Finanziato dall'Unione europea
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Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

SERICS
SECURITY AND RIGHTS IN THE CYBERSPACE

QMSan: Efficiently Detecting Uninitialized Memory Errors During Fuzzing

Matteo Marini (Sapienza)
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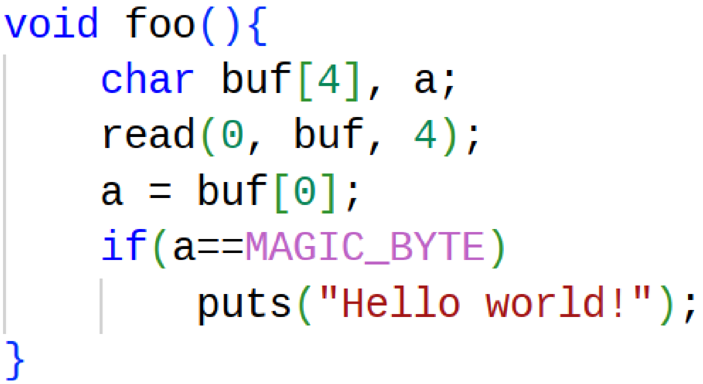
Mathias Payer (EPFL)
Leonardo Querzoni (Sapienza)

UUM Errors



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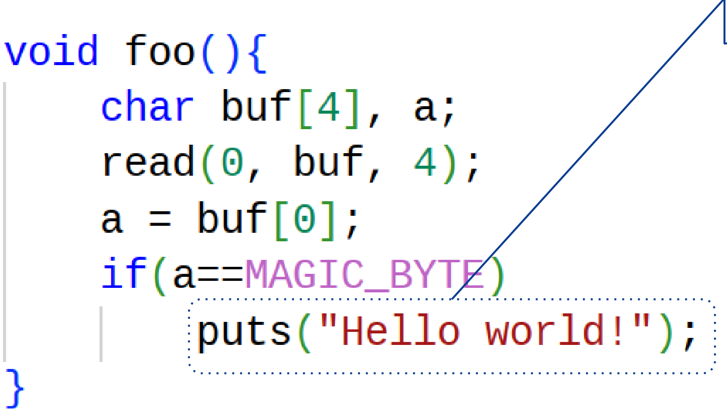

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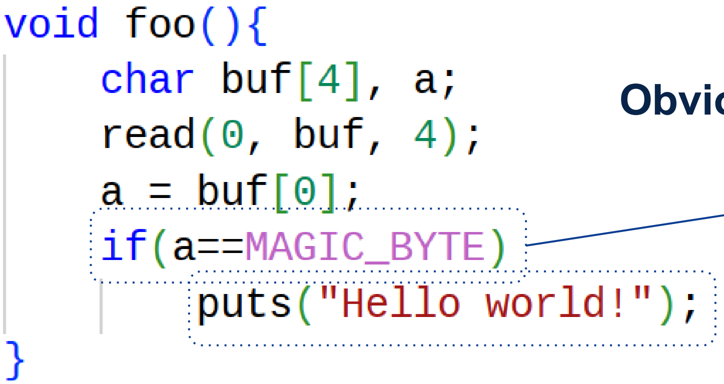

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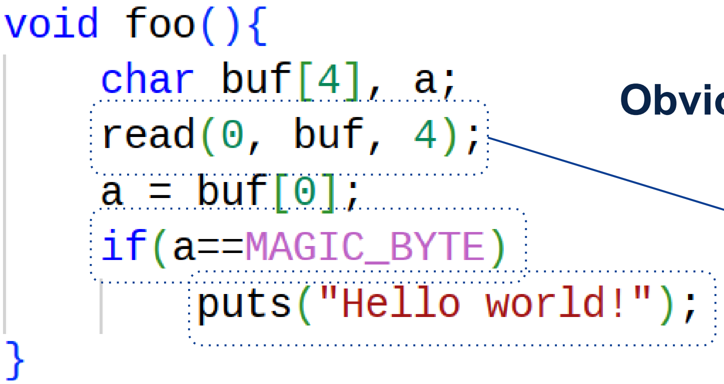

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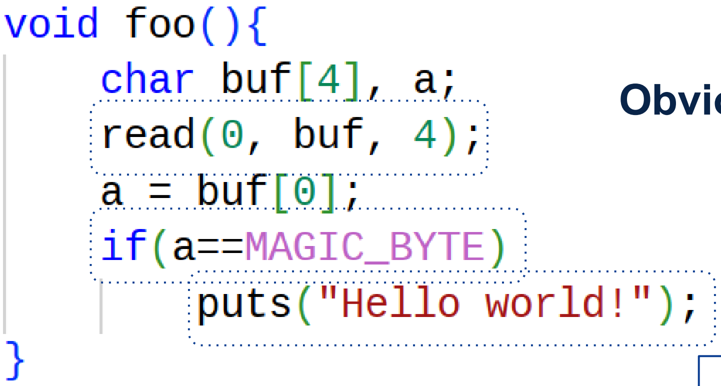

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Use-of-Uninitialized-Memory (UUM) error!

UUM Errors - Detection

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Loading uninitialized data **is allowed…**

…As long as **<u>its content is not used</u>**

Memory Sanitizer (MSan)

- State-of-the-Art UUM detection
  - Compile-time solution

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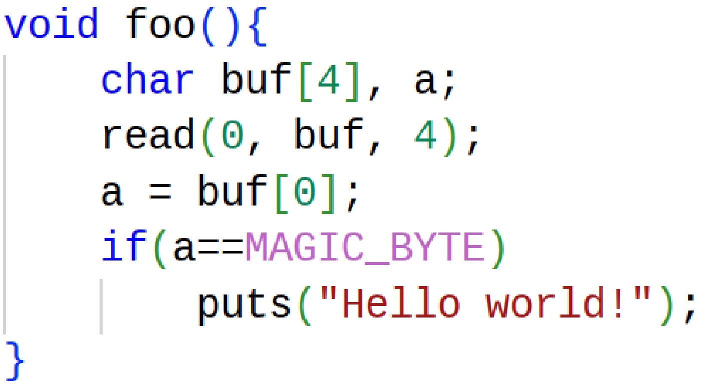
Cons:

- Requires **recompilation**
- **All code** must be instrumented
  - Libraries
- LLVM only

MSan - Workflow



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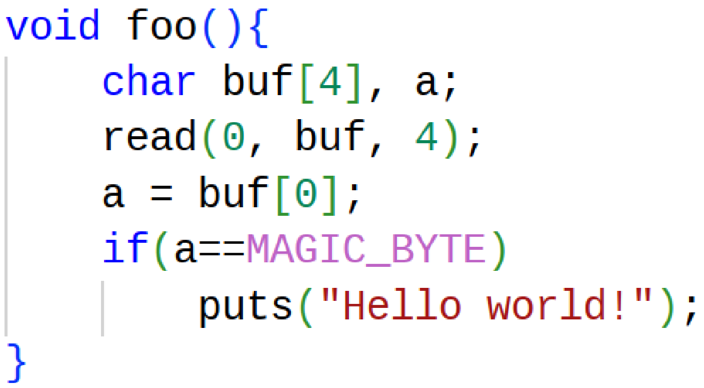
MSan - Workflow

Memory

? Unknown

Shadow memory

🟩 Init 🟥 Uninit



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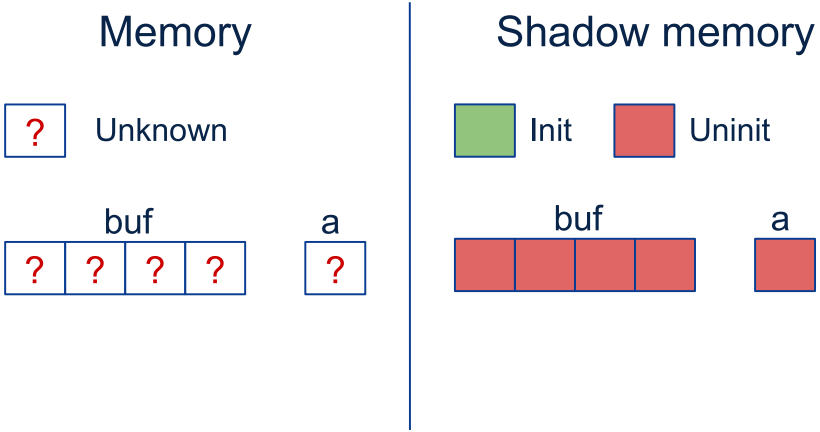

Memory

? Unknown

buf

?	?	?	?

a

?

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buf

🟥	🟥	🟥	🟥

a

🟥

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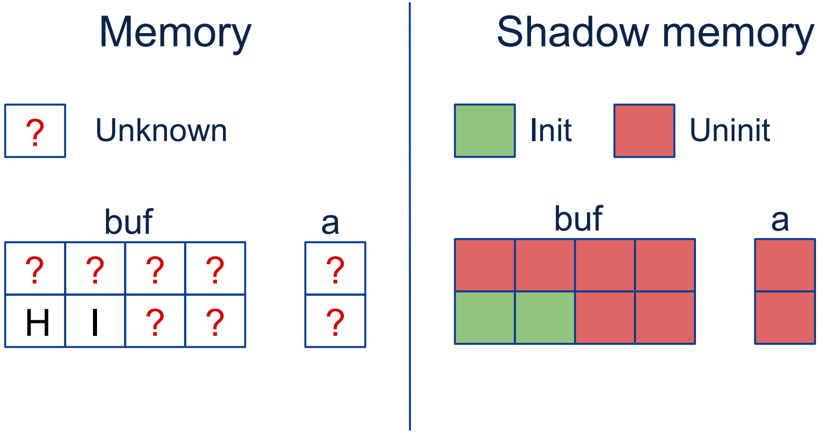

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buf				a
?	?	?	?	?
H	I	?	?	?

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🟥	🟥	🟥	🟥	🟥
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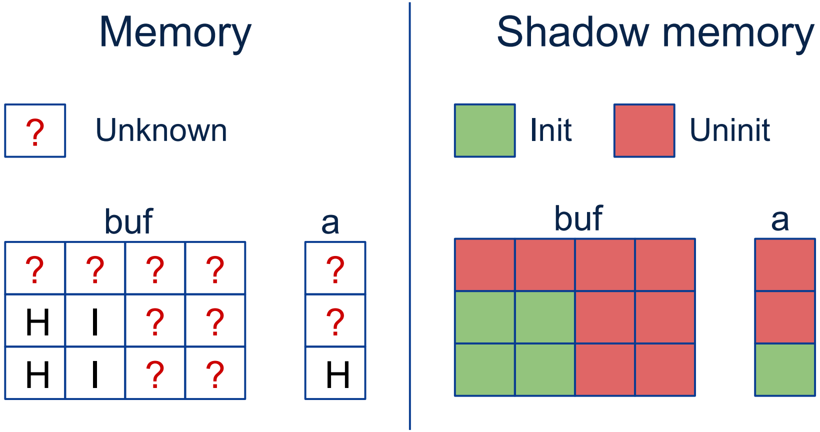

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H	I	?	?	?
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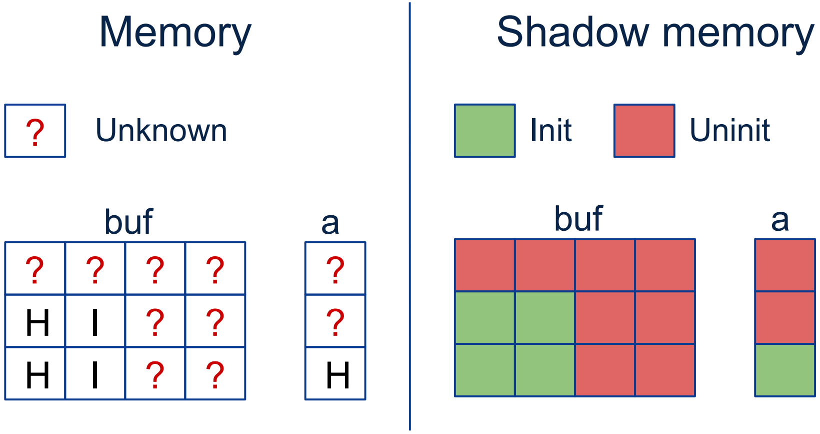

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🟥	🟥	🟥	🟥	🟥
🟩	🟩	🟥	🟥	🟥
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Check *a*’s shadow

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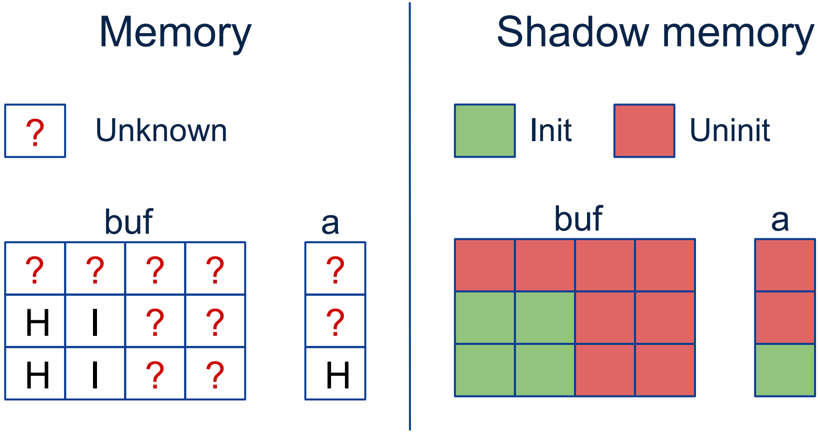

Memory

buf				a
?	?	?	?	?
H	I	?	?	?
H	I	?	?	H

Shadow memory

buf				a
🟥	🟥	🟥	🟥	🟥
🟩	🟩	🟥	🟥	🟥
🟩	🟩	🟥	🟥	🟩

Check *a*’s shadow

Total: **5 operations**

Binary Detection

- Detect UUM errors at the binary level
  - Similar workflow as MSan
  - Much more instrumentation

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Pros:

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  - Similar workflow as MSan
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Pros:

- More generic
  - No recompilation
  - Closed-source software

Cons:

- Slow (10-20x slowdown)
  - Shadow propagation is **much** harder
- No fuzzing compatibility

QMSan - overview

- Binary-based multi-layered solution to detect UUM errors
  - based on the QEMU emulator
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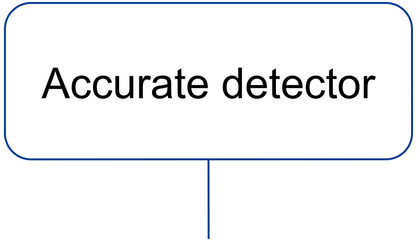

Accurate detector

Similar to binary UUM detectors

Very Accurate, but very slow

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Run-time module

Supports UUM detection with shadow memory management

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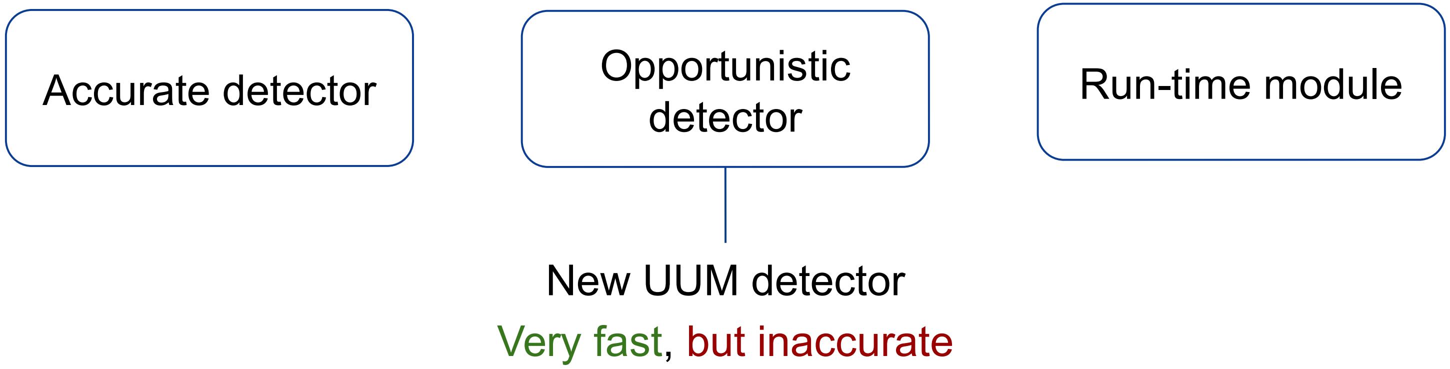

Accurate detector

Opportunistic detector

Run-time module

New UUM detector

Very fast, but inaccurate

QMSan - Workflow

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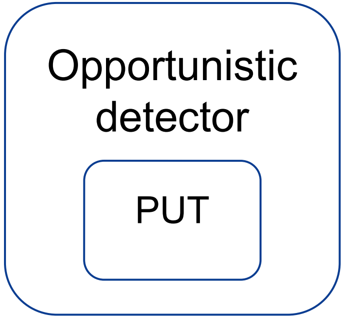
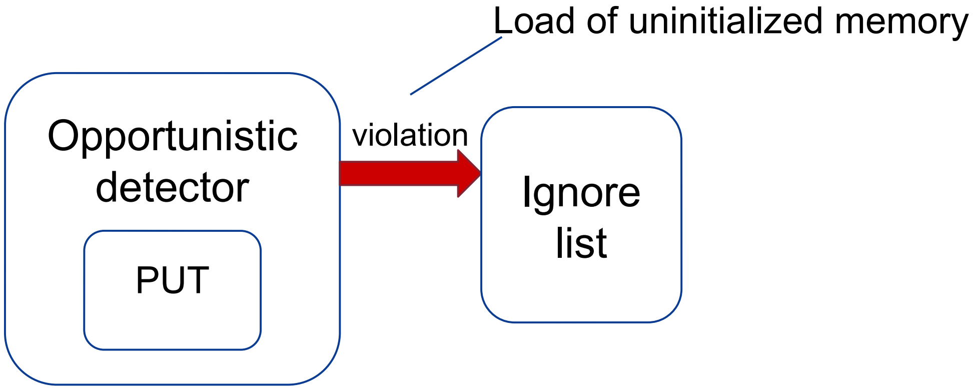


Opportunistic detector

PUT

QMSan - Workflow



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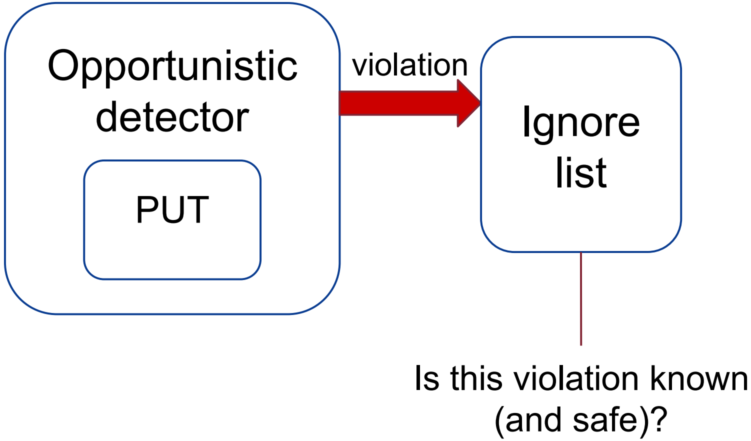

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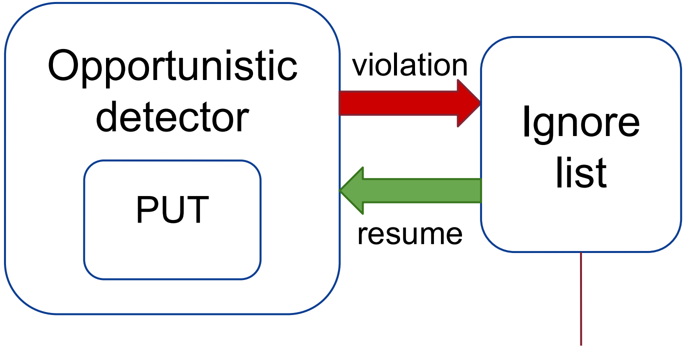


Opportunistic detector

PUT

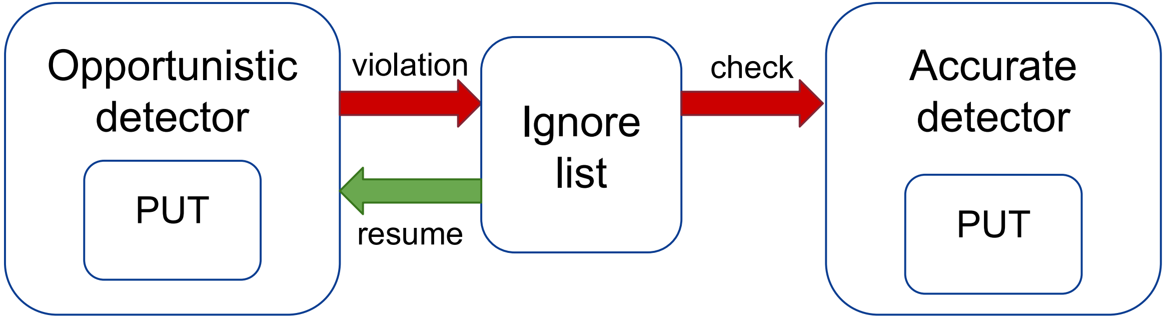
violation

resume

Ignore list

Is this violation known (and safe)?

QMSan - Workflow



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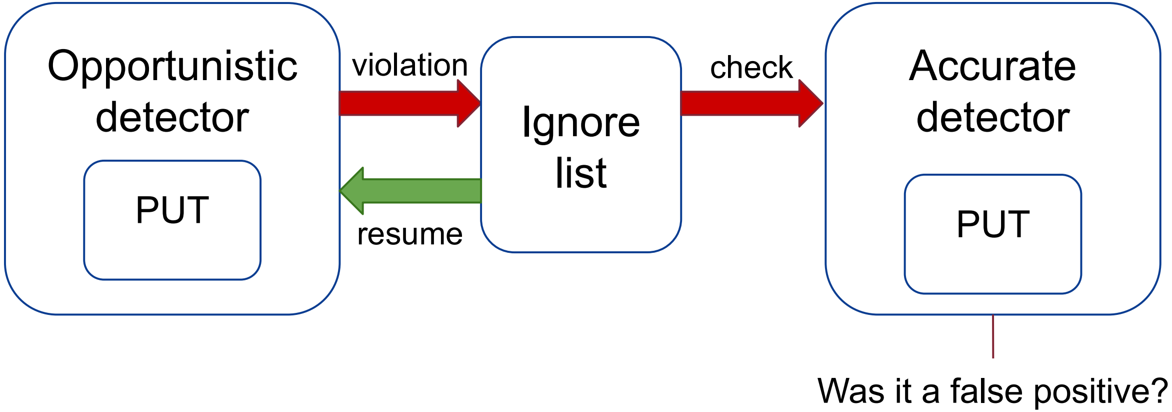

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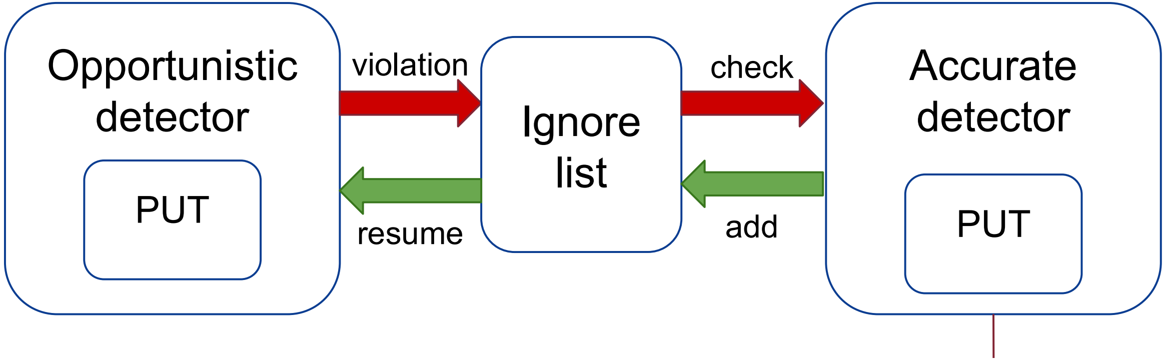


Opportunistic detector

PUT

violation

resume

Ignore list

check

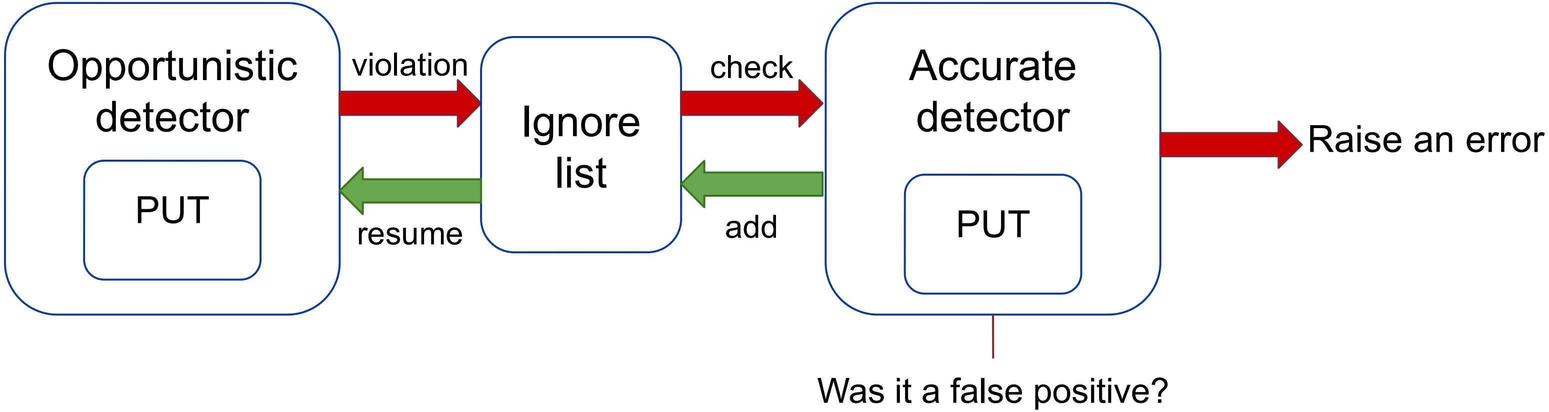
add

Accurate detector

PUT

Was it a false positive?

QMSan - Workflow



Opportunistic detector

PUT

violation

resume

Ignore list

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Accurate detector

PUT

Raise an error

Was it a false positive?

QMSan - Opportunistic Detector

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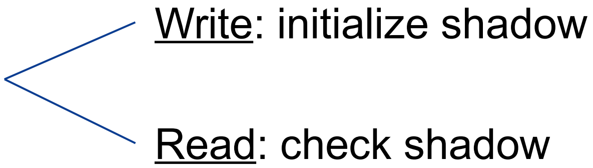

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- When a **violation** occurs:

Write: initialize shadow

Read: check shadow

Known: keep executing

Not Known: Use propagation to check and **remember for next time**

QMSan - Ignore list

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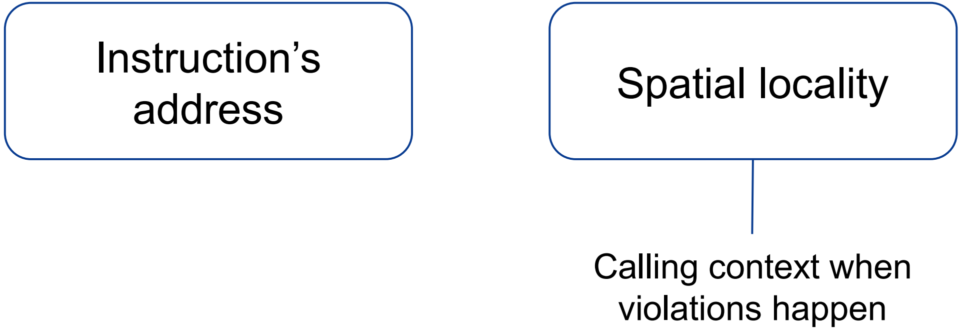

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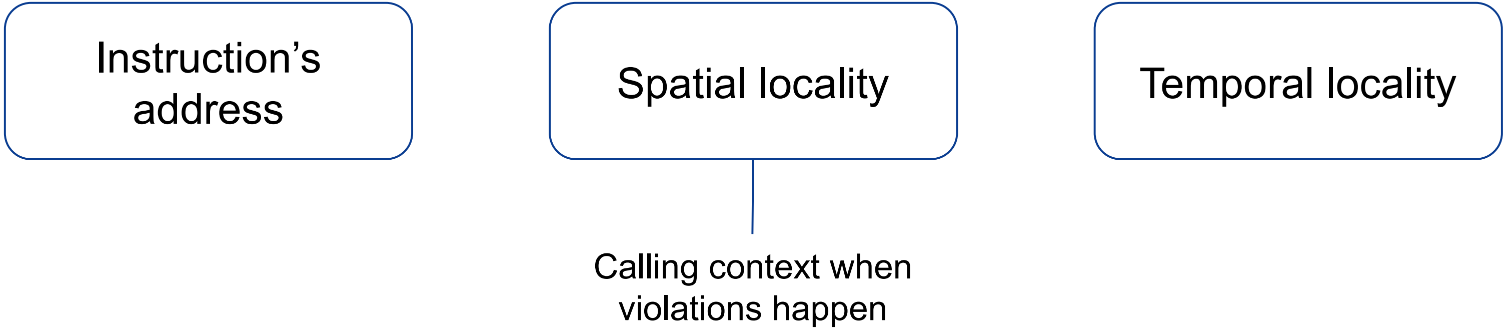

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Temporal locality

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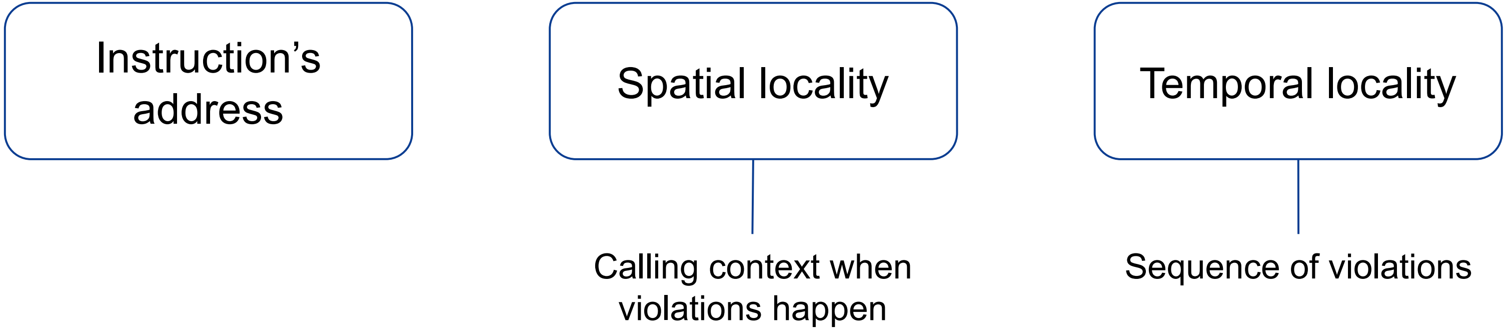

Instruction’s address

Spatial locality

Calling context when violations happen

Temporal locality

Sequence of violations

Evaluation - Bugs

Dataset:

- 9 closed-source binaries
  - 5 projects, multiple versions
- 10 open-source programs (from OSS-Fuzz)

Methodology:

- 72 hours runs
- 3 runs

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Subject	Vendor	Version	Bugs
cuobjdump	NVIDIA	12.3	2
cuobjdump	NVIDIA	12.4	0
nconvert	XnView Software	7.136	5
nconvert	XnView Software	7.155	4
nvdisasm	NVIDIA	12.3	7
nvdisasm	NVIDIA	12.4	3
pngout	Ken Silverman	Jan 15 2020	2
rar	rarlab	6.11	1
rar	rarlab	7.0	3
Total			27

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libredwg	763d702	3
gpac	205bfe3	1
assimp	b71b8f7	2
libdwarf	6178ba8	2
serenity	7914383	1
opensc	fe2c1c8	5
ntopng	8786f06	1
upx	3495d1a	2
radare2	cfe5806	0
libucl	5c58d0d	0
Total		17

Evaluation - Performance

Dataset:

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Project	QMSan		
Name	vs AFL-cc	vs MSan	vs QEMU
c-ares	2,20	1,05	1,04
guetzli	3,17	1,24	1,41
json	2,69	1,24	1,12
libxml2	3,41	0,90	1,42
openssl	19,84	8,24	4,68
pcre2	3,18	1,42	1,40
re2	3,35	1,48	1,48
woff2	2,86	1,34	1,20
geomean	3,75	1,55	1,51

Conclusions

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- Detecting UUM errors is a challenging task due to the **slowdown introduced by shadow propagation**

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- Detecting UUM errors is a challenging task due to the **slowdown introduced by shadow propagation**

- We presented a new design that **drastically limits shadow propagation** at the binary level.
  - 44 new bugs (4 CVEs)
  - 1.51x slowdown over QEMU

Conclusions

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- We presented a new design that **drastically limits shadow propagation** at the binary level.
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https://github.com/Heinzeen/qmsan