Repurposing Segmentation as a Practical LVI-NULL Mitigation in SGX

Lukas Giner, Andreas Kogler, Claudio Canella, Michael Schwarz, Daniel Gruss

May 06, 2022

Who am I?

Lukas Giner

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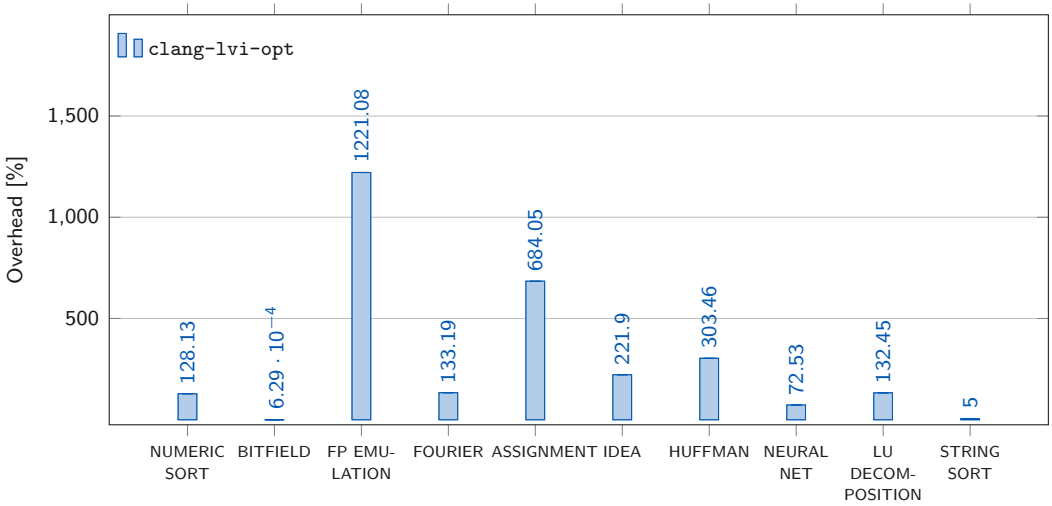
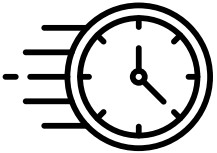
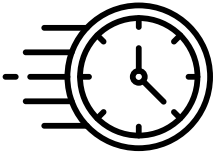
Motivation


clang-lvi-opt
Overhead [%]
1,500
1,000
500
128.13
$6.29 \cdot 10^{-4}$
1221.08
133.19
684.05
221.9
303.46
72.53
132.45
5
NUMERIC SORT
BITFIELD
FP EMU-LATION
FOURIER
ASSIGNMENT
IDEA
HUFFMAN
NEURAL NET
LU DECOM-POSITION
STRING SORT



- CPU does many things, all at once



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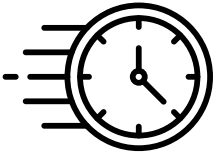
- Parallelizing instructions speeds up execution



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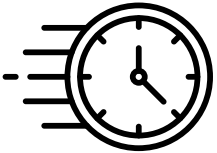

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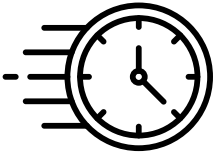

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- Mistakes?
- Roll back to the mistake, either raise an error or try again
- Undone instructions are called transient

- What can an attacker do with transient instructions?

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- Not all state is gone - traces in μArch state

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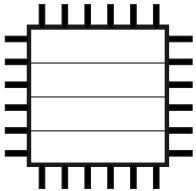
- Not all state is gone - traces in μArch state
- Caching!

Meltdown: Transiently encoding unauthorized memory

User Memory

	𝔸	𝔹
ℂ	𝔻	𝔼
𝔽	𝔾	ℍ
𝕀	𝕁	𝕂
𝕃	𝕄	ℕ
𝕆	ℙ	ℚ
ℝ	𝕊	𝕋
𝕌	𝕍	𝕎
𝕏	𝕐	ℤ

```
char value = kernel[0]
```



Meltdown: Transiently encoding unauthorized memory

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𝕏	𝕐	ℤ

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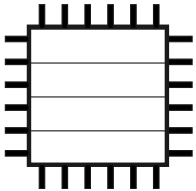
```

Page fault (Exception)



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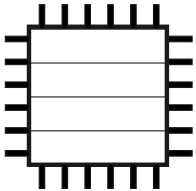
```
char value = kernel[0]
```

Page fault (Exception)

Out of order

```
mem[value]
```

K



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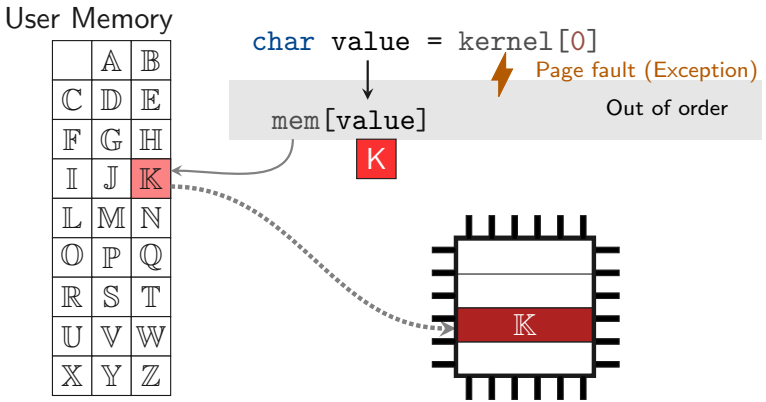
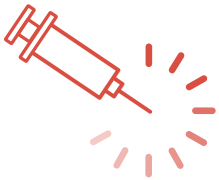
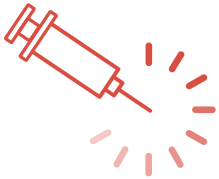




- What if we turn Meltdown around?



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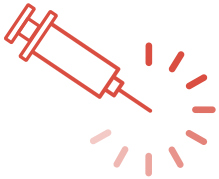
- uʍopʇlǝW



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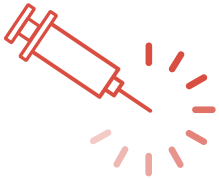

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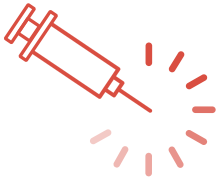
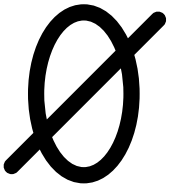
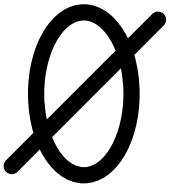
- Transiently steer the victim to give up data!



- What if we turn Meltdown around?
- Instead of leaking, we insert a value
- Transiently steer the victim to give up data!
- Exfiltrate with cache, as usual



- How do these values get there?



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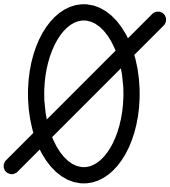

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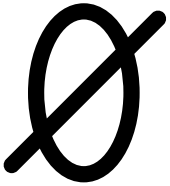

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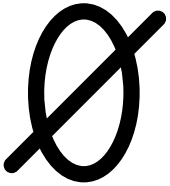

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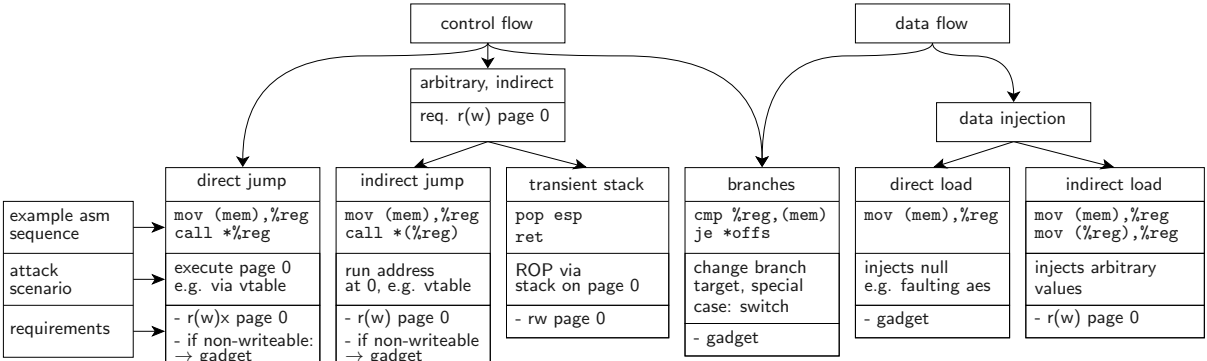
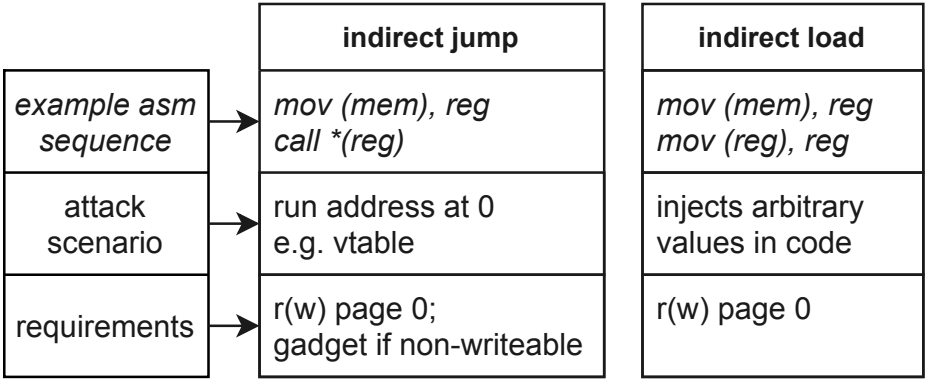
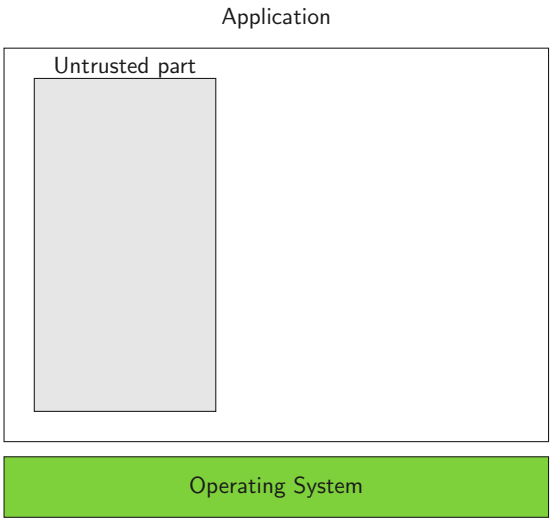
- New CPUs just "inject" 0 instead
- Problem solved?

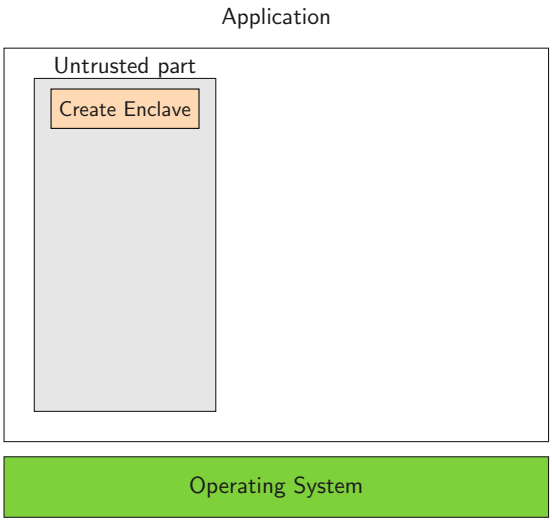
LVI-NULL Vectors




indirect jump
indirect load
example asm sequence
mov (mem), reg
call *(reg)
mov (mem), reg
mov (reg), reg
attack scenario
run address at 0
e.g. vtable
injects arbitrary values in code
requirements
r(w) page 0;
gadget if non-writeable
r(w) page 0



- SGX protects enclave from OS



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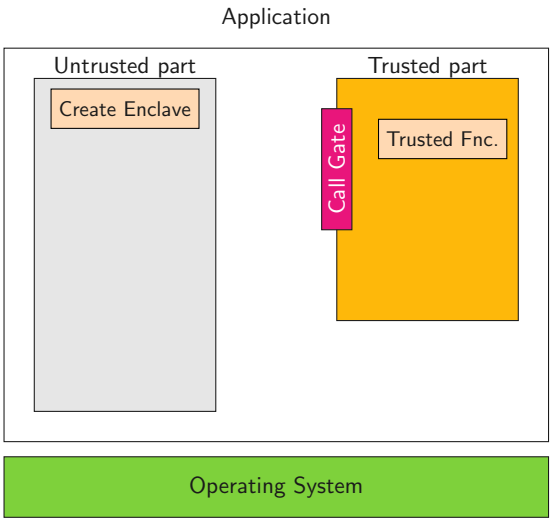

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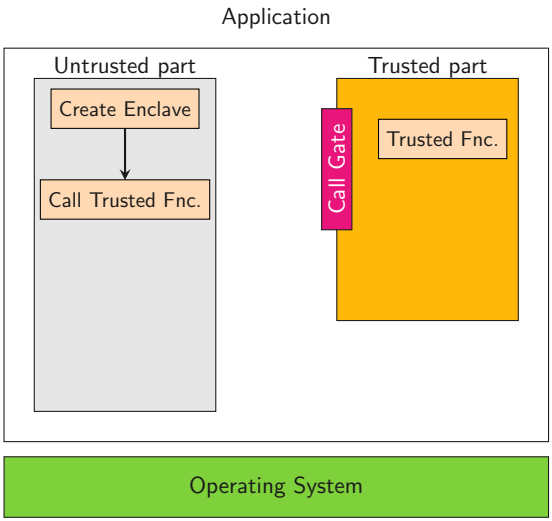

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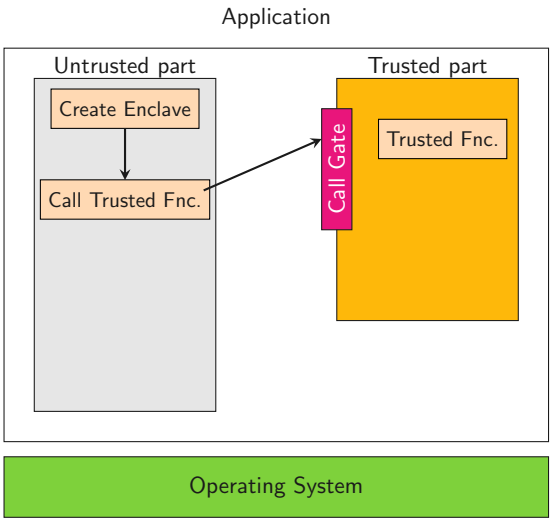

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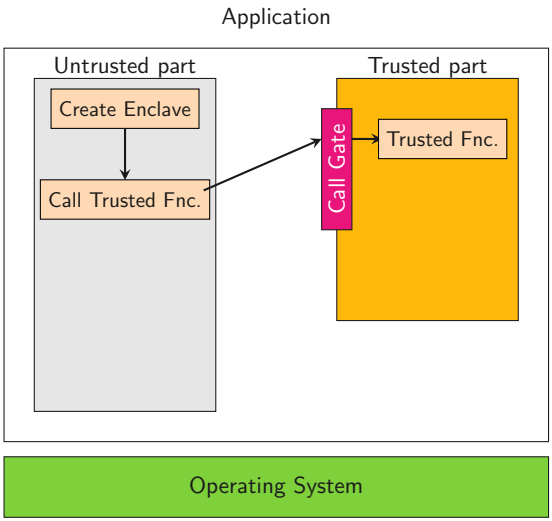

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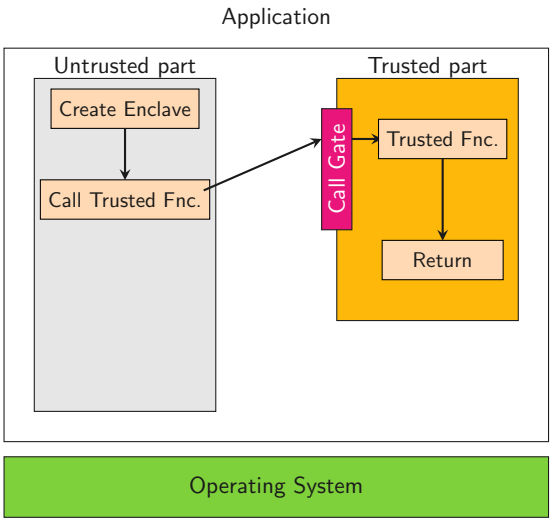

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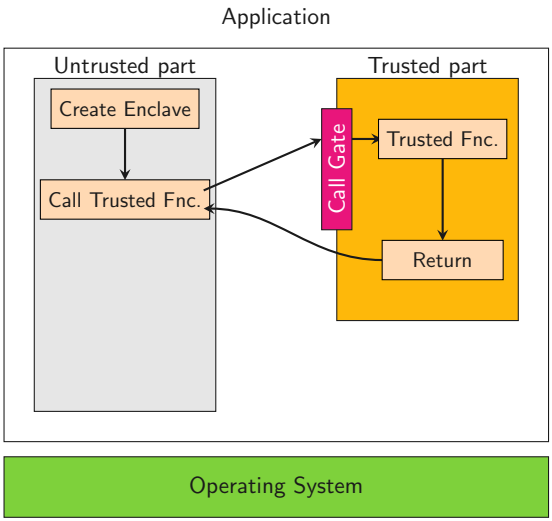

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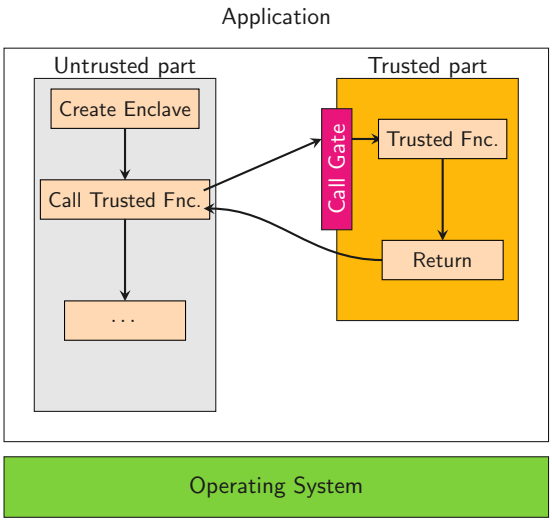

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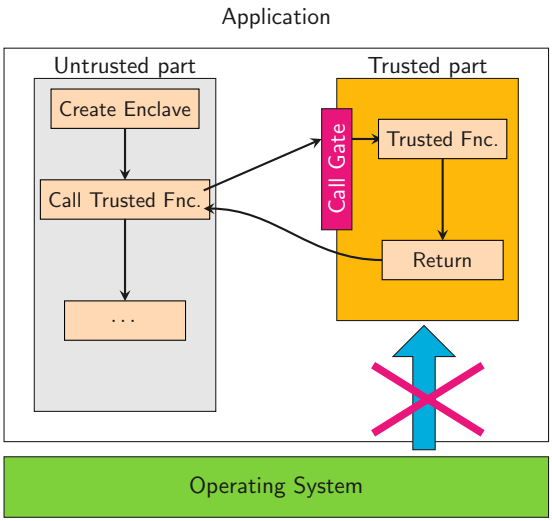

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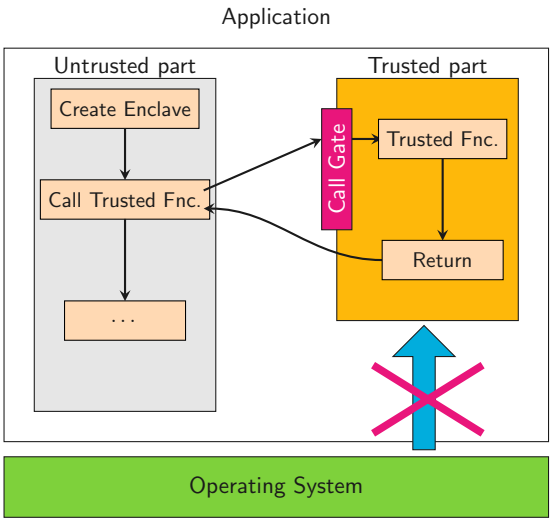

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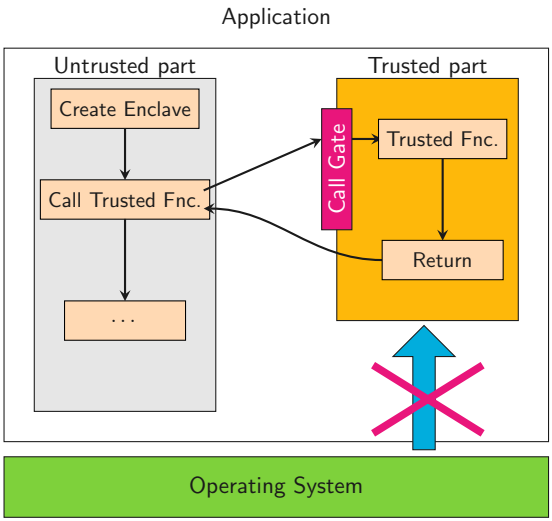
- But OS still controls parts of the PTE



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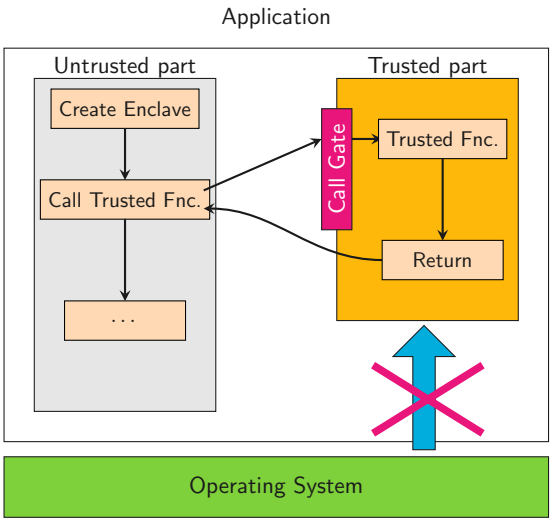

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- Instruction-targeted injection with SGX-Step

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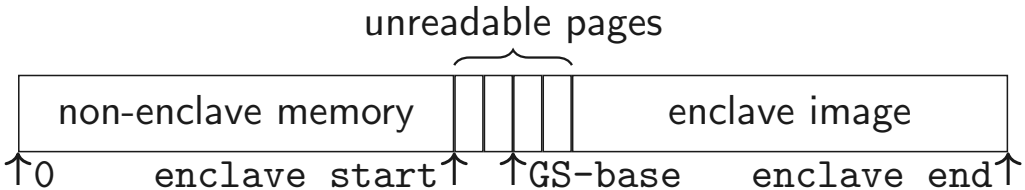

Mitigated Code

```
push %rbp
```

```
sub  $0x8,%rsp
mov  %rbp,%gs:(%rsp)
```

- All loads over gs

Mitigated Code

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- All loads over gs
- Instruction with implicit load→
  replace with other instructions

Mitigated Code

```
push %rbp
```

```
callq 400480 <func>
```

```
sub  $0x8,%rsp
mov  %rbp,%gs:(%rsp)
lea  $return_address(%rip),%r11
sub  $0x8,%rsp
mov  %r11,%gs:(%rsp)
jmpq 400480 <func>
```

- All loads over gs
- Instruction with implicit load→
  replace with other instructions

Mitigated Code

```
push %rbp
```

```
callq 400480 <func>
```

```
pop  %rbp
```

```
sub  $0x8,%rsp
mov  %rbp,%gs:(%rsp)
```

```
lea  $return_address(%rip),%r11
sub  $0x8,%rsp
mov  %r11,%gs:(%rsp)
jmpq 400480 <func>
```

```
mov  %gs:(%rsp),%rbp
add  $0x8,%rsp
```

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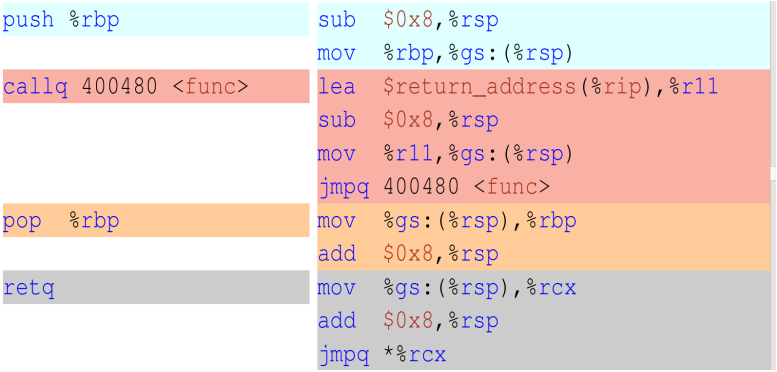
Mitigated Code



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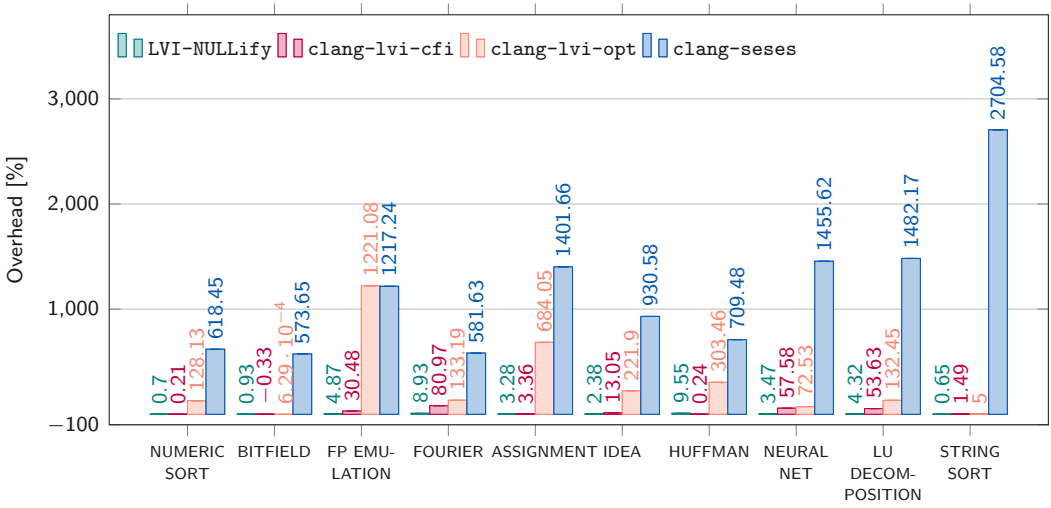
Performance



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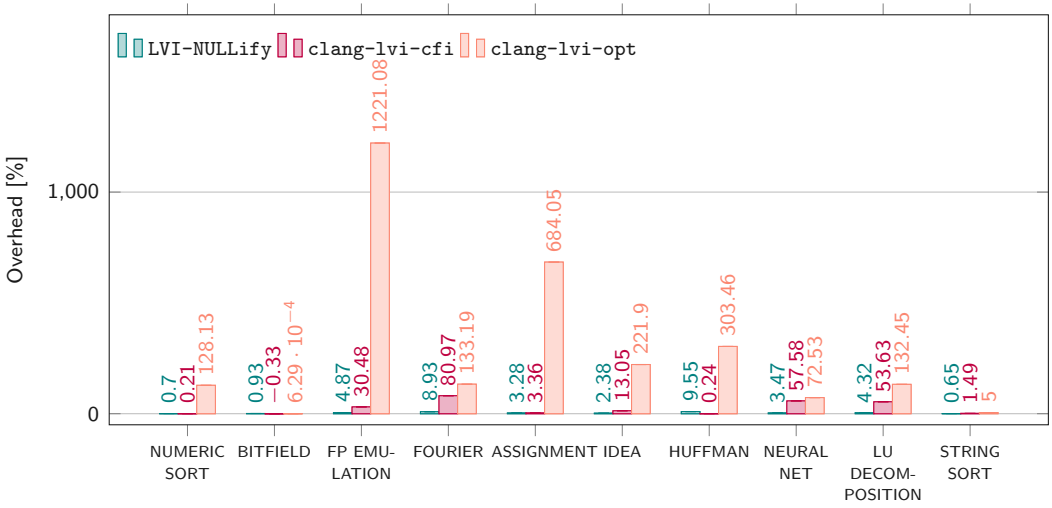

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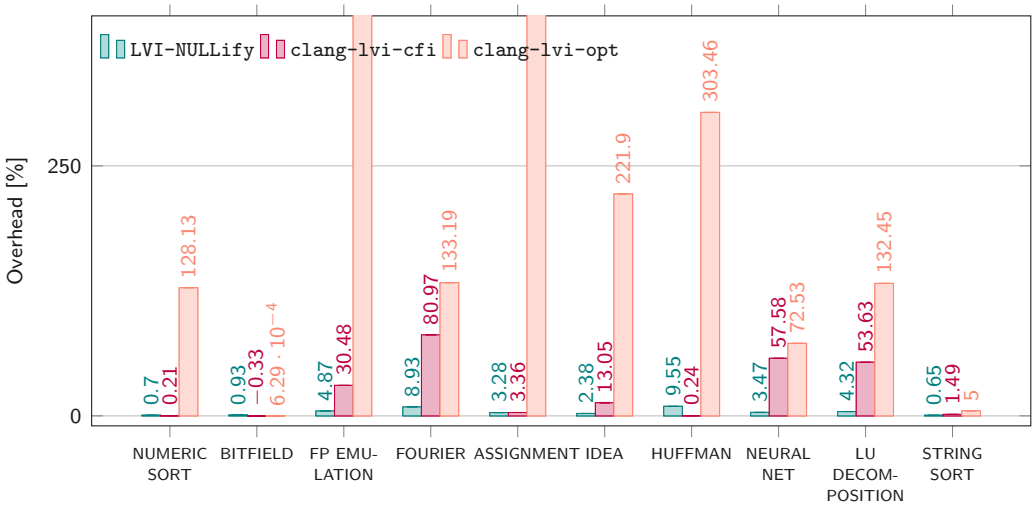

Conclusion

LVI-NULLify on GitHub

- LVI-NULL is still here (in Rocket Lake)..

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LVI-NULLify on GitHub

- LVI-NULL is still here (in Rocket Lake)..
  ..but SGX isn't, in affected models
- For now, only Comet Lake is affected
- Maybe relative addressing will be useful somewhere else?

Repurposing Segmentation as a Practical LVI-NULL Mitigation in SGX

Lukas Giner (@redrabbyte), Andreas Kogler (@0xhilbert), Claudio Canella (@cc0x1f)
Michael Schwarz (@misc0110), Daniel Gruss (@lavados)