Rage Against the Machine Clear: A Systematic Analysis of Machine Clears and Their Implications for Transient Execution Attacks

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[*]Equal contribution joint first authors

Vrije Universiteit Amsterdam

Speculative Execution

```
if (x < array_size ) {
    y = array[x]
}
```

Data cache

Not cached

Speculative Execution

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if (x < array_size ) {
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}
```

Data cache

Cached

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Speculative Execution

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if (x < array_size) {
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}
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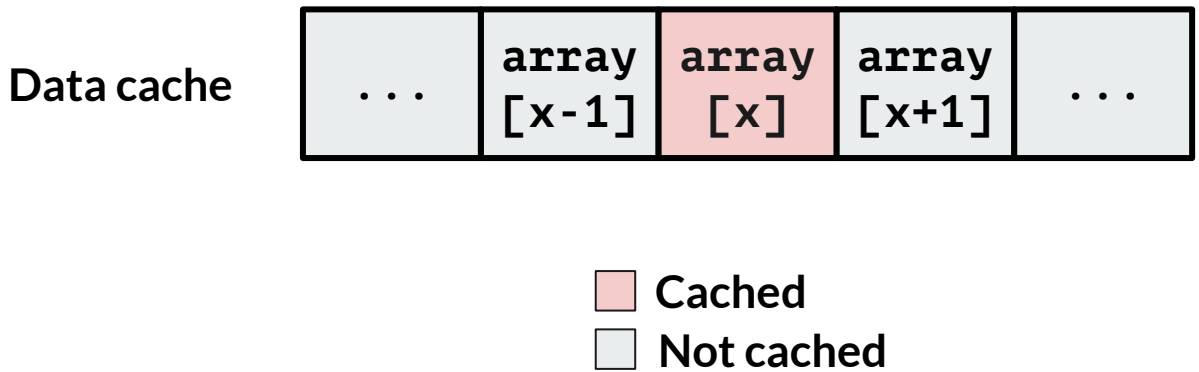

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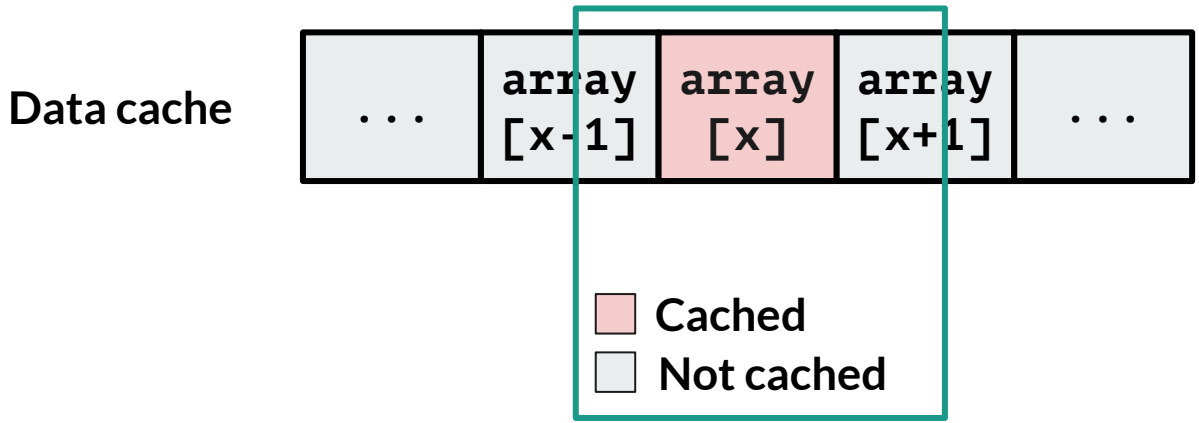

Bad Speculation

The root cause of discarding issued µOps on x86 processors

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Branch Misprediction

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Machine Clear

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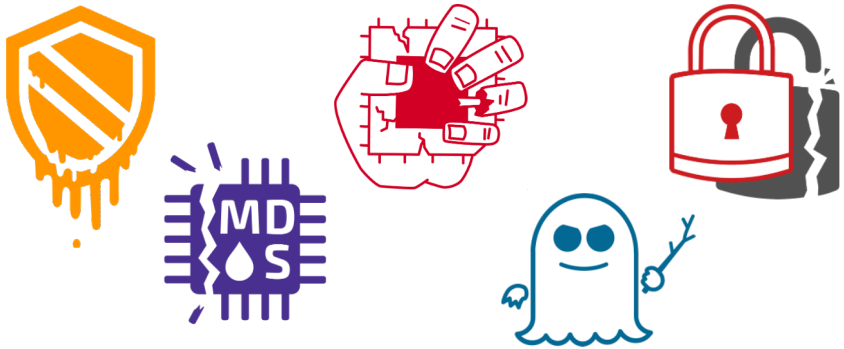
The root cause of discarding issued µOps on x86 processors

Branch Misprediction & Intel TSX



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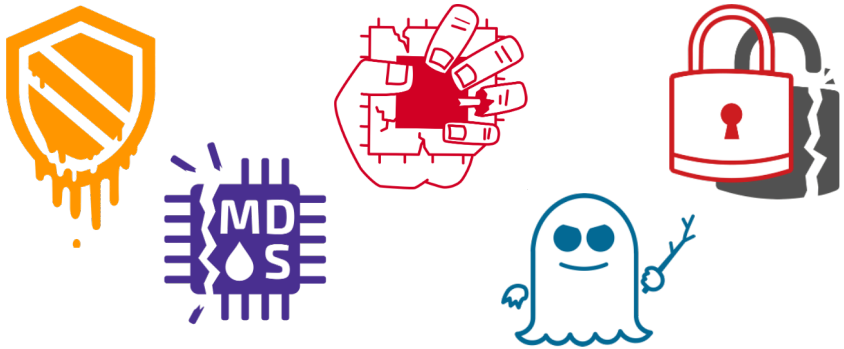

Machine Clear

?

Rage Against The Machine Clear

Self-Modifying Code Machine Clear

Floating-Point Machine Clear

Memory Ordering Machine Clear

Memory Disambiguation Machine Clear

Rage Against The Machine Clear

Self-Modifying Code Machine Clear

Floating-Point Machine Clear

Rage Against The Machine Clear

Self-Modifying Code Machine Clear

Speculative Code Store Bypass (SCSB)

Negligible mitigation overhead

Floating-Point Machine Clear

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Negligible mitigation overhead

Floating-Point Machine Clear

Floating-Point Value Injection (FPVI)

53% Mitigation overhead

Rage Against The Machine Clear

Self-Modifying Code Machine Clear

Floating-Point Machine Clear

End-to-end exploit leaking arbitrary memory in Firefox

With a leakage rate of **13 KB/s**

Security Analysis of Machine Clear

Security Analysis of Machine Clear

1. Architectural Invariant

Security Analysis of Machine Clear

1. Architectural Invariant
2. Invariant Violation

Security Analysis of Machine Clear

1. Architectural Invariant
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3. Security Implications

Security Analysis of Machine Clear

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4. Exploitation

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Self-Modifying Code is a program storing instructions as data, modifying its own code as it is being executed

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```
i1: ...
i2: store nop @ i3
i3: load secret
i4: ...
i5: ...
```

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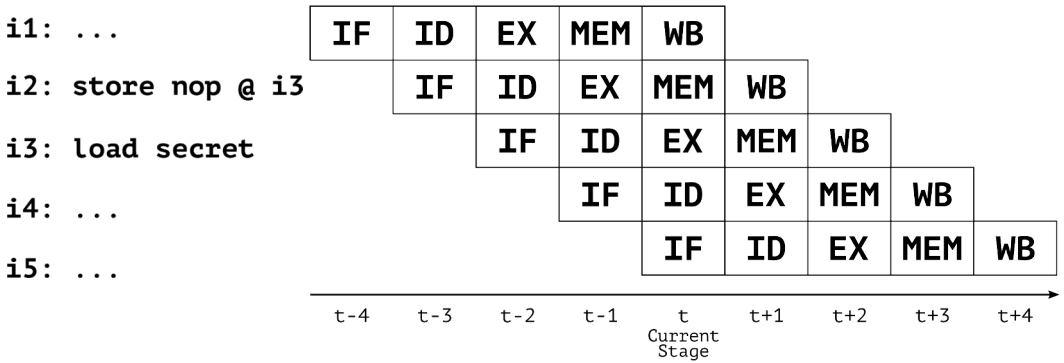

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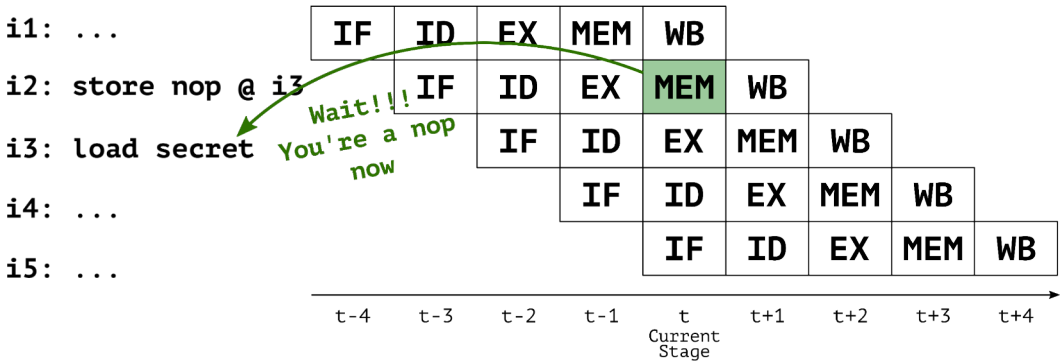

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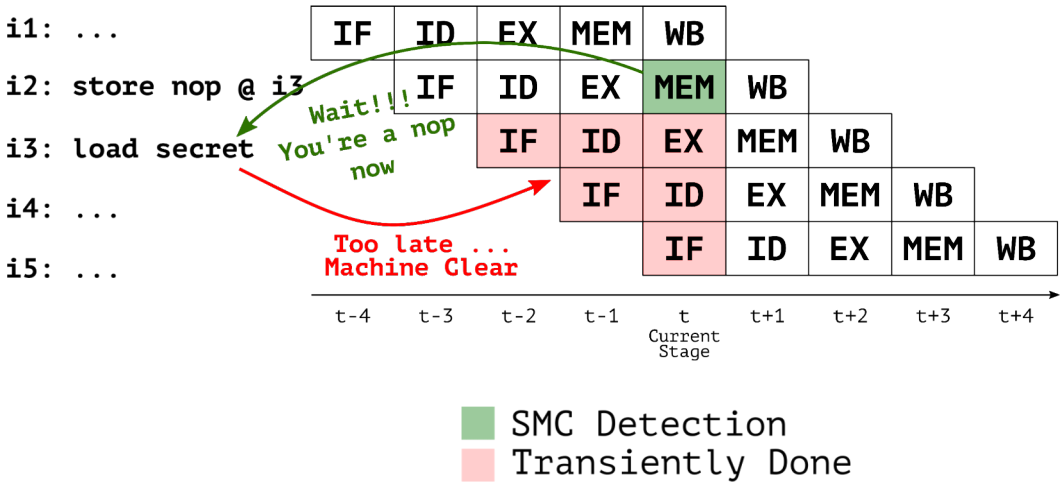

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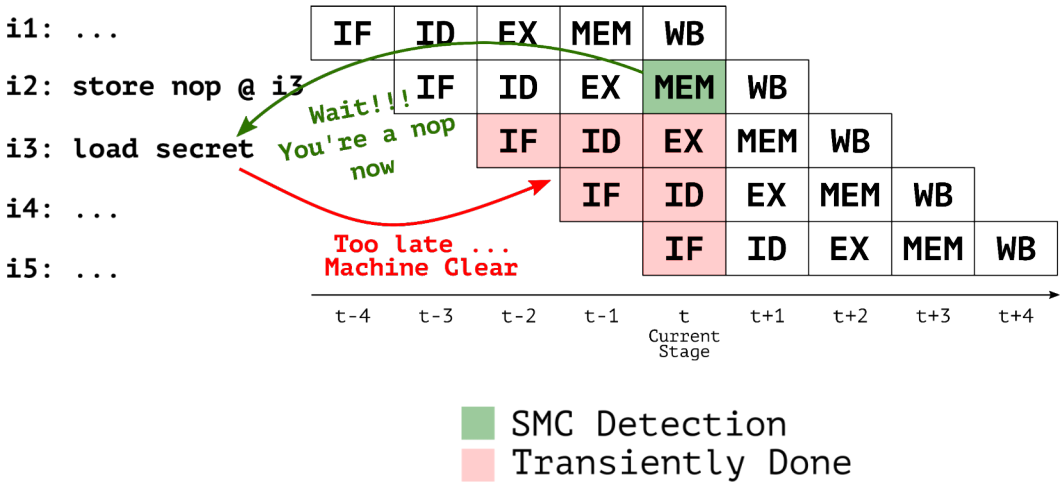
Architectural Invariant

Stores always target data



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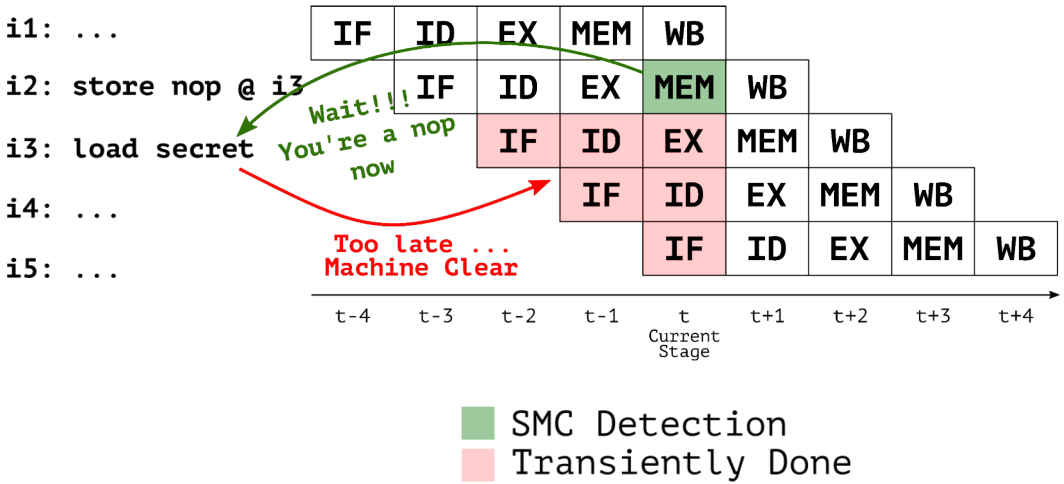

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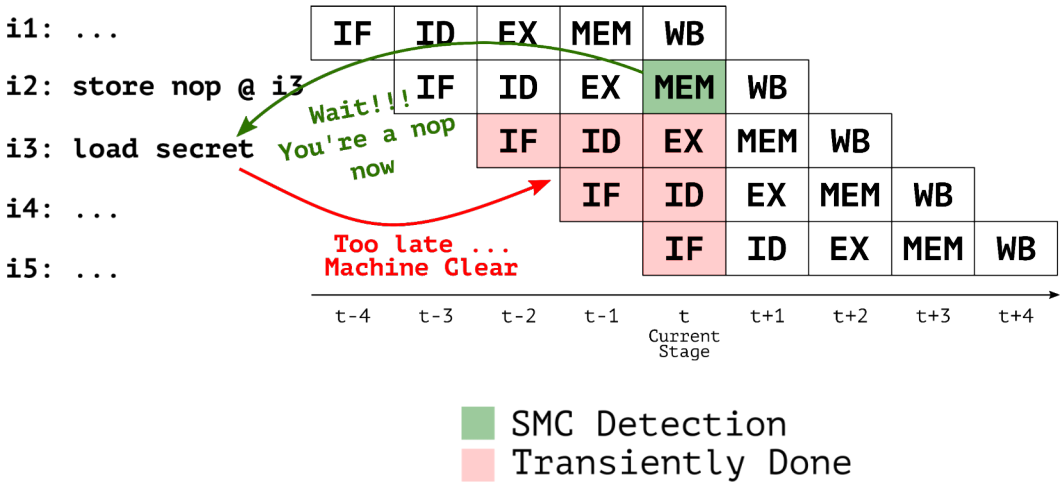
Security Implications

Transiently execute stale code



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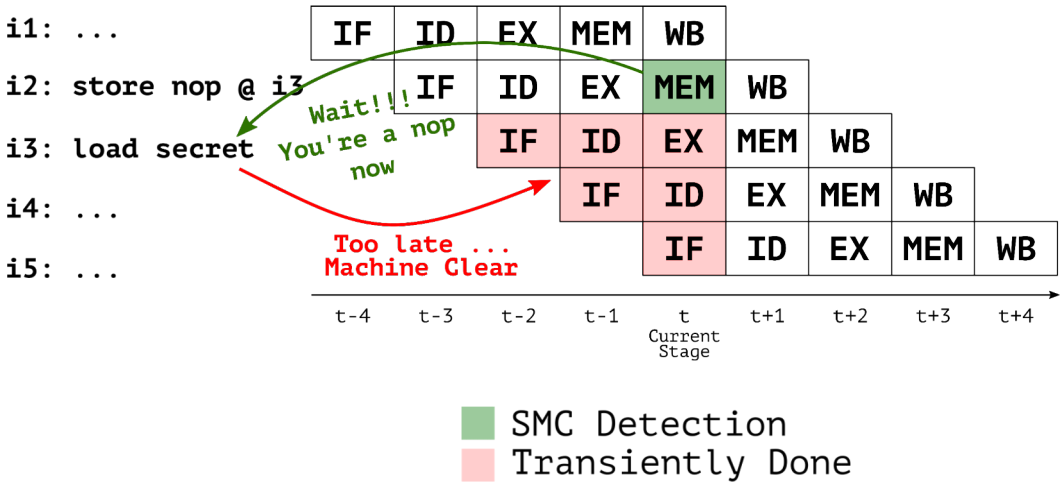

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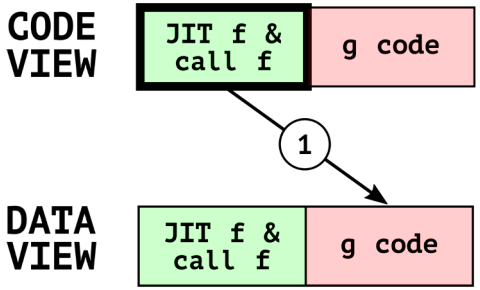

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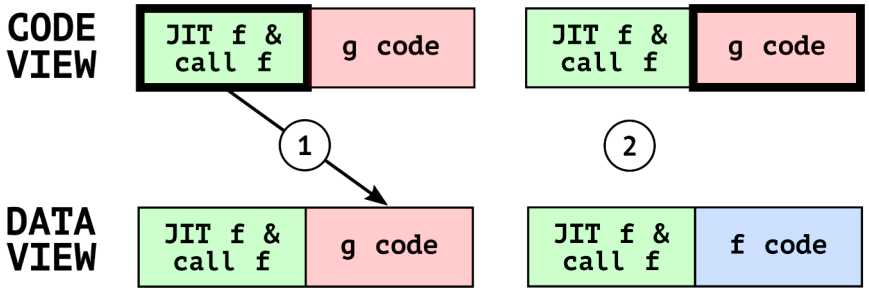

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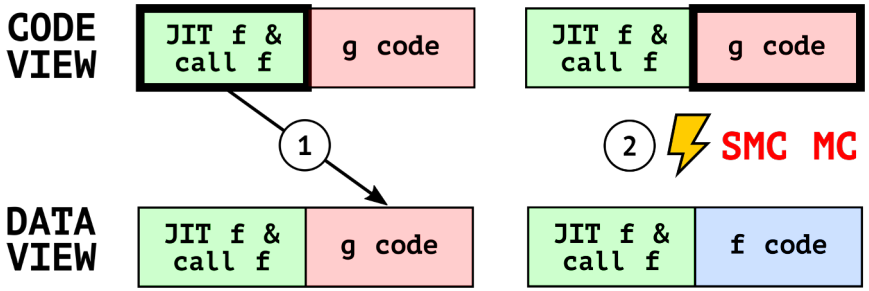

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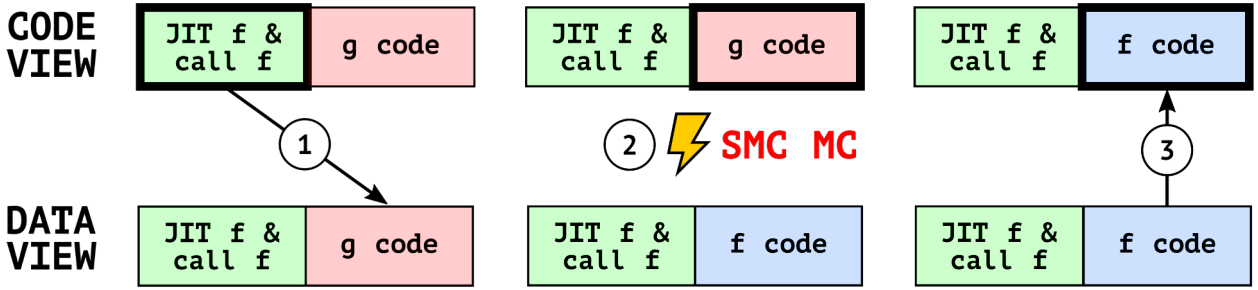

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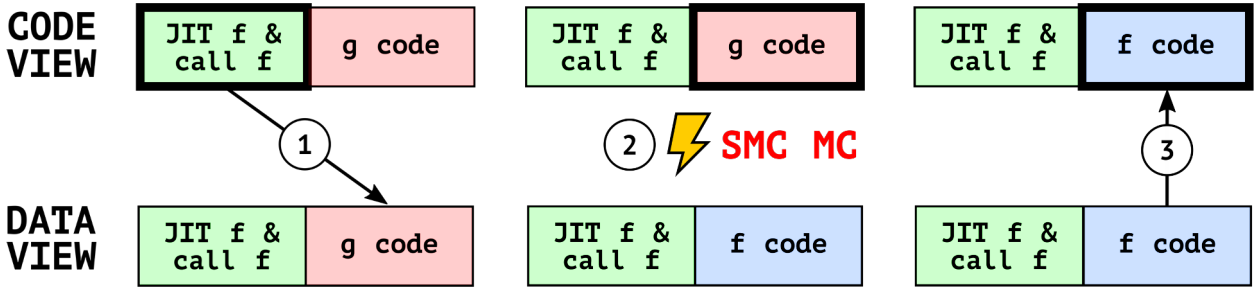

8.1.3 Handling Self- and Cross-Modifying Code

(* OPTION 1 *)
Store modified code (as data) into code segment;
Jump to new code or an intermediate location;
Execute new code;

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Store modified code (as data) into code segment;
Execute a serializing instruction; (* For example, CPUID instruction *)
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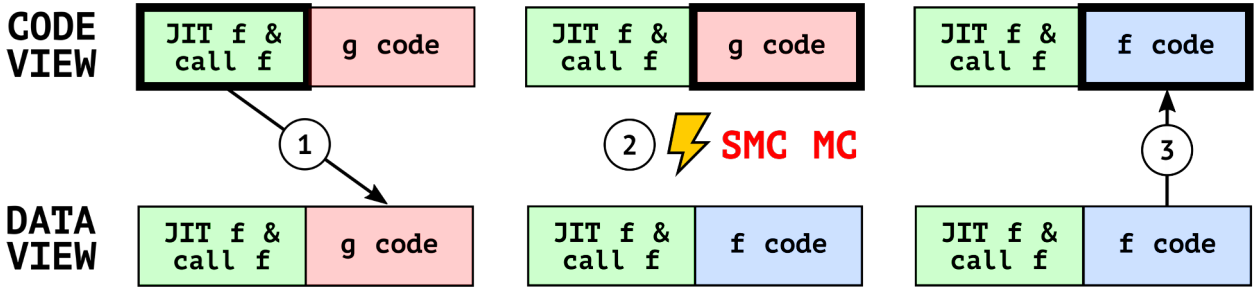

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Architectural Invariant

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Invariant Violation

Self-Modifying Code

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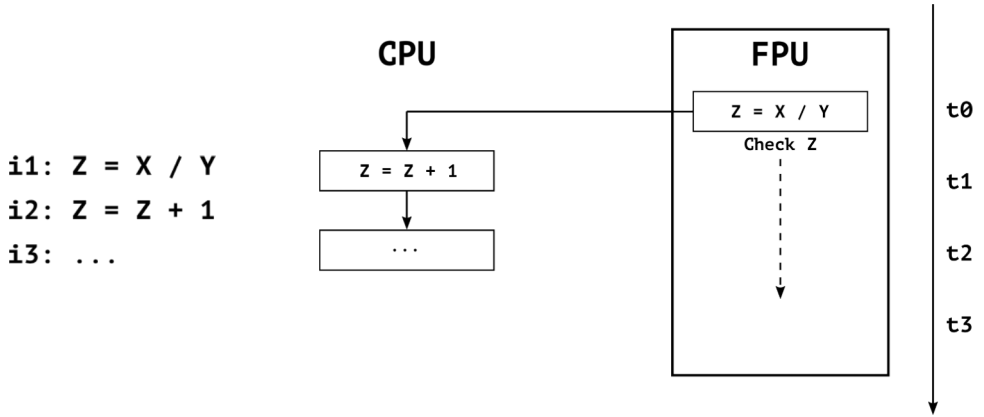

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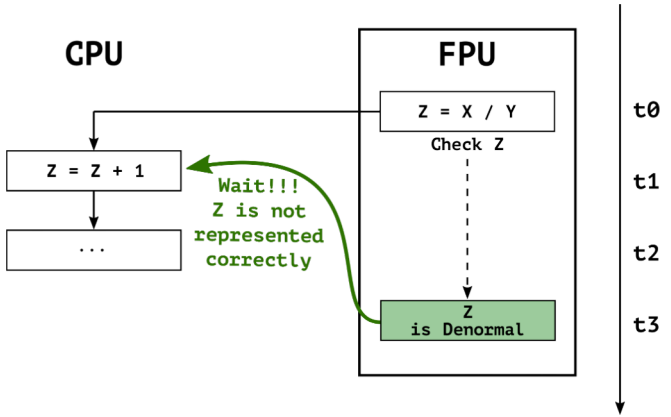

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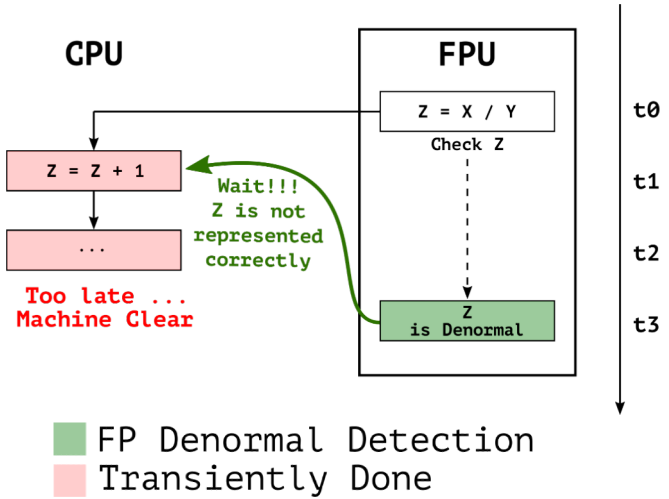

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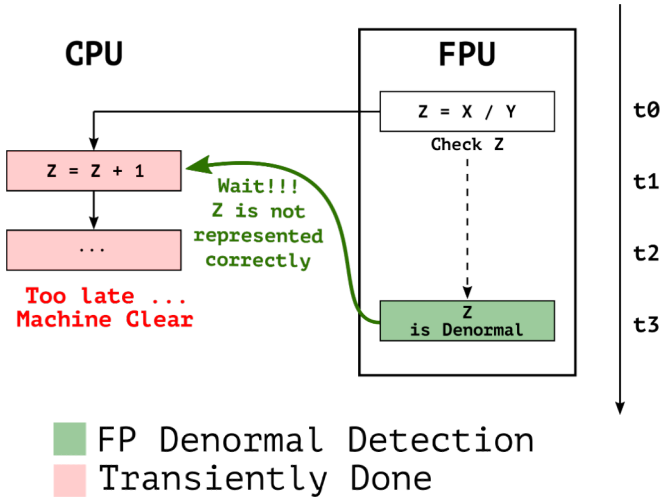

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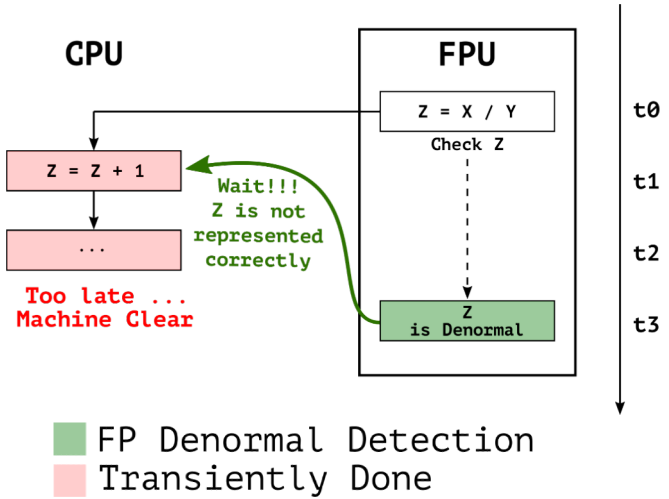

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Security Implications

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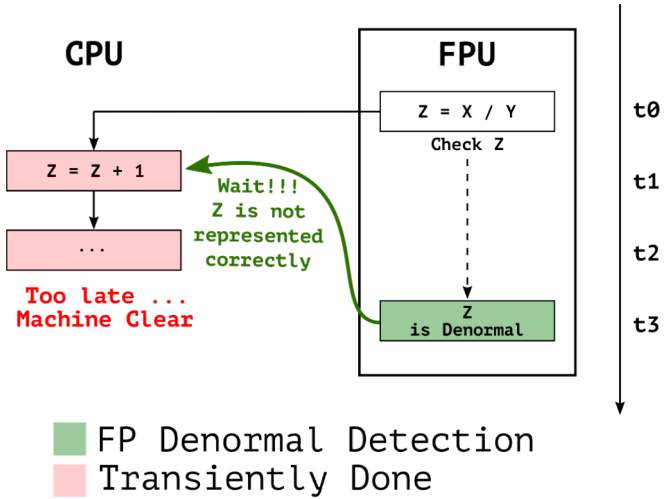

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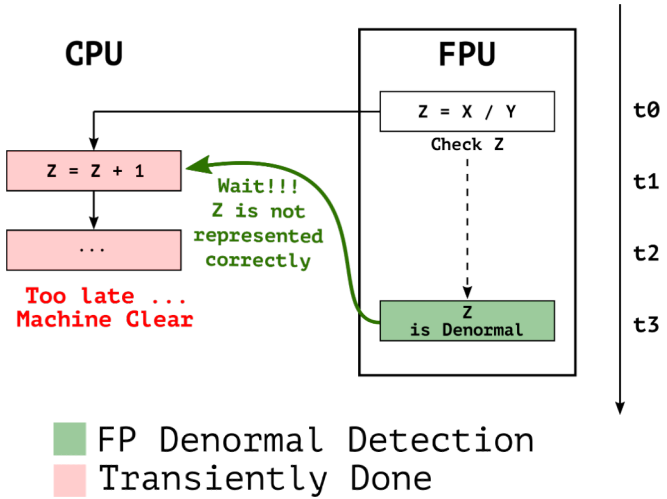
Exploitation



Floating-Point Value Injection (FPVI)

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JSVAL_TYPE_**STRING**
PAYLOAD:
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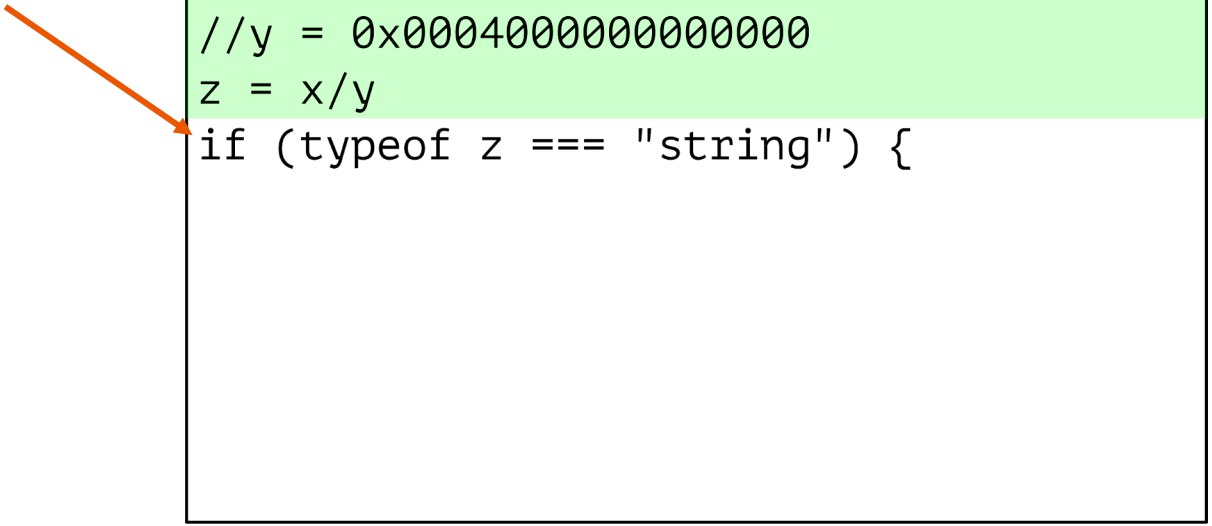

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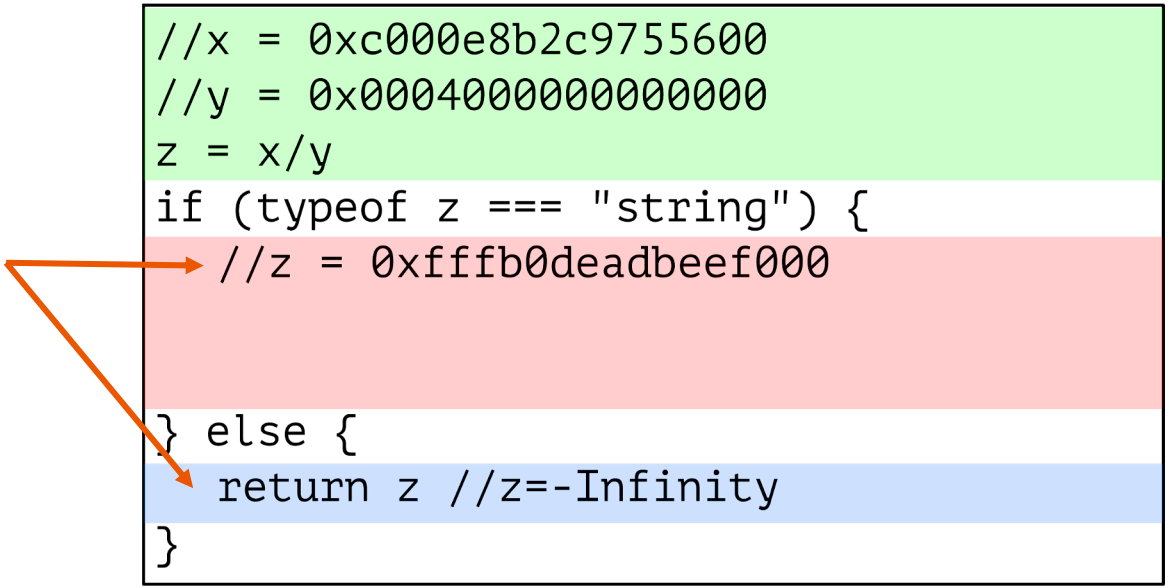

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```
//x = 0xc000e8b2c9755600
//y = 0x0004000000000000
z = x/y
if (typeof z === "string") {
   //z = 0xfffb0deadbeef000
   //leak byte @ 0xdeadbeef004
   return buf[(z.length&0xff)<<10]
} else {
   return z //z=-Infinity
}
```

Floating-Point Value Injection (FPVI)

Architectural Invariant

FPU always operates on normal numbers

Invariant Violation

Denormal FP operations

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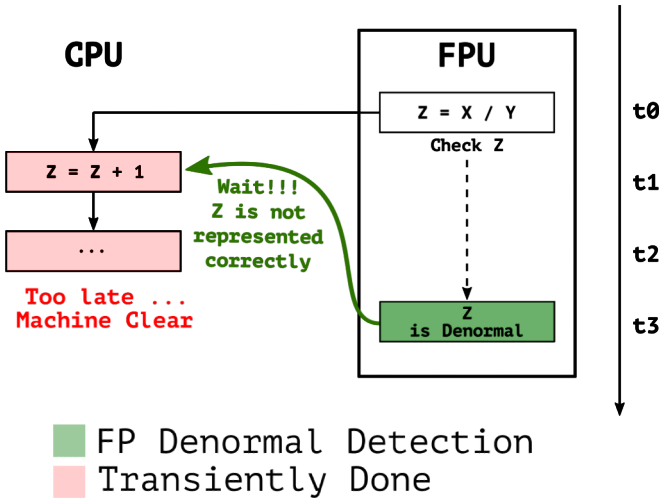
Exploitation

Floating-Point Value Injection

Floating-Point Value Injection (FPVI)

- Exploit leakage rate of 13 KB/s



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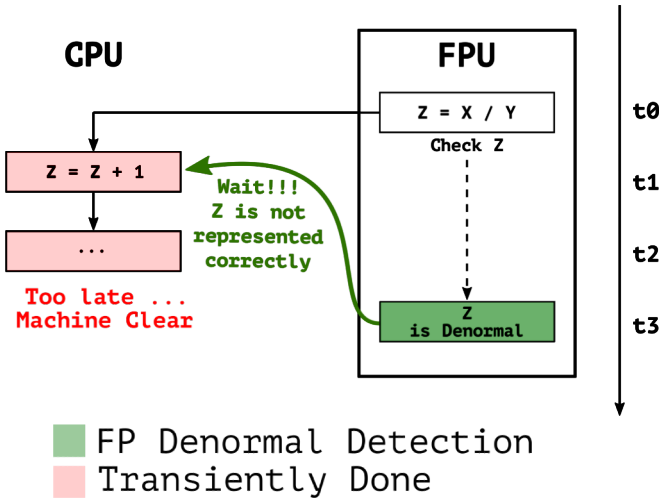

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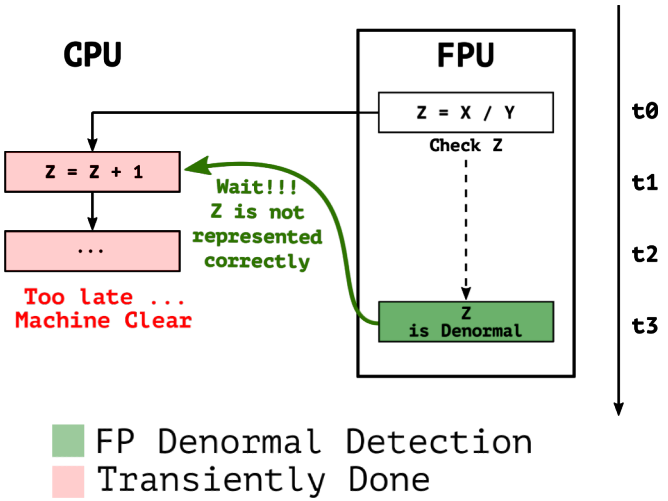

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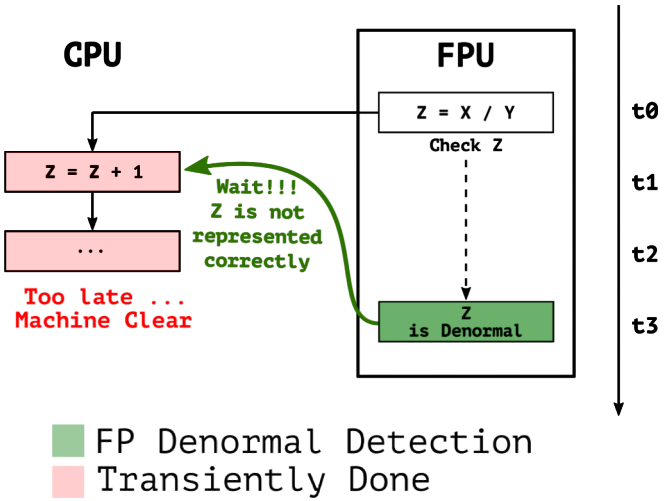
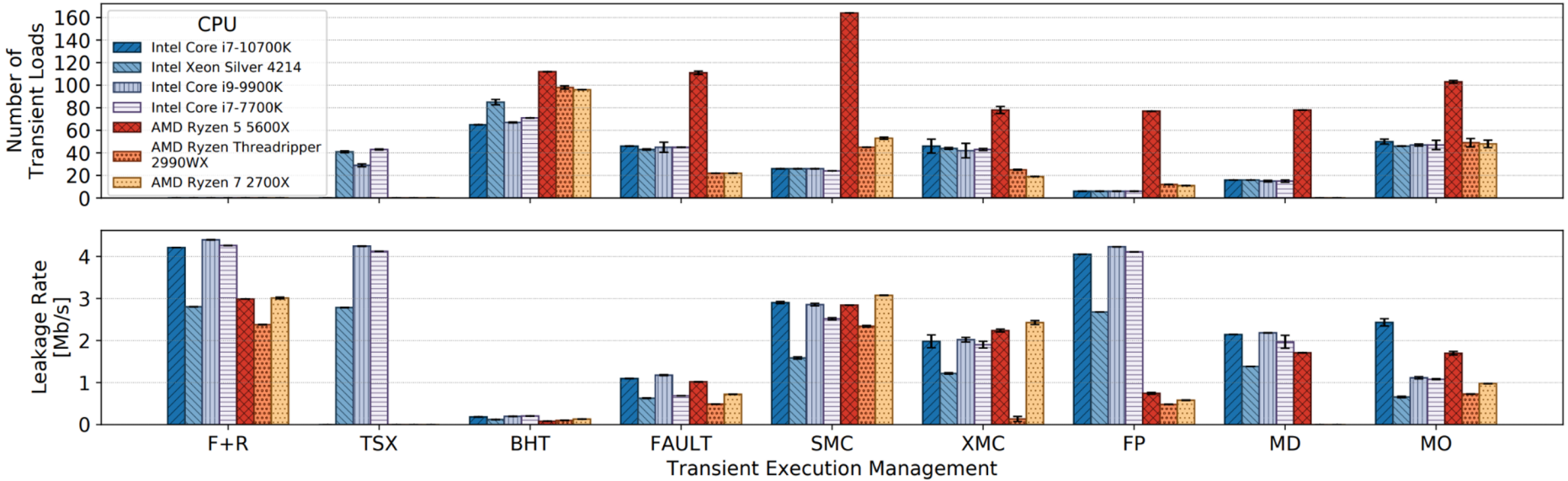
  - ➔ Use **site-isolation** or **conditionally mask FP** operations in the browsers.



Transient Execution Capabilities



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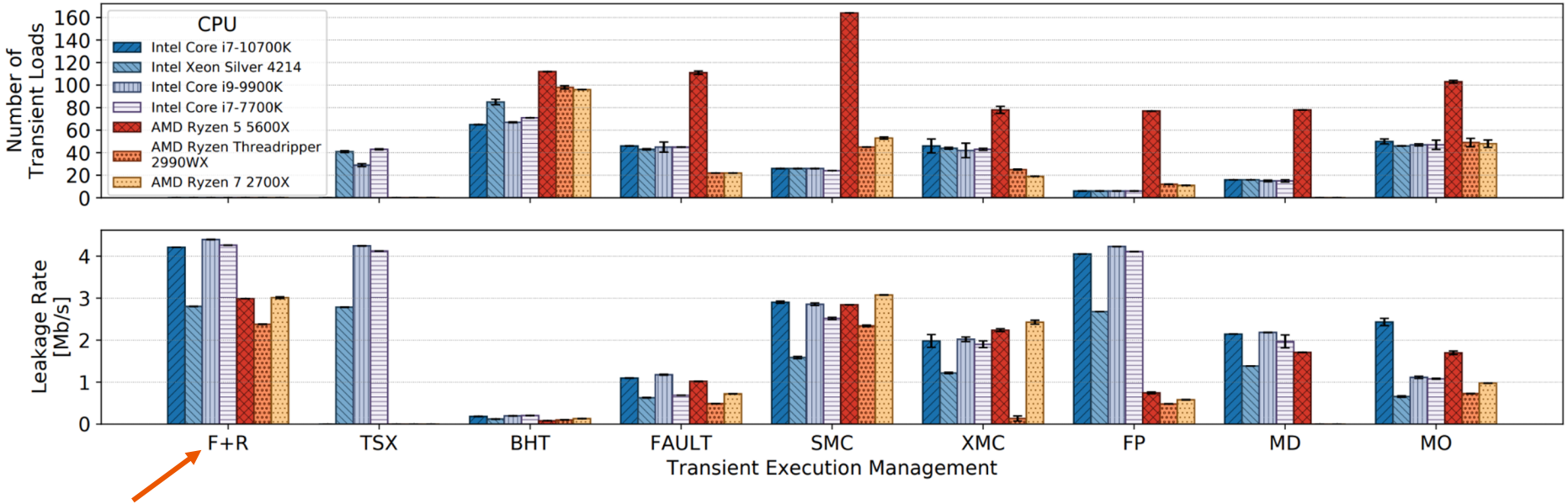
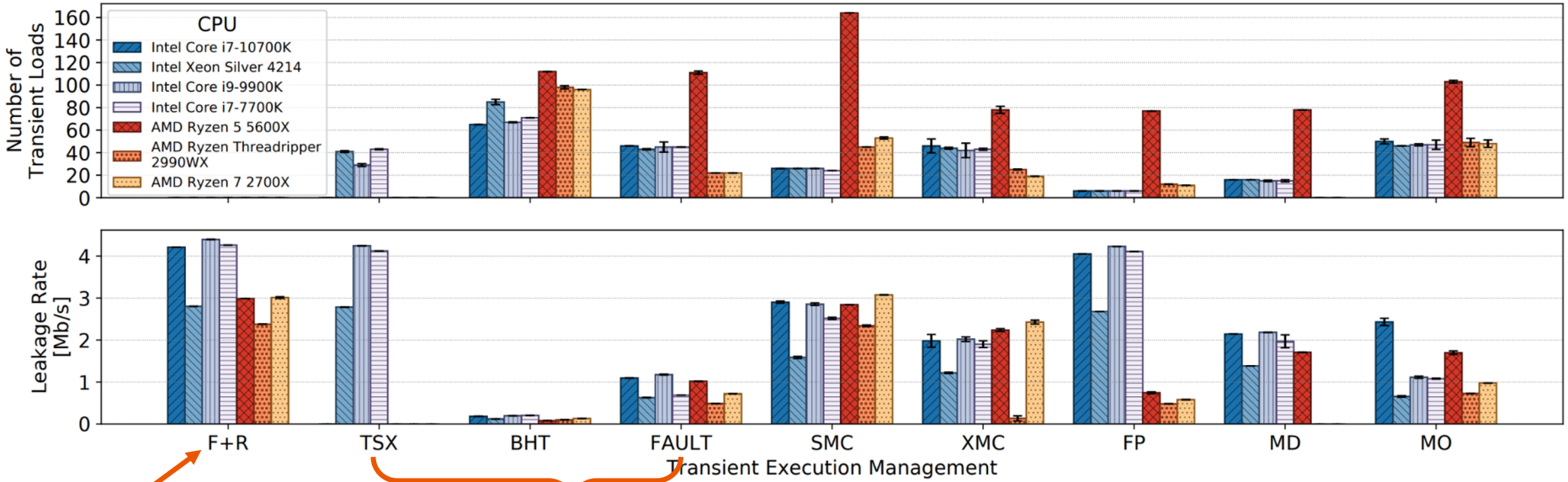


Architectural baseline leakage rate

Transient Execution Capabilities



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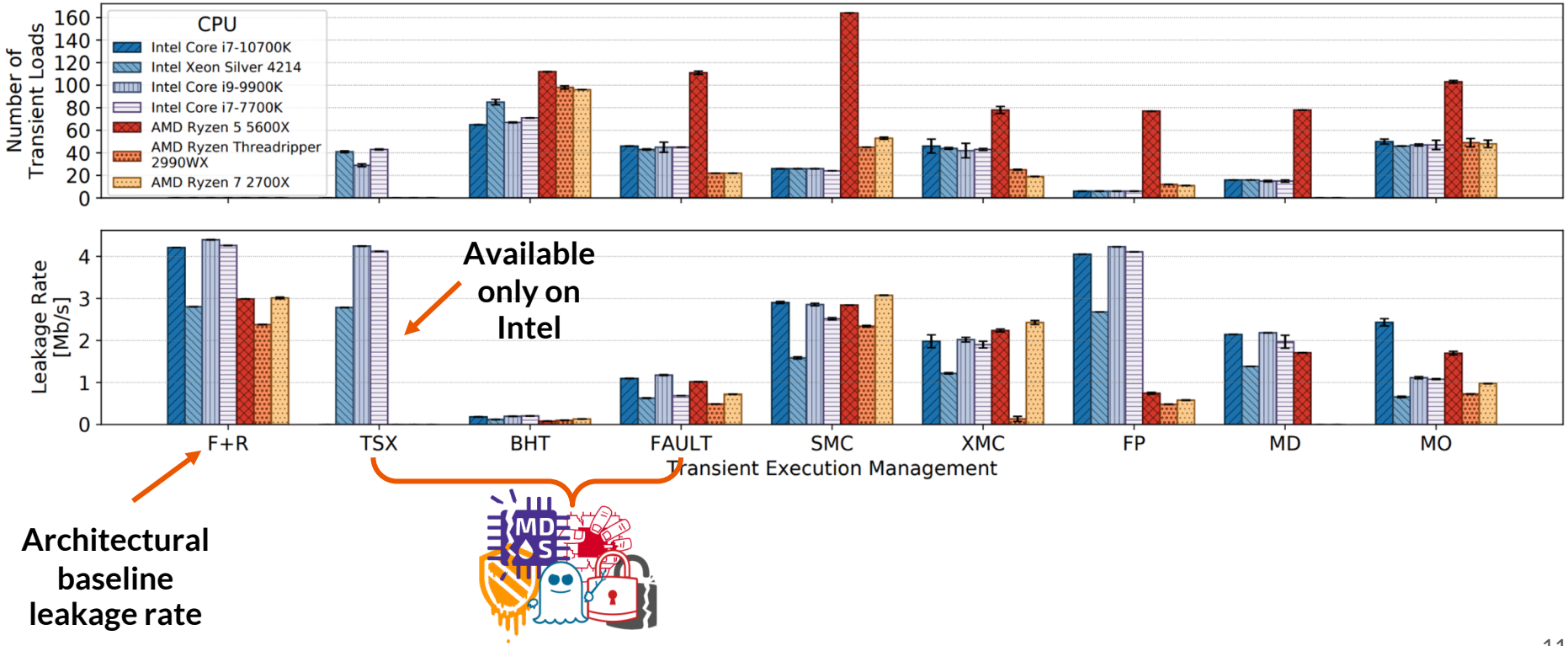

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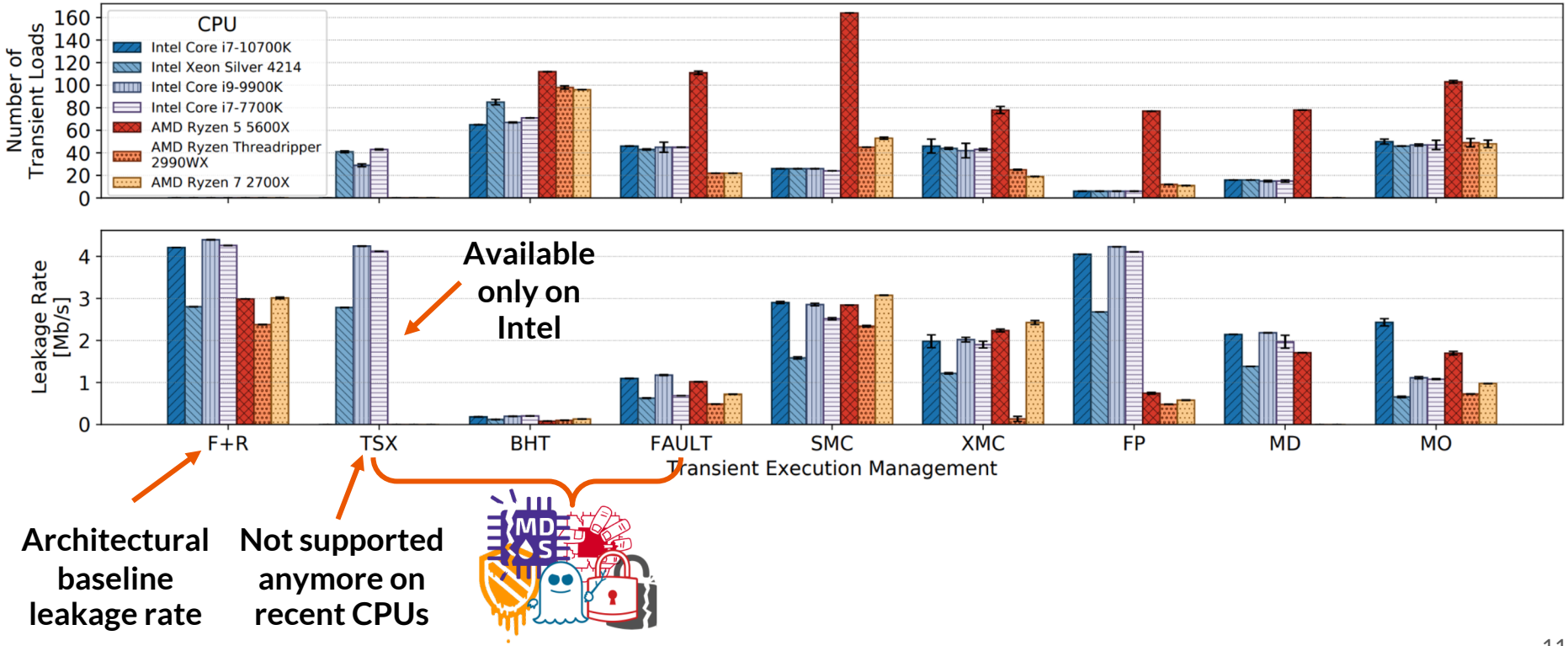

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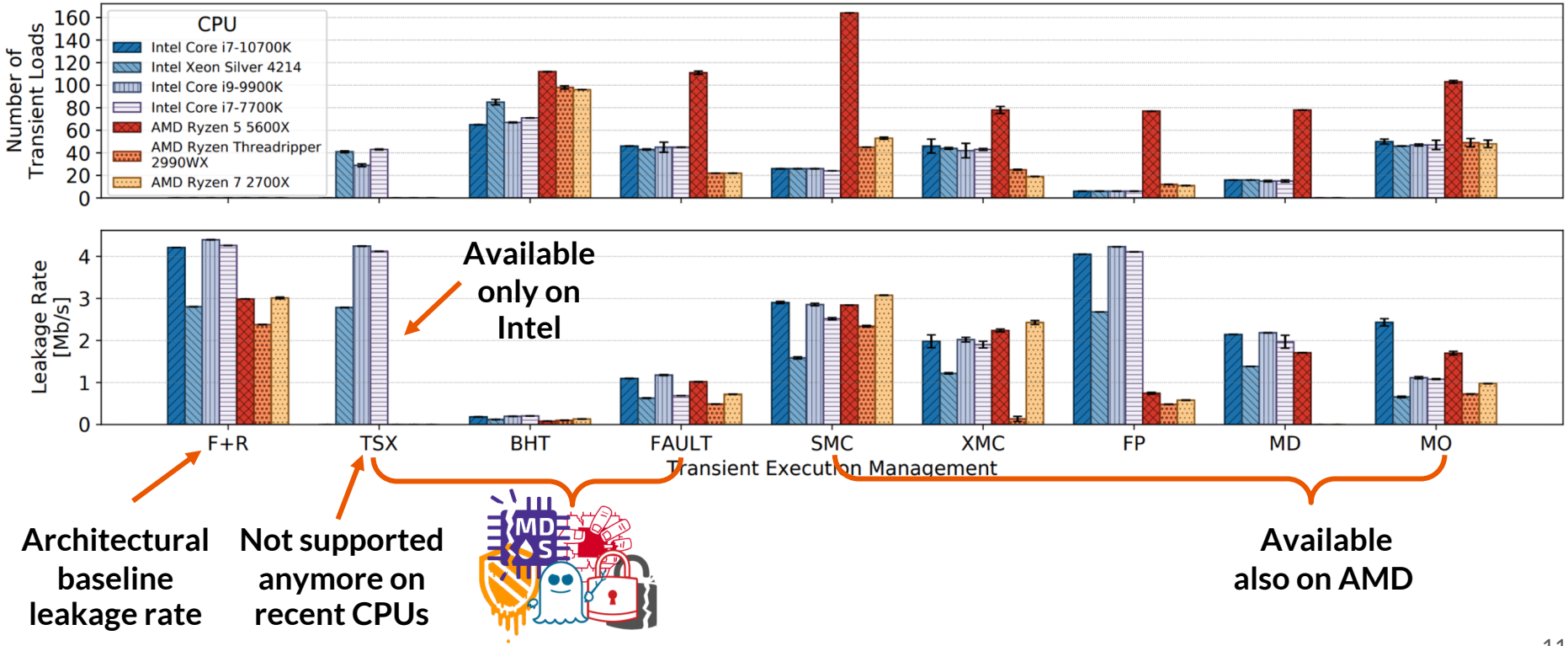

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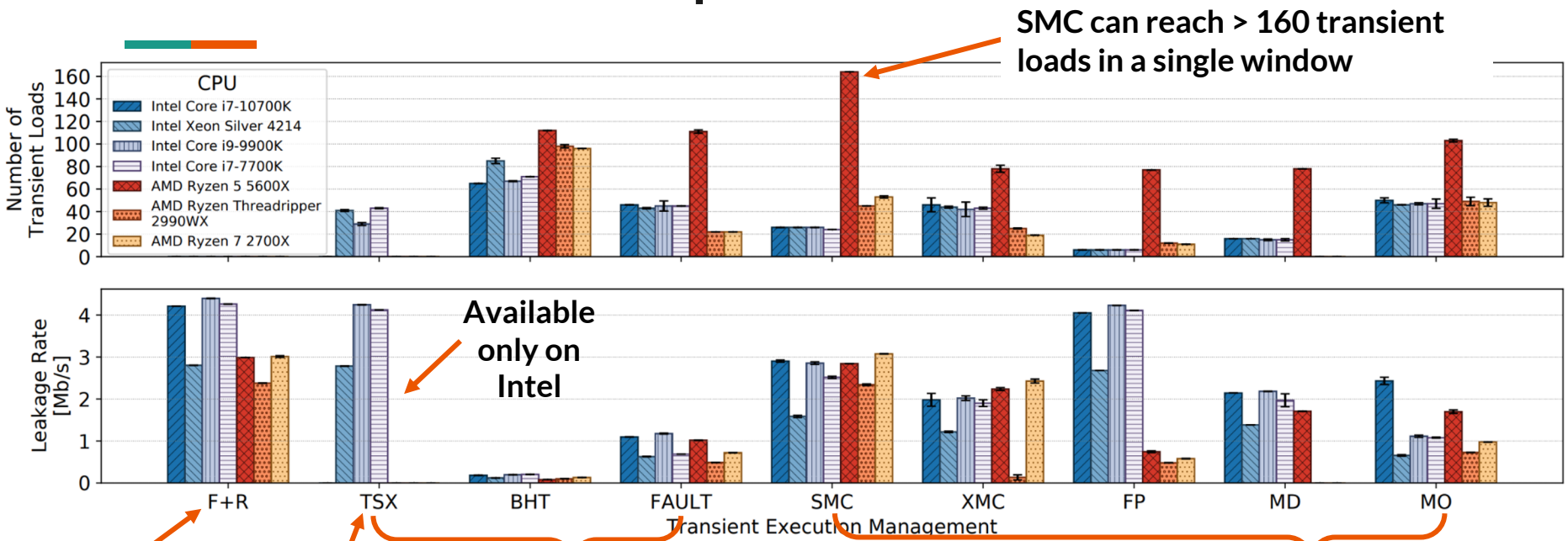

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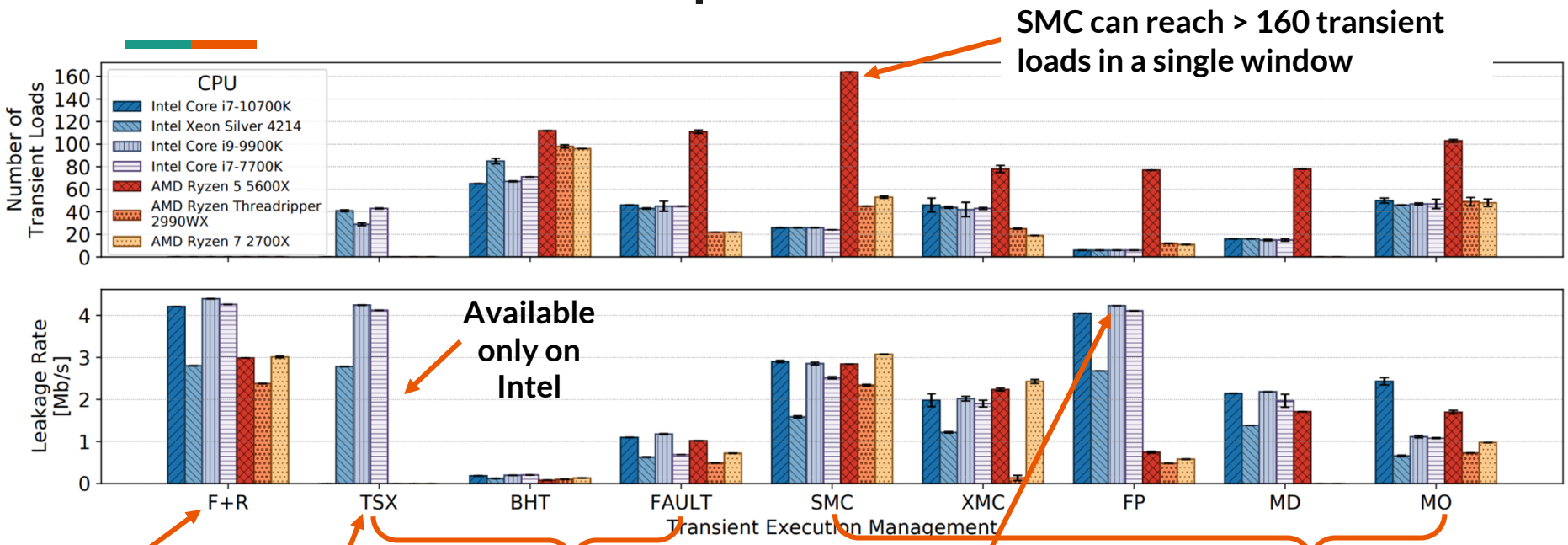

Root-Cause Classification of Transient Execution

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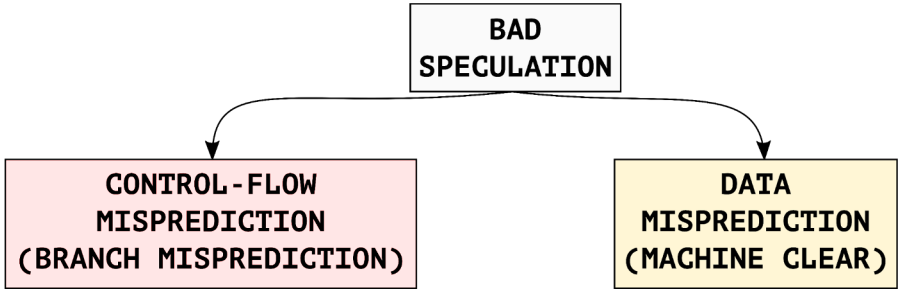

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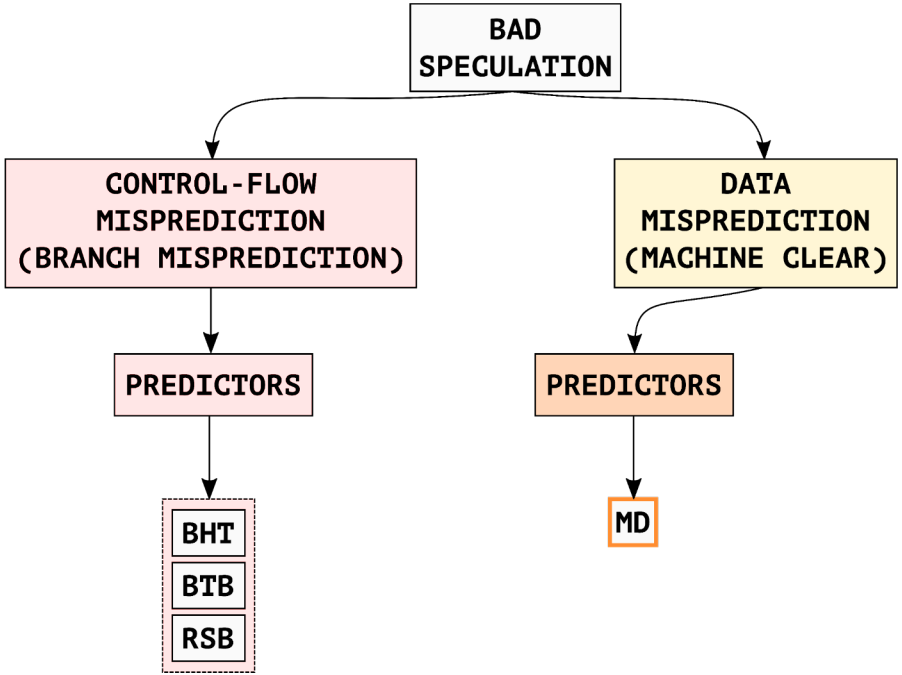

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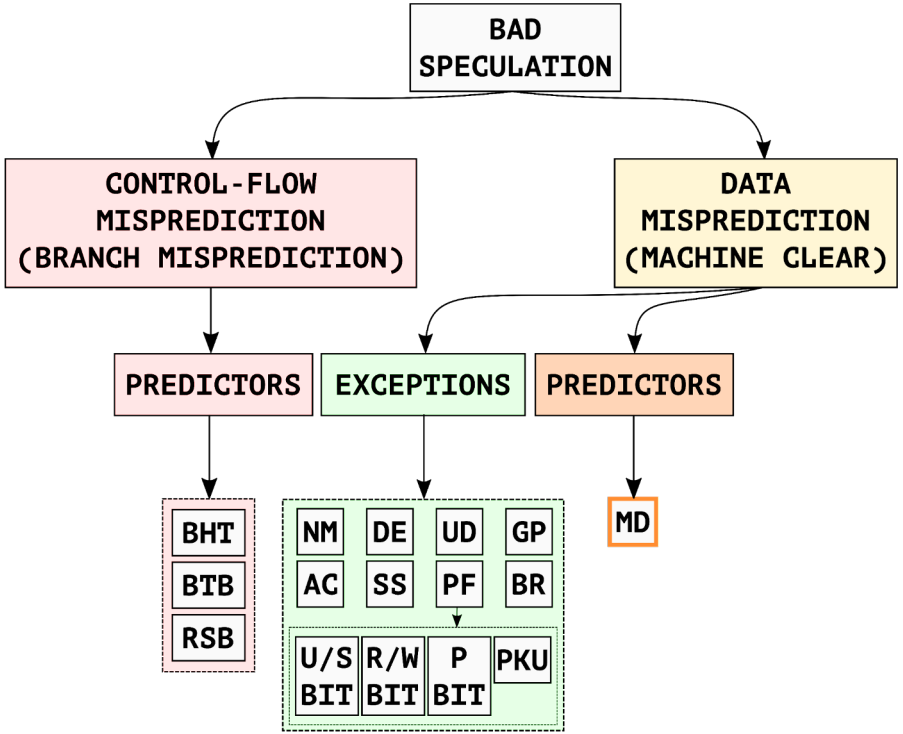

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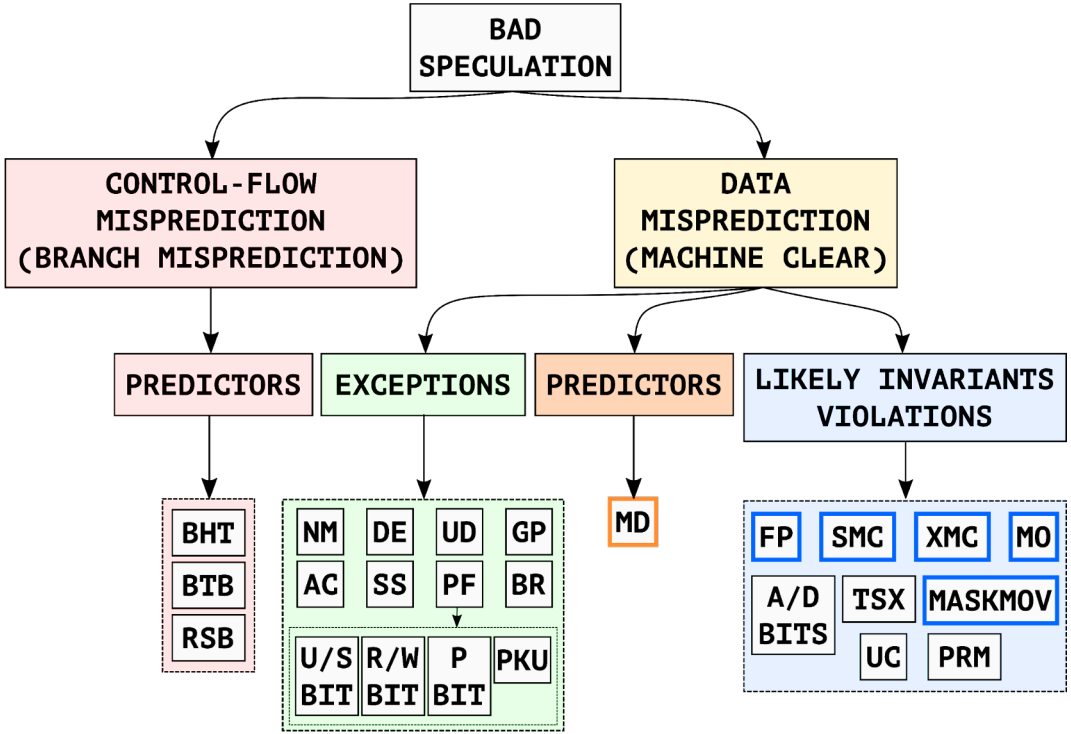

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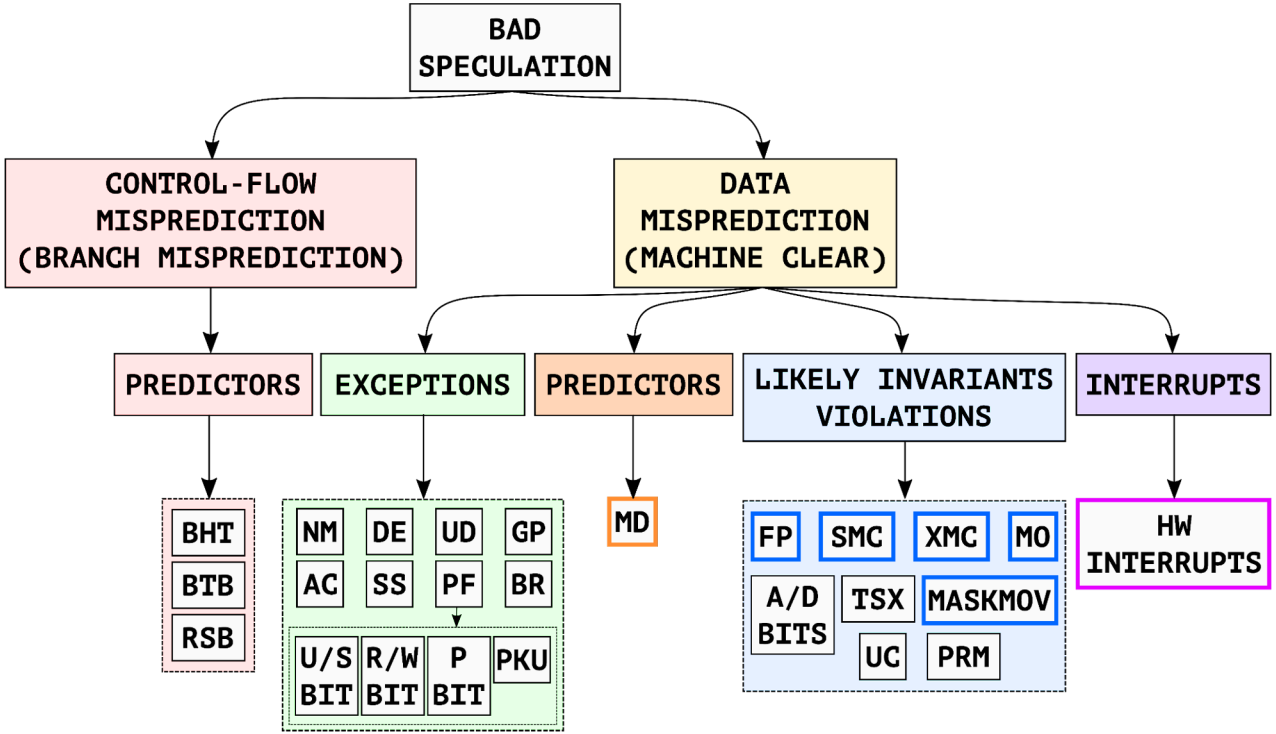

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Intel	✓	✓
AMD	✓	✓*
ARM	✗	✓**

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- Xen hypervisor mitigated SCSB and released a security advisory (XSA-375) following our proposed mitigation.

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VUSec

@hanyrax @enrico_barberis

Code, exploit demo and more can be found here: