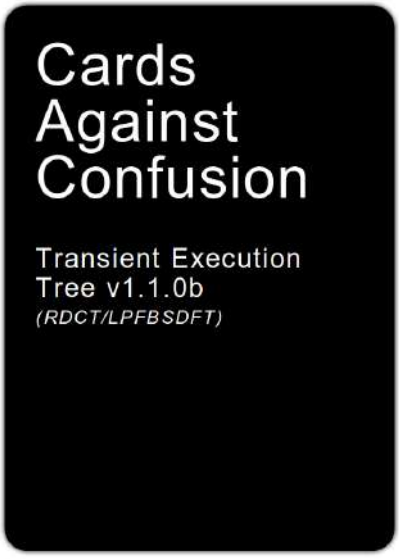
Claudio Canella[1], **Jo Van Bulck**[2], **Daniel Gruss**[1]

September 23, 2019

[1] Graz University of Technology, [2] imec-DistriNet, KU Leuven




side channel
= obtaining meta-data and
deriving secrets from it
CHANGE MY MIND

Intel Analysis of Speculative Execution Side Channels

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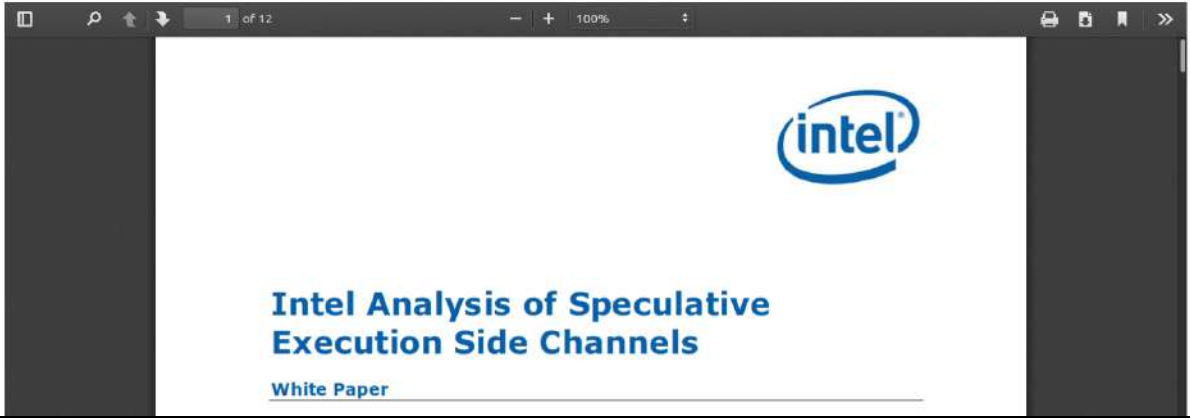

Examples?

Spectre v1,

Examples?

Spectre v1, Spectre v2,

Examples?

Spectre v1, Spectre v2, Meltdown,

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Spectre v1, Spectre v2, Meltdown, Spectre v3,

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Spectre v1, Spectre v2, Meltdown, Spectre v3, LazyFP,

Examples?

Spectre v1, Spectre v2, Meltdown, Spectre v3, LazyFP, Spectre v3.1,

Examples?

Spectre v1, Spectre v2, Meltdown, Spectre v3, LazyFP, Spectre v3.1, Foreshadow,

Examples?

Spectre v1, Spectre v2, Meltdown, Spectre v3, LazyFP, Spectre v3.1, Foreshadow, Foreshadow-NG,

Examples?

Spectre v1, Spectre v2, Meltdown, Spectre v3, LazyFP, Spectre v3.1, Foreshadow, Foreshadow-NG, L1TF,

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Spectre v1, Spectre v2, Meltdown, Spectre v3, LazyFP, Spectre v3.1, Foreshadow, Foreshadow-NG, L1TF, Spectre v1.1,

Spectre v1, Spectre v2, Meltdown, Spectre v3, LazyFP, Spectre v3.1, Foreshadow, Foreshadow-NG, L1TF, Spectre v1.1, Spectre v4,

Examples?

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I guess I missed a few...?

Isn't this just all Spectre?

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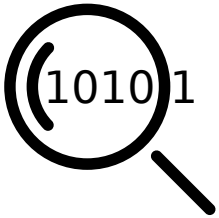
$\rightarrow$ clear difference in behavior

Isn't this side channels?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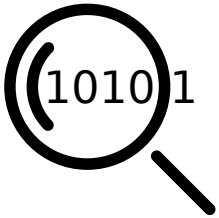
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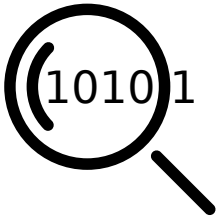

- Step 1: Choose a kernel address and put it in `rcx`

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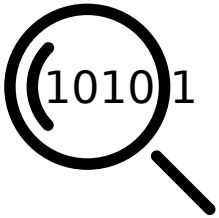
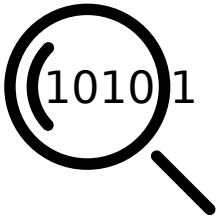


- Step 1: Choose a kernel address and put it in `rcx`
- Step 2: `mov al, byte [rcx]`



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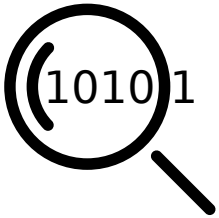

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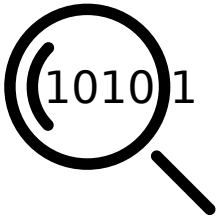

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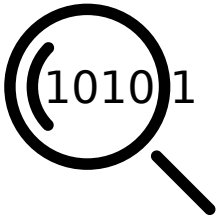

- Step 1: Choose a kernel address and put it in `rcx`
- Step 2: `mov al, byte [rcx]`
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$\rightarrow$ You directly read the value. This is not side channels.

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- Spectre: first class of transient execution attack

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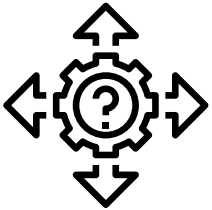
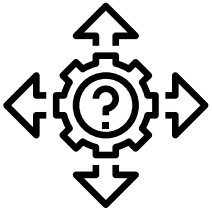
- Exploit control (or data) flow predictions



- Many predictors in modern CPUs



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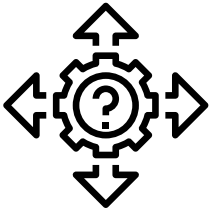

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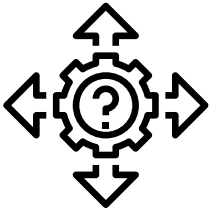

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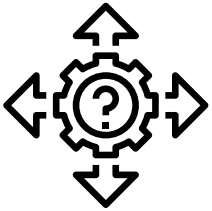

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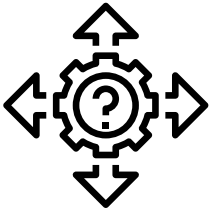
  - Function return destination (RSB)
  - Load matches previous store (STL)



- Many predictors in modern CPUs
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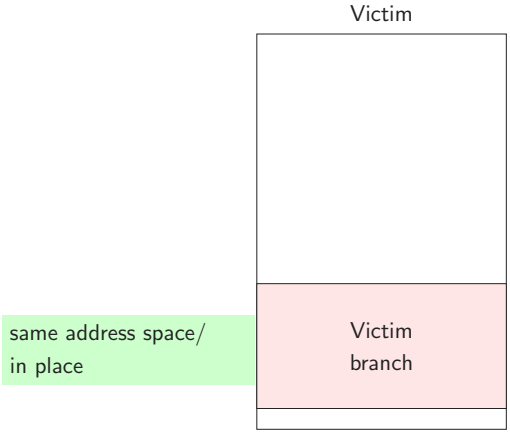
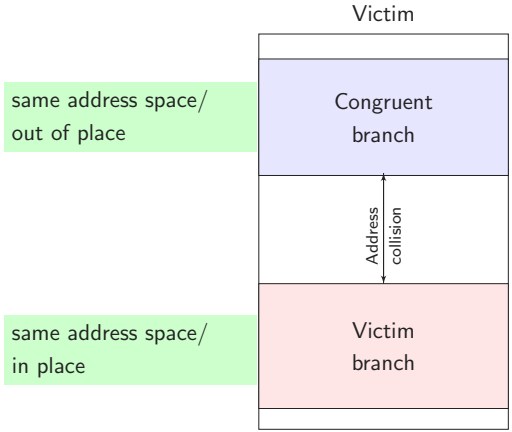
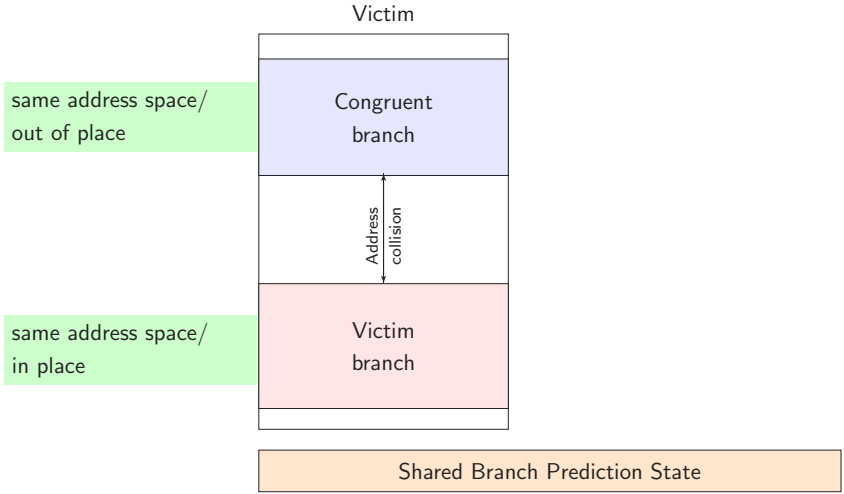
  - Load matches previous store (STL)
- Most are even shared among processes


Victim
same address space/
in place
Victim
branch


Victim
same address space/
out of place
Congruent
branch
Address
collision
same address space/
in place
Victim
branch

Spectre Mistraining



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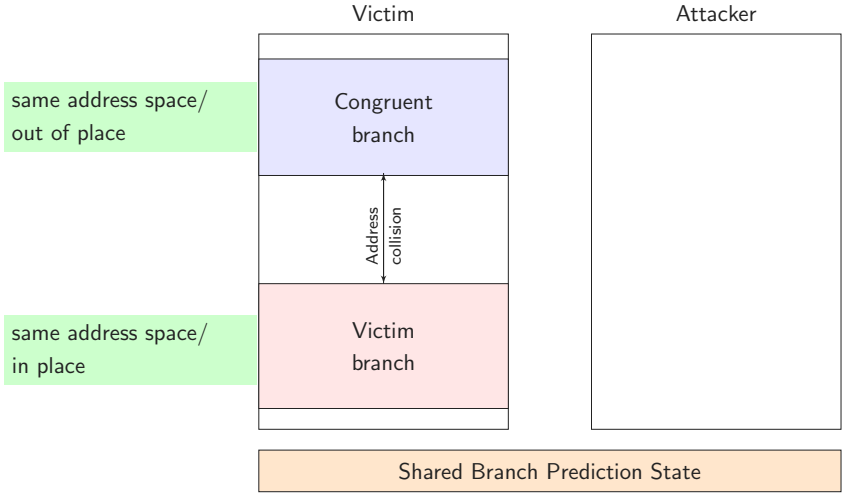

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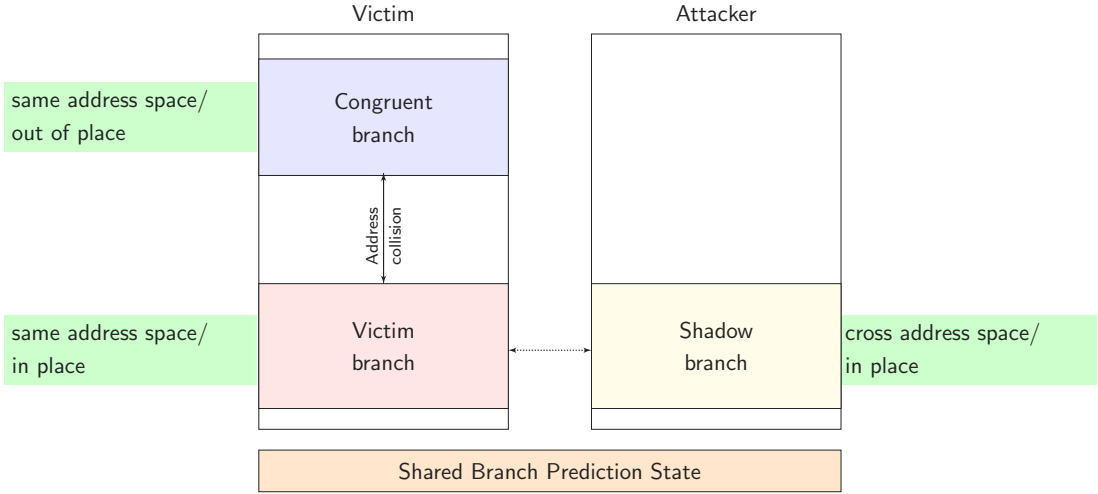

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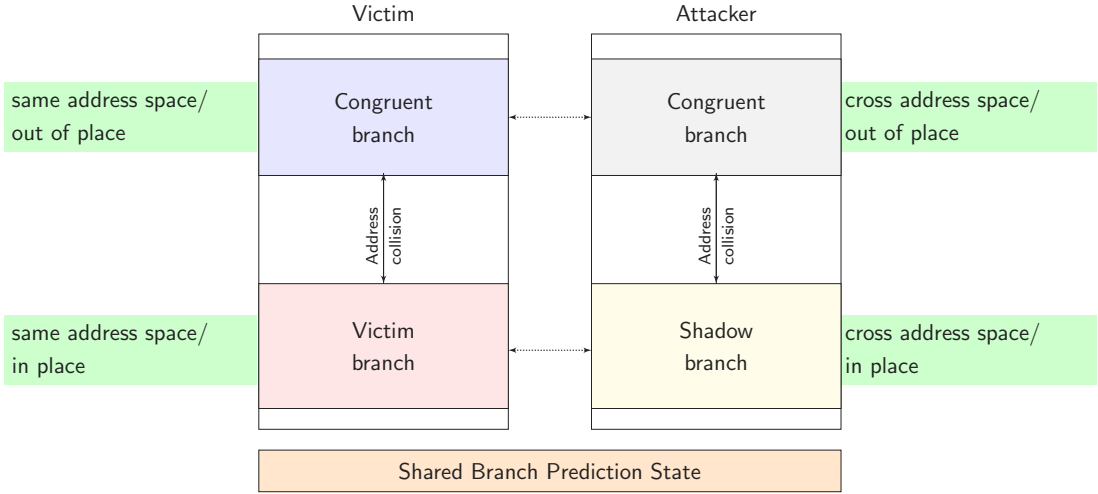
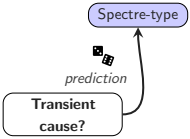


Transient cause?

Spectre Variants



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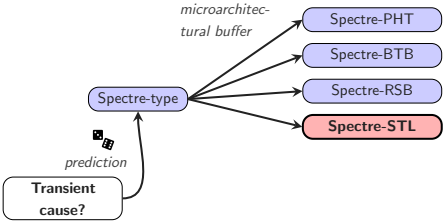

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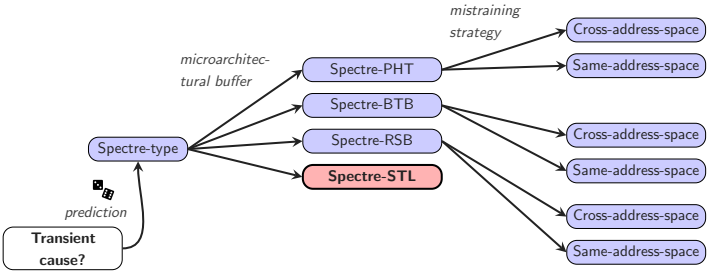

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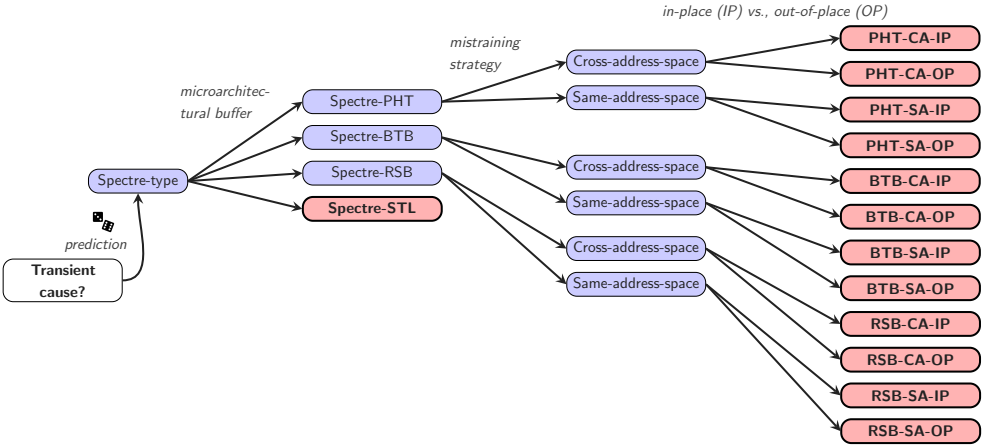

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- Exploit lazy fault handling

Pagefault

Meltdown Variants

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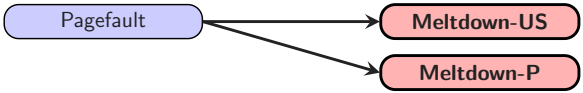

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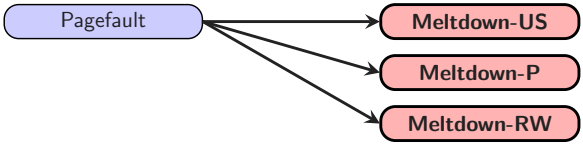
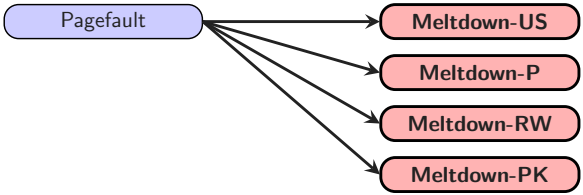
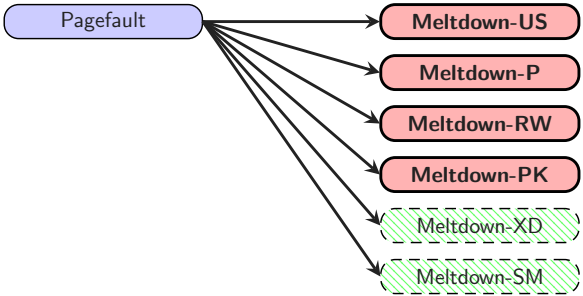
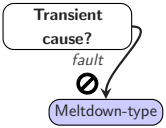


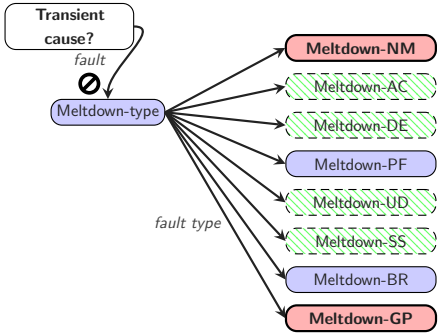

Pagefault
Meltdown-US
Meltdown-P
Meltdown-RW
Meltdown-PK


Pagefault
Meltdown-US
Meltdown-P
Meltdown-RW
Meltdown-PK
Meltdown-XD
Meltdown-SM

Transient cause?


Transient cause?
fault
Meltdown-type

Meltdown Tree



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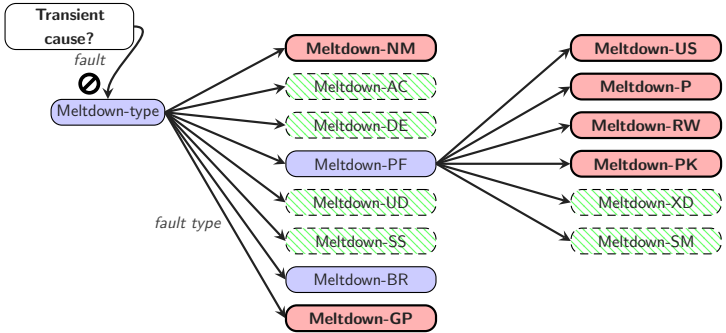

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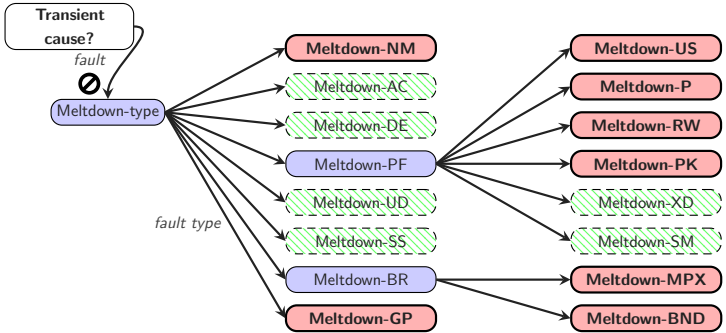
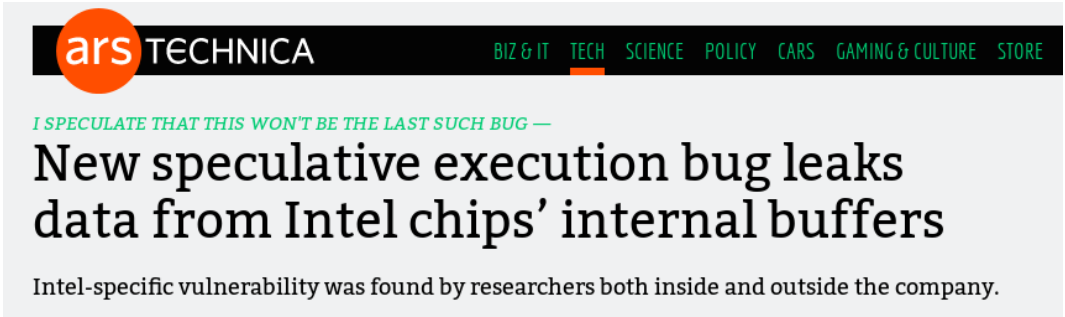


WIRED BUSINESS CULTURE GEAR IDEAS SCIENCE SECURITY TRANSPORTATION

Meltdown Redux: Intel Flaw Lets Hackers Siphon Secrets from Millions of PCs

Two different groups of researchers found another speculative execution attack that can steal all the data a CPU touches.



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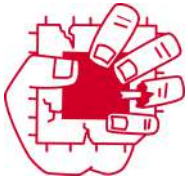
I SPECULATE THAT THIS WON'T BE THE LAST SUCH BUG —

New speculative execution bug leaks data from Intel chips' internal buffers

Intel-specific vulnerability was found by researchers both inside and outside the company.



- May 2019: 3 new Meltdown-type attacks
- Leakage from: line-fill buffer, store buffer, load ports

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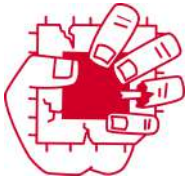
- Key take-aways:
  1. Leakage from intermediate buffers ($\supset$ L1D)
  2. Transient execution through micrcode assists ($\supset$ exceptions)



- May 2019: 3 new Meltdown-type attacks
- Leakage from: line-fill buffer, store buffer, load ports
- Key take-aways:
  1. Leakage from intermediate buffers ($\supset$ L1D)
  2. Transient execution through micrcode assists ($\supset$ exceptions)

$\Rightarrow$ **How to classify in our tree + lessons learned?**

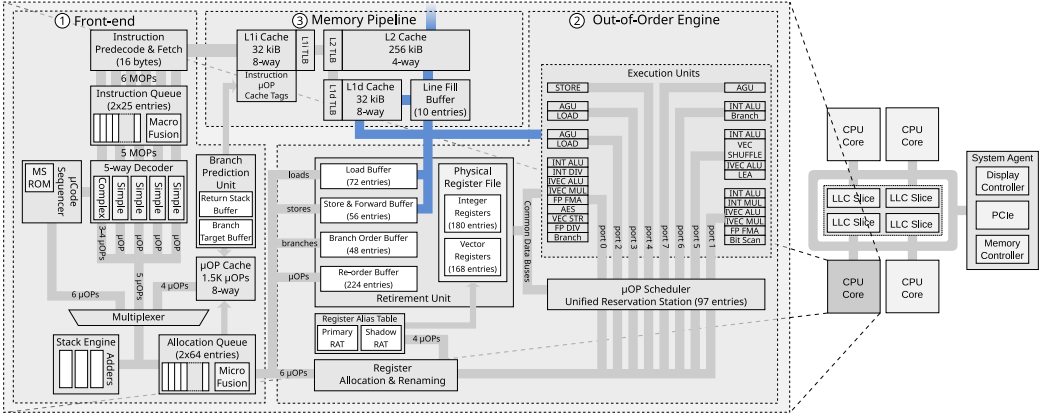


Figure 1: by Stephan van Schaik (`https://mdsattacks.com/`).

- Optimization: only implement fast-path in silicon
- More complex edge cases (slow-path) in microcode

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- More complex edge cases (slow-path) in microcode
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  - assist == "microarchitectural fault"
- Example: setting A/D bits in the page table walk
  - Likely many more!

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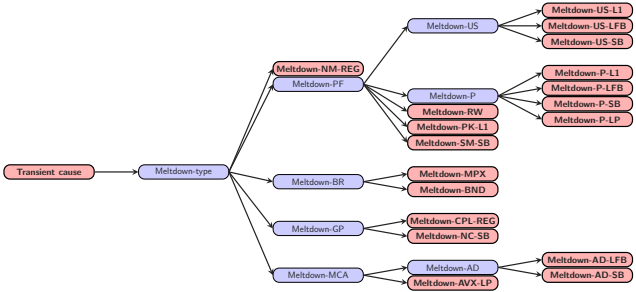
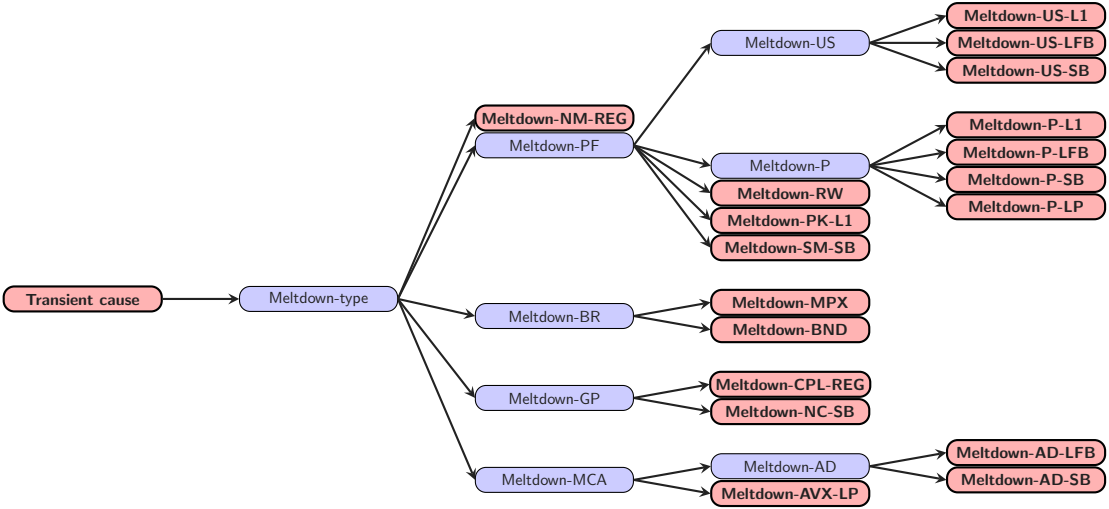


Extended Meltdown tree



2018 era: Depth-first search (e.g., Foreshadow/L1TF)

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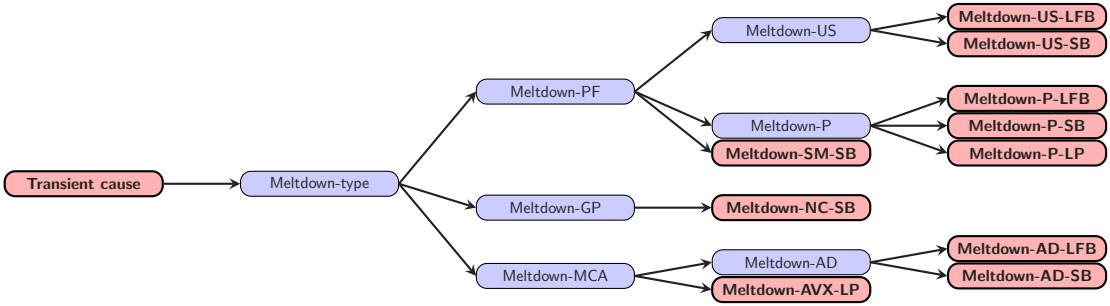
⇒ Our **systematic analysis** (tree search) revealed several overlooked variants

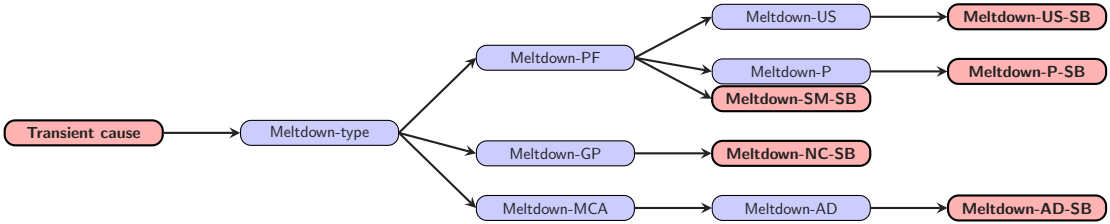
(see Canella et al. "A Systematic Evaluation of Transient Execution Attacks and Defenses", USENIX Security 2019).

2019 era: Breadth-first search (e.g., MDS)



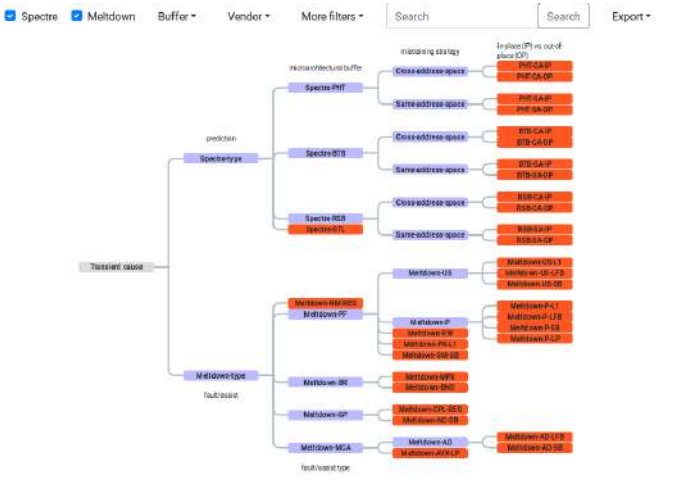
Explore leakage from new **buffers** + microcode **assists**

2019 era: Breadth-first search (e.g., Fallout)



Not "just another buffer", include systematic **fault type analysis**

Interactive JavaScript tree (https://transient.fail)



Details

Transient cause

We split the tree based on what the cause for entering transient execution is. If the cause is the handling of a fault or microcode assist upon instruction retirement, we have a Meltdown-type attack. If the cause is a control or data flow prediction, we have a Spectre-type attack.

References

- **A Systematic Evaluation of Transient Execution Attacks and Defenses**
  Claudio Canella, Jo Van Bulck, Michael Schwarz, Moritz Lipp, Benjamin von Berg, Philipp Ortner, Frank Piessens, Dmitry Evtyushkin, Daniel Gruss (*USENIX Security 2019*)
- **Spectre Attacks: Exploiting Speculative Execution**
  Paul Kocher, Jann Horn, Anders Fogh, Daniel Genkin, Daniel Gruss, Werner Haas, Mike Hamburg, Moritz Lipp, Stefan Mangard, Thomas Prescher, Michael Schwarz, Yuval Yarom (*IEEE S&P 2019*)

- Collect **information record** for each attack:
  - Academic paper references
  - Naming aliases and CVEs
  - Affected vendors (Intel, AMD, ARM)
  - Open-source PoCs
- **Filter** by type, vendor, buffer, etc. $\rightarrow$ understand and build insights
- TikZ/SVG export
- Pull requests welcome! :-)

Claudio Canella[1], **Jo Van Bulck**[2], **Daniel Gruss**[1]

September 23, 2019

[1] Graz University of Technology, [2] imec-DistriNet, KU Leuven