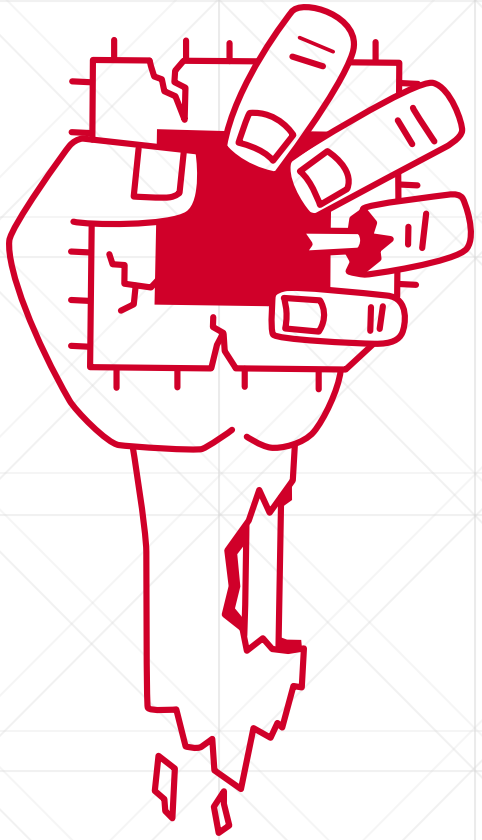
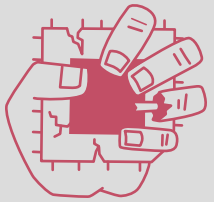


ZombieLoad

Cross-Privilege-Boundary Data Sampling

Michael Schwarz, Moritz Lipp, **Daniel Moghimi**, Jo Van Bulck, Julian Stecklina,
Thomas Prescher, Daniel Gruss

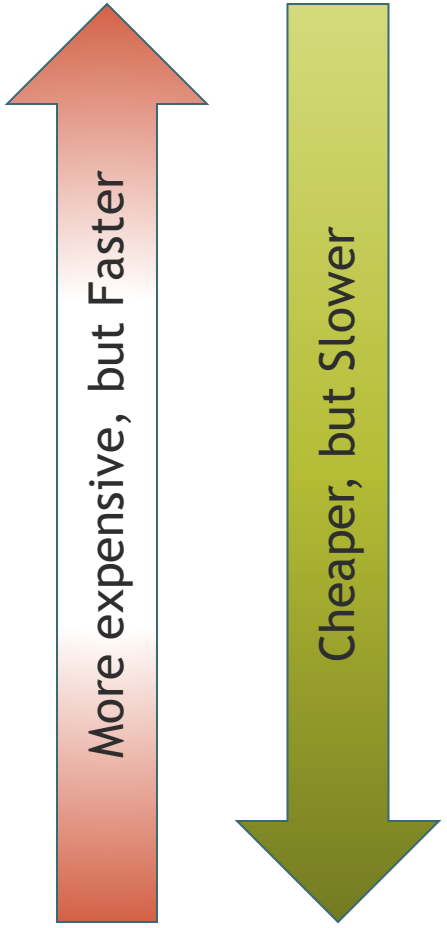
whoami

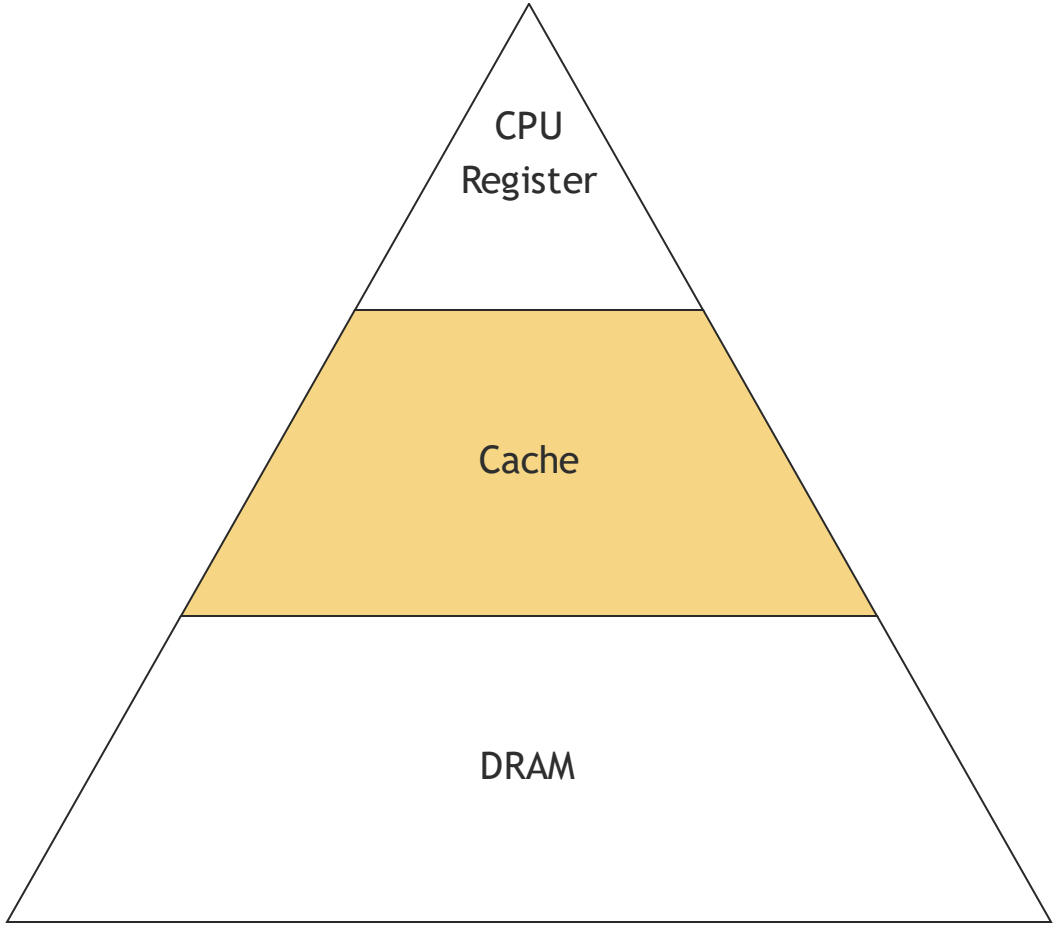


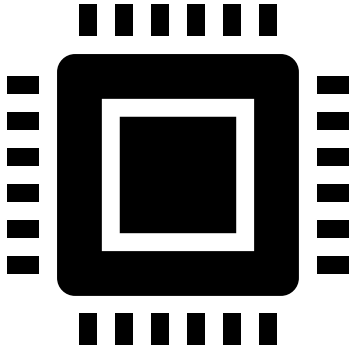
- Daniel Moghimi (@danielmgmi)
- Computer Security *since 2010*
  - Reverse Engineering
  - Binary Analysis
  - Application Security
- PhD Student *since 2017*
  - Microarchitectural Security
  - Side Channels
  - Breaking Cryptographic Implementations


$5,000

Background: Cache Attacks – Cache Memory



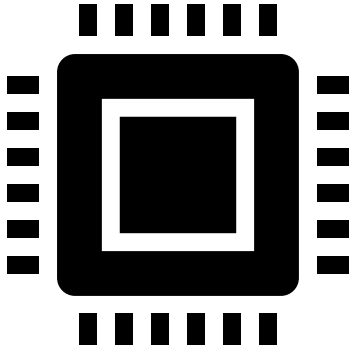




Background: Cache Attacks – Cache Miss

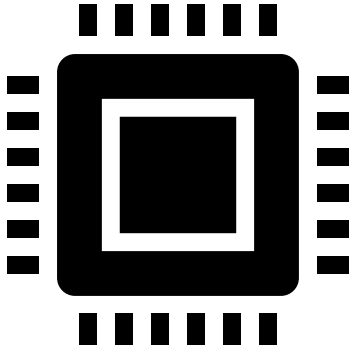
10100110

Cache



Background: Cache Attacks

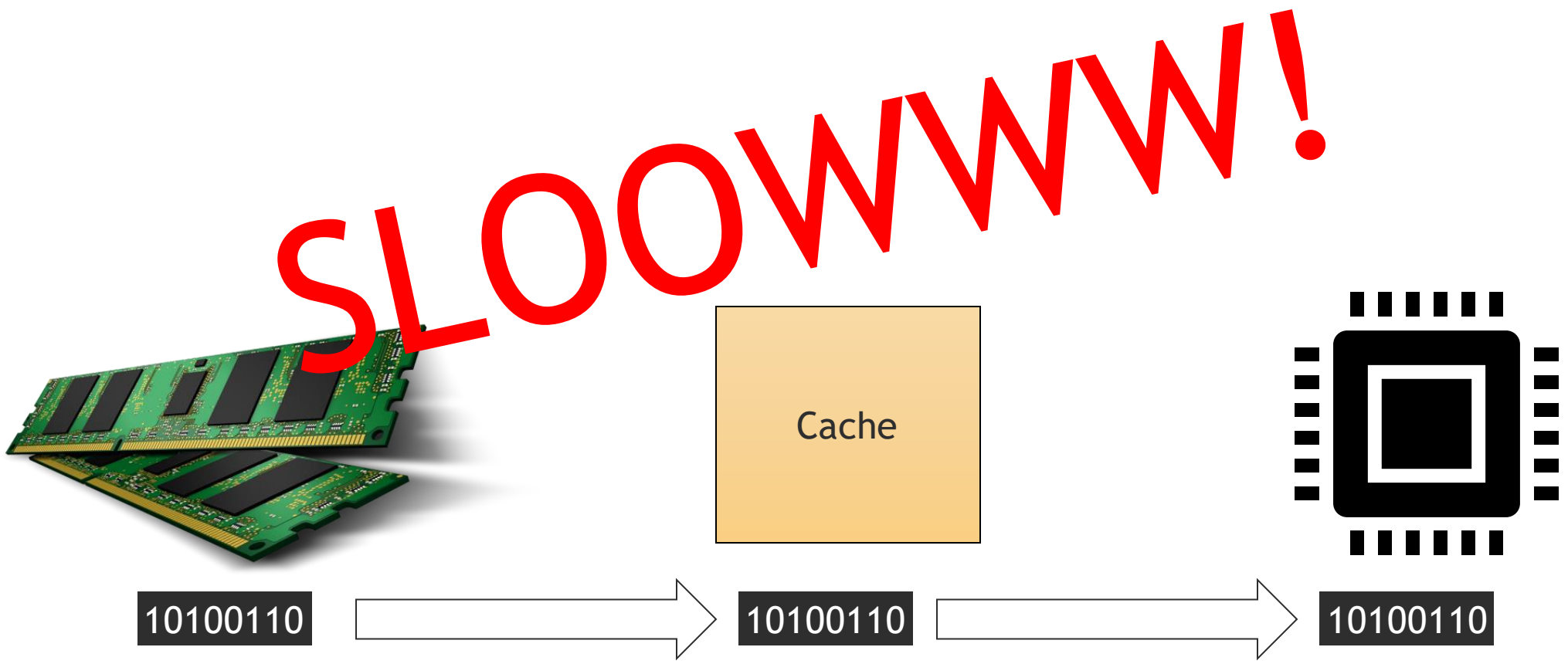
Cache



10100110

10100110

Background: Cache Attacks

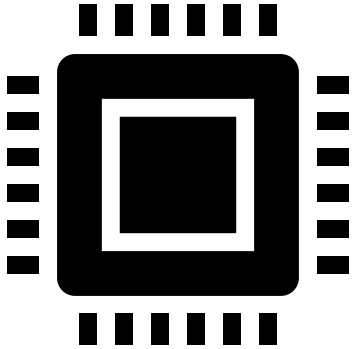


Background: Cache Attacks – Cache Hit

10100110

Cache

10100110

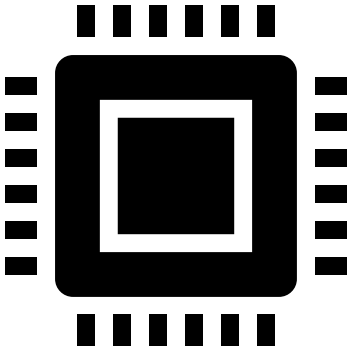


Background: Cache Attacks – Cache Hit

Yeah! Fast!!

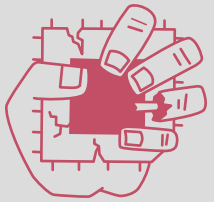
10100110

10100110



10100110

Background: Cache Attacks – Flush & Reload (Yarom et al.)



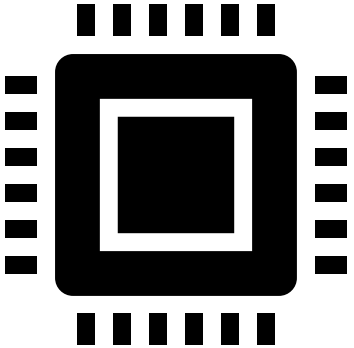
Attacker

Victim

10100110

Cache

10100110



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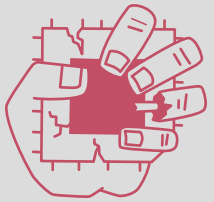
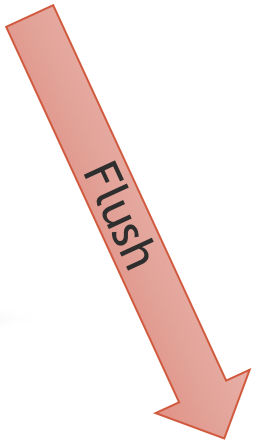
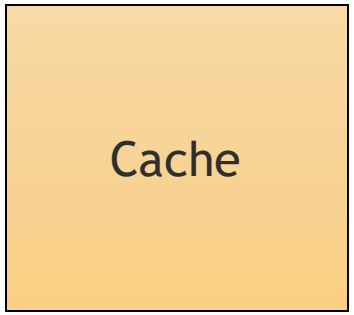


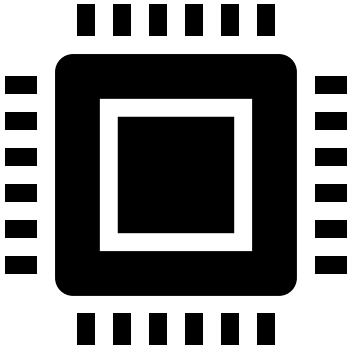
Attacker

Victim

10100110







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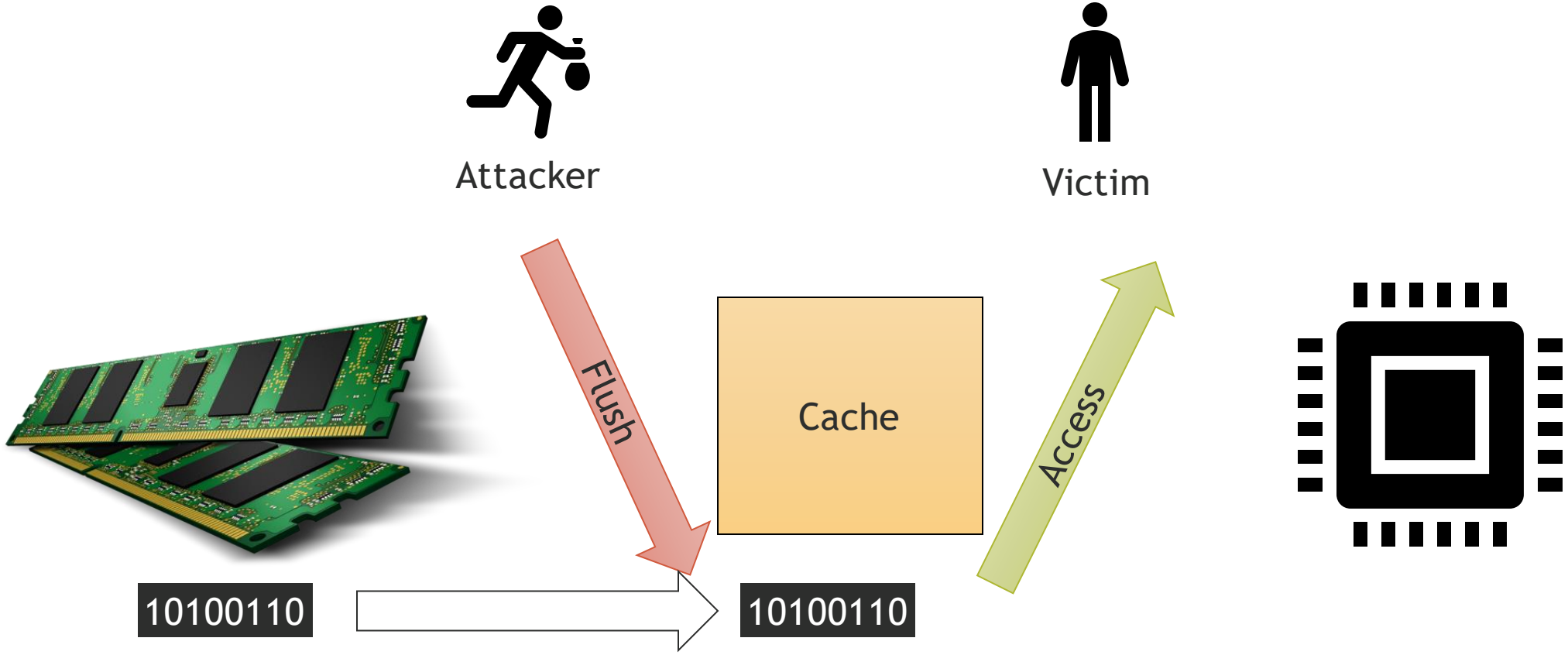
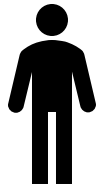


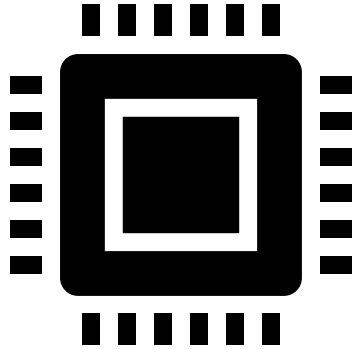
Background: Cache Attacks – Flush & Reload (Yarom et al.)

Attacker



Victim

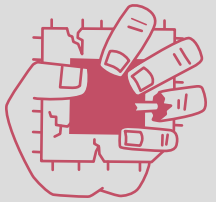
Cache



10100110

10100110

Background: Cache Attacks – Flush & Reload (Yarom et al.)

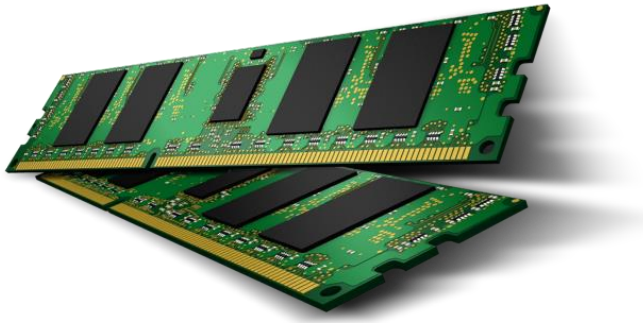


delta > threshold = cache hit

delta < threshold = cache miss

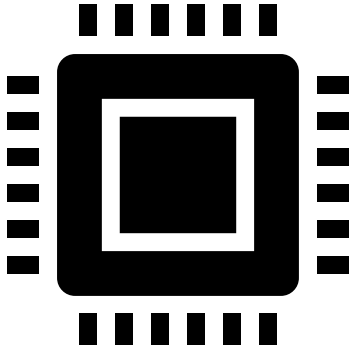
Attacker

Victim



Access

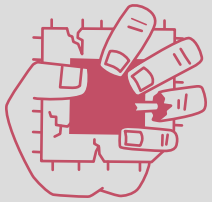
Cache



10100110

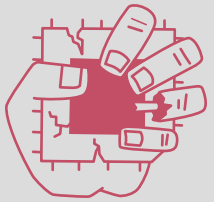
10100110

2018: Meltdown Attack?



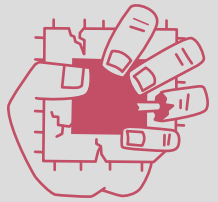
```
char secret = *(char *) 0xffffffff81a0123;
```

2018: Meltdown Attack?



```
char secret = *(char *) 0xffffffff81a0123;
printf("%c\n", secret);
```

2018: Meltdown Attack?



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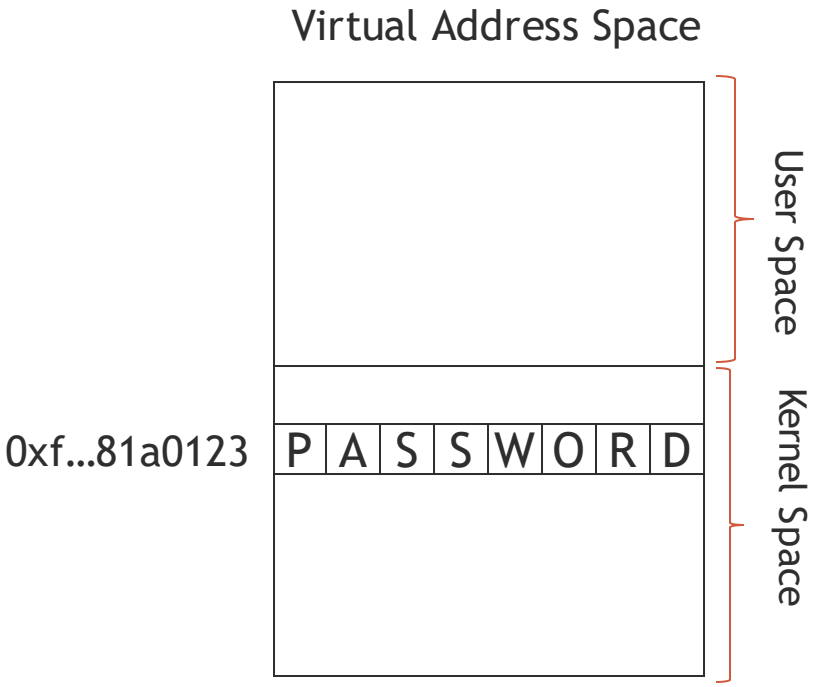
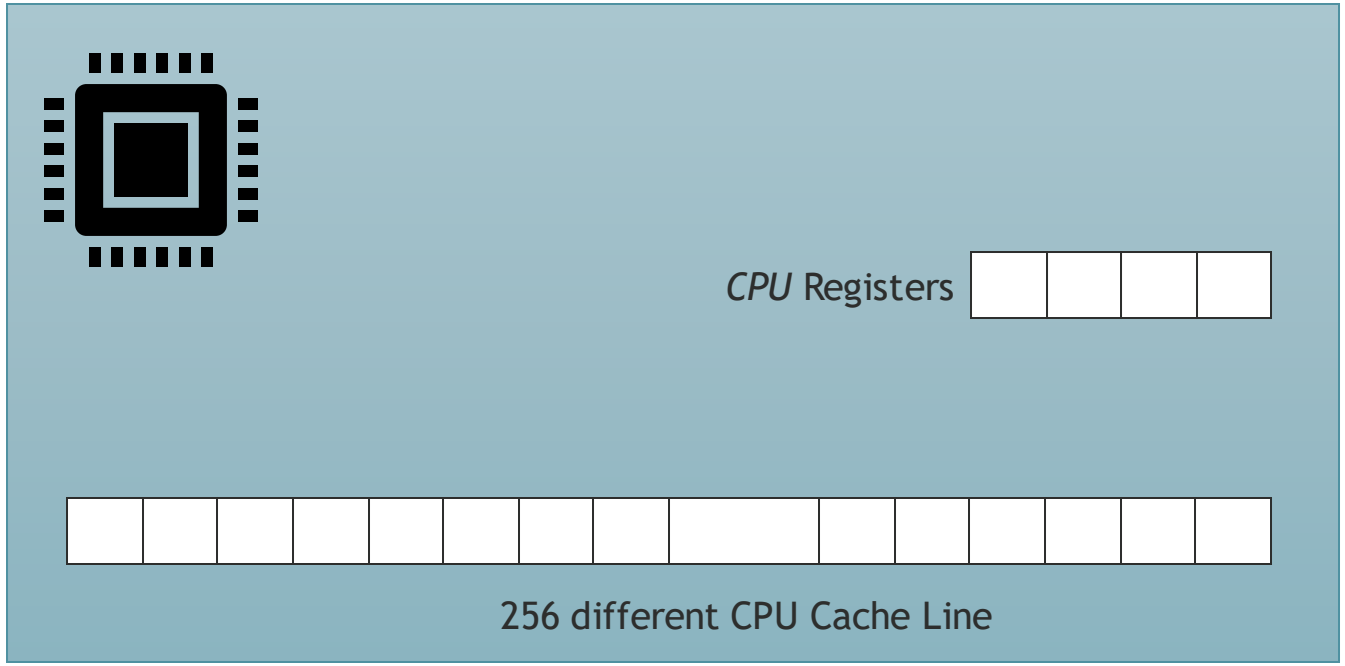
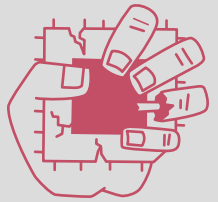




2018: Meltdown Attack?



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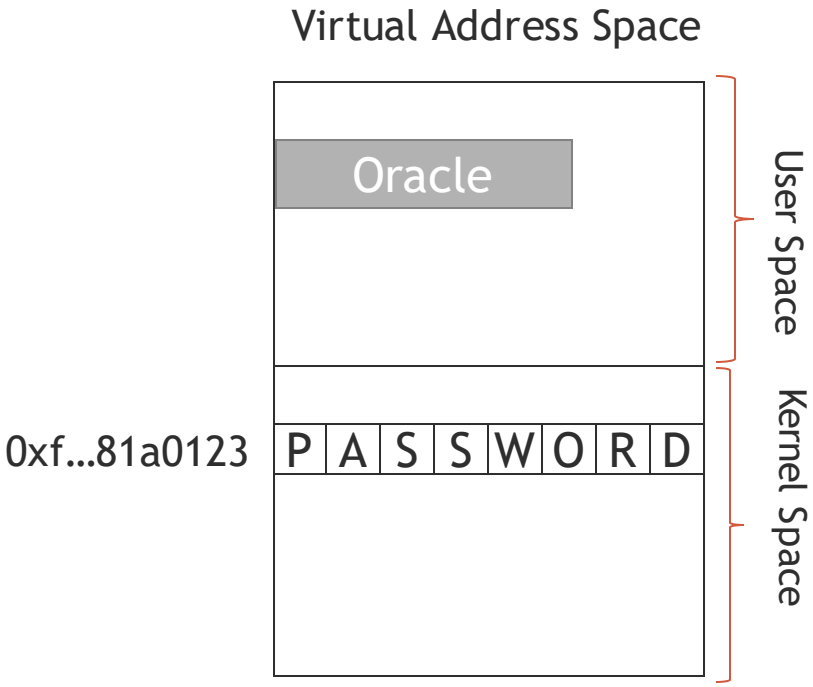
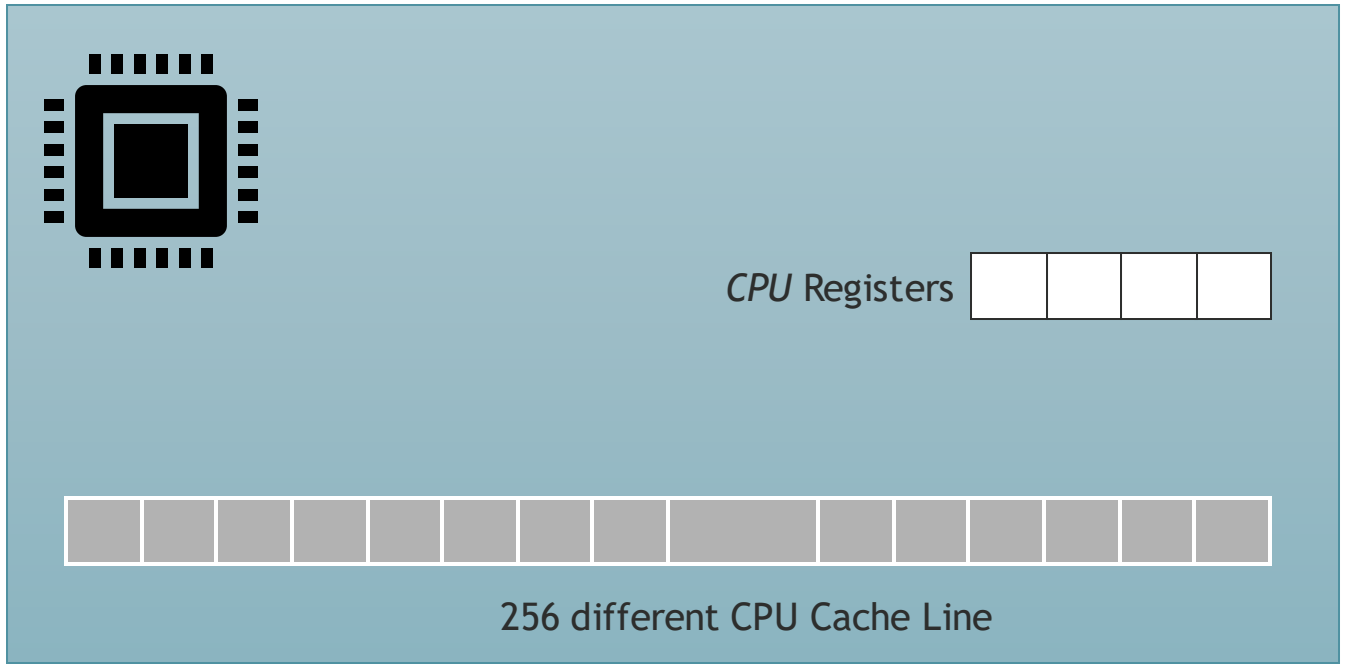
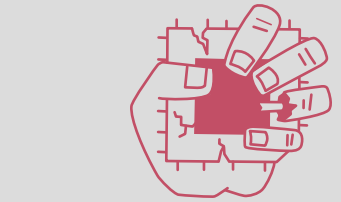




2018: Meltdown Attack?



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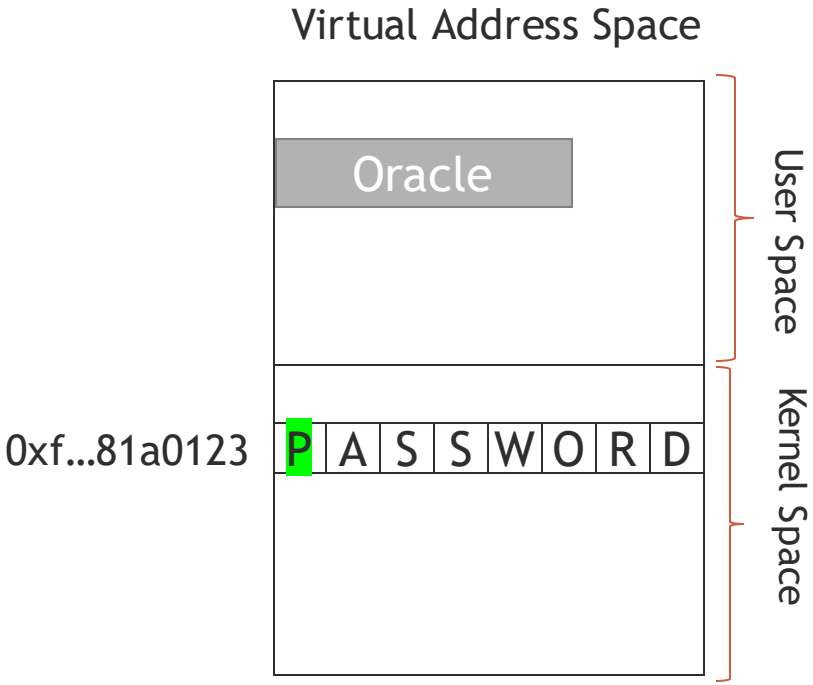
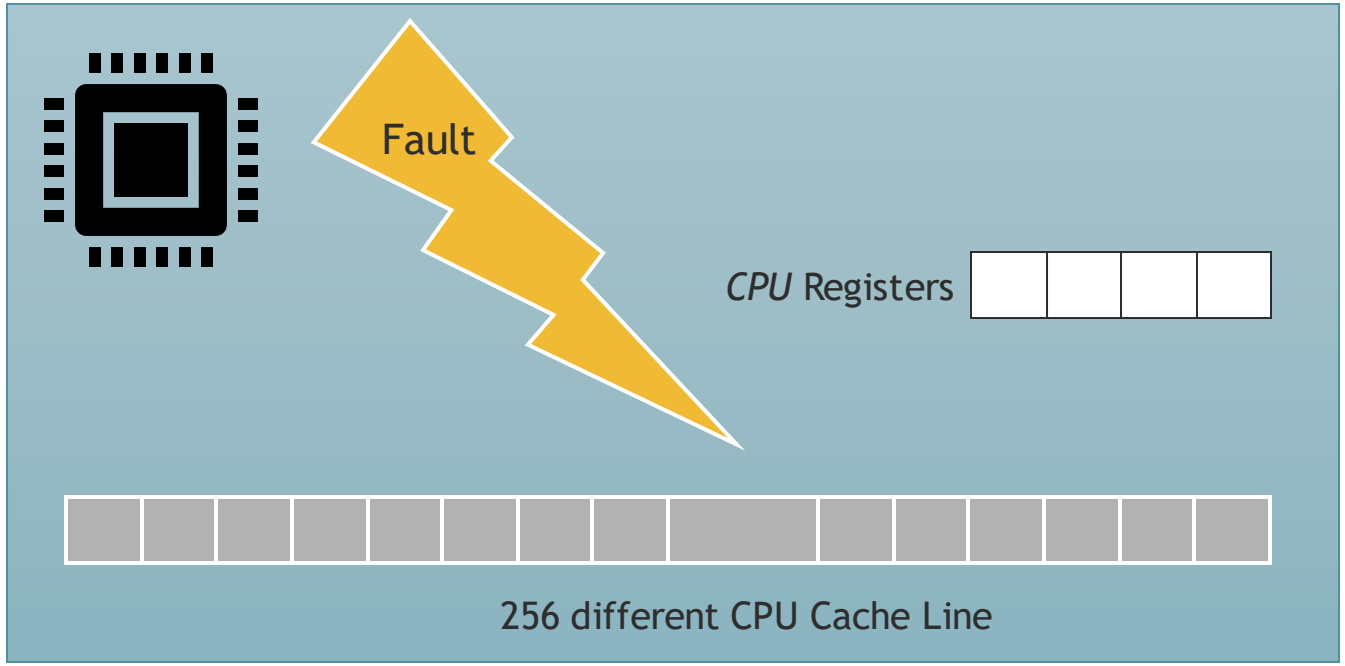
```





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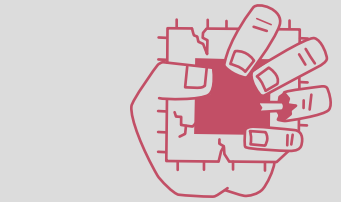

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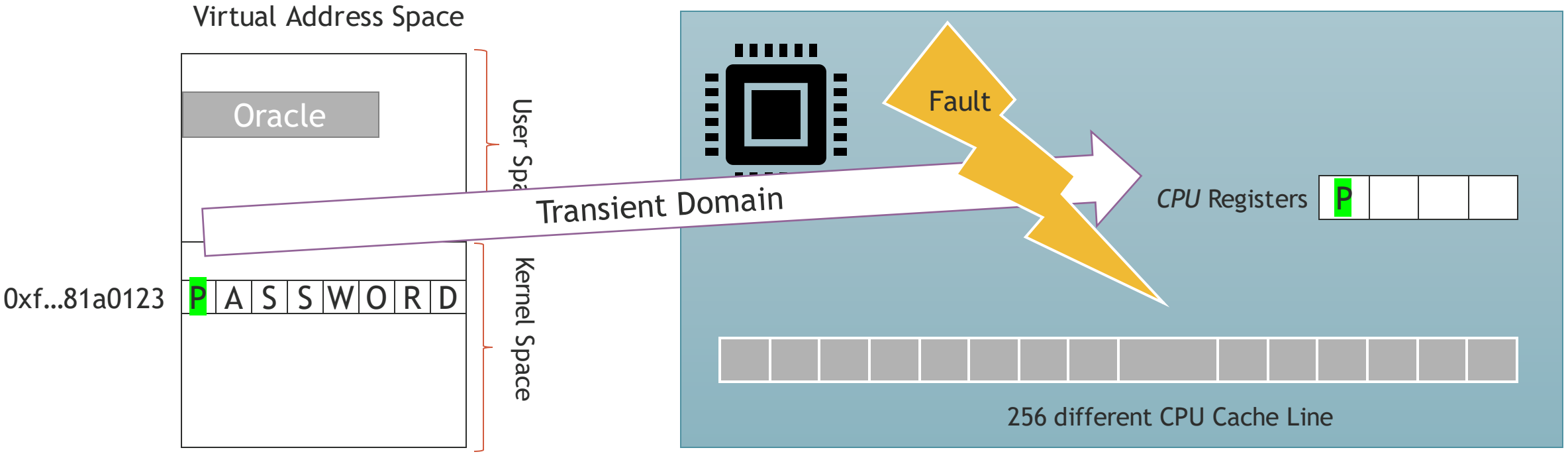
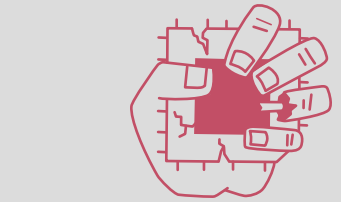


2018: Meltdown Attack?



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char secret = *(char *) 0xffffffff81a0123;
char x = oracle[secret * 4096];
```
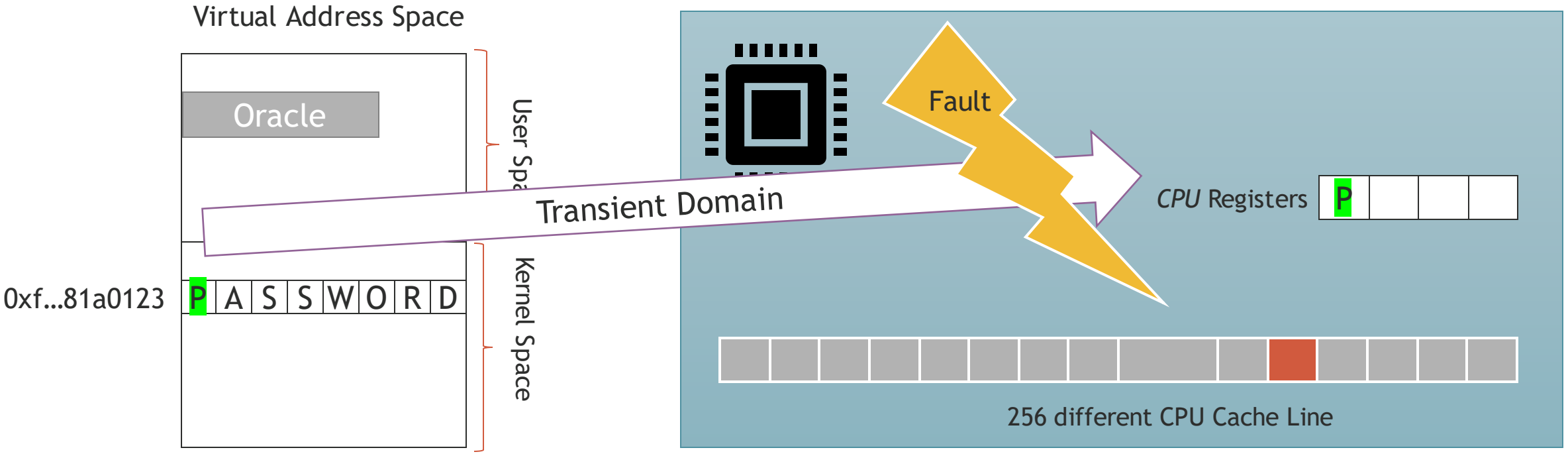
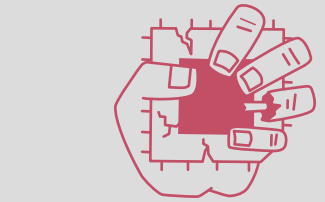



2018: Meltdown Attack?



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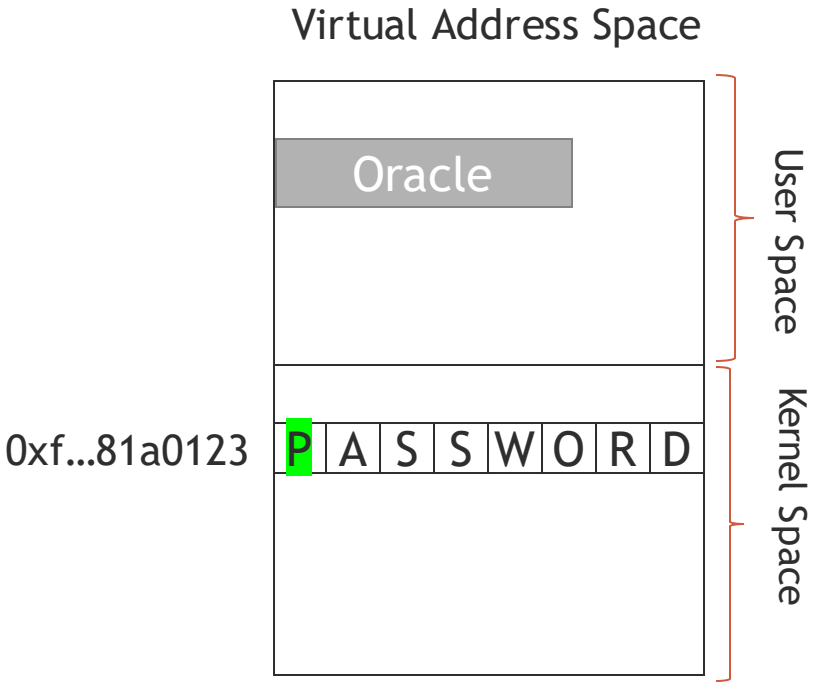
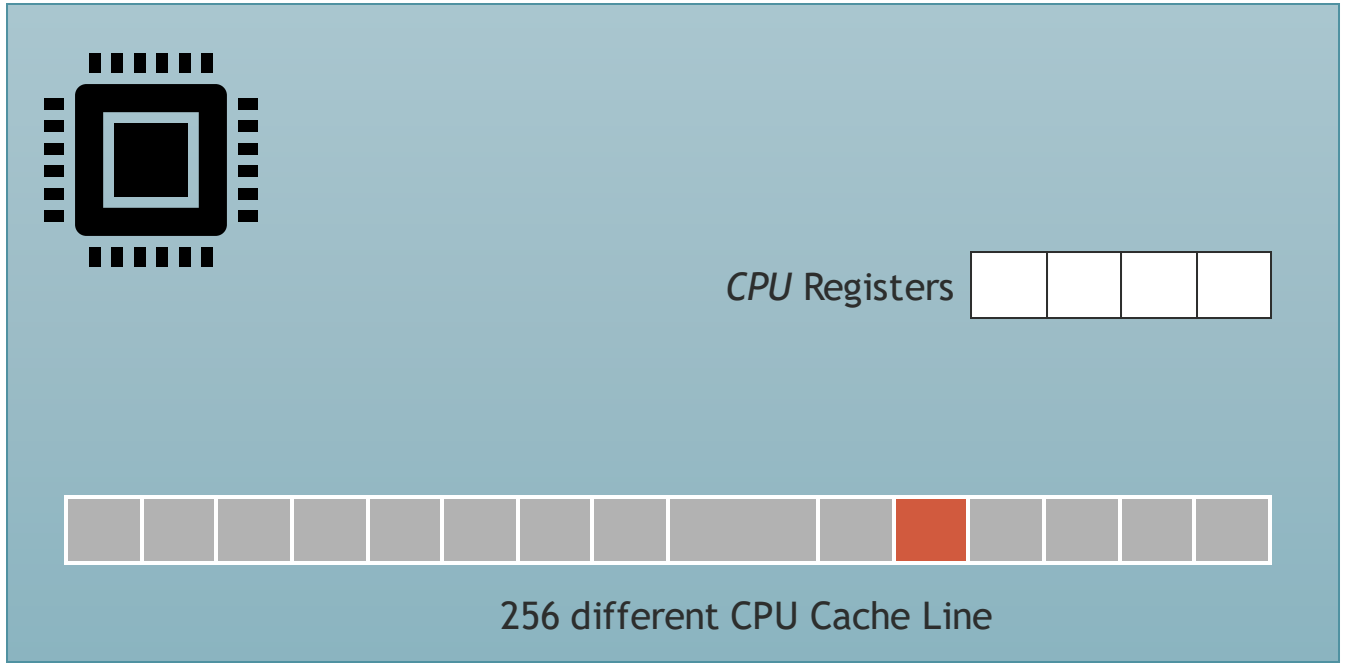
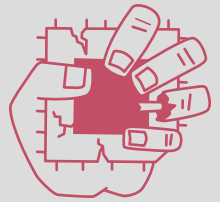




2018: Meltdown Attack?



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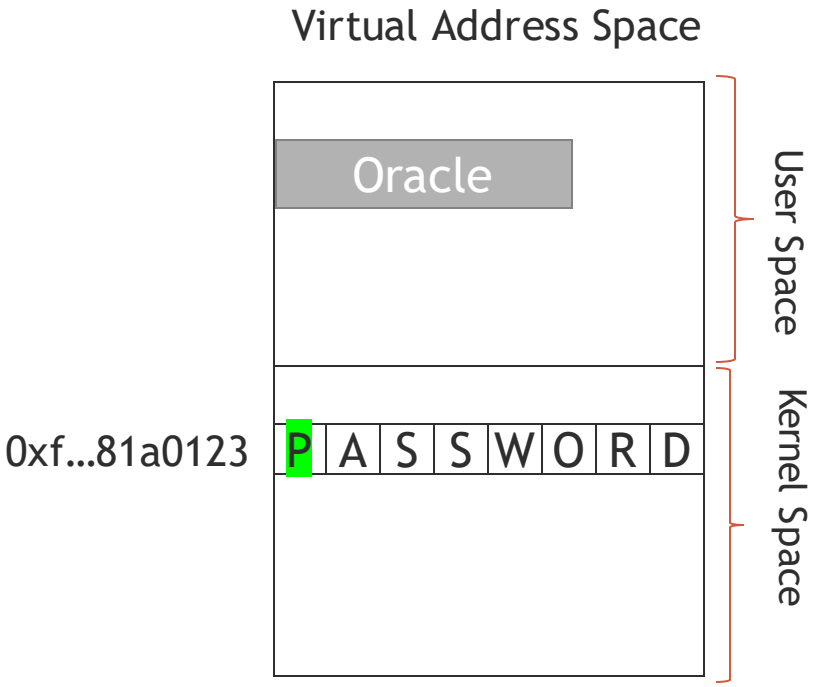
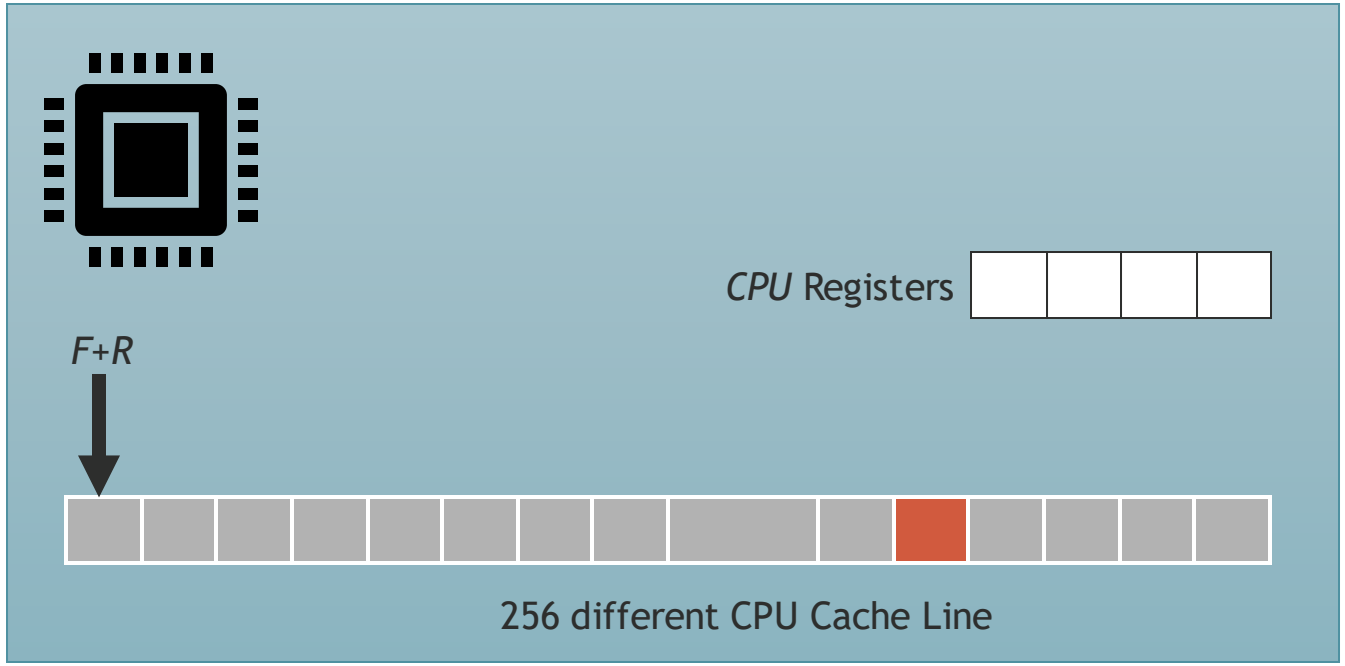
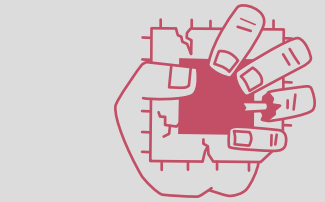




2018: Meltdown Attack?



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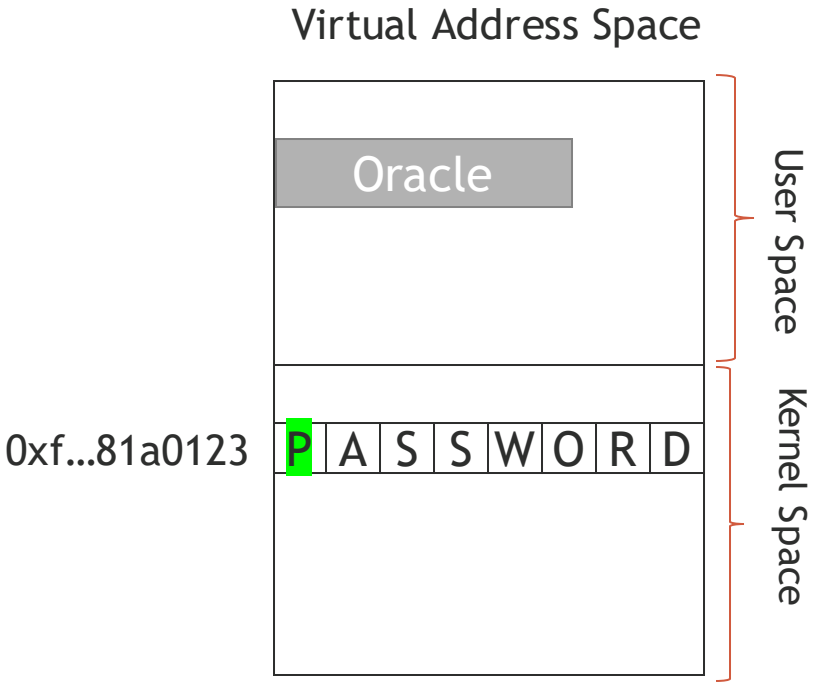

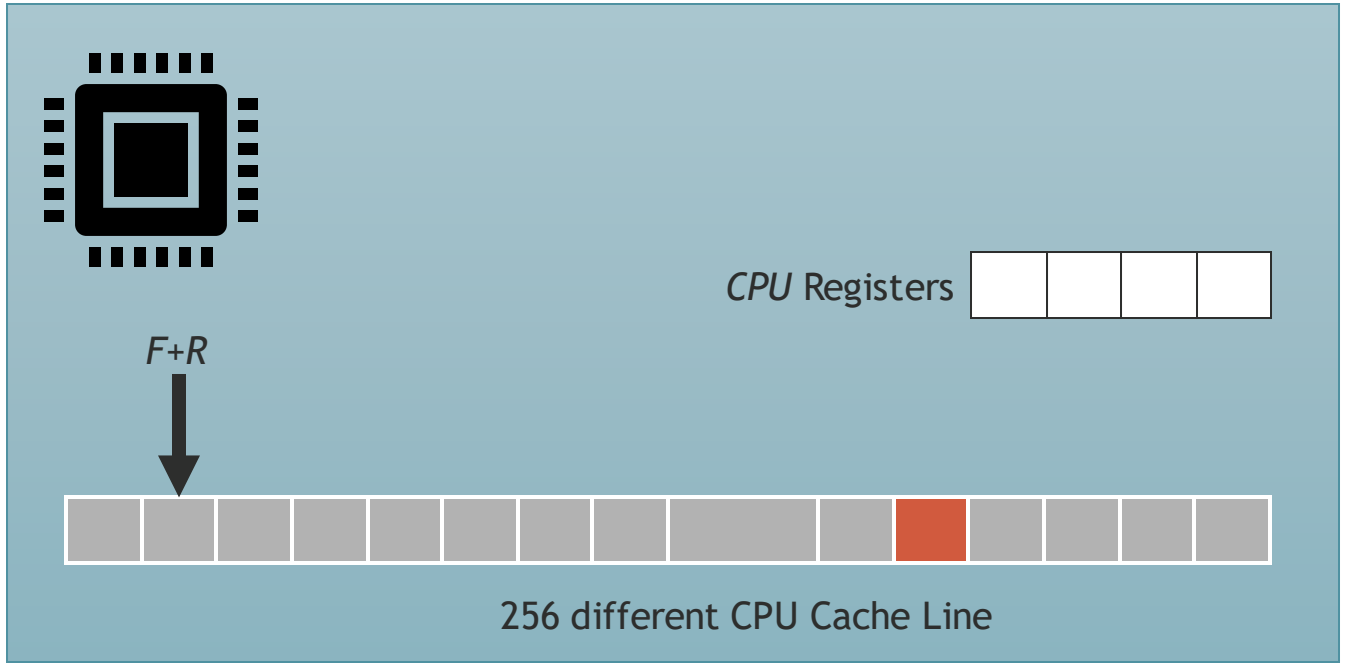

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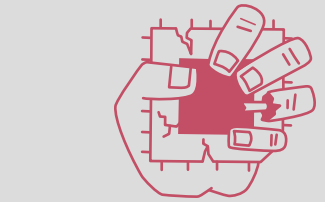

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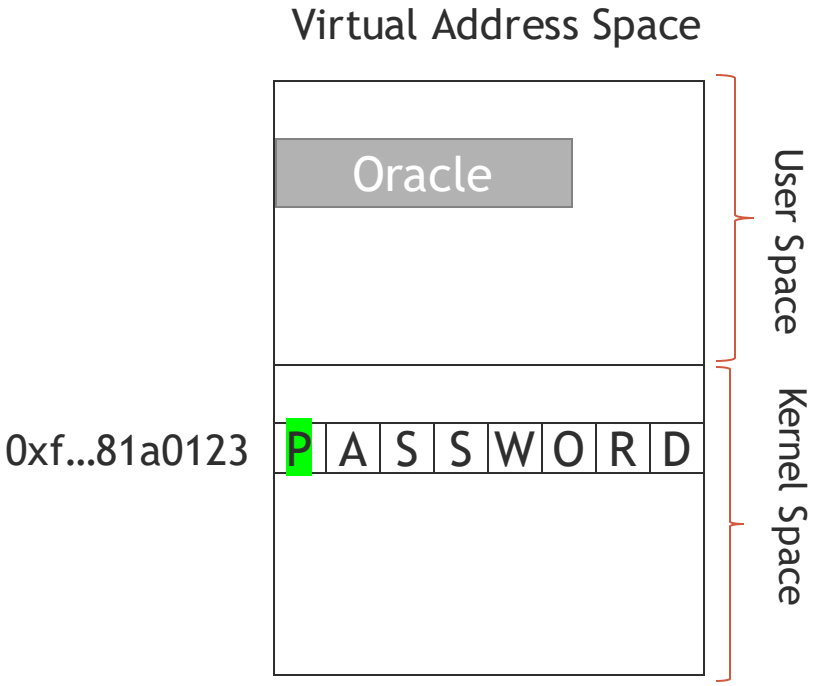
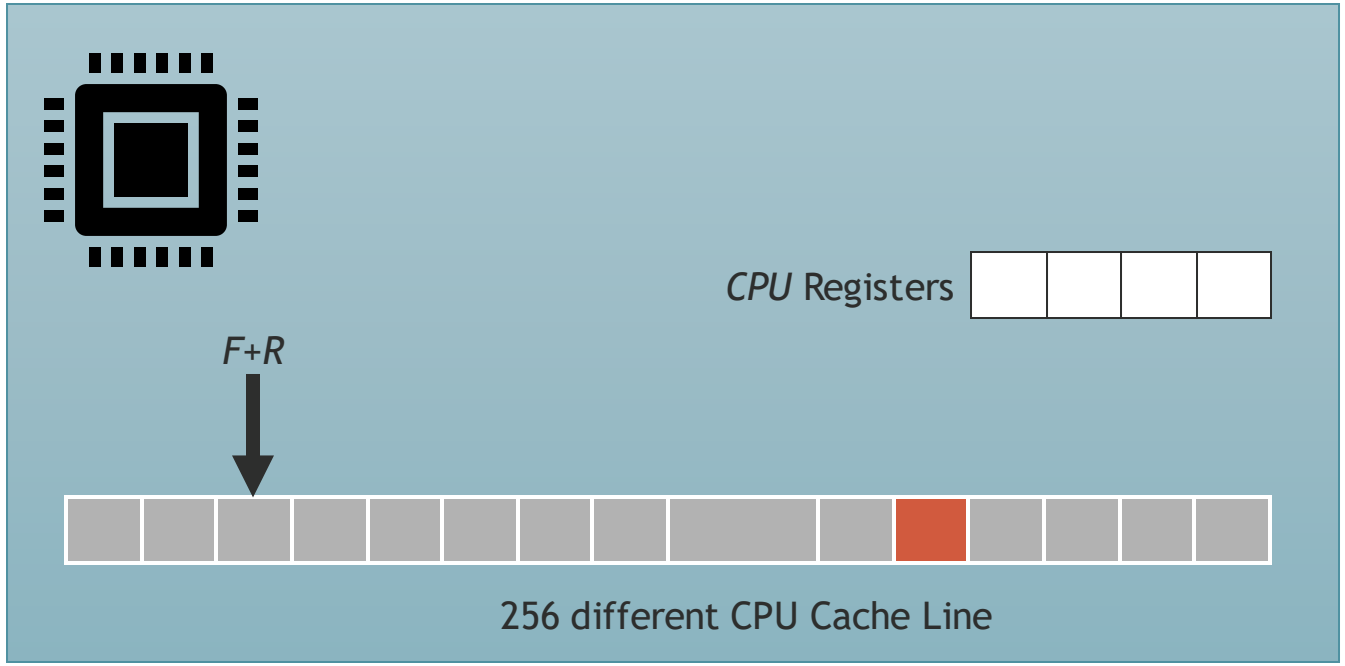
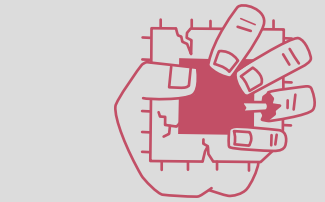




2018: Meltdown Attack?



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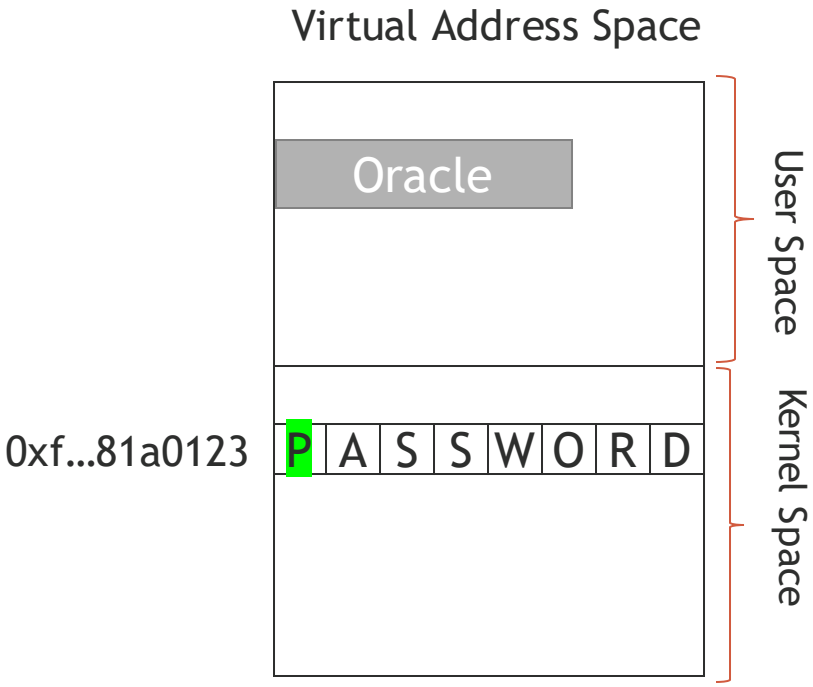
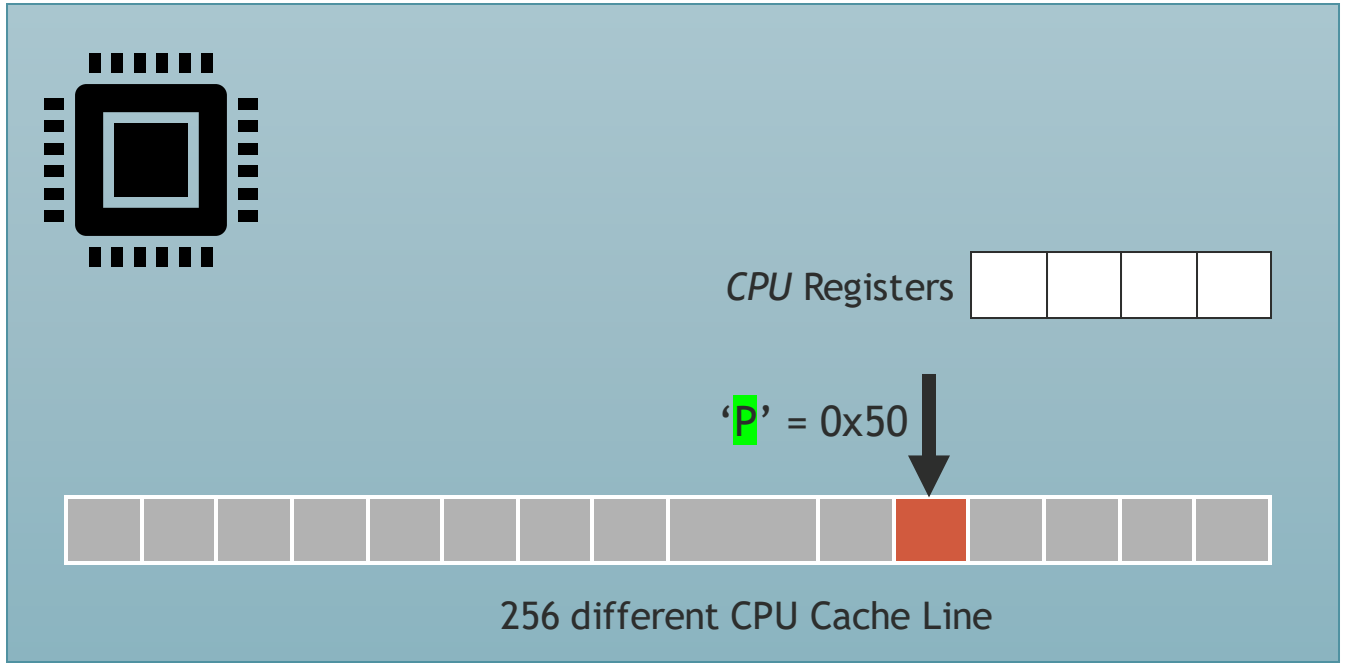
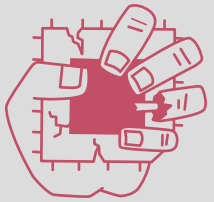




Meltdown-style Attacks !!!

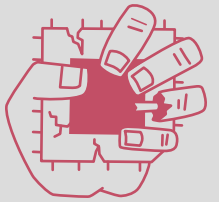


- Can we do Meltdown with other faults/microcode-assists?
- Which part of the CPU leak the data?!

- Can we still leak somebody's data?
  - KPTI
  - Meltdown-resistant CPUs, .e.g. Coffee Lake

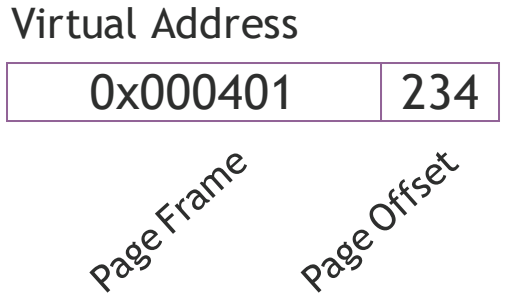

Yes!
Zombie Loads...

ZombieLoad – How does CPU Work these days?

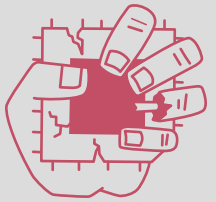


```
mov 0x401234, %rsi

mov (%rsi), %rax
```



ZombieLoad – How does CPU Work these days?



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mov 0x401234, %rsi

mov (%rsi), %rax
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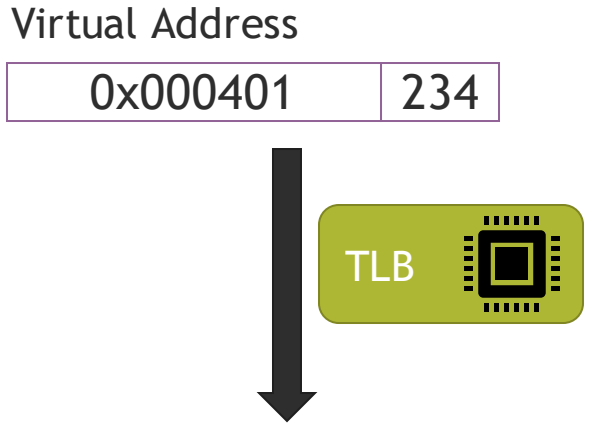

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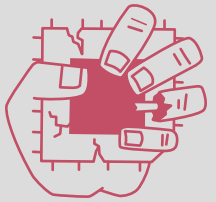

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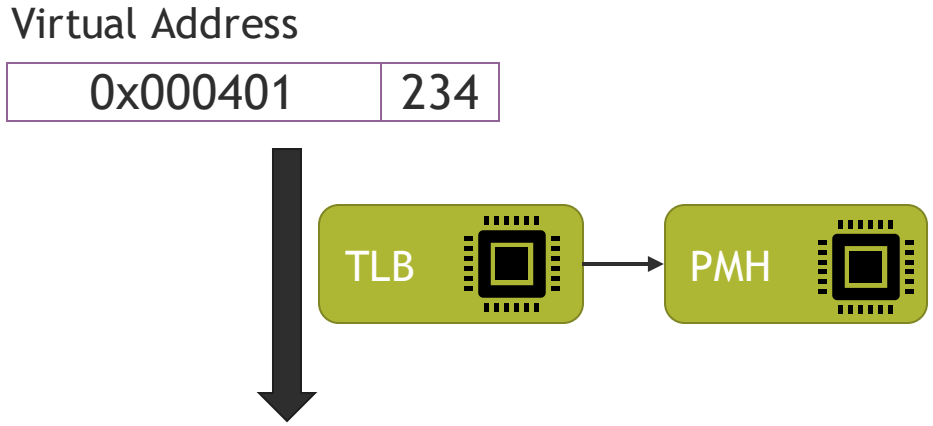

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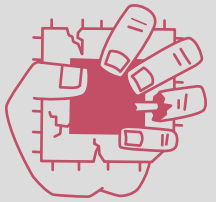

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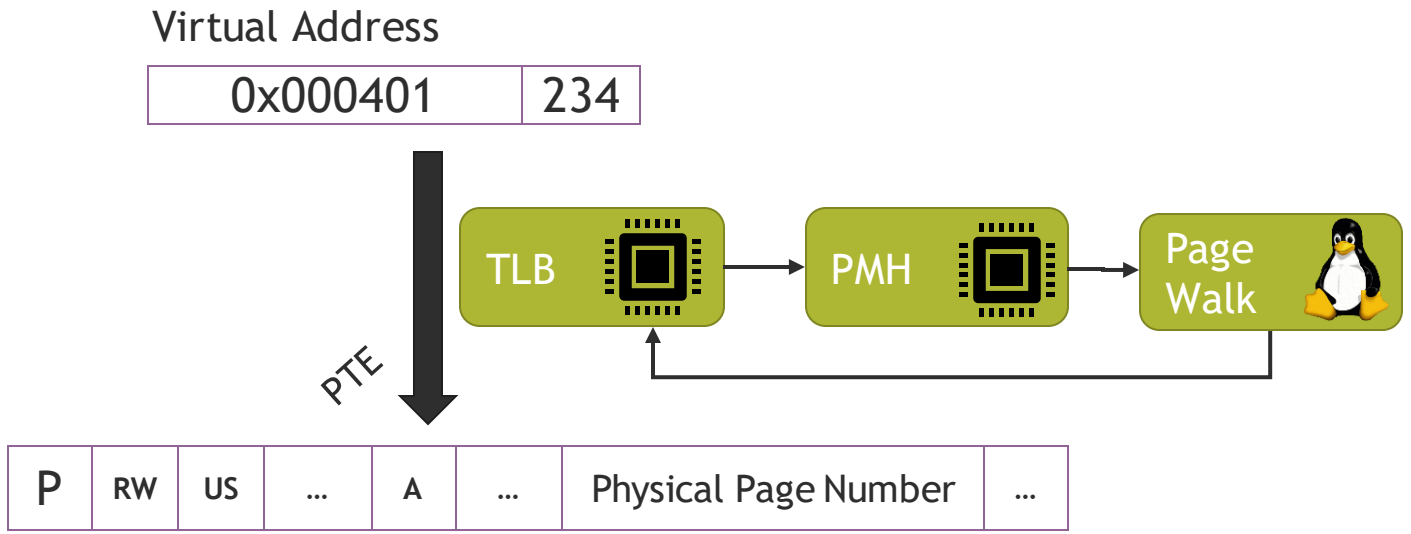

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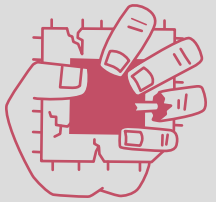

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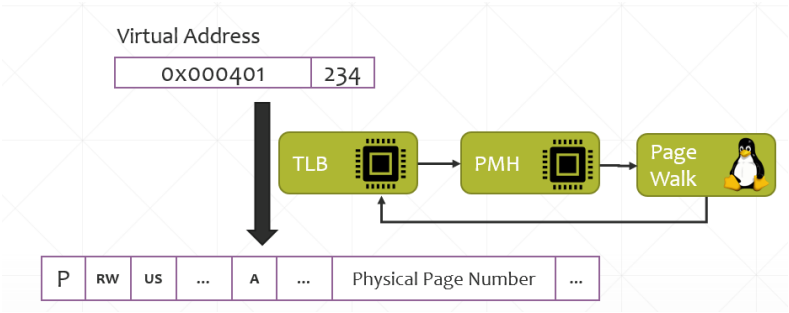

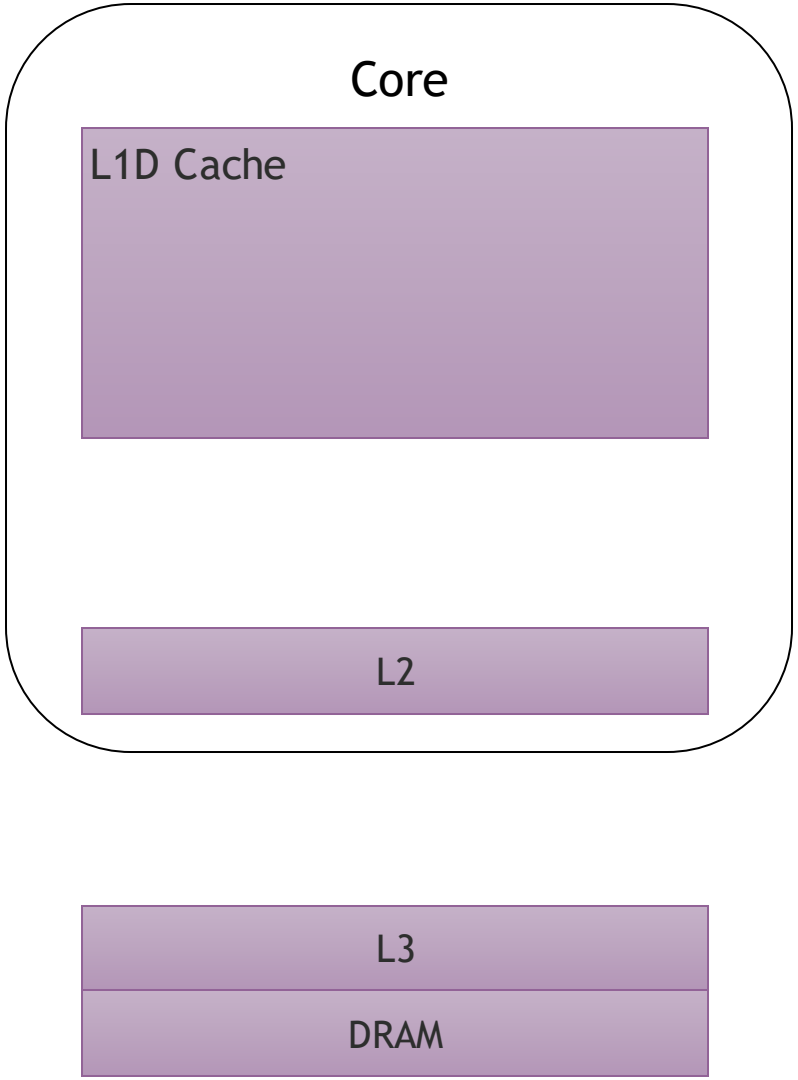

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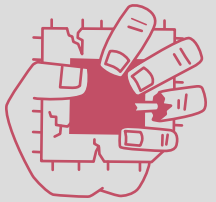

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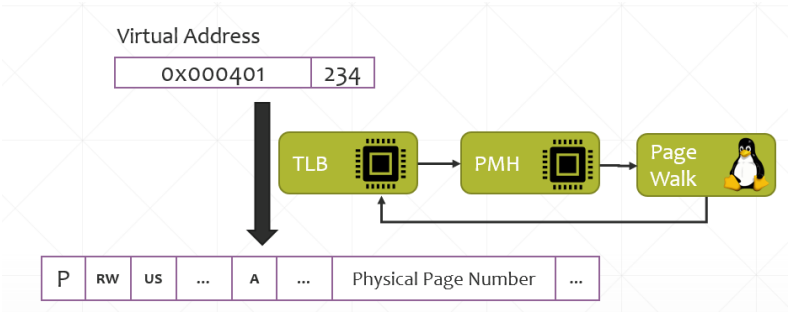

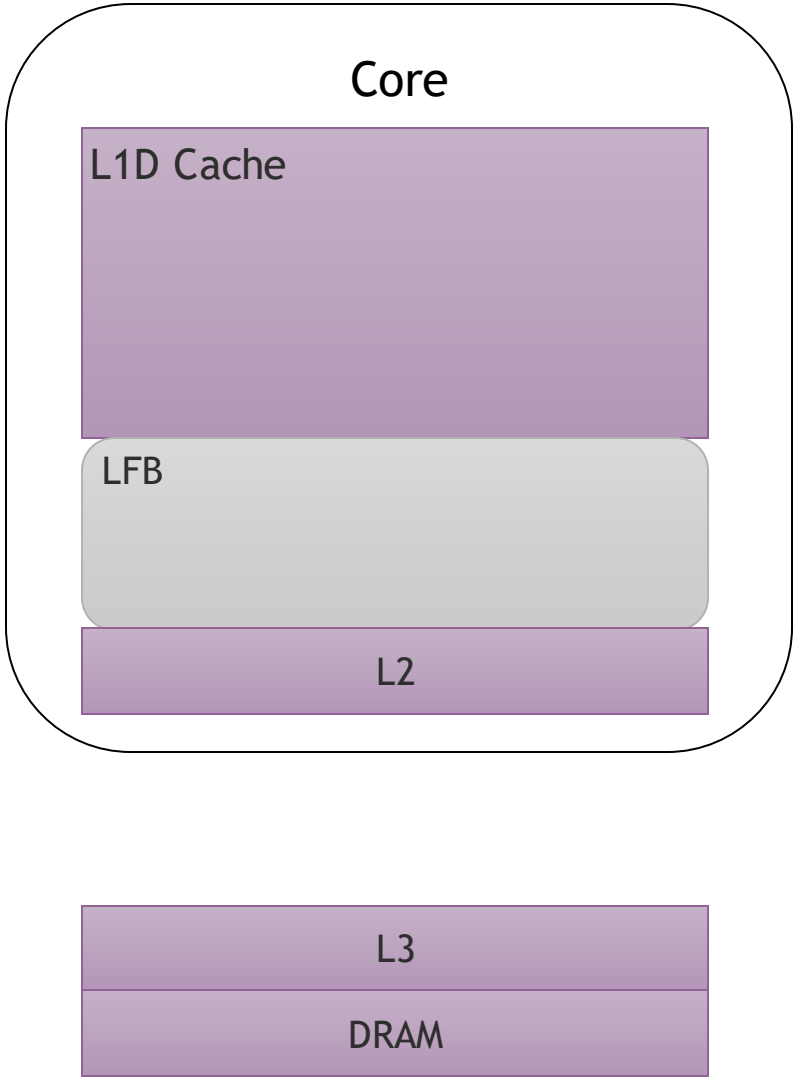

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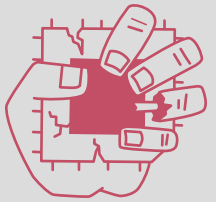

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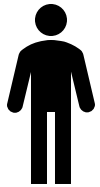

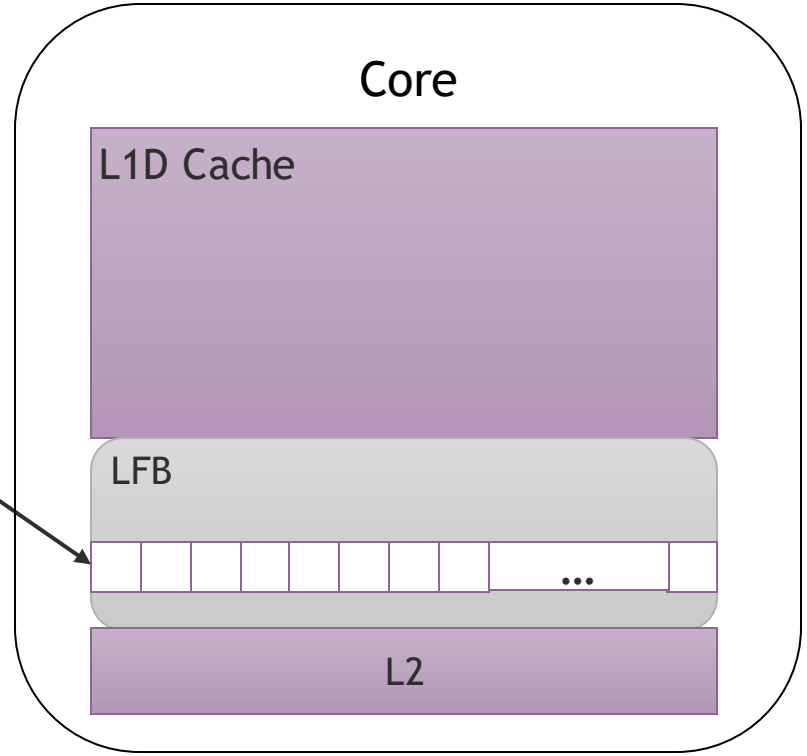

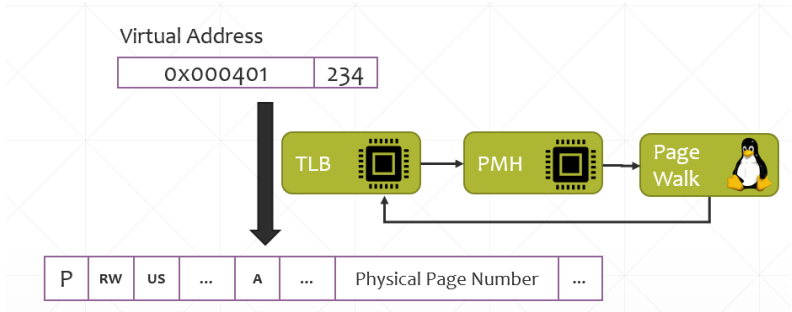

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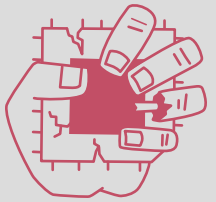

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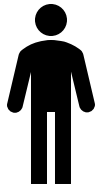

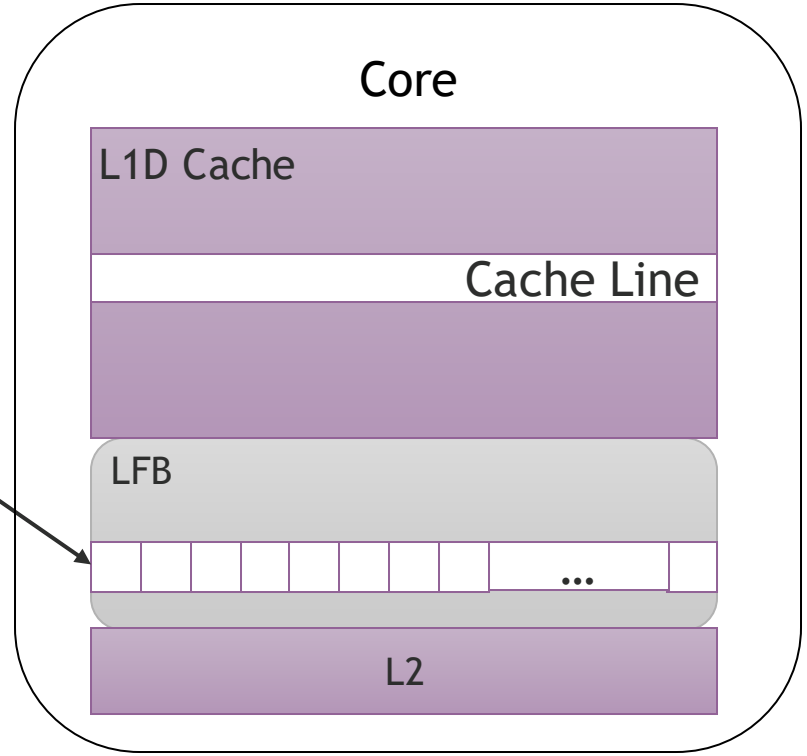

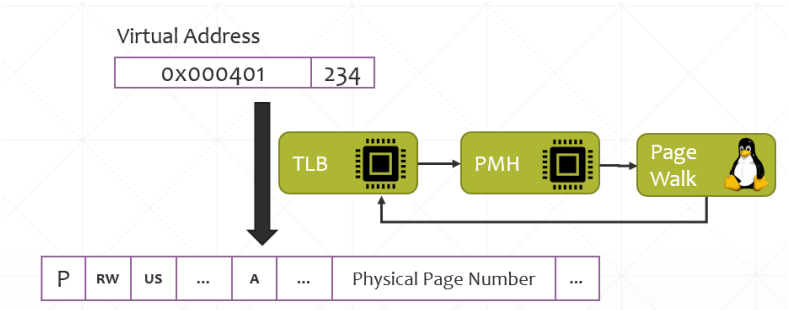

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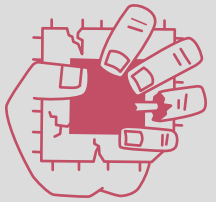

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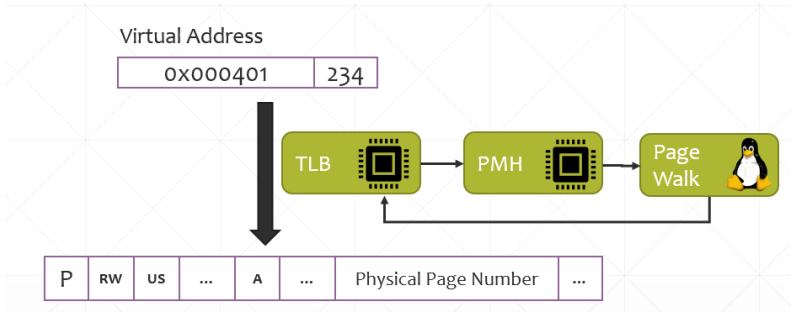

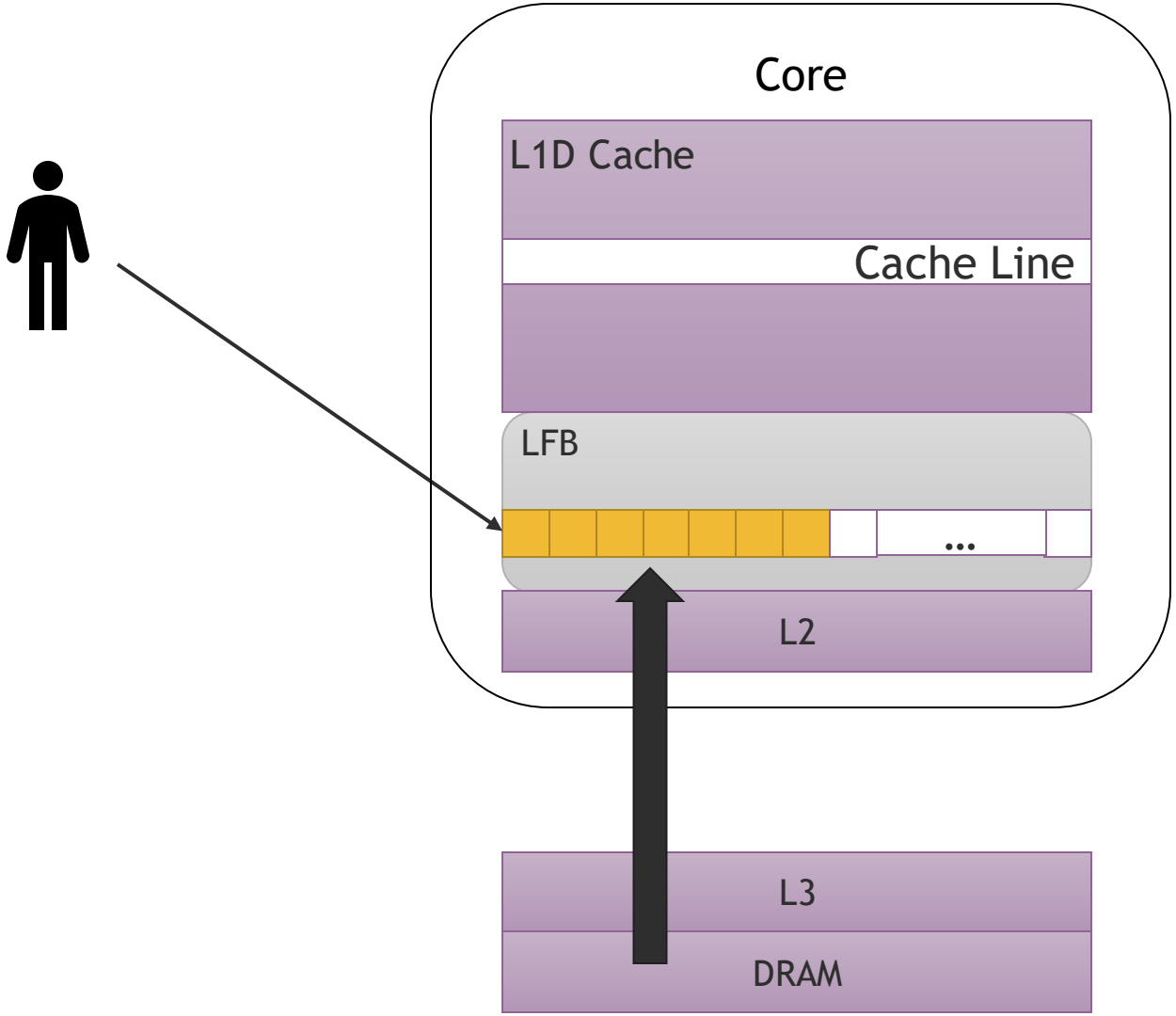

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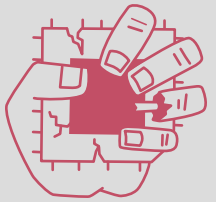

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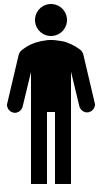
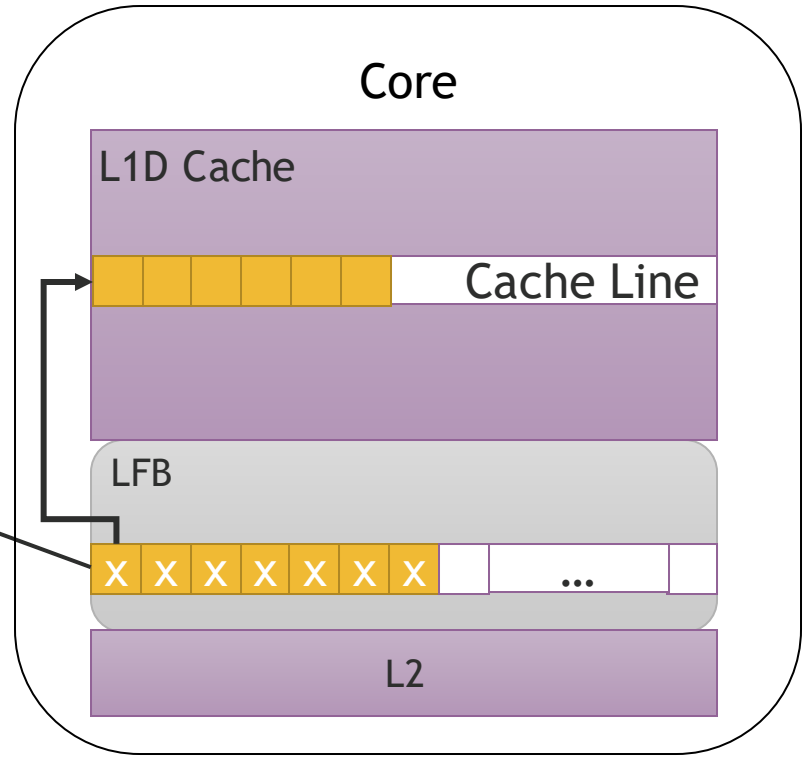
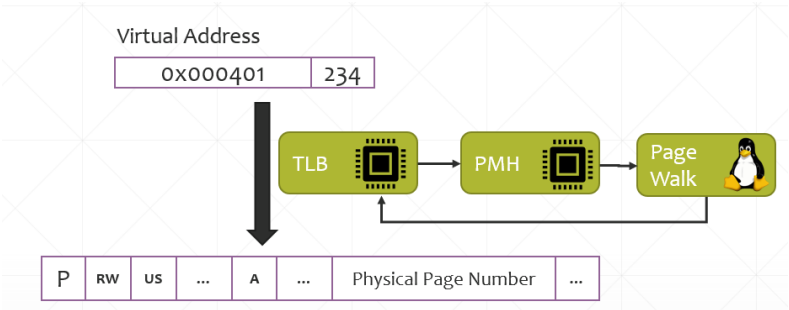
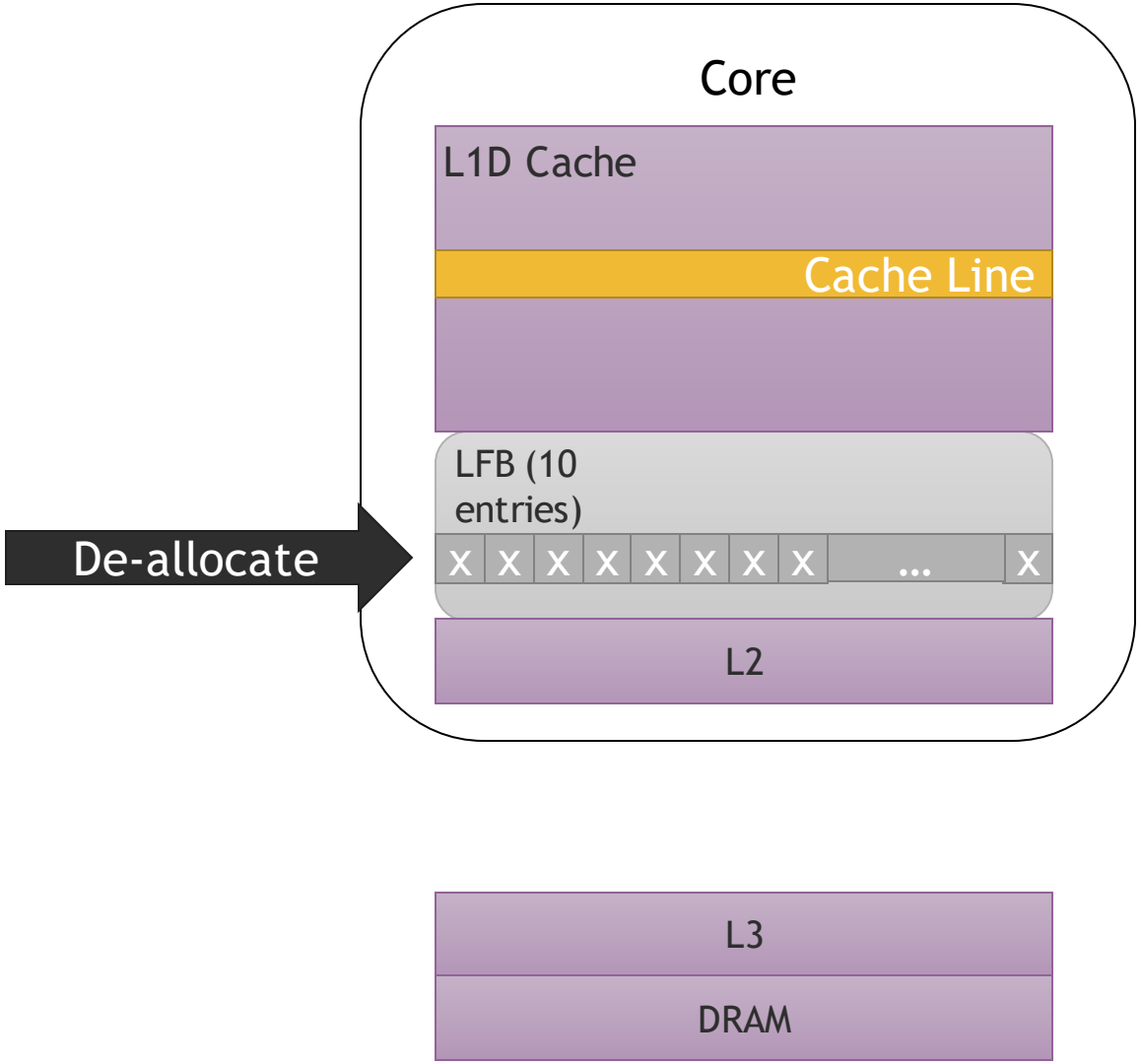






ZombieLoad Attack !?!



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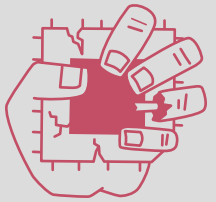
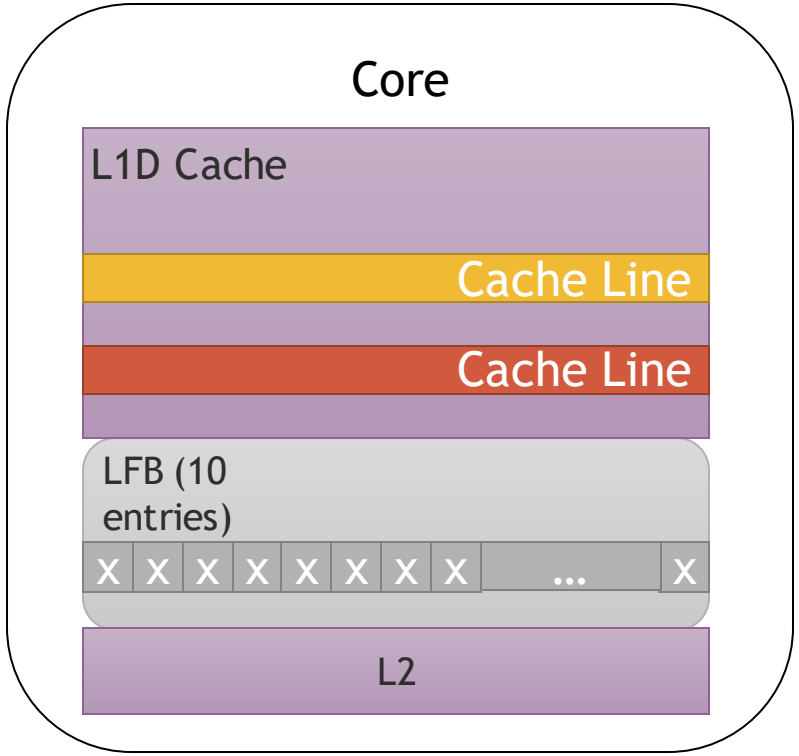
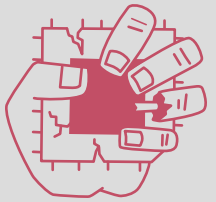


P	RW	US	…	A	…	Physical Page Number	…

```
char secret = *(char *) 0xffffffff81a0123;
```



ZombieLoad Attack !?!



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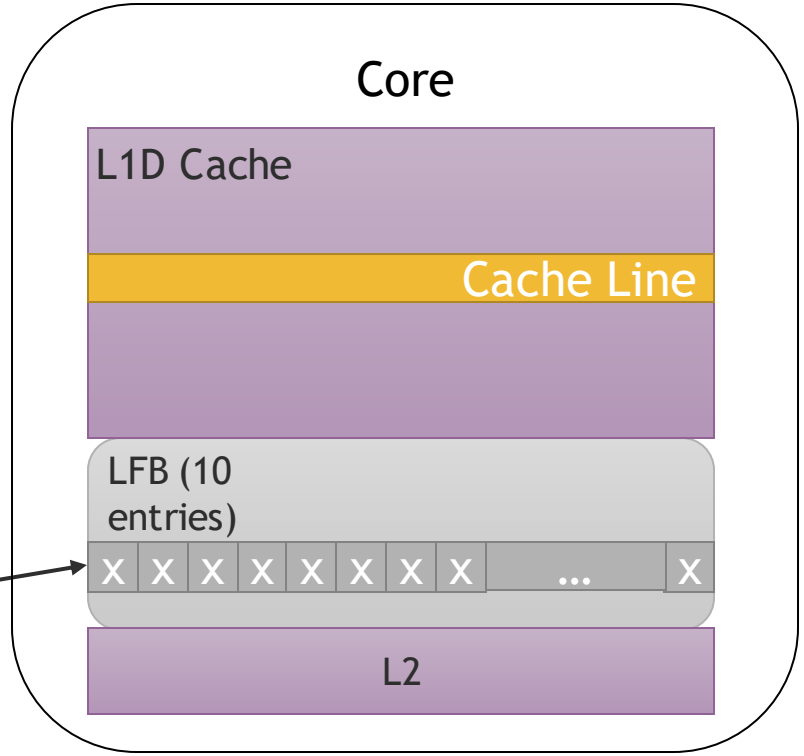


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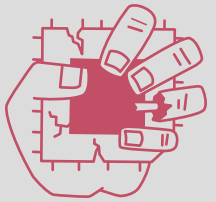

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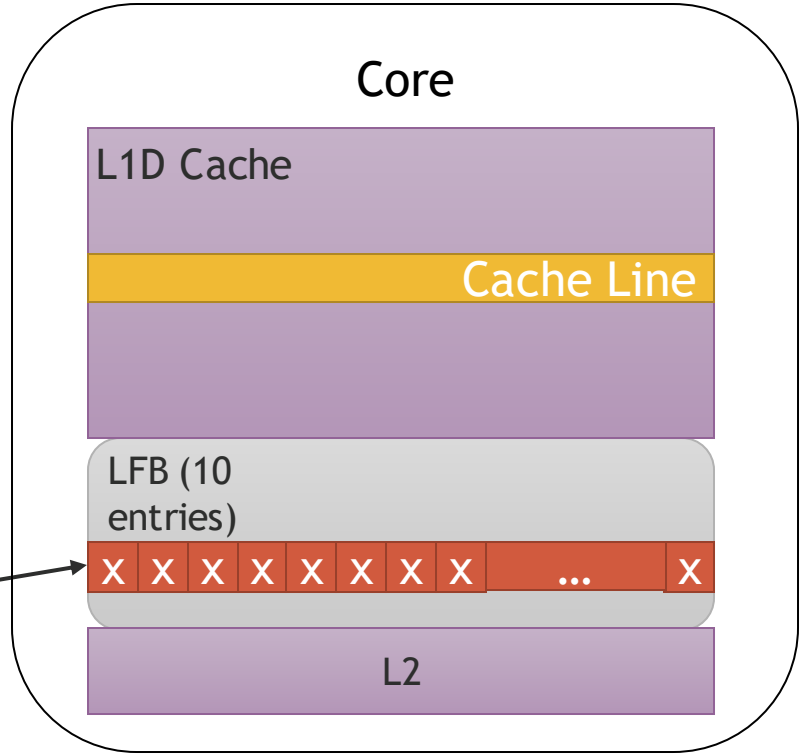


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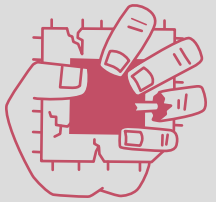

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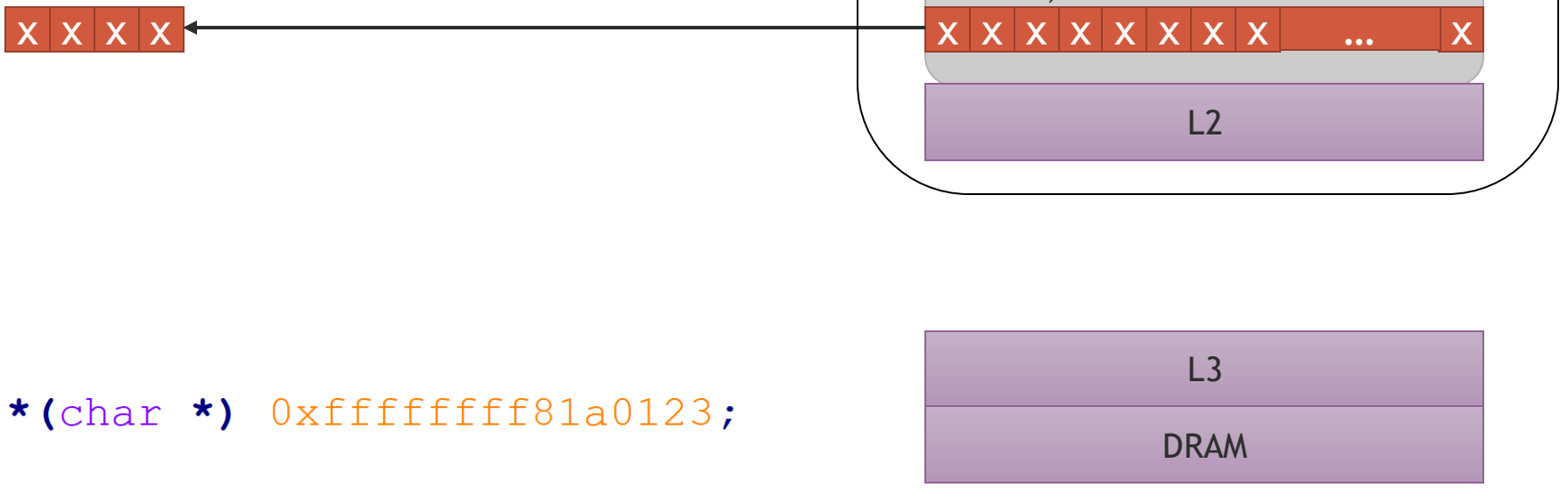

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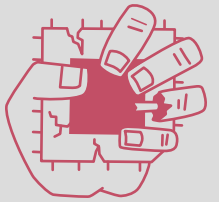

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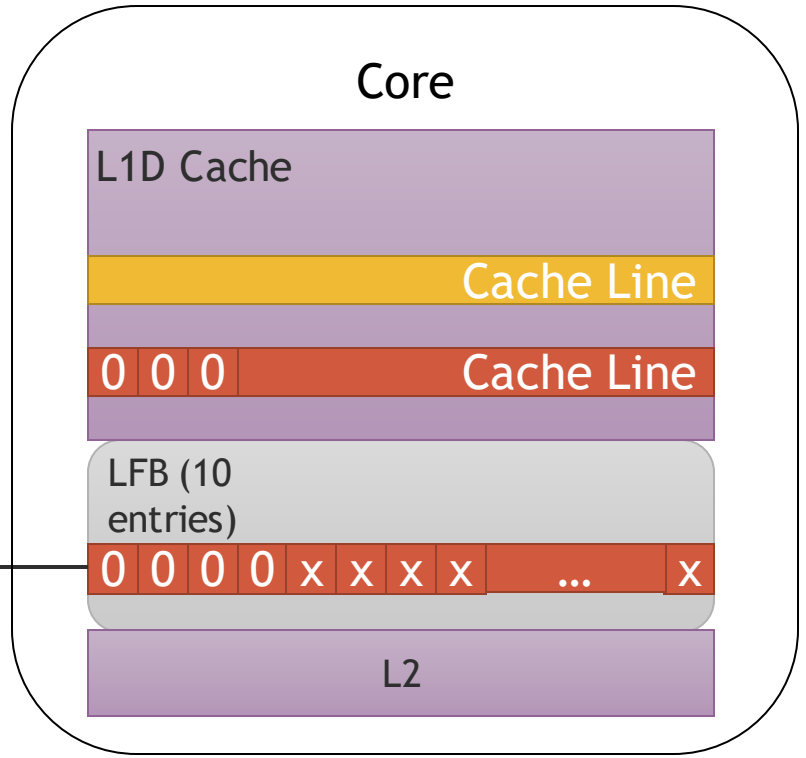
x x x x

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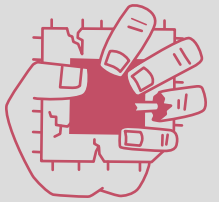
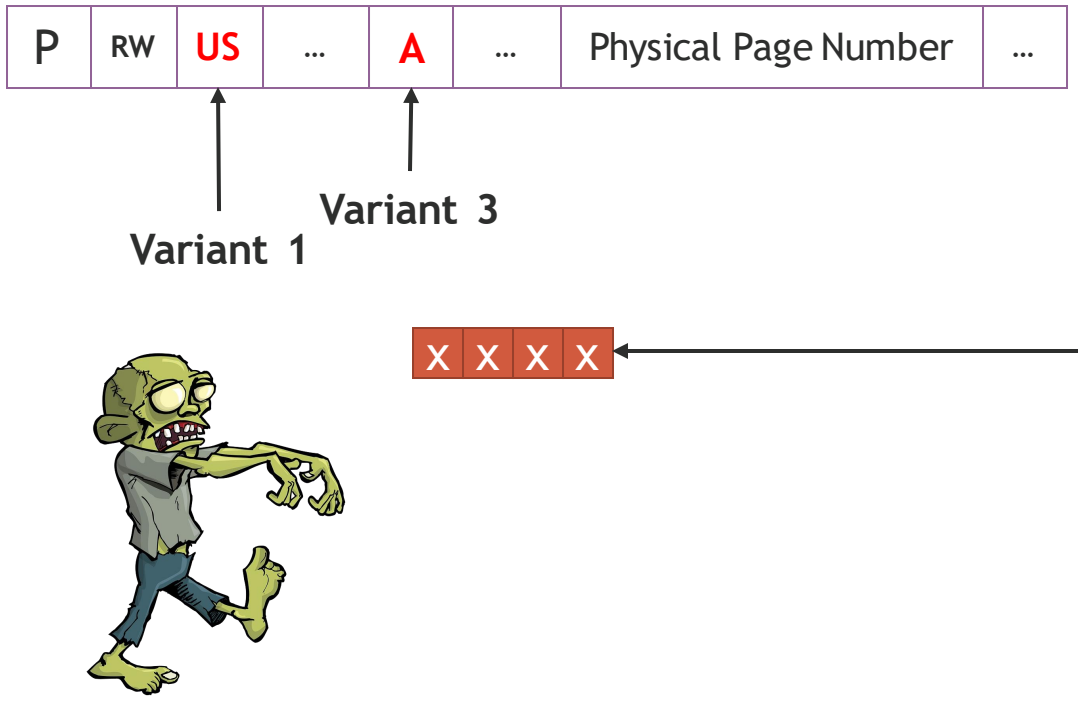
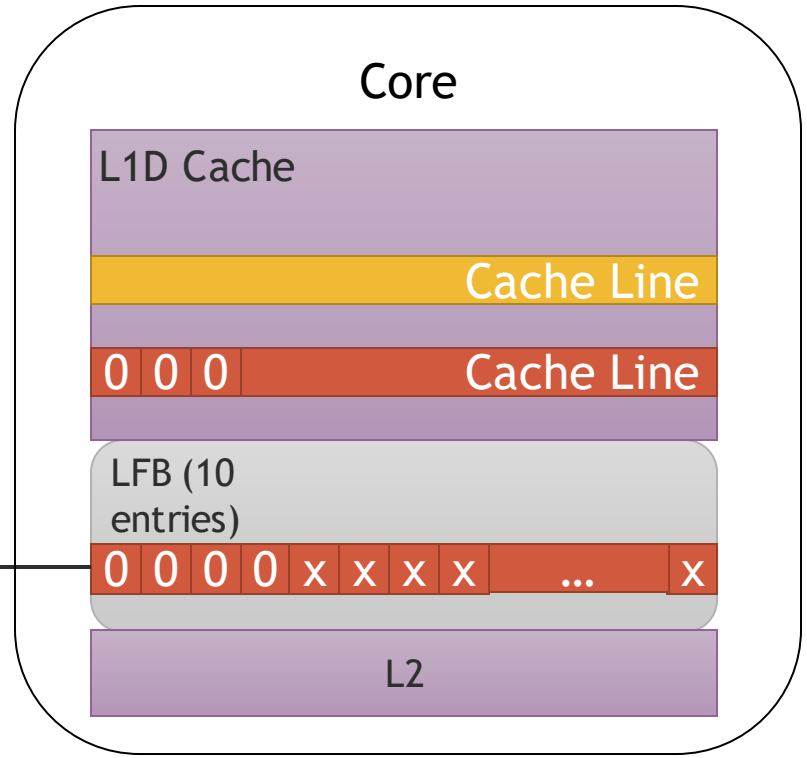
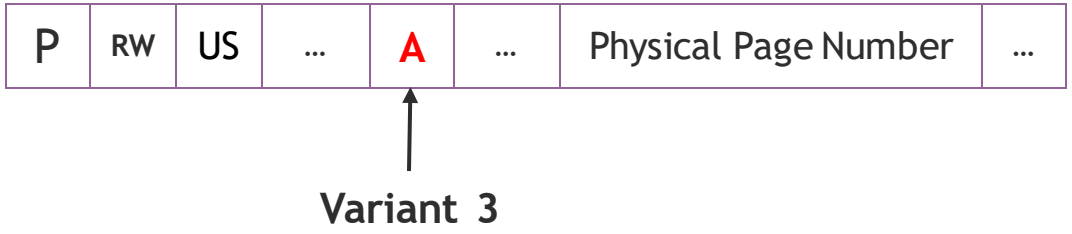






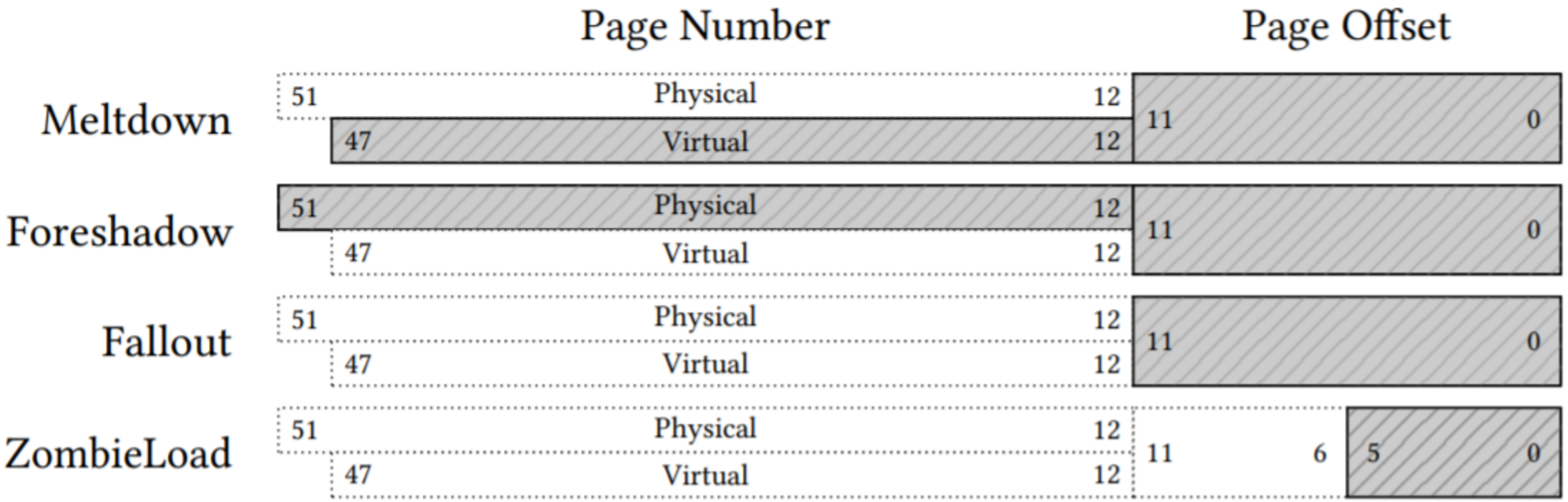
ZombieLoad – Microcode Assist on '*A*' Bit



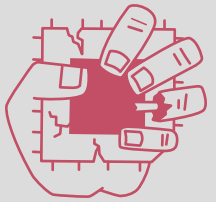
- **Access Bit**
  - **CPU** tells → **OS**: A page has been accessed by setting the 'A' Bit
  - **OS** tells → **CPU:** A page has not been accessed (just allocated) by clearing the bit

- 'A' Bit Microcode Assist
  - Microcode Assists: The CPU executes an internal event handler to service complex instructions/operations
  - The microcode assist flushes the pipeline.
  - Intel CPUs set 'A' bit using a microcode assist

ZombieLoad VS. other Meltdown-Style Attacks



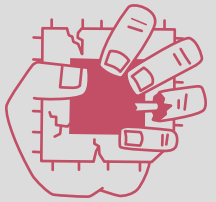
What can we do with this data leakage?



- **Architecturally**
  - Attack across Process Context Switches
  - Attack across Simultaneous Multithreading (SMT) AKA. Intel Hyperthreading

- **Scenarios:**
  - Cross-Process
  - Cross-VM
  - Intel SGX

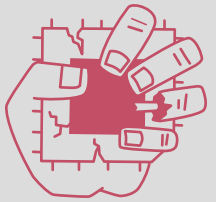
Data Sampling - Domino Attack



- We may leak bytes of data from other unimportant fill buffer entries
- Leak domino bytes to perform error correction

Target Secret				
	1 1 0 1 0 0 1 1	0 1 1 1 1 1 1 1	0 1 1 1 1 1 1 1	…

Data Sampling - Domino Attack



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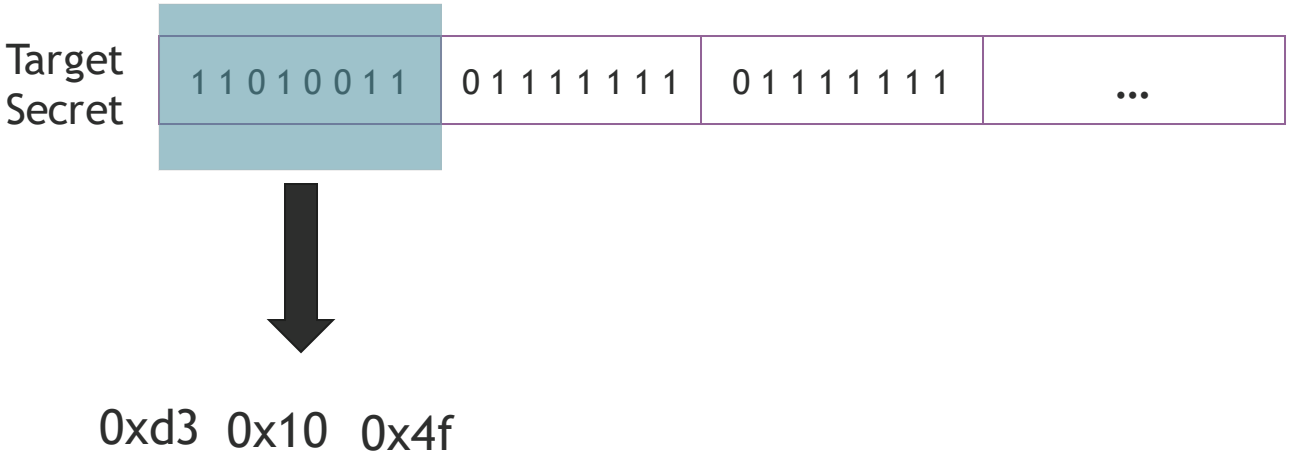

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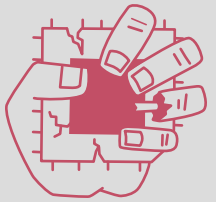

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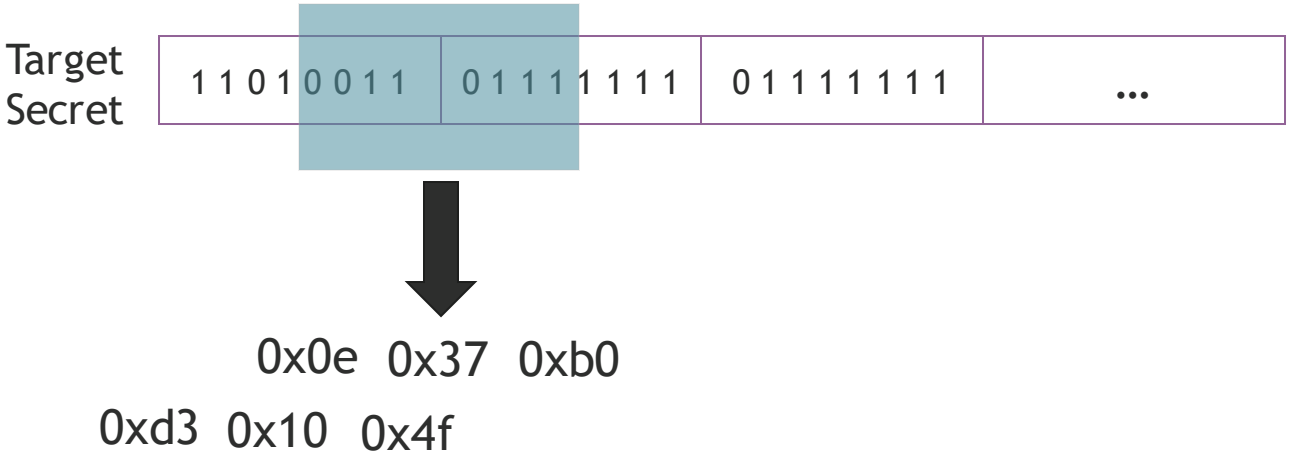

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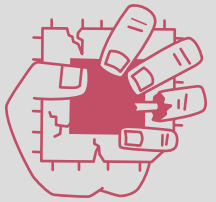

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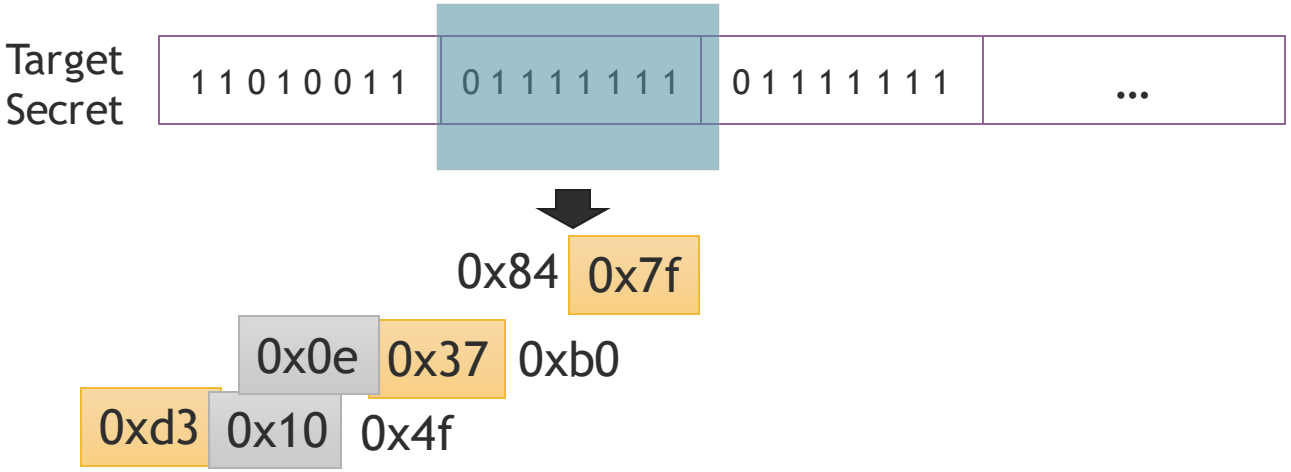

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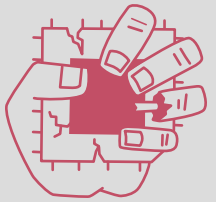

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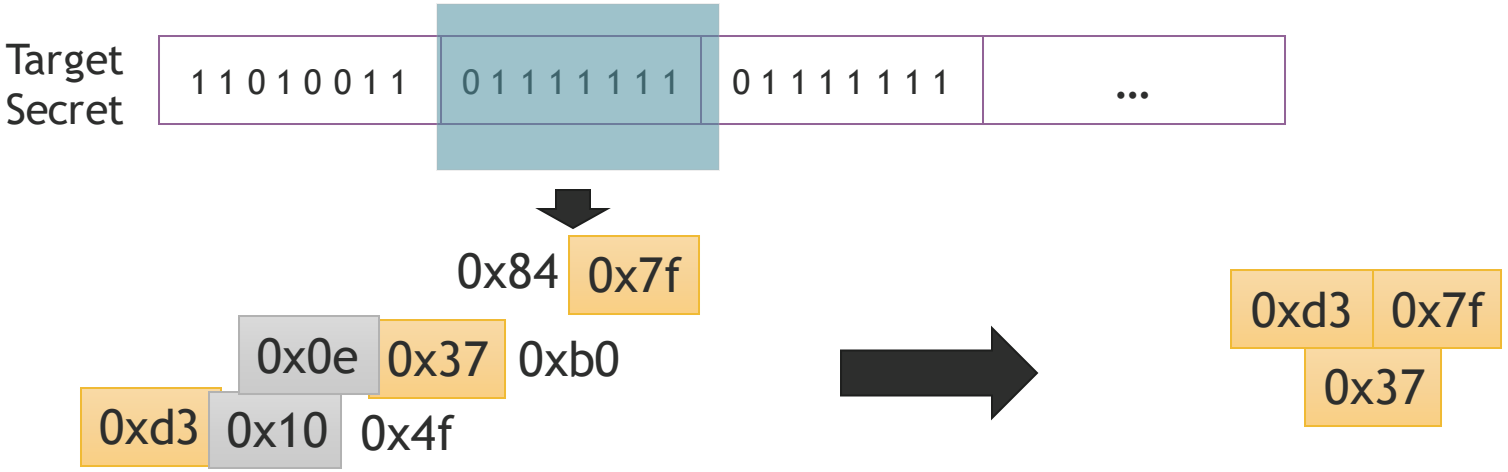
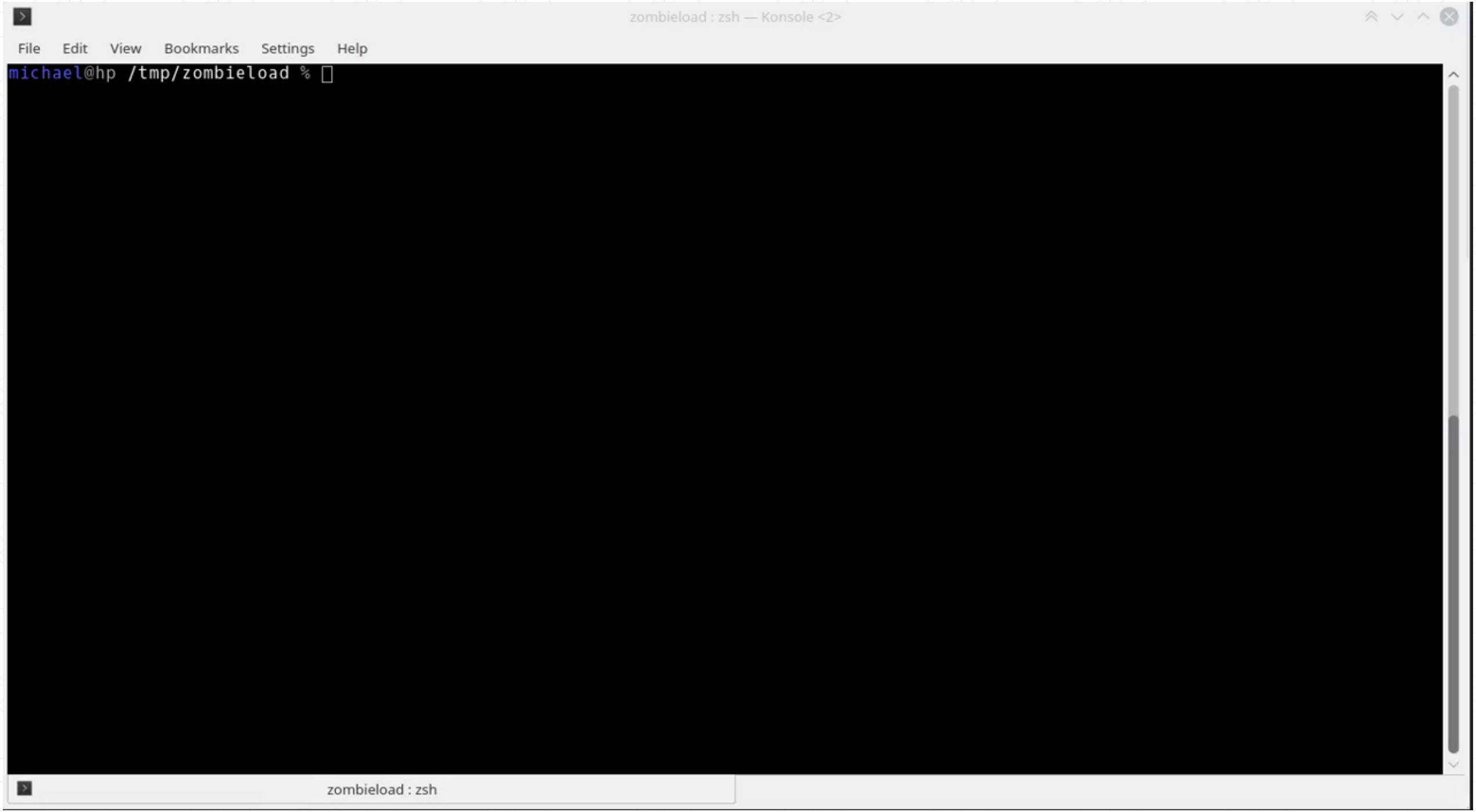
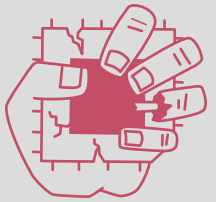



zombieload : zsh — Konsole <2>
File Edit View Bookmarks Settings Help
michael@hp /tmp/zombieload %
zombieload : zsh

Recovering Intel SGX Sealing Key



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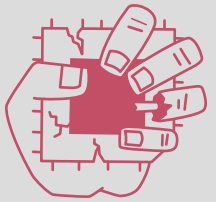

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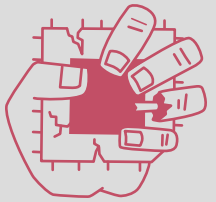

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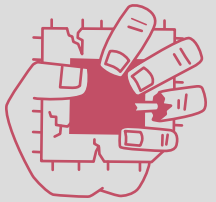

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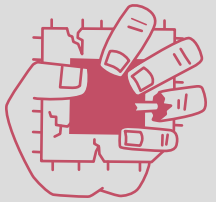

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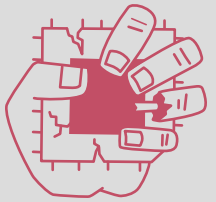

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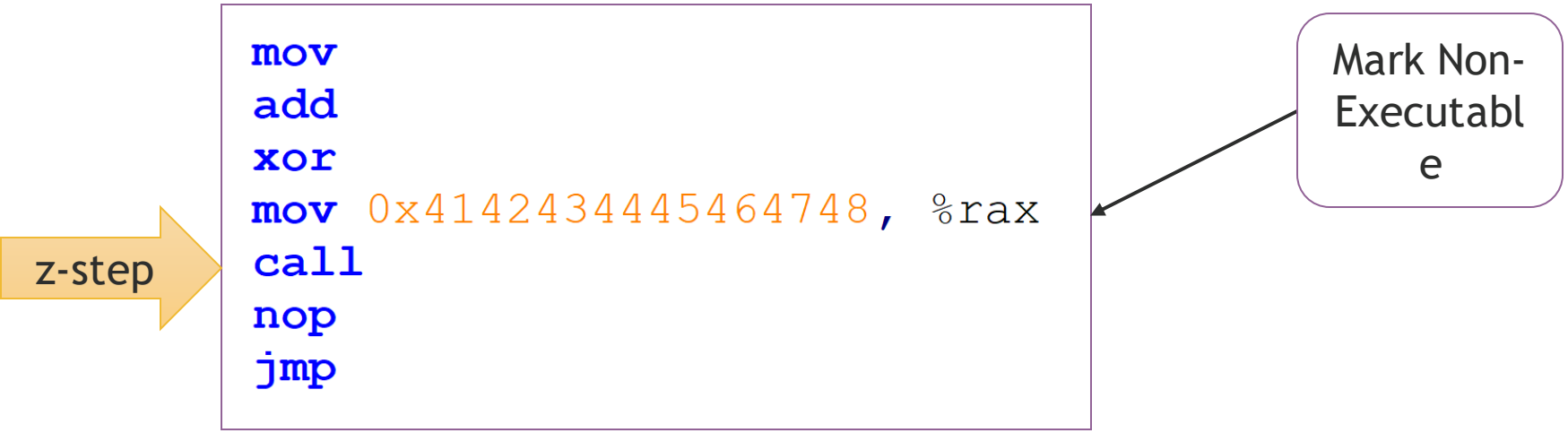

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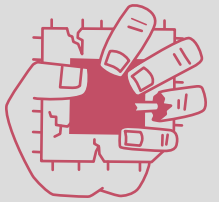

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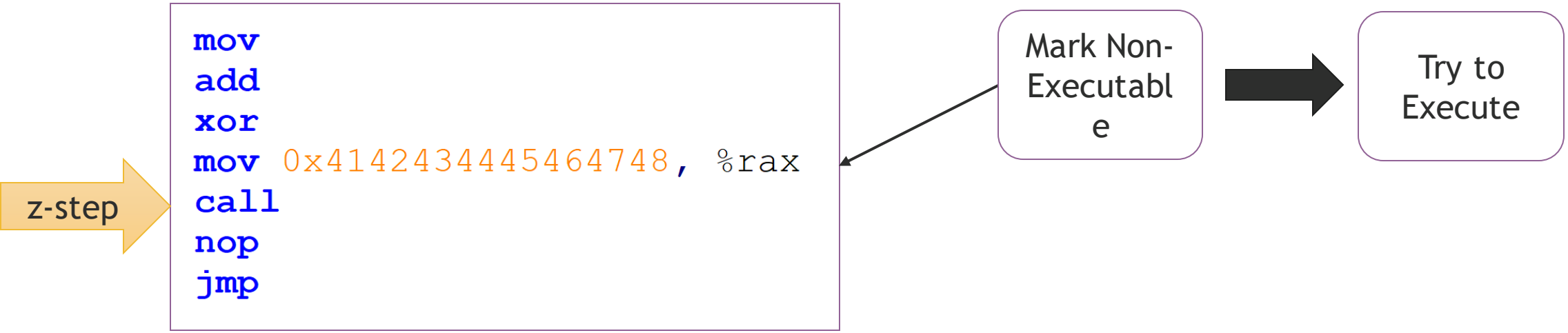

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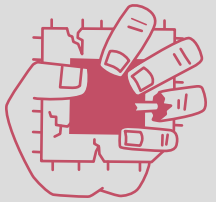

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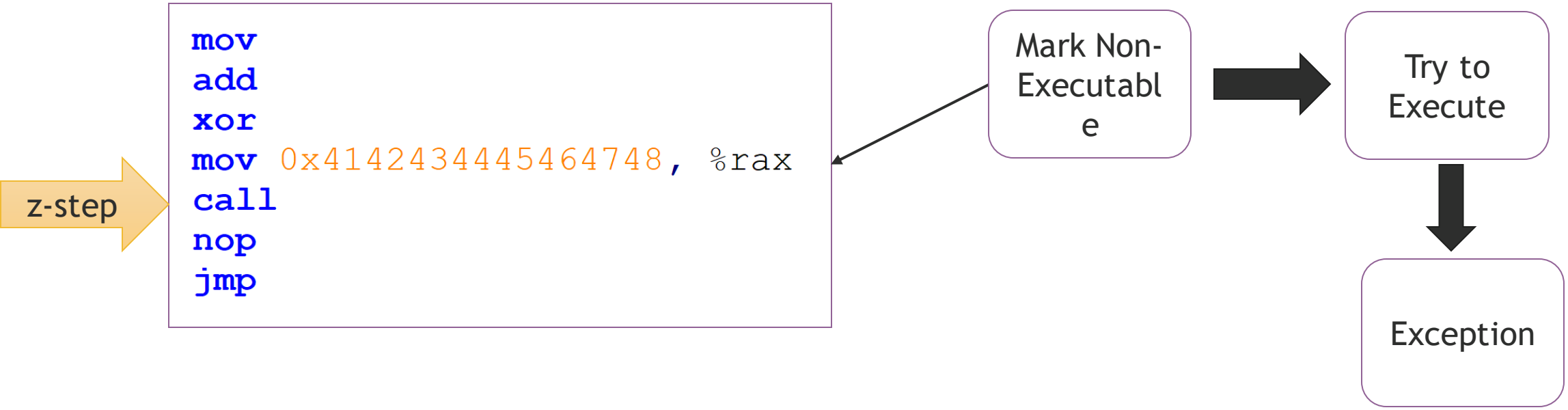

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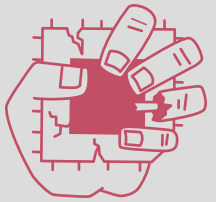

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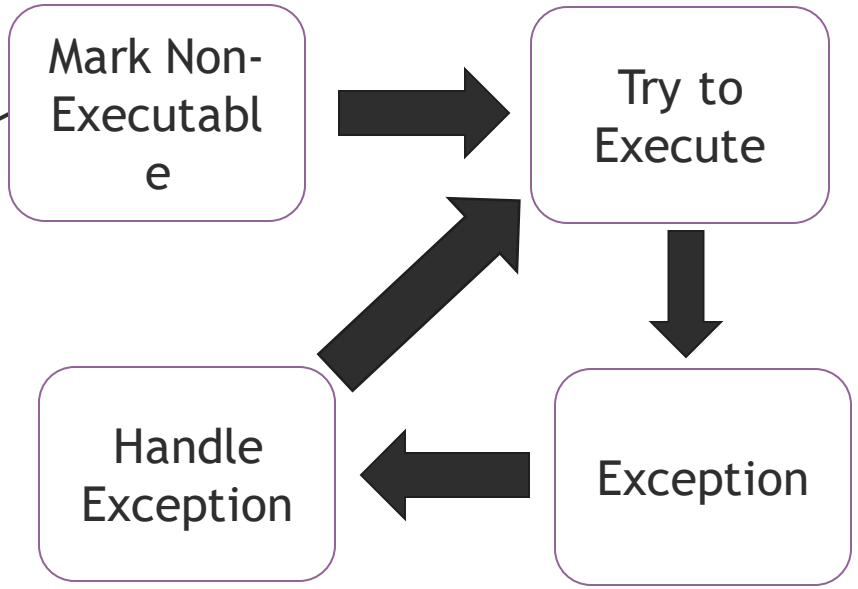

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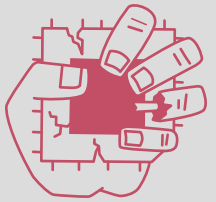

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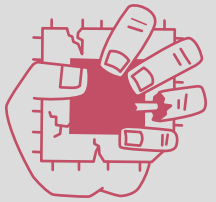
- Repeated Context Switch in the transient domain w/ the same register values

Is there any Mitigation?



- **Short-term**
  - Intel suggested an instruction sequence to fill all the buffers across context switch
  - Disable hyperthreading
  - Intel SGX: Remote attestation to Verify hyperthreading is Disabled

- **Long-term**
  - Microarchitectural hardware fixes (Buy new CPUs !! ☺)

https://zombieloadattack.com/