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 THE **LINUX** FOUNDATION

Linux's response

- Companies were notified, but not developers.
- Developers notified very late, resulting in delay of fixes.
- Majority of the world runs non-corporate kernels.
- Intel is now working with some developers.



Spectre

- Hardware bugs
- Valid code can be “tricked” into exposing sensitive data to attacking programs.
- Exploits the speculative execution model of modern CPUs.
- Many different variants.
- Is going to be with us for a very long time!



Different Variants

- 1 – Bounds Check Bypass (BCB)
- 2 – Branch Target Isolation (BTI)
- 3 – Rogue Data Cash Load (RDCL)
- 3a – Rogue System Register Read (RSRE)
- 4 – Speculative Store Bypass (SSB)
- 5 – Lazy Floating Point State Restore (LazyFP)



variant 1 – Bounds check bypass

- Uses the kernel to read memory of another process or virtual machine.
- Fixed by core kernel changes.
- Lots of individual drivers still need to be fixed.



variant 1 – vulnerable code

```
int load_array(int *array, unsigned int user_value)
{
    if (user_value >= MAX_SIZE)
        return 0;

    return array[user_value];
}
```



variant 1 – vulnerable code

```
int load_dependent_array(int *array1, int *array2,  
                        int index)  
{  
    int value1, value2;  
  
    value1 = load_array(array1, index);  
    value2 = load_array(array2, value1);  
  
    return value2;  
}
```



variant 1 – fixed code

```
int load_array(int *array, unsigned int user_value)
{
    if (user_value >= MAX_SIZE)
        return 0;

    user_value = array_index_nospec(user_value, MAX_SIZE);

    return array[user_value];
}
```




variant 1 – fixed code

```
#define array_index_nospec(index, size) \
({ \
    typeof(index) _i = (index); \
    typeof(size) _s = (size); \
    unsigned long _mask = array_index_mask_nospec(_i, _s); \
 \
    BUILD_BUG_ON(sizeof(_i) > sizeof(long)); \
    BUILD_BUG_ON(sizeof(_s) > sizeof(long)); \
 \
    (typeof(_i)) (_i & _mask); \
})
```



variant 1 – fixed code - x86

```
static inline unsigned long
array_index_mask_nospec(unsigned long index,
                        unsigned long size)
{
    unsigned long mask;

    asm ("cmp %1,%2; sbb %0,%0;"
        : "=r" (mask)
        : "g"(size), "r" (index)
        : "cc");

    return mask;
}
```



variant 1 – fixed code

```
int load_array(int *array, unsigned int user_value)
{
    if (user_value >= MAX_SIZE)
        return 0;

    user_value = array_index_nospec(user_value, MAX_SIZE);

    return array[user_value];
}
```



variant 1 – Fix dates*

x86

4.14.14 17 January 2018

4.9.77 17 January 2018

4.4.113 23 January 2018

ARM

4.15.4 17 February 2018

4.14.21 22 February 2018



*Fixes keep coming

- These are the “first fixed” dates.
- Later kernels get more fixes and improvements.
- Keep updating your kernel & microcode!



variant 1 – Fix dates again

x86

4.16.11 22 May 2018

4.14.43 22 May 2018

4.9.102 22 May 2018

ARM

4.16 1 April 2018

4.9.95 20 April 2018



variant 2 – Branch target injection

- Abuses the CPU branch predictor.
- Read data from kernel or other virtual machine.
- Fixed by compiler, kernel, & microcode updates.
- “[retpoline](#)”



variant 2 – Fix dates*

x86

4.15.9	11 March 2018
4.14.26	11 March 2018
4.9.87	11 March 2018
4.4.121	11 March 2018

*More fixes and optimizations happened in later kernels



Meltdown

- Spectre variant “3”
- Read kernel data from userspace.
- Fixed with page table isolation kernel changes (Kaiser for older kernels).
- Fix slows down enter/exit of the kernel.
- Implemented differently for different kernel releases and distros.



Meltdown – fix dates

x86

4.14.11	02 January 2018
4.9.75	05 January 2018
4.4.110	05 January 2018

ARM

4.15.4	17 February 2018
4.14.20	17 February 2018
4.9.93	08 April 2018



variant 3a – Rouge system register read

- Abuses the reading of system registers.
- Read data from kernel or other virtual machine.
- Kernel fix for Meltdown solves this problem.



variant 4 – Speculative Store Bypass

- Can execute and read beyond what is expected.
- Read data from kernel or other virtual machine.
- Minor kernel changes.
- Microcode update required for full protection.



variant 4 – Speculative Store Bypass

x86

4.16.11 22 May 2018

4.14.43 22 May 2018

4.9.102 22 May 2018



variant 5 – Lazy FP state restore

- Uses the old “lazy floating point restore” method to read memory of another process or virtual machine.
- Details to be published June 27.
- Linux kernel fixed in 2016.



variant 5 – Fix dates

x86

4.6 15 May 2016

4.4.138 16 June 2018

Why this is such a big deal

- CPU bugs require software & microcode fixes.
- All operating systems are affected.
- Performance will decrease.
- Totally new class of vulnerabilities.
- We will be finding, and fixing, these for a very long time.

Keeping a secure system

- Take ALL stable kernel updates.
 - Do **NOT** cherry-pick patches.
- Enable hardening features.
- Update to a newer major kernel version where ever possible.
- Update your microcode/BIOS!