CSE551: Advanced Computer Security

8. Canary & DEP

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Department of Computer Science and Engineering

The slide is based on Prof. Sang Kil Cha's lecture slide

Project Checkpoint

- Submit a single PDF file consisting of multiple presentation slides!
- For this checkpoint, there will be no presentation session; only the checkpoint submission is required
- Due: 10/23, 11:59PM

Project Checkpoint

- You should upload a single PDF file on BlackBored.
- The name of the PDF file should have the following format: `[your ID-last name.pdf]`
  - If your name is Gil-dong Hong, and your ID is 20231234, then you should submit a file named “20231234-Hong.pdf”
  - If your team consists of two people, each member must submit a PDF file
- Submit a single PDF file consisting of multiple presentation slides. The PDF should include the following topics and contents (must be written in English!):
  - Introduction
  - Background
  - Motivation
  - Approach
  - Your Progress

How to defend against buffer overflows?

Defense: Prevention vs. Mitigation

- ***Preventing*** buffer overflows
  - Buffer overflows will never happen

- ***Mitigating*** buffer overflows
  - Buffer overflows will happen, but will be ***hard to exploit them***

How to Prevent Buffer Overflows?

Do NOT use C/C++!

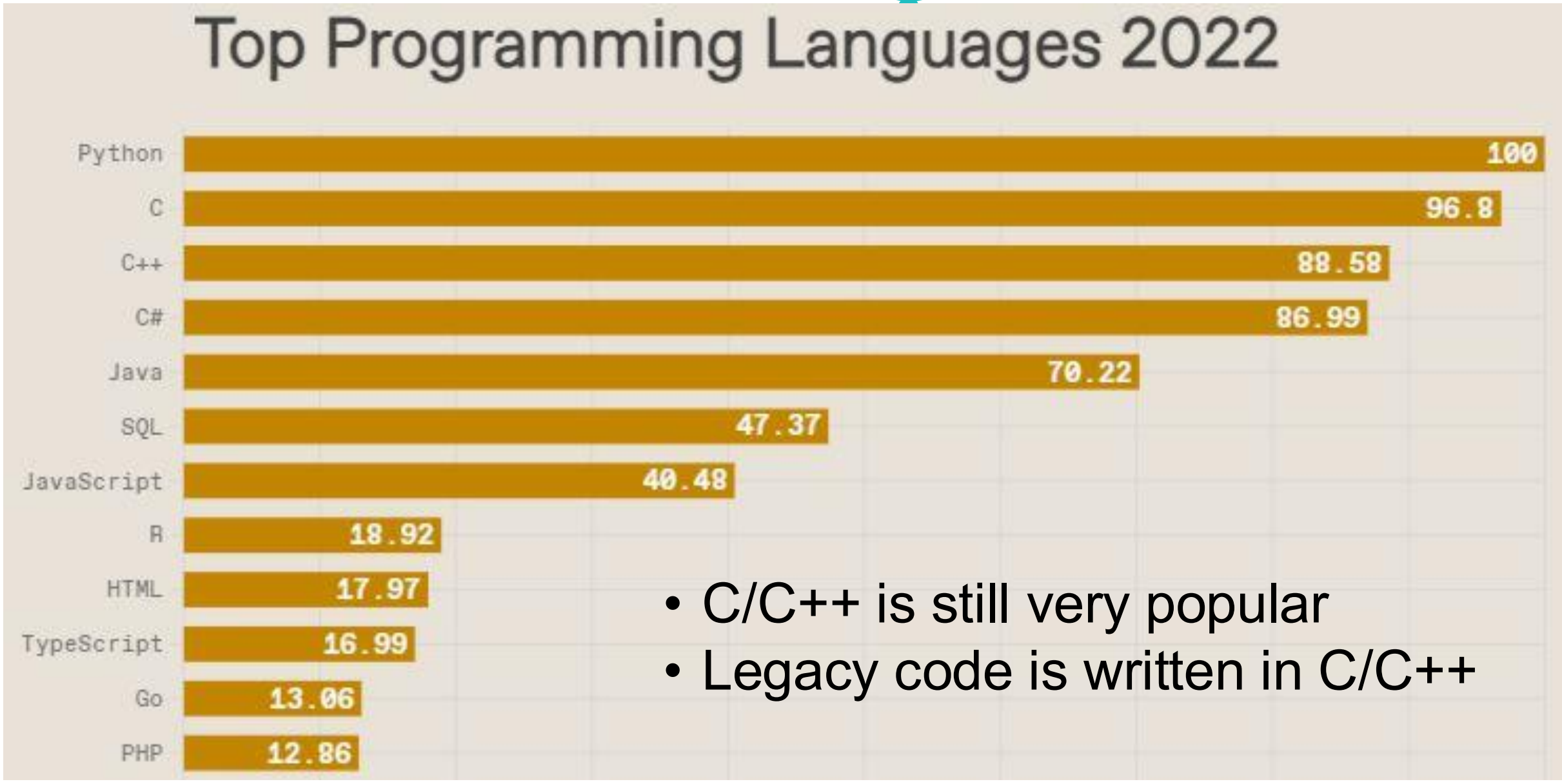
C is the root of evil!

Easy to Prevent Buffer Overflows!

Have you ever seen buffer overflows in other safe languages such as F#, OCaml, Haskell, Python, etc.?

```
>>> x = array('l', [1,2,3])
>>> x[4]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: array index out of range
```

Unfortunately though ...



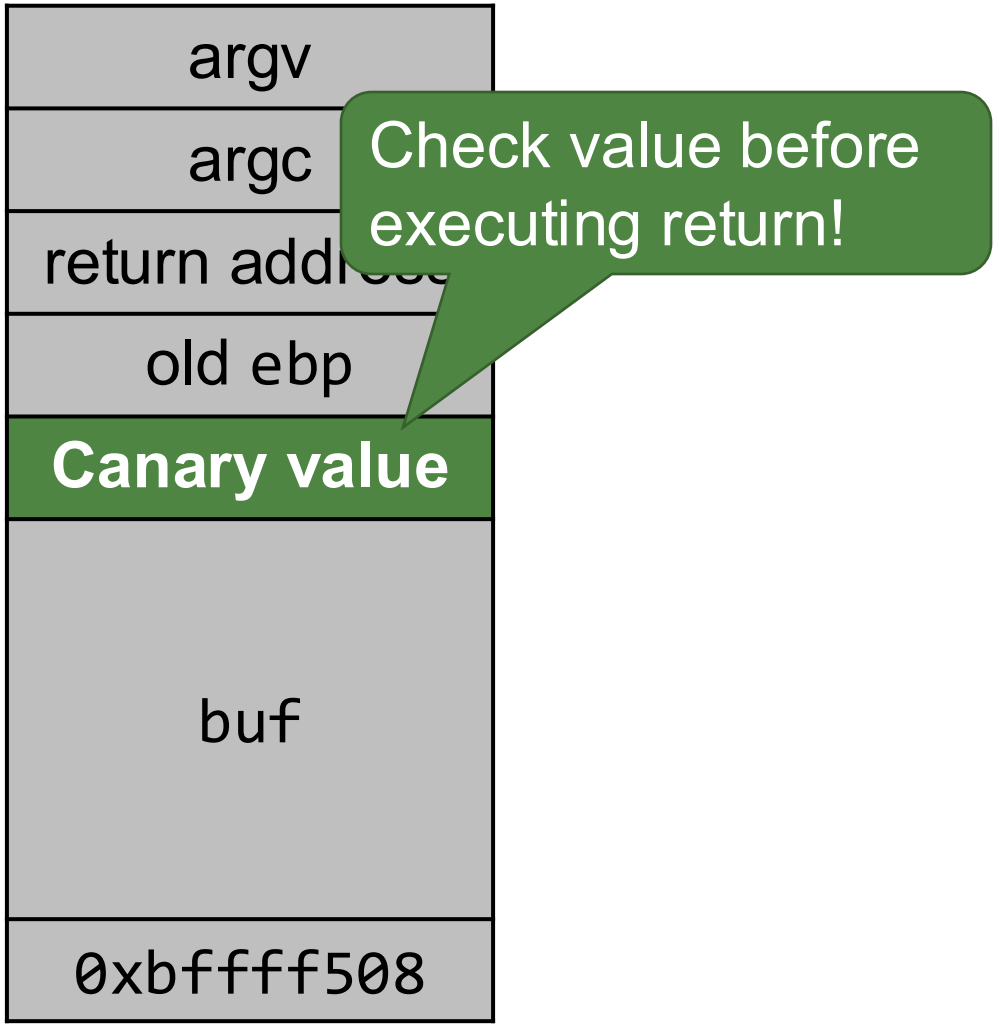
- C/C++ is still very popular
- Legacy code is written in C/C++

Okay …

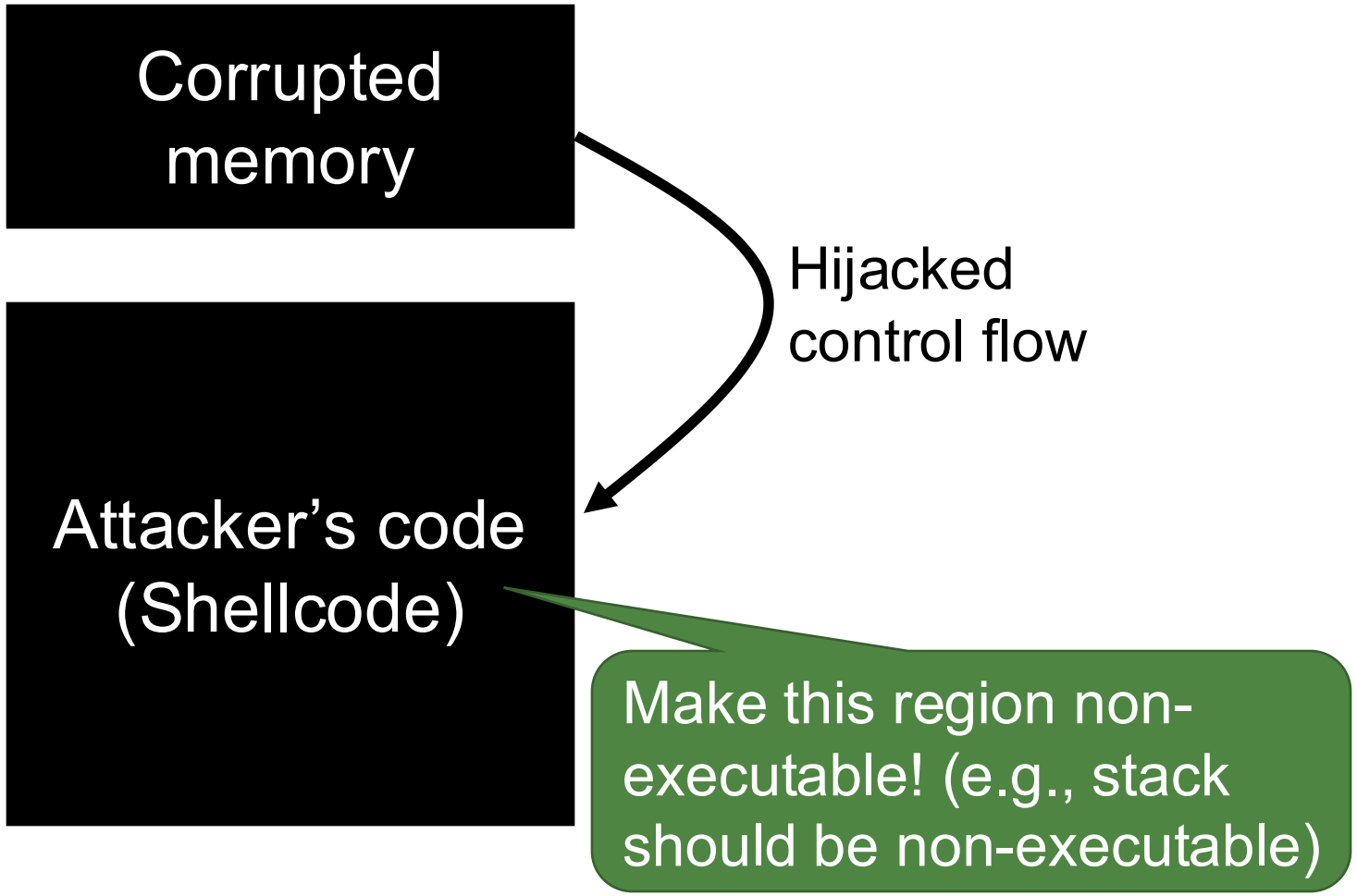
Let’s mitigate it then ☹

Preview: Mitigating Memory Corruption Bugs

Mitigation #1: Canary



Mitigation #2: NX (No eXcute)



Buffer Overflow Mitigation #1:
Canary

Image from https://naturalworldpets.co.uk/blogs/pet-advice/guide-to-caring-for-canaries

Canary in a Cole Mine

- The bird would act as an early warning for harmful gas

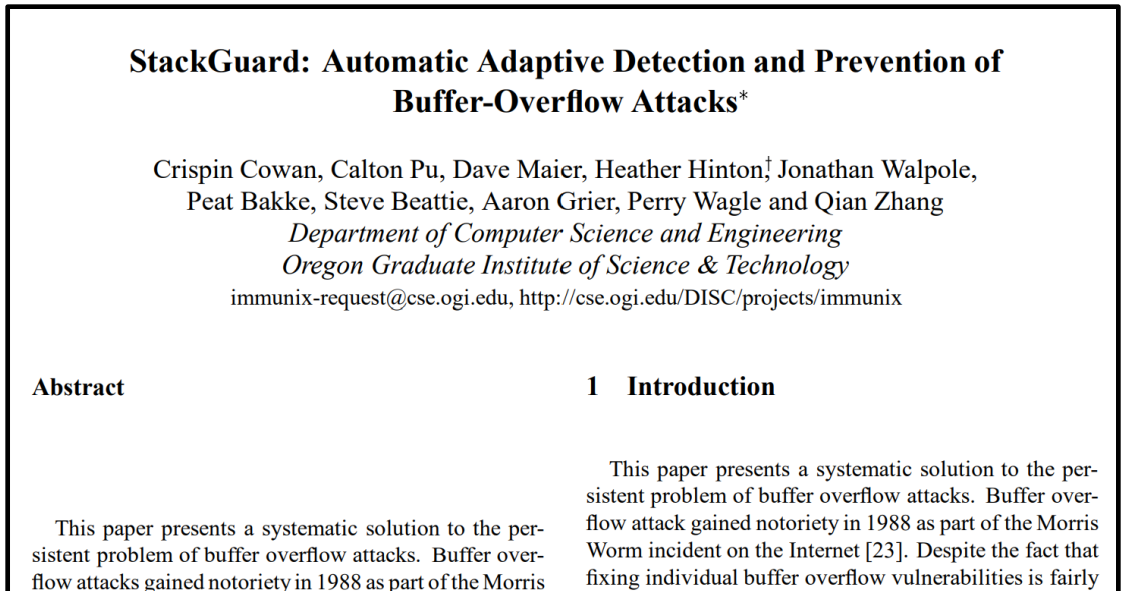
Image from https://www.forbes.com/sites/kionasmith/2019/12/31/the-canary-in-the-coal-mine-isnt-ancient-history

Mitigating Buffer Overflows with Canary

- Early warnings of buffer overflows

- First introduced in 1998

StackGuard: Automatic Adaptive Detection and Prevention of Buffer-Overflow Attacks, ***USENIX Security 1998***



StackGuard: Automatic Adaptive Detection and Prevention of Buffer-Overflow Attacks*

Crispin Cowan, Calton Pu, Dave Maier, Heather Hinton†, Jonathan Walpole,
Peat Bakke, Steve Beattie, Aaron Grier, Perry Wagle and Qian Zhang
Department of Computer Science and Engineering
Oregon Graduate Institute of Science & Technology
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Abstract

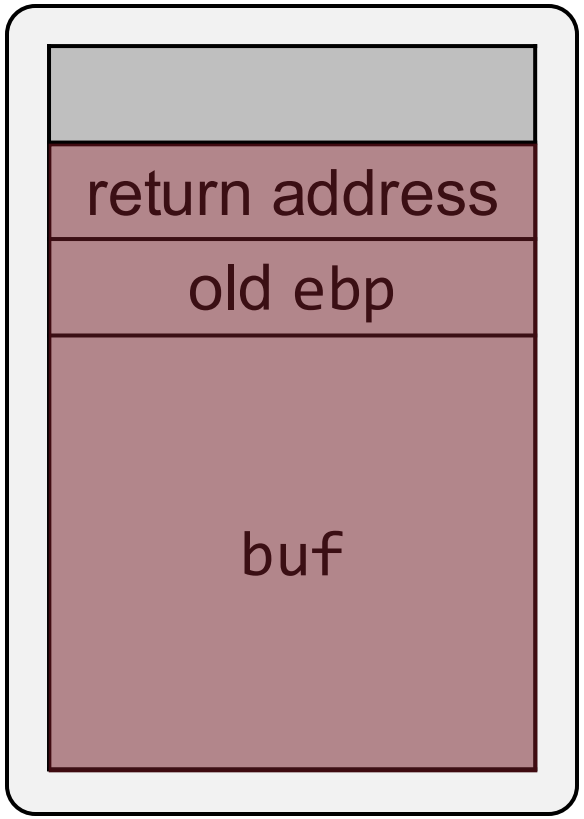
This paper presents a systematic solution to the persistent problem of buffer overflow attacks. Buffer overflow attacks gained notoriety in 1988 as part of the Morris

1 Introduction

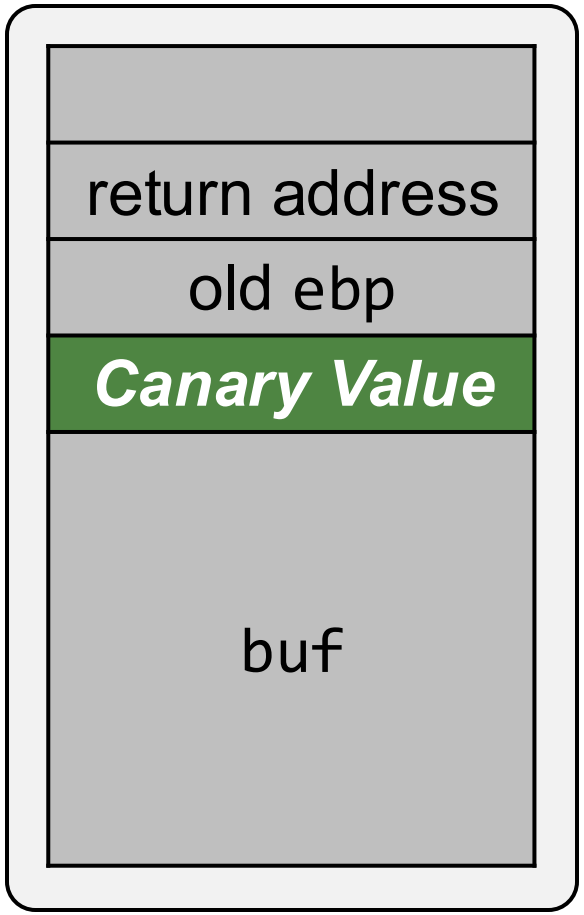
This paper presents a systematic solution to the persistent problem of buffer overflow attacks. Buffer overflow attack gained notoriety in 1988 as part of the Morris Worm incident on the Internet [23]. Despite the fact that fixing individual buffer overflow vulnerabilities is fairly

Stack Canary (a.k.a. Stack Cookie)

- Key idea: insert a checking value before the return address



Without stack canary



With stack canary

Stack Canary (a.k.a. Stack Cookie)

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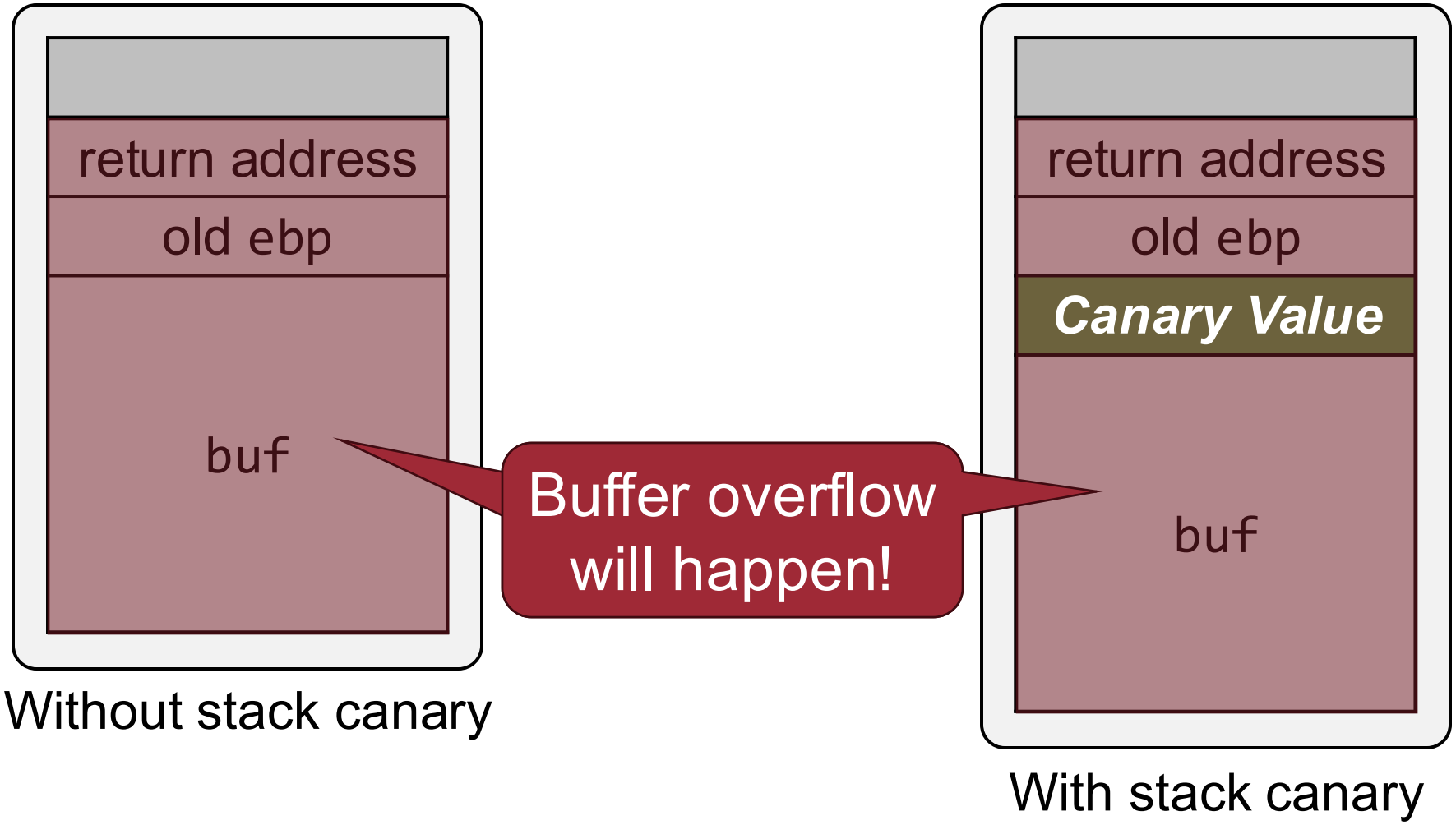

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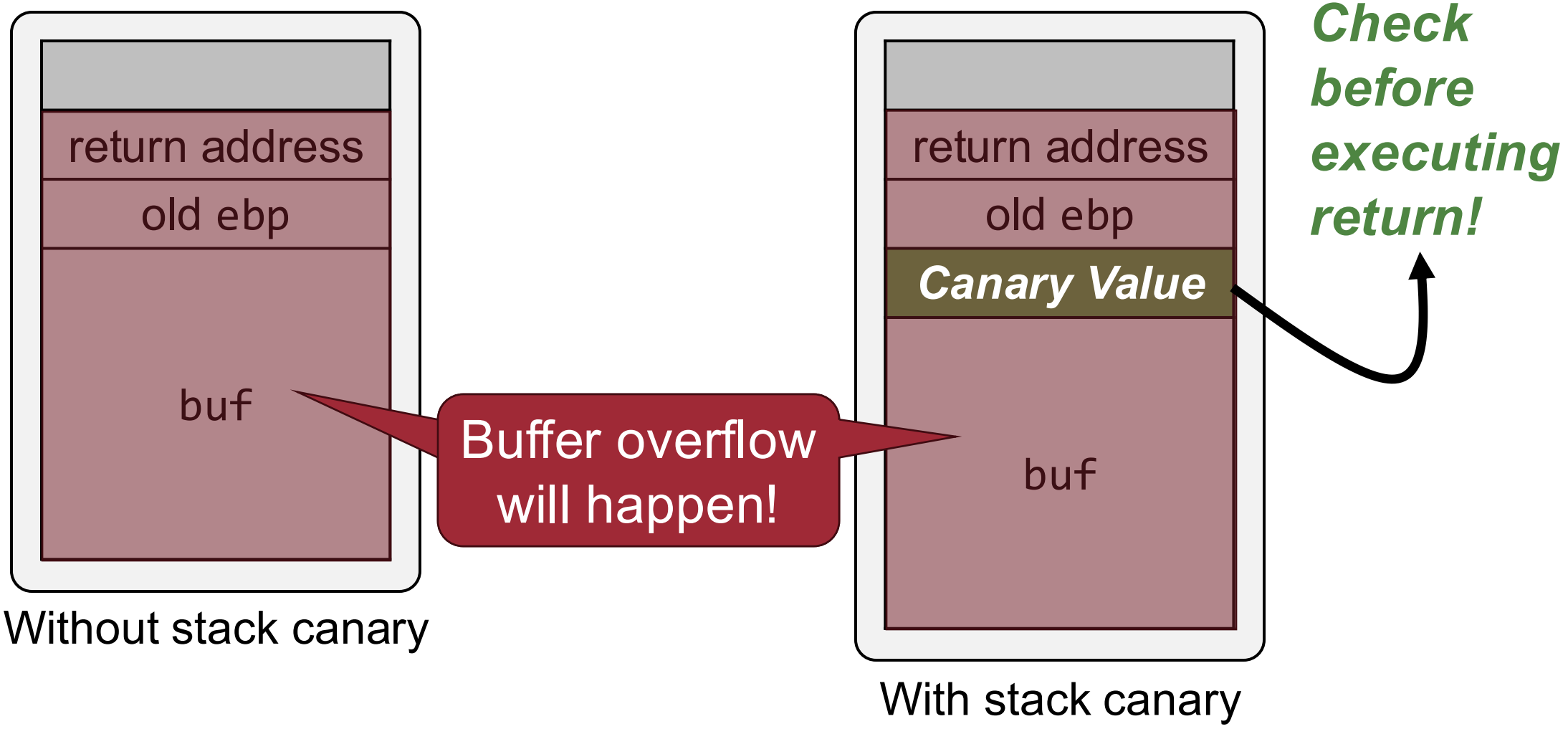


Stack Canary (a.k.a. Stack Cookie)

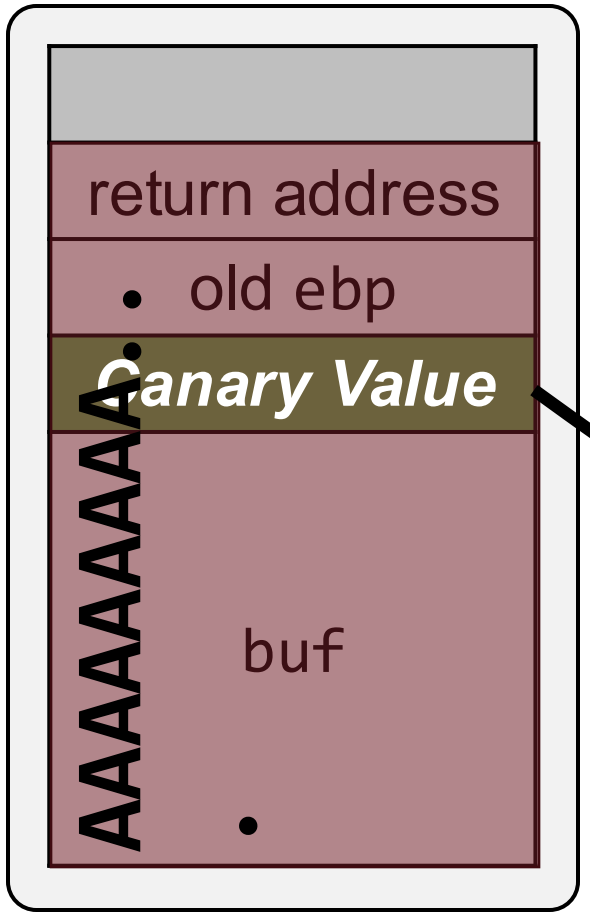
- Key idea: insert a checking value before the return address

Before executing return, check…

(Inserted canary value) ≠ (Current canary value)

Canary Value ≠ **0x41414141**

Overflow is occurred!
Stop the program

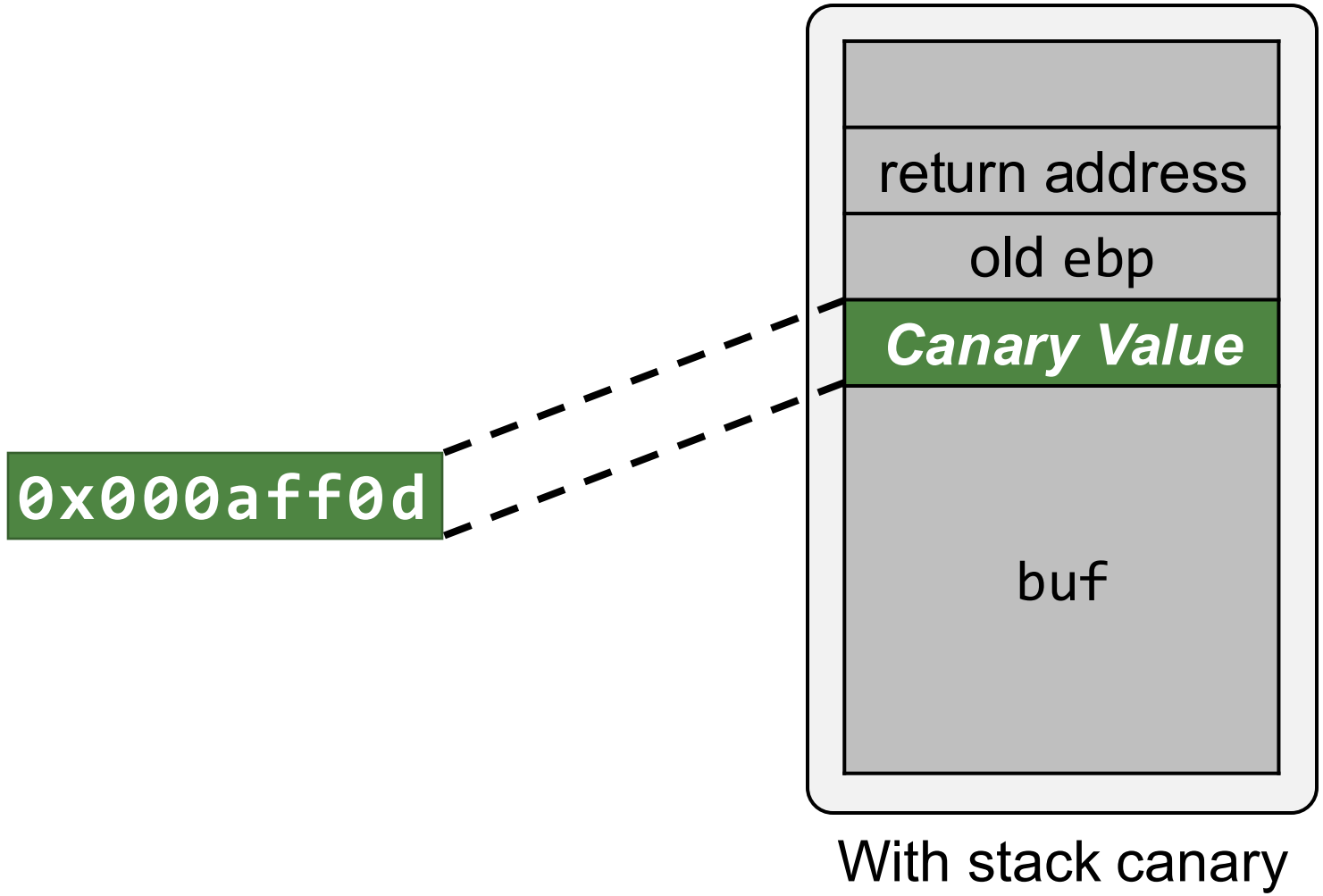


Check before executing return!

With stack canary

StackGuard (1998)

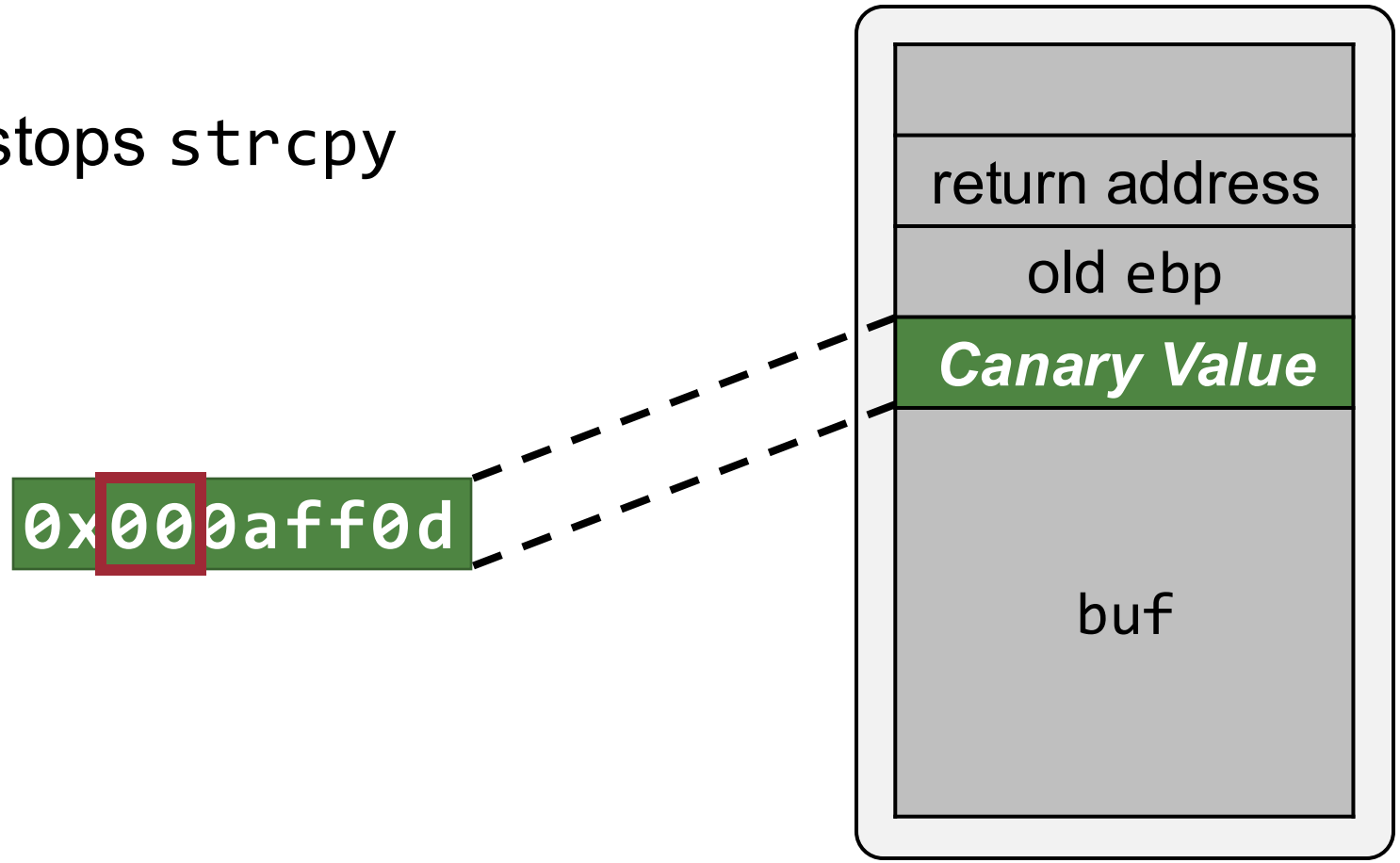
- Uses a constant canary value `0x000aff0d`



StackGuard (1998)

- Uses a constant canary value `0x000aff0d`

  ✓ `0x00` stops `strcpy`

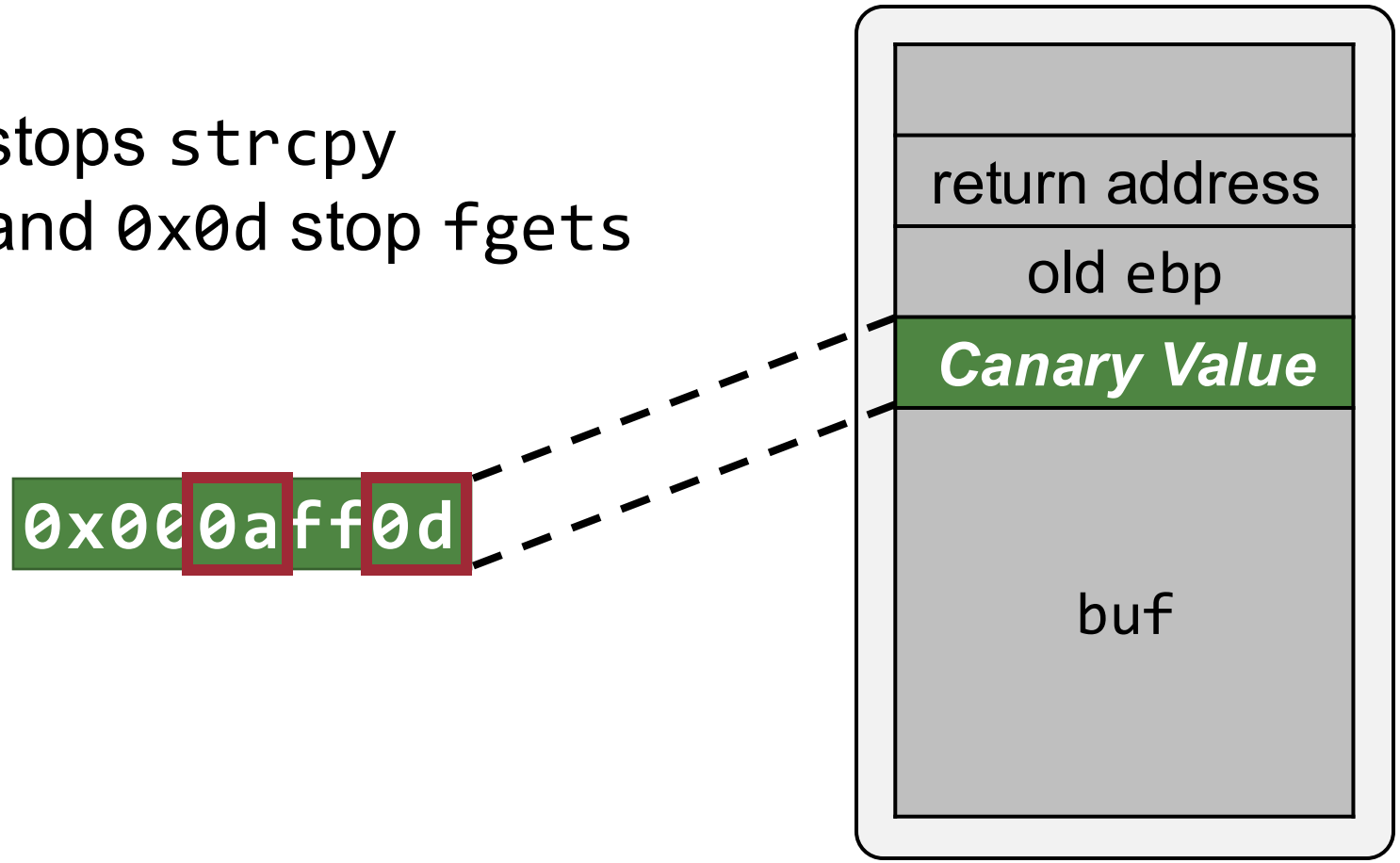


With stack canary

StackGuard (1998)

- Uses a constant canary value `0x000aff0d`

  - ✓ `0x00` stops `strcpy`
  - ✓ `0x0a` and `0x0d` stop `fgets`

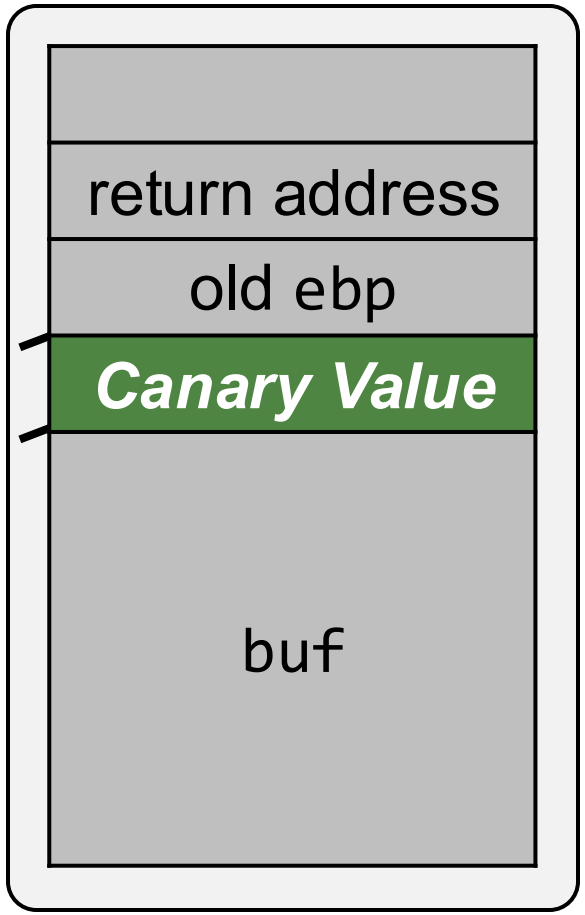


With stack canary

StackGuard (1998)

- Uses a constant canary value `0x000aff0d`

✓ `0x00` stops `strcpy`
✓ `0x0a` and `0x0d` stop `fgets`
✓ `0xff` stops `EOF` checks



With stack canary

Problem of Using a Constant Canary Value

memcpy?

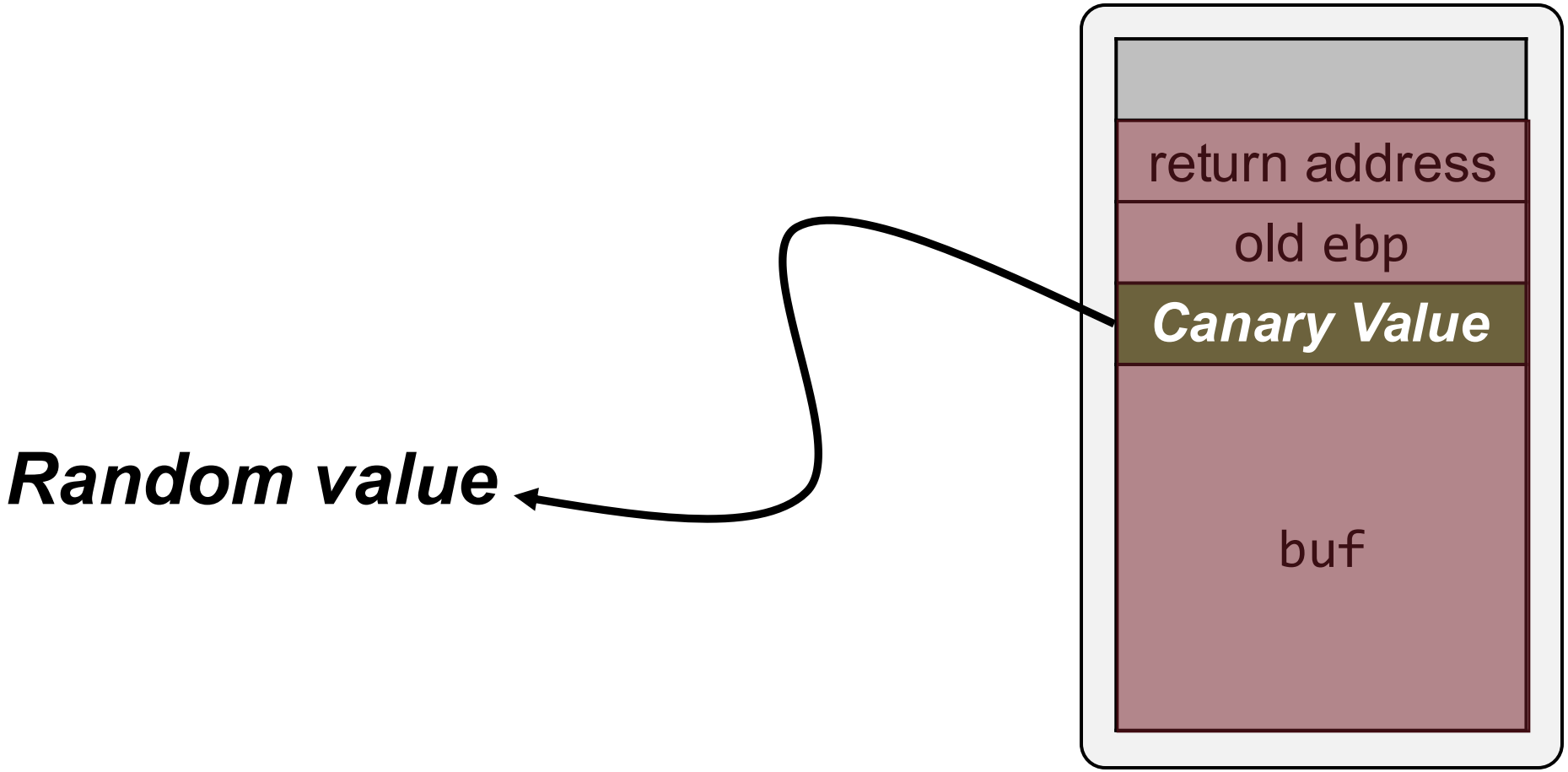
Problem of Using a Constant Canary Value


```
memcpy(void dest, void src, size_t n)
```

The `memcpy()` function copies **`n` bytes** from memory area `src` to memory area `dest`

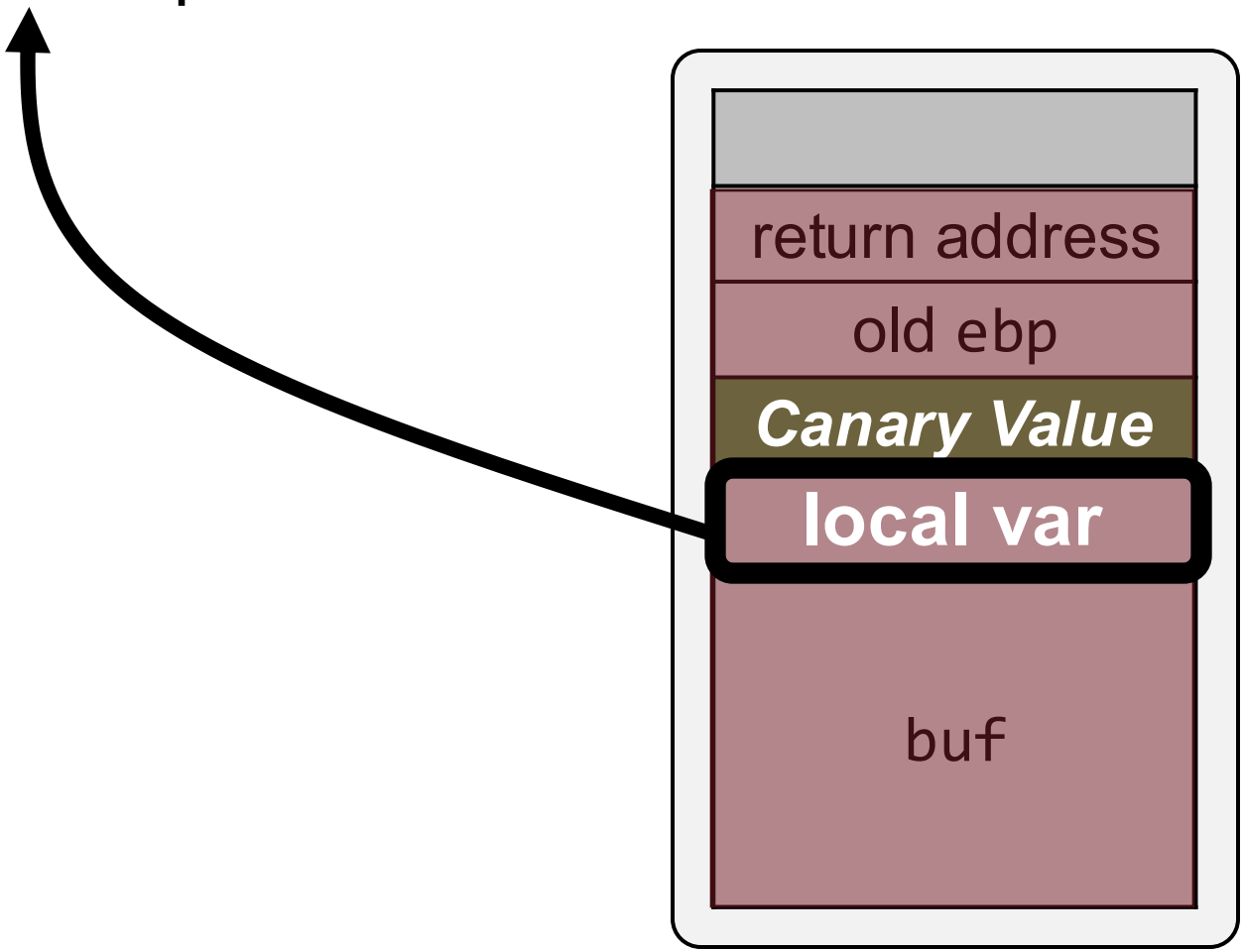
Random Canaries

- Pick a ***random value*** at process initialization, put it on the stack



Problem Still Exists

- Local variables are not protected!



With stack canary

Solution: Reordering Local Variables

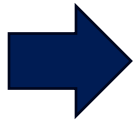
- Always put local buffers after local pointers
- This idea is implemented by GCC 4.1 in 2005

GCC Stack Canary Implementation


```
80483fb: push  ebp
80483fc: mov   ebp, esp
80483fe: sub   esp, 0x100
8048404: push  DWORD PTR [ ebp+0x8 ]
8048407: lea   eax, [ ebp-0x100 ]
804840d: push  eax
804840e: call  80482d0 <strcpy@plt>
8048413: add   esp, 0x8
8048416: leave
8048417: ret
```

Without stack canary

gcc -fno-stack-protector



```
804844b: push ebp
804844c: mov  ebp, esp
804844e: sub  esp,0 x108
8048454: mov  eax,DWORD PTR [ ebp+0x8 ]
8048457: mov  DWORD PTR [ ebp-0x108 ], eax
804845d: mov  eax, gs:0x14
8048463: mov  DWORD PTR [ ebp-0x4 ], eax
8048466: xor  eax, eax
8048468: push DWORD PTR [ ebp-0x108 ]
804846e: lea  eax, [ ebp-0x104 ]
8048474: push eax
8048475: call 8048320
804847a: add  esp, 0x8
804847d: mov  eax, DWORD PTR [ ebp-0x4 ]
8048480: xor  eax, DWORD PTR gs:0x14
8048487: je   804848e
8048489: call 8048310 <__stack_chk_fail@plt>
804848e: leave
804848f: ret
```

With **stack canary**

gcc -fstack-protector

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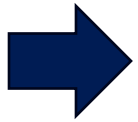

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With **stack canary**

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GCC Stack Canary Implementation

Random canary value at gs:0x14

```
                                    esp
                                    x108
                                    eax,DWORD PTR [ ebp+0x8 ]
8048457: mov                        RD PTR [ ebp-0x108 ], eax
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```

With **stack canary**

gcc -fstack-protector

Who Initializes [gs:0x14]?

Runtime Dynamic Linker (RTLD) does it every time it launches **a process**

```
// Below is roughly what RTLD does at process creation time

uintptr_t ret;
int fd = open("/dev/urandom", O_RDONLY);
if (fd >= 0) {
    ssize_t len = read(fd, &ret, sizeof(ret));
    if (len == (ssize_t) sizeof(ret)) {
        // inlined assembly for moving ret to [gs:0x14]
    }
}
```

GCC Stack Canary Implementation

Random canary value at gs:0x14

Move canary value onto the stack

Why?

```
                                esp
                                x108
                                eax,DWORD PTR [ ebp+0x8 ]
8048457: mov                    RD PTR [ ebp-0x108 ], eax
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With **stack canary**

gcc -fstack-protector

GCC Stack Canary Implementation


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```

Get current canary value from stack

Compare to the original canary value

Jump to the `leave` instruction if equal

With **stack canary**

`gcc -fstack-protector`

GCC Stack Canary Implementation


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804848f: ret
```

With **stack canary**

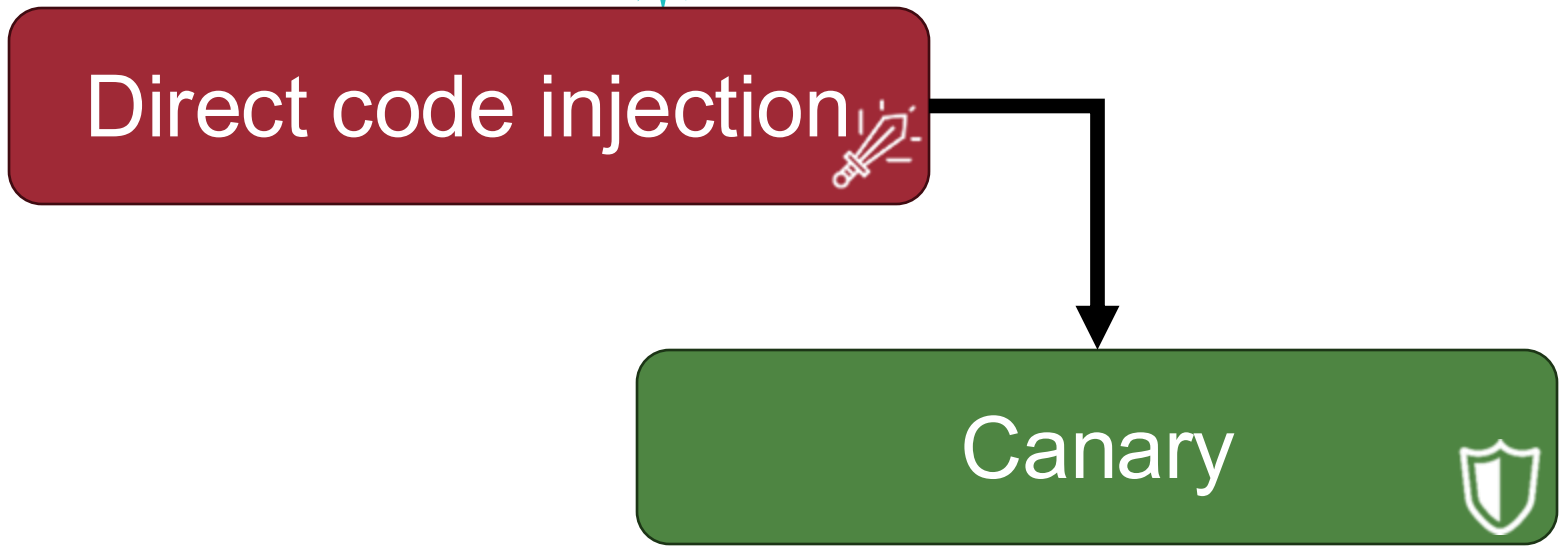
gcc -fstack-protector

Stack smashing detected!
(terminated)

GCC Canary Implementation

- Uses a random canary value for every process creation
- Puts buffers after any local pointers on the stack

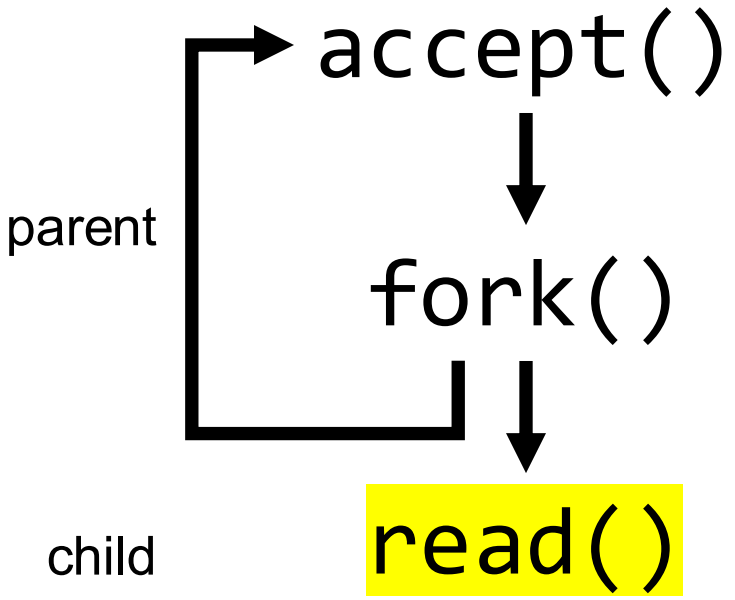
Control Hijack Attack / Defense So Far



Bypassing Canary Protection

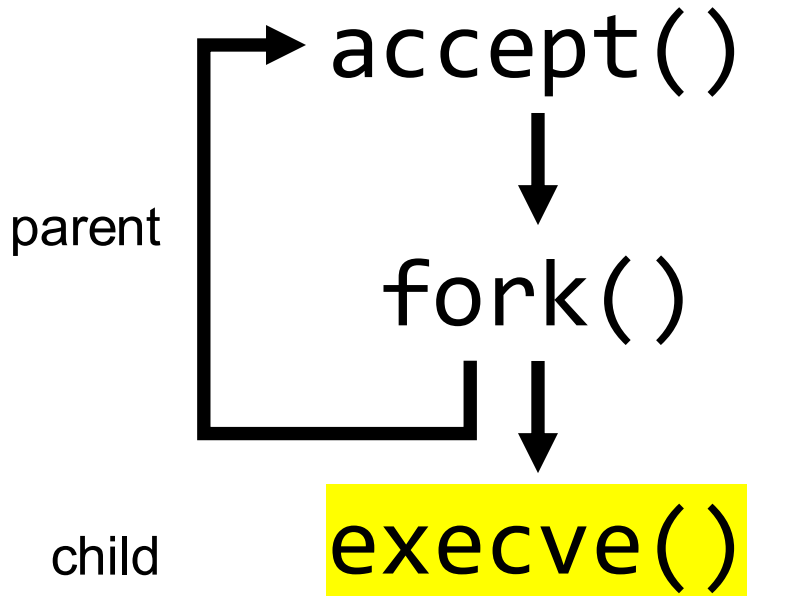
Reused Canary Value

- Uses a random canary value for ***every process creation***



Server Type #1

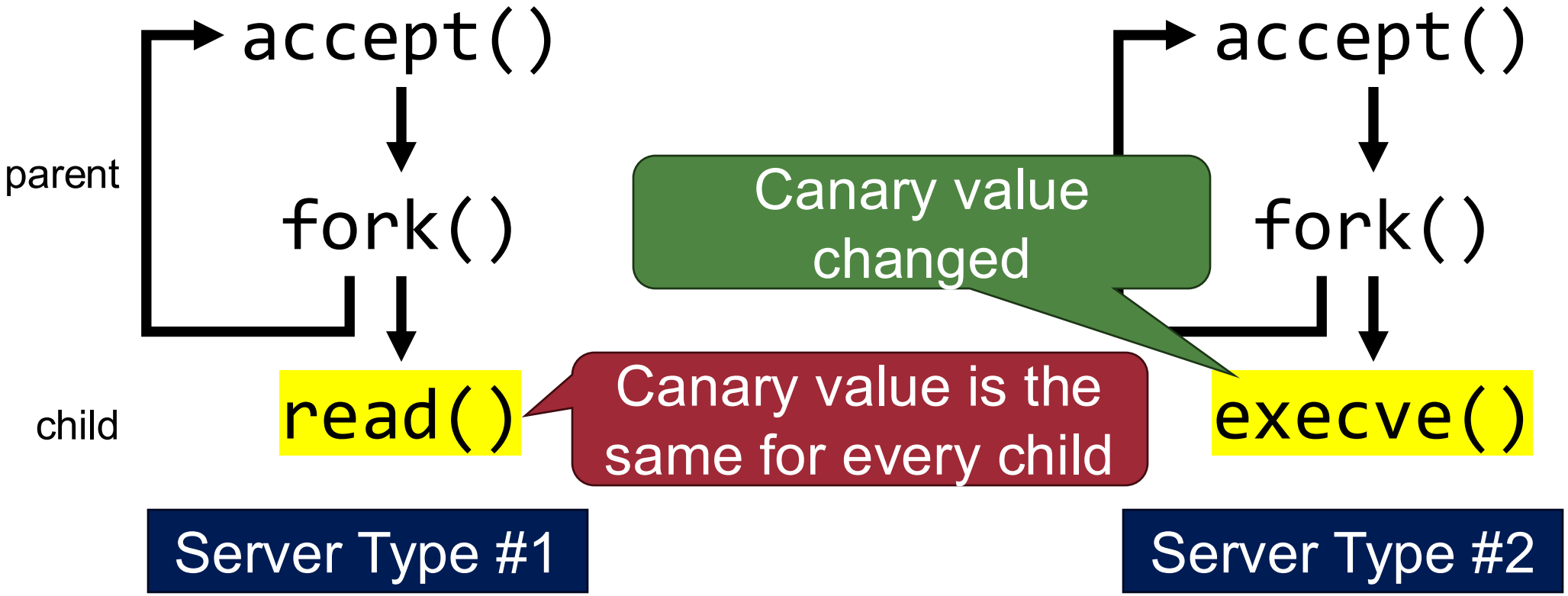
e.g., OpenSSH does this



Server Type #2

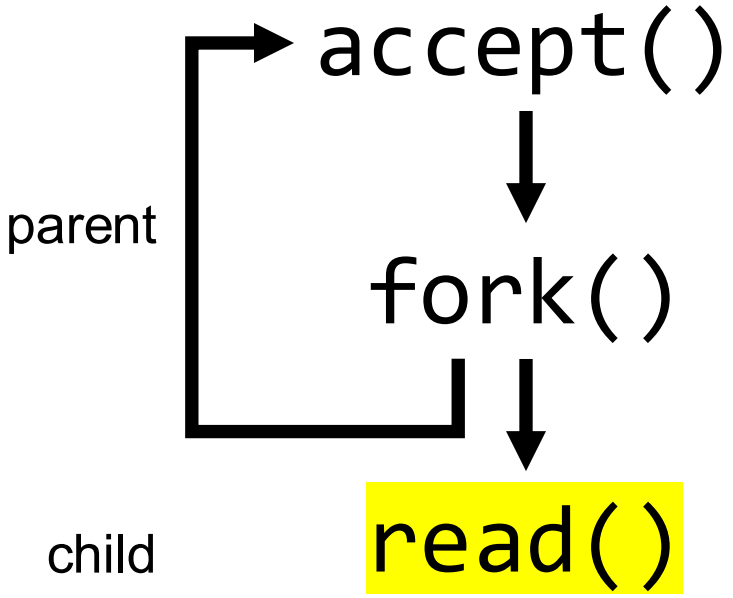
Reused Canary Value

- Uses a random canary value for ***every process creation***

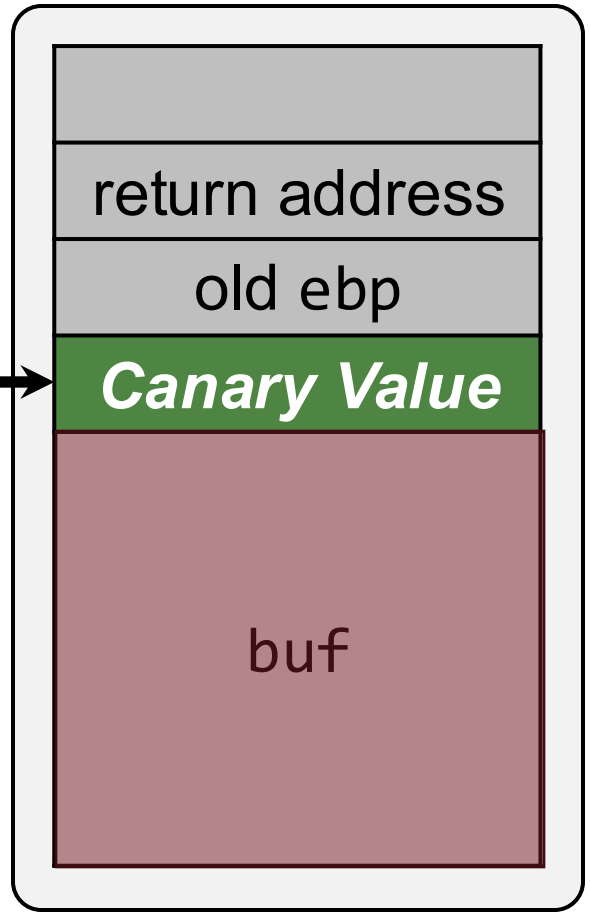


e.g., OpenSSH does this

Attack #1: Byte-by-Byte Brute Forcing



Random canary:
0x429af70c

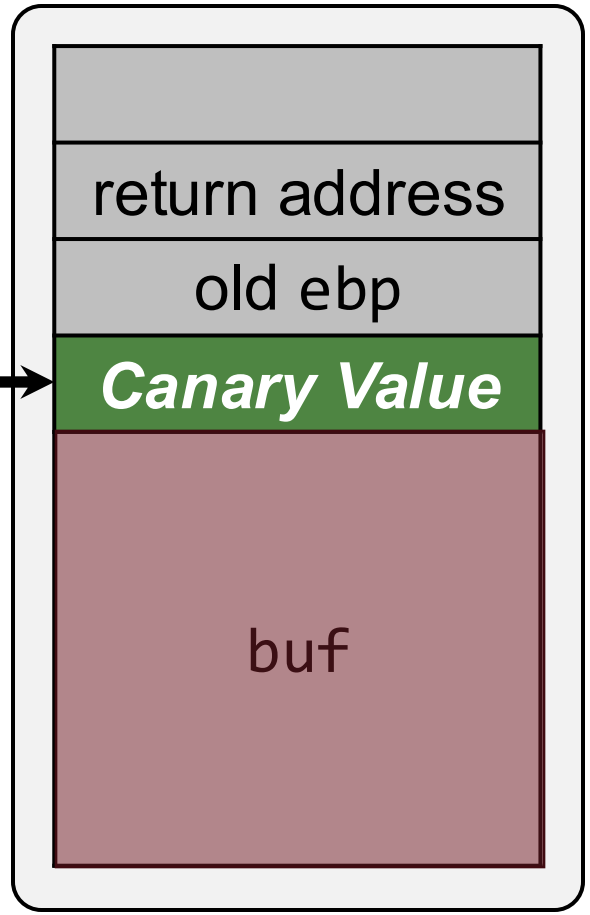


With stack canary

Attack #1: Byte-by-Byte Brute Forcing

Try to overwrite only 1 byte with a character from `\x00` to `\xff` until the program does not crash

Random canary:
`0x429af70c`



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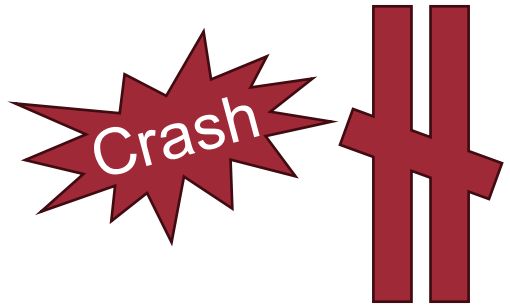
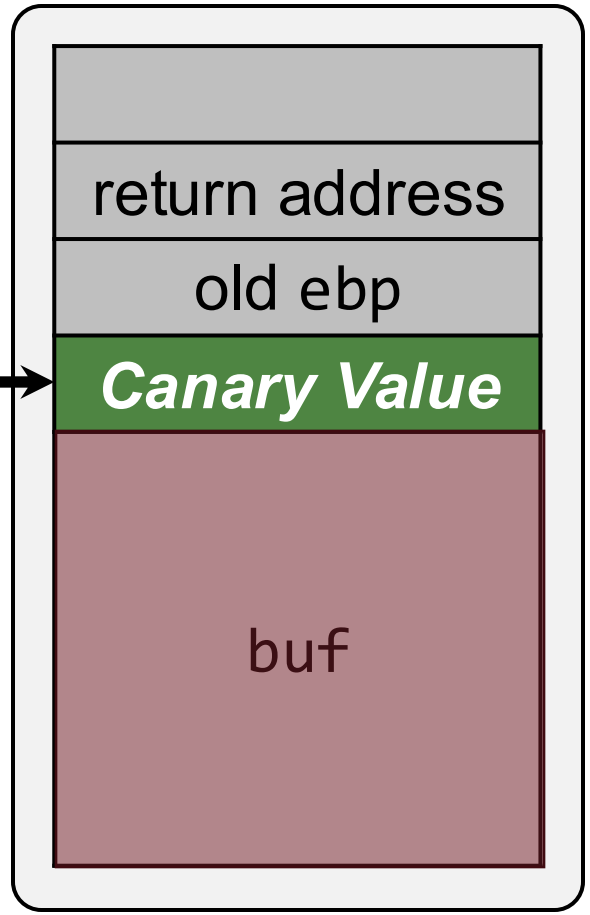


1st try: insert `\x00`



With stack canary

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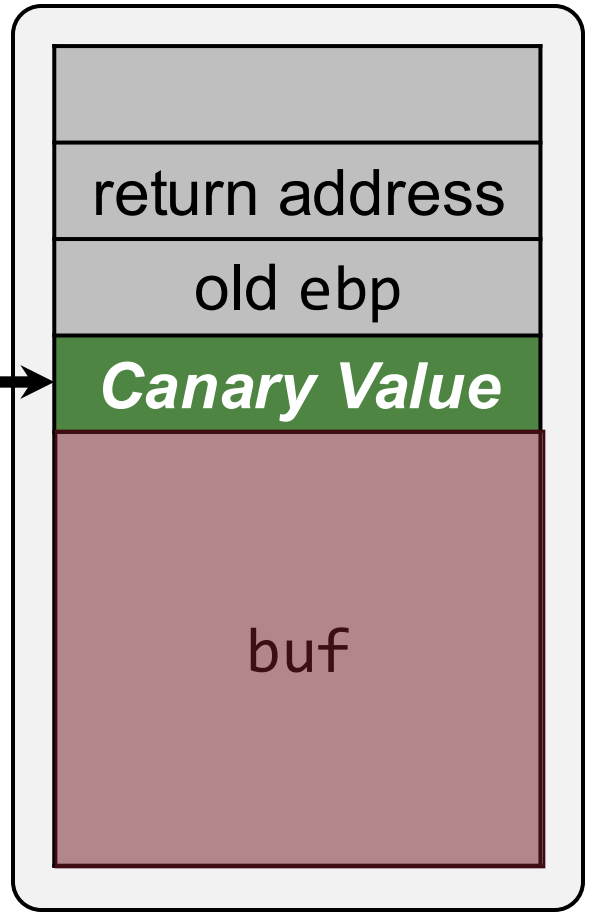
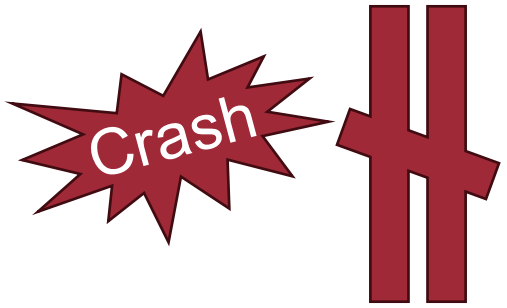


With stack canary

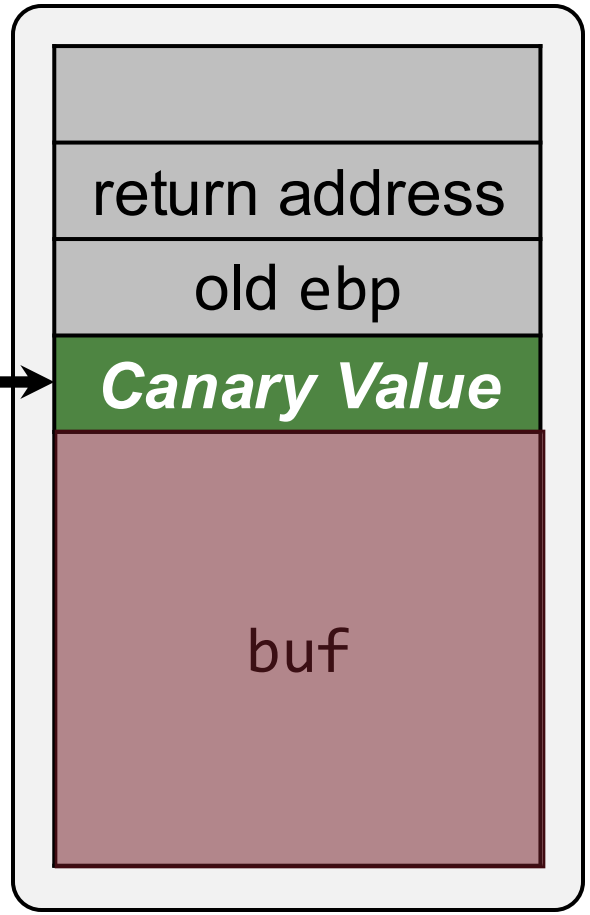


2nd try: insert `\x01`

Attack #1: Byte-by-Byte Brute Forcing

Try to overwrite only 1 byte with a character from `\x00` to `\xff` until the program does not crash

Random canary:
`0x429af70c`



With stack canary

67th try: insert `\x42`

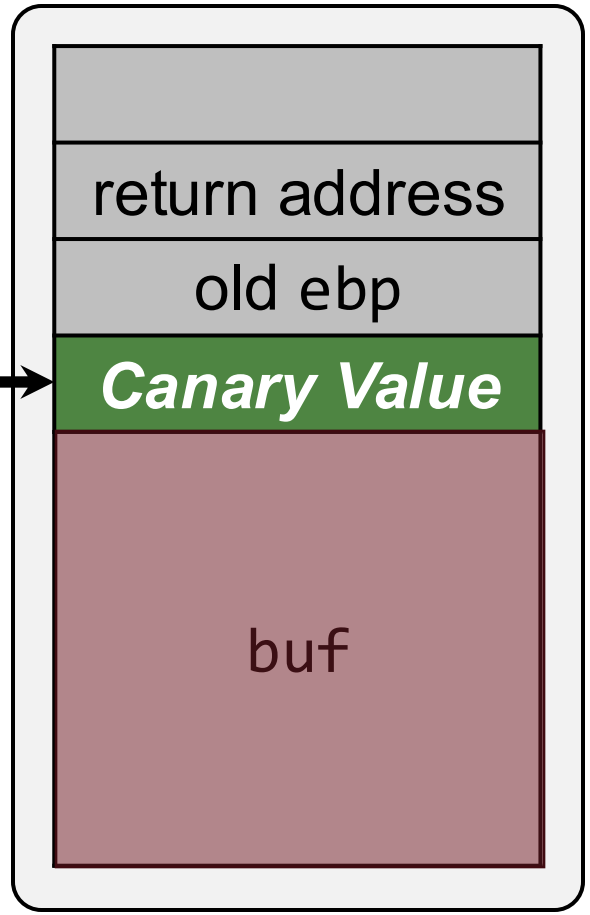
Attack #1: Byte-by-Byte Brute Forcing

Try to overwrite only 1 byte with a character from `\x00` to `\xff` until the program does not crash

Random canary:
`0x429af70c`

Do the same for all 4 bytes!
⇒ Worst case?

67th try: insert `\x42`



With stack canary

Protecting Canary Brute-Forcing Attack

(Optional Reading)

DynaGuard: Armoring Canary-based Protections against Brute-force Attacks, ***ACSAC 2015***

DynaGuard: Armoring Canary-based Protections against Brute-force Attacks

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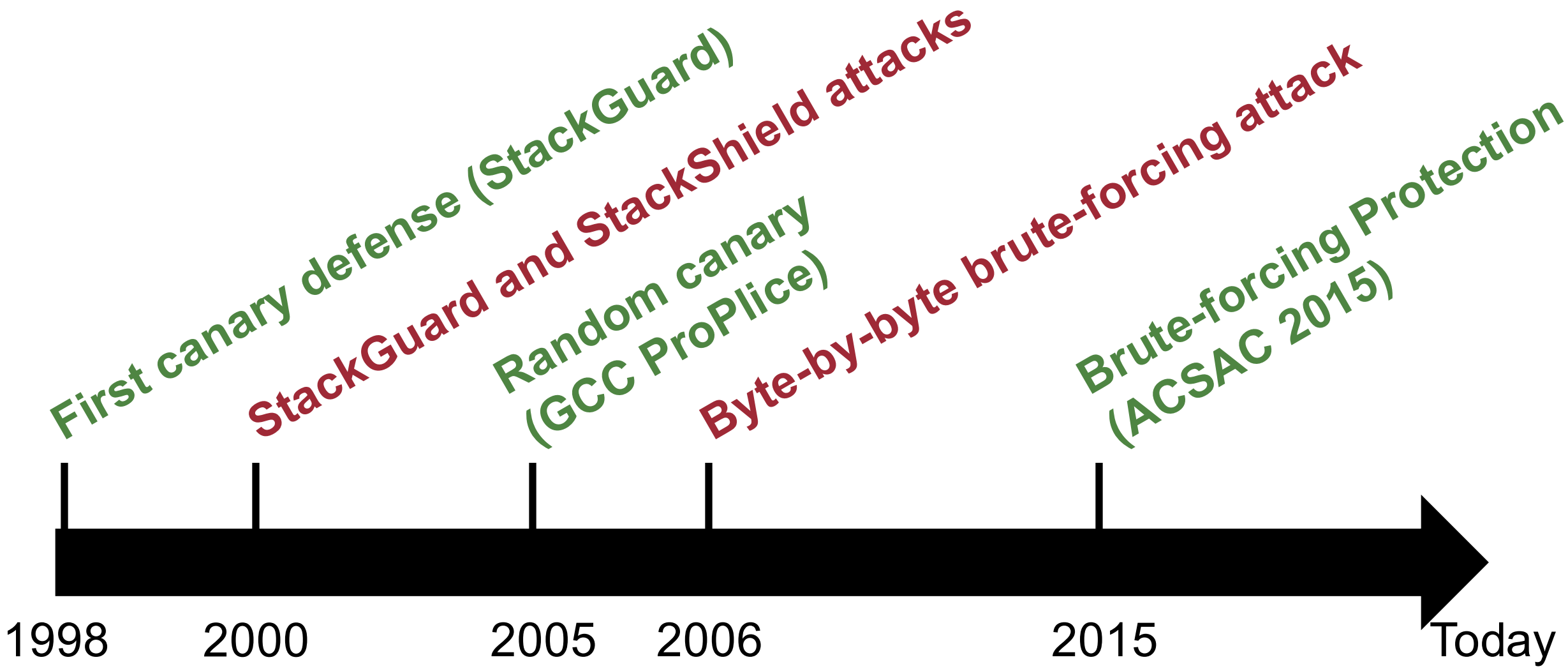
ABSTRACT

Over the past decade many exploit mitigation techniques have been introduced to defend against memory corruption attacks. W^X, ASLR, and canary-based protections are nowadays widely deployed and considered standard prac-

1. INTRODUCTION

Among the many different types of memory corruption vulnerabilities actively exploited throughout the past two decades, stack buffer overflows remain the most frequently encountered [45], and various protection mechanisms have

Canary Attack and Defense Timeline

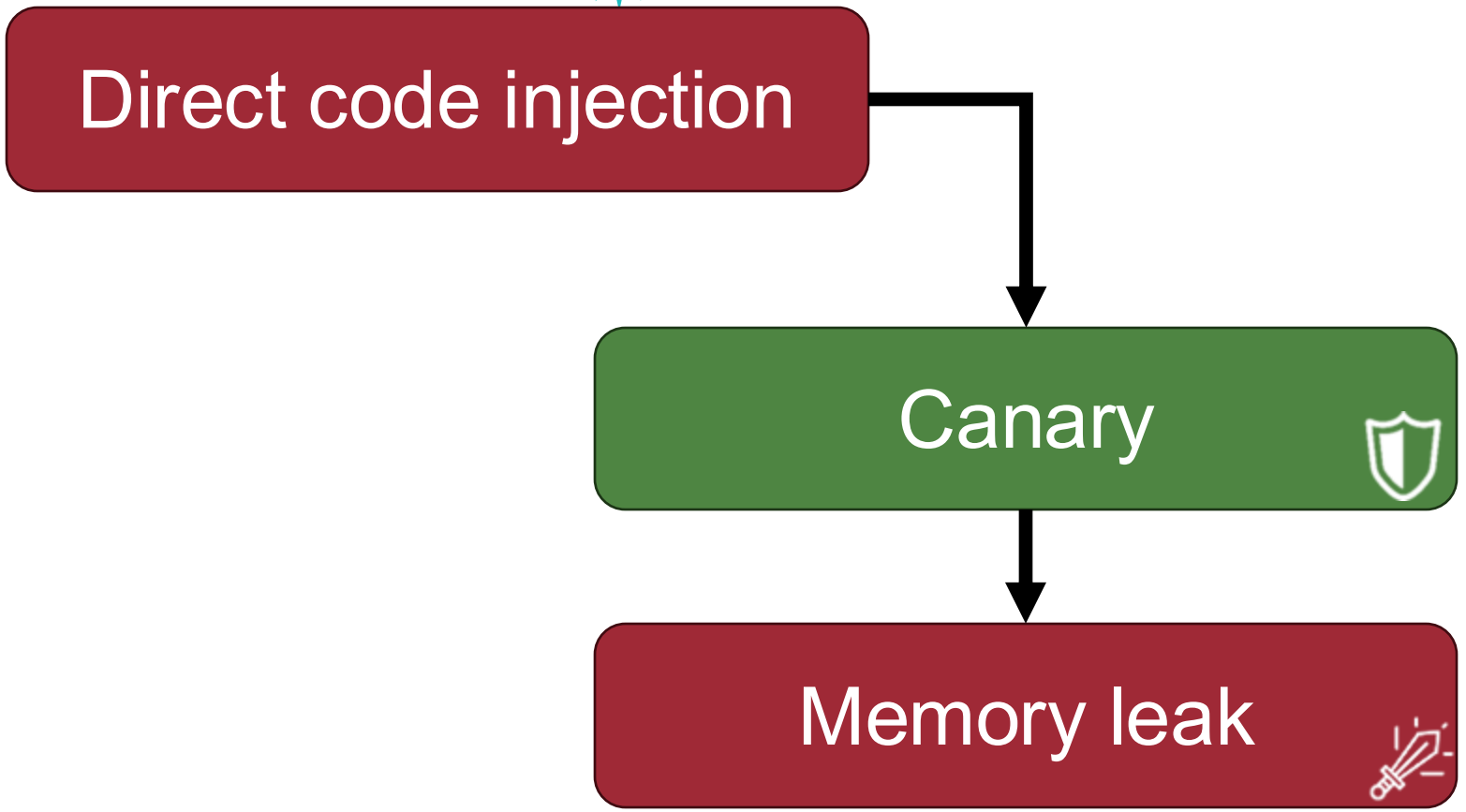


Attack #2: Leaking Canary Value

- If there is another vulnerability that allows us to ***leak*** stack contents, then we can easily bypass the canary check

- Canary is inherently vulnerable to *format string attacks*

Control Hijack Attack / Defense So Far



Buffer Overflow Mitigation #2: NX

NX (No eXecute)

a.k.a Data Execution Prevention* (***DEP***)

Stack stores data, but not code. Therefore, OS makes the stack memory area ***non-executable***

* DEP ***prevents*** data execution, but it does not prevent buffer overflows

NX (No eXecute)

AMD Athlon™ Processor Competitive Comparison

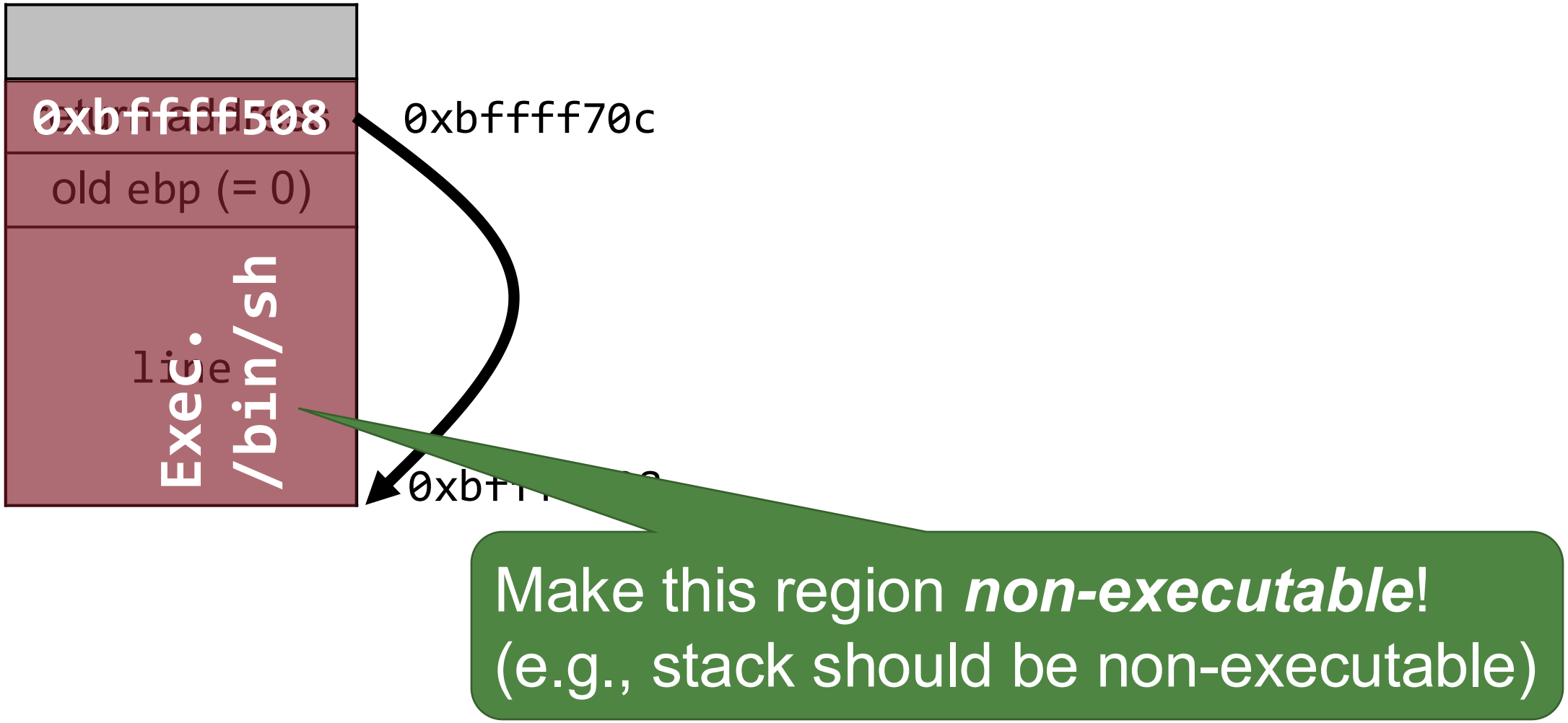
FEATURES	AMD ATHLON™ CPU	PENTIUM® 4
Architecture Introduction	2006	2000
Infrastructure	Socket AM2	Socket LGA775
Process Technology	90 nanometer, SOI 65 nanometer, SOI	90 nanometer
64-bit Instruction Set Support	Yes, AMD64 technology	Depends, EM64T on some Pentium® 4 series
Enhanced Virus Protection for Windows® XP SP2*	Yes	Depends

W ⊕ X (Write XOR eXecute) Policy

On Linux, it is called W ⊕ X

- Every page should be either writable or executable, but NOT both
- Even though we can put a shellcode to a writable buffer, we cannot execute it if this policy is enabled

Mitigating Control Flow Hijack with DEP



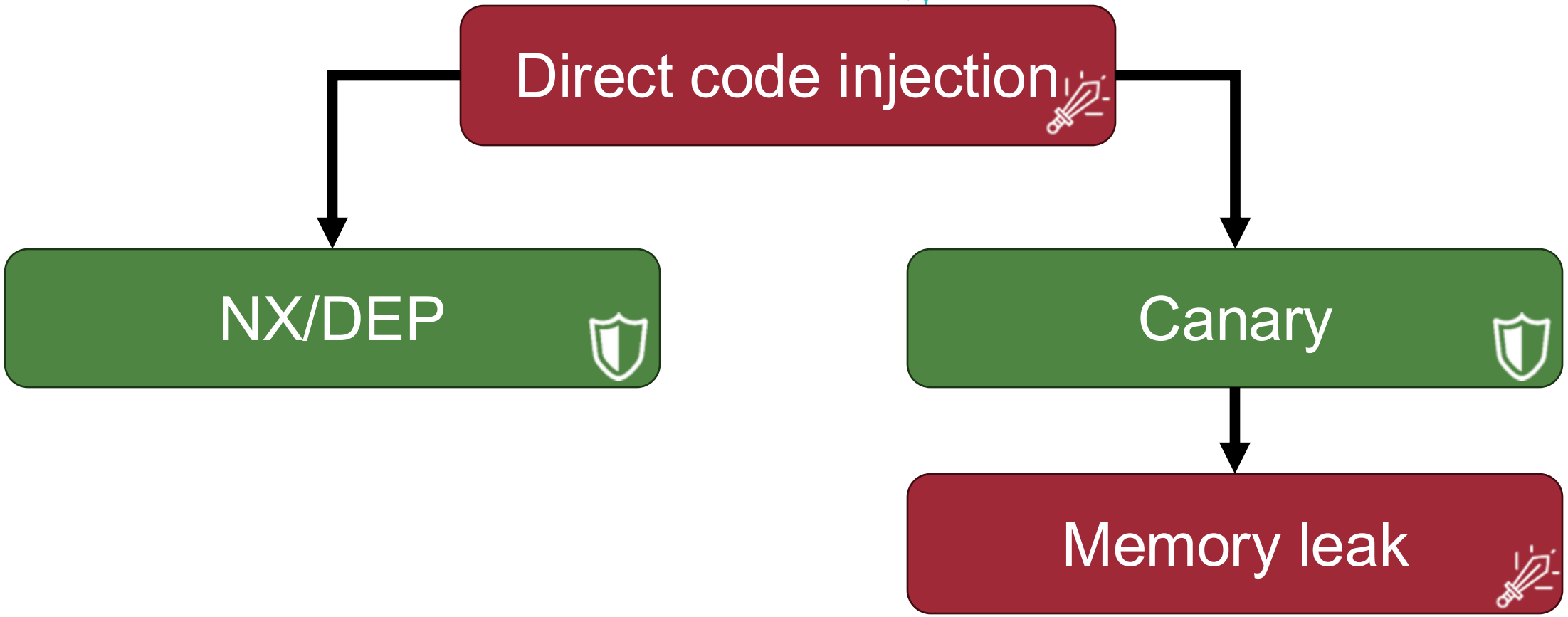
DEP on Stack using execstack

- Tool to set, clear, or query NX stack flag of binaries

```
$ /usr/sbin/execstack -c <filename> ; clear NX flag
$ /usr/sbin/execstack -s <filename> ; set NX flag
$ /usr/sbin/execstack -q <filename> ; query NX flag
```

When NX is set, return-to-stack exploit will fail
(i.e., the program will crash)

Control Hijack Attack / Defense So Far



But,

DEP does not prevent buffer overflows. It prevents return-to-stack exploits, though

Any other ways to exploit buffer overflows?

Next topic!

Summary

- Two mitigation techniques against control flow hijacks
  - Stack canary
  - NX (or DEP)

Question?