CSE 484 : Computer Security and Privacy

(More) Side Channel Attacks

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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](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!
Timing threshold
Eviction set

Prime targeted set
Wait
[Timed]
Prime targeted set
Victim accesses targeted set

**Analysis**
Victim access if time > threshold

**Pre-Attack**

**Active Attack**

**Analysis**

**PRIME+PROBE**
Cache set 0

**FLUSH+RELOAD**
Cache set 1
(requires shared memory)

Cache set 2

Pre-existing data
Attacker’s data
Victim’s data

Many thanks to Craig Disselkoen for the animations.

3/8/2021
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

• 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

```c
int foo(int* address) {
    int y = globalarray[0];
    int x = *address;
    if (x < 100) {
        y = globalarray[10];
    }
    return y;
}
```
Example: Speculate on *indirect* branch

```c
int caller(int(*fptr)()){ int foo(){
    return 10;
    int y = fptr();
    return y;
}
int bar(){
    return 0;
}
int foo(){
    return 10;
    int y = fptr();
    return y;
}
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

```c
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
     \[ x < 100 \]
     \[ x > 100 \]
     leave traces in cache
  3. Recover leftover state information
     cache attack, to recover
Spectre variant 1

• “Bounds-check bypass”

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

not in cache

x in cache

addr = secret
Spectre variant 1

• “Bounds-check bypass”

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

---

`array2[secret]`
Spectre variant 2

• “Branch target injection”

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

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

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

```c++
virtual function tables
```
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, [...]

Anders Fogh (2017, July)
Enduring legacy: MDS

• Microarchitectural Data Sampling attacks
• Related type of speculative attack
• Still 'a bug' not 'a feature'
• Leaks from 'leftover' or 'in-flight' data via:
  • Store/forward buffers
  • Uncacheable memory
  • Line fill buffers
  • L1 cache
  • Load ports

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