CSE 484 : Computer Security and Privacy

(More) Side Channel Attacks

Fall 2021

David Kohlbrenner

dkohlbre@cs.washington.edu

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

- **Lab 3** due Wednesday
- **Last extra credit** reading due Friday
  - No late days
- **Final project due** 12/13
  - 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/249000
  - Or check email

- In fact, lets do that now ☺

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

Timing threshold

Eviction set

Active Attack

Prime targeted set

Wait

[Timed] Prime targeted set

Victim accesses targeted set

Analysis

Victim access if time > threshold

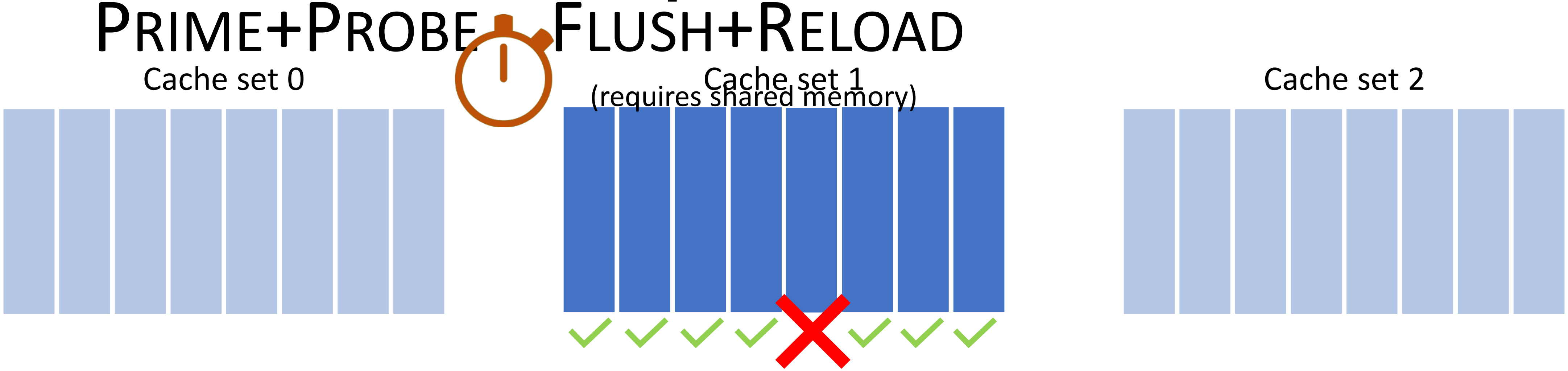
PRIME+PROBE FLUSH+RELOAD

(requires shared memory)

Cache set 0

Cache set 1

Cache set 2



Pre-existing data

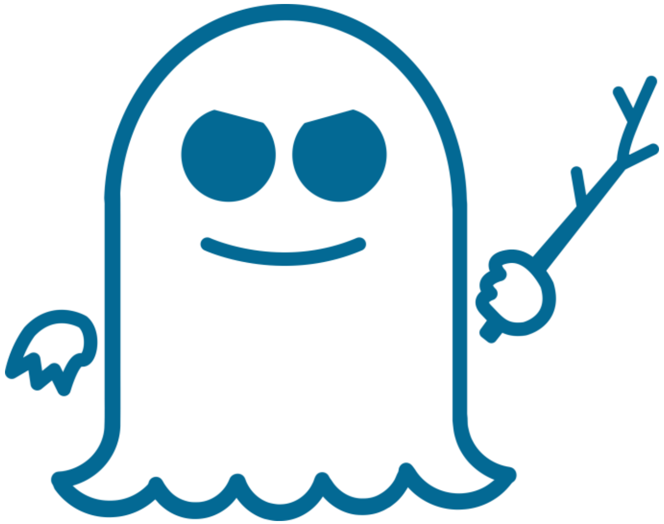
Attacker's data

Victim's data

FLUSH + RELOAD

- 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
  - https://googleprojectzero.blogspot.com/2018/01/reading-privileged-memory-with-side.html
- 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;
}
```

Example: Speculate on branch

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

Example: Speculate on branch

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

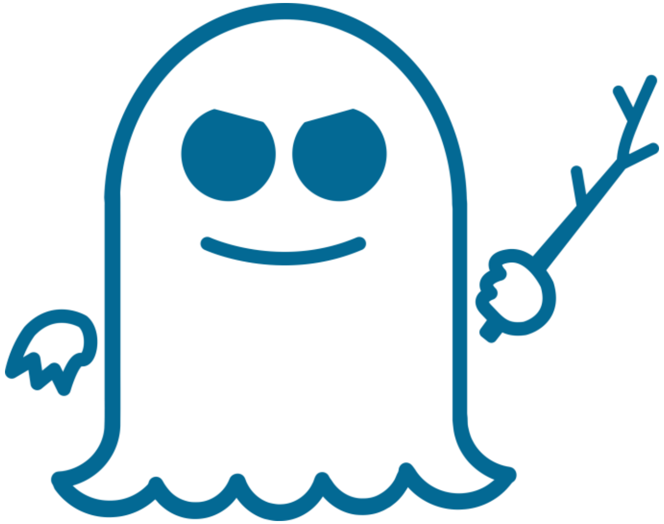
Example: Speculate on *indirect* branch

```
int caller(int(*fptr)()){

    int y = fptr();

    return y;
}
```

```
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

Three stages:

1. Mistrain predictor
2. Run mistrained code with adversarial input
3. Recover leftover state information

Spectre variant 1

- “Bounds-check bypass”

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

Spectre variant 1

- "Bounds-check bypass"

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

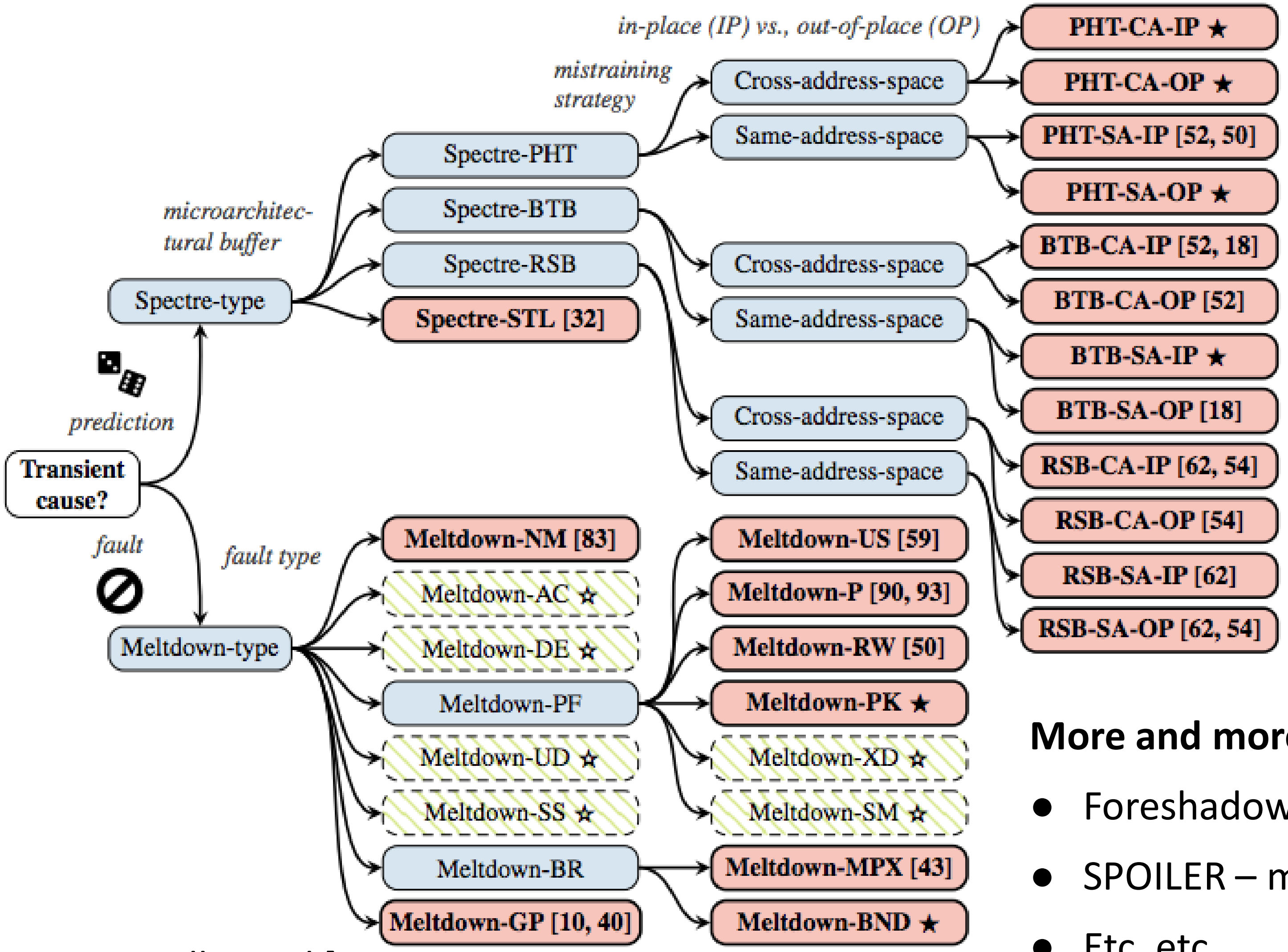
Spectre variant 2

- "Branch target injection"

```
int caller(int(*fptr)()){

    int y = fptr(x);

    return y;
}
```

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

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

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”)

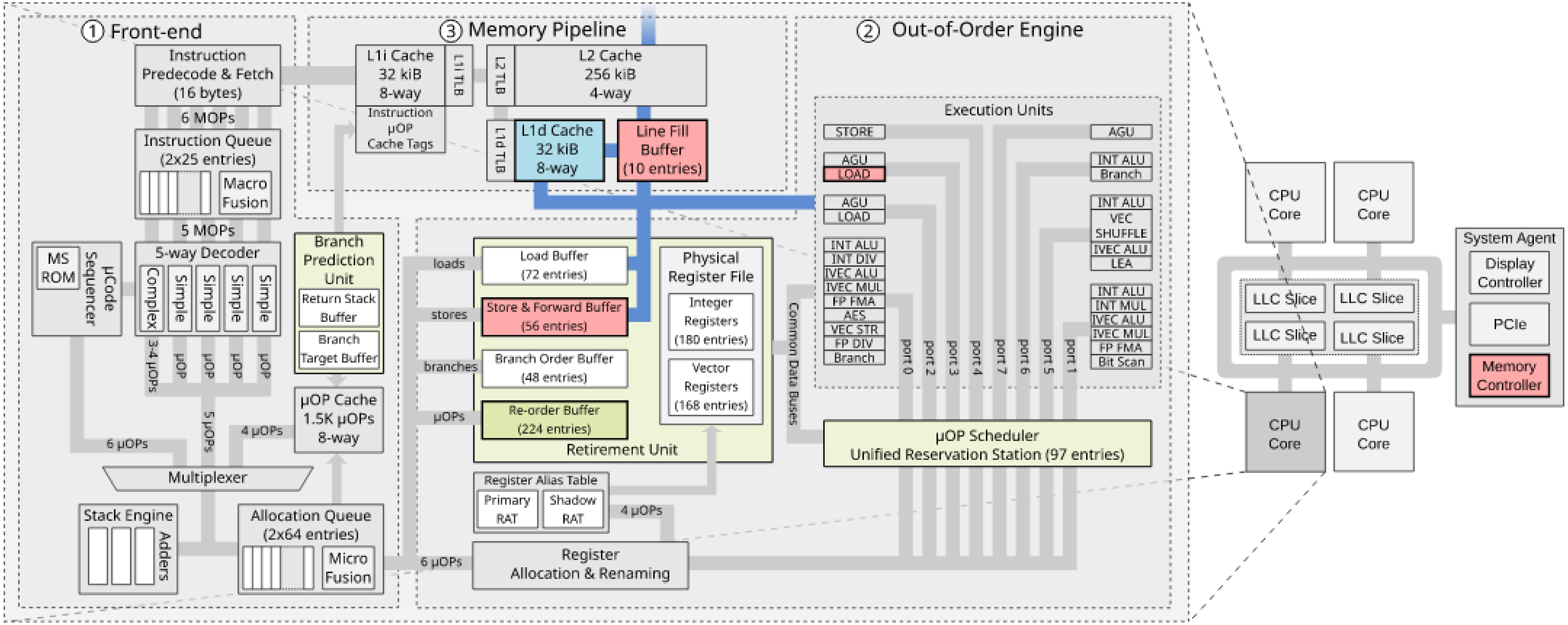
- Spectre v1/v2 require the victim program to have the vulnerable code pattern
  - Just like the victim program has to have a buffer overflow!
  - Spectre is a global problem with speculation conceptually

- Meltdown allows the attacking program to do whatever it wants!

Meltdown: An Intel specific problem

- 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, [...]"



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