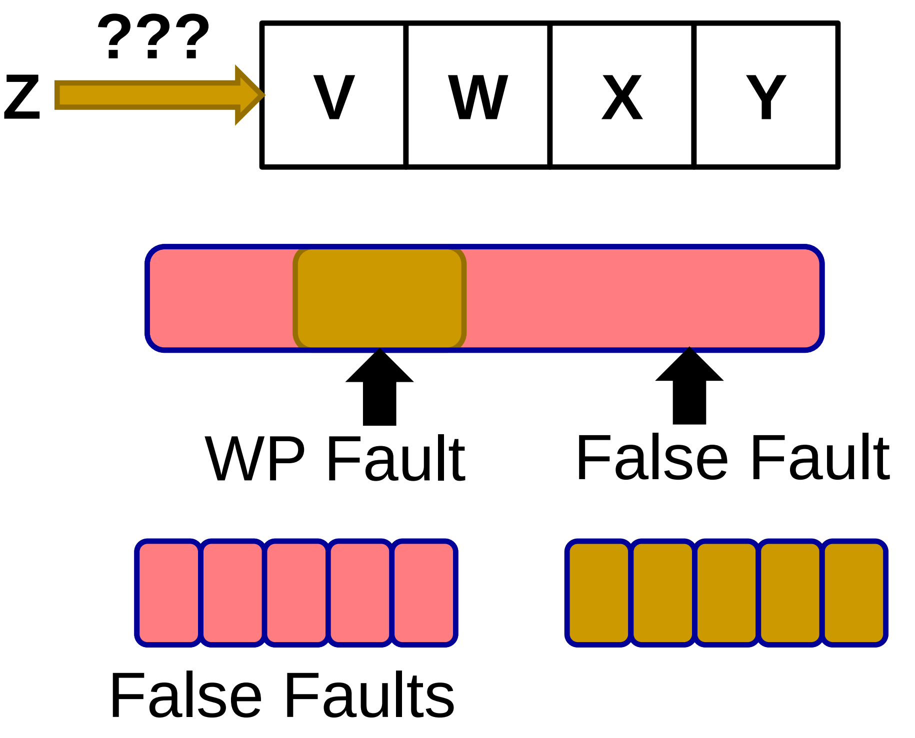

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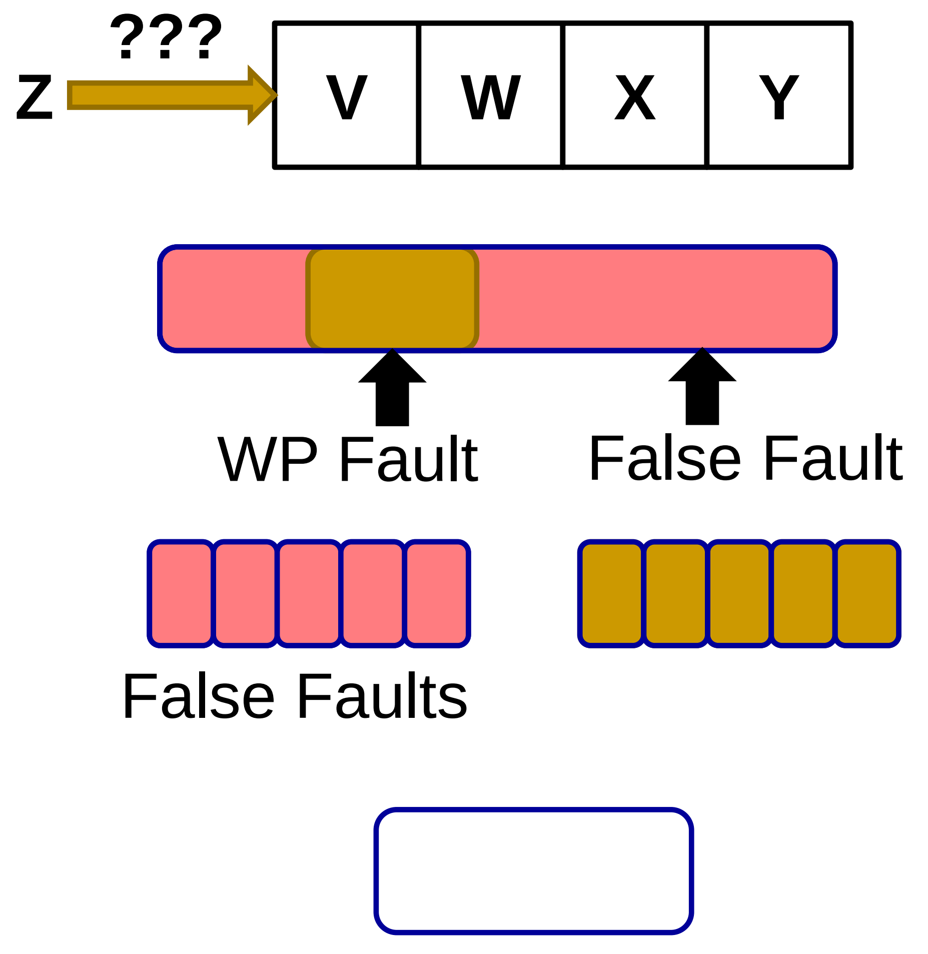

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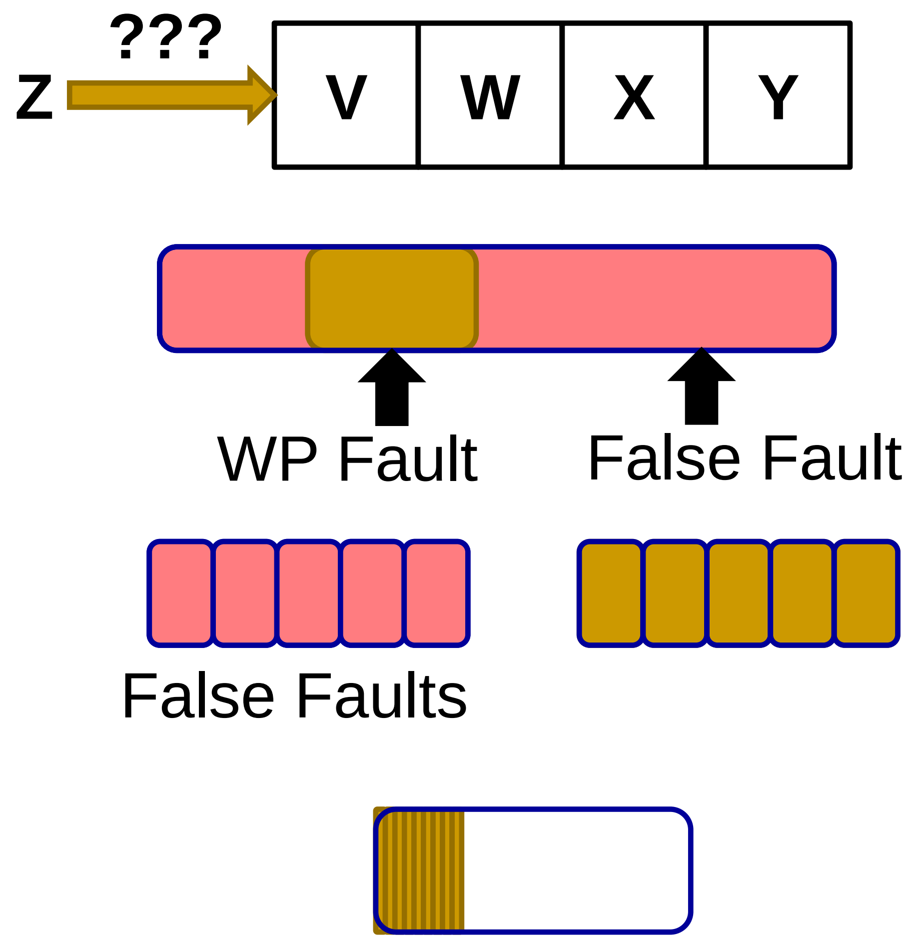

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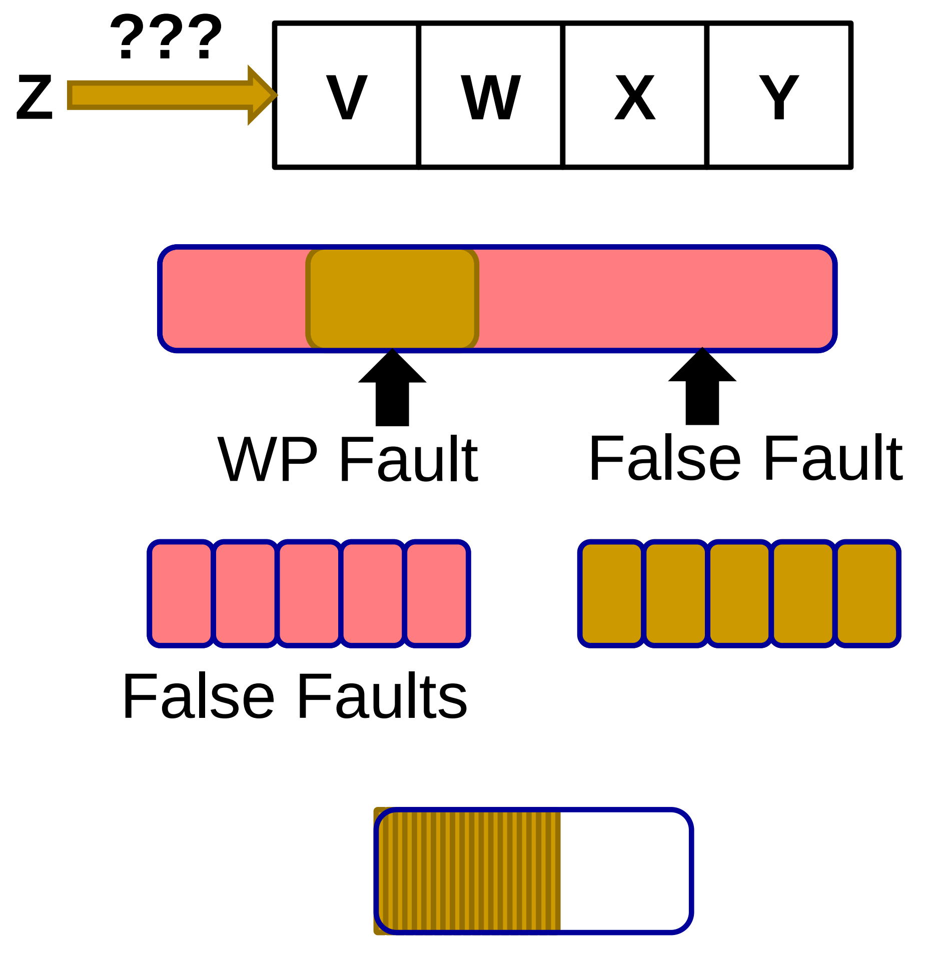

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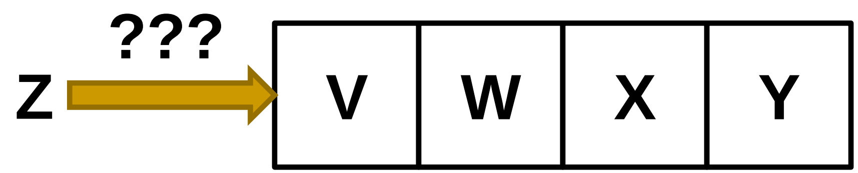

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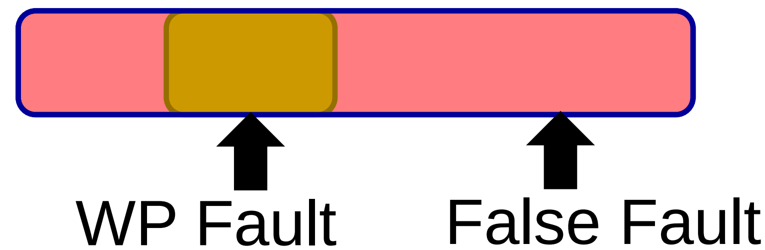
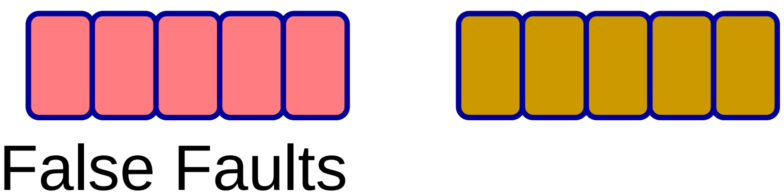
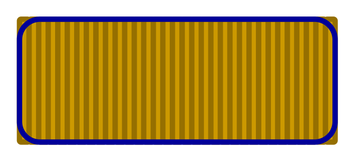


- Per Thread



- Ranges



Needed Watchpoint Capabilities

- Large Number
- Fine-grained
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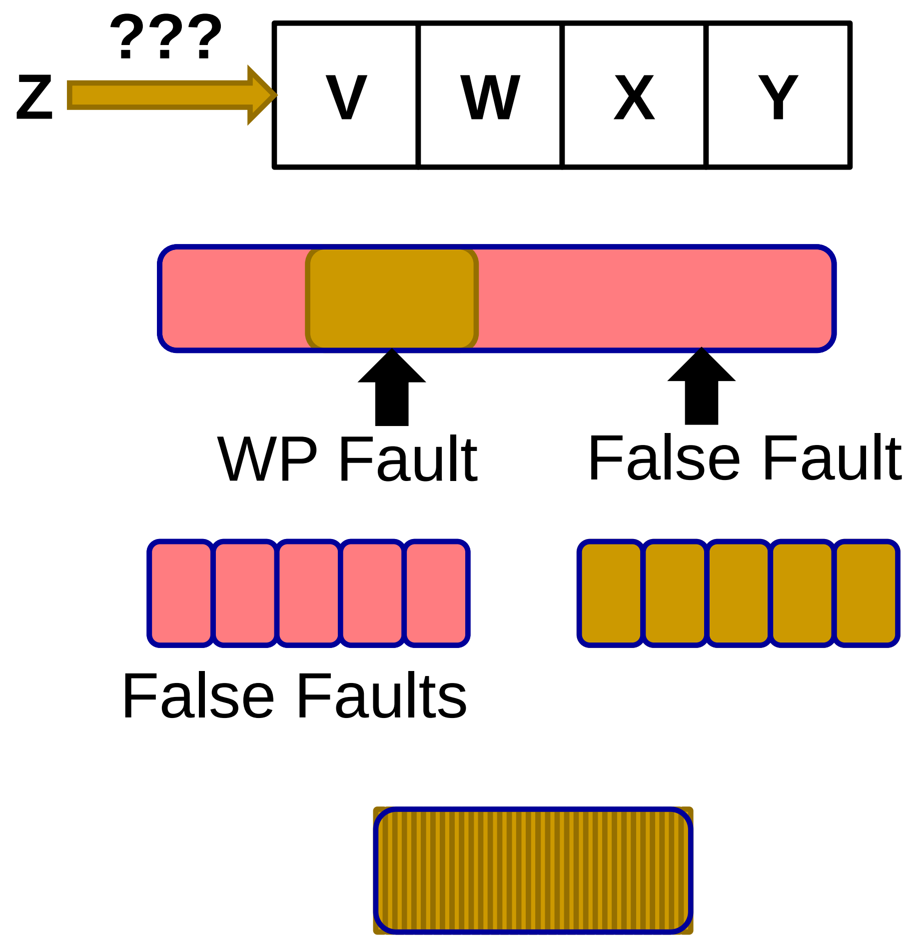
- Others in Paper



Existing Watchpoint Solutions

- Watchpoint Registers
  – Limited number (4-16), small reach (4-8 bytes)

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  - Coarse-grained, per-process, *only* aligned ranges
- ECC Mangling
  - Per physical address, all cores, no ranges

Meeting These Requirements

- Unlimited Number of Watchpoints
  - Store in memory, <u>cache</u> on chip
- Fine-Grained
  - Watch full virtual addresses
- Per-Thread
  - Watchpoints cached per core/thread
  - TID Registers
- Ranges
  - **Range Cache**

Range Cache

Start Address	End Address	Watchpoint?	Valid
0x0	0xffff_ffff	Not Watched	1
			0
			0

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Set Addresses
0x5 – 0x2000
R-Watched

Range Cache

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0x0	0x4	Not Watched	1
0x5	0x2000	R Watched	1
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Load Address
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WP Interrupt

Load Address 0x400

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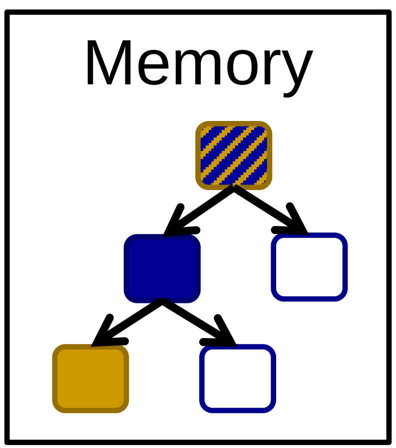

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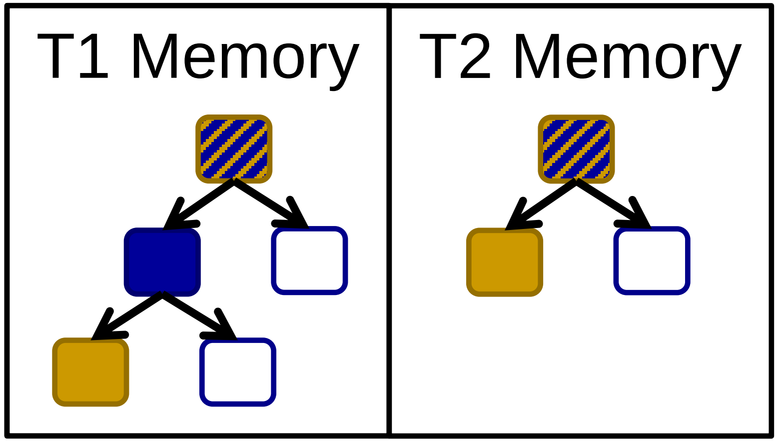

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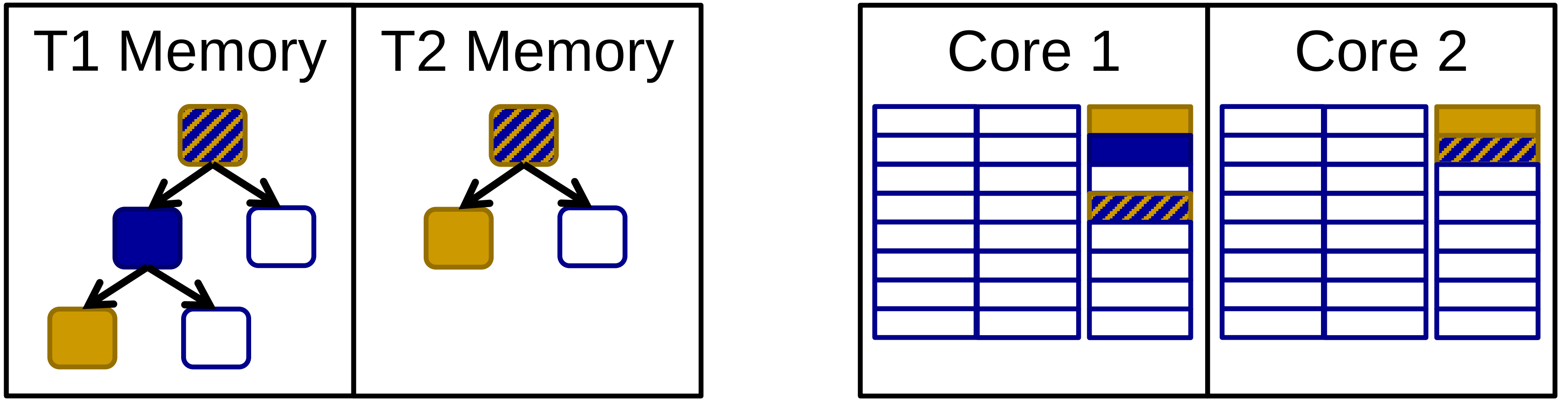

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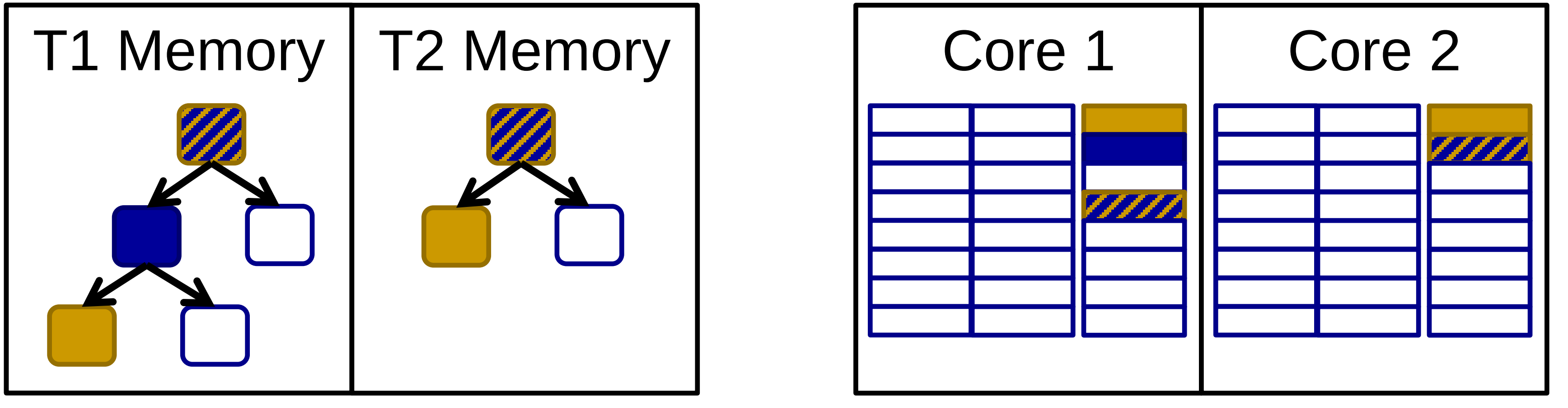

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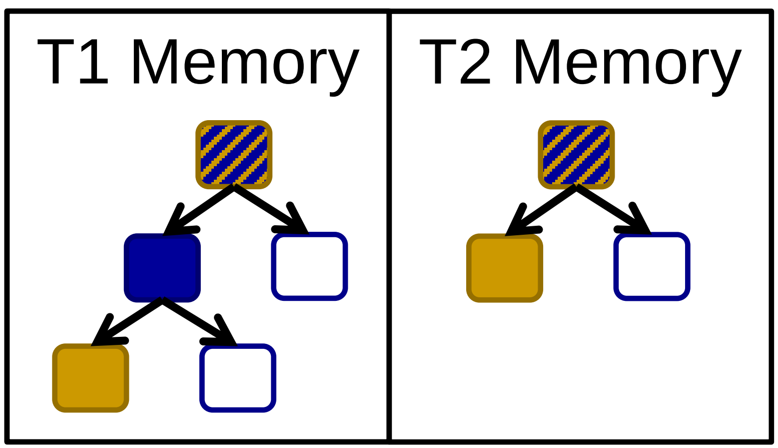

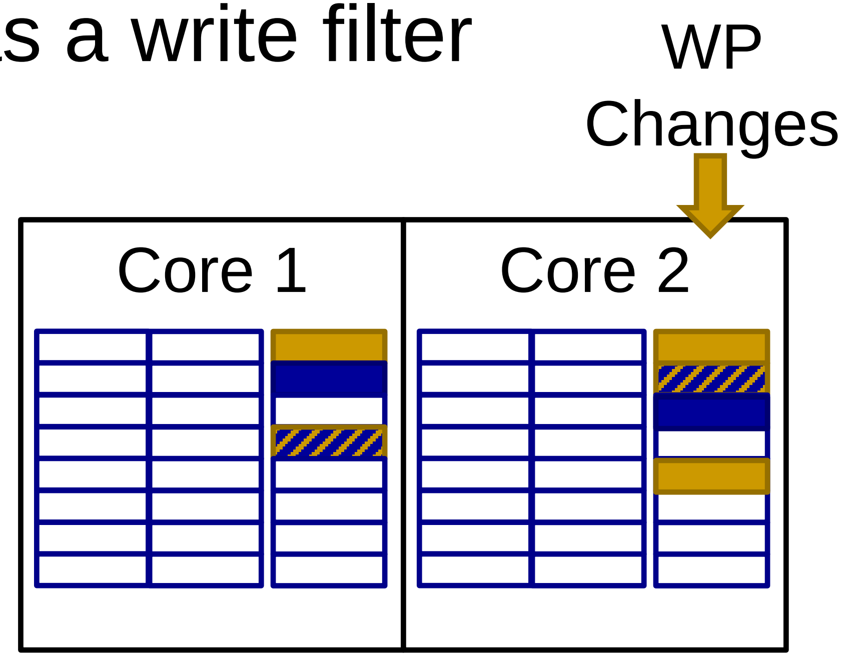

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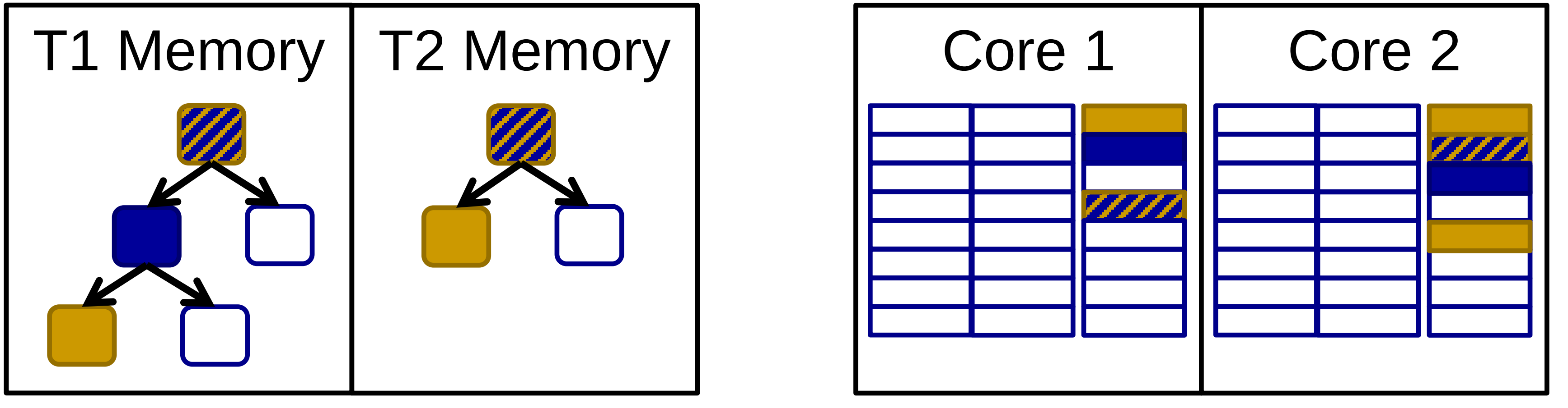


Experimental Evaluation Setup

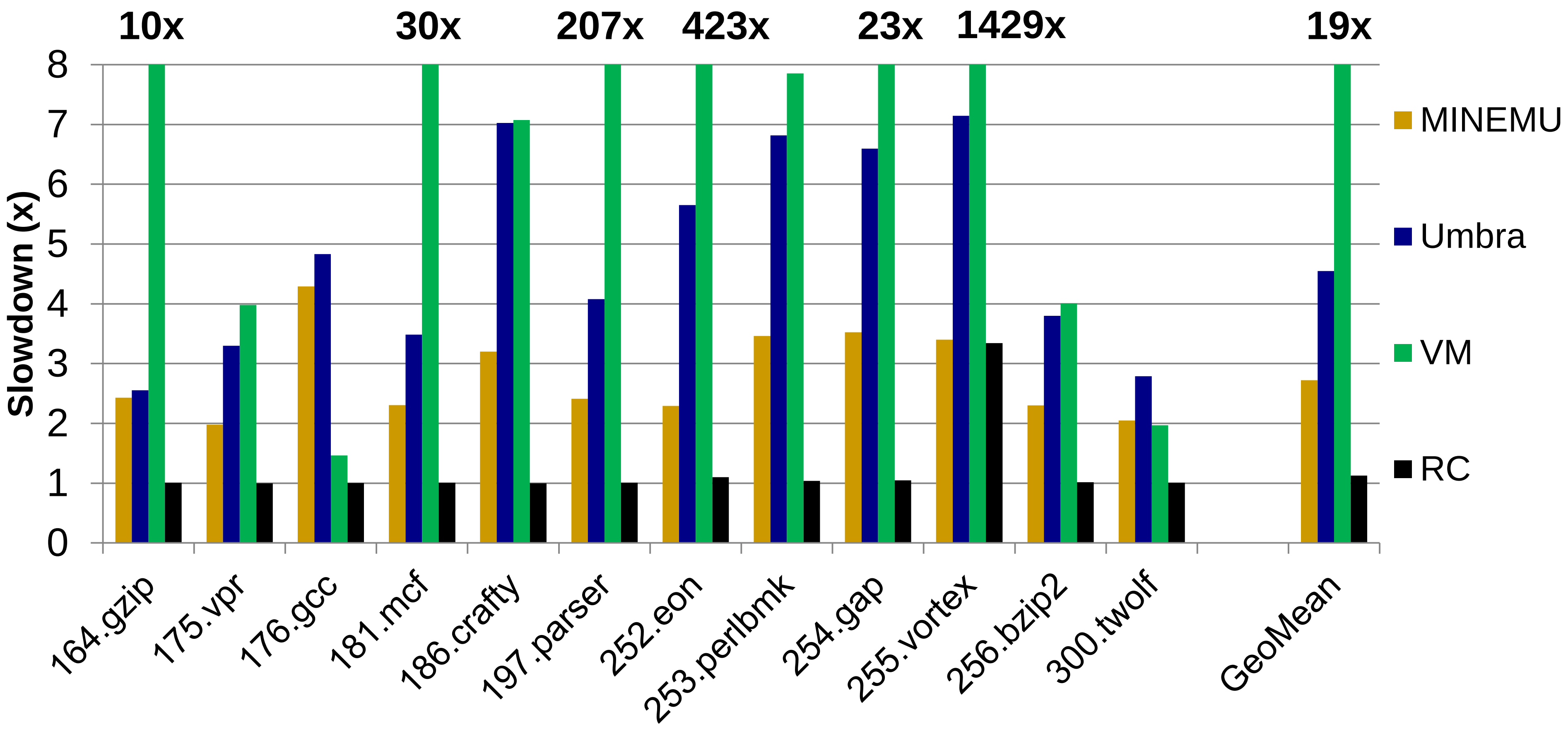
- Pin-based Simulation
  - Every memory access through HW simulator
  - Count pipeline-exposed events
  - Record all other events
- Trace-based timing simulator

- Taint analysis on SPEC INT2000
- Race Detection on Phoenix and PARSEC

- <u>Comparing only shadow value checks</u>

Watchpoint-Based Taint Analysis

- 128 entry Range Cache



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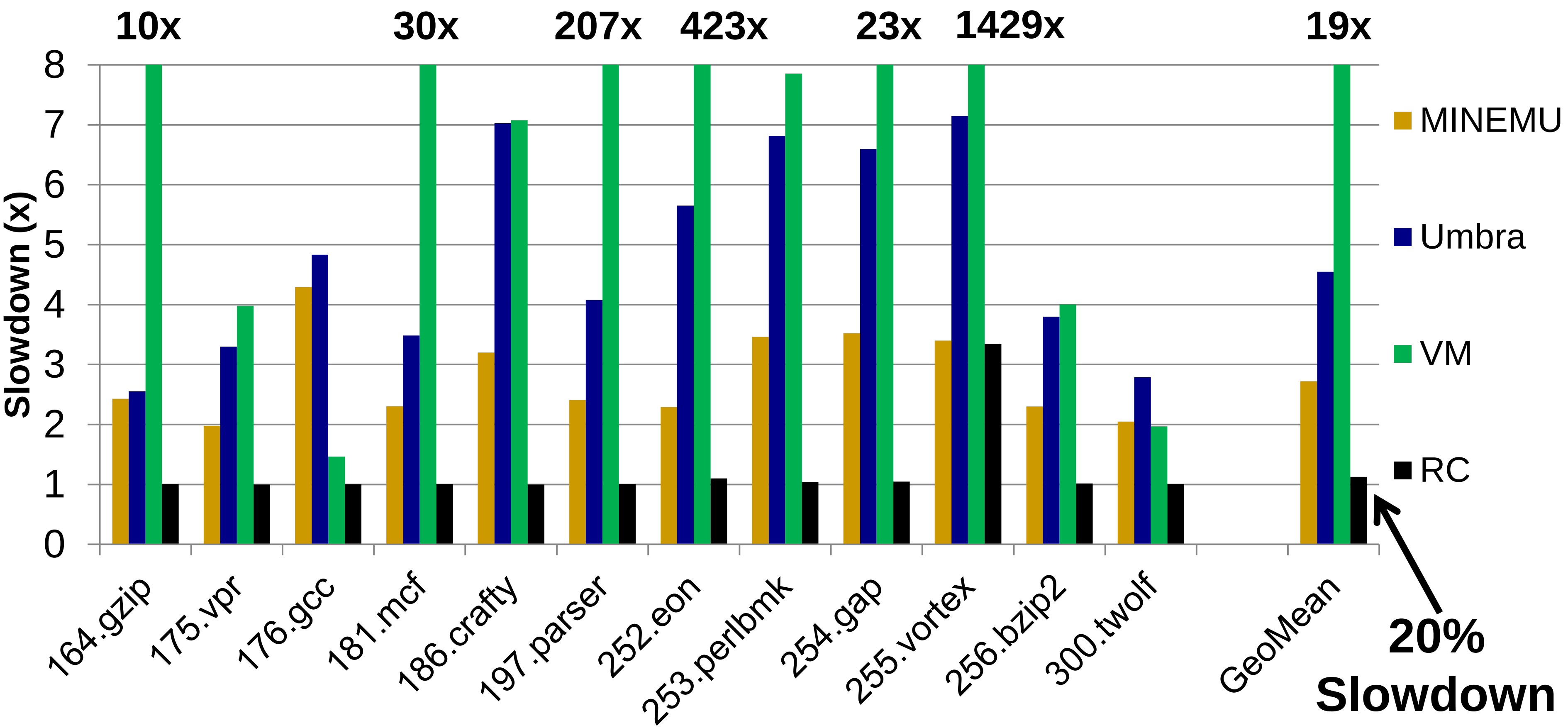

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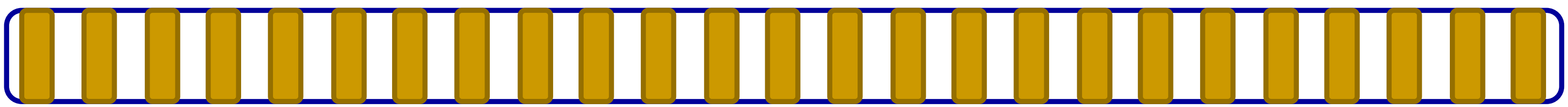

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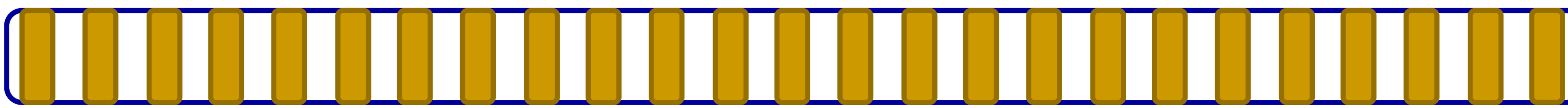

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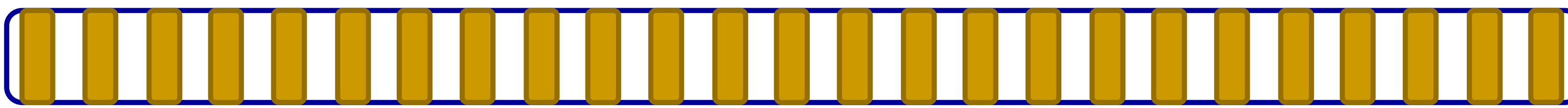

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- Taint analysis has good ranges
- Byte-accurate race detection does not..

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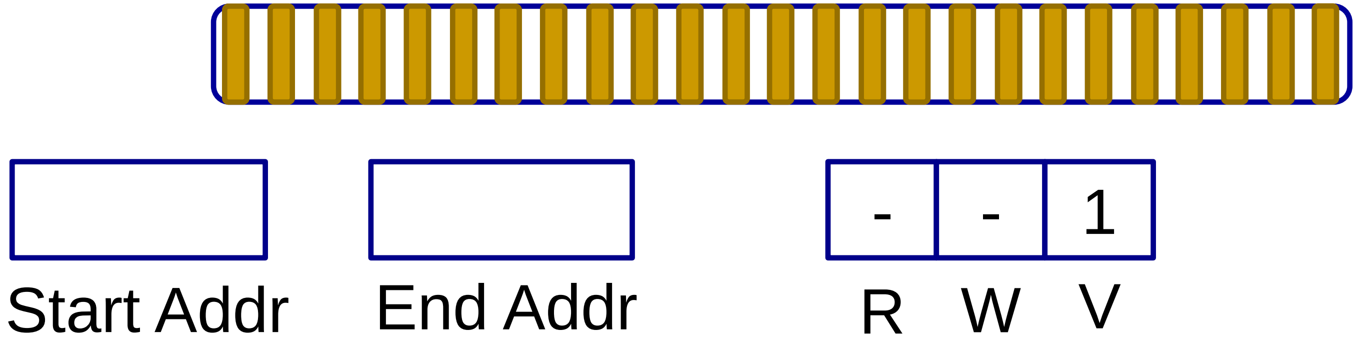

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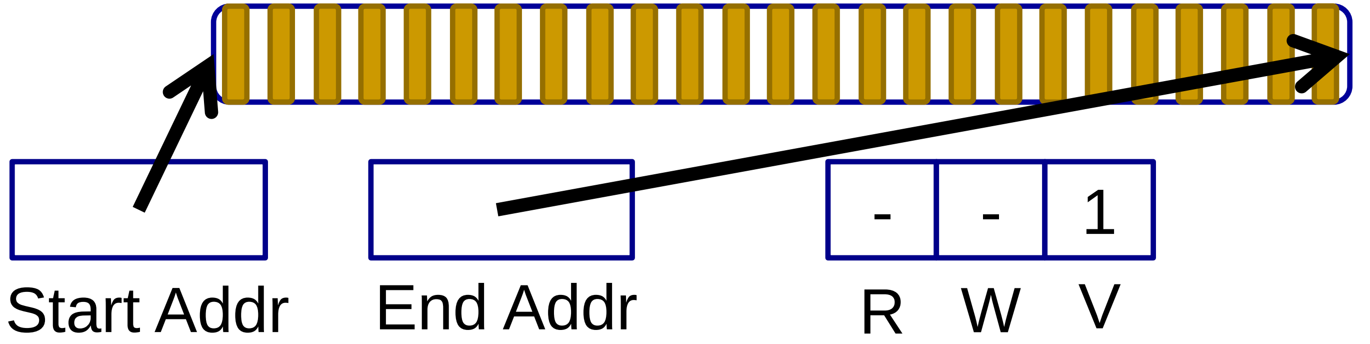

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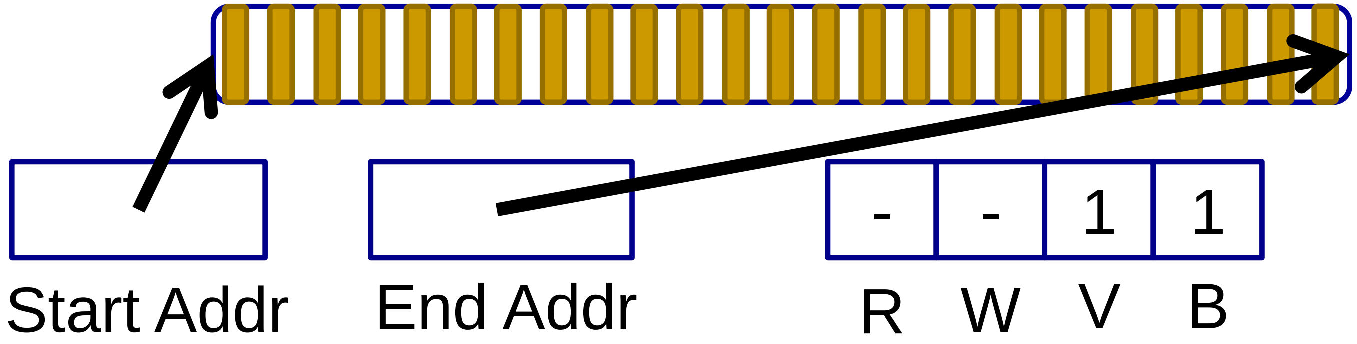

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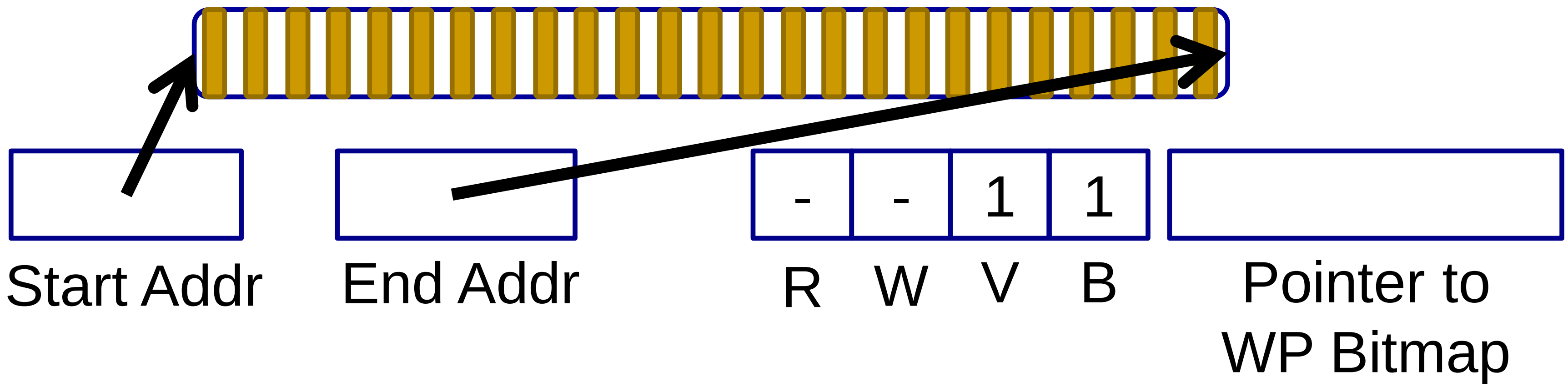

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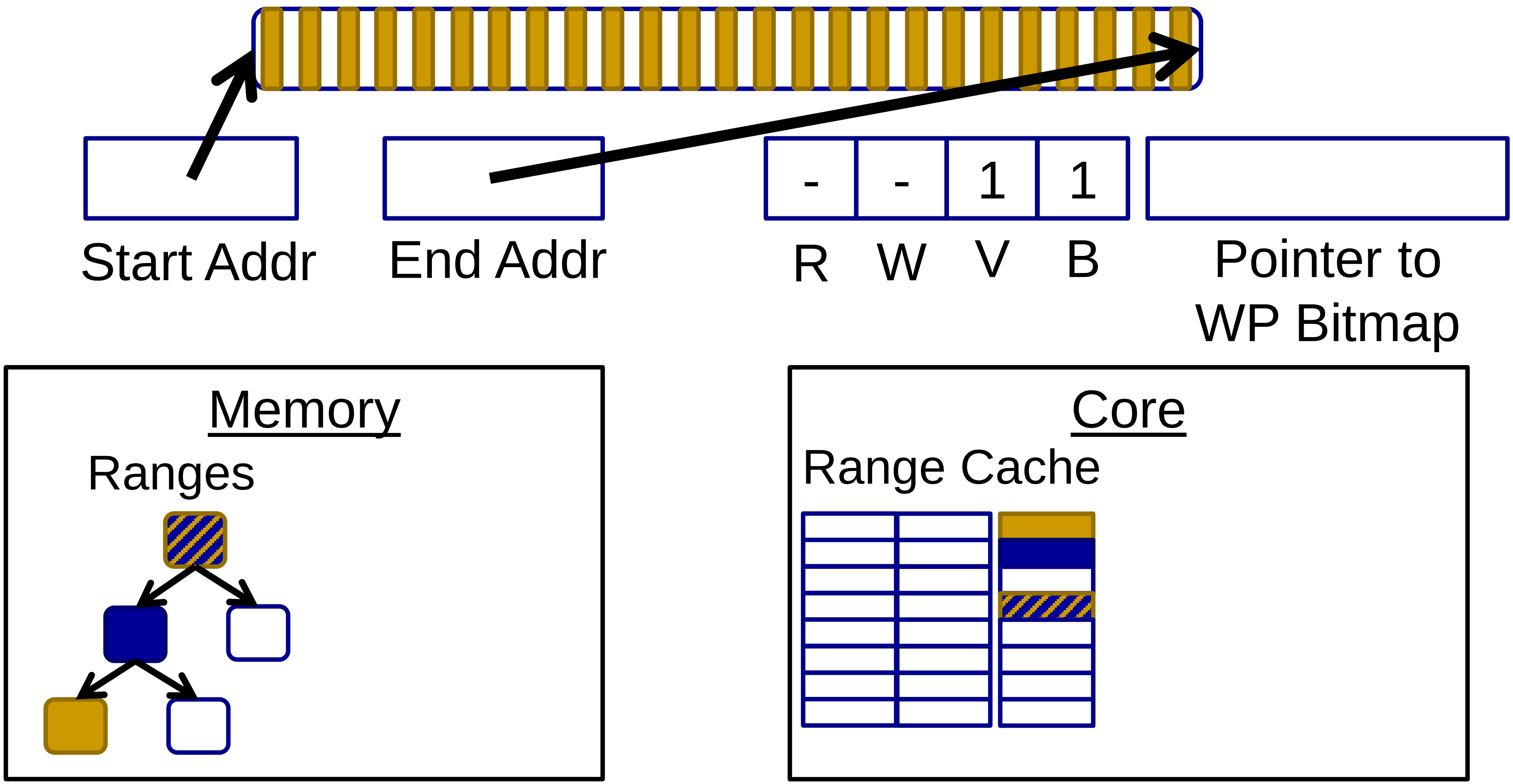

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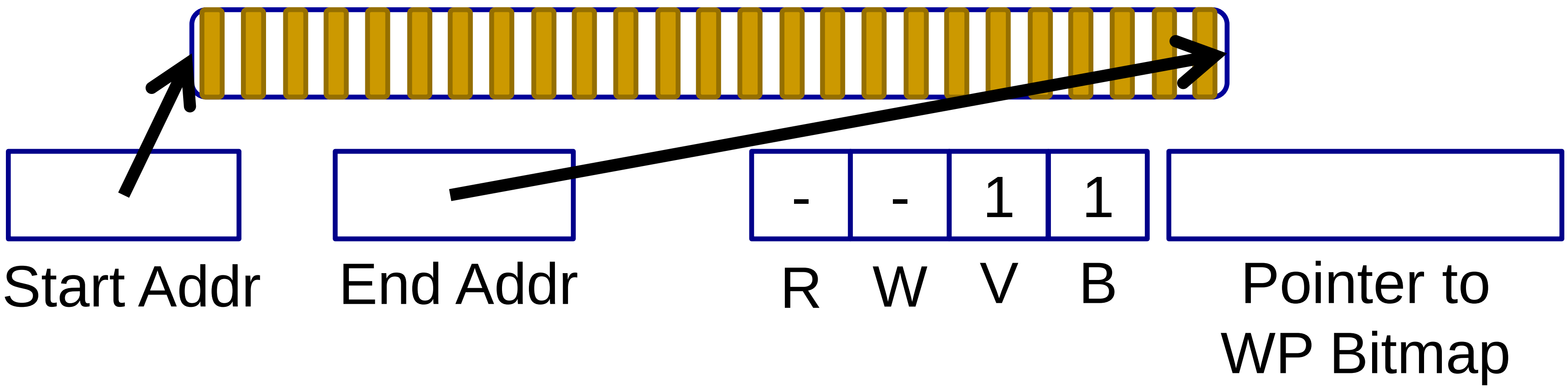

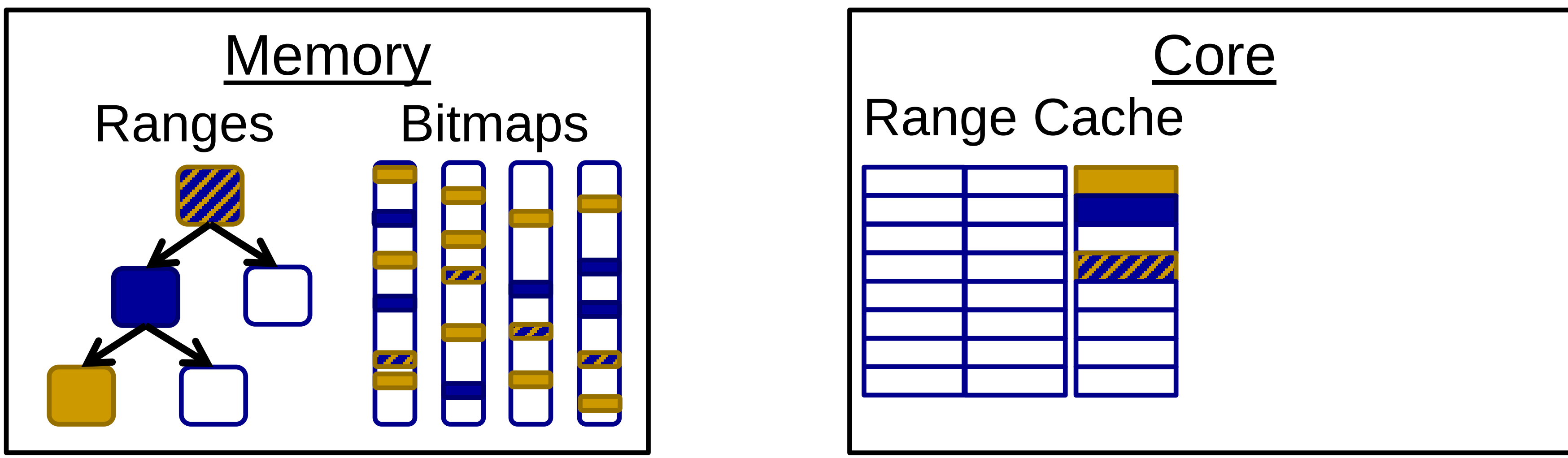

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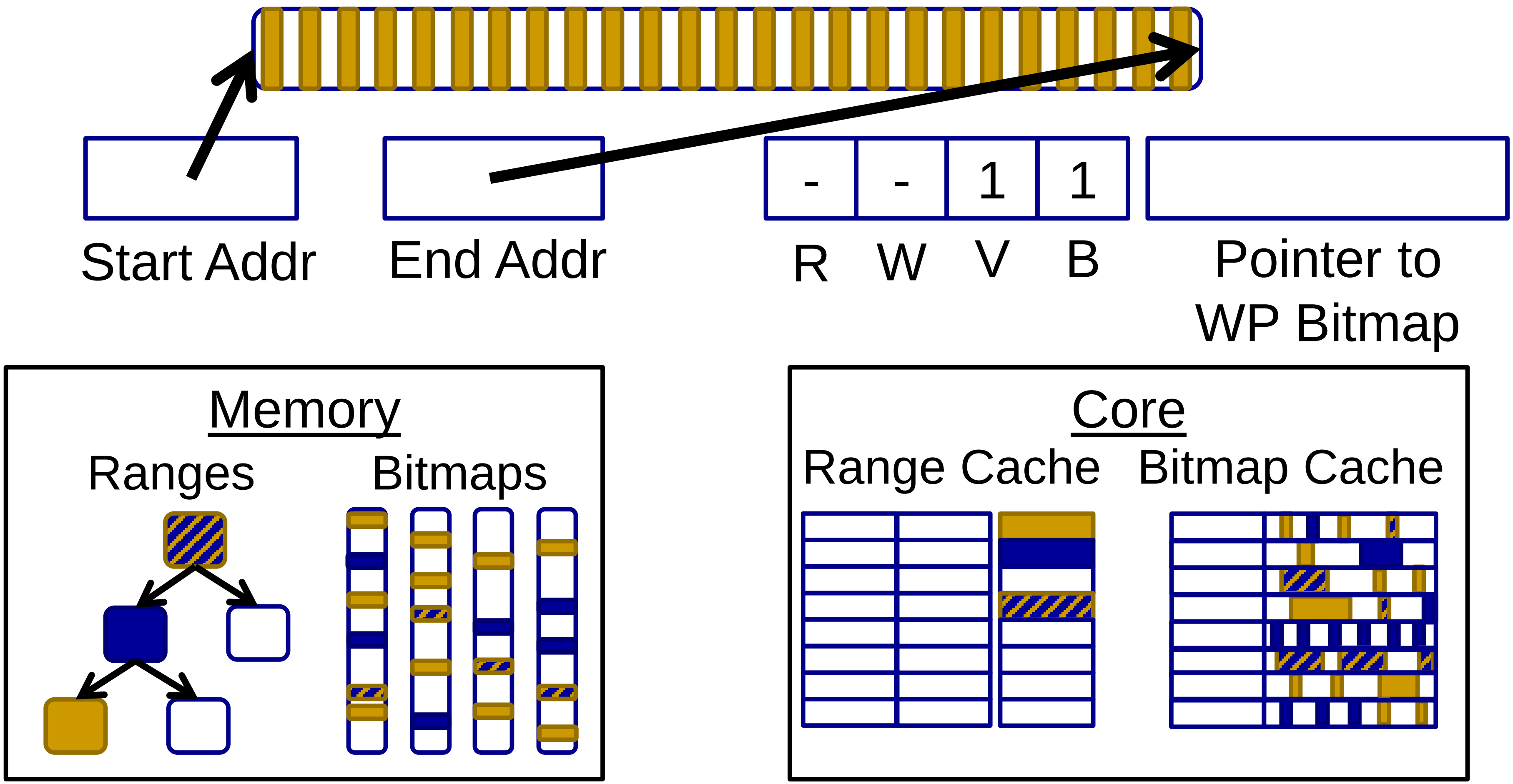

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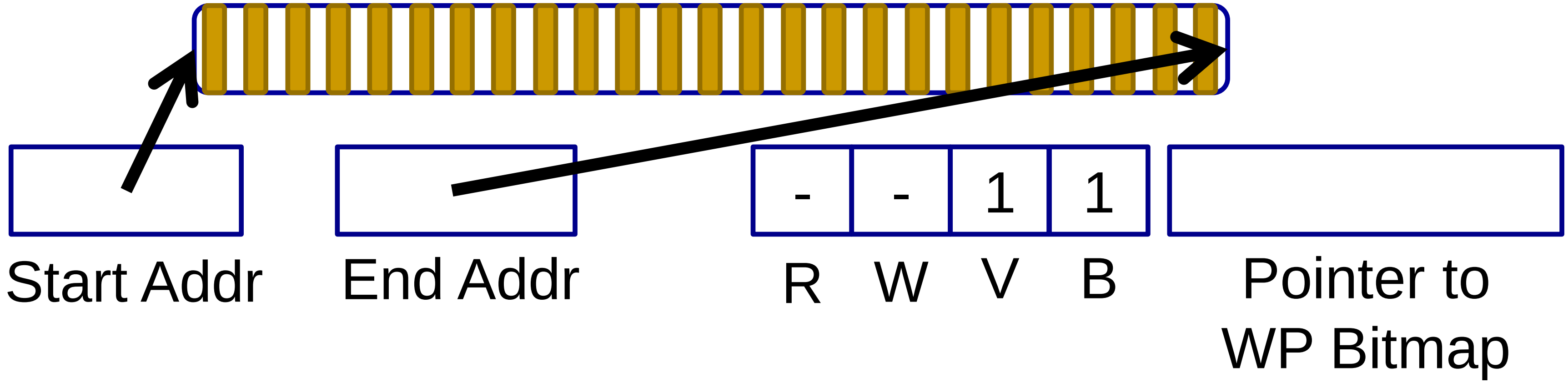
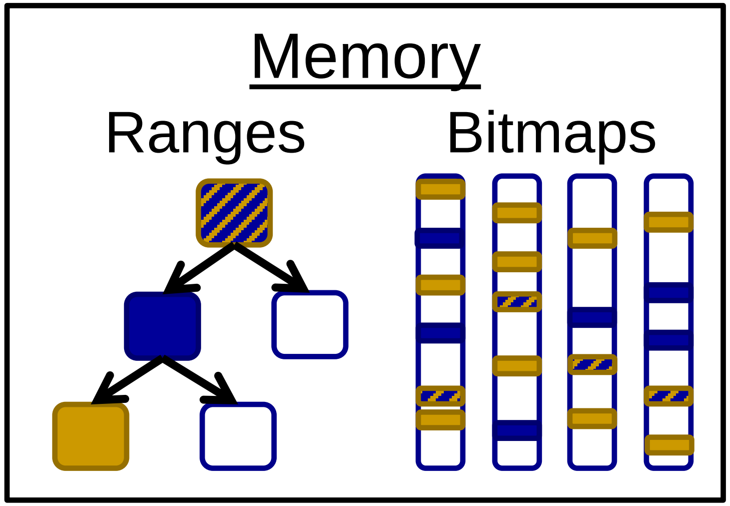
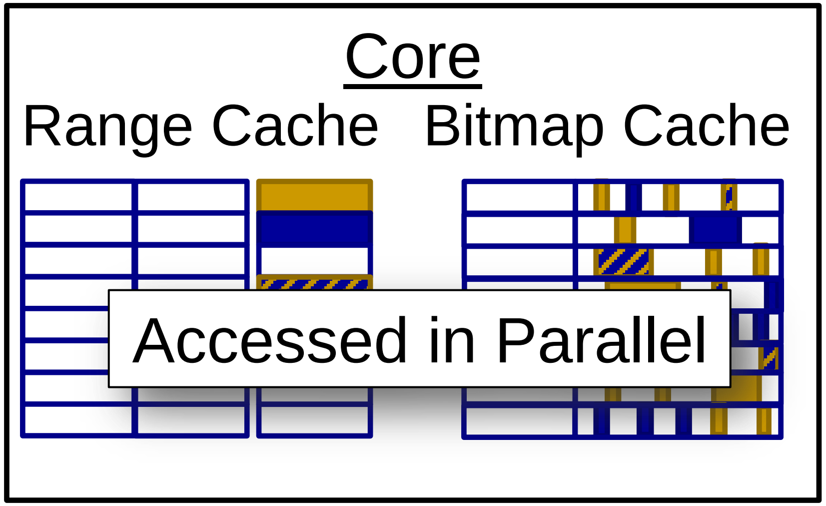
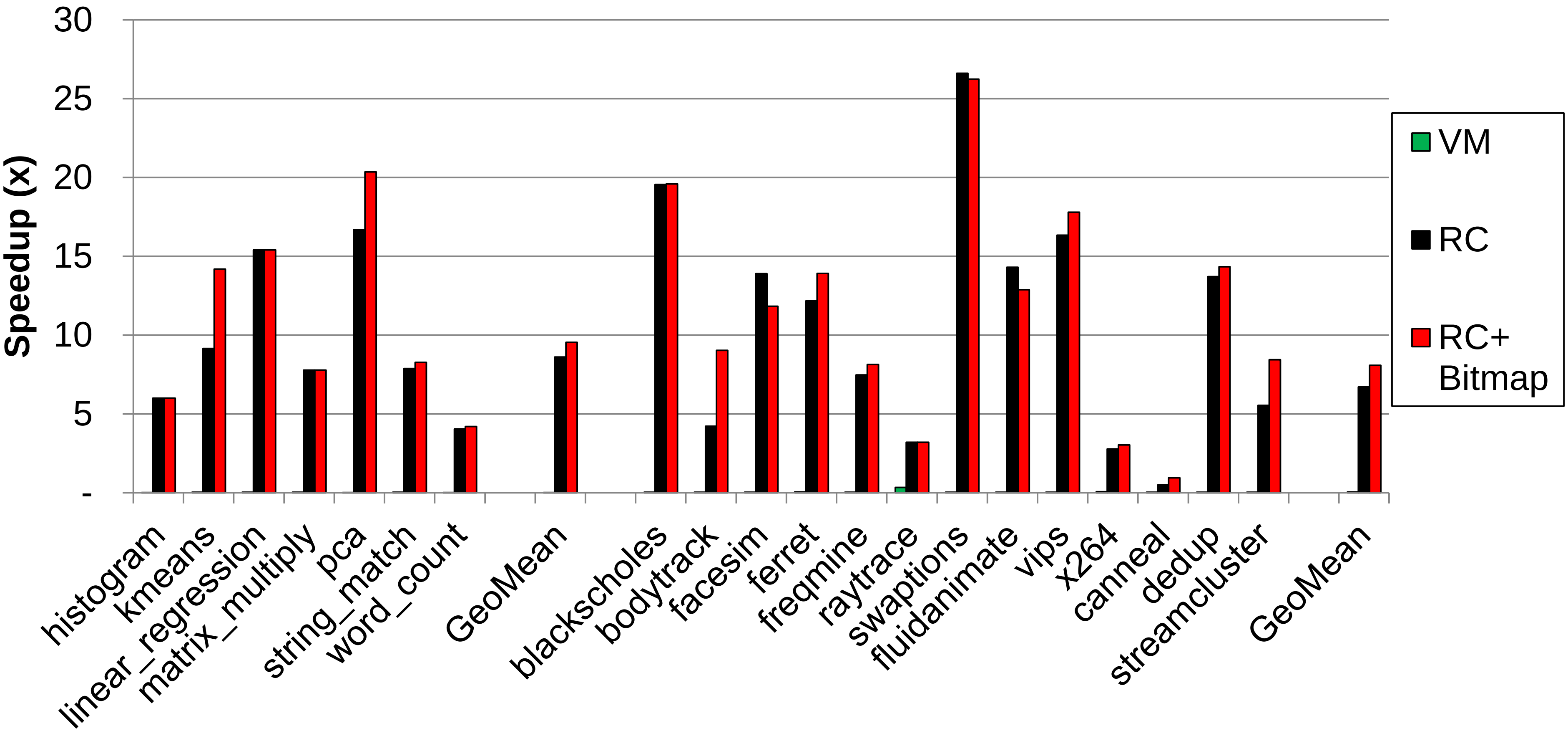






Watchpoint-Based Data Race Detection

- RC now 64 entries, added 2KB bitmap cache



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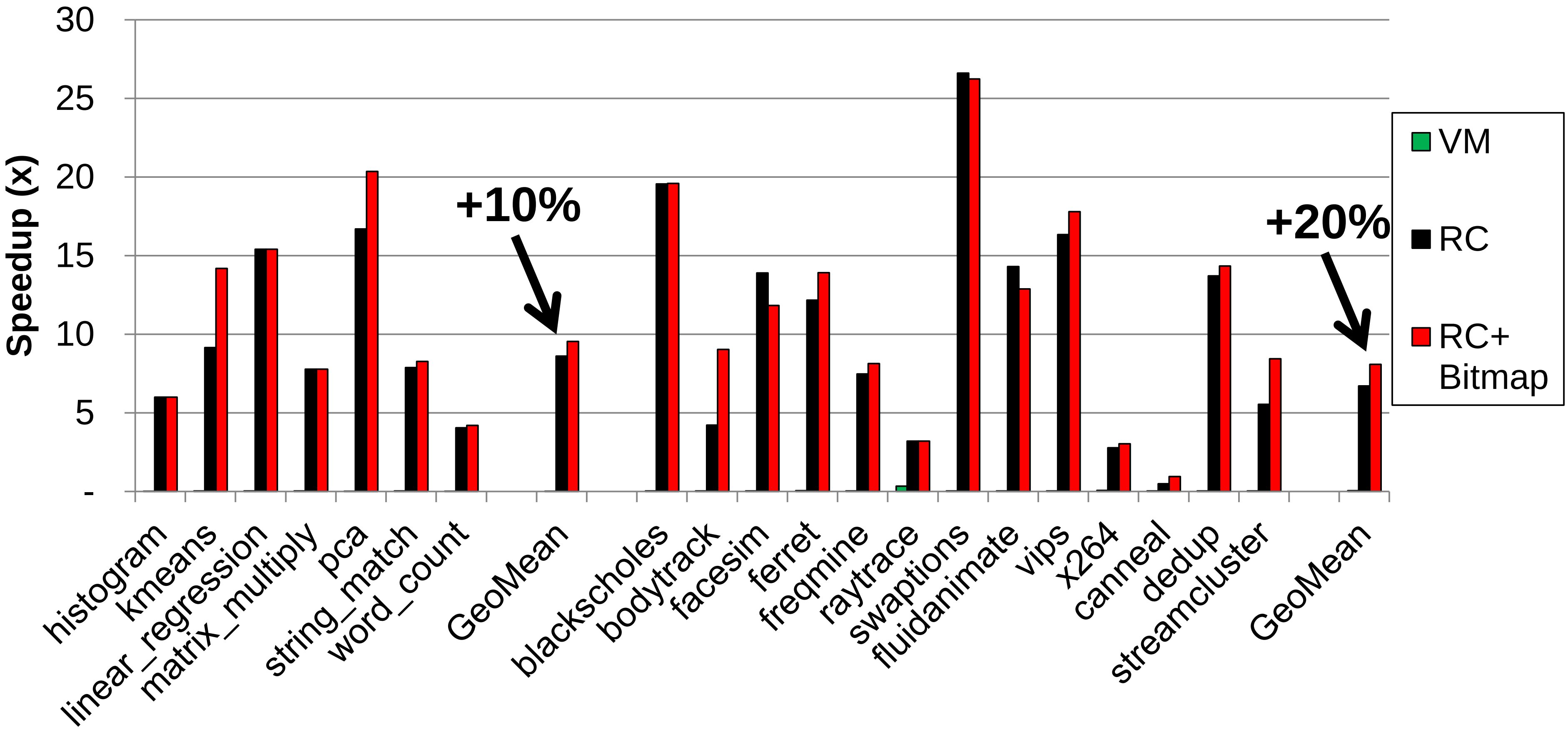

Conclusions & Future Directions

- **Watchpoints** a useful generic mechanism
- Numerous SW systems can utilize a well-designed WP system
- In the future:
  - Clear microarchitectural analysis
  - **More** software systems, different algorithms

Thank You

BACKUP SLIDES

Existing Watchpoint Solutions

- Watchpoint Registers
  - \+ Fine-grained, *can* be per-thread
  - – Limited number (4-16), small reach (4-8 bytes)
- Virtual Memory
  - \+ Virtually unlimited number
  - – Coarse-grained, per-process, *only* aligned ranges
- ECC Mangling
  - \+ Unlimited, finer-grained
  - – Per physical address, no ranges

Width Test