GadgetMeter: Quantitatively and Accurately Gauging the Exploitability of Speculative Gadgets

Qi Ling, Yujun Liang, Yi Ren, Baris Kasikci, Shuwen Deng

Purdue University, University of Washington, Tsinghua University

Spectre Attacks

01-04-18

“Spectre” And “Meltdown” Chip Flaws Touch “Almost Every System,” Say Researchers

The critical vulnerabilities in Intel, AMD, and ARM processors will “haunt us for some time.”

```
e01d8340: 65 3a 20 68 74 74 70 3a  2f 2f 6d 65 73 61 33 64 |e: http://mesa3
e01d8350: 2e 6f 72 67 2f 0a 4f 72  69 67 69 6e 61 6c 2d 4d |.org/.Original
e01d8360: 61 69 6e 74 61 69 6e 65  72 3a 20 44 65 62 69 61 |aintainer: De
```

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New Spectre Chip Security Vulnerability Found That Leaves Billions Of PCs Still Defenseless

by Nathan Ord — Saturday, May 01, 2021, 10:04 AM EDT

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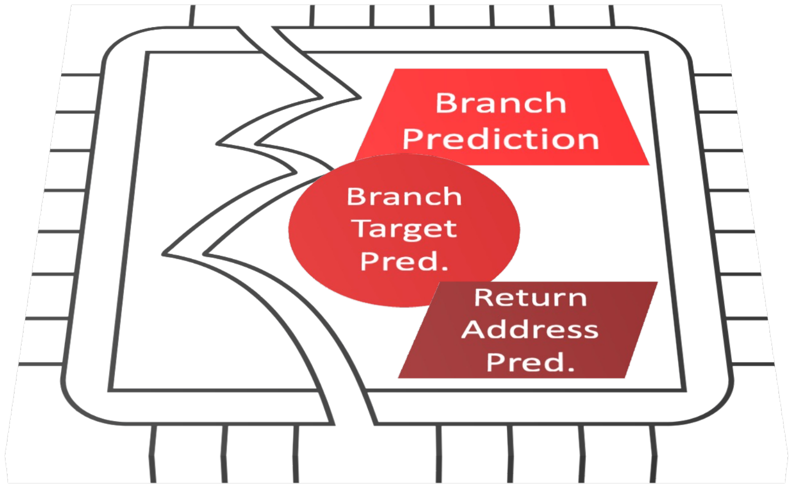

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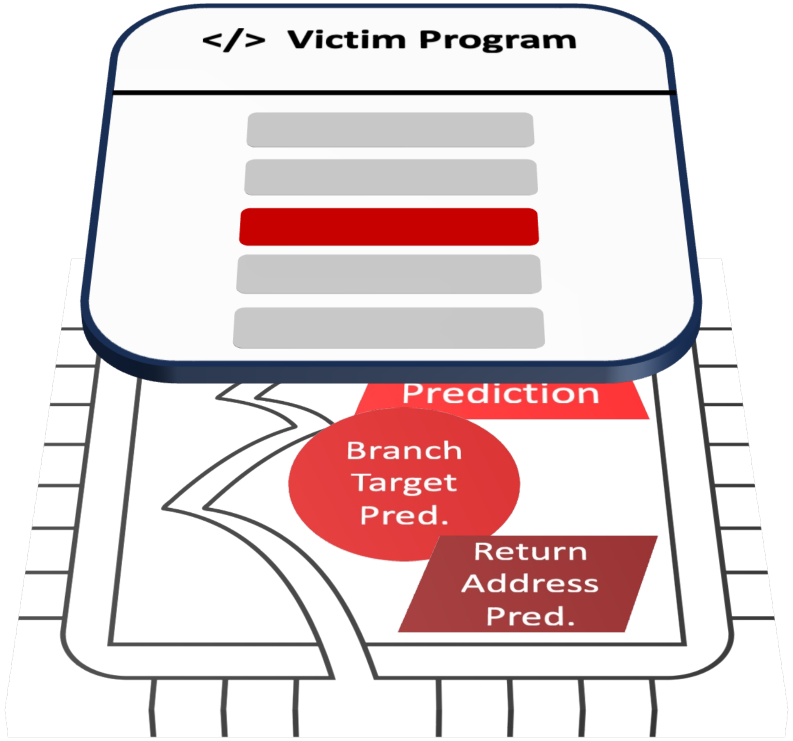

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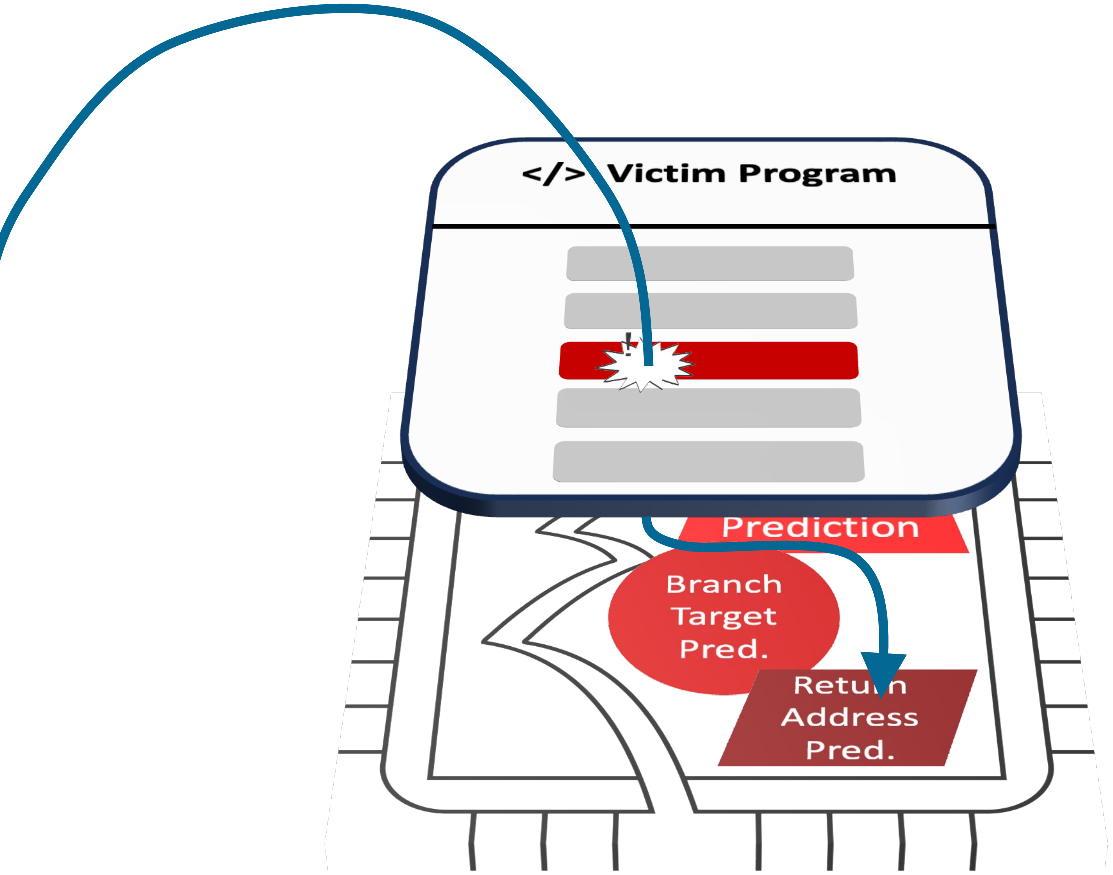

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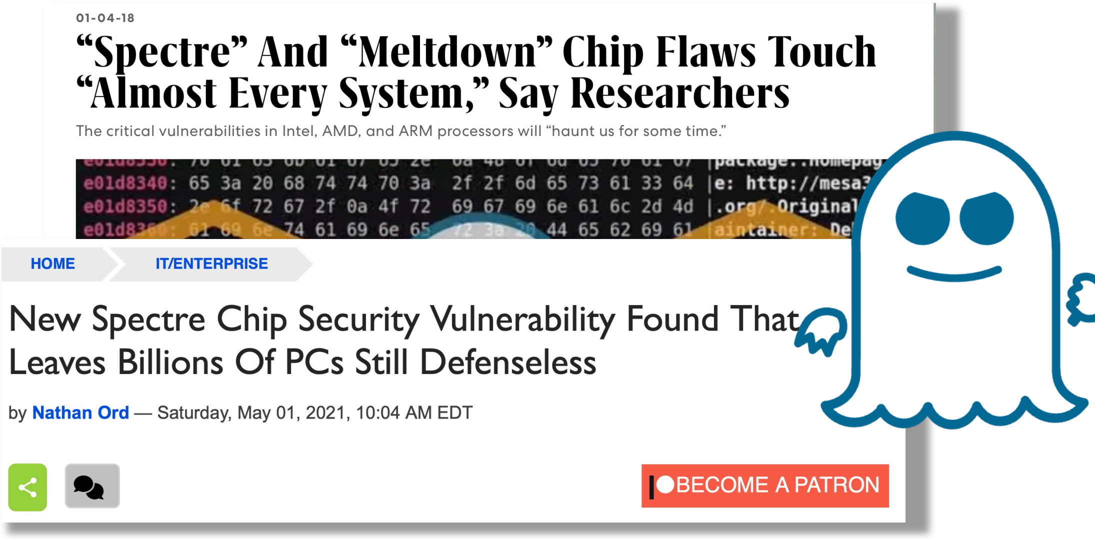

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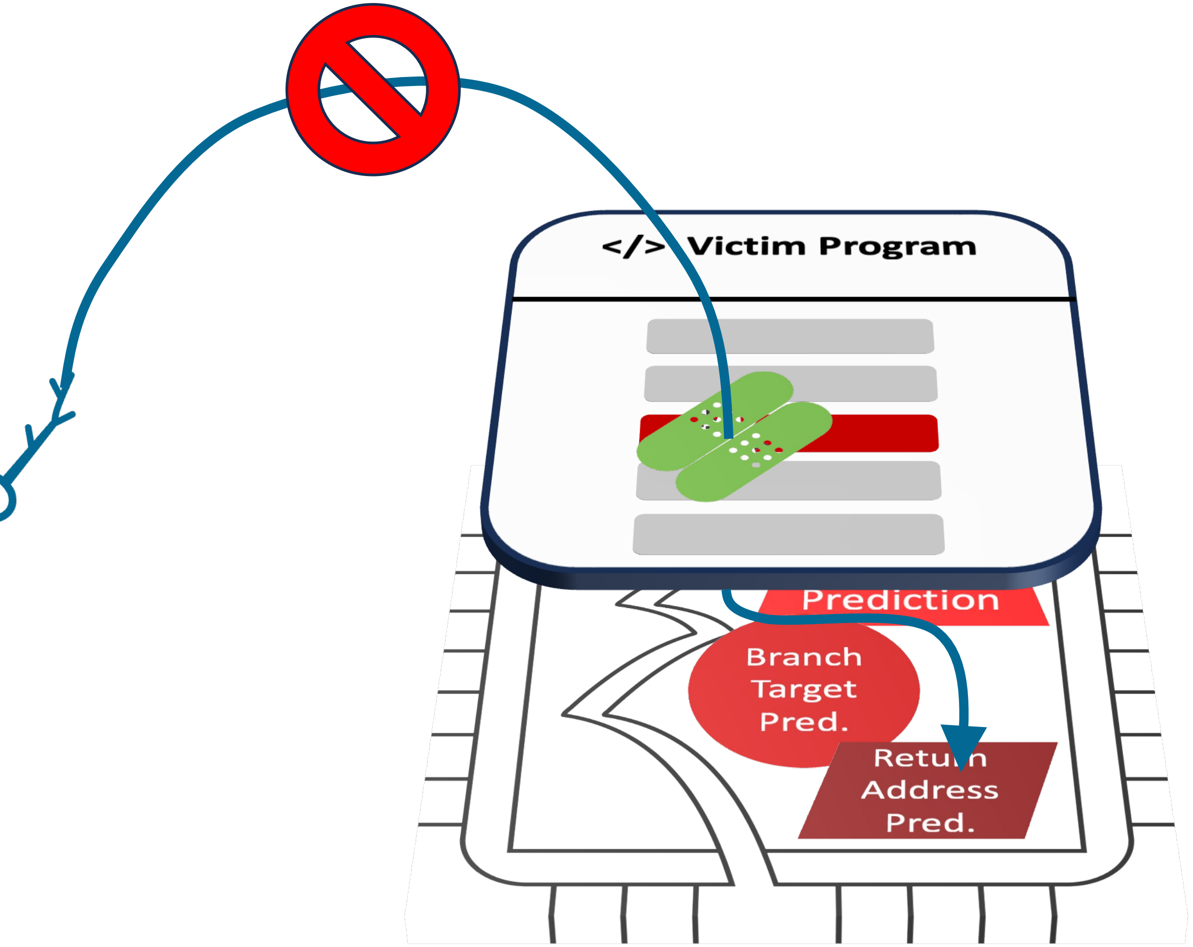

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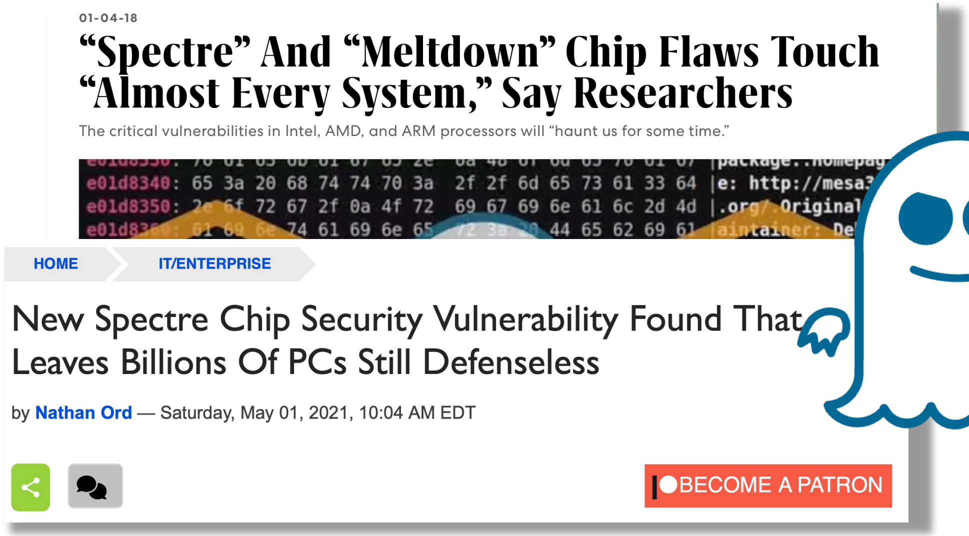

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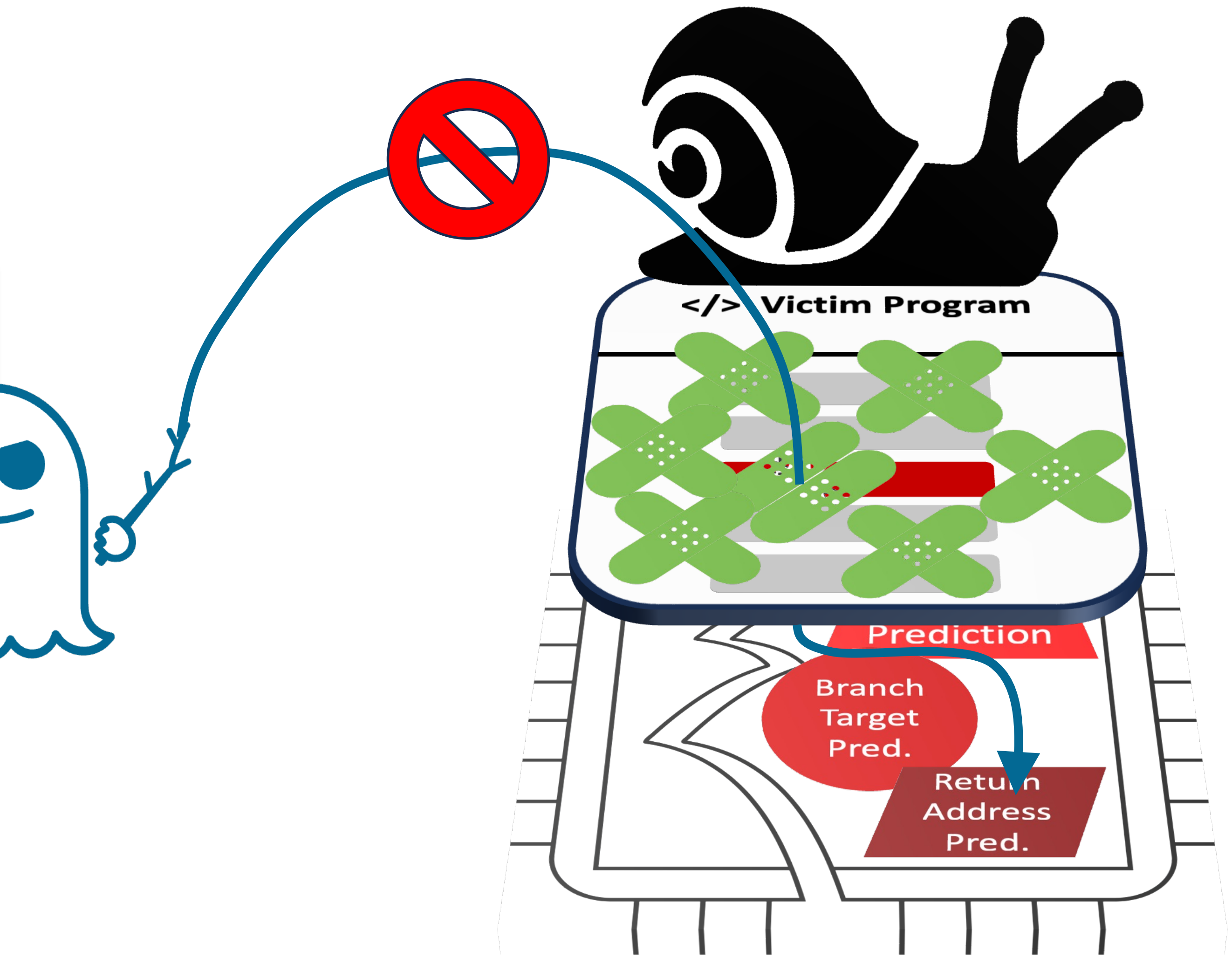

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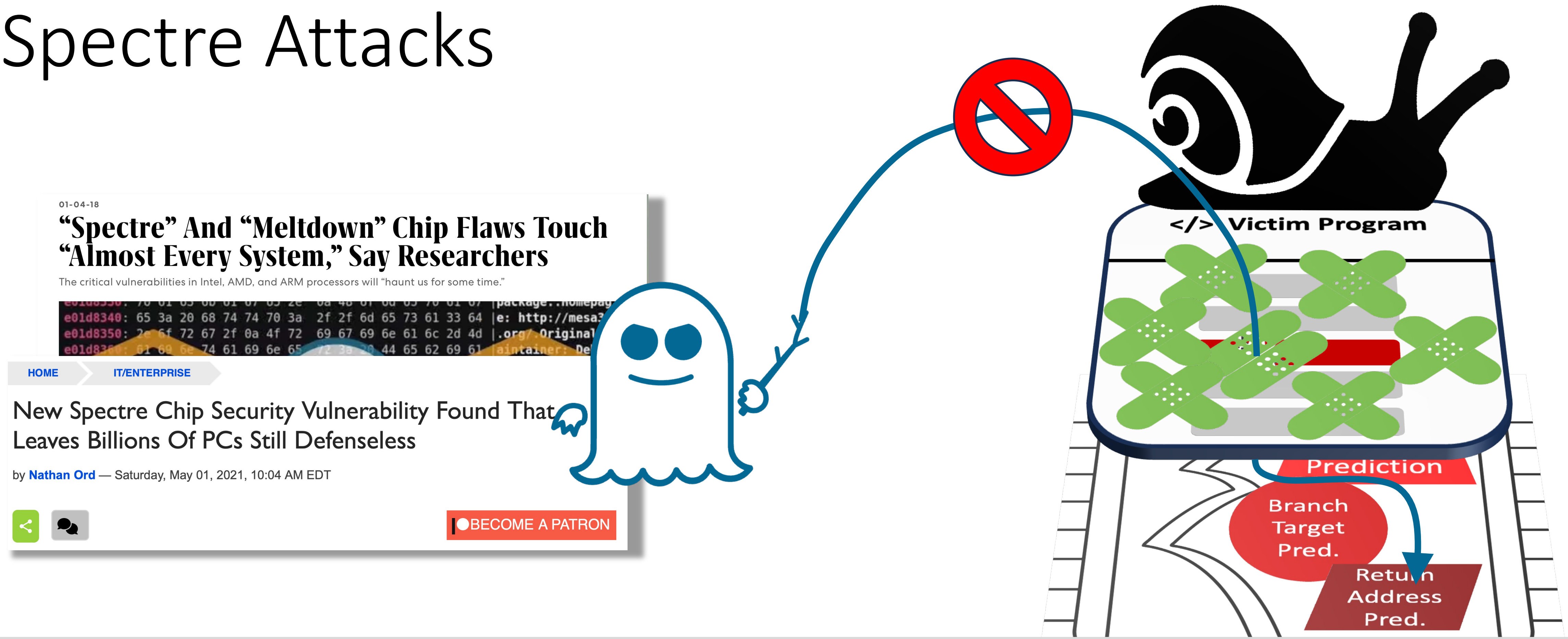

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```

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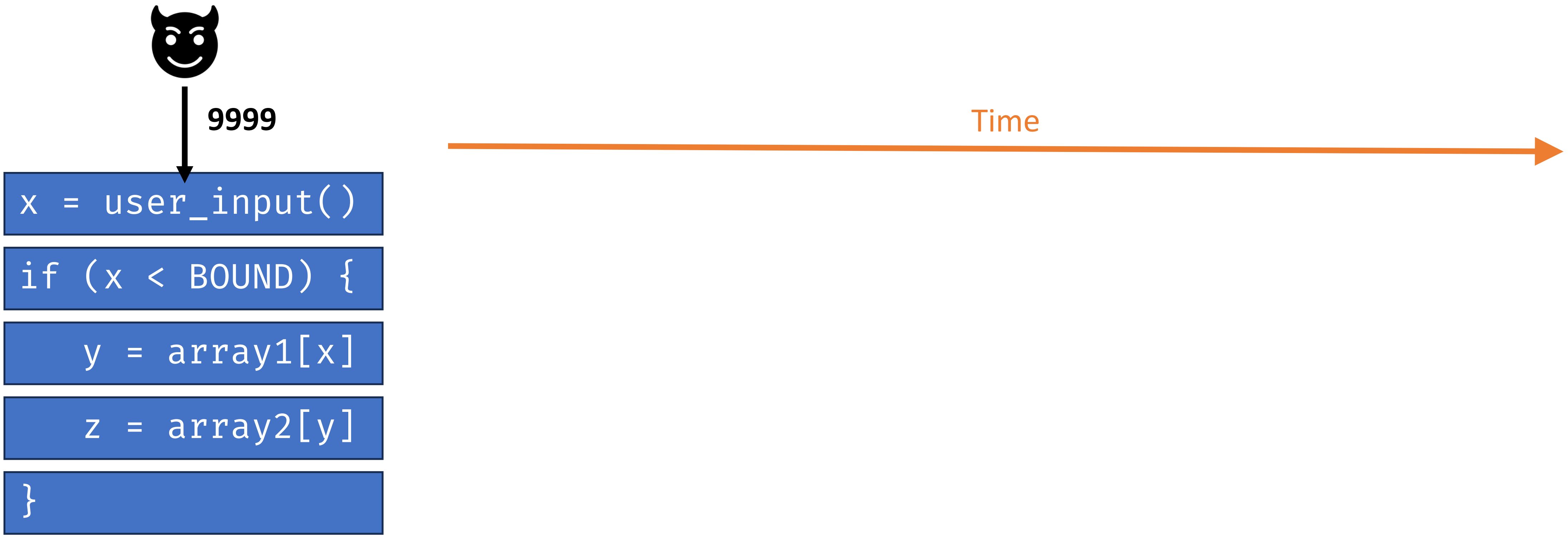
BECOME A PATRON

Accurate detection of Spectre gadgets.

What is a Spectre gadget?



```
x = user_input()
if (x < BOUND) {
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```

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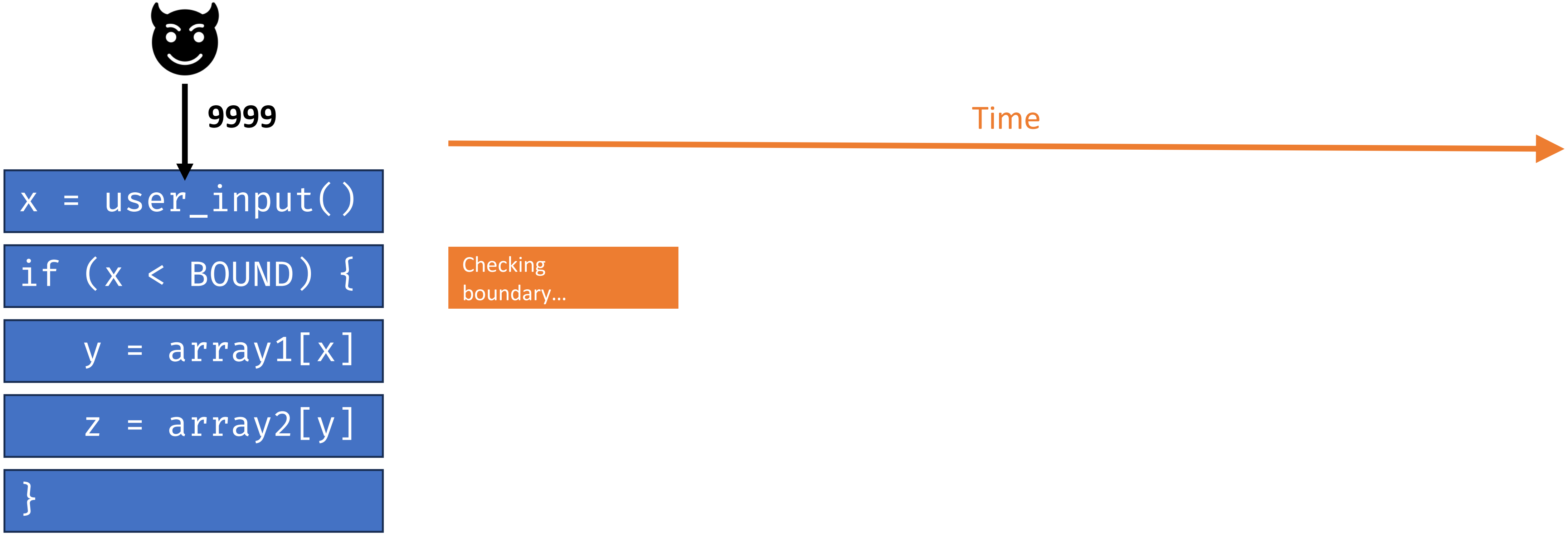

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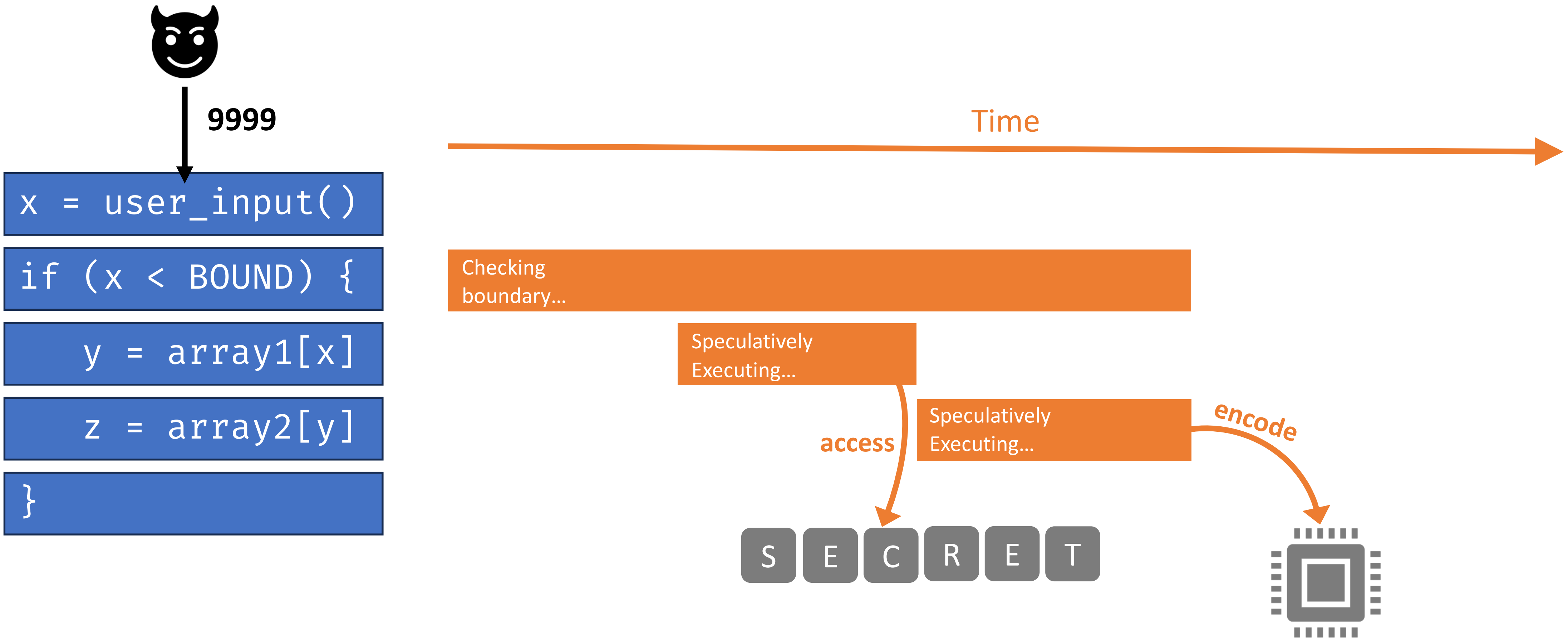

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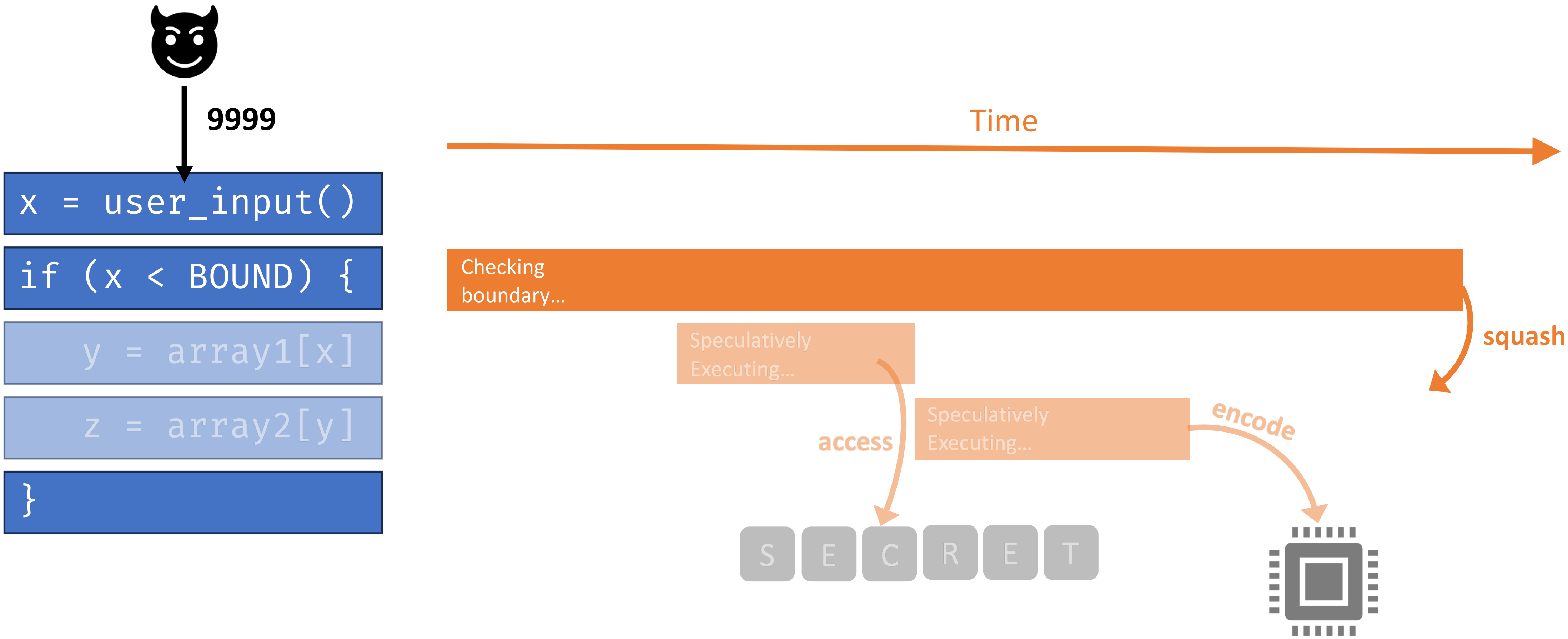

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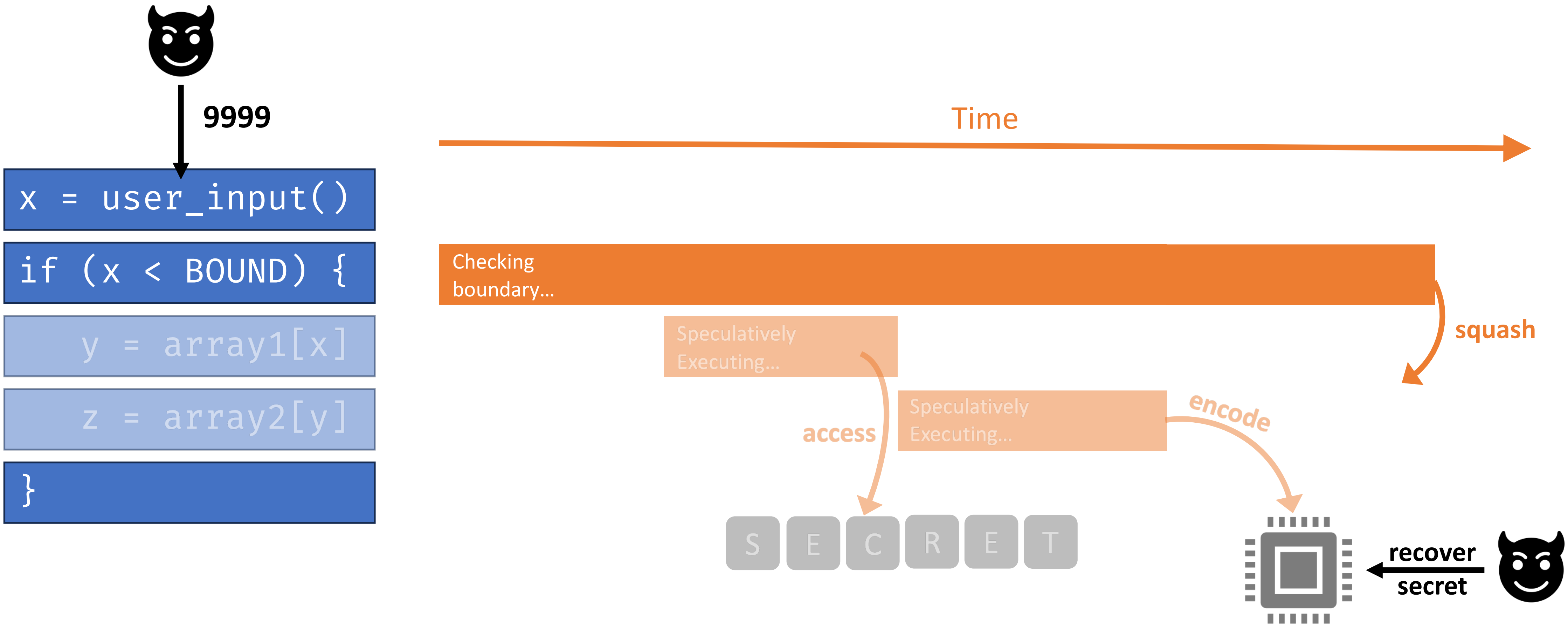

```
x = user_input()
if (x < BOUND) {
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```

How do existing gadget scanners work?

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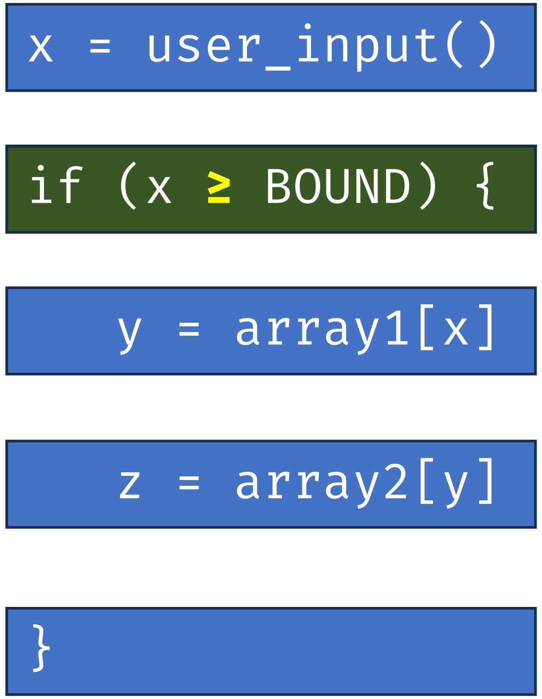
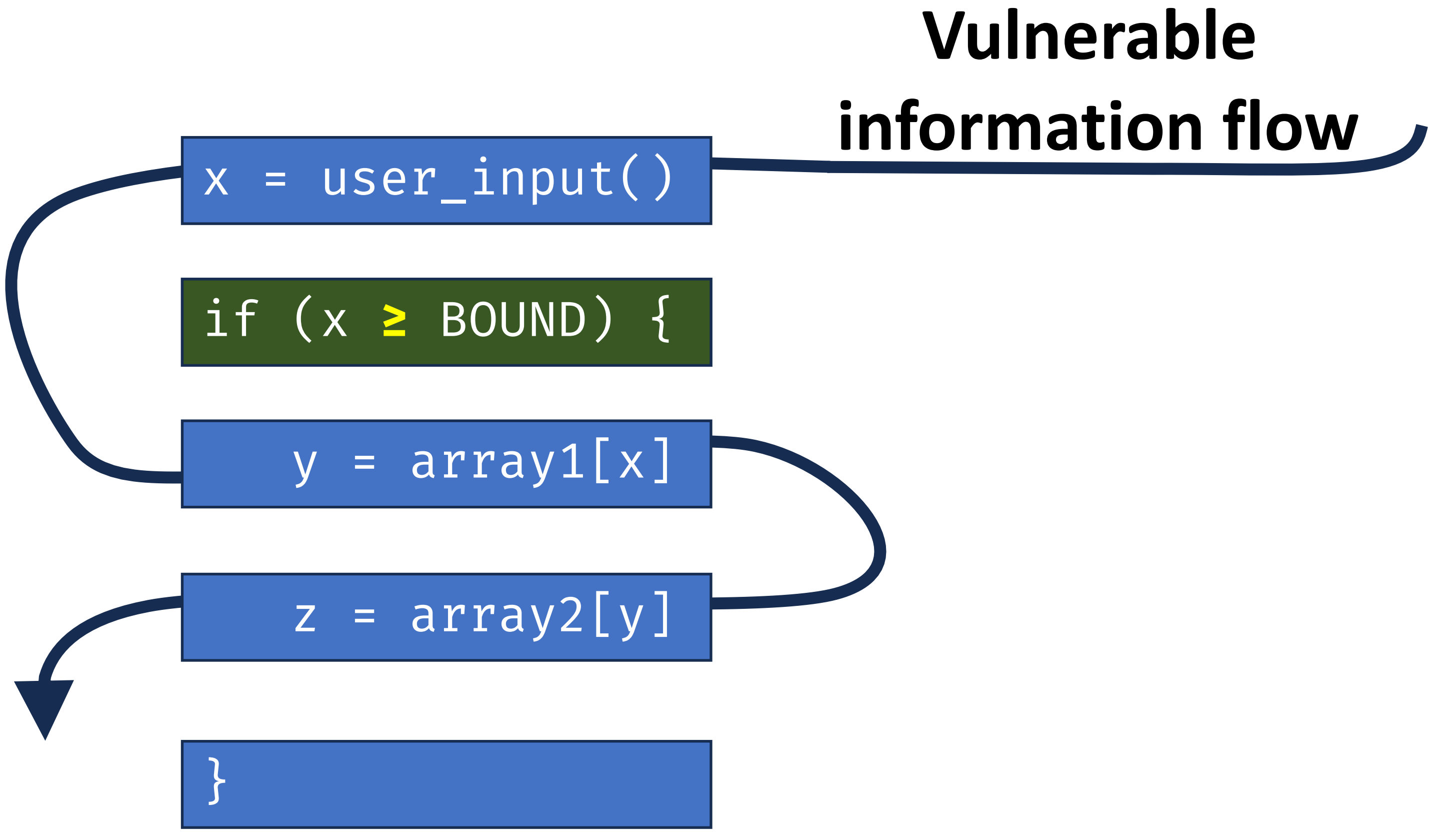


```
x = user_input()
if (x ≥ BOUND) {
   y = array1[x]
   z = array2[y]
}
```

How do existing gadget scanners work?



Vulnerable information flow

```
x = user_input()
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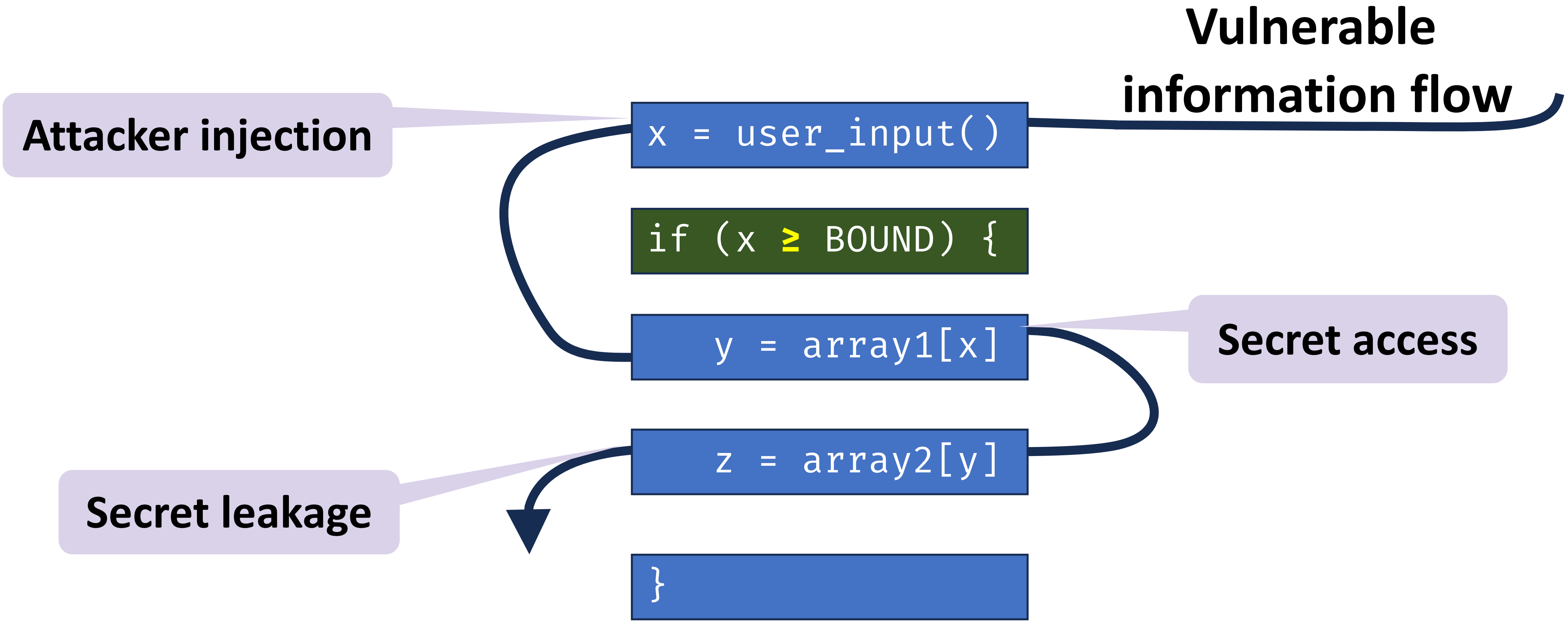
How do existing gadget scanners work?



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x = user_input()
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```

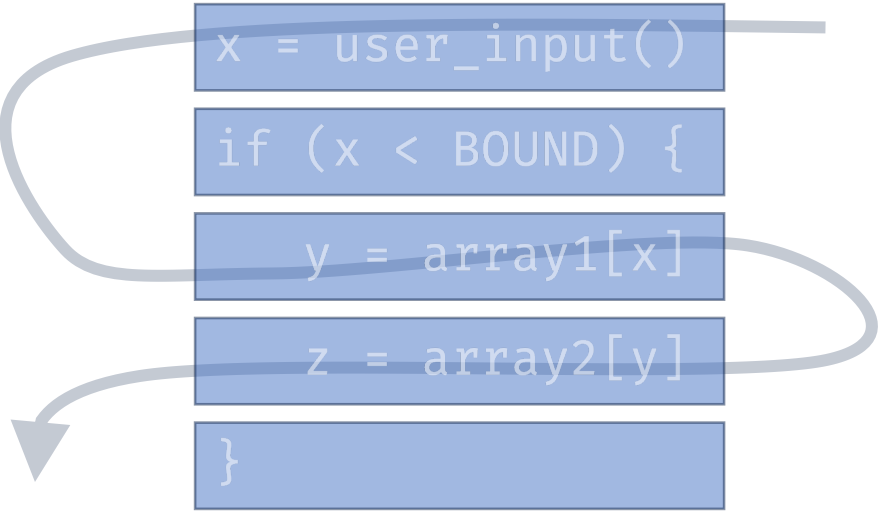
Vulnerable information flow

Attacker injection

Secret access

Secret leakage

Missing piece: Timing condition



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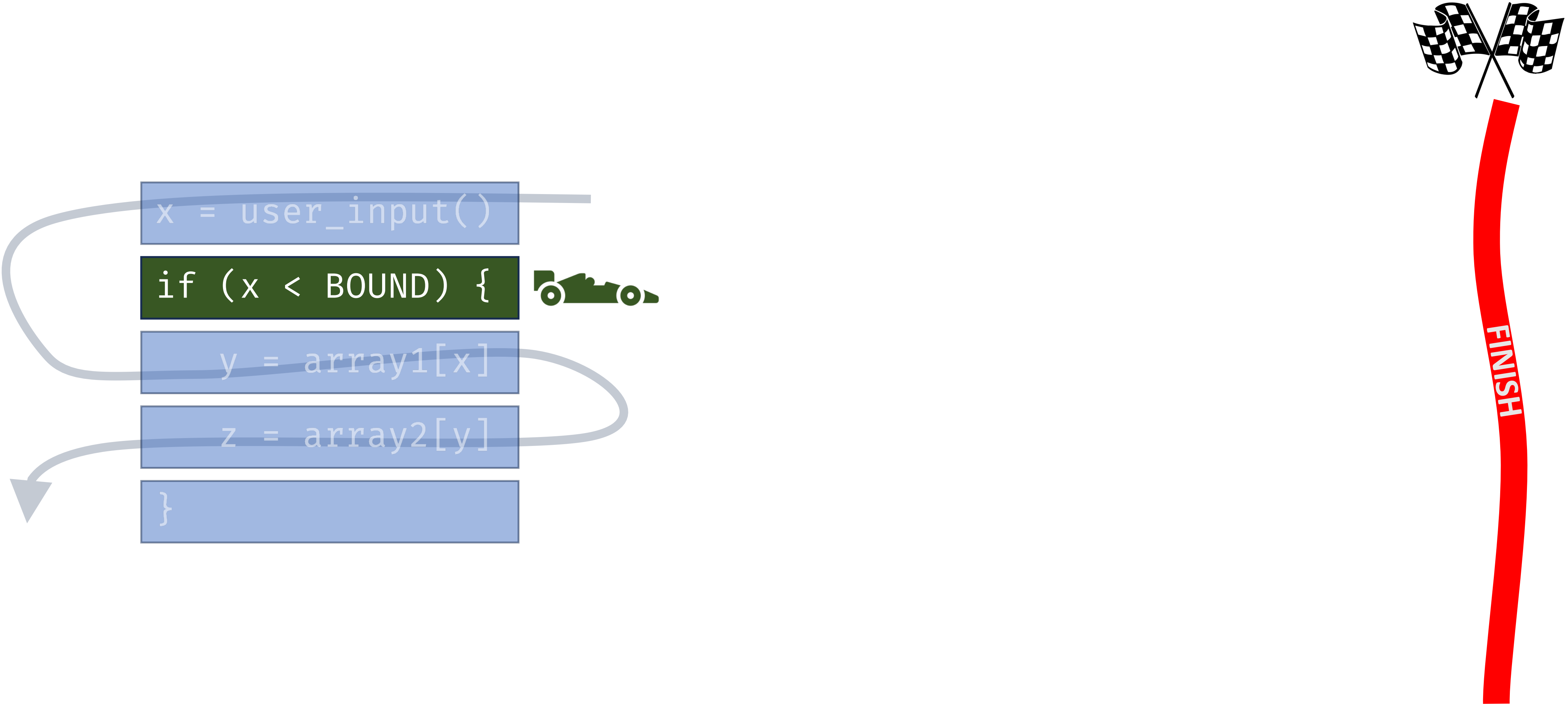

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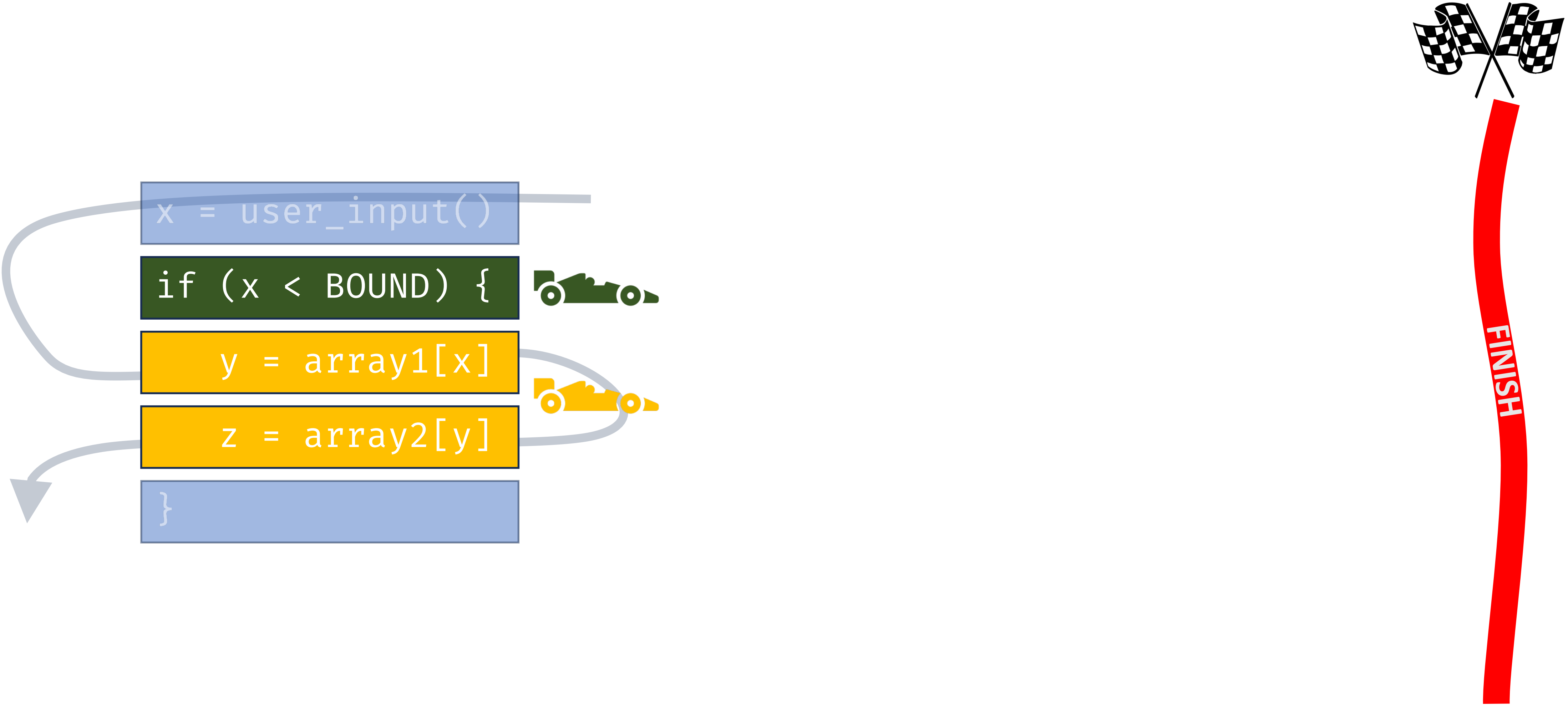

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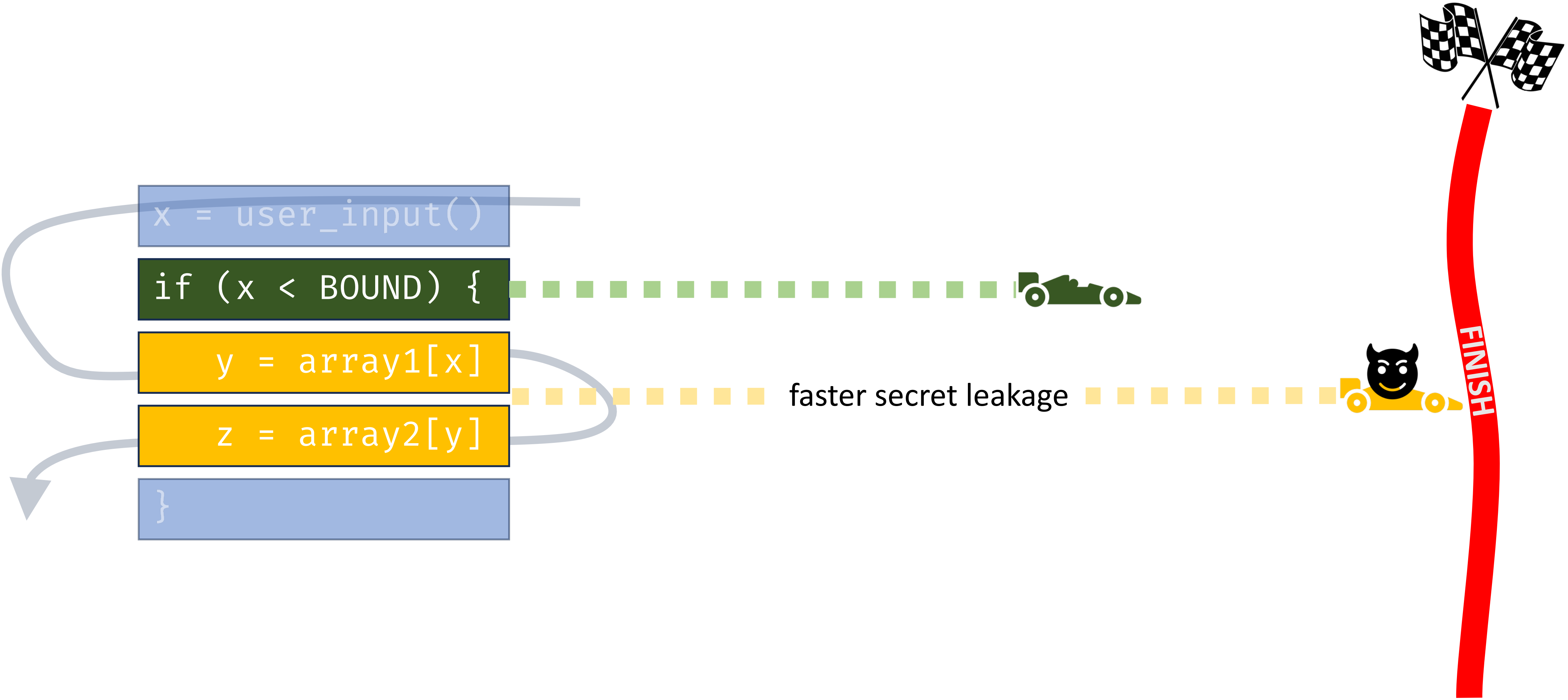

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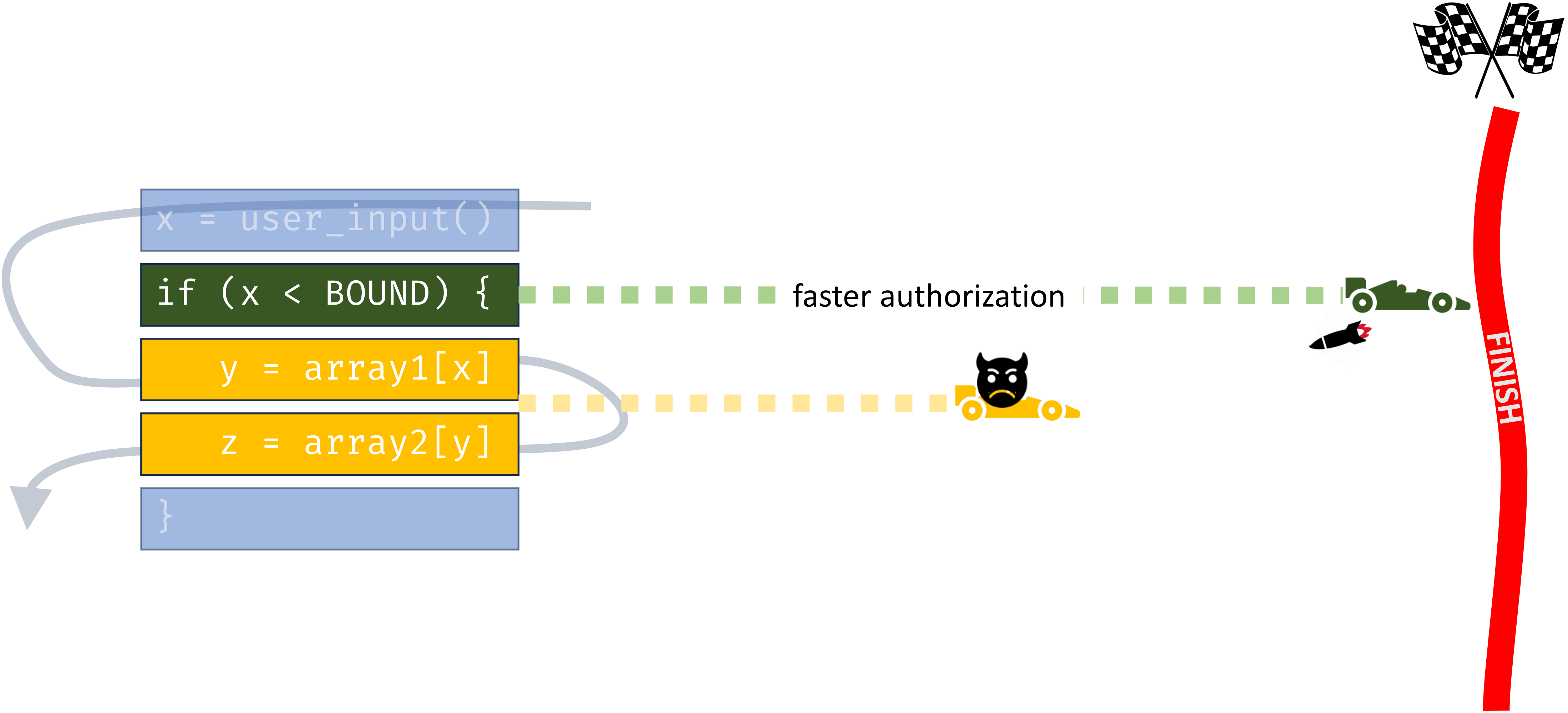

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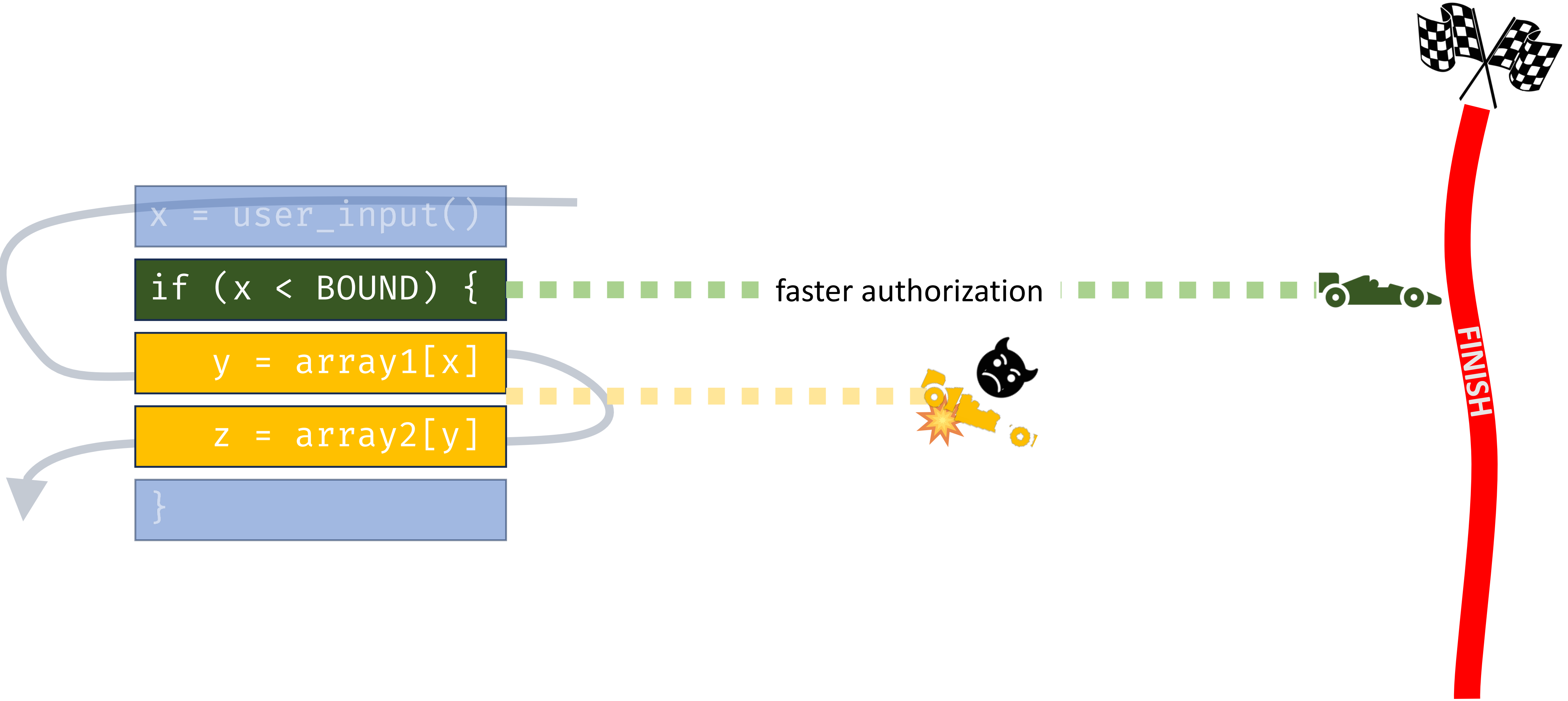

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Satisfying the **timing condition** is necessary for a gadget to be **exploitable**.

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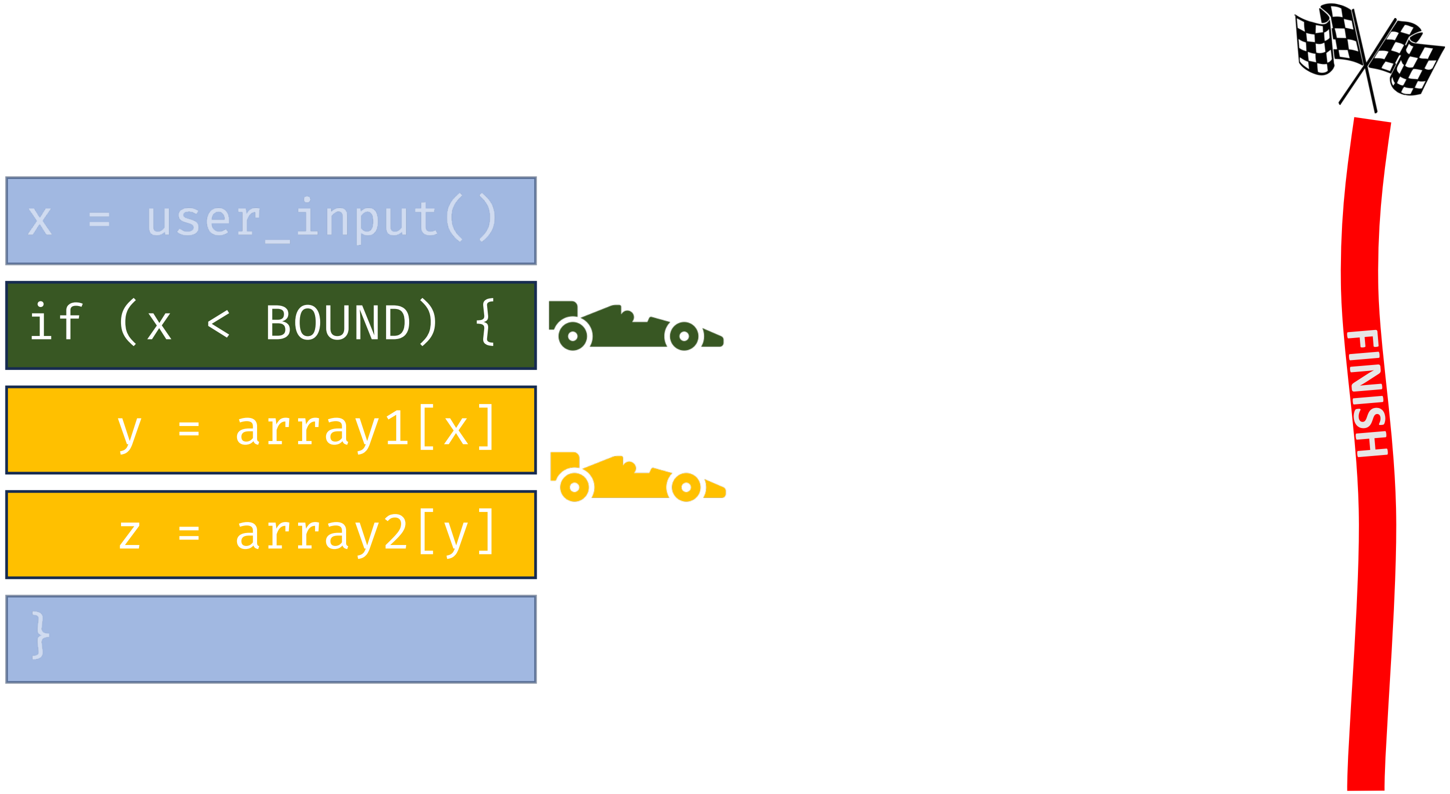
How do **existing works** model the timing condition?

Most scanners: Approximating with RoB size



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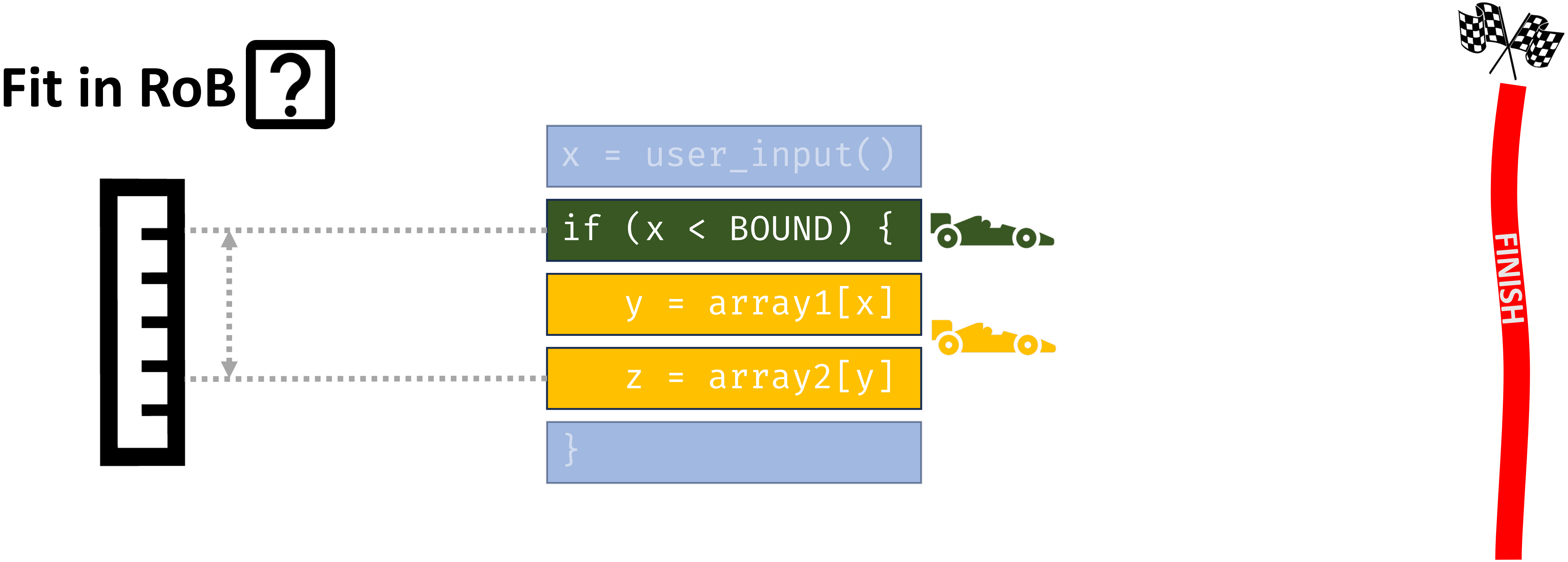

Fit in RoB ?

```
x = user_input()
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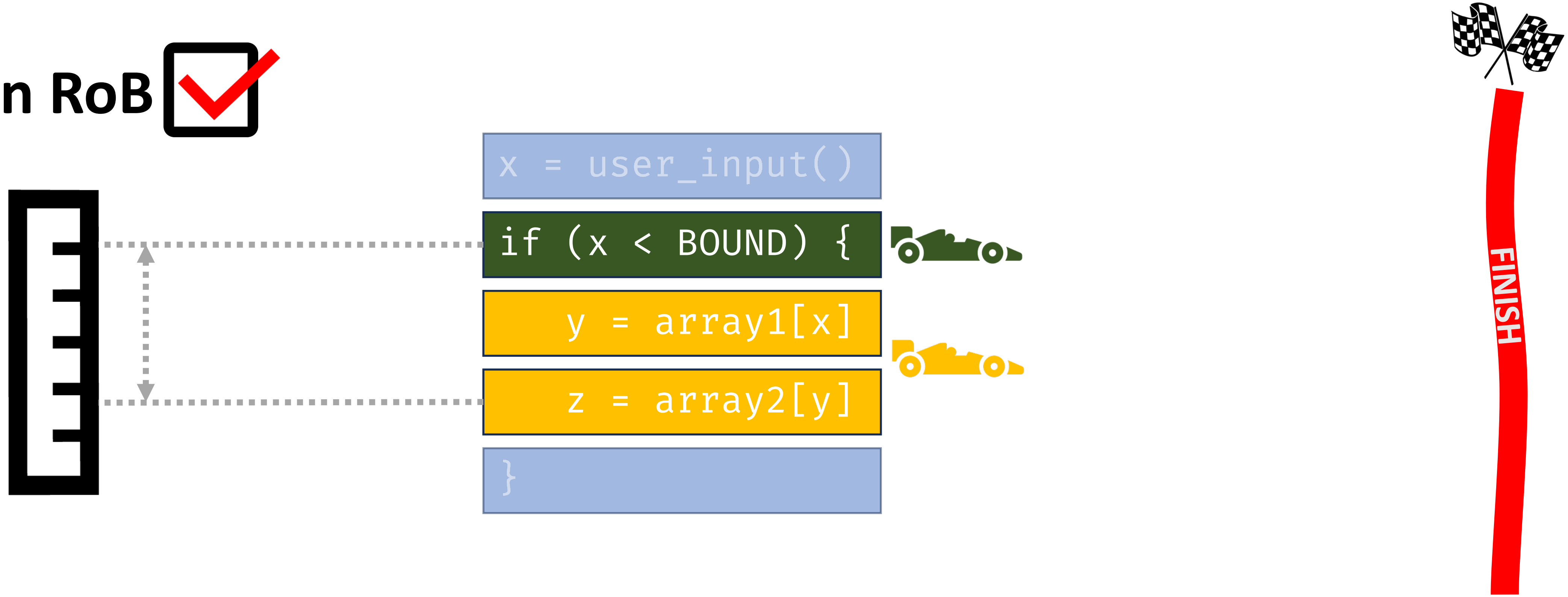
    z = array2[y]
}
```

Most scanners: Approximating with RoB size

Fit in RoB ☑



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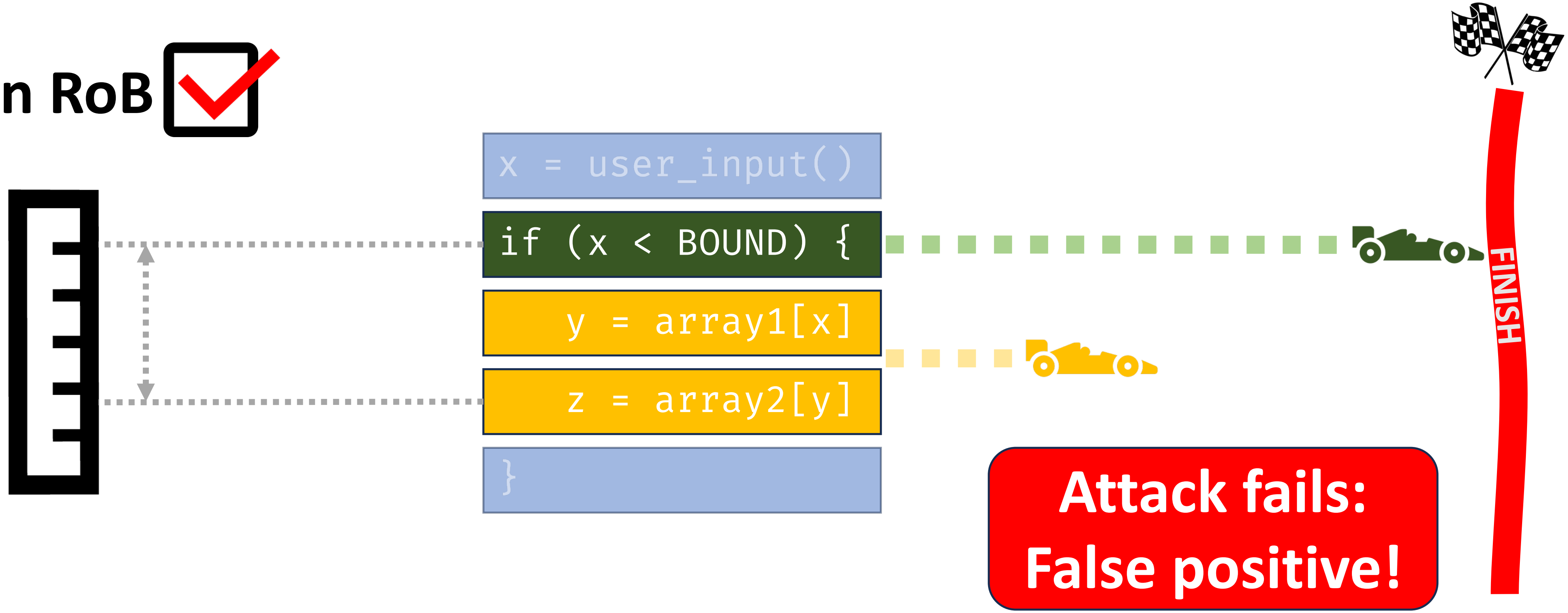

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if (x < BOUND) {
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}
```
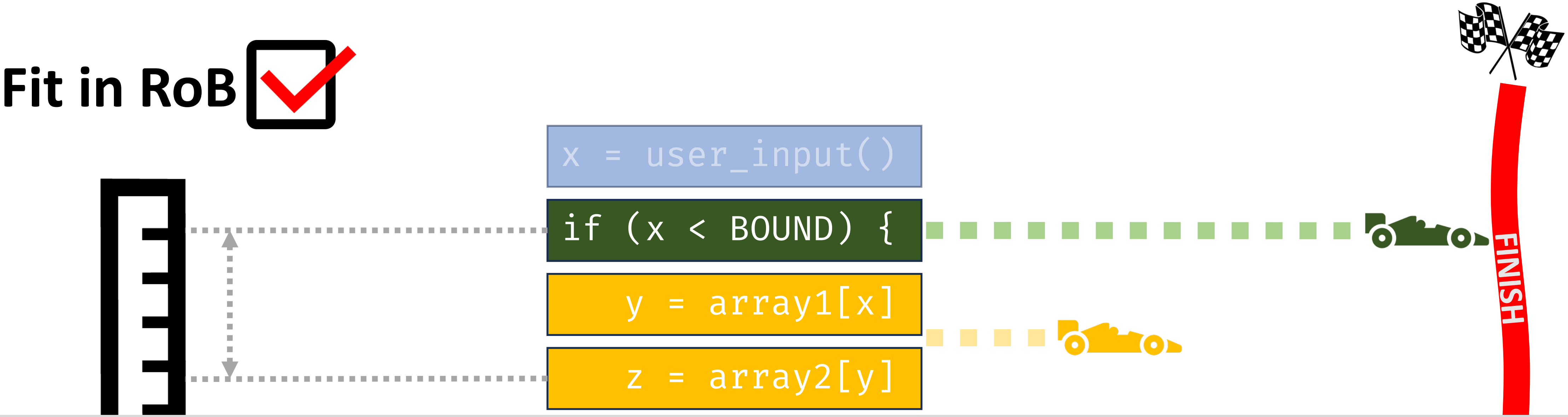

Attack fails:
False positive!

Most scanners: Approximating with RoB size



Fit in RoB ☑

```
x = user_input()
if (x < BOUND) {
    y = array1[x]
    z = array2[y]
```

Measure the timing condition accurately!

Some others: Timing modelling

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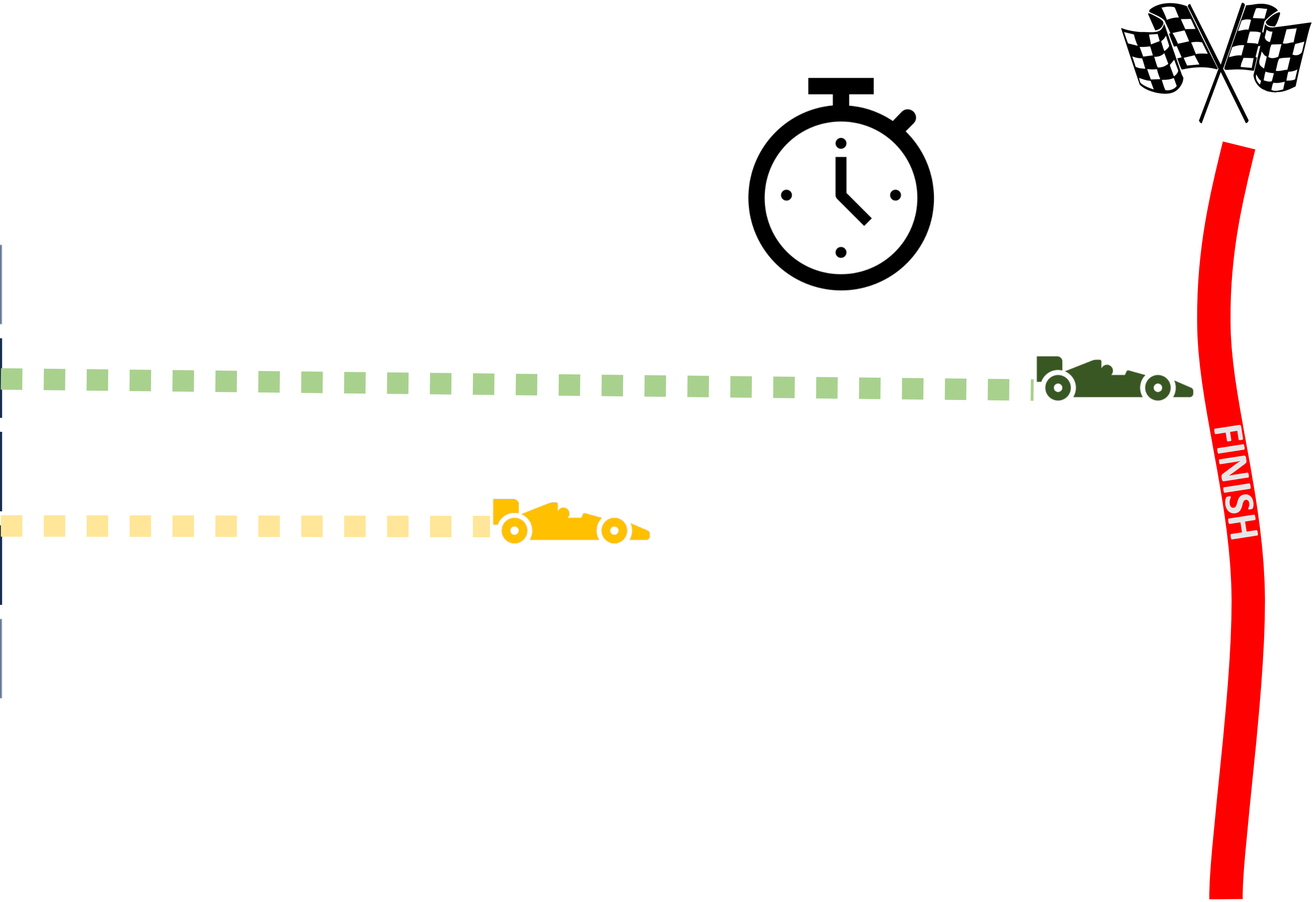

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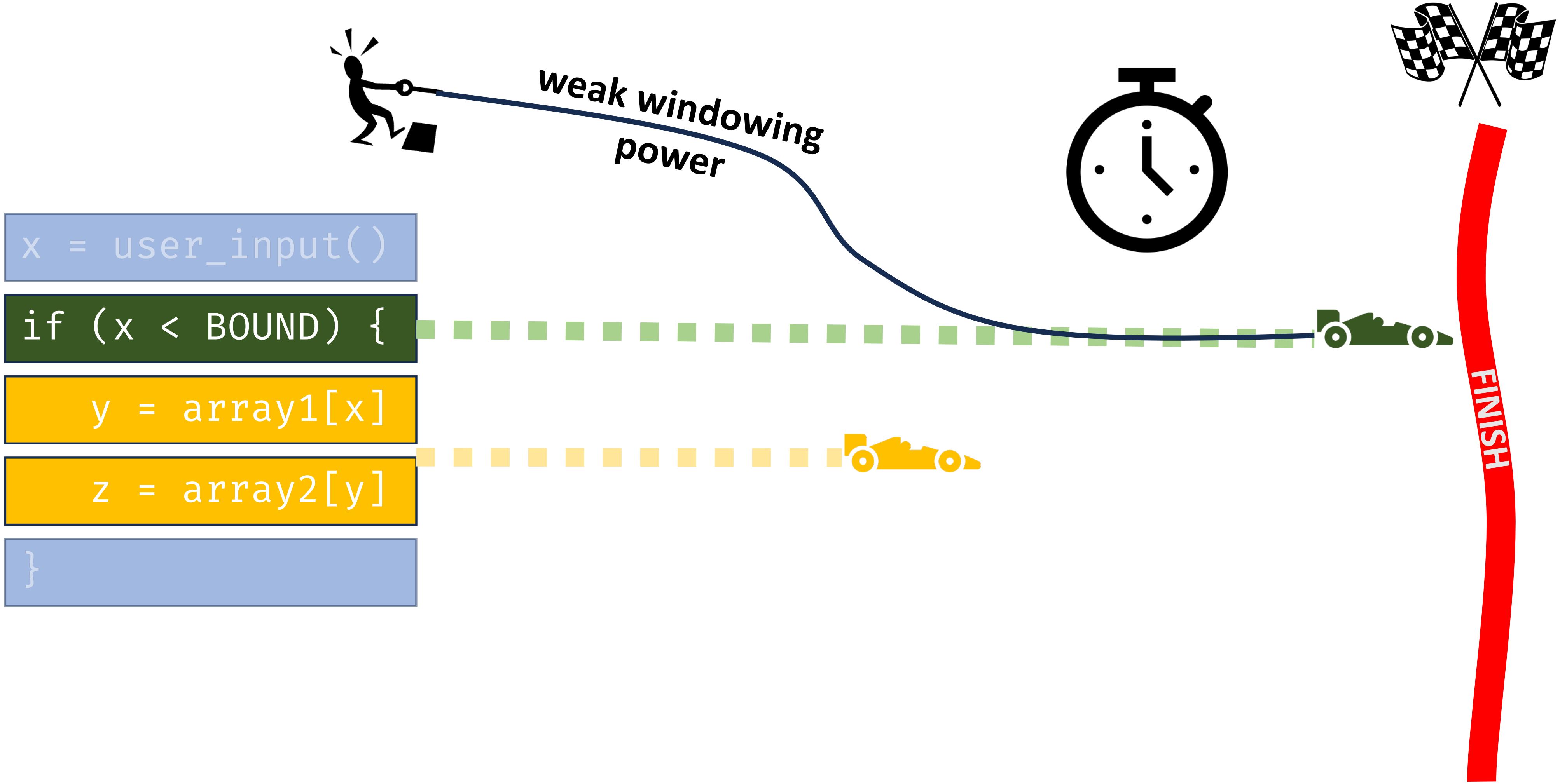

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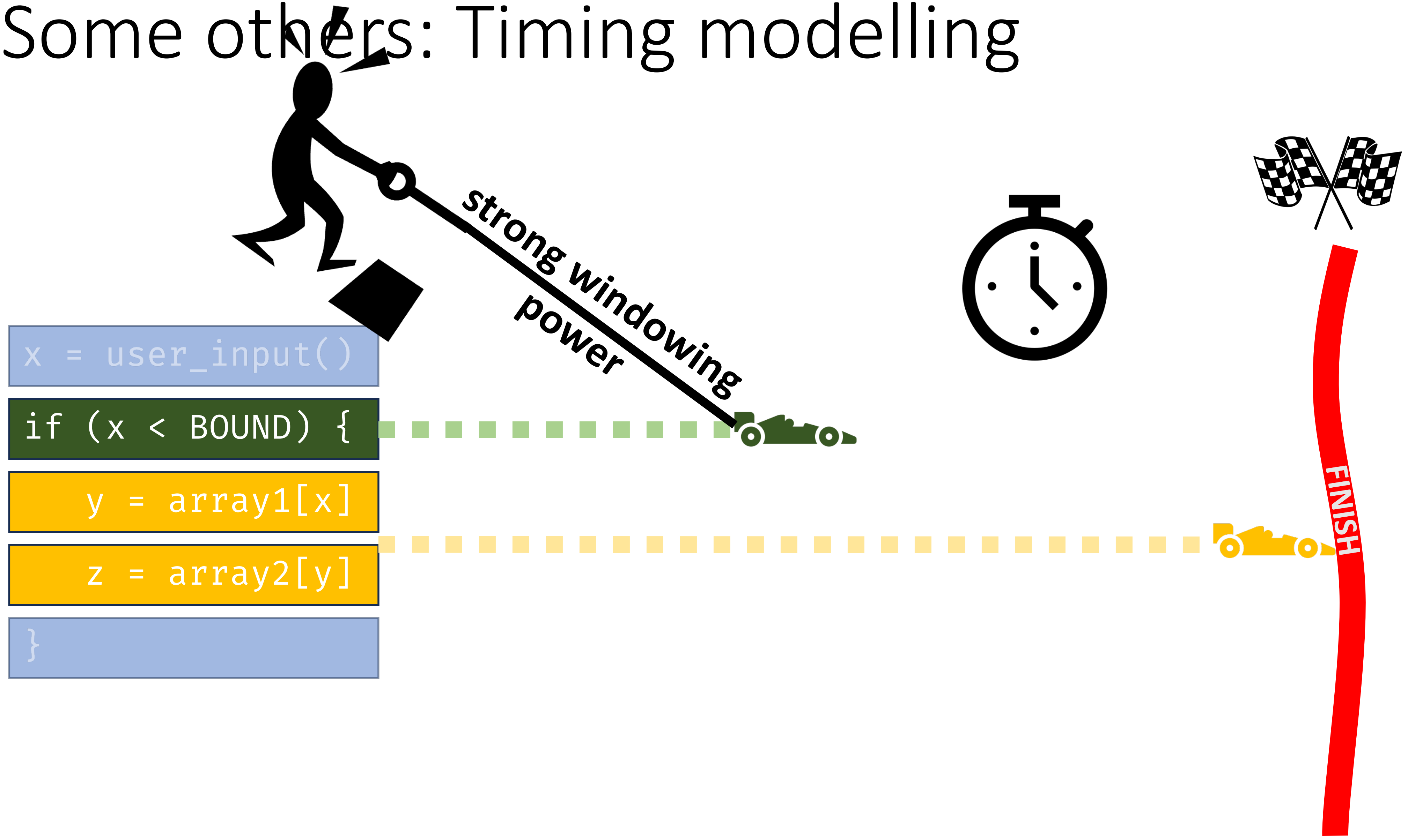

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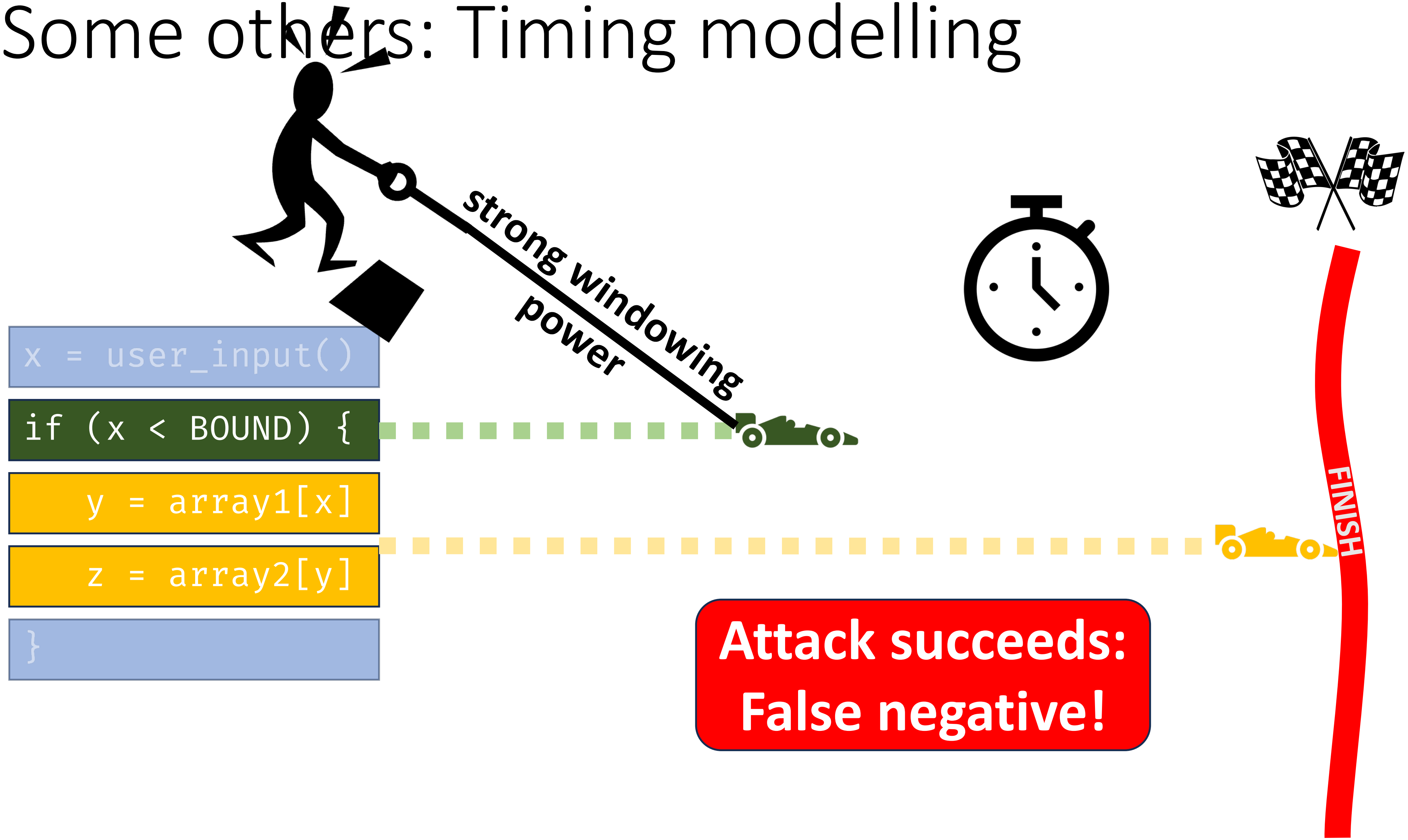

```
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}
```
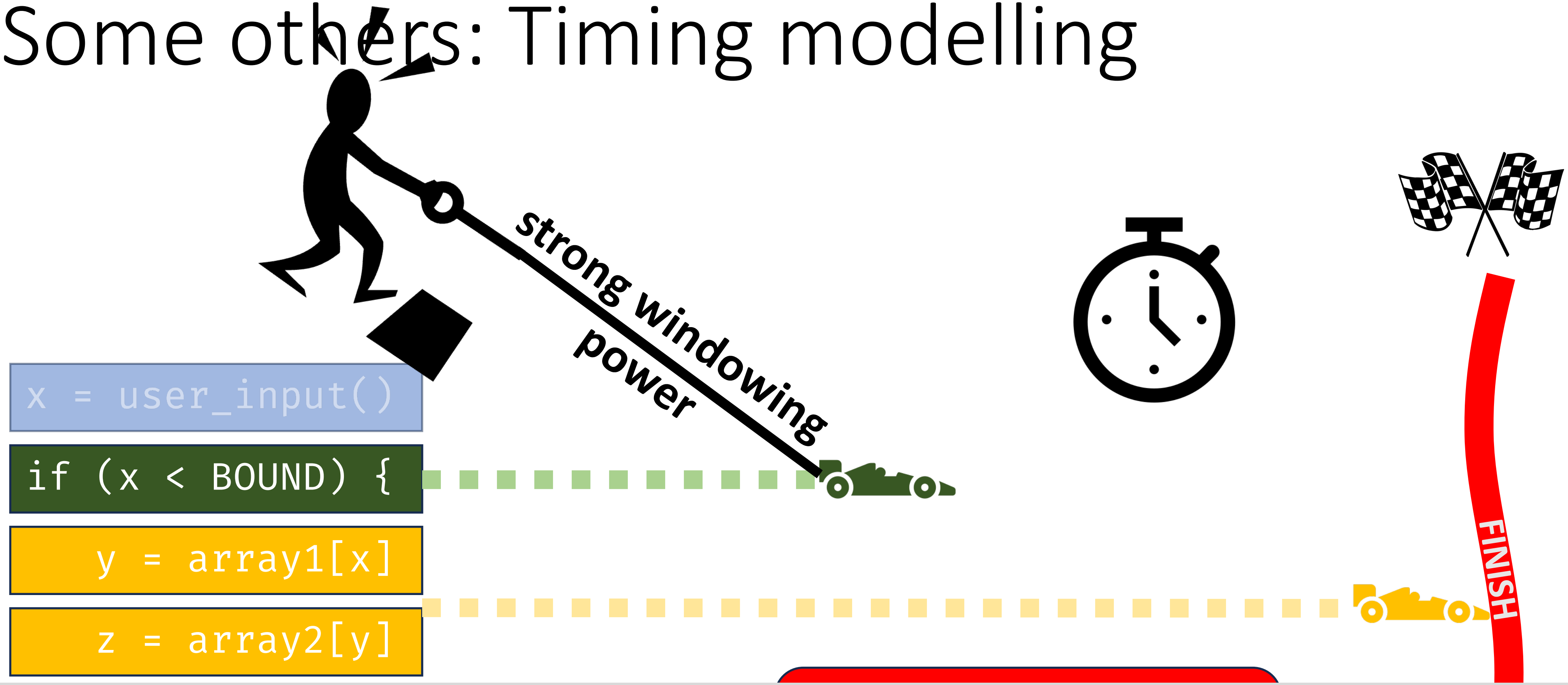

Attack succeeds:
False negative!

Some others: Timing modelling



```
x = user_input()
if (x < BOUND) {
    y = array1[x]
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```
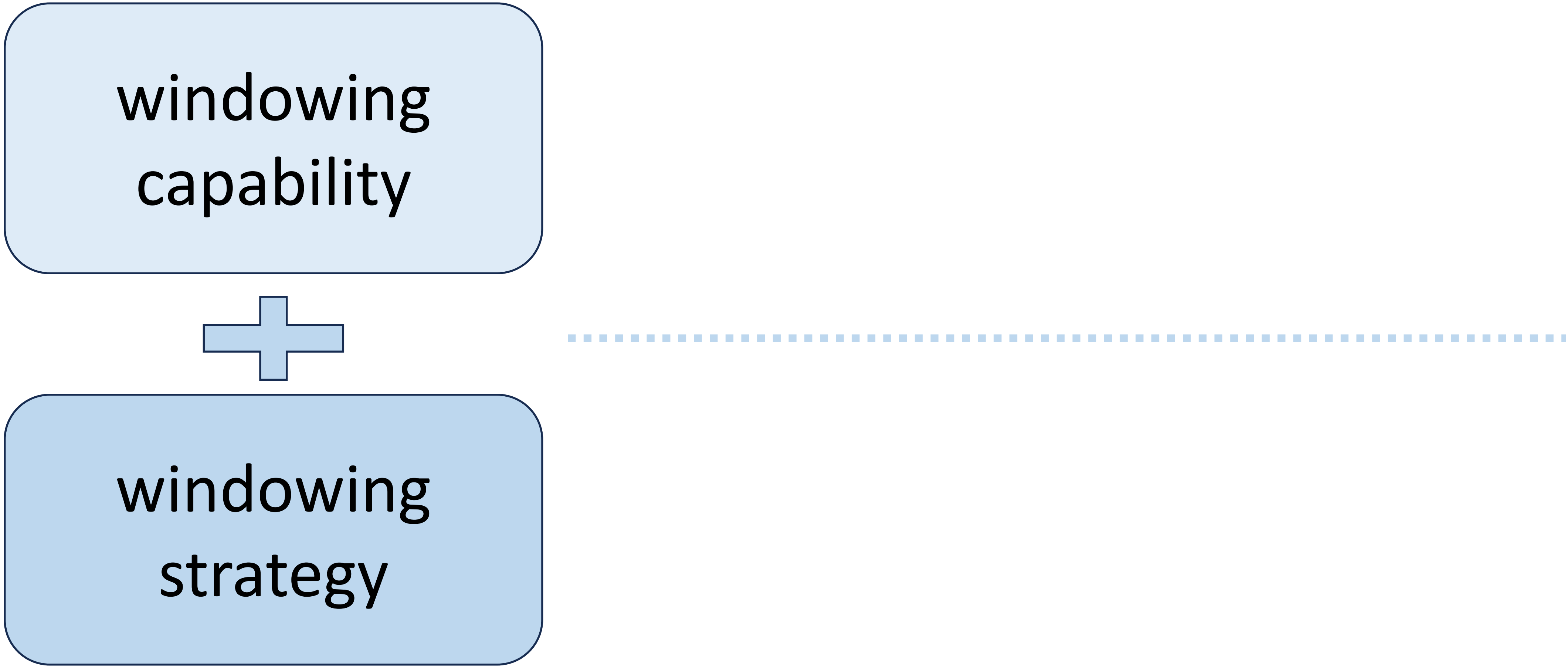

Measure the timing condition accurately,

under strong windowing power!

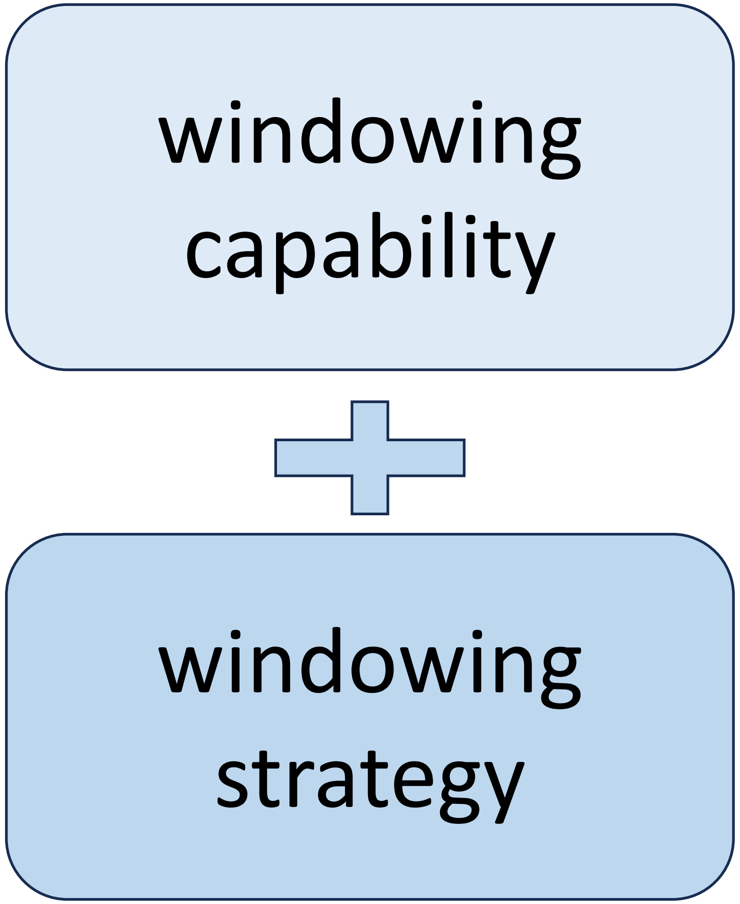
Our approach: Modelling windowing power



windowing capability

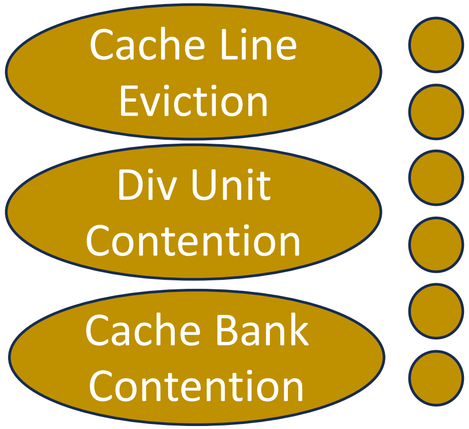
windowing strategy

Our approach: Modelling windowing power



windowing capability

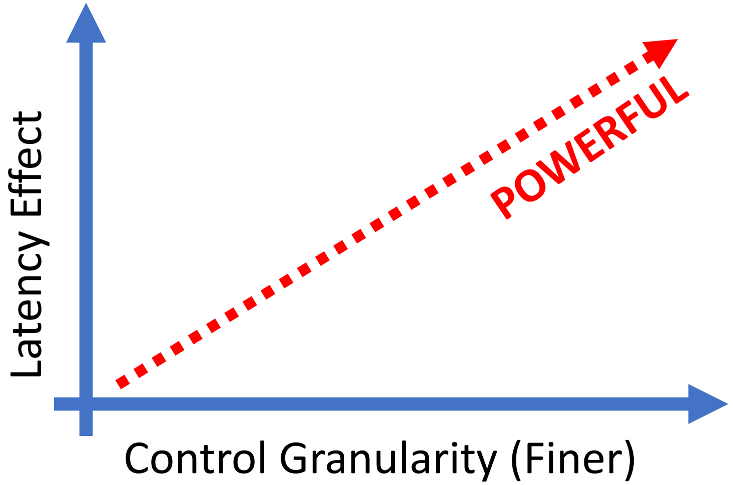
windowing strategy



Cache Line Eviction

Div Unit Contention

Cache Bank Contention

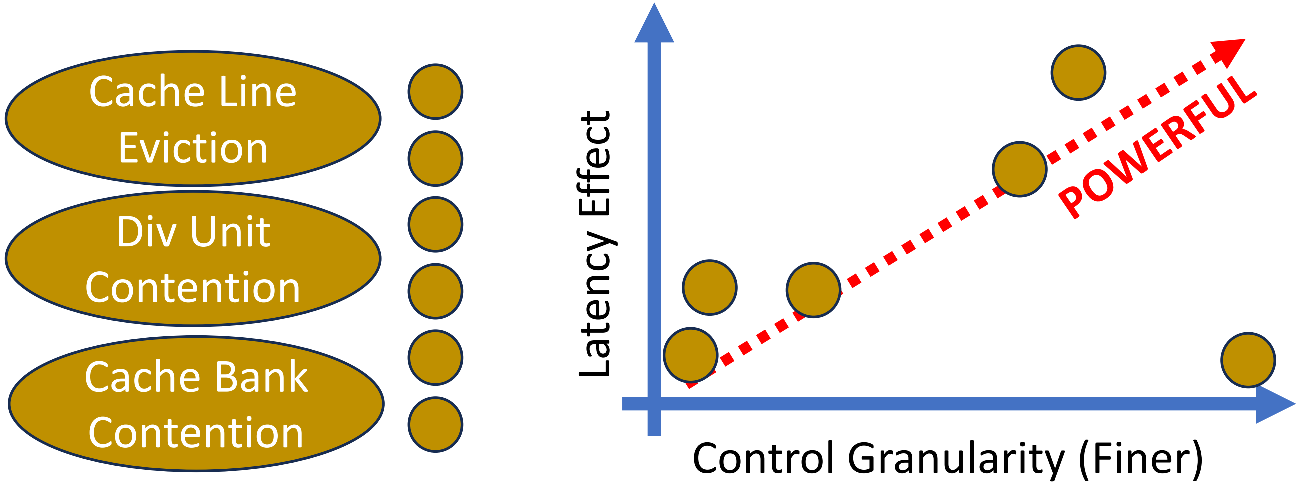


Our approach: Modelling windowing power

windowing capability

+

windowing strategy



Our approach: Modelling windowing power

windowing capability

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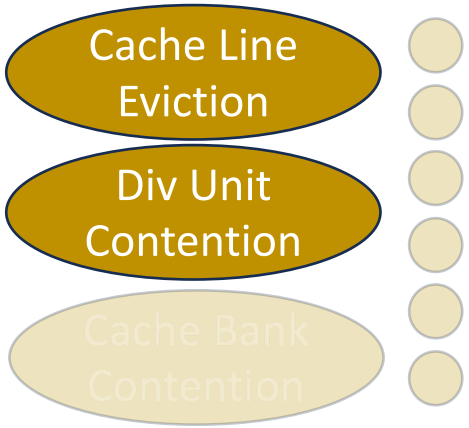
Cache Line Eviction

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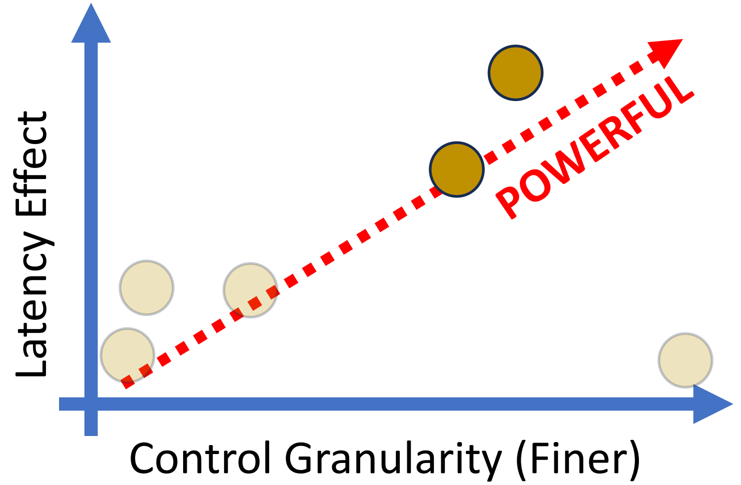

Our approach: Modelling windowing power

windowing capability

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windowing strategy

Cache Line Eviction

Div Unit Contention

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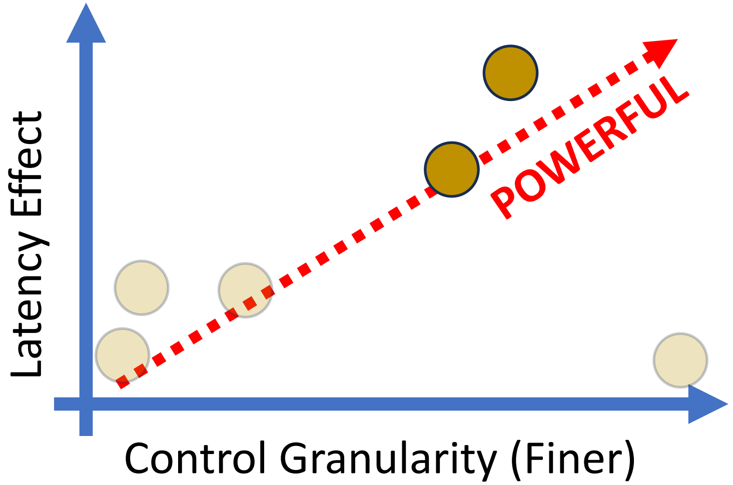
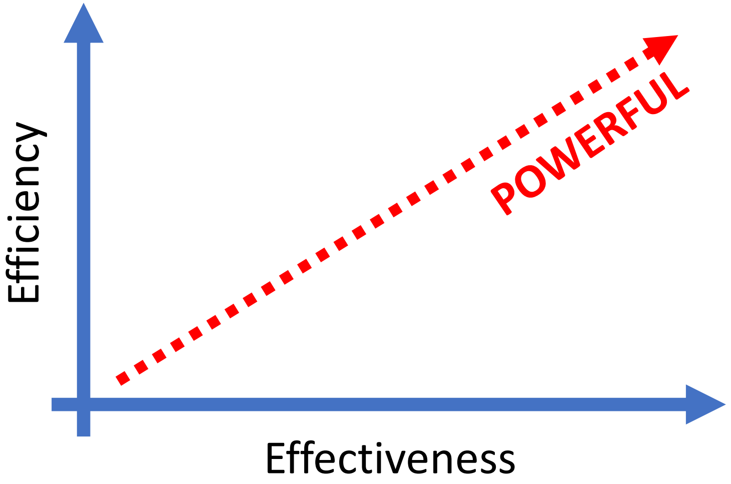
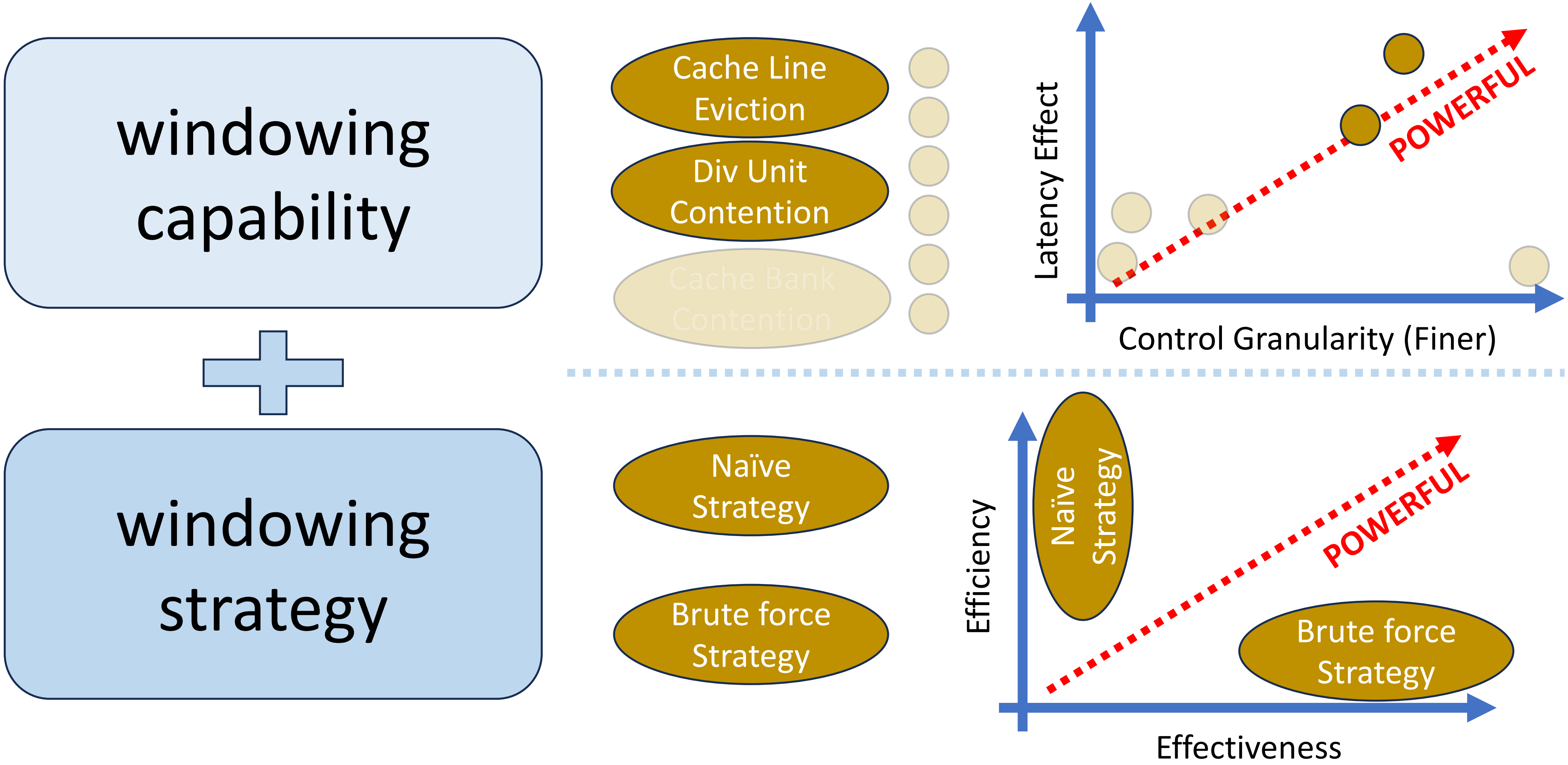


Naïve Strategy

Brute force Strategy



Our approach: Modelling windowing power



Our approach: Modelling windowing power

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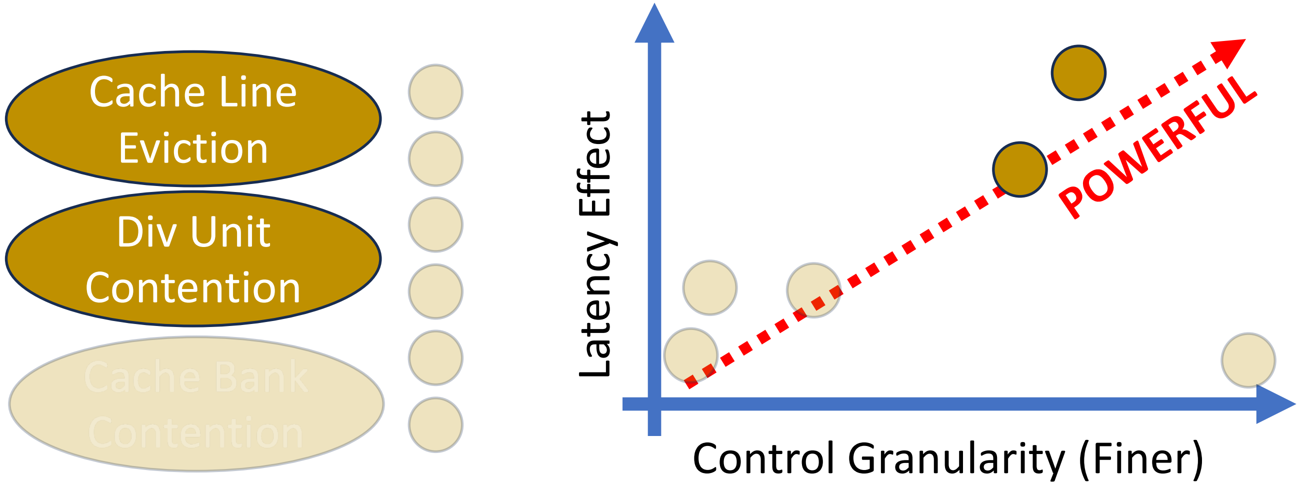

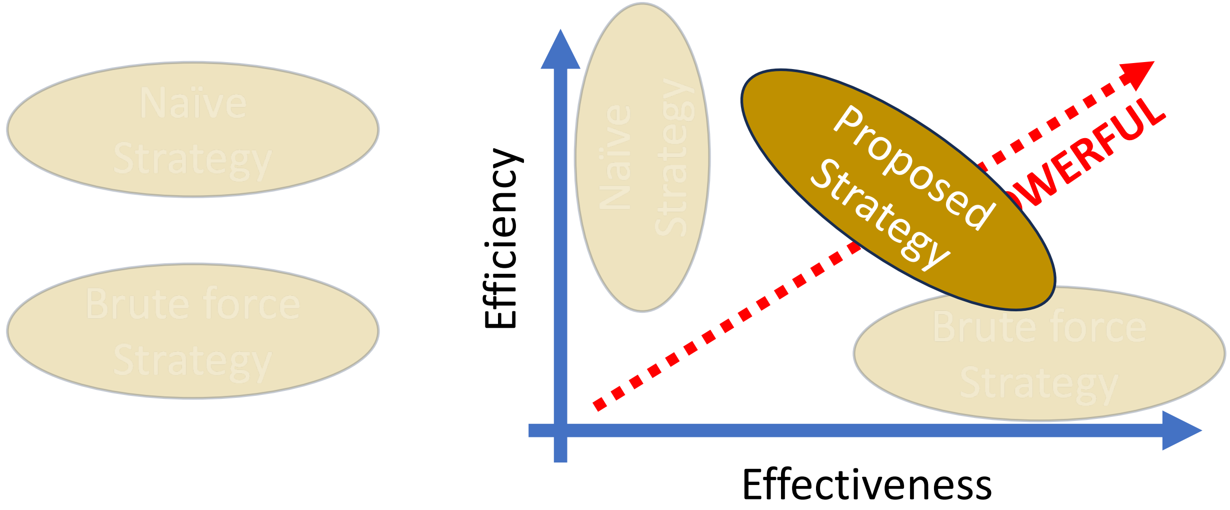

Well, how do we evaluate gadgets?

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Step A: **Modelling** timing condition

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Step A: **Modelling** timing condition

Step B: **Simulating** windowing power

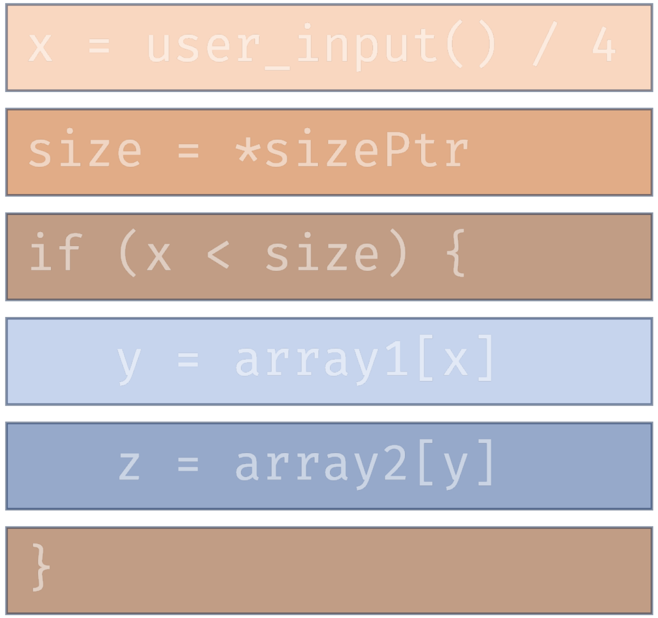
Well, how do we evaluate gadgets?

Step A: **Modelling** timing condition

Step B: **Simulating** windowing power

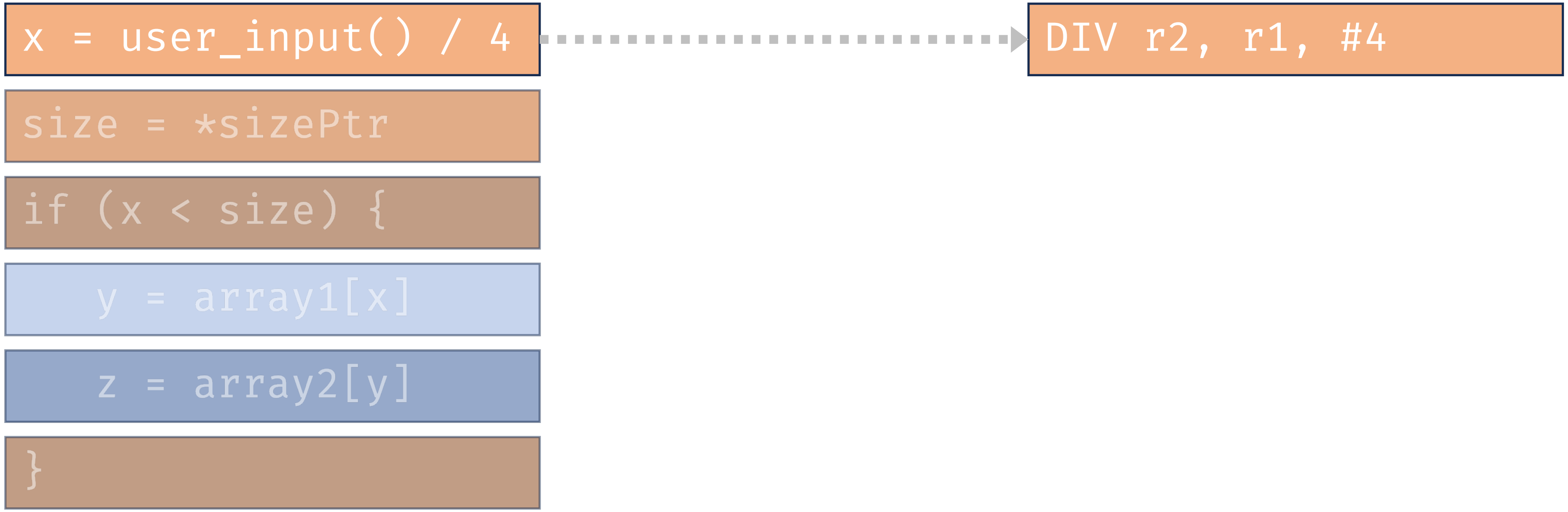
Step C: **Quantifying** exploitability

Our approach: An example



```
x = user_input() / 4
size = *sizePtr
if (x < size) {
   y = array1[x]
   z = array2[y]
}
```

Our approach: An example



```
x = user_input() / 4
size = *sizePtr
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    y = array1[x]
    z = array2[y]
}
```

```
DIV r2, r1, #4
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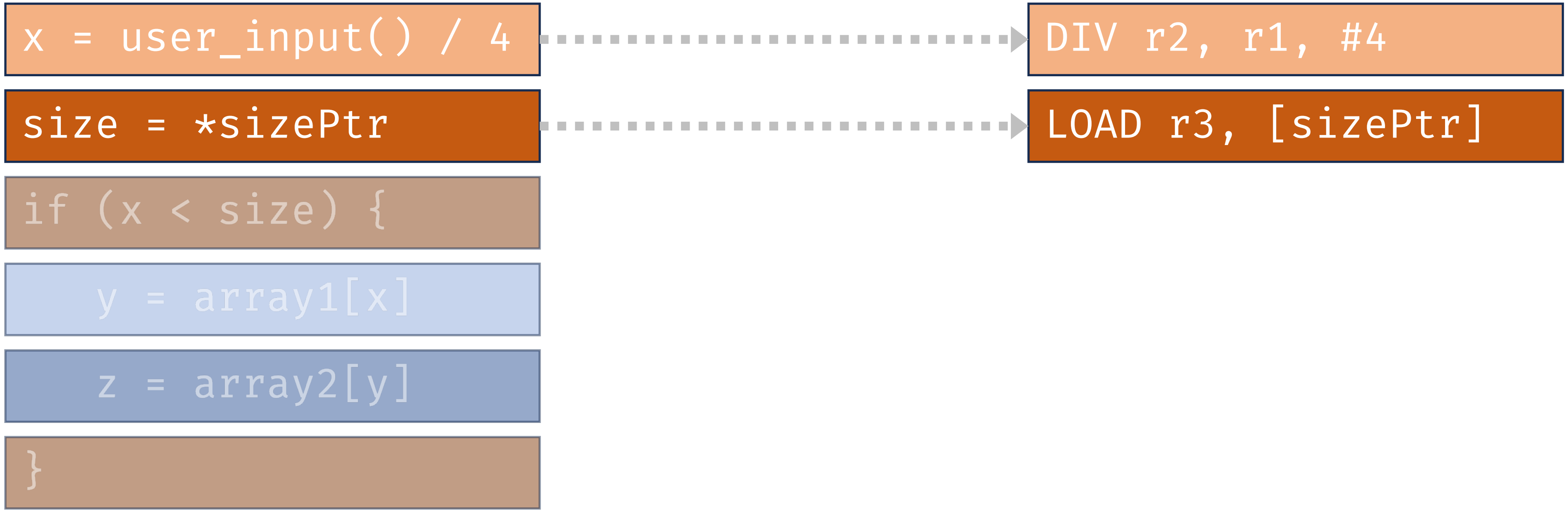

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if (x < size) {
    y = array1[x]
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}
```
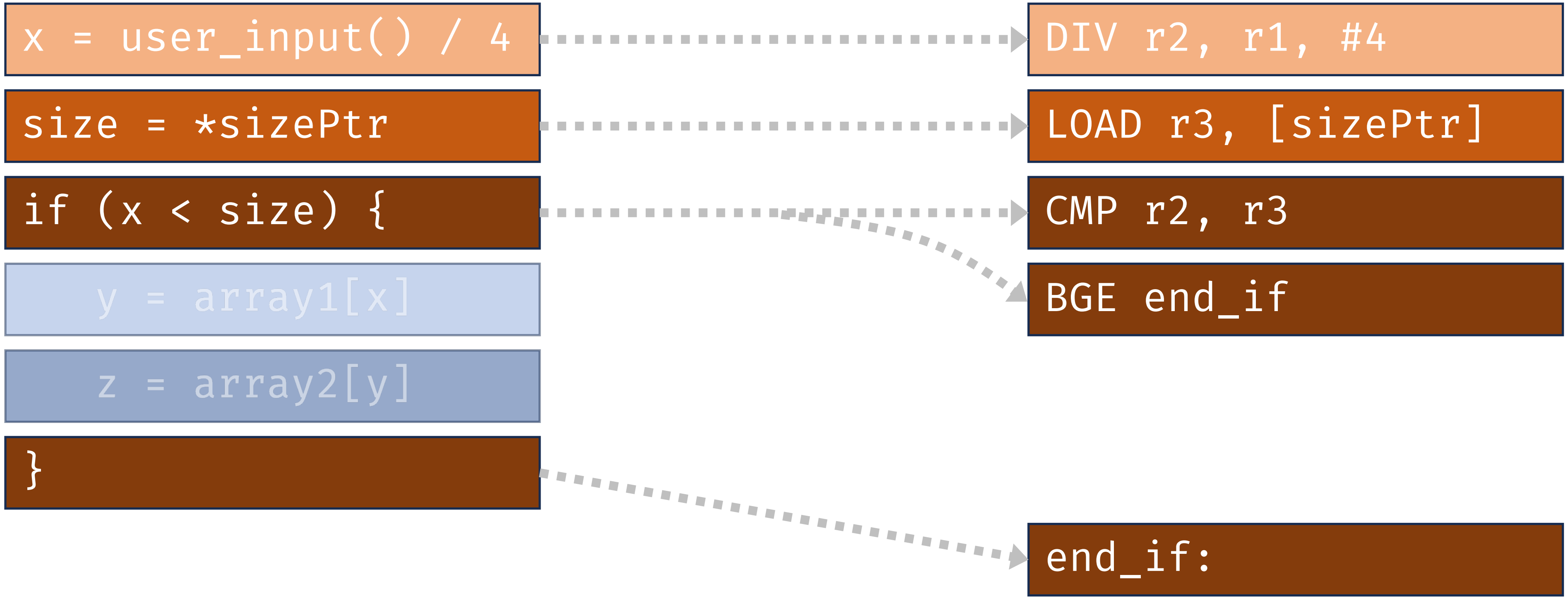

```
DIV r2, r1, #4
LOAD r3, [sizePtr]
```

Our approach: An example



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}
```

```
DIV r2, r1, #4
LOAD r3, [sizePtr]
CMP r2, r3
BGE end_if

end_if:
```

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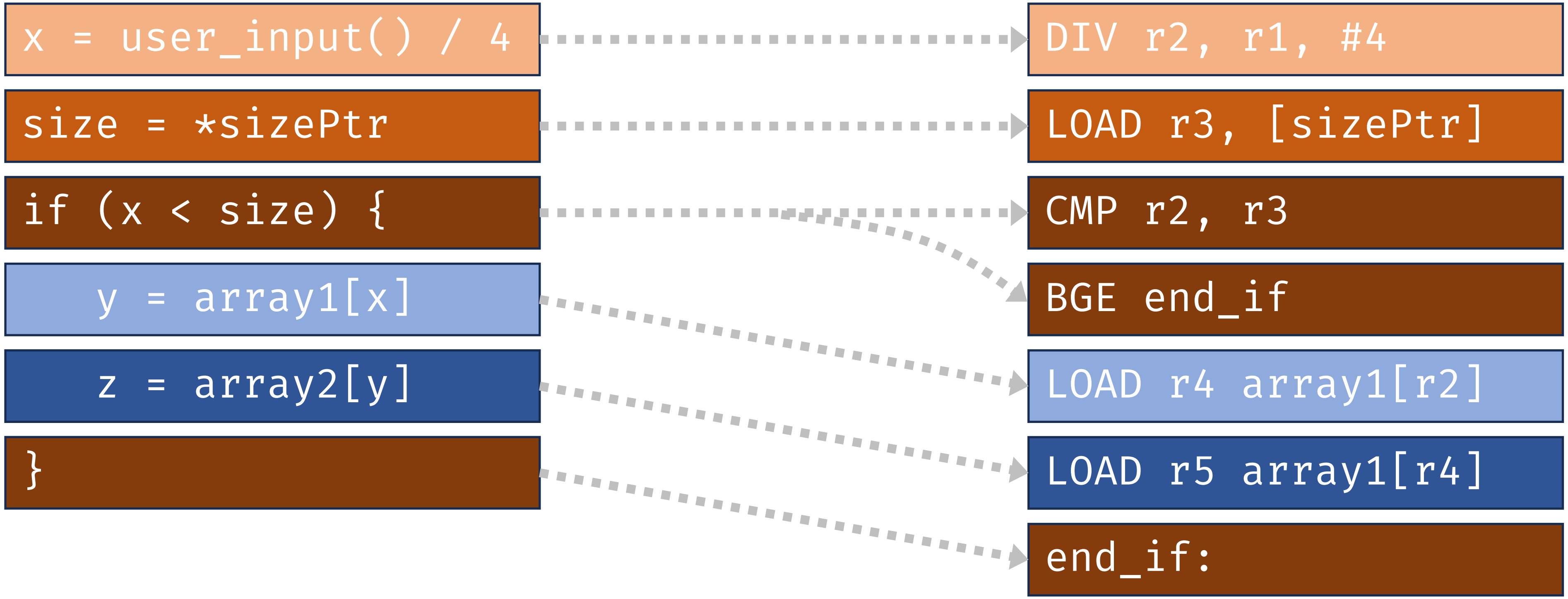

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LOAD r5 array1[r4]
end_if:
```

Step A: Modelling timing condition

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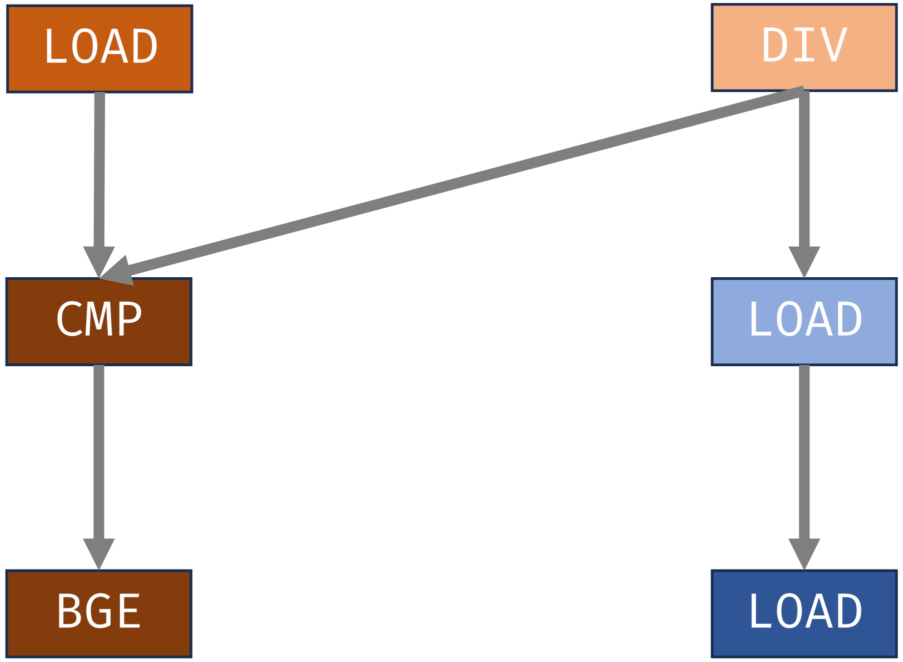

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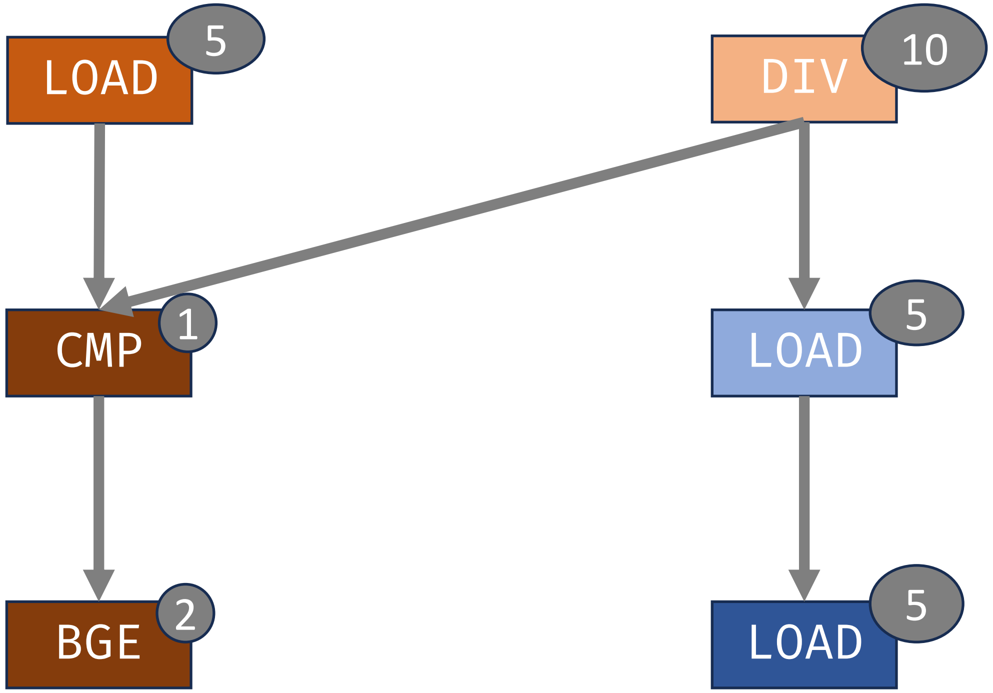

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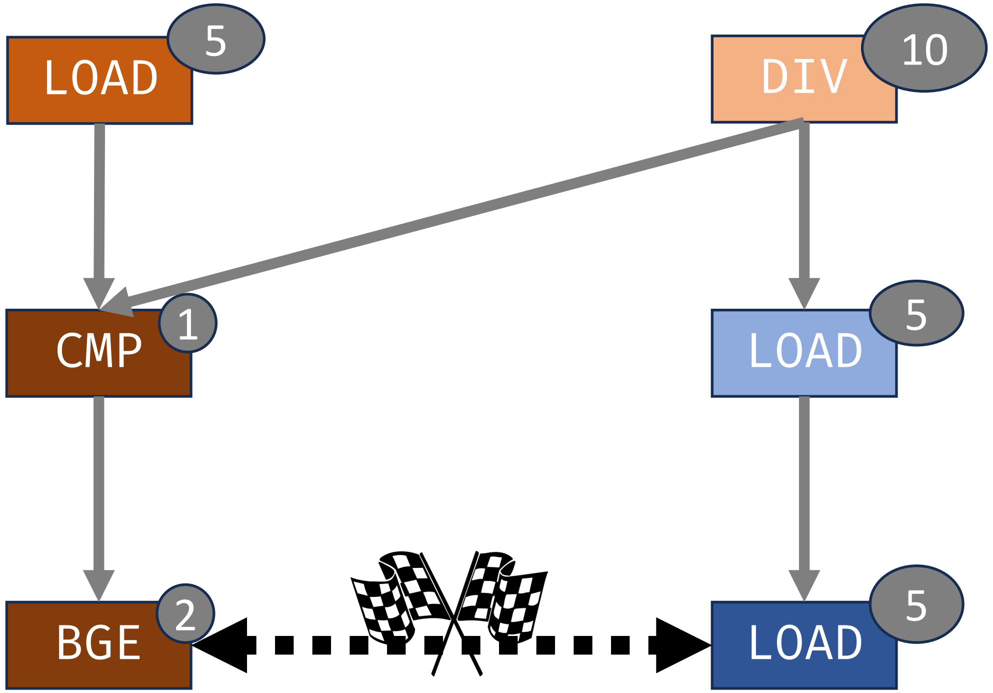

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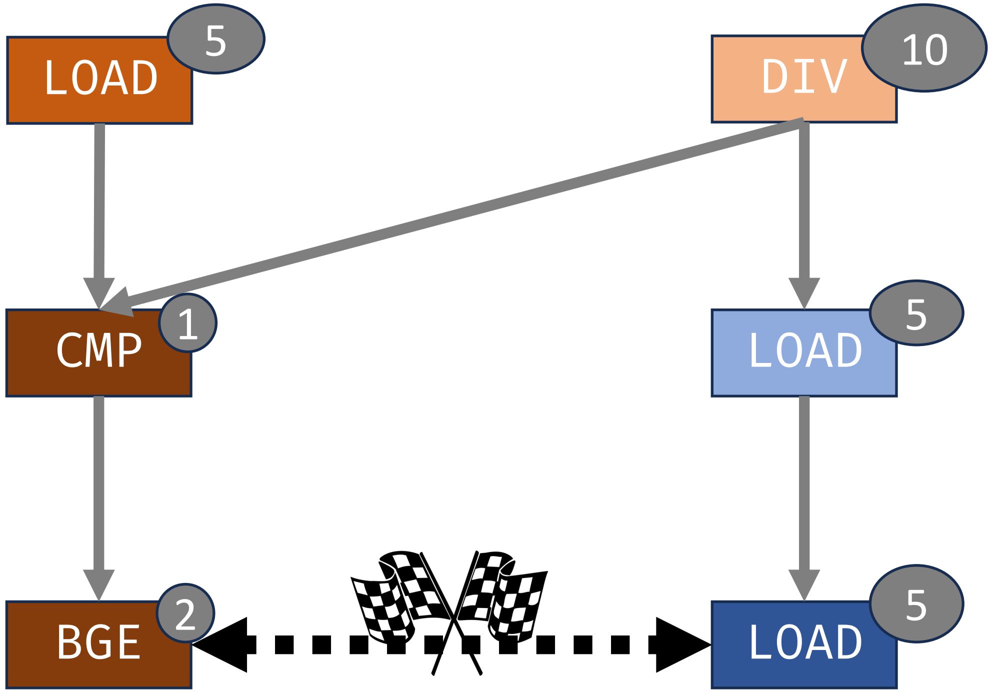

MaxPathWeight(BGE) **−** ***MaxPathWeight***(LOAD)

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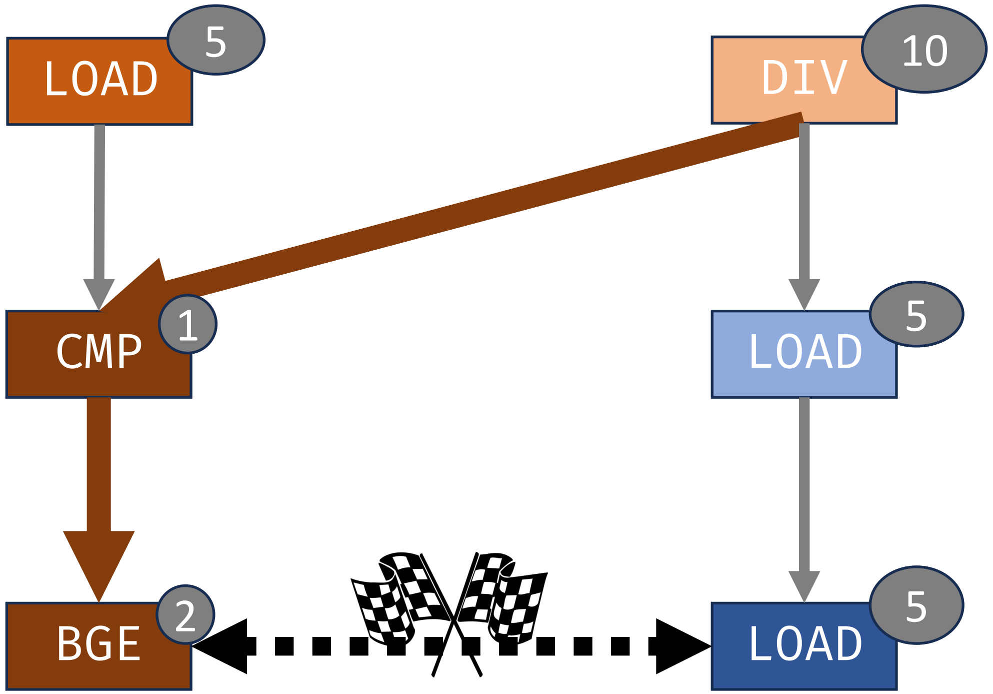

MaxPathWeight(BGE) − ***MaxPathWeight***(LOAD)

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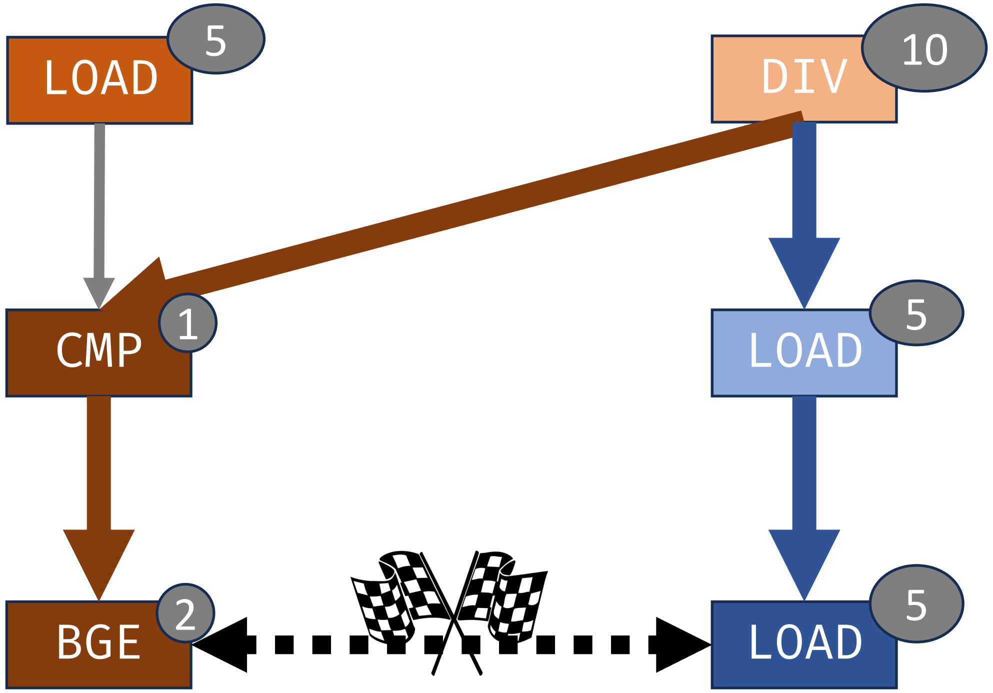

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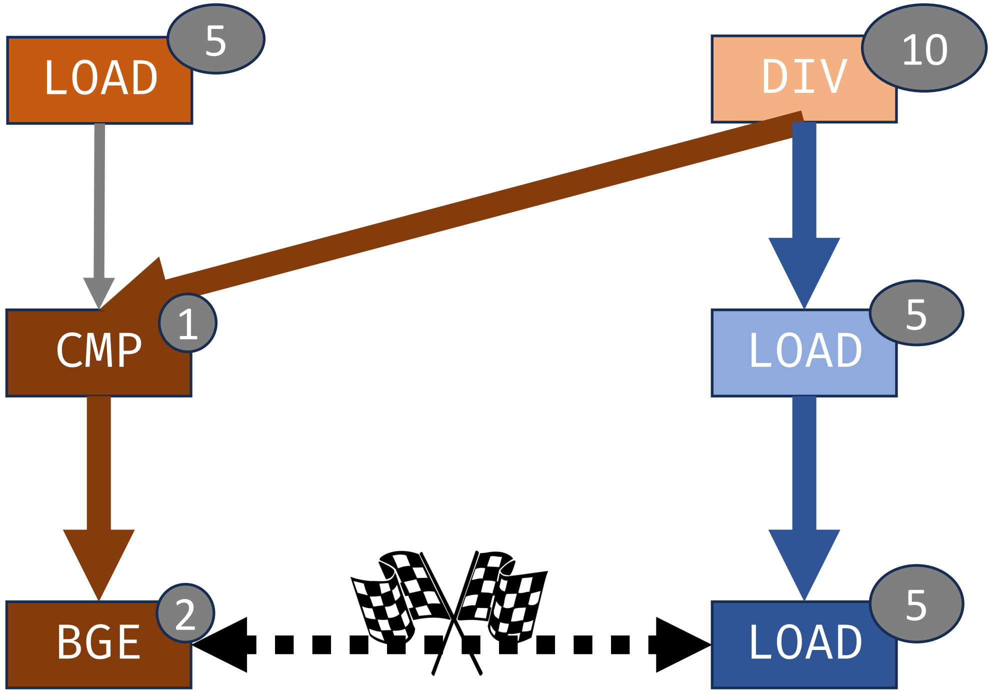
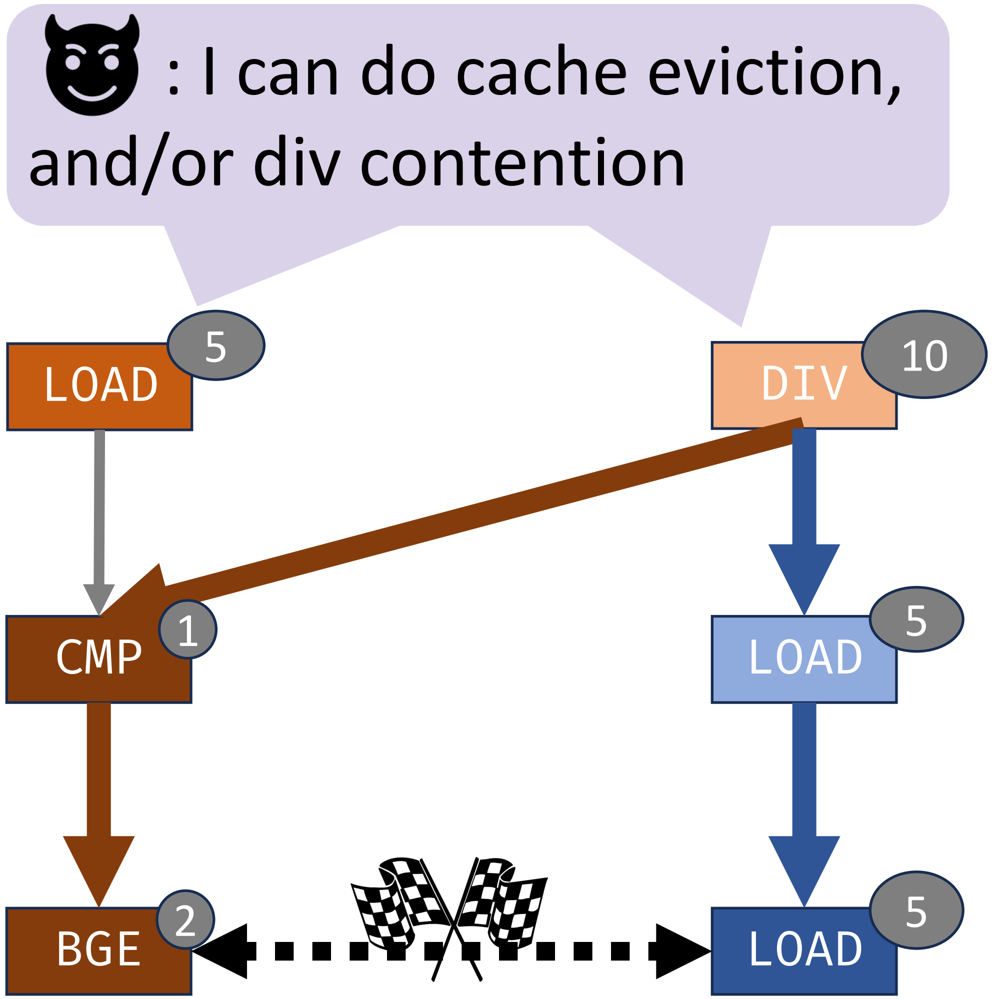


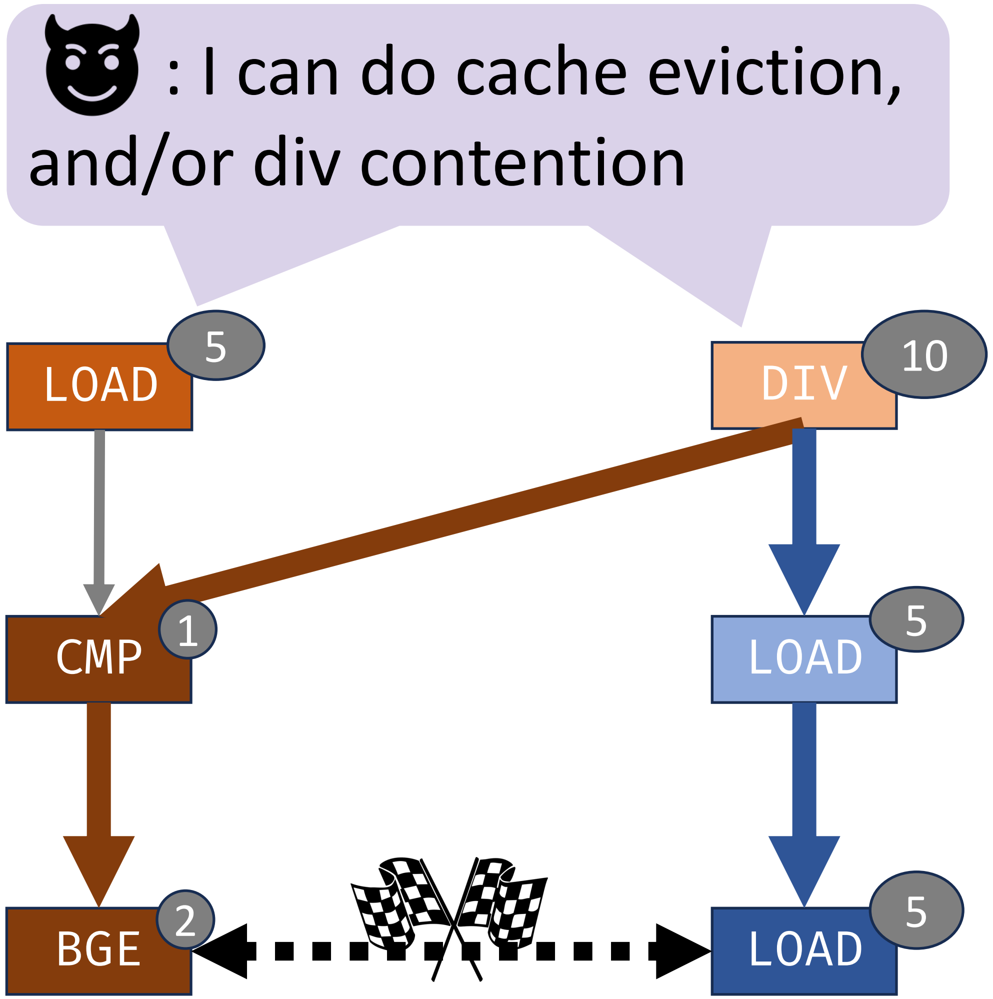
Timing Condition Index **=** ***MaxPathWeight***(BGE) **–** ***MaxPathWeight***(LOAD)

Step B: Simulating windowing power



😈 : I can do cache eviction, and/or div contention

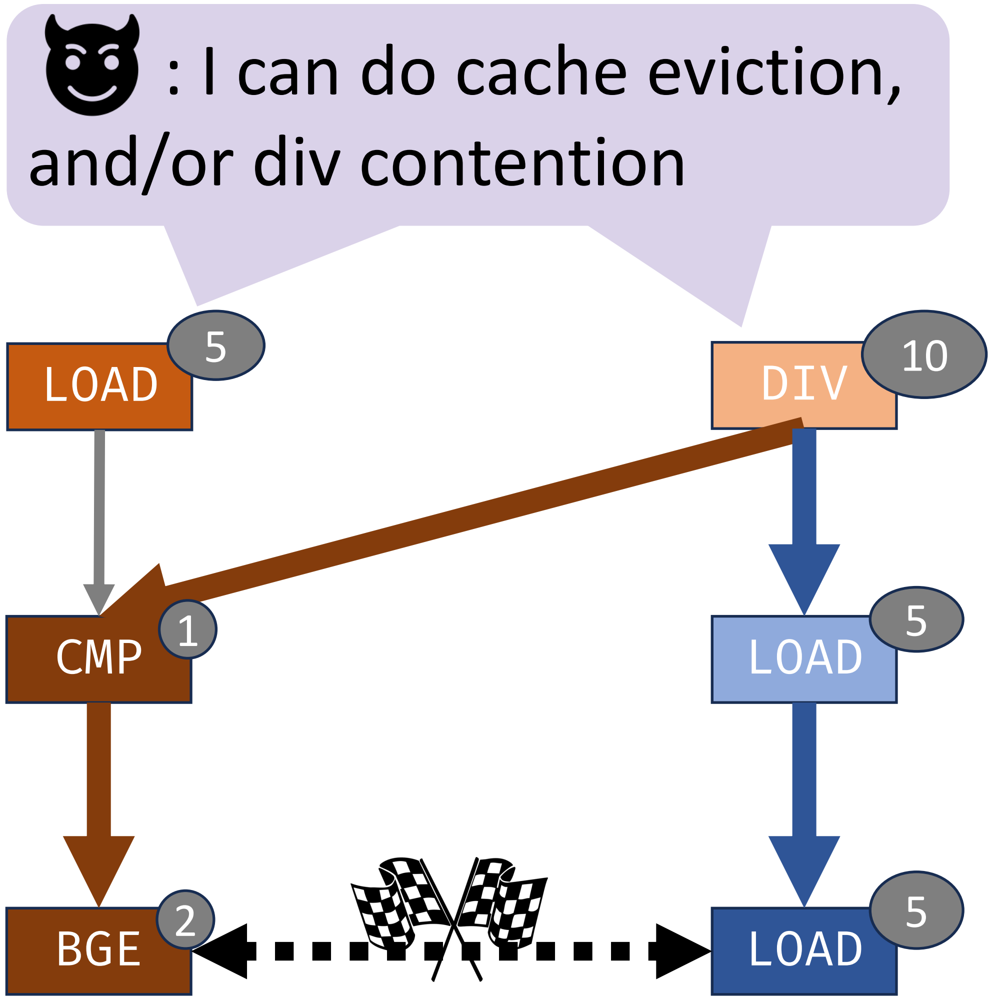
Step B: Simulating windowing power



: I can do cache eviction, and/or div contention

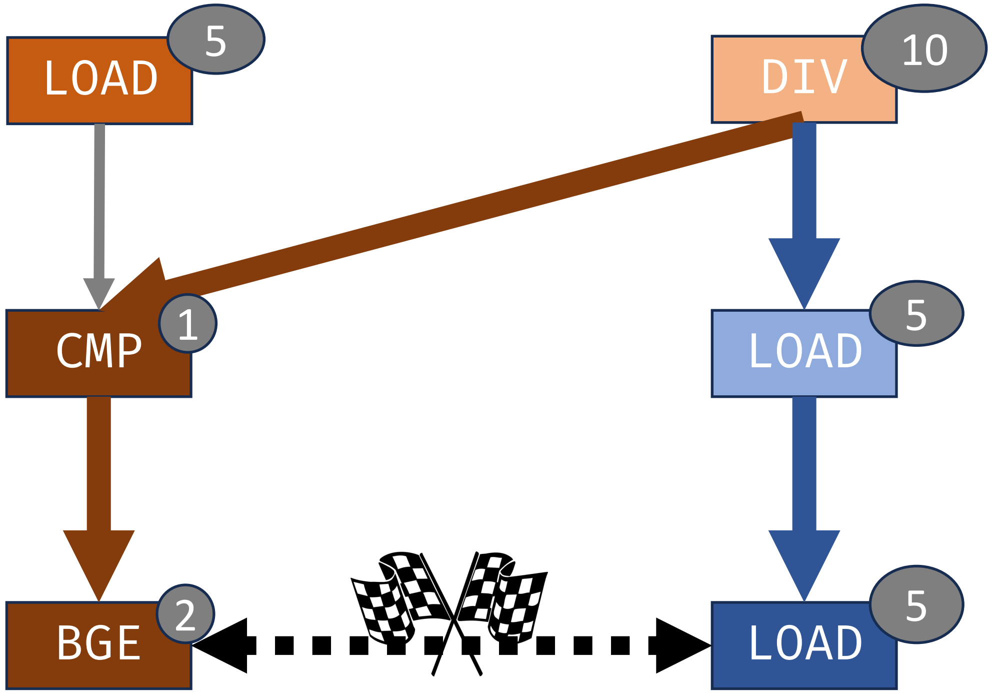
Attack Pattern
Do nothing
Cache eviction
Div contention
Cache eviction + Div contention

Step B: Simulating windowing power



Attack Pattern	**Increase** in Timing Condition Index
Do nothing	?
Cache eviction	?
Div contention	?
Cache eviction + Div contention	?

What if I do cache eviction?



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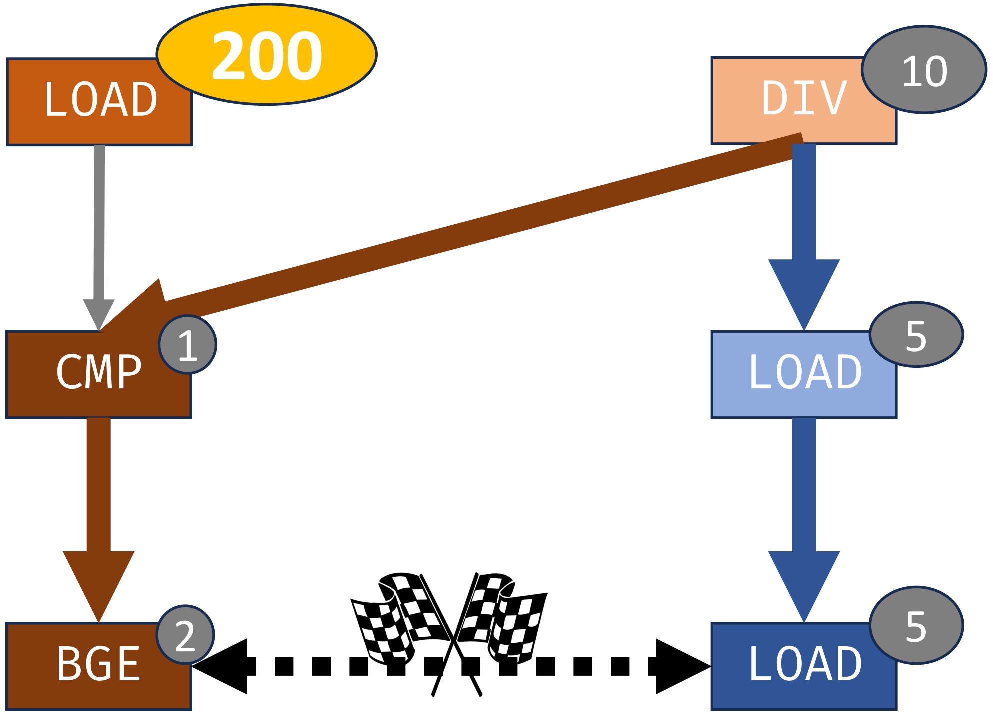

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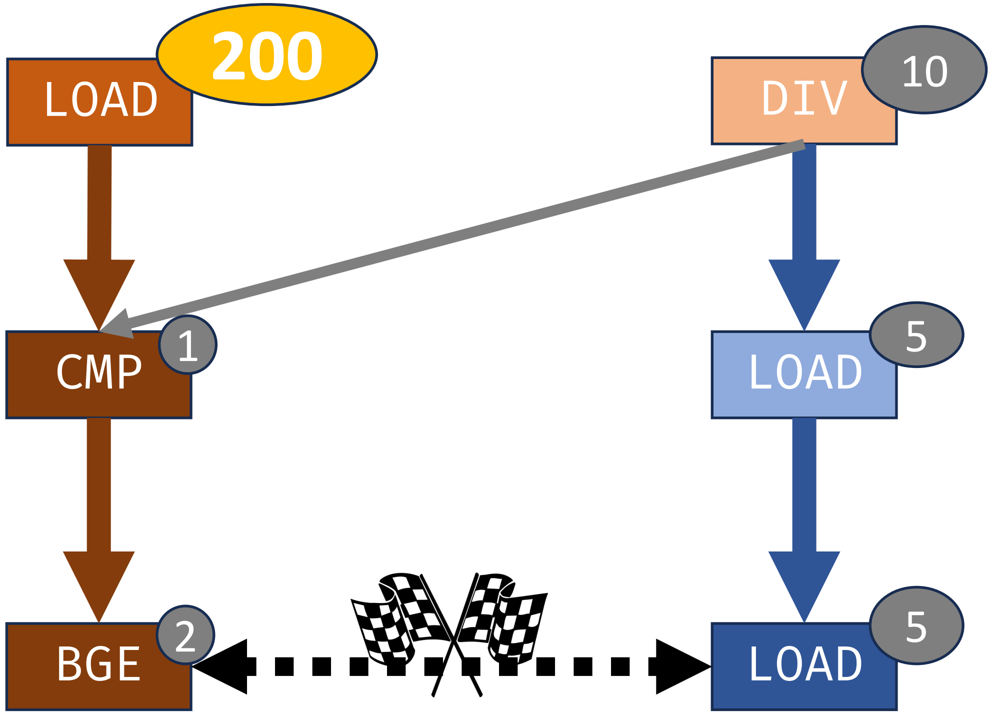

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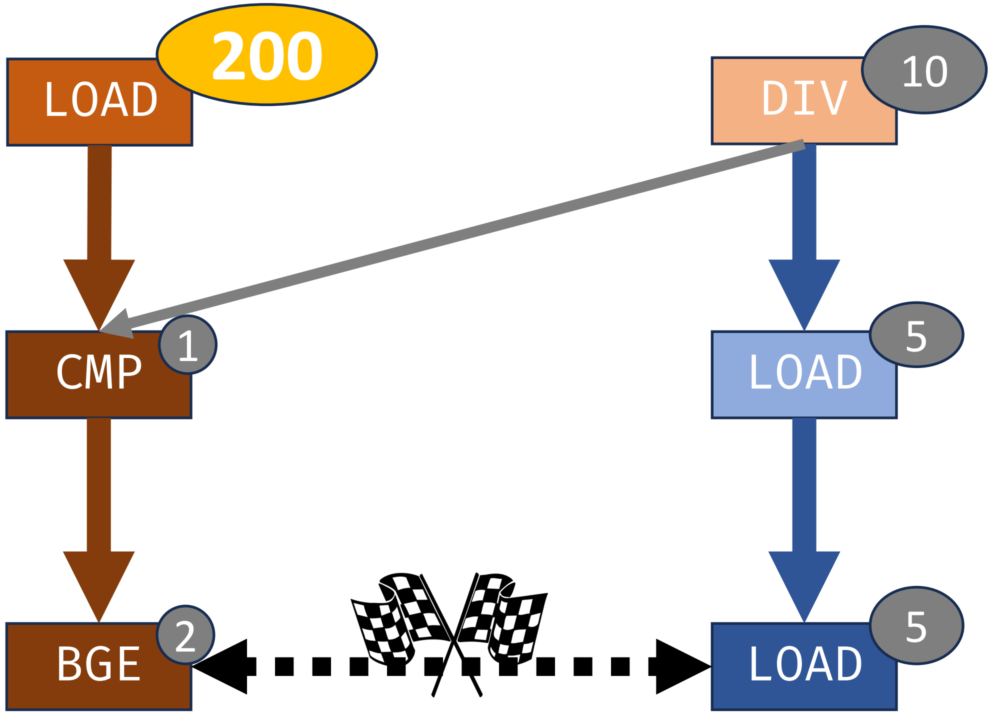
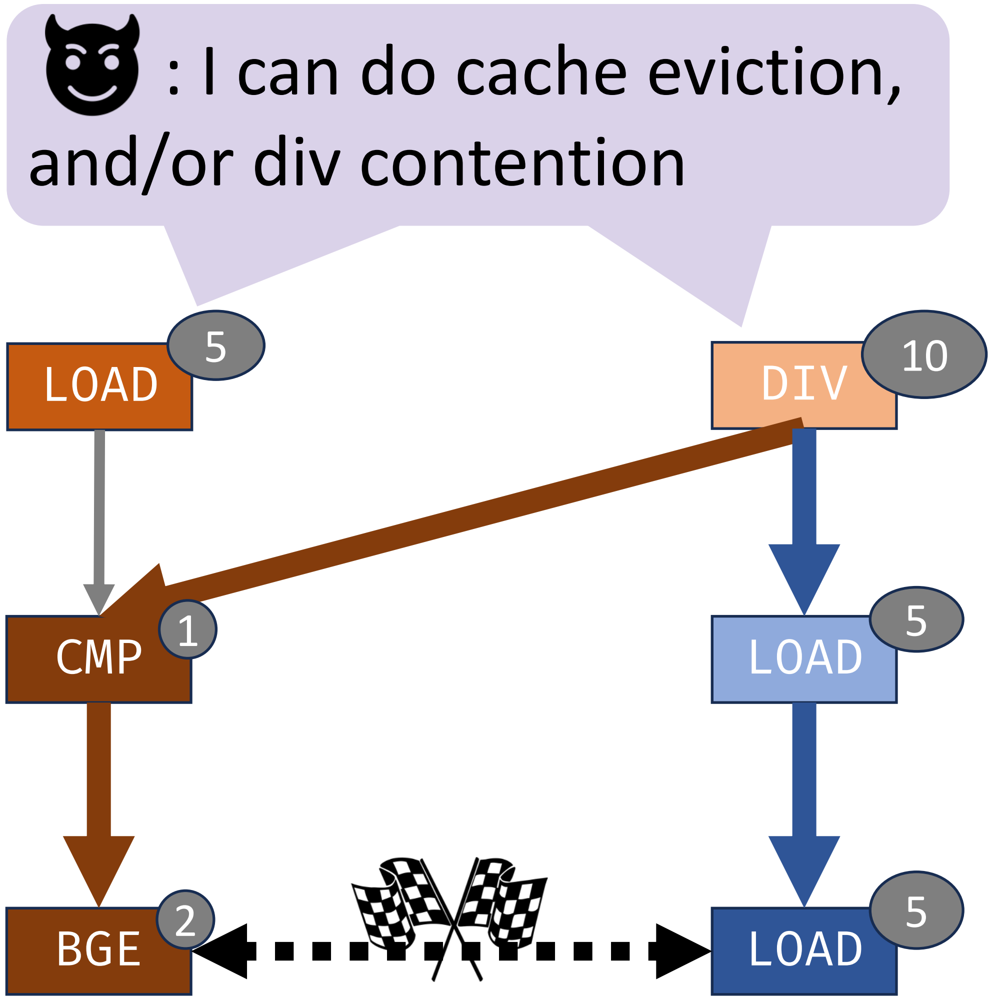


Timing Condition Index was -7.

Now, it increases to **183**!

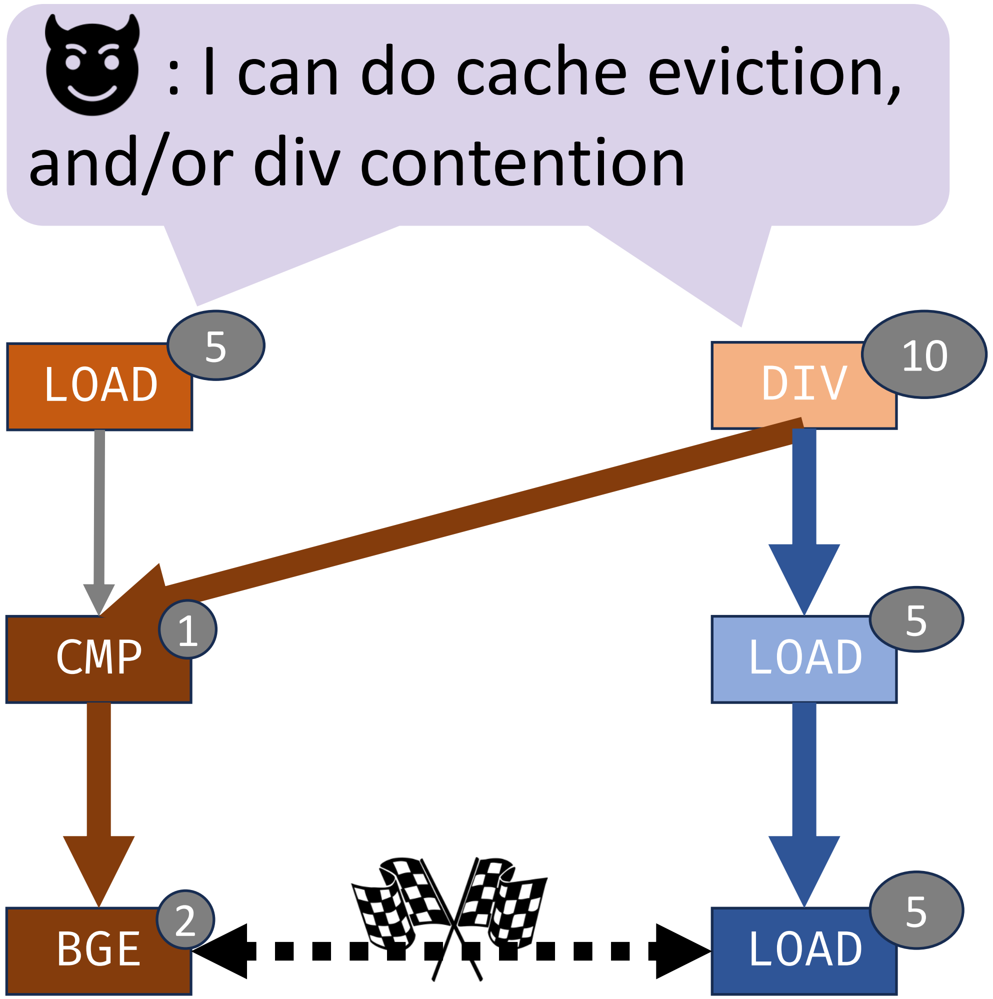
The attack pattern is effective :-)

Step B: Simulating windowing power



Attack Pattern	**Increase** in Timing Condition Index
Do nothing	0
Cache eviction	+190
Div contention	-140
Cache eviction + Div contention	+50

Step B: Simulating windowing power



Attack Pattern	**Increase** in Timing Condition Index
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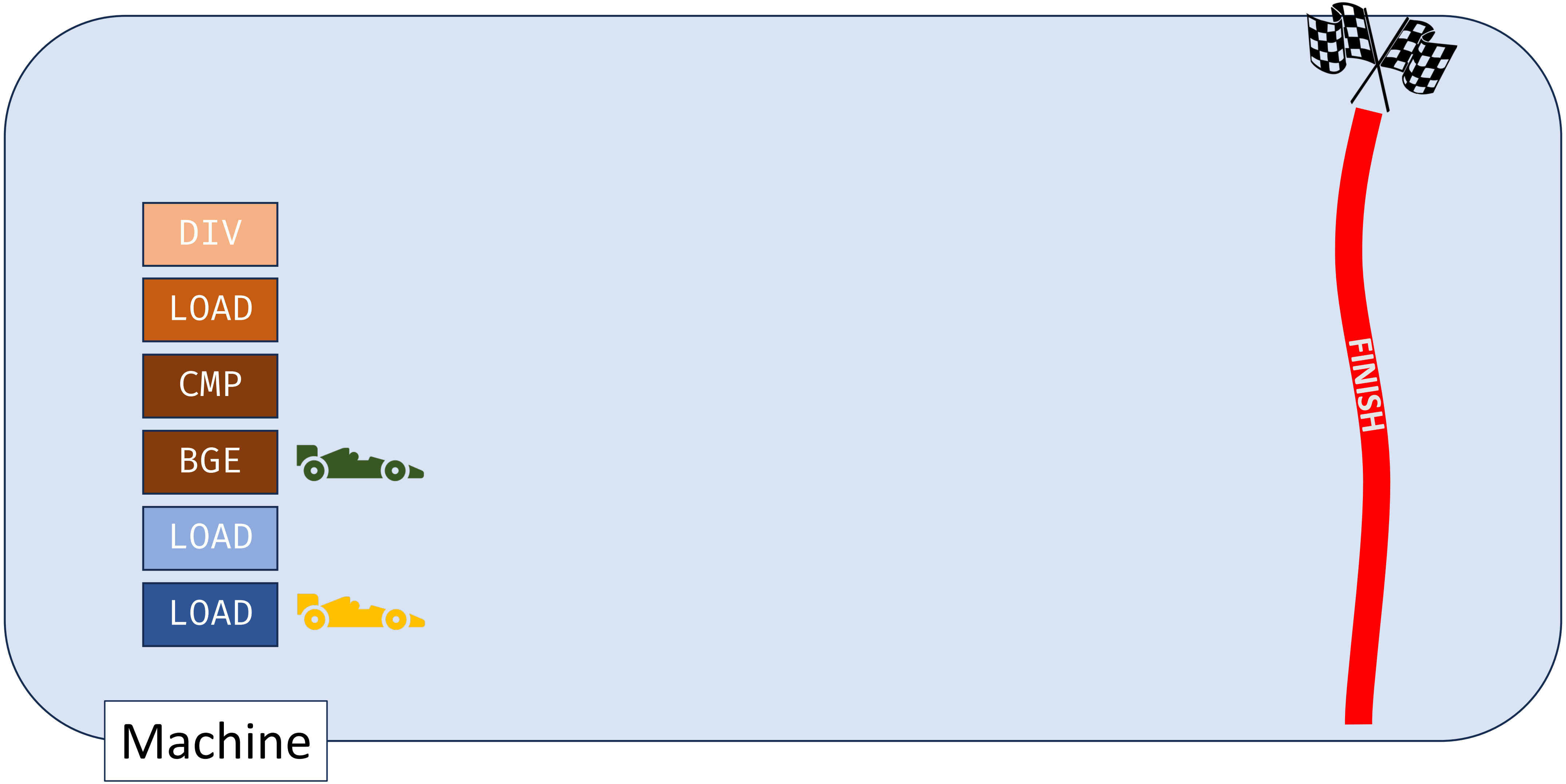
Step C: Measuring exploitability



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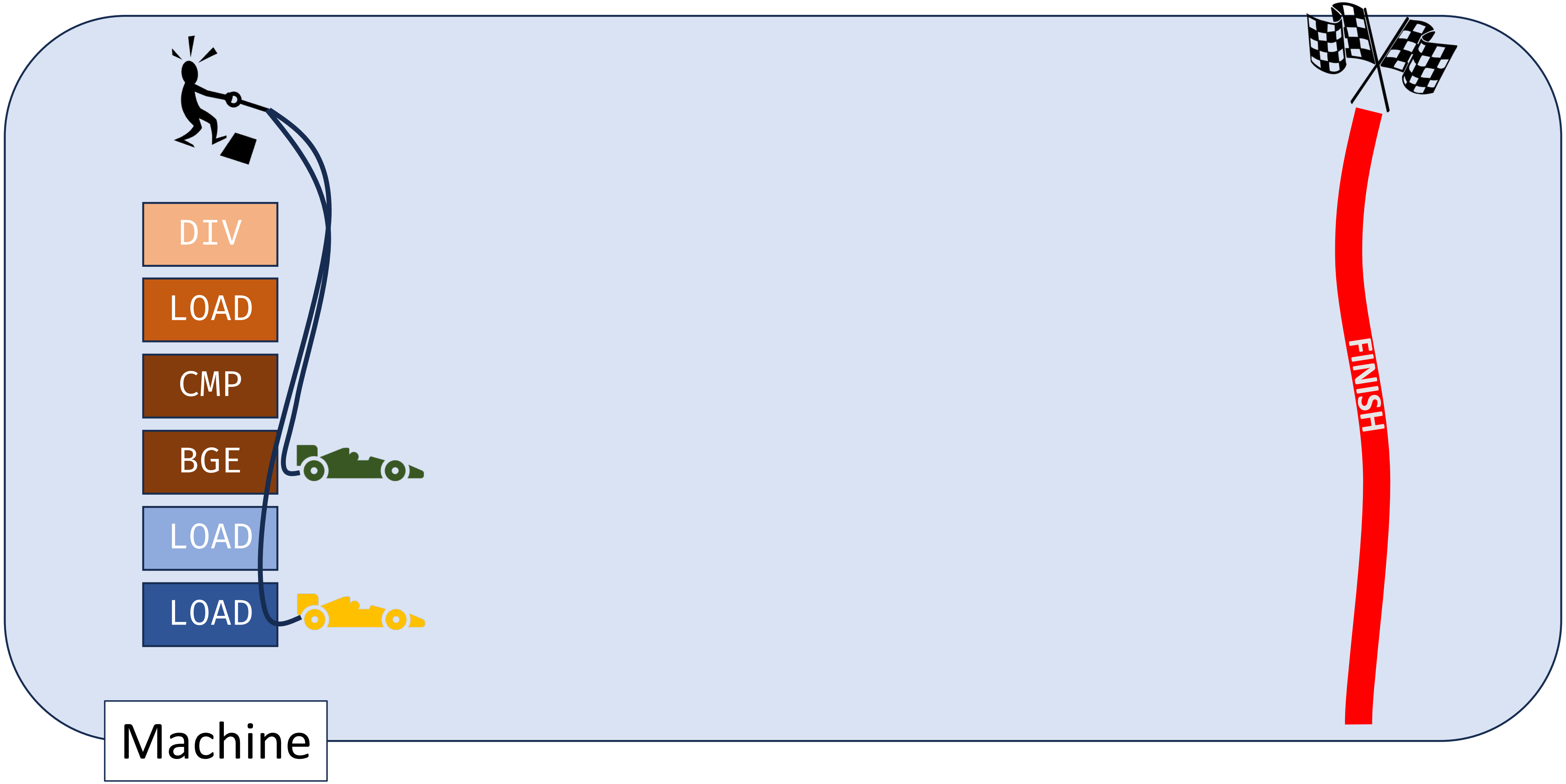
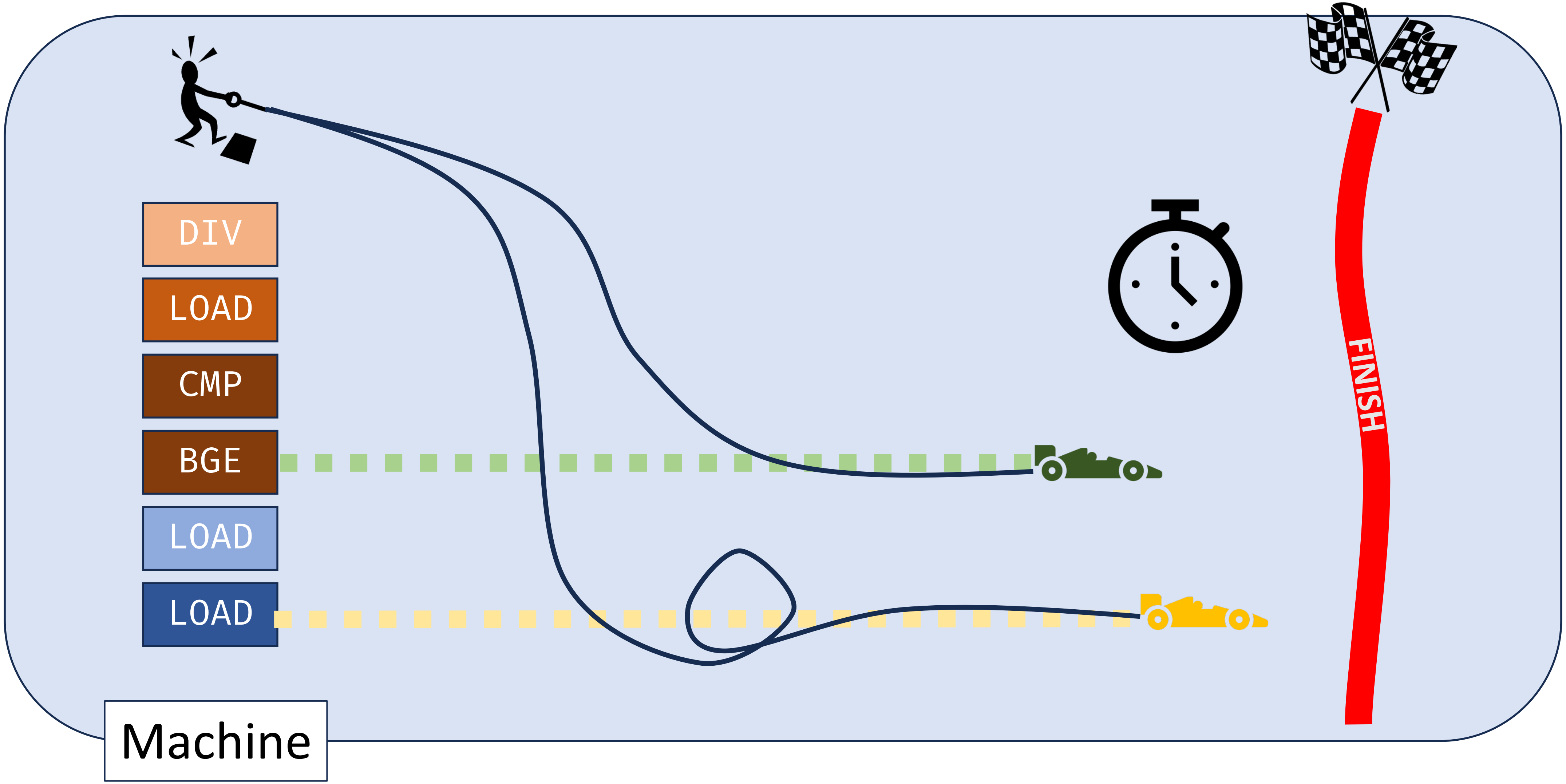


Step C: Measuring exploitability



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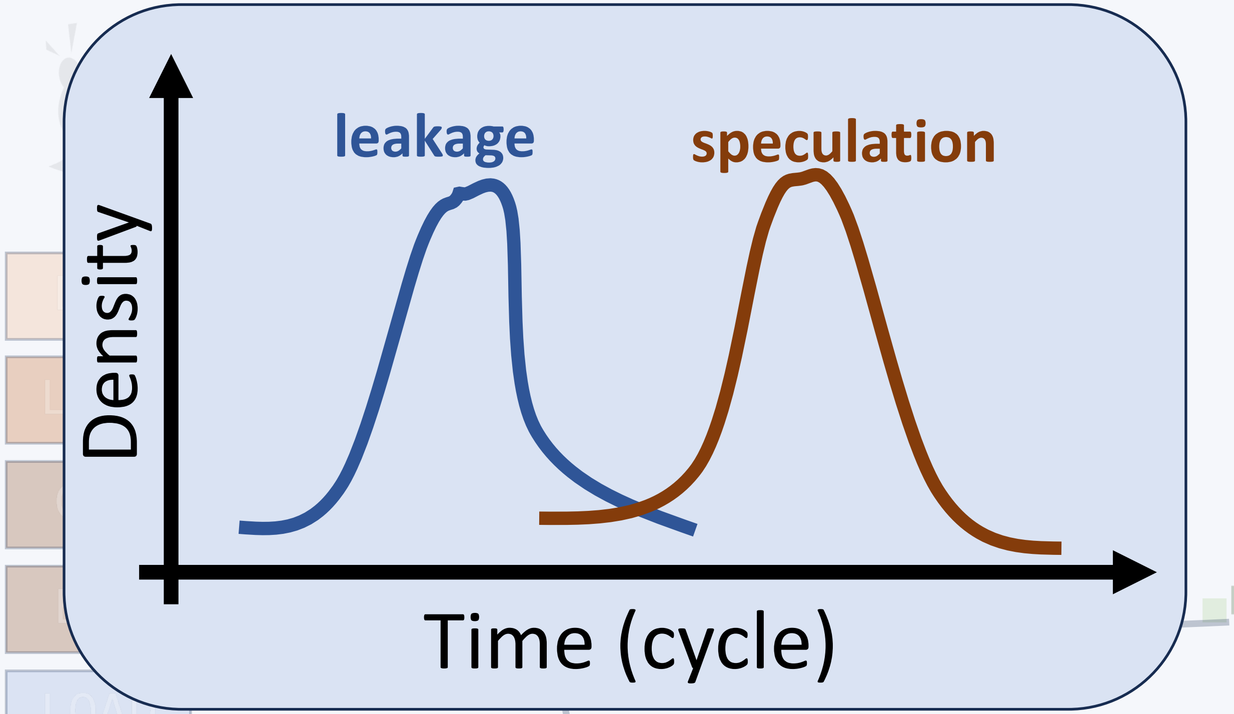
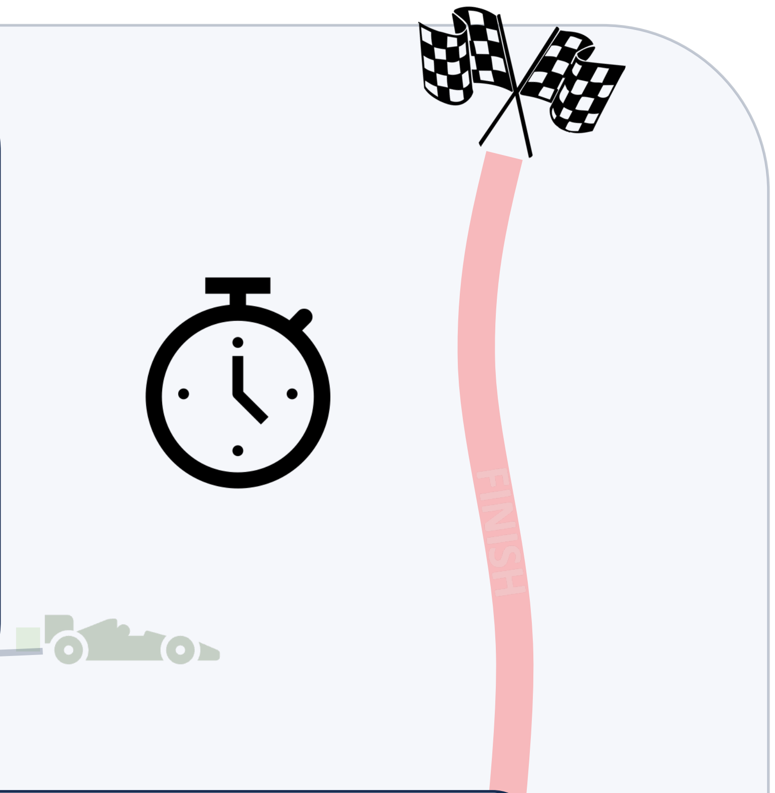
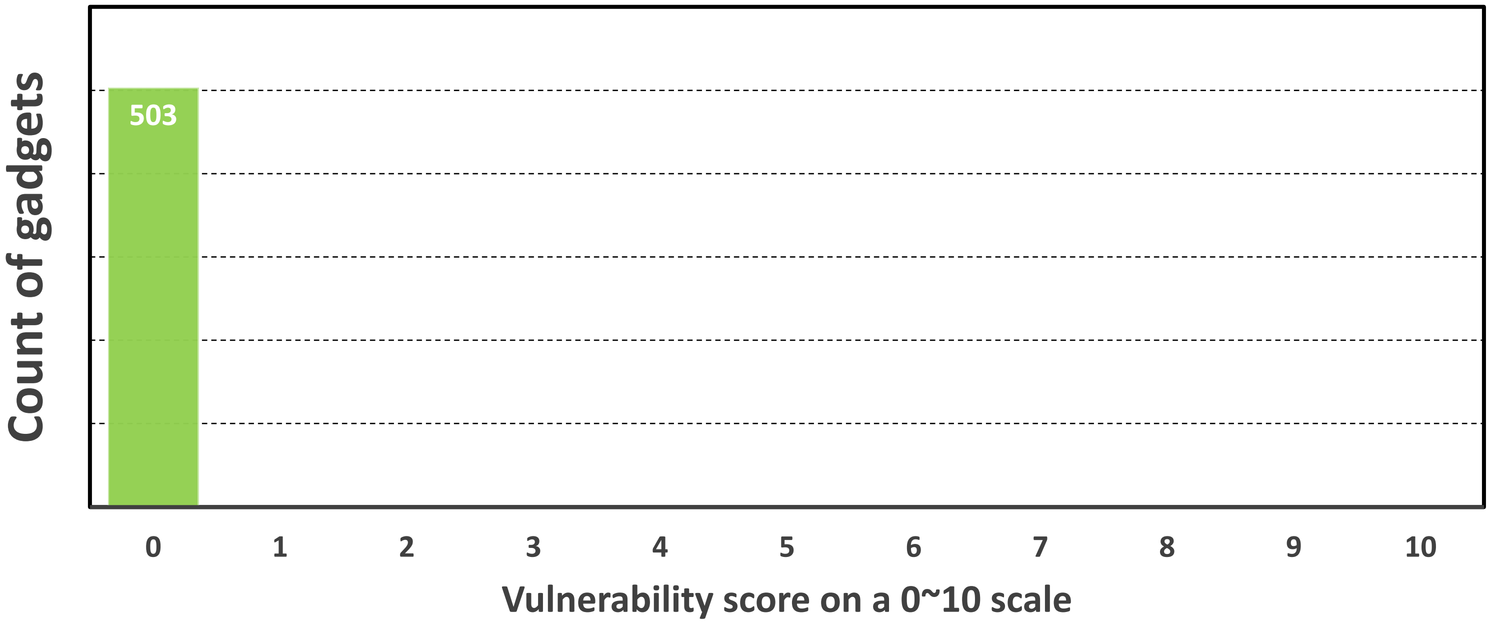




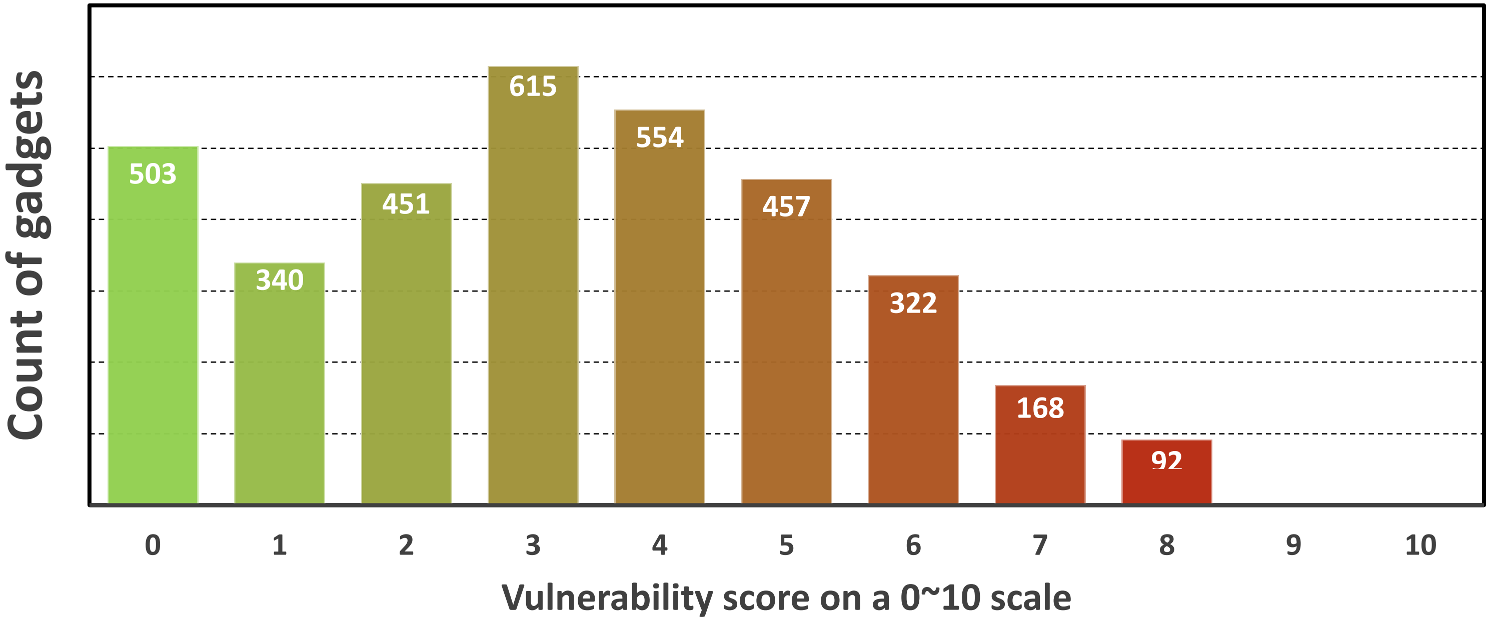
score = 10 * P[speculation > leakage] = **10**/10

Evaluation: Gauging exploitability



- Target: gadgets with vulnerable information flow, identified by SOTA scanners.
- Applications: 6 security-centric applications and Linux kernel

Evaluation: Gauging exploitability



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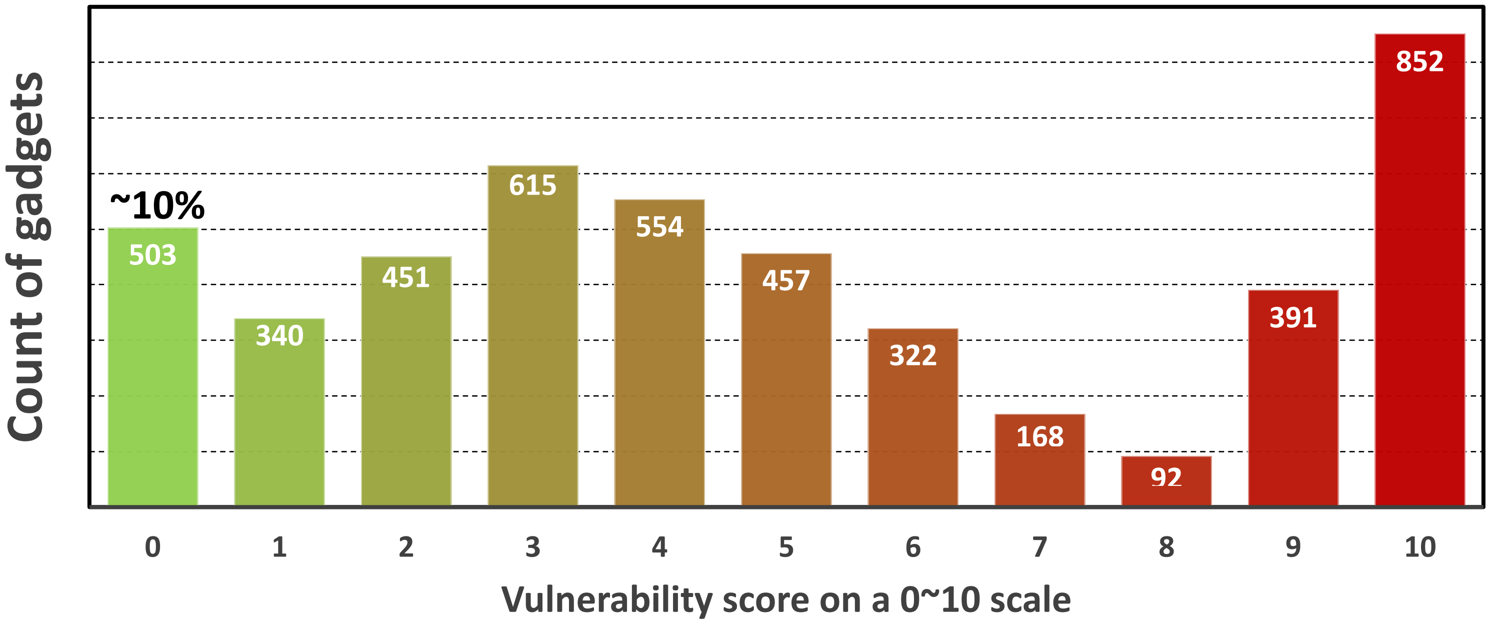
Evaluation: Gauging exploitability



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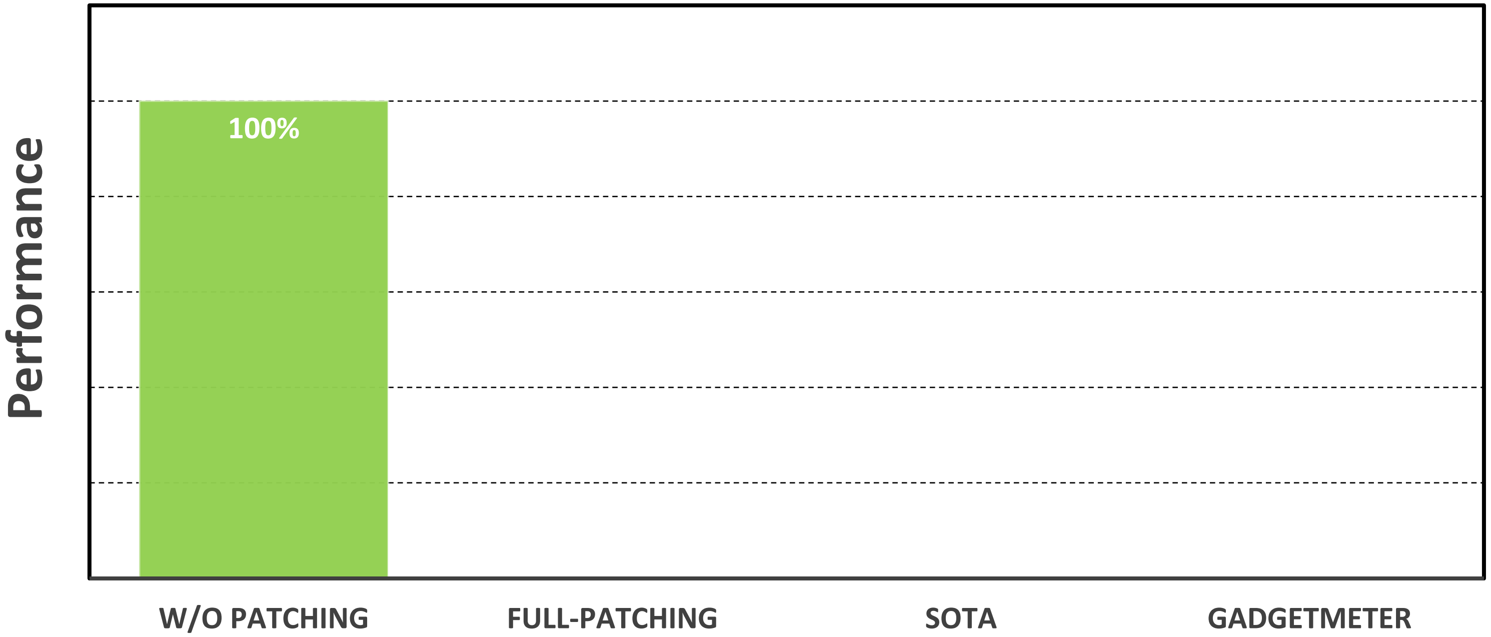
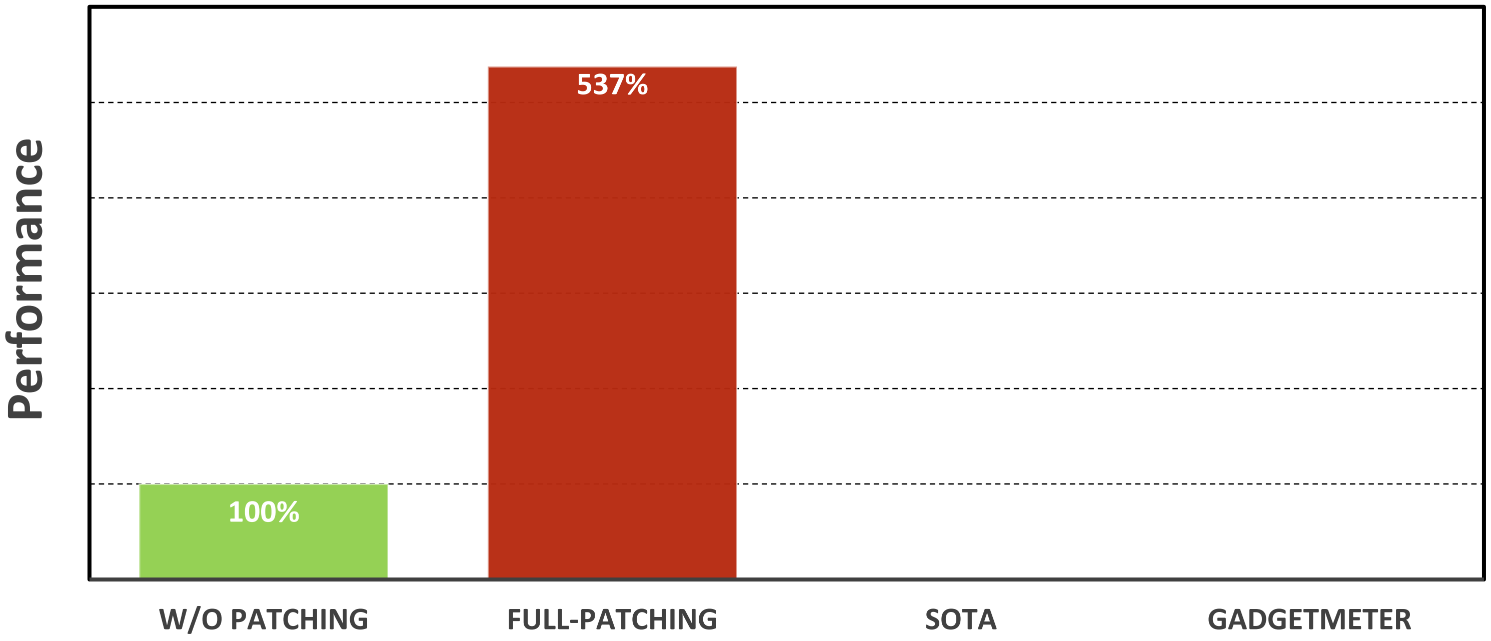
Evaluation: Performance improvement



- Patching method: LFENCE serialization.

Evaluation: Performance improvement



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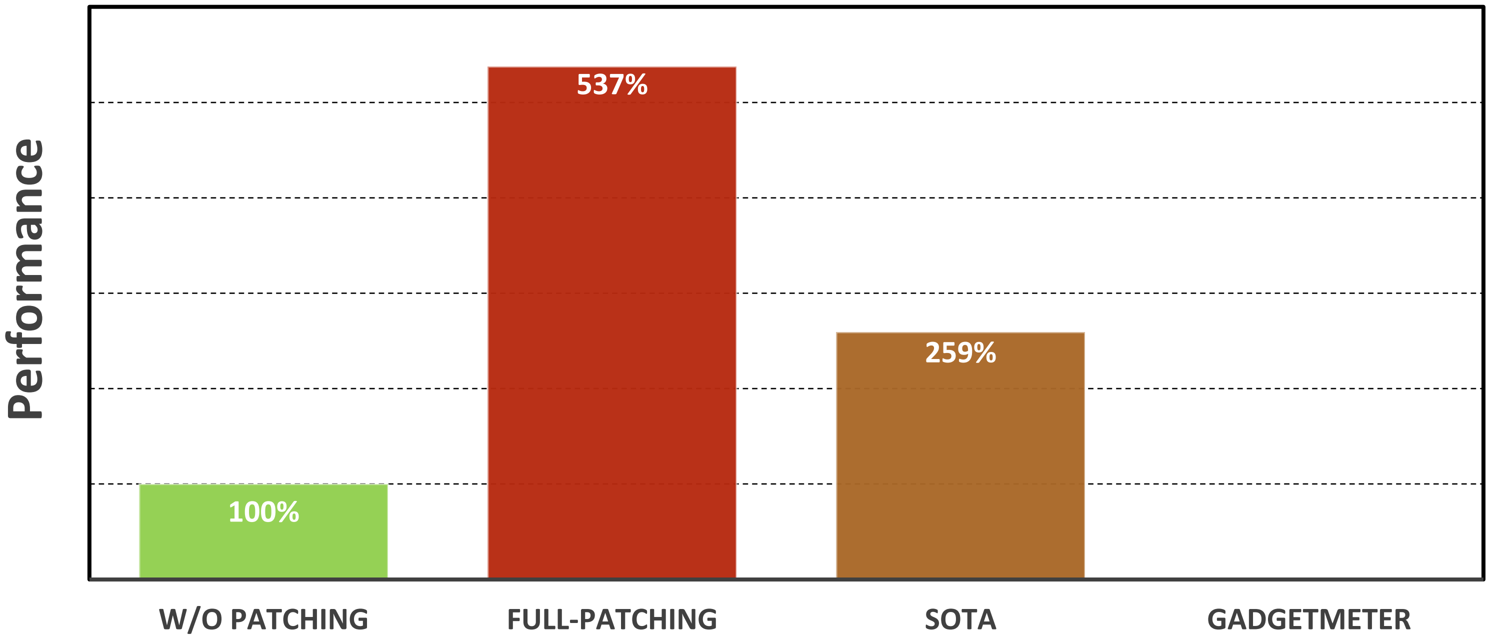

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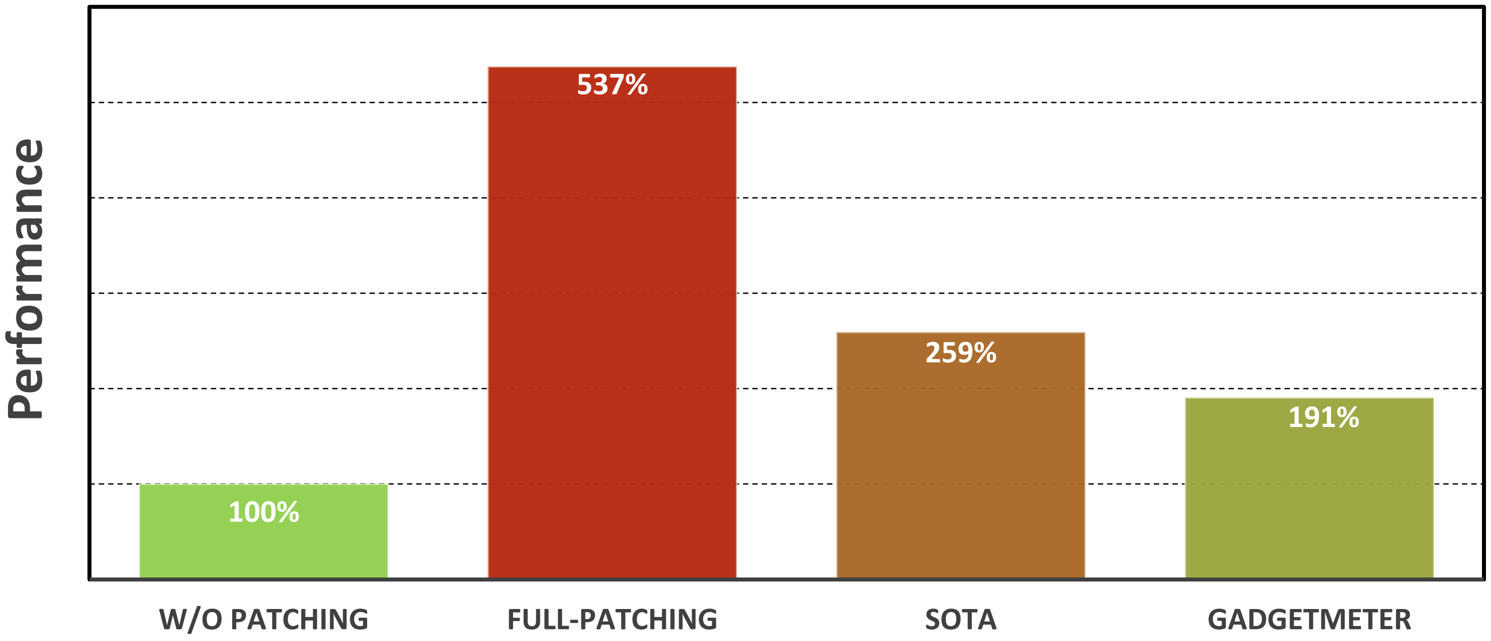
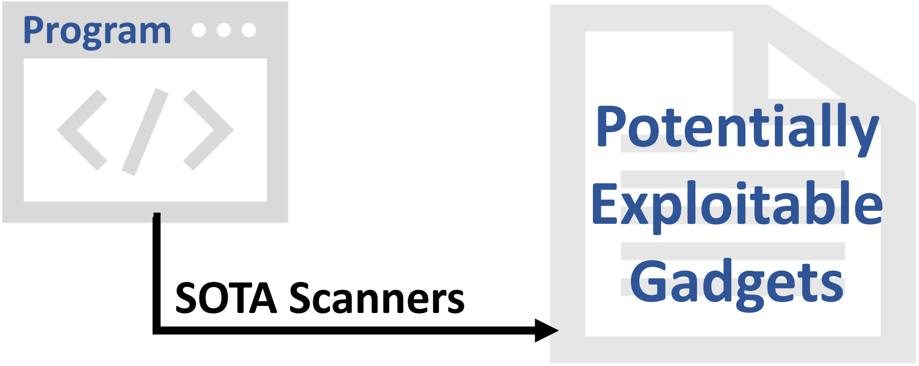


- Patching method: LFENCE serialization.
- Reduce overhead by 20.66%, compared with SOTA.

Conclusion

qiling07.github.io



✓ **Few** false negatives

✗ **Many** false positives

✗ **Binary** detection results

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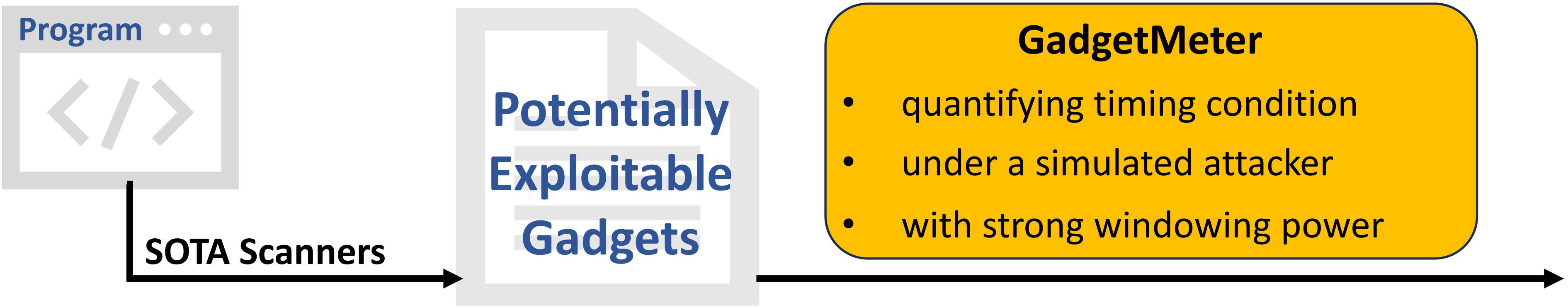

Program

SOTA Scanners

Potentially Exploitable Gadgets

GadgetMeter

- quantifying timing condition
- under a simulated attacker
- with strong windowing power

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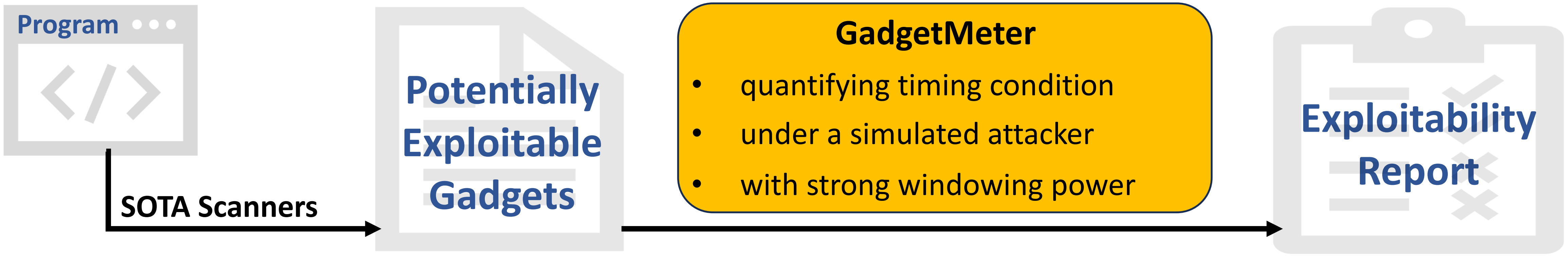

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SOTA Scanners

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Exploitability Report

✓ **Few** false negatives

✗ **Many** false positives

✗ **Binary** detection results

✓ **Few** false negatives

✓ **Few** false positives

✓ **Quantitative** evaluation results