Secure Software Development

Countermeasures: Exploitation Prevention & Privilege Minimization

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Defense In Depth

Attacker's perspective

- Vulnerability discovery ☑
- Exploitation ☑
- Privilege elevation ☑

Defender's perspective

- Vulnerability prevention ☑
- Exploit prevention (today)
- Privilege minimization (today)

Defense In Depth

Attacker's perspective

- Vulnerability discovery
  - buffer/integer overflow, use-after-free, format strings, type confusion
- Exploitation
  - Data corruption, shellcode, code reuse, ROP, return-to-libc
- Privilege elevation
  - exploit suid binaries, kernel exploits, crack root PW hash ;)

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Defender's perspective

- Vulnerability prevention
  - Code quality, memory safety, type safety, error handling ...
- Exploit prevention
  - Compiler/runtime defenses, hardware defenses
- Privilege minimization
  - System call filtering, sandboxing, virtualization

Recap: What if Vulnerability Prevention Fails?

- Attacker triggered a vulnerability

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- Attacker triggered a vulnerability
  - Part 1: Can we prevent exploitation? → Exploit Prevention
- Attacker gained arbitrary code execution
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- Defenses must be cheap!

Stack Buffer Overflows

Recap: Buffer overflow


```c
void printName(char* buffer) {
  char name[16];
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  - Cannot hit arbitrary memory, unlike format string vulnerabilities

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- Observation 1: Buffer overflows are mostly linear
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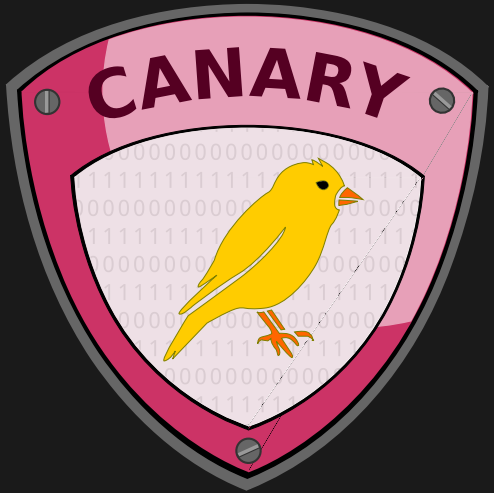
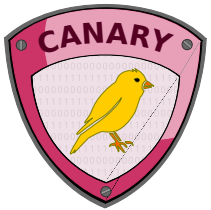
- Observation 2: Attackers typically overwrite code pointer (return address)
- How can we detect linear buffer overflows?


CANARY

Using Canaries for Safety

- If the mine canary is dead, get out immediately

Stack Canary I



- Idea: Introduce a canary on the stack that signals a hazard

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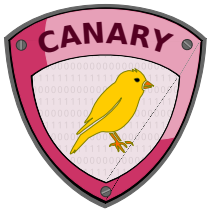

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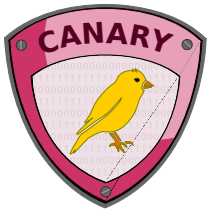

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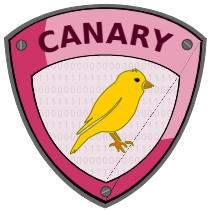

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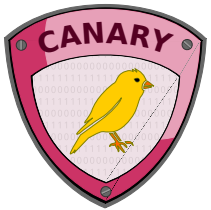

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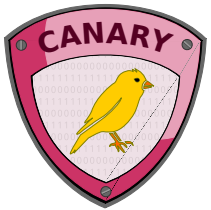

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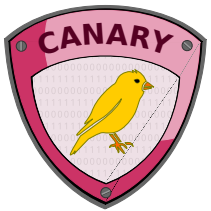

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  - Simple compiler extension
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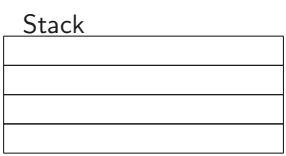
  - Function epilogue: check if canary is valid (unmodified) before doing `retq`

Stack Canary II




```
<func>:
  Setup stack frame
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  [...]
  ; check canary
  RET

<main>:
  [...]
  CALL func
  [...]
```

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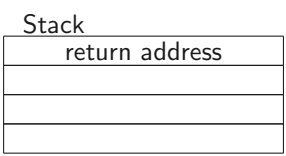


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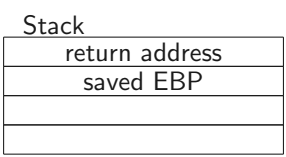


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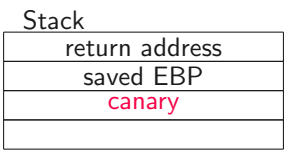


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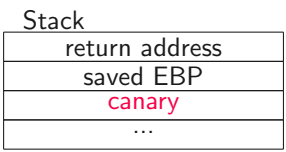


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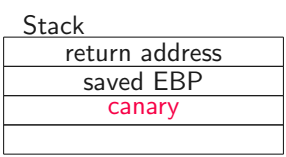


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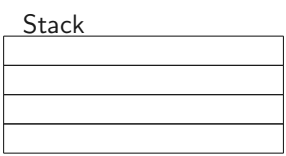


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```

Stack Canary Example I

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#include <string.h>

void printName(char* buffer) {
  char name[16];
  strcpy(name, buffer);
  printf("Hello %s\n", name);
}

int main(int argc, char* argv[]) {
  if(argc > 1) printName(argv[1]);
  return 0;
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Stack Canary Example II

```
% gcc -o stack -fno-stack-protector stack.c
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% gcc -o stack -fstack-protector stack.c
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Hello AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
*** stack smashing detected ***: ./stack terminated
```

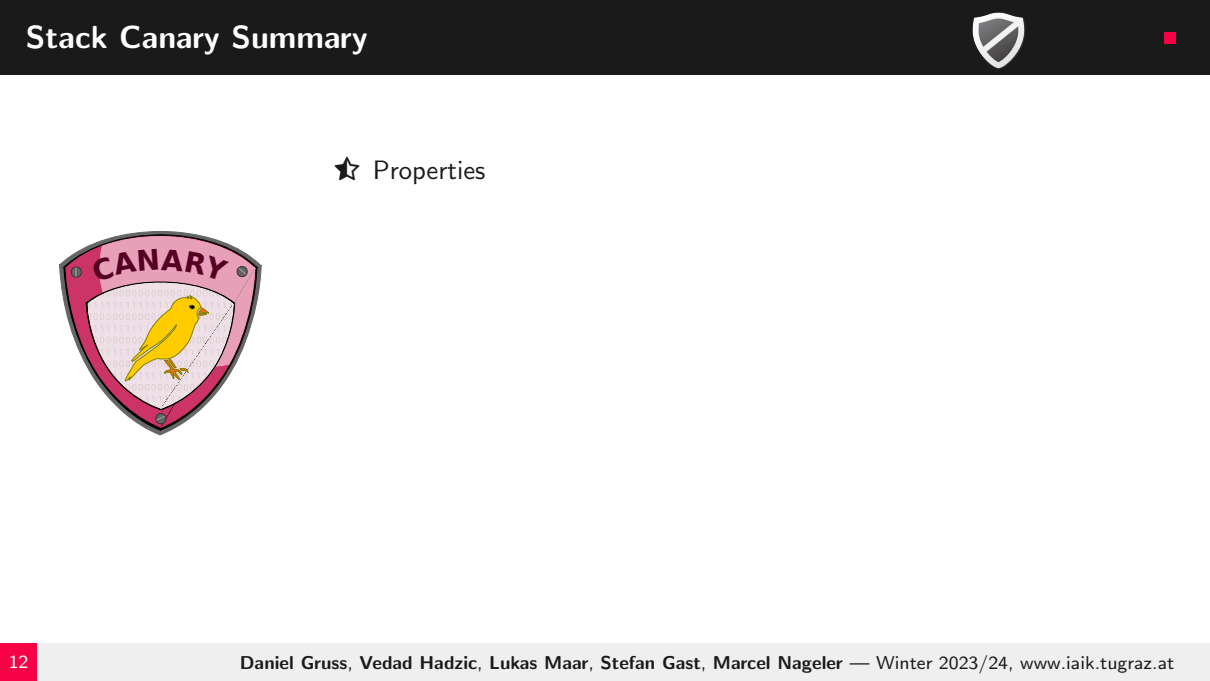
Stack Canary Example III

```
% objdump -d stack
```

Stack Canary Example III

```
% objdump -d stack
00000000004005d6 <printName>:
  // function prologue
  ...
  4005e2: mov    %fs:0x28,%rax   // load canary value
  4005eb: mov    %rax,-0x8(%rbp) // store canary on stack
  4005ef: xor    %eax,%eax
  ...
  // function epilogue
  40061b: mov    -0x8(%rbp),%rax // load canary from stack
  40061f: xor    %fs:0x28,%rax   // compare
  400628: je     40062f <printName+0x59>
  40062a: callq  4004a0 <__stack_chk_fail@plt>
  40062f: leaveq
  400630: retq
```

Stack Canary Summary



- Properties

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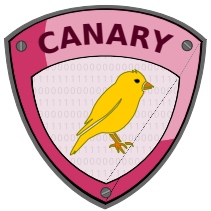

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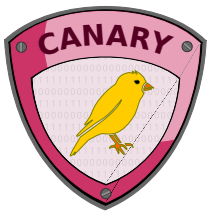

- Properties
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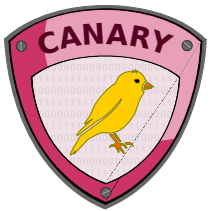

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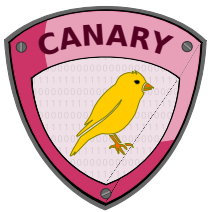

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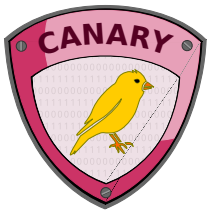

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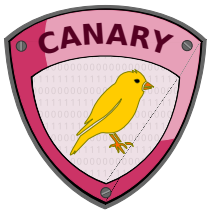

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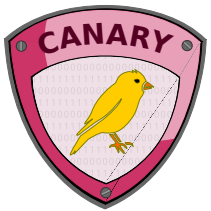

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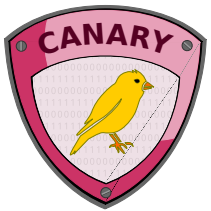

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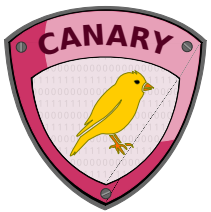

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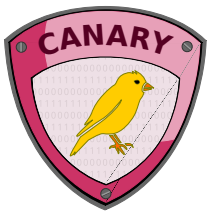

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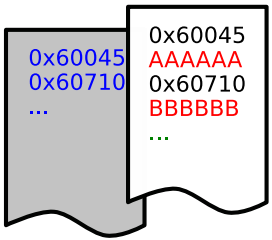
    - format string vulnerabilities ...
  - Probabilistic defense
    - Ineffective if attacker can guess or leak the canary value
  - Animal welfare compatible (no bird has to die ;)
- If we push/pop a canary for each return address, why not just duplicate return addresses instead?

Shadow Stack



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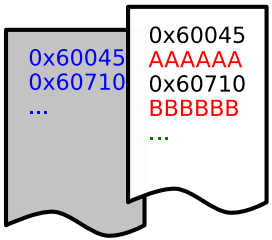

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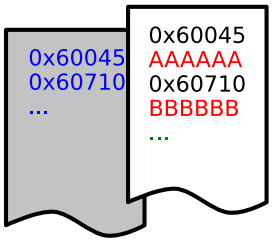

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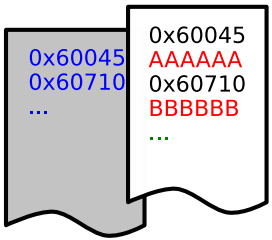

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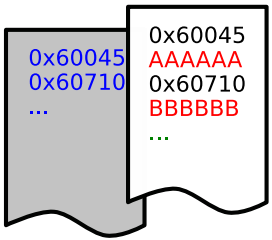

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  - Epilogue: verify return address before doing `retq`

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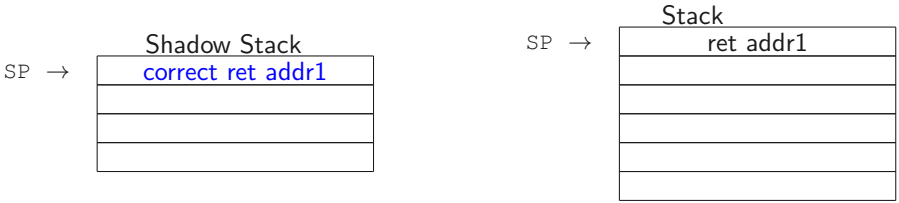

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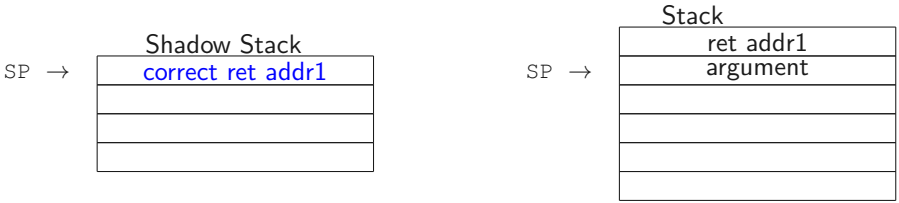

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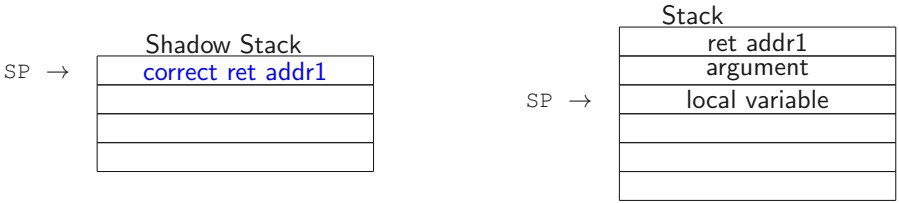

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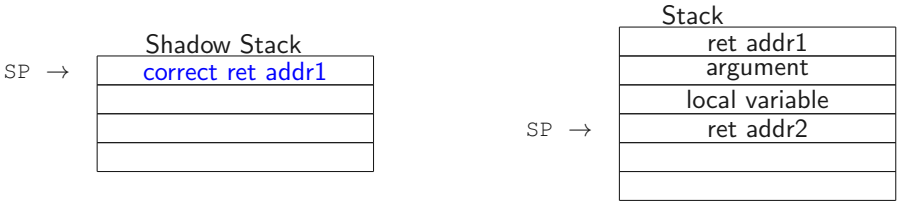

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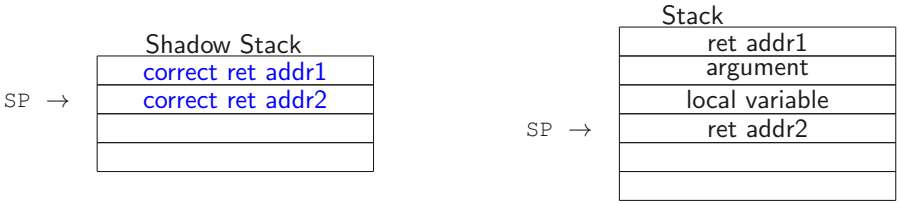

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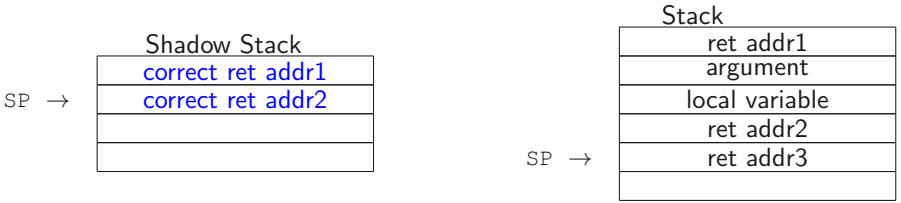

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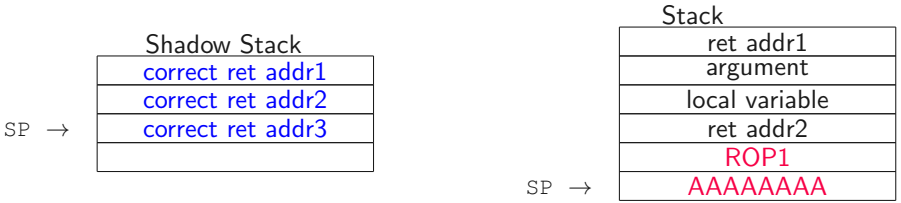

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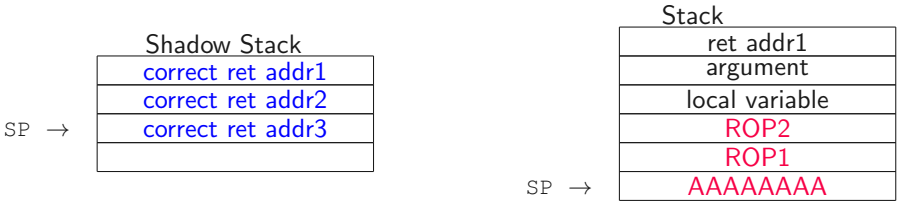

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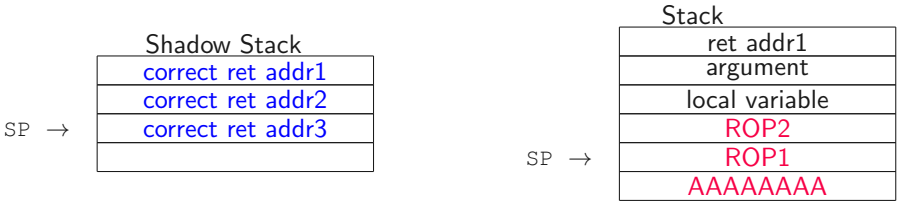

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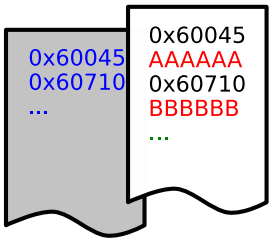

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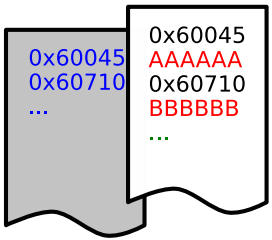

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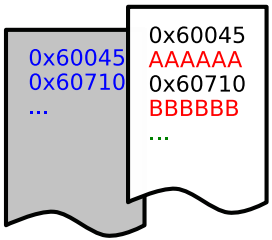

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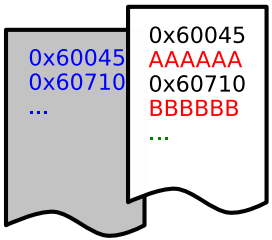

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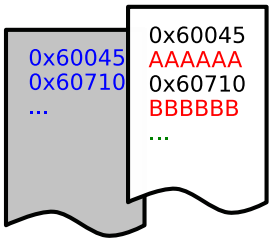

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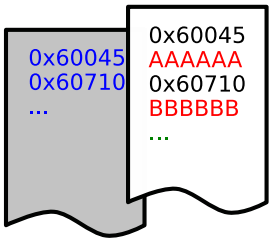

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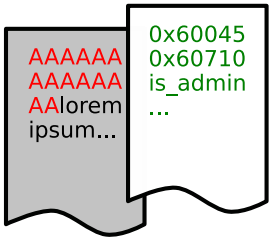

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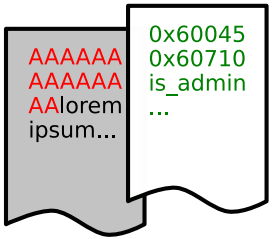

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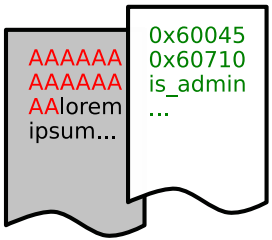

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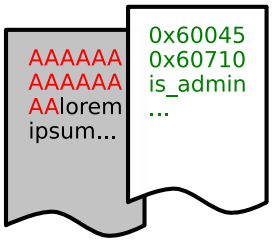

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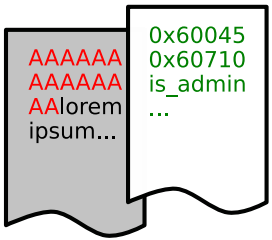

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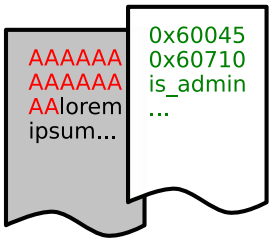

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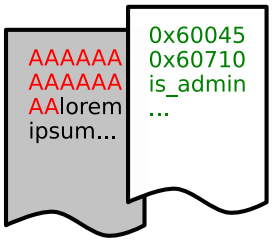

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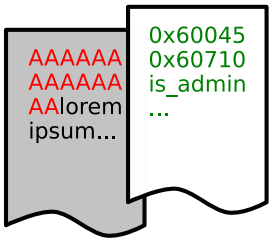

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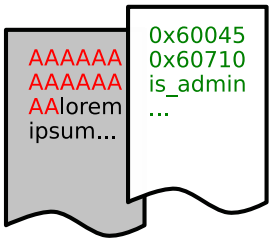

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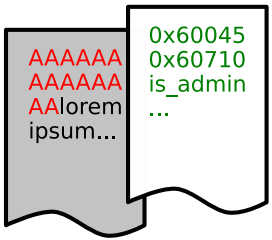

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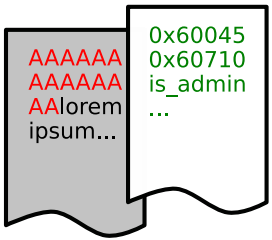

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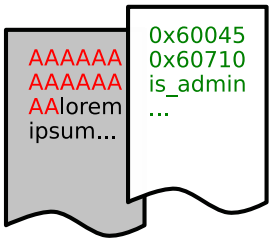

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Code Injection Attacks

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  - Hardware support in the page tables
    - Intel: XD-bit, AMD: NX-bit, ARM: XN-bit

Data Execution Prevention Example I

```
#include <stdio.h>
#include <string.h>

char code[] = "\x31\xc0\x48\xbb\xd1\x9d\x96\x91\xd0\x8c\x97\xff\x48\xf7\xdb\x53\
    x54\x5f\x99\x52\x57\x54\x5e\xb0\x3b\x0f\x05";

int main()
{
    printf("len:%d bytes\n", strlen(code));
    (*(void(*)()) code)();
    return 0;
}
```

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process 9494 is executing new program: /bin/dash
$
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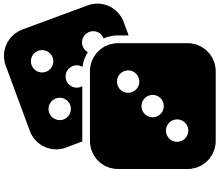
- How to protect just-in-time (JIT) compiled code? JIT compiler needs to modify code at runtime ...

Code Reuse Attacks

Randomization-based Defenses



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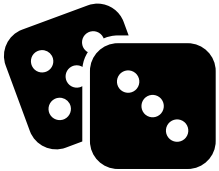

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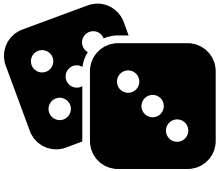

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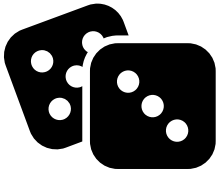

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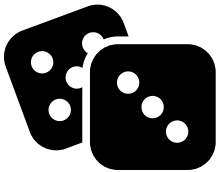

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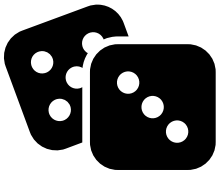

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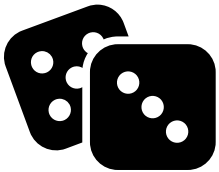

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    - How big is the entropy?


ASLR

Address Space Layout Randomization (ASLR)

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    - Linux `/proc/sys/kernel/randomize_va_space`

ASLR on Stack and Heap

```c
#include <stdio.h>
#include <stdlib.h>

int main() {
  int x;
  printf("Stack: %p\n", &x);
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Heap:  0x124b420
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ASLR on Stack, Heap, and Libraries

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% cat /proc/self/maps
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% cat /proc/self/maps
00400000-0040c000 r-xp 00000000 fd:00 395191            /bin/cat
0060b000-0060c000 r--p 0000b000 fd:00 395191            /bin/cat
0060c000-0060d000 rw-p 0000c000 fd:00 395191            /bin/cat
00b0c000-00b2d000 rw-p 00000000 00:00 0                 [heap]
7efcbb558000-7efcbb87e000 r--p 00000000 fd:00 11534857  /usr/lib/locale/locale-archive
7efcbb87e000-7efcbba3e000 r-xp 00000000 fd:00 4587769   /lib/x86_64-linux-gnu/libc-2.23.so
7efcbba3e000-7efcbbc3e000 ---p 001c0000 fd:00 4587769   /lib/x86_64-linux-gnu/libc-2.23.so
7efcbbc3e000-7efcbbc42000 r--p 001c0000 fd:00 4587769   /lib/x86_64-linux-gnu/libc-2.23.so
7efcbbc42000-7efcbbc44000 rw-p 001c4000 fd:00 4587769   /lib/x86_64-linux-gnu/libc-2.23.so
7efcbbc44000-7efcbbc48000 rw-p 00000000 00:00 0
7efcbbc48000-7efcbbc6e000 r-xp 00000000 fd:00 4588089   /lib/x86_64-linux-gnu/ld-2.23.so
7efcbbe38000-7efcbbe3b000 rw-p 00000000 00:00 0
7efcbbe4b000-7efcbbe6d000 rw-p 00000000 00:00 0
7efcbbe6d000-7efcbbe6e000 r--p 00025000 fd:00 4588089   /lib/x86_64-linux-gnu/ld-2.23.so
7efcbbe6e000-7efcbbe6f000 rw-p 00026000 fd:00 4588089   /lib/x86_64-linux-gnu/ld-2.23.so
7efcbbe6f000-7efcbbe70000 rw-p 00000000 00:00 0
7ffff84c6000-7ffff84e7000 rw-p 00000000 00:00 0         [stack]
7ffff8536000-7ffff8538000 r--p 00000000 00:00 0         [vvar]
7ffff8538000-7ffff853a000 r-xp 00000000 00:00 0         [vdso]
ffffffffff600000-ffffffffff601000 r-xp 00000000 00:00 0 [vsyscall]
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ASLR on Stack, Heap, Libraries

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00799000-007ba000 rw-p 00000000 00:00 0                                  [heap]
7fec1f08d000-7fec1f3b3000 r--p 00000000 fd:00 11534857                   /usr/lib/locale/locale-archive
7fec1f3b3000-7fec1f573000 r-xp 00000000 fd:00 4587769                    /lib/x86_64-linux-gnu/libc-2.23.so
7fec1f573000-7fec1f773000 ---p 001c0000 fd:00 4587769                    /lib/x86_64-linux-gnu/libc-2.23.so
7fec1f773000-7fec1f777000 r--p 001c0000 fd:00 4587769                    /lib/x86_64-linux-gnu/libc-2.23.so
7fec1f777000-7fec1f779000 rw-p 001c4000 fd:00 4587769                    /lib/x86_64-linux-gnu/libc-2.23.so
7fec1f779000-7fec1f77d000 rw-p 00000000 00:00 0
7fec1f77d000-7fec1f7a3000 r-xp 00000000 fd:00 4588089                    /lib/x86_64-linux-gnu/ld-2.23.so
7fec1f96d000-7fec1f970000 rw-p 00000000 00:00 0
7fec1f980000-7fec1f9a2000 rw-p 00000000 00:00 0
7fec1f9a2000-7fec1f9a3000 r--p 00025000 fd:00 4588089                    /lib/x86_64-linux-gnu/ld-2.23.so
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7fec1f9a4000-7fec1f9a5000 rw-p 00000000 00:00 0
7ffeffa30000-7ffeffa51000 rw-p 00000000 00:00 0                          [stack]
7ffeffa7f000-7ffeffa81000 r--p 00000000 00:00 0                          [vvar]
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ASLR on Shared Libraries

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❓ How does randomized code remain functional?

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  - Compiler replaces absolute addresses with (rip-)relative addresses
  - Code can be executed from virtually any offset
  - Shared libraries: compile flags `-fpic`, `-fPIC`
  - Executable: compile flags `-fpie`, `-fPIE`

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- Across modules
  - Runtime linker resolves addresses via:
  - Global Offset Table (GOT) for arbitrary addresses
  - Procedure Linkage Table (PLT) for function calls

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  4009ae: 55                    push   %rbp
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  4009b2: bf a4 11 4a 00        mov    $0x4a11a4,%edi    # Address of Hi
  4009b7: e8 24 f2 00 00        callq  40fbe0 <_IO_puts> # Direct call
  4009bc: b8 00 00 00 00        mov    $0x0,%eax
  4009c1: 5d                    pop    %rbp
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     531: e8 ca fe ff ff        callq  400 <puts@plt> # PLT
     536: b8 00 00 00 00        mov    $0x0,%eax
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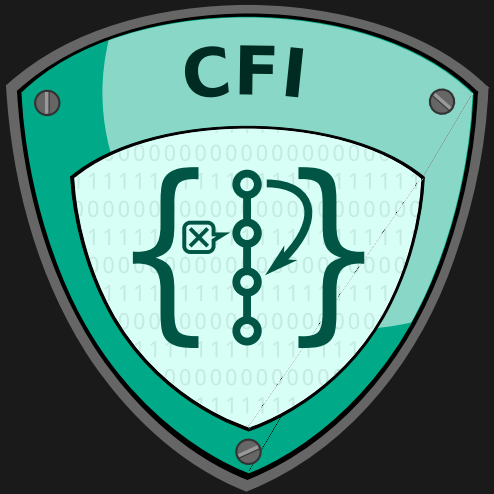
- How to protect ASLR against information leakage?
  - Execute-only memory (non-readable)

Challenge #6 - Selective ASLR

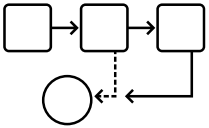
Change the randomization of the code segment

- You should generate two binaries with ASLR enabled
- One binary should have randomization for stack, heap, and code
- The other binary should only have randomization for stack and heap, but not for code
- Both binaries must run for at least 5 seconds (e.g., `sleep(5);` before return) but not longer than 10 seconds
- Upload your binaries at `https://challenges.sasectf.student.iaik.tugraz.at/aslr/index.php`
- If it is correct, you will get the flag
- Test system is Debian 11.8, kernel 5.10.0-26


CFI

Control Flow Integrity (CFI)

- Observation: most attacks corrupt code pointers



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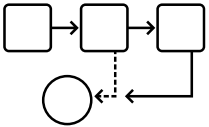

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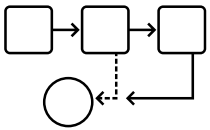

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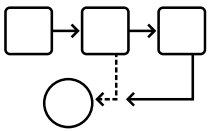

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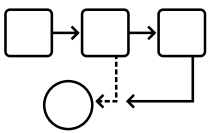

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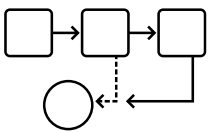

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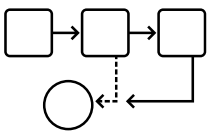

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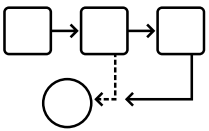

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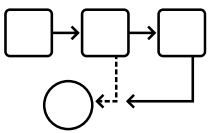

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  - C++ vtables

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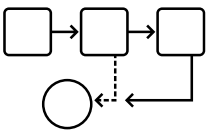

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  - CFI: Program must stay inside its approximated Control Flow Graph (CFG)
  - Attacker cannot (arbitrarily) change control flow
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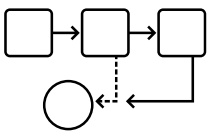

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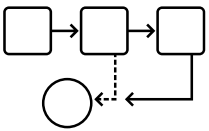

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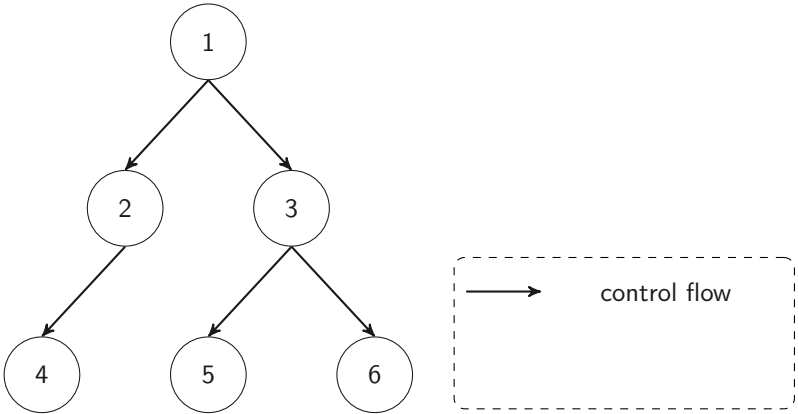

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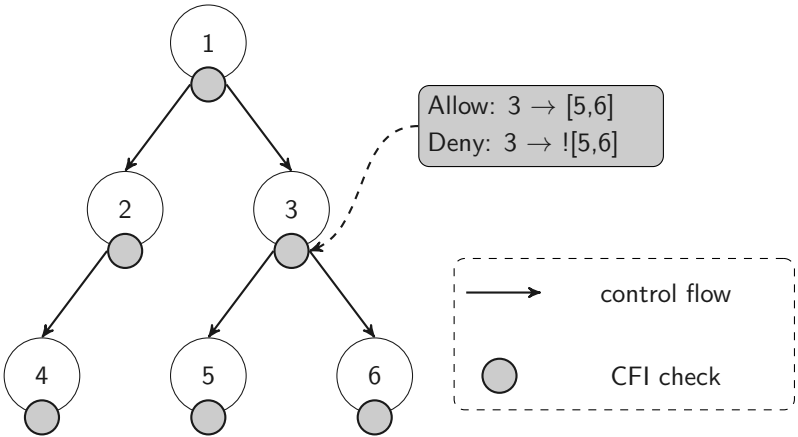

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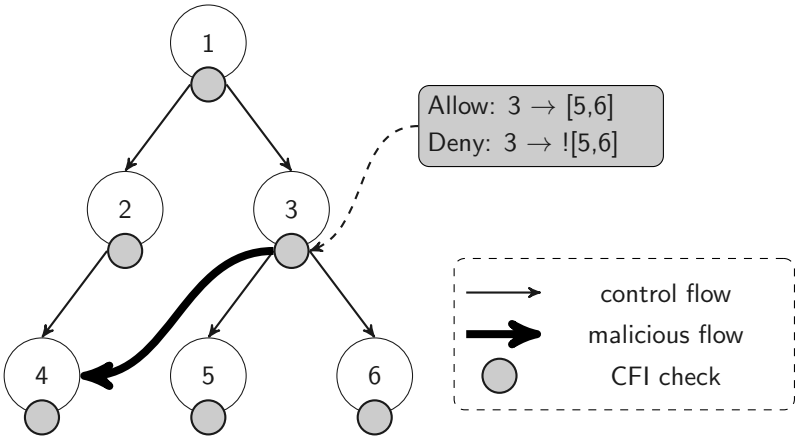

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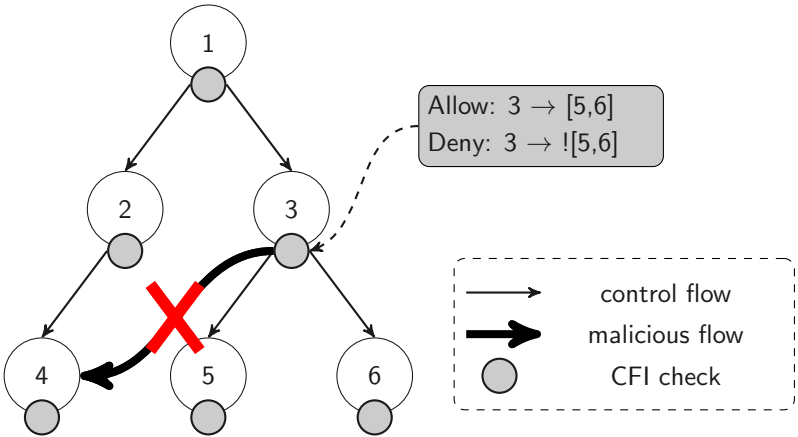

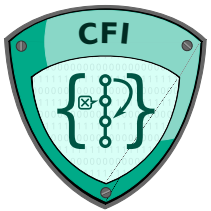

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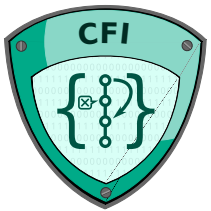

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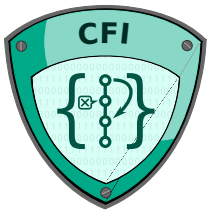

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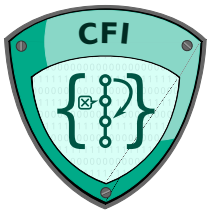

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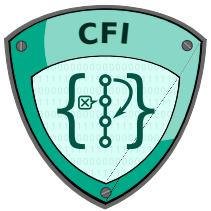

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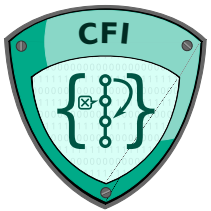

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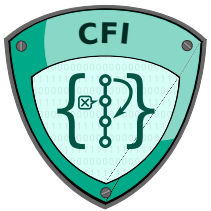

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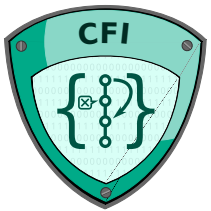

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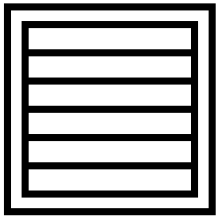

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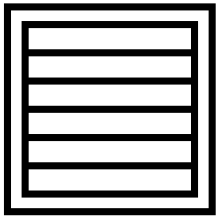

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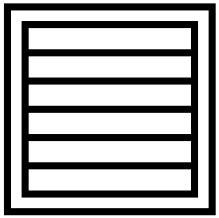

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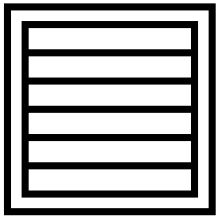

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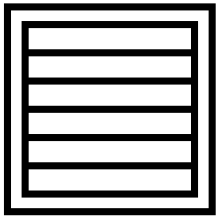

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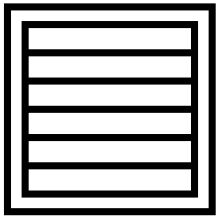

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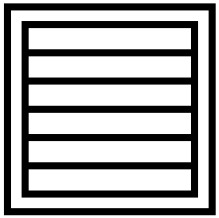

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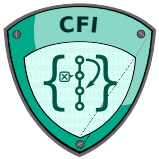
What are **legitimate targets** for an indirect function call?



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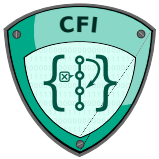

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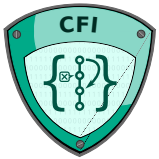

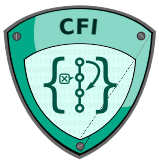

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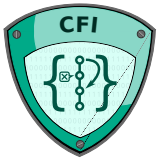

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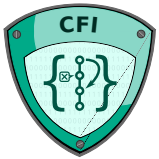

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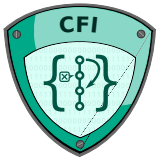

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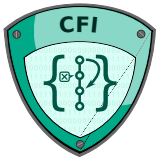

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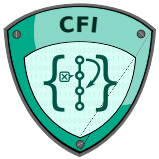

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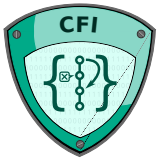

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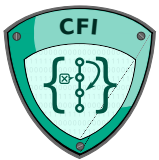

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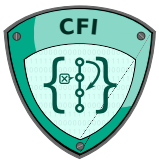

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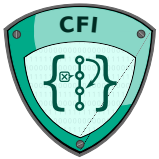
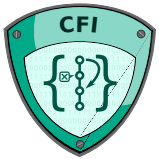


Examples for Hardware/Software CFI mechanisms



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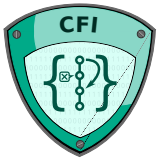

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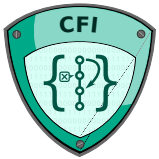

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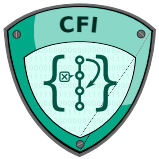

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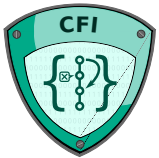

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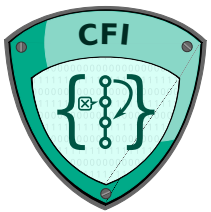

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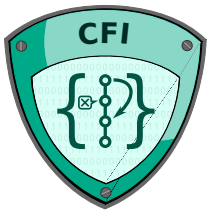

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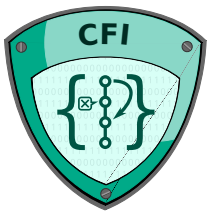

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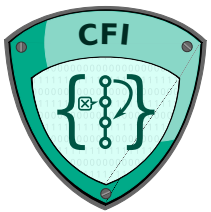


```
% objdump -d main
0000000000001149 <test>:
    1149:  f3 0f 1e fa    endbr64
    114d:  55             push   %rbp
    114e:  48 89 e5       mov    %rsp,%rbp
    ...

0000000000001160 <test2>:
    1160:  f3 0f 1e fa    endbr64
    1164:  55             push   %rbp
    1165:  48 89 e5       mov    %rsp,%rbp
    ...
```

CFI – Clang I

```cpp
#include <iostream>

class A {
  public: virtual const char* name() { return "A"; };
};
class B {
  public:  const char* name() { return "B"; };
  private: virtual const char* secret() { return "secret"; };
};

int main() {
  A* a = new A();
  std::cout << a->name() << std::endl;
  B* b = new B();
  std::cout << b->name() << std::endl;

  a = (A*)b; // type confusion vulnerability
  std::cout << a->name() << std::endl;
}
```

```
% ./test
A
```

```
% ./test
A
B
```

```
% ./test
A
B
secret
```

CFI – Clang II

```
% ./test
A
B
secret
```

```
% clang++ -flto -fsanitize=cfi -fvisibility=hidden \
  -fno-sanitize-trap=all tc.cpp -o tc
```

CFI – Clang II

```
% ./test
A
B
secret
```

```
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% ./tc
A
```

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% ./tc
A
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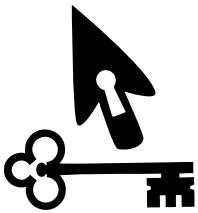
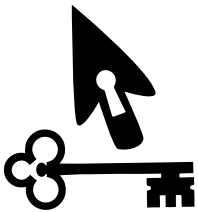
tc.cpp:21:9: runtime error: control flow integrity check for
type 'A' failed during cast to unrelated type
(vtable address 0x00000042bd40)
0x00000042bd40: note: vtable is of type 'B'
00 00 00 00  d0 4b 42 00 00 00 00 00  01 1b 03 3b cc 11 00
             ^
```



ARMv8.3 hardware-based pointer authentication

CFI – Pointer Authentication



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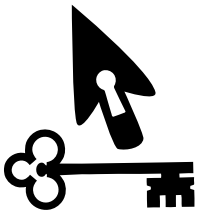

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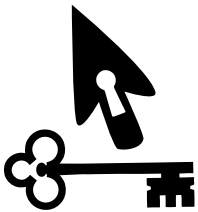

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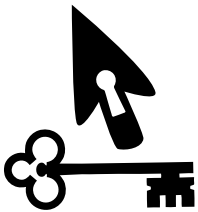

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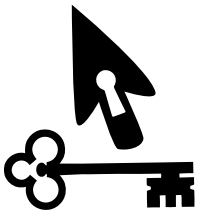

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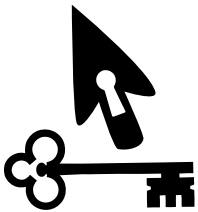

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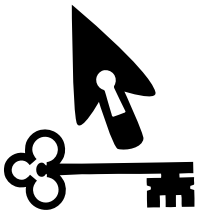

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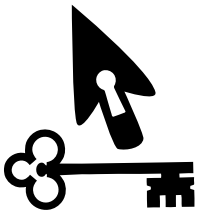

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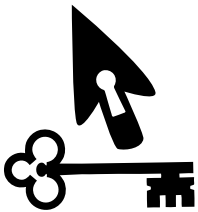

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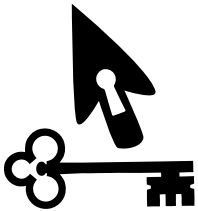
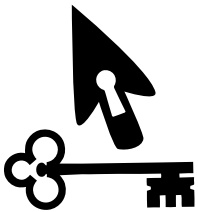
MAC algorithm has three inputs





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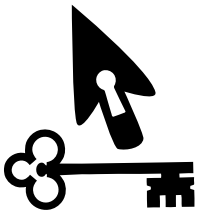
CFI – Pointer Authentication



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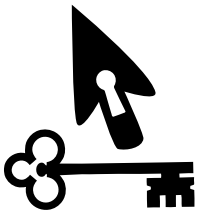

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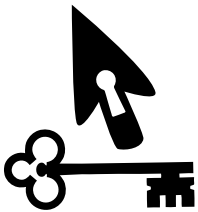

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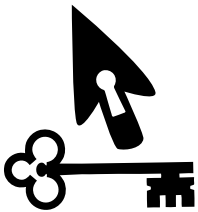

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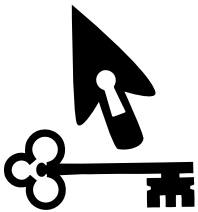

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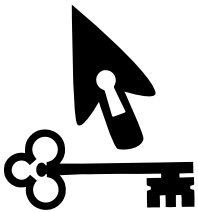

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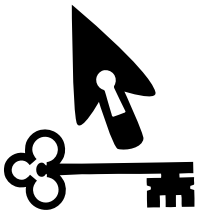

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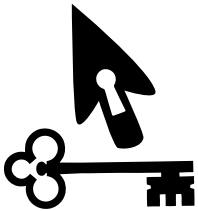

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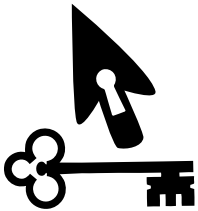

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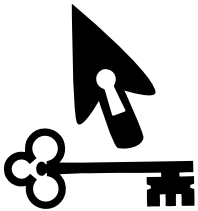

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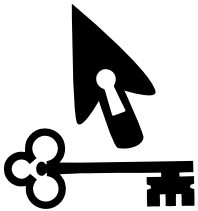

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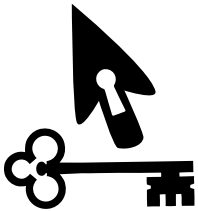

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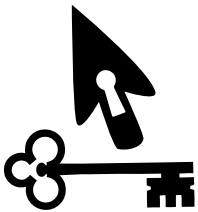

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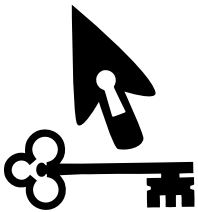

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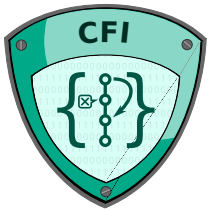
    - Imprecision, allows brute-force/collision attacks

Control Flow Integrity (CFI) Summary



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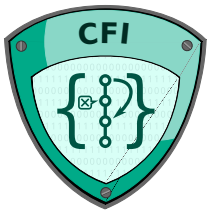

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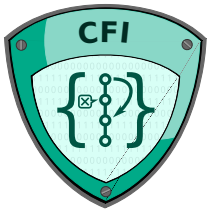

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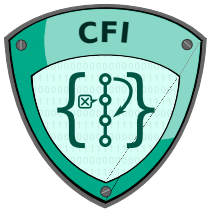

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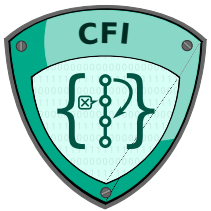

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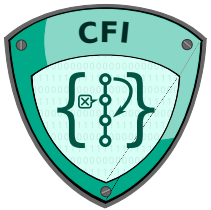

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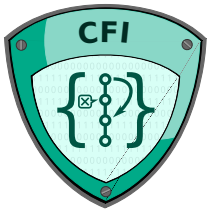

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  - CFI does not prevent data-only attacks
    - E.g., is_admin flag, loop counters, syscall arguments?

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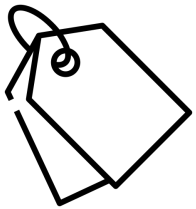
Memory Tagging Extention



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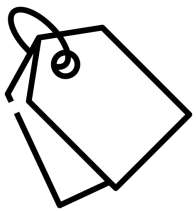

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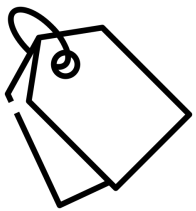

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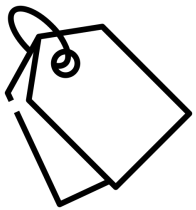

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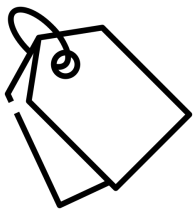

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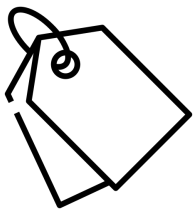

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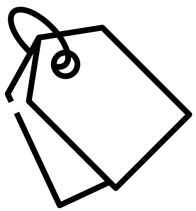

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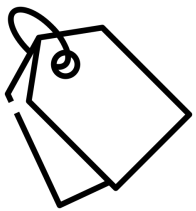

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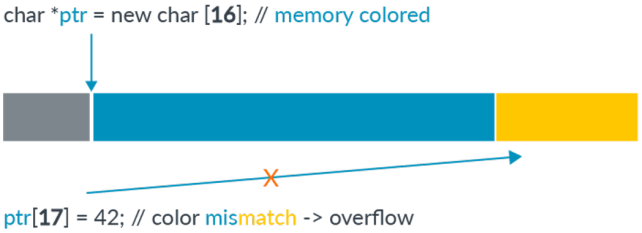
Memory Tagging II



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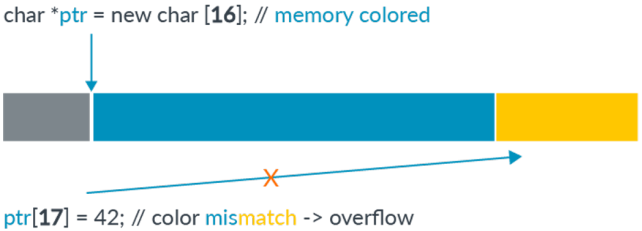
Memory Tagging II



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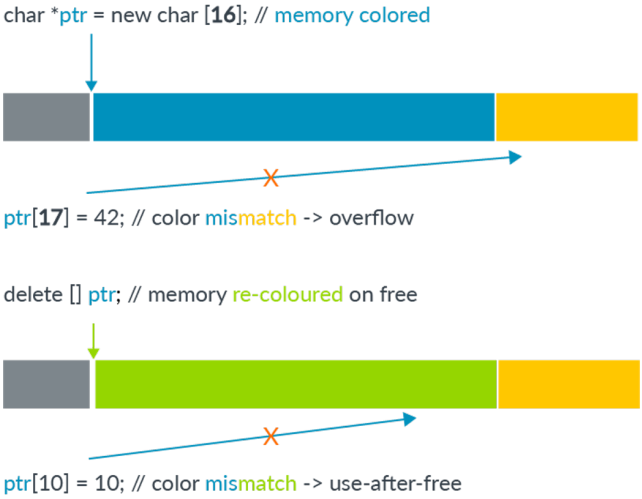

- Security claims
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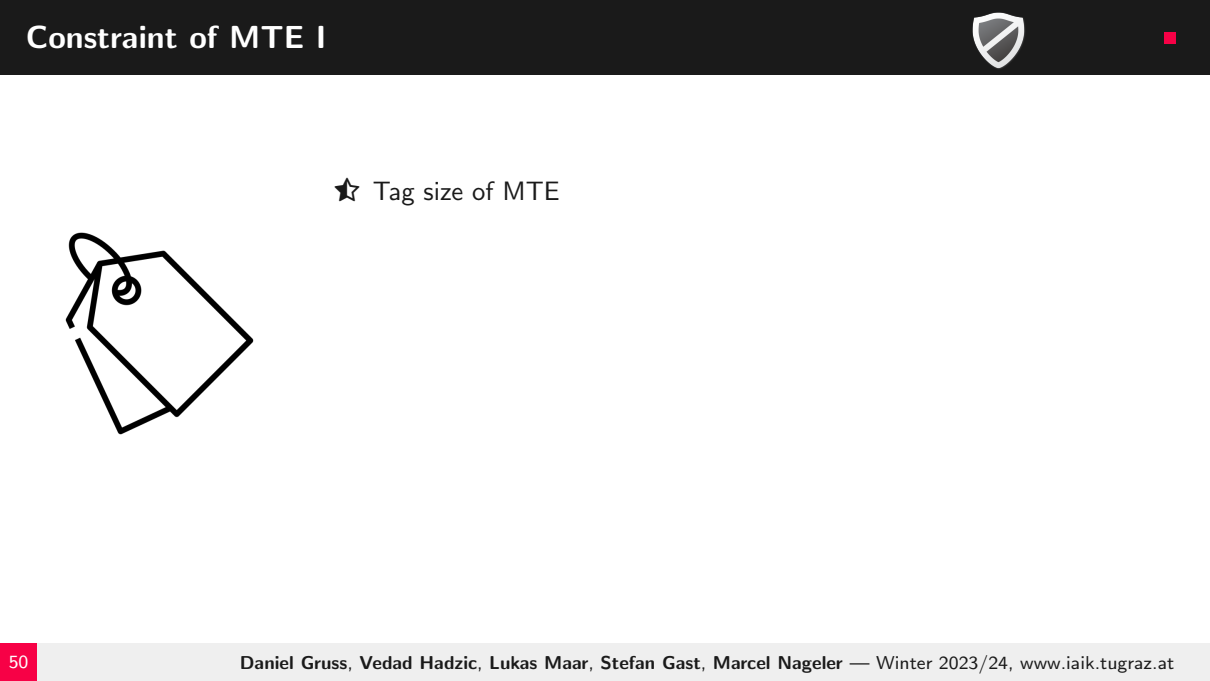
Constraint of MTE I



- Tag size of MTE

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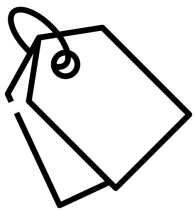

- Tag size of MTE
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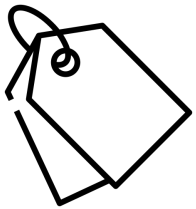

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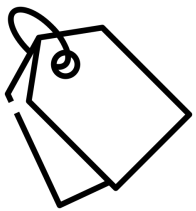

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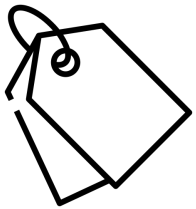

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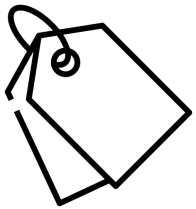

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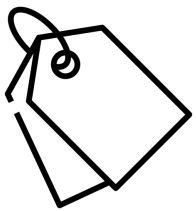

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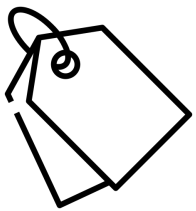

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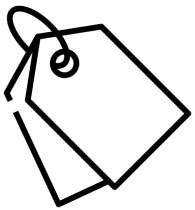

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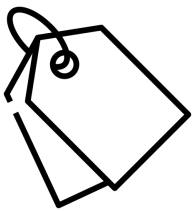

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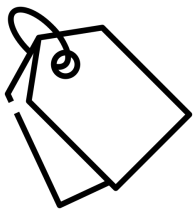

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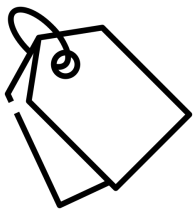
    - 3.125 % memory overhead with 4 bit tag size
    - Two memory lookups for dereferencing a pointer

Constraint of MTE II



- Given 16 tags, how likely is it to detect an arbitrary memory access or a use-after-free?

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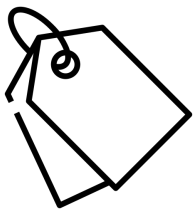

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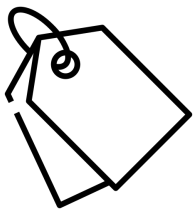

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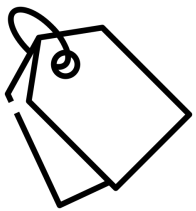

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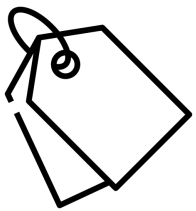

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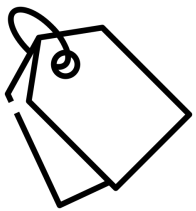

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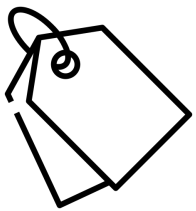

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  - Currently only 4 bit supported

Defense In Depth

Attacker's perspective

- Vulnerability discovery ☑
- Exploitation ☑
- Privilege elevation ☑

Defender's perspective

- Vulnerability prevention ☑
- Exploit prevention ☑
- Privilege minimization (today)

Privilege Minimization

How to minimize the impact of Arbitrary Code Execution

Think inside boxes ...

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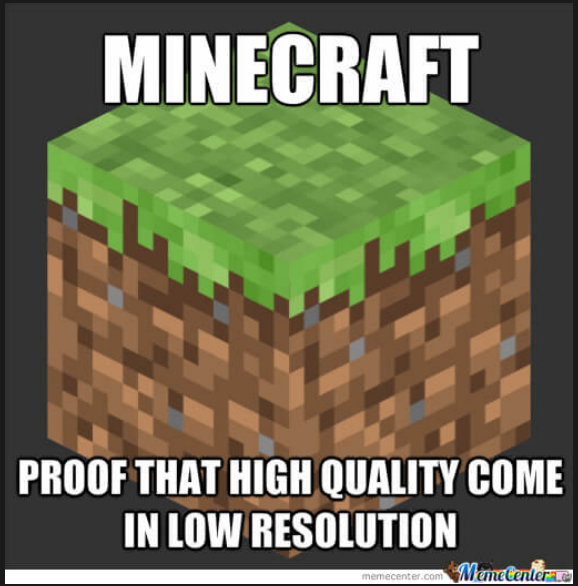
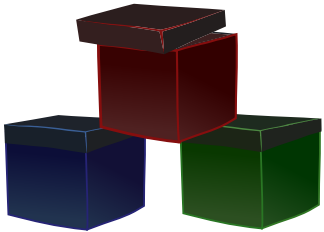


Privilege Minimization Overview



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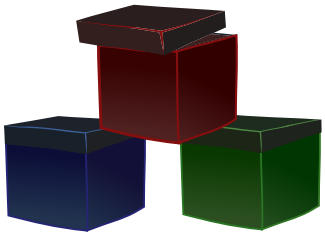

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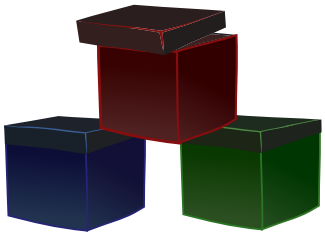

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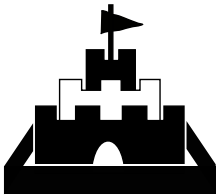
- Isolation
  - Isolate boxes from each other
  - Safeguard all interfaces
    - File permissions, network firewall ... system calls

In-process Sandboxing

In-process Sandboxing

- Goal: confine parts of an application



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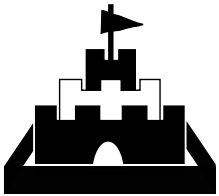

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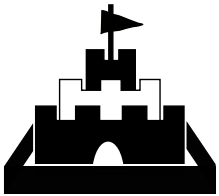

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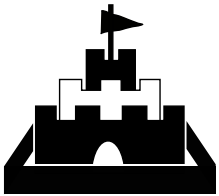

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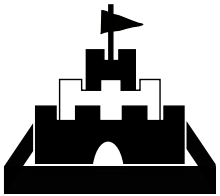

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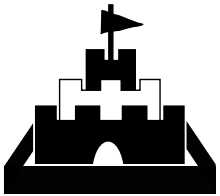

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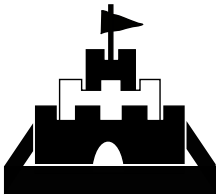

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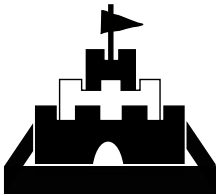

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- Hardware-enforced:
  - Memory Protection Keys (MPK)

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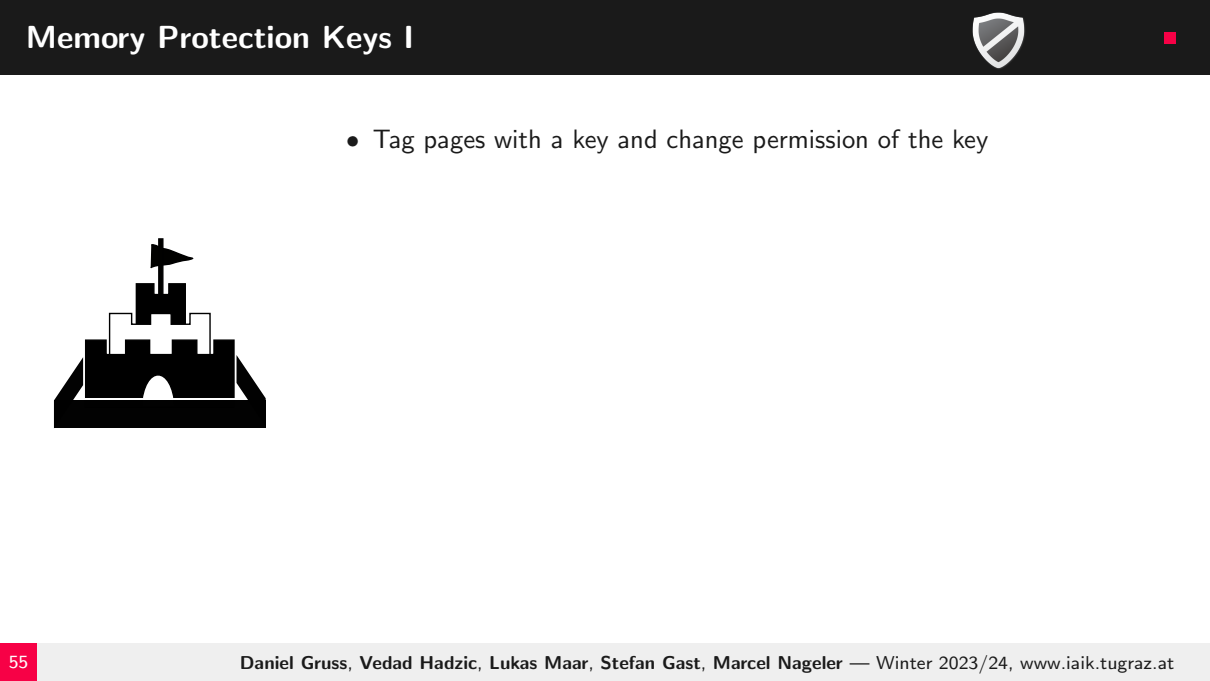

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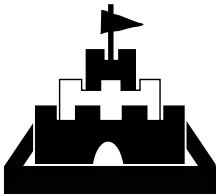

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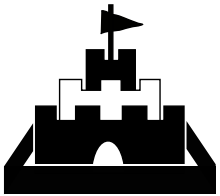

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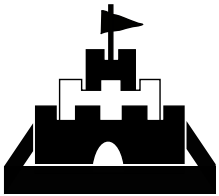

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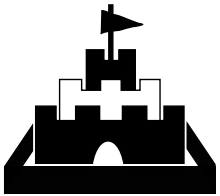

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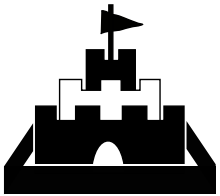

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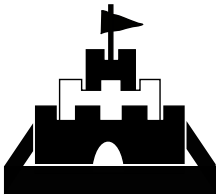

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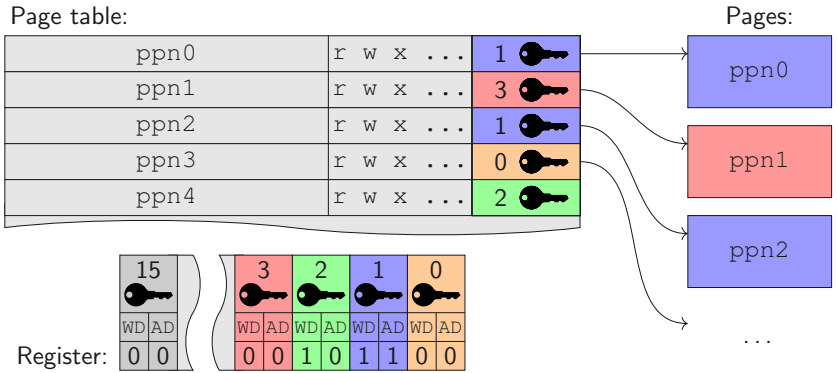
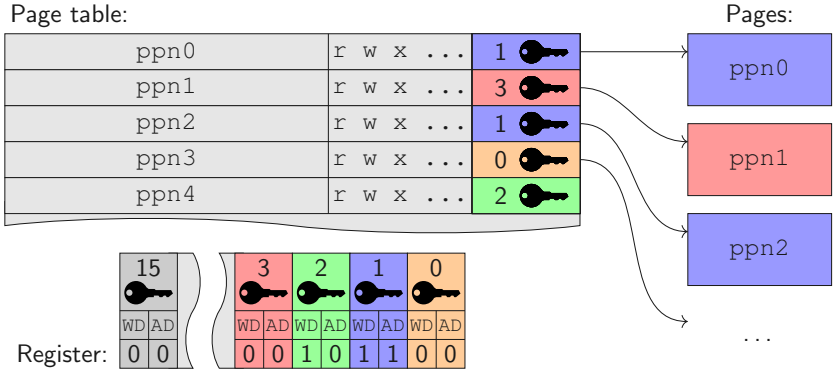


Figure 1: Working prinicple of MPK, where `AD` and `WD` stands for access and write disable, respectively. Pages tagged with key 0 are write- and access-permitted, while pages tagged with key 1 are write- and access-prohibited, and pages tagged with key 2 are only write-prohibited.



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Process Sandboxing


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  - Kernel does the filtering (e.g., executes the BPF program) on every system call
  - On a filter violation: deny syscall, send signal, kill program ...

Seccomp Example I

```c
#include <stdio.h>          /* printf */
#include <sys/prctl.h>      /* prctl */
#include <linux/seccomp.h> /* seccomp's constants */
#include <unistd.h>         /* dup2: just for test */

int main() {
  printf("step 1: unrestricted\n");
  prctl(PR_SET_SECCOMP, SECCOMP_MODE_STRICT); // Enable filtering
  printf("step 2: only 'read', 'write', '_exit' and 'sigreturn' syscalls\n");
  dup2(1, 2); // redirect stderr to stdout
  printf("step 3: !! YOU SHOULD NOT SEE ME !!\n");
  return 0;
}
```

https://blog.yadutaf.fr/2014/05/29/introduction-to-seccomp-bpf-linux-syscall-filter/

Seccomp Example II

```
dgruss@t460sdg ~ % gcc seccomp.c
dgruss@t460sdg ~ % ./a.out
step 1: unrestricted
step 2: only 'read', 'write', '_exit' and 'sigreturn' syscalls
[1]    19622 killed     ./a.out
137 dgruss@t460sdg ~ %
```

Seccomp Example III

```c
int main() {
  printf("step 1: init\n");
  prctl(PR_SET_NO_NEW_PRIVS, 1);
  prctl(PR_SET_DUMPABLE, 0);      // ptrace on this process / childs is not allowed
  scmp_filter_ctx ctx;
  ctx = seccomp_init(SCMP_ACT_KILL);                          // Denylist everything
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(rt_sigreturn), 0);   // Allowlist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(exit), 0);           // Allowlist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(exit_group), 0);     // Allowlist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(read), 0);           // Allowlist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(write), 0);          // Allowlist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(dup2), 2,            // Allowlist
                   SCMP_A0(SCMP_CMP_EQ, 1), SCMP_A1(SCMP_CMP_EQ, 2)); // Allowlist
  seccomp_load(ctx);
  printf("step 2: only 'write' and dup2(1, 2) syscalls\n");
  dup2(1, 2);    // redirect stderr to stdout
  printf("step 3: stderr redirected to stdout\n");
  dup2(2, 42);   // redirect stderr to stdout
}
```

Seccomp Example IV

```
dgruss@t460sdg ~ % gcc seccomp.c -lseccomp && ./a.out
step 1: init
step 2: only 'write' and dup2(1, 2) syscalls
step 3: stderr redirected to stdout
[1]    23312 invalid system call  ./a.out
159 dgruss@t460sdg ~ %
```

Challenge #7 - Secwrap

Write a secure wrapper binary

- Usage: `./secwrap <command>`
- The wrapper shall start the program specified by `<command>`
- Anything `<command>` does may not be allowed to create new processes!

→ Very convenient to use :)

- Upload your wrapper binary at `https://challenges.sasectf.student.iaik.tugraz.at/secwrap/index.php`
- If it is correct, you will get the flag
- Test system is Debian 11.8, kernel 5.10.0-26

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Simple sandboxing with Seccomp

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- Example: Google *sandbox2*
  `https://developers.google.com/sandboxed-api/`

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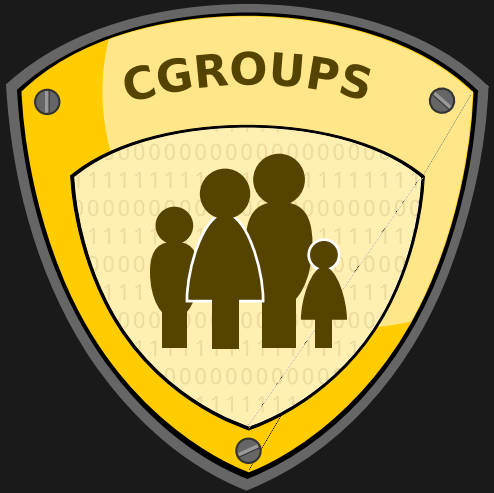
- How can we virtualize resources?


CGROUPS

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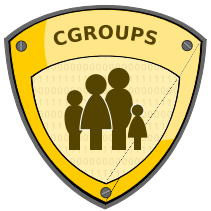

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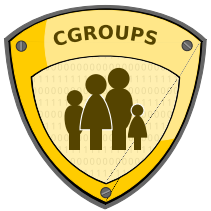

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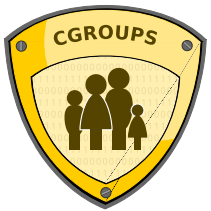

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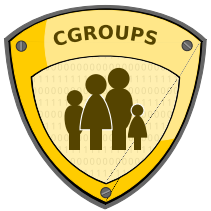

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  - Can prevent some Denial-of-Service (DoS) attacks
  - Cannot prevent privilege escalation


NAMESPACES

Namespaces

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Docker Containers

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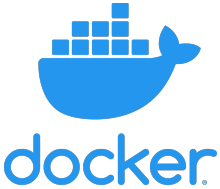

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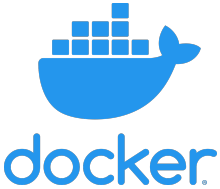

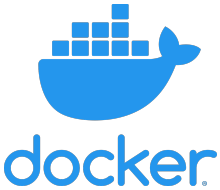

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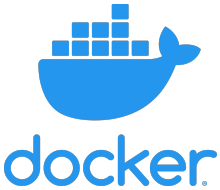

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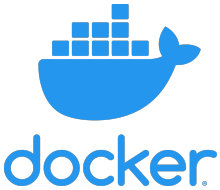

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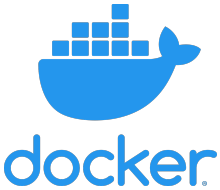

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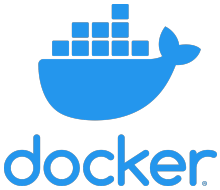

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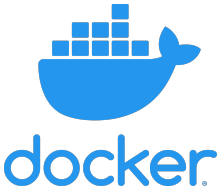

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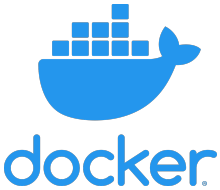

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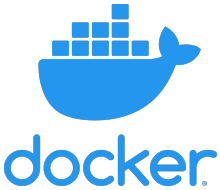

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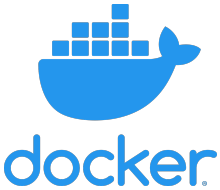

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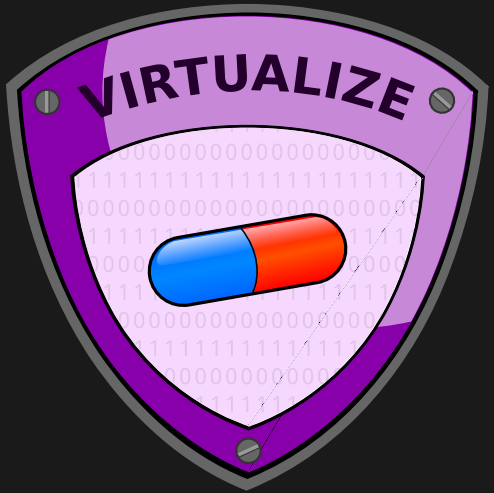
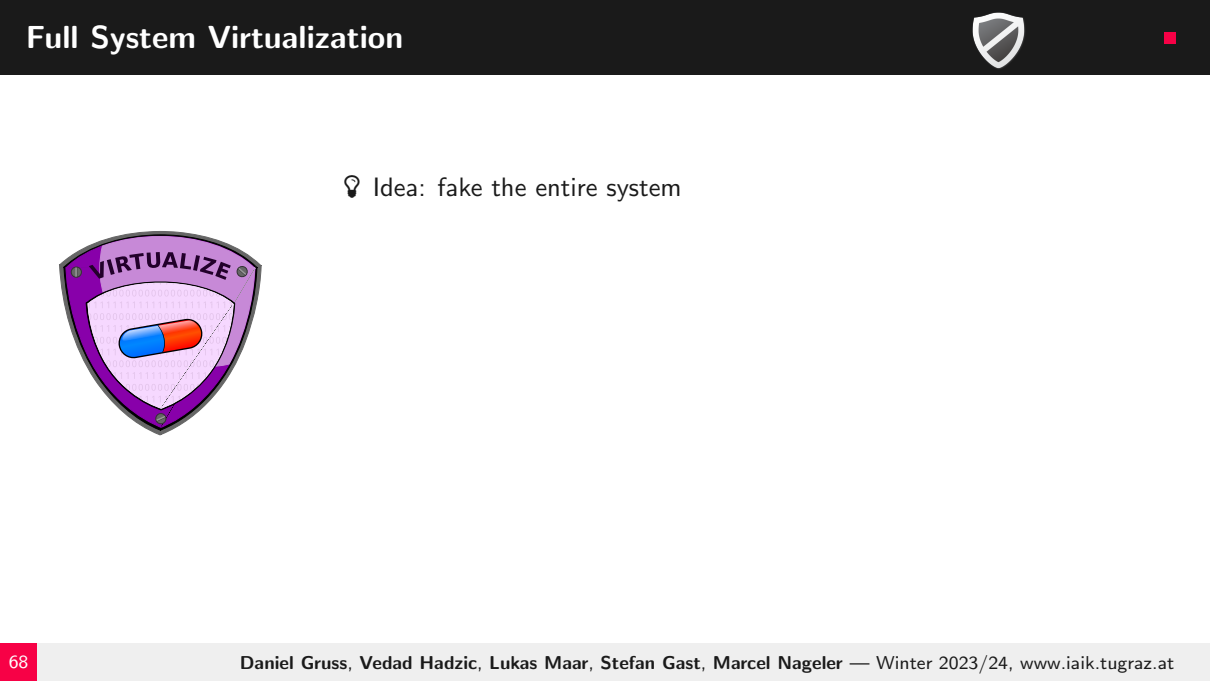
  GVisor/Kata to harden Docker containers

Virtualization


VIRTUALIZE

Full System Virtualization



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- Is there an end to this recursive problem?

Enclaves


ENCLAVES

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  - Example: Intel SGX/TDX, AMD-SEV, ARM Trustzone

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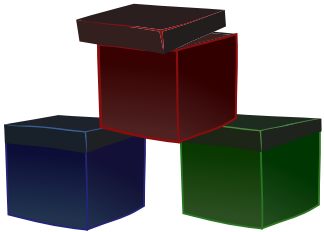
Summary & Outlook

Privilege Minimization Overview



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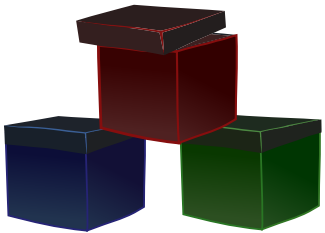

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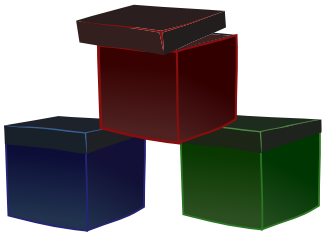

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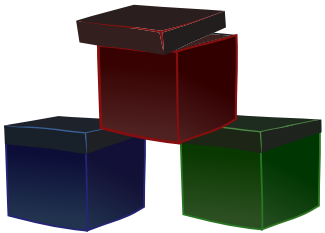

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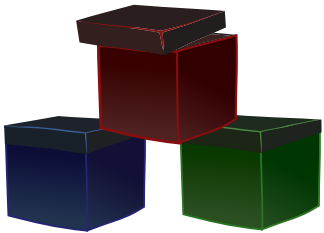
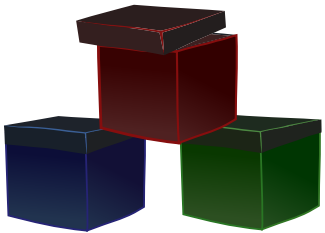
Isolation techniques





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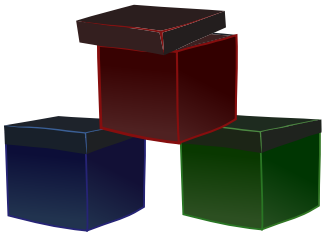

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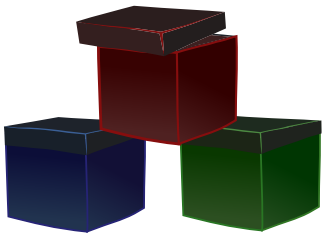

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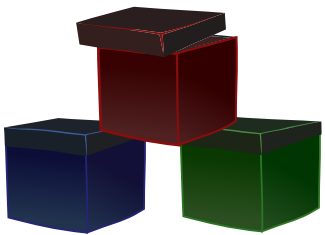

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  - Reverse sandbox

Summary

Recap: Defense In Depth

Attacker's perspective

- Vulnerability discovery ☑
- Exploitation ☑
- Privilege elevation ☑

Defender's perspective

- Vulnerability prevention ☑
- Exploit prevention ☑
- Privilege minimization ☑

Questions?


OUR DEVICES ARE NOW 100% SECURE.
I TURNED THEM ALL OFF.
HOW DID YOU DO THAT?
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