CSE 484 : Computer Security and Privacy

(More) Side Channel Attacks

Spectre

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Thanks to Franzi Roesner, Dan Boneh, Dieter Gollmann, Dan Halperin, Yoshi Kohno, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

Admin

- **Homework 3 due** today
- **Last extra credit** reading due Thursday
  - No late days
- **Lab3 due** Friday
- **Final project due** 03/16
  - No late days
  - Make sure you:
    - Include references
    - Include at least one legal/ethics discussion slide
    - Create original content
    - Go beyond class materials (if it's a topic we also covered)

Admin

- **Final day?**
  - Pollev.com/dkohlbre

Course Eval

- Please fill out the course evaluation!
  - https://uw.iasystem.org/survey/236212
  - Or check email

Side-channels: conceptually

- A program's implementation (that is, the final compiled version **+ hardware**) is different from the conceptual description
- Side-effects of the difference between the implementation and conception can reveal unexpected information
  - Thus: Side-channels

Cache side-channels

- **Idea**: The cache's current state implies something about prior memory accesses

- **Insight**: Prior memory accesses can tell you a lot about a program!

Many thanks to Craig Disselkoen for the animations.

Pre-Attack | **Active Attack** | **Analysis**

Timing threshold

Eviction set

Prime targeted set

Wait

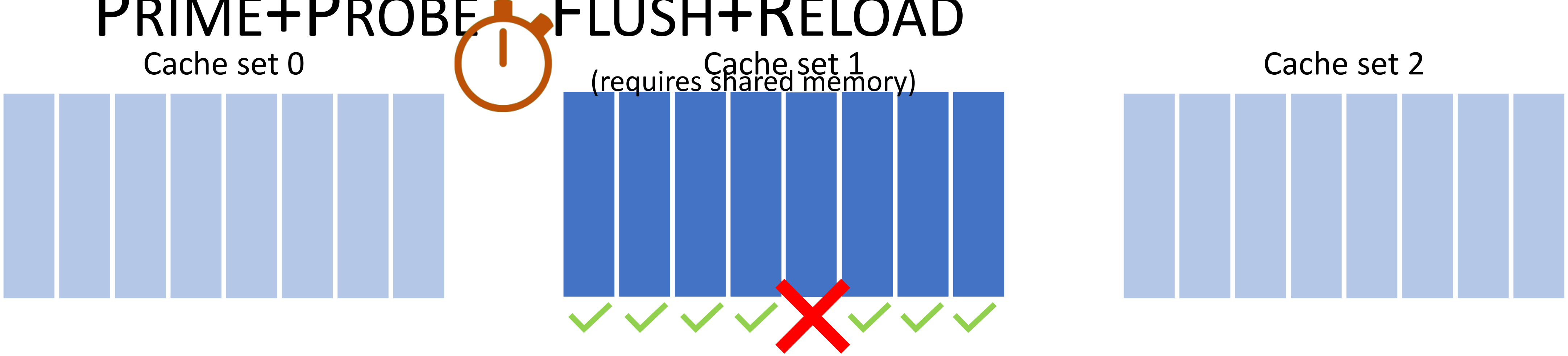
[Timed] Prime targeted set

Victim accesses targeted set

Victim access if time > threshold

PRIME+PROBE FLUSH+RELOAD

(requires shared memory)



Pre-existing data

Attacker's data

Victim's data

FLUSH + RELOAD

F+R P+P

- Even simpler!
- Kick line L out of cache
- Let victim run
- ~~Access L~~
  - Fast? Victim touched it
  - Slow? Victim didn't touch it

Spectre + Friends

- First reported in 2017
- Disclosed in 2018 Jan 3rd
  - https://googleprojectzero.blogspot.com/2018/01/reading-privileged-memory-with-side.html

Jann Horn

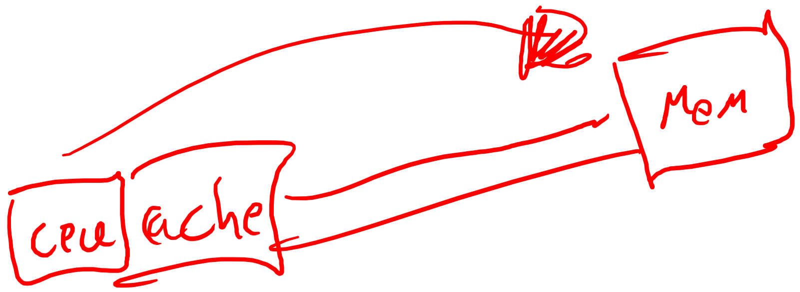
- Novel class of attack: speculative execution attacks
  - Aka: Spectre-class attacks
- (Academic paper published 2019… long story)

Two pieces of background

- Cache attacks (last week)
- Speculative execution (right now!)

Speculative Execution (the fast version)

- All modern processors are capable of speculative execution
- How much, in what ways, and when differs



- Speculative execution allows a processor to ‘guess’ about the result of an instruction
    - And either confirm or correct itself later
- A branch predictor bases a guess on the program’s previous behavior

Example: Speculate on branch

```
int foo(int* address){
      int y = globalarray[0];
      int x = *address;
      if( x < 100 ){
            y = globalarray[10];
      }
      return y;
}
```

yes/no

Example: Speculate on *indirect* branch

```
int caller(int(*fptr)()){
    int y = fptr();
    return y;
}
```

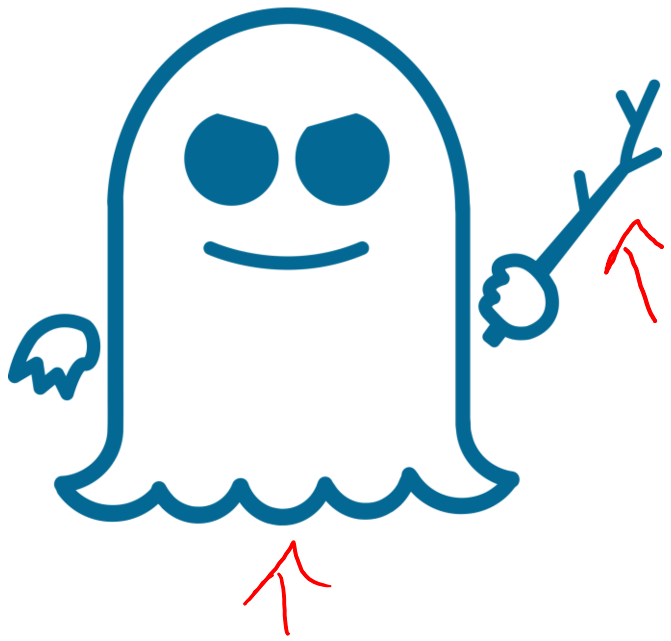
address??

```
int foo(){
    return 10;
}

int bar(){
    return 0;
}
```

What happens when we speculate wrong?

- Eventually, a *squash* occurs
    - All work done under the incorrect guess is undone
- Bad guess on branch?
    - Undo everything in the branch!
    - Undo everything related!
- World reverts back to before guess …almost



Example: Speculate on branch

```
int foo(int* address){
      int y = globalarray[0];   // Brought into cache
      int x = *address; // Brought into cache
      if( x < 100 ){
            y = globalarray[10]; // Brought into cache maybe
      }
      return y;
}
```

Speculative attacks

$x < 100$?

- Three stages:

1. Mistrain predictor

$x > 100$!

2. Run mistrained code with adversarial input

leave traces in cache

3. Recover leftover state information

cache attack, to recover

Spectre variant 1

1.2
4

- “Bounds-check bypass”

```
if( x < len(array))
    array[x];
```

not in cache

x in cache

addr

~~array[x]~~ = secret

Spectre variant 1

- “Bounds-check bypass”

```
if( x < len(array))
      array2[array[x] * 4096];
```

urg
universal
read
gadget

secret

array2 [secret]

Spectre variant 2

- "Branch target injection"

```
int caller(int(*fptr)(int)){
    int y = fptr(x);
    return y;
}
```

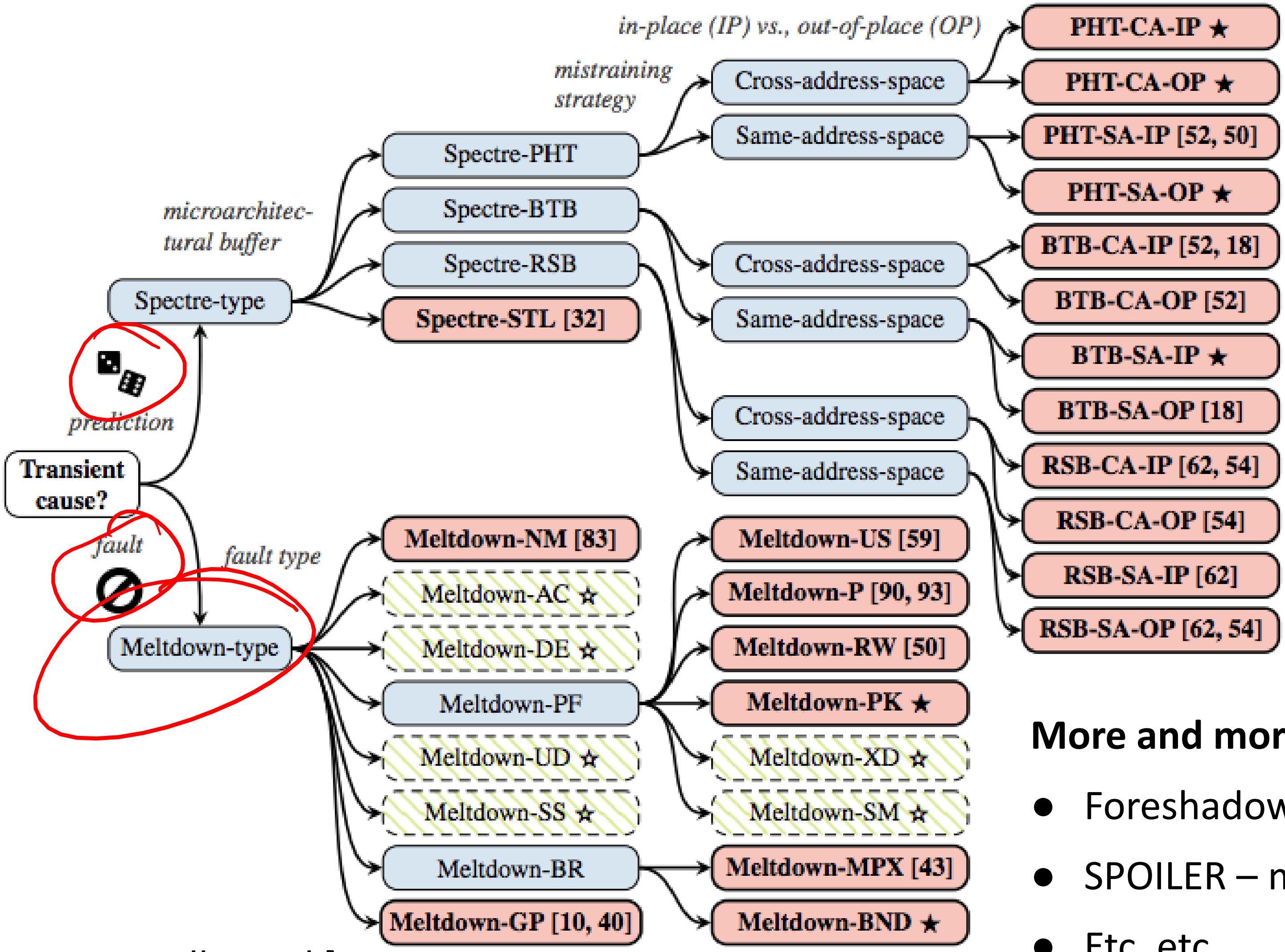
```
int foo(x){
    array2[array1[x] * 4096];
}

int bar(x){
    return x;
}
```

C++

virtual function tables

It’s A Party



[From Canella et al.]

More and more:

- Foreshadow – attacks SGX
- SPOILER – mem dependence
- Etc. etc.

What about ‘Meltdown’?

- Also called Spectre variant 3 (“rogue data cache load”)
- Spectre v1/v2 require the victim program to have the vulnerable code pattern
  - Just like the victim program has to have a buffer overflow!
  - Spectre is a global problem with speculation conceptually
- Meltdown allows the attacking program to do whatever it wants!

Meltdown: An Intel specific problem

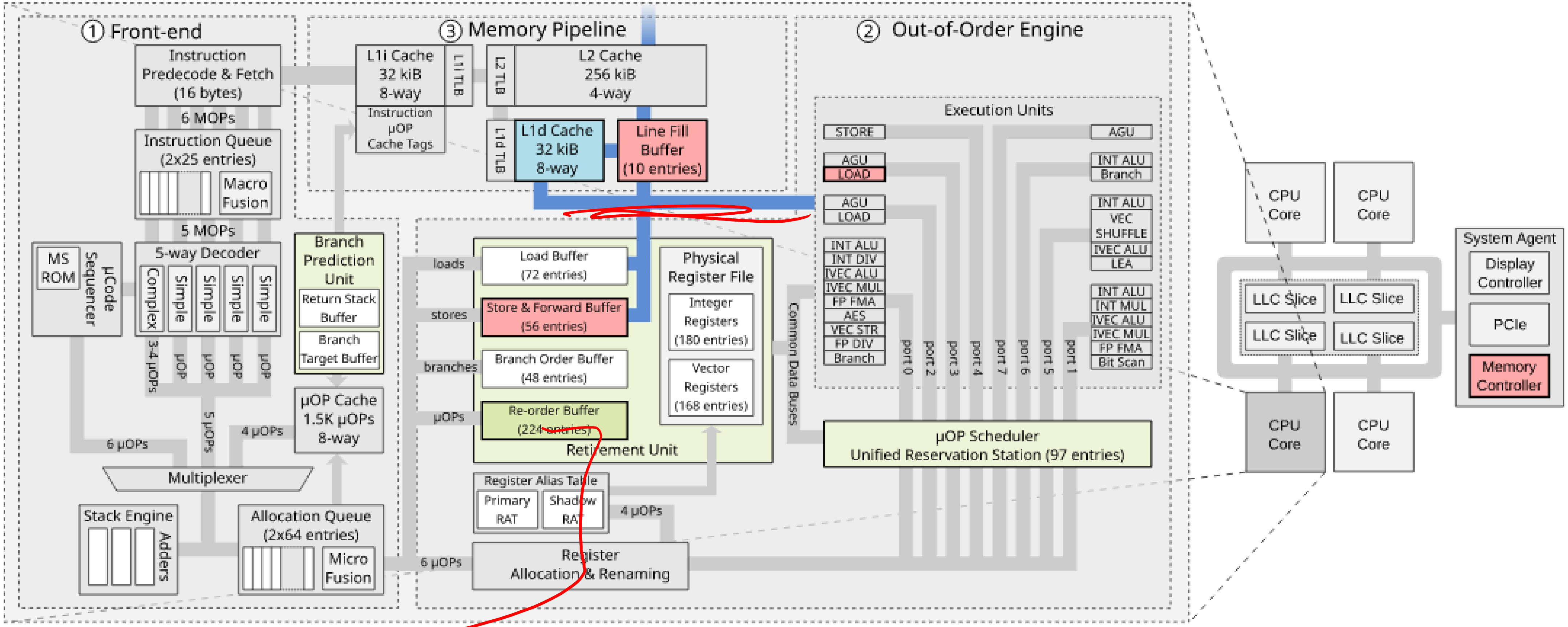
L1 cache

- Memory permissions weren't checked during speculation
  - At least for some cases

"Imagine the following instruction executed in usermode
`mov rax,[somekernelmodeaddress]`
It will cause an interrupt when retired, [...]"

Anders Fogh (2017, July)

array2[secret],



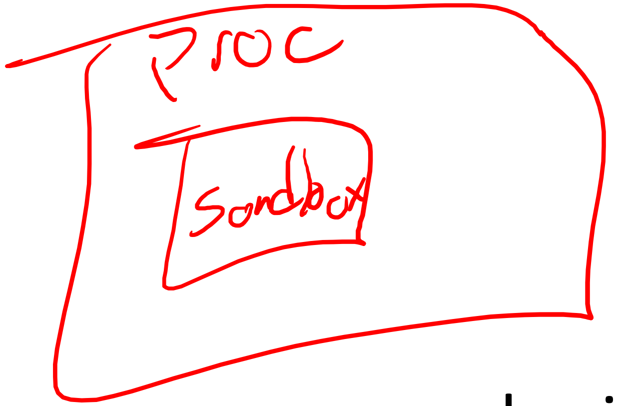
Click on the various components to interact with them. The full interactive version can be found here and the raw SVG can be found here. There is also a more vibrant colored version (the one used in our paper), which can be found here. These diagrams have been made by Stephan van Schaik (@themadstephan).

https://mdsattacks.com/

Canvas

- Browsers had to scramble to deal with Spectre type vulnerabilities as they were exploitable from webpages and allowed for arbitrary memory reads.

- How would you have tried to handle receiving a disclosure like this **as the browser vendors**?
- You can either discuss technical ideas **or** policy objectives for a strategy to handle the vulnerabilities.



Defenses

- Disable User/Kernel memory space sharing
  - KAISER defense

process sandboxing also

- “Fence” dangerous code patterns
  - Extra instruction that block speculation past some point

lfence

mfence

a
b
c
fence
d

- Microcode updates for processors
  - MDS-class fixes

Speculative Attacks wrapup

- Spectre vulnerabilities are here to stay, for a long time
- MDS+Meltdown (hopefully) aren't

1) mistrain

2) leave side effects

3) recover side-effects

not just cache!