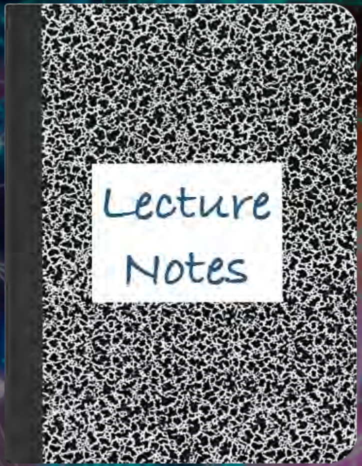


CS 419: Computer Security

Week 7: Memory Corruption & Code Injection

Paul Krzyzanowski

Part 1

Hijacking & Injection

Hijacking & Injection

Hijacking: Taking control of a process by intercepting, manipulating, or redirecting its intended behavior for unintended purposes without injecting new code

- **Session hijacking: take over someone's authenticated session**
  - Snoop on a communication session to get authentication info
  - Access someone's cookies for a web session
  - Perform an Adversary-in-the-Middle (AitM) attack to let a user log in and use that session
- **Control flow hijacking: alter program execution**
  - Use *return-to-libc* or *return-oriented programming* techniques to alter execution
- **Other forms of hijacking**
  - Browser redirection hijacking: Redirect a victim's web browser to a malicious site
  - Domain hijacking: Change DNS (IP address lookup) results to direct users to malicious addresses
  - Search Engine Poisoning: Change the browser's default search engine

Hijacking & Injection

Injection

Inserting arbitrary code or commands into a process to execute unintended operations

- **Command injection: get a process to run arbitrary system commands**
  - Send commands to a program that are then executed by the system shell
  - Includes SQL injection – send database commands
- **Code injection: get a process to run arbitrary code**
  - Overflow an input buffer and cause new code to run
  - Provide JavaScript as input that will later get executed (Cross-site scripting)
- **Library injection: have a process run with different linked libraries**
  - Alter the search path or force a program to load alternate DLL/shared libraries

Security-Sensitive Programs & Remote Services

Hijacking or injection isn't interesting for regular programs on your system

- You might as well just run the commands from the shell or write a program

- **It *is* interesting if**
  - The program runs with elevated privileges (*setuid*), especially if it runs as root
  - Runs on a system you don't have access to (most servers)
    - This is **Remote Code Execution** (RCE)

- **It is super interesting if**
  - The program runs with elevated privileges on a remote system you can't access directly

Bugs and mistakes

- **Most attacks are due to**
  - Social engineering: getting a legitimate user to do something
  - Or exploiting vulnerabilities: using a program in a way it was not intended
    - This includes buggy security policies
- **An attacked system may be further weakened because of poor access control rules**
  - Allowing the attacker to do more than the compromised application – a violation of the *Principle of Least Privilege*
- **Cryptography won't save us!**
  - And cryptographic software can also be buggy

Unchecked Assumptions

- **Unchecked assumptions can lead to vulnerabilities**
  - Vulnerability: weakness that can be exploited to perform unauthorized actions
- **Attack**
  - Discover these assumptions
  - Craft an exploit to render them invalid … and run the exploit
- **Four common assumptions:**
  1. The buffer is large enough for the data
  2. Integer overflow doesn’t exist
  3. User input will never be processed as a command
  4. A file is in a proper format

Memory Corruption Vulnerabilities

- **Buffer overflow**
  - Writing more data to a buffer than it can hold, leading to overwriting adjacent memory
- **Heap attacks**
  - Exploit vulnerabilities in dynamic memory allocation
  - **Heap overflow**: write beyond allocated space (a buffer overflow)
  - **Use-After-Free**: access memory after it's been freed (and possibly reallocated)
- **Integer overflow/underflow**
  - Arithmetic operation exceeds the maximum or minimum value a data type can hold
  - This can lead to unexpected behavior like buffer overflows or bad logic

Buffer Overflow

What is a buffer overflow?

Programming error that allows more data to be stored in an array than there is allocated space for the object

- **Buffer = chunk of memory on the stack, heap, or static data**
- **Overflow means adjacent memory will be overwritten**
  - Program data can be modified
  - New code can be injected
  - Unexpected transfers of control can be launched

Buffer overflows

Buffer overflows used to be responsible for ~50% of vulnerabilities

- **We know how to defend ourselves but**
  - Average time to discover and patch a bug is more than 1 year
  - People delay updating systems … or refuse to
  - Embedded systems often never get patched
    - Routers, cable modems, set-top boxes, access points, IP phones, and security cameras
  - Embedded systems often don't defend against this (in the name of efficiency)
  - Insecure access rights often help with gaining access or more privileges
  - We continue to write buggy code!

cve.mitre.org reports 125 CVE records for buffer overflows in 2025 so far
1,284 vulnerabilities in 2024

Buffer overflows … still happening in 2025

Feb 19, 2025: CVE-2025-0999, and CVE-2025-1426
- Heap buffer overflow in Google Chrome browser
- Allows attackers to execute arbitrary code and seize control of affected systems.

Jan 22, 2025: CVE-2025-20128
- Cisco ClamAV anti-virus software – heap buffer overflow
- Can lead to a denial-of-service attack

Jan 21, 2025: CVE-2024-54887
- Stack buffer overflow on TP-Link TL-WR940N routers
- Allows authenticated attackers to execute arbitrary code remotely.

Jan 15, 2025: CVE-2024-12084 (9.8)
- Rsync file synchronization software heap buffer overflow
- Improper checksum length handling can lead to arbitrary code execution on a server

Jan 9, 2025: CVE-2025-0282
- Stack-based buffer overflow in Ivanti Connect Secure, Policy Secure, and Neurons for ZTA
- Allows a remote unauthenticated attacker to achieve remote code execution

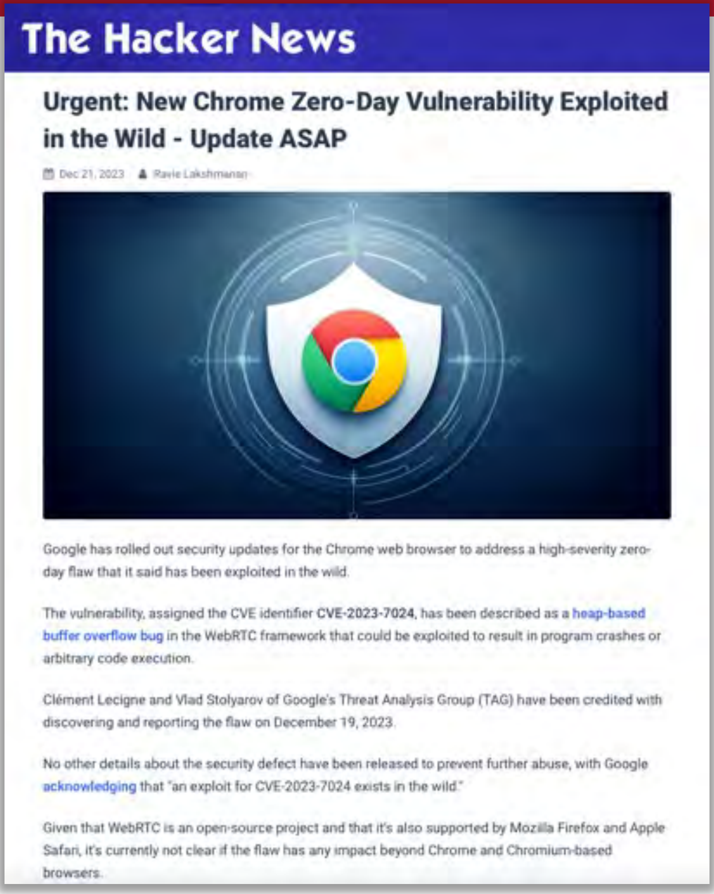
Buffer overflows … a few examples from 2024

Sep 9, 2024: CVE-2017-1000253
- Linux Kernel PIE Stack Buffer Corruption Vulnerability
- May cause a system crash or remotely execute code

Jul 22, 2024: CVE-2024-35467
- Stack-based buffer overflow in ASUS's RT-AC87U devices
- May cause a system crash or remotely execute code

May 8, 2024: CVE-2024-4559
- Heap buffer overflow in WebAudio in Google Chrome
- An attacker could exploit this via a crafted HTML page.

Apr 26, 2024: CVE-2024-25048
- **Heap buffer overflow in IBM MQ**
- caused by improper bounds checking.
- A remote authenticated attacker could overflow a buffer and execute arbitrary code on the system or cause the server to crash.


The Hacker News

Urgent: New Chrome Zero-Day Vulnerability Exploited in the Wild - Update ASAP

Dec 21, 2023 Ravie Lakshmanan

Google has rolled out security updates for the Chrome web browser to address a high-severity zero-day flaw that it said has been exploited in the wild.

The vulnerability, assigned the CVE identifier **CVE-2023-7024**, has been described as a heap-based buffer overflow bug in the WebRTC framework that could be exploited to result in program crashes or arbitrary code execution.

Clément Lecigne and Vlad Stolyarov of Google's Threat Analysis Group (TAG) have been credited with discovering and reporting the flaw on December 19, 2023.

No other details about the security defect have been released to prevent further abuse, with Google acknowledging that "an exploit for CVE-2023-7024 exists in the wild."

Given that WebRTC is an open-source project and that it's also supported by Mozilla Firefox and Apple Safari, it's currently not clear if the flaw has any impact beyond Chrome and Chromium-based browsers.

Buffer overflows … a few examples from 2024

Dec 10, 2024: CVE-2024-49138
- Windows Common Log File System (CLFS) heap buffer overflow
- Heap overflow and free memory reuse allows hijacking function pointers for arbitrary code execution

Sep 13, 2024: CVE-2025-42642 (9.8)
- Stack buffer overflow on Crucial MX500 Series Solid State Drives
- An attacker can corrupt data, gain unauthorized access, or complete system compromise

Sep 23, 2024: CVE-2024-7490 (9.5)
- Microchip Advanced Software Framework (ASF) – stack buffer overflow
- Remote code execution via tinydhcp server – software is no longer supported (but widely deployed)

June 20, 2024: CVE-2024-0762
- Phoenix SecureCode UEFI firmware buffer overflow
- Tens of millions of Intel-based laptops vulnerable to malicious code execution

Buffer overflow affecting UEFI

Jan 17, 2024: PixieFail

- Collection of 9 vulnerabilities that affect UEFI
  - Computer firmware that runs the bootloader
- Includes 3 buffer overflows
  - Choosing an overly long Server ID option in the DHCPv6client
  - Processing DNS Servers option in a DHCPv6
  - handling a Server ID option from a DHCPv6 proxy Advertise message

ars TECHNICA

PIXIEFAIL —

New UEFI vulnerabilities send firmware devs industry wide scrambling

PixieFail is a huge deal for cloud and data centers. For the rest, less so.

1/17/2024

A motley bunch

PixieFail is a motley mix of different vulnerability types, ranging from buffer overflows and integer underflows, both of which allow for remote code execution, to the lack of standard but crucial security practices, such as a properly functioning pseudorandom number generator. There was also a TCP implementation that didn't follow a basic IETF RFC that has been recommended since 2012. The nine vulnerabilities are:

- https://nvd.nist.gov/vuln/detail/CVE-2023-45229: an integer underflow when processing configurations contained in a DHCPv6 advertise message. The underflows from the failure of EDK II—and all the affected UEFIs that rely on it—perform basic "sanity checking" that is designed to flag when memory contents are too small. The base score severity rating is 6.5 out of a possible 10.
- https://nvd.nist.gov/vuln/detail/CVE-2023-45230: A buffer overflow in the DHCPv6client. This vulnerability also stems from a sanity-checking failure. It can be exploited by choosing an overly long Server ID option during what's known in PXE as the Solicit/Advertise exchange. Base score 8.3.
- https://nvd.nist.gov/vuln/detail/CVE-2023-45231: An out-of-bounds read that can occur during the Network Discovery phase. Base score 6.5
- https://nvd.nist.gov/vuln/detail/CVE-2023-45232: An infinite loop when parsing unknown options in the Destination Options header, Base score 7.5
- https://nvd.nist.gov/vuln/detail/CVE-2023-45233: An infinite loop when parsing a PadN option in the Destination Options header. Base score 7.5
- https://nvd.nist.gov/vuln/detail/CVE-2023-45234 A buffer overflow when processing DNS Servers option in a DHCPv6 Advertise message. Base score 8.3
- https://nvd.nist.gov/vuln/detail/CVE-2023-45235: A buffer overflow when handling a Server ID option from a DHCPv6 proxy Advertise message. Base score 8.3
- https://nvd.nist.gov/vuln/detail/CVE-2023-45236: Predictable TCP Initial Sequence Numbers. Base score 5.7
- https://nvd.nist.gov/vuln/detail/CVE-2023-45237: Use of a weak pseudorandom number generator. Base score 5.3

The makers of the affected UEFIs are in the process of getting updates pushed out to customers. And from there, those customers are making patches available to their customers, who usually are end users. AMI confirmed the vulnerability affects its Optio V line of firmware and said it has made patches available to its customers. AMI provided a public advisory here and customer-only ones here and here.

Microsoft, meanwhile, issued a statement that said the company was taking "appropriate action" without saying what that was. Microsoft also claimed—in error, Arce said—that exploiting the vulnerability required the attacker to first establish a malicious server on the affected network. Arce says no such requirement exists.

https://arstechnica.com/security/2024/01/new-uefi-vulnerabilities-send-firmware-devs-across-an-entire-ecosystem-scrambling/2/

Buffer overflow affecting dynamic loading

October 5, 2023

- GNU C Library's dynamic loader
- Affects the processing of the GLIBC_TUNABLES environment variable, a feature introduced in glibc to allow users to fine-tune the library's behavior at runtime.
- "Can allow attackers to gain root privileges, enabling unauthorized data access, alteration or deletion and potentially leveraging further attacks by escalating privileges"
- Easily exploitable, and arbitrary code execution is a real and tangible threat


Infosecurity Magazine

NEWS 5 OCT 2023

Critical Glibc Bug Puts Linux Distributions at Risk

Alessandro Mascellino

Security researchers from the Qualys Threat Research Unit (TRU) have uncovered a new buffer overflow vulnerability within the GNU C Library's dynamic loader, shedding light on this flaw's potential risks to Linux distributions.

The vulnerability in question affects the processing of the GLIBC_TUNABLES environment variable, a feature introduced in glibc to allow users to fine-tune the library's behavior at runtime.

"A successful exploit can allow attackers to gain root privileges, enabling unauthorized data access, alteration or deletion and potentially leveraging further attacks by escalating privileges," commented Saeed Abbasi, manager of vulnerability research at Qualys.

You may also like

Zyxel Vulnerability Exploited by DDoS Botnets on Linux Systems

Exploitation of Vulnerabilities Have Soared, Unit 42 Report Finds

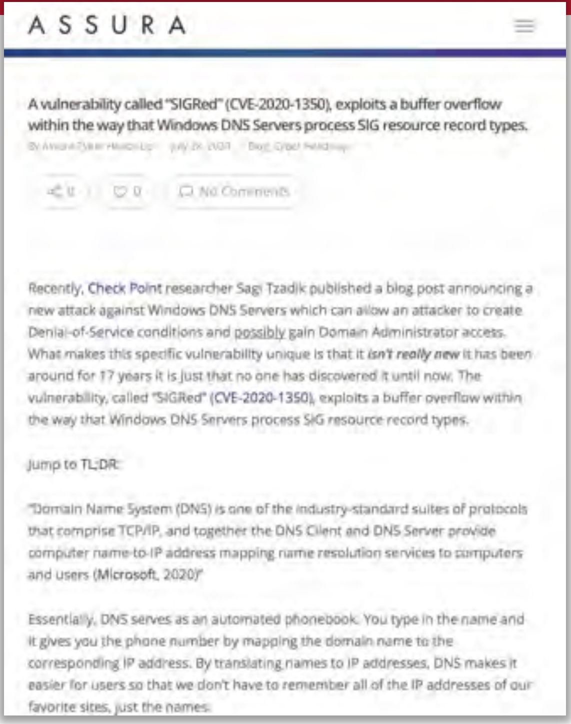
Threat Actors Use Malicious File Systems to Scale Crypto-Mining Operations

https://www.infosecurity-magazine.com/news/critical-glibc-bug-puts-linux-risk/

Buffer overflows: SigRed – a 17-year-old bug!

July 28, 2020 – SIGRed vulnerability

- Exploits buffer overflow in Windows DNS Server processing of SIG records
  - A field that holds a signature for use with secure DNS
- Allows an attacker to create a denial-of-service attack
- Bug existed for 17 years – discovered in 2020!
  - A function expects 16-bit integers to be passed to it
  - If they are not the proper size, it will overflow other integers
  - Attacker needs to create a DNS response that contains a SIG record > 64KB



ASSURA

A vulnerability called "SIGRed" (CVE-2020-1350), exploits a buffer overflow within the way that Windows DNS Servers process SIG resource record types.

No Comments

Recently, Check Point researcher Sagi Tzadik published a blog post announcing a new attack against Windows DNS Servers which can allow an attacker to create Denial-of-Service conditions and possibly gain Domain Administrator access. What makes this specific vulnerability unique is that it *isn't really new* it has been around for 17 years it is just that no one has discovered it until now. The vulnerability, called "SIGRed" (CVE-2020-1350), exploits a buffer overflow within the way that Windows DNS Servers process SIG resource record types.

Jump to TL;DR:

"Domain Name System (DNS) is one of the industry-standard suites of protocols that comprise TCP/IP, and together the DNS Client and DNS Server provide computer name-to-IP address mapping name resolution services to computers and users (Microsoft, 2020)"

Essentially, DNS serves as an automated phonebook. You type in the name and it gives you the phone number by mapping the domain name to the corresponding IP address. By translating names to IP addresses, DNS makes it easier for users so that we don't have to remember all of the IP addresses of our favorite sites, just the names.

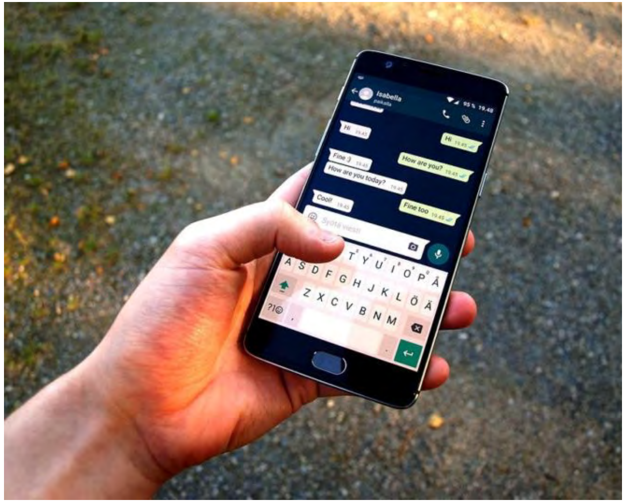
https://www.assurainc.com/a-vulnerability-called-sigred-cve-2020-1350-exploits-a-buffer-overflow-within-the-way-that-windows-dns-servers-process-sig-resource-record-types/amp-on/

ars technica

WhatsApp vulnerability exploited to infect phones with Israeli spyware

Attacks used app's call function. Targets didn't have to answer to be infected.

DAN GOODIN - 5/13/2019, 10:00 PM



Attackers have been exploiting a vulnerability in WhatsApp that allowed them to infect phones with advanced spyware made by Israeli developer NSO Group, the Financial Times reported on Monday, citing the company and a spyware technology dealer.

A representative of WhatsApp, which is used by 1.5 billion people, told Ars that company researchers discovered the vulnerability earlier this month while they were making security improvements. CVE-2019-3568, as the vulnerability has been indexed, is a buffer overflow vulnerability in the WhatsApp VOIP stack that allows remote code execution when specially crafted series of SRTCP packets are sent to a target phone number, according to this advisory.

https://arstechnica.com/information-technology/2019/05/whatsapp-vulnerability-exploited-to-infect-phones-with-israeli-spyware/

2019 WhatsApp Buffer Overflow Vulnerability

- **WhatsApp messaging app could install malware on Android, iOS, Windows, & Tizen operating systems**

  An attacker did not have to get the user to do anything: the attacker just places a WhatsApp voice call to the victim.

- **This was a zero-day vulnerability**
  - Attackers found & exploited the bug before the company could patch it

- **WhatsApp used by 1.5 billion people**
  - Vulnerability discovered in May 2019 while developers were making security improvements

https://arstechnica.com/information-technology/2019/05/whatsapp-vulnerability-exploited-to-infect-phones-with-israeli-spyware/

Buggy libraries can affect a lot of code bases

July 2017 – Devil's Ivy (CVE-2017-9765)

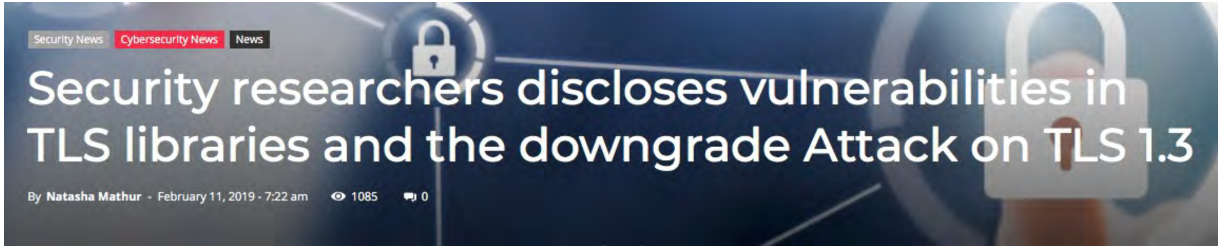
- gsoap open source toolkit
- Enables remote attacker to execute arbitrary code
- Discovered during the analysis of an internet-connected security camera

Millions of IoT devices are vulnerable to buffer overflow attack

July 18, 2017 · Eslam Medhat · 104 Views · 0 Comments · buffer overflow

A buffer overflow flaw has been found by security researchers (at the IoT-focused security firm Senrio) in an open-source software development library that is widely used by major manufacturers of the Internet-of-Thing devices.

The buffer overflow vulnerability (CVE-2017-9765), which is called "Devil's Ivy" enables a remote attacker to crash the SOAP (Simple Object Access Protocol) WebServices daemon and make it possible to execute arbitrary code on the affected devices.



https://latesthackingnews.com/2017/07/18/millions-of-iot-devices-are-vulnerable-to-buffer-overflow-attack/

The classic buffer overflow bug

gets.c from macOS:
© 1990,1992 The Regents of the University of California.

```
gets(buf)
char *buf;
  register char *s;
  static int warned;
  static char w[] = "warning: this program uses gets(),
  which is unsafe.\r\n";

  if (!warned) {
      (void) write(STDERR_FILENO, w, sizeof(w) - 1);
      warned = 1;
  }
  for (s = buf; (c = getchar()) != '\n';)
      if (c == EOF)
          if (s == buf)
              return (NULL);
          else
              break;
      else
          *s++ = c;
  *s = 0;
  return (buf);
}
```

gets.c from OS X: © 1990,1992 The Regents of the University of California.

```
gets(buf)
char *buf;
  register char *s;
  static int warned;
```

```
gets(),
```

```
1);
```

```
for (s = buf; (c = getchar()) != '\n';)
  if (c == EOF)
     if (s == buf)
        return (NULL);
     else
        break;
  else
     *s++ = c;
```

Note there's no check for the length of the buffer!

```
  *s = 0;
  return (buf);
}
```

T

An issue with C++ too – and no warnings!

```
#include <iostream>

using namespace std;

int main()
{
    char x[4] = "cat";
    char y[4];
    char z[4] = "dog";

    cout << "Enter a word:";
    cin >> y;
    cout << "Read " << strlen(y) << " characters." << endl;
    cout << "x: " << x << endl;
    cout << "y: " << y << endl;
    cout << "z: " << z << endl;
}
```

An issue with C++ too – and no warnings!

```
#include <iostream>

using names

int main()
{
    char x[
    char y[
    char z[

    cout <<
    cin >>
    cout <<
    cout <<
    cout <<
    cout <<
}
```

```
$ g++ -o cin cin.cpp
Enter a word:abcdefg
Read 7 characters.
x: efg
y: abcdefg
z: dog
```

The data in `y` overflowed to `x`
`x` got corrupted

An issue with C++ too – and no warnings!

```
#include <iostream>

using names

int main()
{
	char x[
	char y[
	char z[

	cout <<
	cin >>
	cout <<
	cout <<
	cout <<
	cout <<
}
```

```
$ g++ -o cin cin.cpp
Enter a word:abcdefghijklmnopqrstuvwxyz0123456789
Read 36 characters.
x: efghijklmnopqrstuvwxyz0123456789
y: abcdefghijklmnopqrstuvwxyz0123456789
z: dog
Bus error: 10
```

With even more data,
`x` got corrupted
AND the program crashed!

Buffer overflow examples

```
void test(void) {
    char name[10];

    strcpy(name, "krzyzanowski");
}
```

That's easy to spot!

Another example

How about this?

```
char configfile[256];
char *base = getenv("BASEDIR");

if (base != NULL)
    sprintf(configfile, "%s/config.txt", base);
else {
    fprintf(stderr, "BASEDIR not set\n");
}
```

Buffer overflow attacks

To exploit a buffer overflow, identify if there's an overflow vulnerability in a program

- **Black box testing**
  - Trial and error
  - Fuzzing tools (more on that …)
- **Inspection**
  - Study the source
  - Trace program execution

You don't have access to the source

You have access to the source

Understand where the buffer is in memory and whether there is potential for corrupting surrounding data

What's the harm?

Execute arbitrary code, such as starting a shell

Code injection*, *stack smashing

- Code runs with the privileges of the program
  - If the program is *setuid root* then you have root privileges
  - If the program is on a server, you can run code on that server

- **Even if you cannot inject code…**
  - You may crash the program (Denial of Service attack)
  - Change how it behaves
  - Modify data

- **Sometimes the crashed code can leave a core dump**
  - You can access that and grab data the program had in memory

Taking advantage of unchecked bounds

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

int
main(int argc, char **argv)
{
	char pass[5];
	int correct = 0;

	printf("enter password: ");
	gets(pass);
	if (strcmp(pass, "test") == 0) {
		printf("password is correct\n");
		correct = 1;
	}
	if (correct) {
		printf("authorized: running with root privileges...\n");
		exit(0);
	}
	else
		printf("sorry - exiting\n");
	exit(1);
}
```

```
$ ./buf
enter password: abcdefghijklmnop
authorized: running with root privileges...
```

Run on my Raspberry Pi 5
Debian 1:6.6.74-1+rpt1
6.6.74+rpt-rpi-2712

Note: this test did *not* succeed

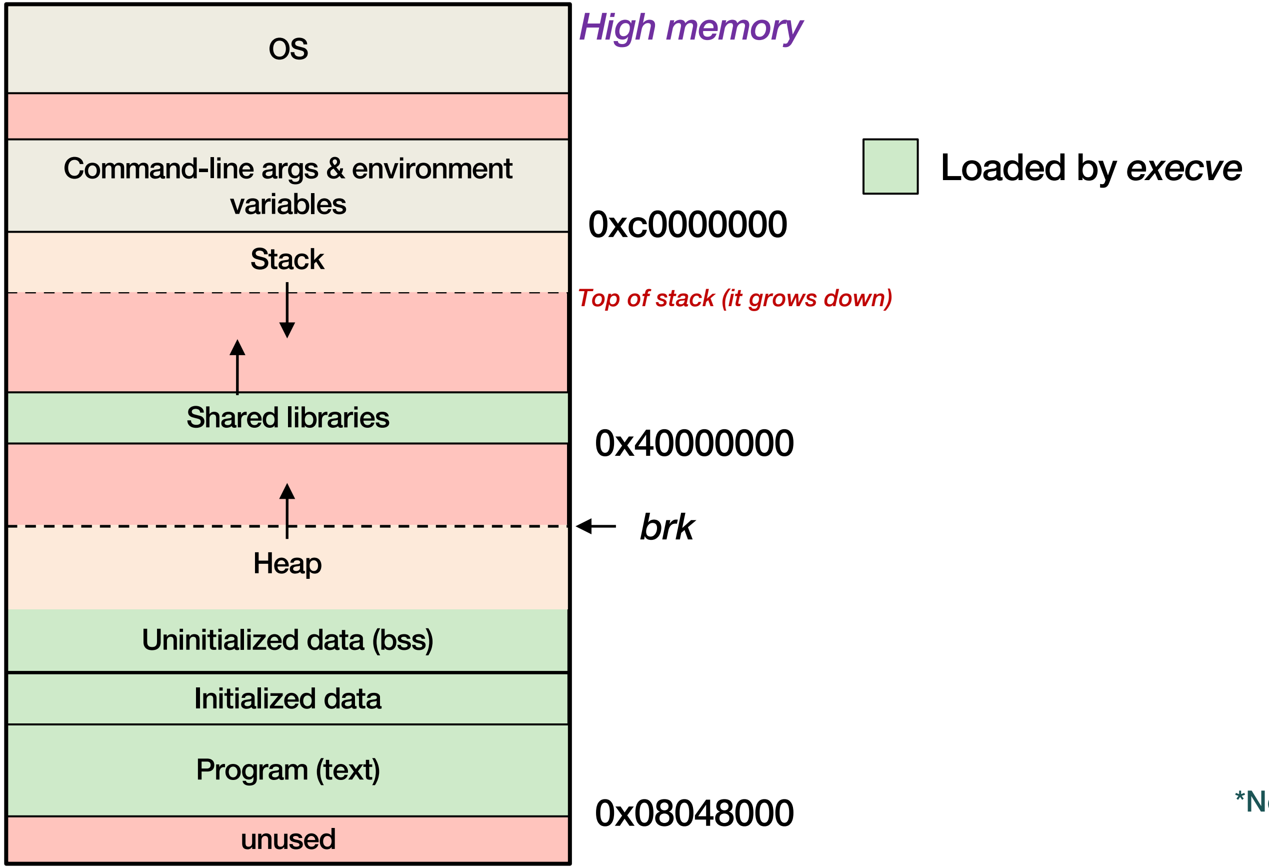
It's a bounds checking problem

- **C and C++**
  - Allow direct access to memory
  - Do not check array bounds
  - Functions often do not even know array bounds
    - They just get passed a pointer to the start of an array
- **This is not a problem with strongly typed languages**
  - Java, C#, Python, etc. check sizes of structures
- **But C is in the top 4-5 of popular programming languages**
  - #1 for system programming & embedded systems
  - And most compilers, interpreters, databases, browsers, and libraries are written in C or C++

Part 2

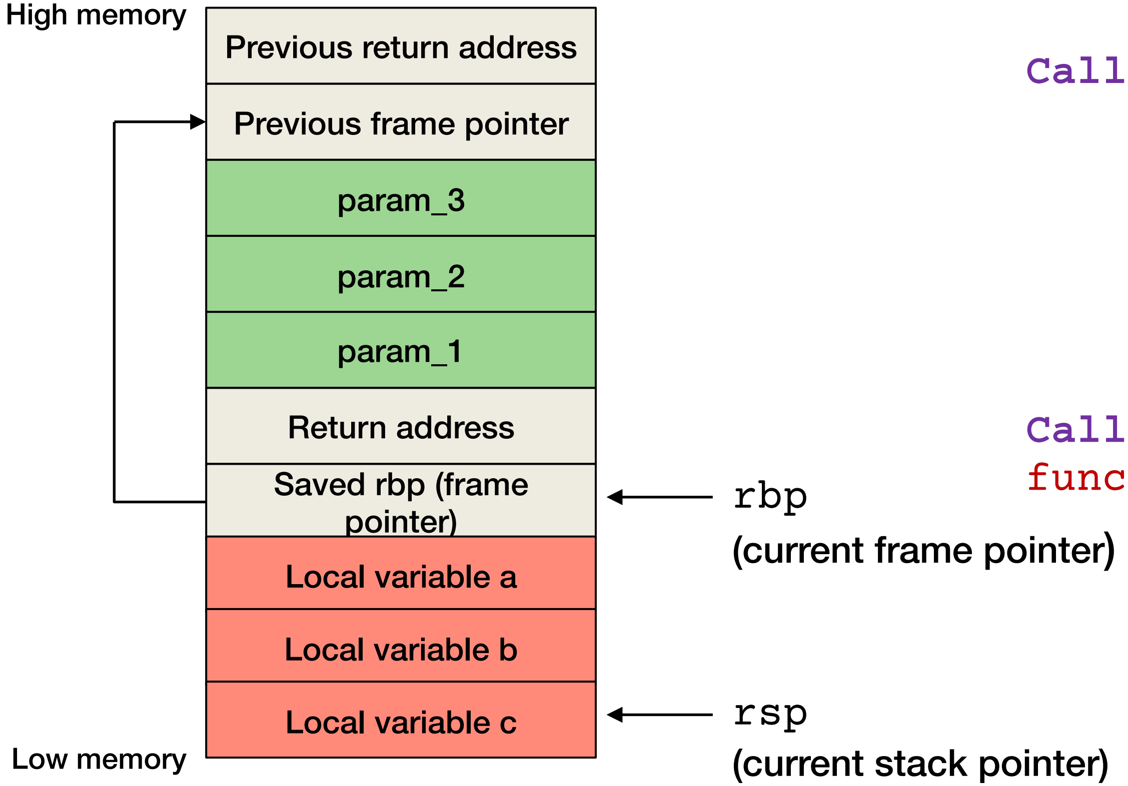
Anatomy of overflows

Linux process memory map*



*Not to scale

The stack




```
func(param_1, param_2, param_3)

Calling function:
        pushl param_3
        pushl param_2
        pushl param_1
        call func
        . . .

Called function:
func:   pushl rbp
        movl %rsp, %rbp
        subl $20, %rsp
        . . .
        movl %rbp, %rsp
        pop  %rbp
        ret
```

What’s a frame pointer?

- **Frame pointer: a register that points to the base of the current function’s stack frame**
  - Provides a stable reference for accessing function parameters and local variables (as offsets from the frame pointer) even as the stack pointer changes during execution
- **The current frame pointer is saved on the stack when a function is called**
  - When a function returns, it:
    - Restores the stack pointer to the current frame pointer
    - Restores the saved frame pointer
    - Returns from the function, popping the return value from the stack to the program counter
- **The danger of overwriting a saved frame pointer**
  - The restored frame pointer can point to a fake stack structure
    - Corrupting stack unwinding – changing function return sequences or crashes
    - Control flow hijacking – redirect it to malicious code or other areas of execution

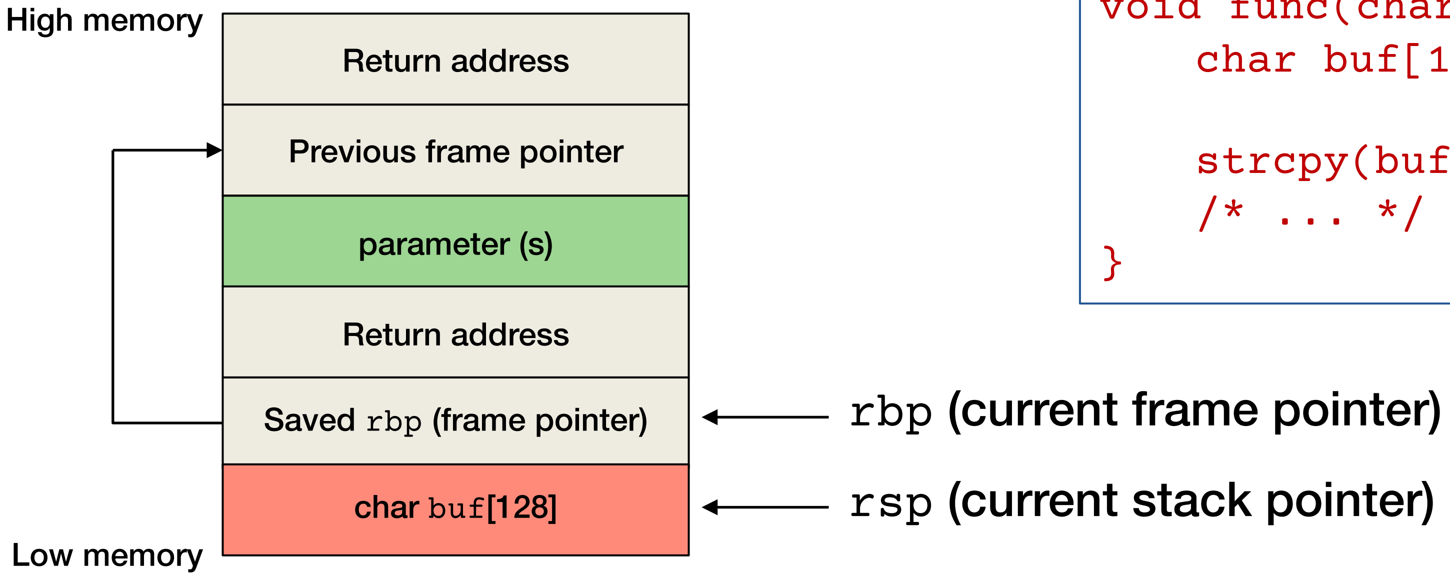
Causing overflow

Overflow can occur when programs do not validate the length of data being written to a buffer

This could be in your code or one of several “unsafe” libraries

- `strcpy(char *dest, const char *src);`
- `strcat(char *dest, const char *src);`
- `gets(char *s);`
- `scanf(const char *format, …)`
- Others…

Overflowing the buffer




```
void func(char *s) {
    char buf[128];

    strcpy(buf, s);
    /* ... */
}
```

What if `strlen(s)` is >127 bytes?

You overwrite the saved *rbp* and then the *return address*

Overwriting the return address

- **If we overwrite the return address**
  - We change what the program executes when it returns from the function
- **"Benign" overflow**
  - Overflow with garbage data
  - Chances are that the return address will be invalid
  - Program will die with a SEGFAULT
  - **Availability attack**

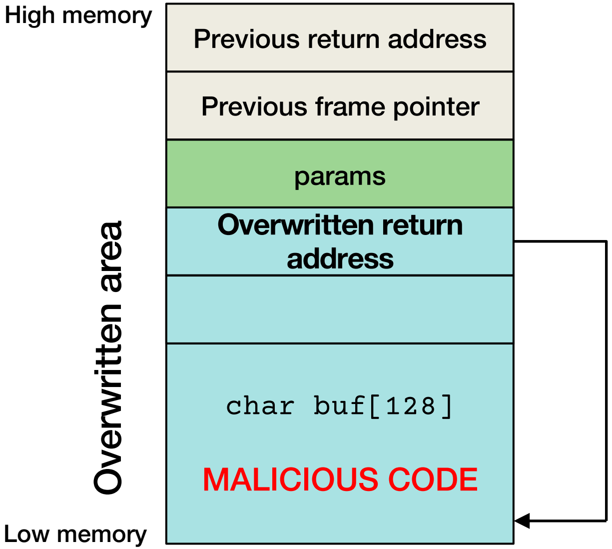
Programming at the machine level

- **High level languages (even C) constrain you in**
  - Access to variables (local vs. global)
  - Control flows in predictable ways
    - Loops, function entry/exit, exceptions
- **At the machine code level**
  - No restriction on where you can jump
    - Jump to the middle of a function … or to the middle of a C statement
    - Frame pointer will be restored to whatever address is on the stack before the return
    - Returns will go to whatever address is on the top of the stack
    - Unused code can be executed (e.g., library functions not used by the program)

Subverting control flow

Malicious overflow

- Fill the buffer with malicious code
- Overflow to overwrite saved frame pointer `%rbp`
- Then overwrite saved the stack pointer (the return address) with the address of the malicious code in the buffer

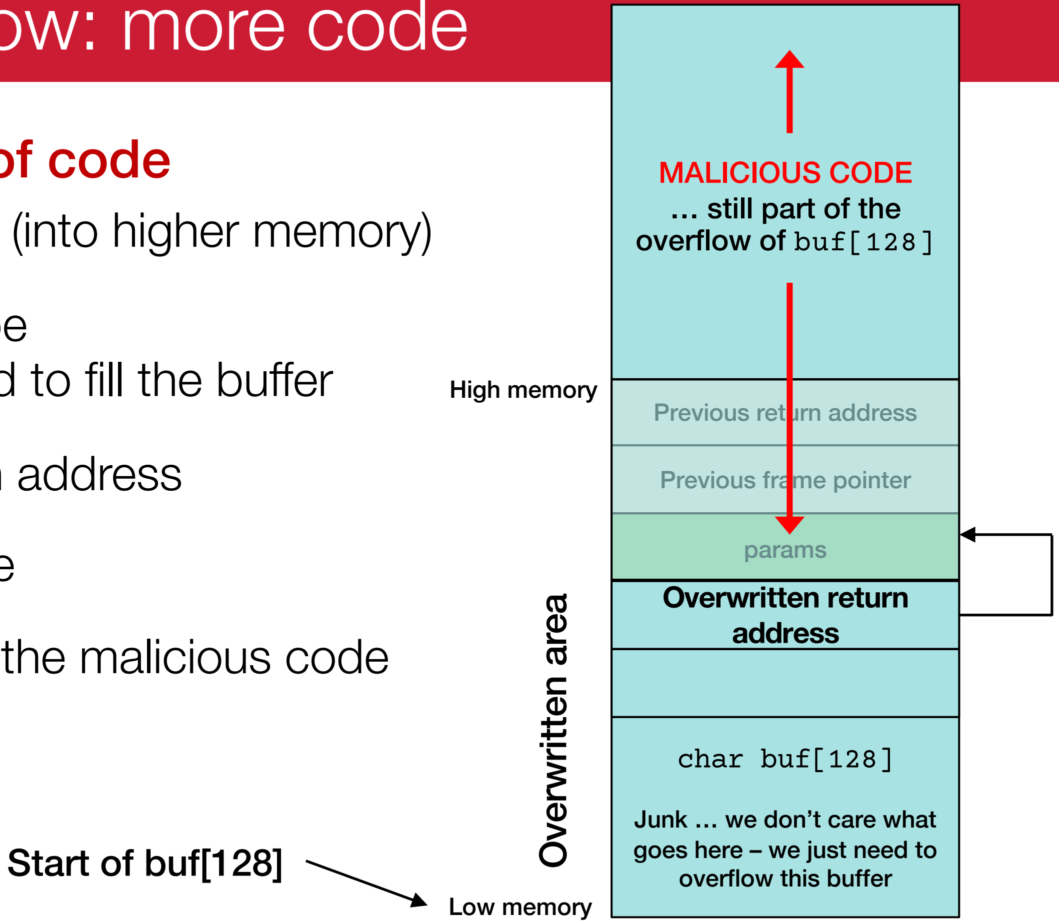


Subverting control flow: more code

If you want to inject a lot of code

Just go further down the stack (into higher memory)

- Initial parts of the buffer will be garbage data … we just need to fill the buffer
- Then we have the new return address
- Then we have malicious code
- The return address points to the malicious code

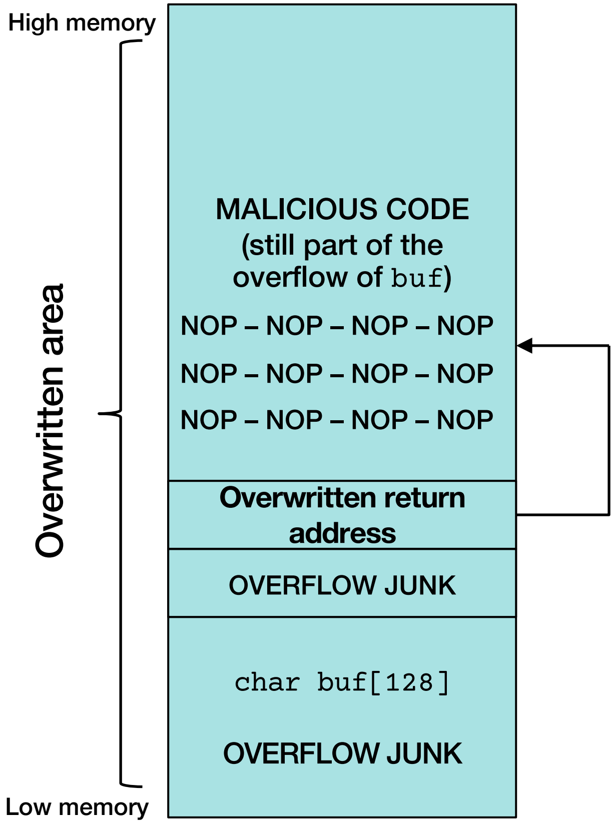


Address Uncertainty

What if we're not sure what the exact address of our injected code is?

NOP slide = NOP sled = landing zone

- Pre-pad the code with lots of NOP instructions
  - NOP
  - moving a register to itself
  - adding 0
  - etc.
- Set the return address on the stack to any address within the landing zone



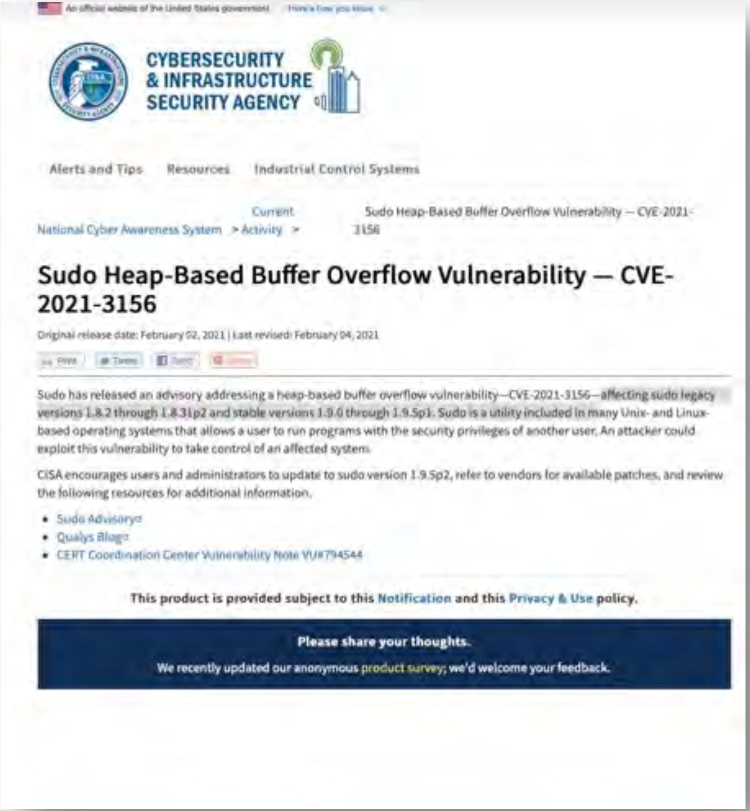
Off-by-one overflows

Off-by-one overflow

Feb. 2, 2021: Linux sudo

- Heap-based buffer overflow vulnerability
- An attacker could exploit this vulnerability to take control of an affected system.

- Off-by-one error
  - Can result in a heap-based buffer overflow, which allows privilege escalation to root via "`sudoedit -s`" and a command-line argument that ends with a single backslash character.



https://www.cisa.gov/uscert/ncas/current-activity/2021/02/02/sudo-heap-based-buffer-overflow-vulnerability-cve-2021-3156

Safe functions aren't always safe

- **Safe counterparts require a count**
  - *strcpy → strncpy*
  - *strcat → strncat*
  - *sprintf → snprintf*
- **But programmers can miscount!**

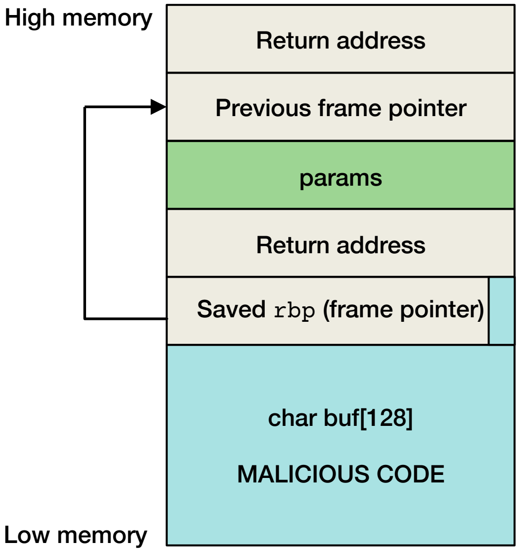
```
char buf[512];
int i;

for (i=0; i<=512; i++)
    buf[i] = stuff[i];
```

Off-by-one errors

- **We can't overwrite the return address**
- **But we can overwrite one byte of the saved frame pointer**
  - Least significant byte on Intel/ARM systems
    - Little-endian architecture

What's the harm of overwriting one byte of the frame pointer?



Off-by-one errors: frame pointer mangling

At the end of a function:

- The compiler resets the stack pointer (%rsp) to the base of the frame (%rbp):

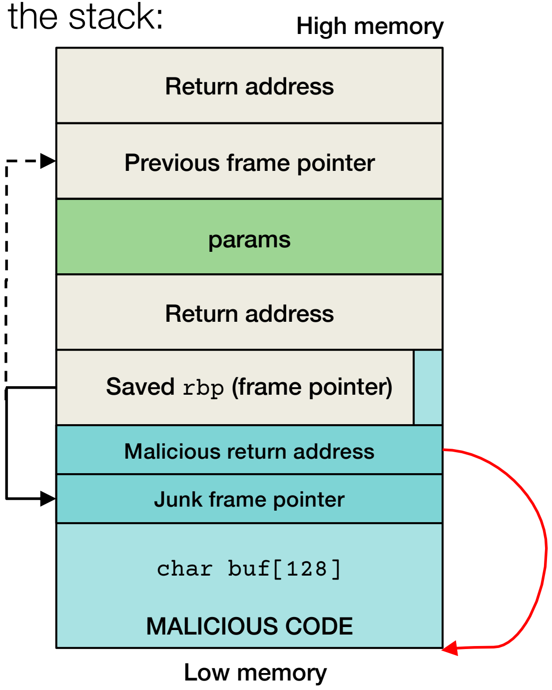
```
movl %rbp, %rsp
```

- and restores the saved frame pointer (which we corrupted) from the top of the stack:

```
pop %rbp
ret
```

pops corrupted frame pointer into rbp, the frame pointer

The program now has the wrong frame pointer when the function returns



The function returns normally – we could not overwrite the return address

BUT … when the function that called it tries to return, it will update the stack pointer to what it thinks was the valid base pointer and return there:

```
mov %rsp, %rbp
pop %rbp
ret
```

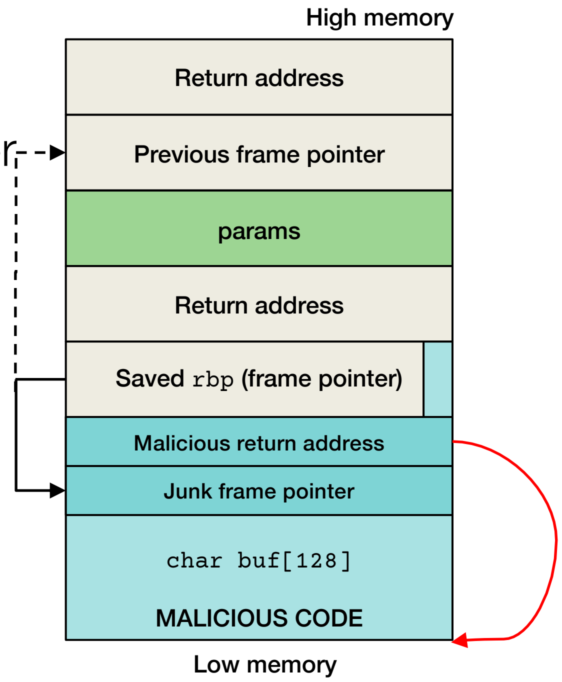
rbp is our corrupted FP that is now the stack pointer

we don't care about the base pointer

return pops the stack from our buffer, so we can jump anywhere

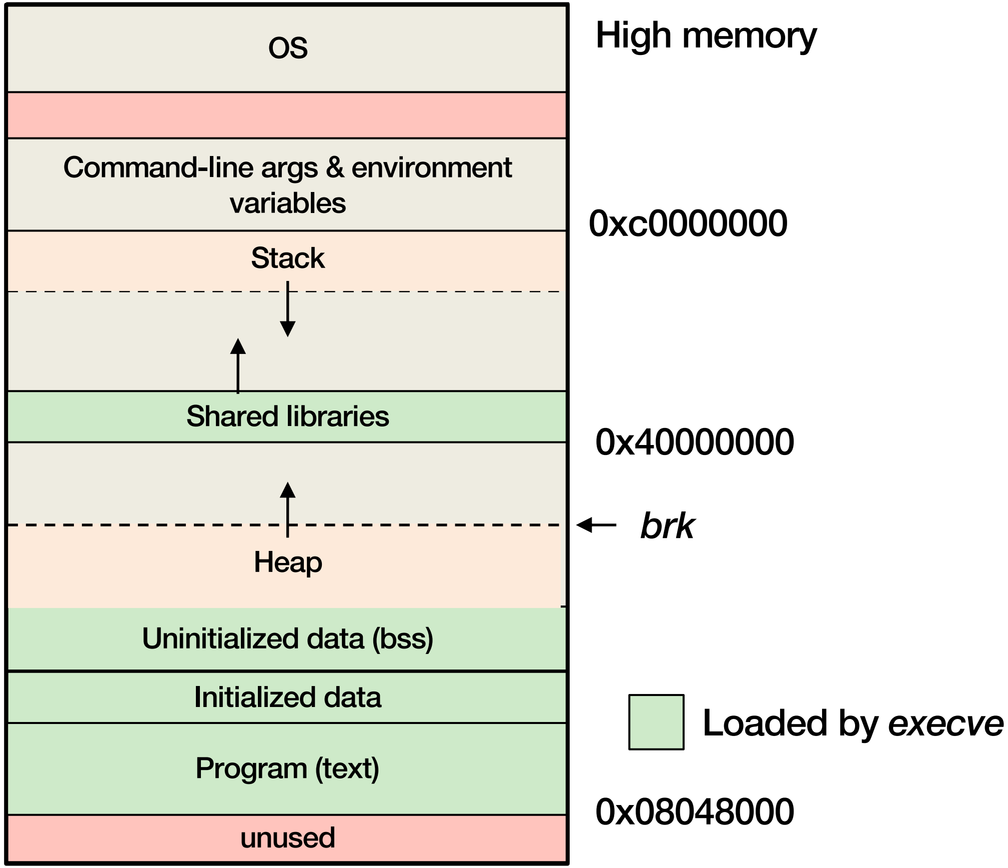
Off-by-one errors: frame pointer mangling

- **Stuff the buffer with**
  - Malicious code, pointed to by “saved” %rip (instruction pointer)
  - “saved” %rbp (can be garbage)
  - “saved” %rip (return address)
  - 1 byte overflow to have the saved FP point to the buffer
- **When the function’s calling function returns**
  - It will return to the “saved” %rip, which points to malicious code in the buffer



Heap & text overflows

Linux process memory map



- Statically allocated variables & dynamically allocated memory (*malloc*) are not on the stack
- Heap data & static data do not contain return addresses
  – No ability to overwrite a return address

Are we safe?

Memory overflow

We may be able to overflow a buffer and overwrite other variables in ***higher*** memory

For example, overwrite a file name

The program

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

char a[15];
char b[15];

int
main(int argc, char **argv)
{
   strcpy(b, "abcdefghijklmnopqrstuvwxyz");
   printf("a=%s\n", a);
   printf("b=%s\n", b);
   exit(0);
}
```

The output
(Linux 4.4.0-59, gcc 5.4.0)

```
a=qrstuvwxyz
b=abcdefghijklmnopqrstuvwxyz
```

Memory overflow – filename example

The program

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

char afile[20];
char mybuf[15];

int main(int argc, char **argv)
{
     strncpy(afile, "/etc/secret.txt", 20);
     printf(”Planning to write to %s\n", afile);
     strcpy(mybuf, "abcdefghijklmnop/home/paul/writehere.txt");
     printf("About to open afile=%s\n", afile);
     exit(0);
}
```

`mybuf` ***can overflow into*** *`afile`*

We overwrote the file name `afile` by writing too much into `mybuf`!

The output
(Linux 5.10.63, gcc 8.3.0)

```
Planning to write to /etc/secret.txt
About to open afile=/home/paul/writehere.txt
```

Overwriting variables: changing control flow

- **Even if a buffer overflow does not touch the stack, it can modify global or static variables**
- **Example:**
  - Overwrite a function pointer
  - Function pointers are often used in callbacks

```
int callback(const char* msg)
{
     printf(“callback called: %s\n”, msg);
}

int main(int argc, char **argv)
{
     static int (*fp)(const char *msg);
     static char buffer[16];

     fp = (int(*)(const char *msg))callback;
     strcpy(buffer, argv[1]);
     (int)(*fp)(argv[2]);     // call the callback
}
```

The exploit

- **The program takes the first two arguments from the command line**
- **It copies `argv[1]` into a buffer with no bounds checking**
- **It then calls the callback, passing it the message from the 2nd argument**

```
int callback(const char* msg)
{
     printf(“callback called: %s\n”, msg);
}

int main(int argc, char **argv)
{
     static int (*fp)(const char *msg);
     static char buffer[16];

     fp = (int(*)(const char *msg))callback;
     strcpy(buffer, argv[1]);
     (int)(*fp)(argv[2]);     // call the callback
}
```

The exploit

– Overflow the buffer

– The overflow bytes will contain the address you really want to call

  - They’re strings, so bytes with 0 in them will not work … making this a more difficult attack

printf attacks

printf and its variants

Standard C library functions for formatted output

- printf: print to the standard output
- wprintf: wide character version of printf
- fprintf, wfprintf: print formatted data to a FILE stream
- sprintf, swprintf: print formatted data to a memory location
- vprintf, vwprintf,vfprintf, vwfprintf :
  print formatted data containing a pointer to argument list

Usage

```
printf(format_string, arguments ...)
printf("The number %d in decimal is %x in hexadecimal\n", n, n);
printf("my name is %s\n", name);
```

Bad usage of printf

Programs often make mistakes with printf

Valid:

```
printf("hello, world!\n")
```

Also accepted … but not right

```
char *message = "hello, world\n");
printf(message);
```

This works but exposes the chance that *message* will be changed

This should be a format string

Dumping memory with printf

```
$ ./tt hello
hello

$ ./tt "hey: %012lx"
hey: 7fffe14a287f
```

printf does not know how many arguments it has.
It deduces that from the format string.

If you don't give it enough, it keeps reading from the stack

We can dump arbitrary memory by walking up the stack

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

int show(char *buf)
{
    printf(buf); putchar('\n');
    return 0;
}

int main(int argc, char **argv)
{
    if (argc == 2)
        show(argv[1]);
}
```

```
$ ./tt 0x%08x.0x%08x.0x%08x.0x%08x.0x%08x
0x6ed0cf98.0x6ed0cfb0.0xd4ec1db8.0x17f4ff10.0x17f95040
```

Getting into trouble with printf

Have you ever used `%n` ?

Format specifier that will store into memory the number of bytes written so far

```
int printbytes;
printf("paul%n says hi\n", &printbytes);
```

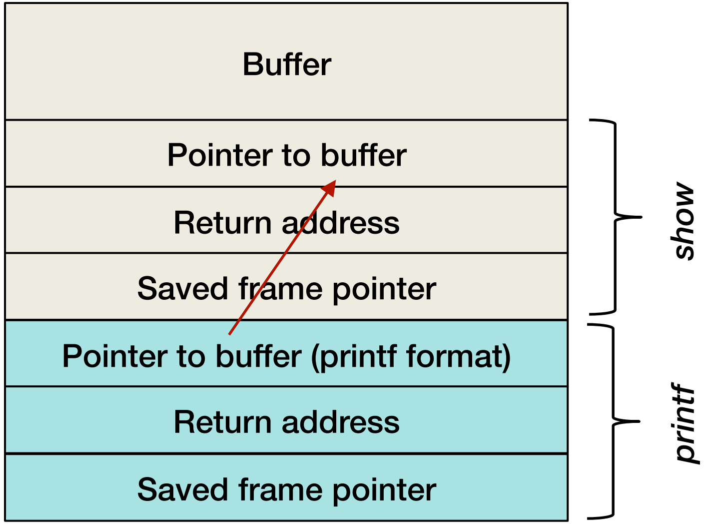
Will print

```
paul says hi
```

and will store the number `4` (which is the value of `strlen("paul")`) into the variable `printbytes`

If we combine this with the ability to change the format specifier, we can write to other memory locations

Bad usage of printf: %n



printf treats this as the 1st parameter after the format string.

- We can skip ints with formatting strings such as %x
- The buffer can contain the address that we want to overwrite

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

int
show(char *buf)
{
    printf(buf);
    putchar('\n');
    return 0;
}

int
main(int argc, char **argv)
{
    char buf[256];

    if (argc == 2) {
        strncpy(buf, argv[1], 255);
        show(buf);
    }
}
```

printf attacks: %n

What good is %n when it's just # of bytes written?

– You can specify an arbitrary number of bytes in the format string

```
printf("%.622404x%.622400x%n" . . .
```

Will write the value 622404+622400 = 1244804 = 0x12fe84

What happens?

– `%.622404x` = write at least 622404 characters for this value
– Each occurrance of `%x` (or `%d`, `%b`, ...) will go down the stack by one parameter (usually 8 bytes). We don't care what gets printed
– The `%x` directives enabled us to get to the place on the stack where we want to change a value
– `%n` will write that value, which is the sum of all the bytes that were written

Part 3

Defending against hijacking attacks

Fix bugs

- **Audit software**
- **Check for buffer lengths whenever adding to a buffer**
- **Search for unsafe functions**
  – Use *nm* and *grep* to look for function names
- **Use automated tools**
  – Clockwork, CodeSonar, Coverity, Parasoft, PolySpace, Checkmarx, PREfix, PVS-Studio, PCPCheck, Visual Studio
- **Most compilers and/or linkers now warn against bad usage**

```
tt.c:7:2: warning: format not a string literal and no format arguments [-Wformat-security]
zz.c:(.text+0x65): warning: the 'gets' function is dangerous and should not be used.
```

Fix bugs: Fuzzing

Do what the attackers do and try to locate unchecked assumptions!

- **Generate semi-random data as input to detect bugs**
  - Locating input validation & buffer overflow problems
  - Enter unexpected input
  - See if the program crashes
- **Enter long strings with searchable patterns**
- **If the app crashes**
  - Search the core dump for the fuzz pattern to find where it died
- **Automated fuzzer tools help with this**
  - E.g., libFuzzer and AFL in C/C++; cargo-fuzz in Rust, Go Fuzzing
- **Or … try to construct exploits using gdb**

Don't use C or C++

- **Most other languages feature**
  - Run-time bounds checking
  - Parameter count checking
  - Disallow reading from or writing to arbitrary memory locations
- **Hard to avoid in many cases**
  - Lots of legacy code
  - Performance concerns, CPU load
  - Programmer skill, availability of libraries, long-term support
  - Top contenders: **Rust** and **Go**
    - Rust: created by Mozilla – Memory safety with the efficiency of C/C++
    - Go: created by Google – fast, compiled code
    - Go designed for faster compilation, Rust is designed for faster execution

CYBERSECURITY INFORMATION SHEET

PRESS RELEASE | Nov. 10, 2022

NSA Releases Guidance on How to Protect Against Software Memory Safety Issues

FORT MEADE, Md. — The National Security Agency (NSA) published guidance today to help software developers and operators prevent and mitigate software memory safety issues, which account for a large portion of exploitable vulnerabilities.

The "Software Memory Safety" Cybersecurity Information Sheet highlights how malicious cyber actors can exploit poor memory management issues to access sensitive information, promulgate unauthorized code execution, and cause other negative impacts.

"Memory management issues have been exploited for decades and are still entirely too common today," said Neal Ziring, Cybersecurity Technical Director. "We have to consistently use memory safe languages and other protections when developing software to eliminate these weaknesses from malicious cyber actors."

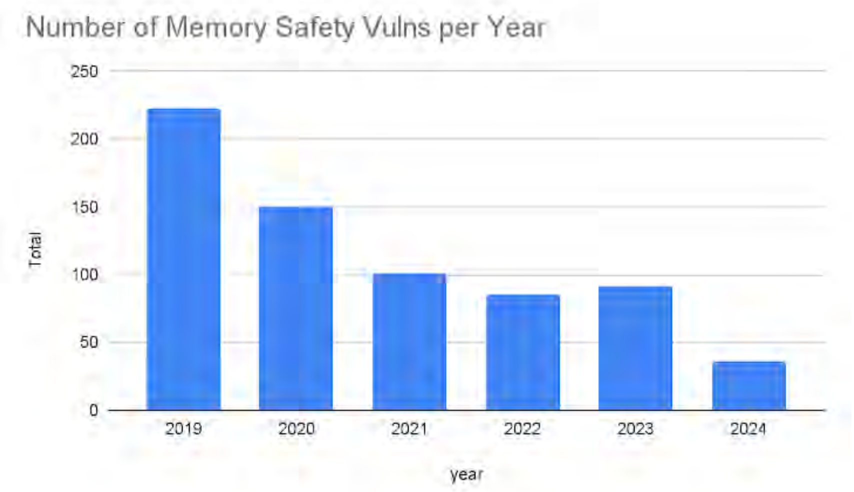
Microsoft and Google have each stated that software memory safety issues are behind around 70 percent of their vulnerabilities. Poor memory management can lead to technical issues as well, such as incorrect program results, degradation of the program's performance over time, and program crashes.

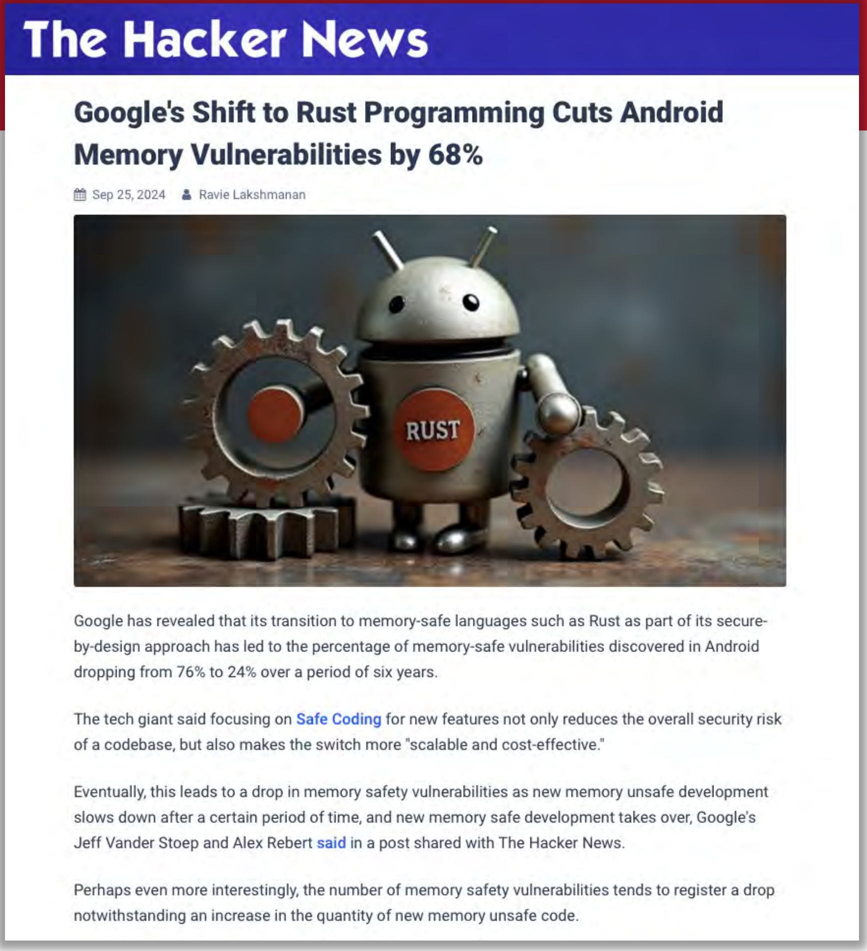
NSA recommends that organizations use memory safe languages when possible and bolster protection through code-hardening defenses such as compiler options, tool options, and operating system configurations.

https://www.nsa.gov/Press-Room/News-Highlights/Article/Article/3215760/nsa-releases-guidance-on-how-to-protect-against-software-memory-safety-issues/

Don’t use C or C++

- **Google’s switch to memory-safe languages led to the % of memory-safe vulnerabilities in Android dropping from 76% to 24% over six years.**
- **Google announced support for Rust in Android in 2021**





The Hacker News

Google's Shift to Rust Programming Cuts Android Memory Vulnerabilities by 68%

Sep 25, 2024 Ravie Lakshmanan

Google has revealed that its transition to memory-safe languages such as Rust as part of its secure-by-design approach has led to the percentage of memory-safe vulnerabilities discovered in Android dropping from 76% to 24% over a period of six years.

The tech giant said focusing on Safe Coding for new features not only reduces the overall security risk of a codebase, but also makes the switch more "scalable and cost-effective."

Eventually, this leads to a drop in memory safety vulnerabilities as new memory unsafe development slows down after a certain period of time, and new memory safe development takes over, Google's Jeff Vander Stoep and Alex Rebert said in a post shared with The Hacker News.

Perhaps even more interestingly, the number of memory safety vulnerabilities tends to register a drop notwithstanding an increase in the quantity of new memory unsafe code.

https://thehackernews.com/2024/09/googles-shift-to-rust-programming-cuts.html

Don't use C or C++

- **White House Office of the National Cyber Director called on developers to use languages without memory safety vulnerabilities**

InfoWorld

News

White House urges developers to dump C and C++

Biden administration calls for developers to embrace memory-safe programing languages and move away from those that cause buffer overflows and other memory access vulnerabilities.

CREDIT: MAGDALENA PETROVA

US President Joe Biden's administration wants software developers to use memory-safe programming languages and ditch vulnerable ones like C and C++.

The White House Office of the National Cyber Director (ONCD), in a report released Monday, called on developers to reduce the risk of cyberattacks by using programming languages that don't have memory safety vulnerabilities. Technology companies "can prevent entire classes of vulnerabilities from entering the digital ecosystem" by adopting memory-safe programming languages, the White House said in a news release.

https://www.whitehouse.gov/wp-content/uploads/2024/02/Final-ONCD-Technical-Report.pdf

https://www.infoworld.com/article/2336216/white-house-urges-developers-to-dump-c-and-c.html

Don’t use C or C++

The Register®

DARPA suggests turning old C code automatically into Rust – using AI, of course

Who wants to make a TRACTOR pull request?

Thomas Claburn Sat 3 Aug 2024 10:03 UTC

To accelerate the transition to memory safe programming languages, the US Defense Advanced Research Projects Agency (DARPA) is driving the development of TRACTOR, a programmatic code conversion vehicle.

The term stands for TRanslating All C TO Rust. It's a DARPA project that aims to develop machine-learning tools that can automate the conversion of legacy C code into Rust.

https://www.theregister.com/2024/08/03/darpa_c_to_rust/

Ongoing attempts to fix C/C++

- **Safe C++ Extensions proposal for inclusion in the C++ standard**
  - Separate the safe and unsafe parts clearly – keep the safe parts useful
  - Don’t break existing code
  - Addresses these categories of safety:
    - **Lifetime safety** (preserve objects with references), **type safety** (initialized vs. uninitialized data),
    - **Thread safety** (synchronization objects aren’t opt-in), **runtime checks** (array bounds, bad division, bad references)
  - Safe Standard Library: Memory-safe implementations of essential algorithms

- **TrapC – A propose fork of C**
  - Removes goto and union
  - Adopts a few C++ features that improve safety: Constructors & destructors, member functions
  - Automatic memory management
  - Limited lifetime for pointers

TrapC: https://www.infoworld.com/article/3836025/trapc-proposal-to-fix-c-c-memory-safety.html
Safe C++: https://safecpp.org/draft.html

Specify & test code

- **If it's in the specs, it is more likely to be coded & tested**
- **Document acceptance criteria**
  - "File names longer than 1024 bytes must be rejected"
  - "User names longer than 32 bytes must be rejected"
- **Use safe functions that check & allow you to specify buffer limits**
- **Ensure consistent checks to the criteria across entire source**
  - Example, you might `#define` limits in a header file but some files might use a mismatched number.
- **Don't allow user-generated format strings and check results from *printf***

Safer libraries

- **Compilers warn against unsafe *strcpy* or *printf***
- **Ideally, fix your code!**
- **Sometimes you can't recompile (e.g., you lost the source)**
- `libsafe`
  - Dynamically loaded library
  - Intercepts calls to unsafe functions
  - Validates that there is sufficient space in the current stack frame

    `(framepointer – destination) > strlen(src)`

Dealing with buffer overflows: **No Execute (NX)**

Data Execution Prevention (DEP)

- Disallow code execution in data areas – on the stack or heap
- Set MMU per-page *execute* permissions to *no-execute*
- Intel and AMD added this support in 2004

Used in Windows, Linux, and macOS

No Execute – not a complete solution

No Execute Doesn't solve all problems

- Some legacy applications need an executable stack
- Some applications need an executable heap
  - code loading/patching
  - JIT (just-in-time) compilers
- NX does not protect against heap & function pointer overflows
- NX does not protect against `printf` and related format string problems

Return-to-libc

- **Allows bypassing need for non-executable memory**
  - With DEP, we can still corrupt the stack … just not execute code from it
- **No need for injected code**
- **Instead, reuse functionality within the exploited app**
- **Use a buffer overflow attack to create a fake frame on the stack**
  - Transfer program execution to a library function, running with the "restored" frame pointer
  - `libc` = standard C library … every program uses it!
  - Most common library function to exploit: `system`
    - Runs the shell with a specified command
    - New frame in the buffer contains a pointer to the command to run (which is also in the buffer)
      - E.g., `system("/bin/sh")`

Return Oriented Programming (ROP)

- **Generalize return-to-libc:**
  Overwrite the return address on the stack with the address of a library function
  - Does not have to be the start of the library routine
    - Use "borrowed chunks" of code from various libraries
  - When the library gets to a RET instruction, that location is on the stack, under the attacker's control

- **Chain together sequences of code ending in RET**
  - Build together "gadgets" for arbitrary computation
  - Buffer overflow contains a sequence of addresses that direct each successive RET instruction

- **An attacker can use ROP to execute arbitrary algorithms without injecting new code into an application**
  - Removing dangerous functions, such as *system*, is ineffective
  - To make attacking easier: use a compiler that combines gadgets!
    - Example: **ROPC** – a Turing complete compiler, `https://github.com/pakt/ropc`

Dealing with buffer overflows & ROP: ASLR

Addresses of everything in the code were well known

- Dynamically-loaded libraries were loaded in the same place each time, as was the stack & memory-mapped files
- Well-known locations make them branch targets in a buffer overflow attack

Address Space Layout Randomization (ASLR)

- Position stack and memory-mapped files to random locations
- Position libraries at random locations
  - Libraries must be compiled to produce position-independent code
- Implemented in all modern operating systems
  - OpenBSD, Windows ≥Vista, Windows Server ≥2008, Linux ≥2.6.15, macOS, Android ≥4.1, iOS ≥4.3
- But … not all libraries (modules) can use ASLR
  - And it makes debugging difficult

Address Space Layout Randomization

- **Entropy**
  - How random is the placement of memory regions?
  - If it's not random enough then attackers can guess
- **Examples**
  - Linux Exec Shield
    - 19 bits of stack entropy, 16-byte alignment – resulted in > 500K positions
  - Windows 7
    - Only 8 bits of randomness for DLLs
      - Aligned to 64K page in a 16MB region: resulted in 256 choices – far too easy to try them all!
  - Windows 8 onward
    - 24 bits for randomness on 64-bit processors: >16M possible placements

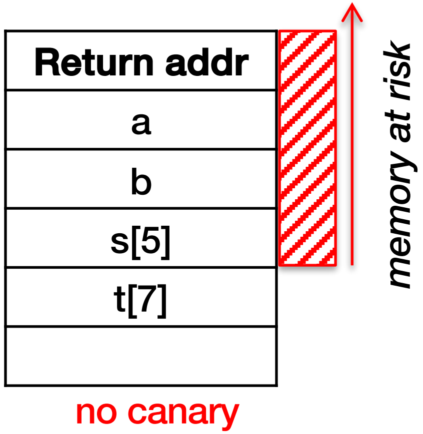
Dealing with buffer overflows: Canaries

Stack canaries

- Place a random integer before the return address on the stack
- Before a return, check that the integer is there and not overwritten: a buffer overflow attack cannot overwrite the return address without changing the canary

```
int a, b=999;
char s[5], t[7];

gets(s);
```



Dealing with buffer overflows: Canaries

Stack canaries

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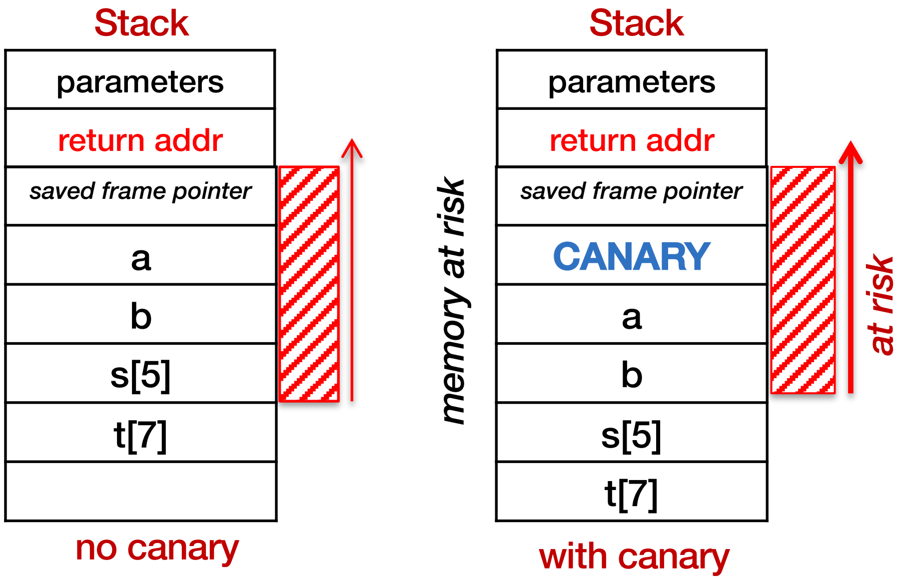


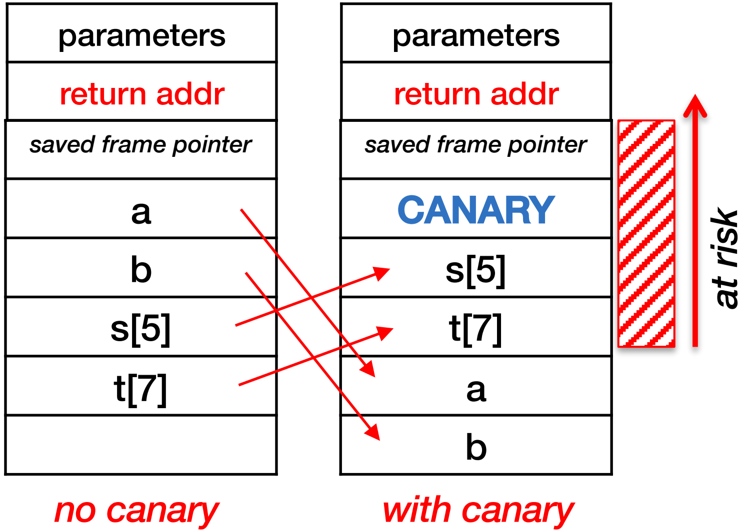
Refining Stack Canaries: Reordering Variables

IBM's ProPolice gcc patches – later incorporated into gcc

- Allocate local arrays into higher memory (below) other local variables in the stack
- Ensures that a buffer overflow attack will not clobber non-array variables
- Increases the likelihood that the overflow won't attack the logic of the current function

```
int a, b=999;
char s[5], t[7];

gets(s);
```



Stack canaries

- **Not foolproof**
- **Heap-based attacks are still possible**
- **Performance impact**
  - Need to generate a canary on entry to a function and check canary prior to a return
  - Minimal performance degradation ~8% for apache web server

Intel CET: Control-Flow Enforcement Technology

Developed by Intel & Microsoft to thwart ROP attacks

- Available starting with the Tiger Lake microarchitecture (mid-2020)

Two mechanisms

1. **Shadow stack**
   - Secondary stack
     - Only stores return addresses
     - MMU attribute disallows use of regular *store* instructions to modify it
   - Stack data overflows cannot touch the shadow stack – cannot change the control flow

2. **Indirect branch tracking**

Intel CET: Control-Flow Enforcement Technology

Indirect Branch Tracking

- Restrict a program's ability to use jump tables

- Jump table = table of memory locations the program can branch
  - Used for switch statements & various forms of lookup tables

- **Jump-Oriented Programming** (JOP) and **Call Oriented Programming** (COP)
  - Techniques where attackers abuse JMP or CALL instructions
  - Like Return-Oriented Programming but use gadgets that end with indirect branches

- New `ENDBRANCH` (ENDBR64) instruction allows a programmer to specify valid targets for indirect jumps
  - If you take an indirect jump, it has to go to an ENDBRANCH instruction
  - If the jump goes anywhere else, it will be treated as an invalid branch and generate a fault

Heap attacks – Protecting Pointers

- **Encrypt pointers (especially function pointers)**
  - Example: XOR with a stored random value
  - Any attempt to modify them will result in invalid addresses
  - XOR with the same stored value to restore original value
- **Degrades performance when function pointers are used**

Hardware Attacks: Example - Rowhammer

DDR4 memory protections are broken wide open by new Rowhammer technique

ars technica

Researchers build "fuzzer" that supercharges potentially serious bitflipping exploits.

Dan Goodin • 11/15/2021

Rowhammer exploits that allow unprivileged attackers to change or corrupt data stored in vulnerable memory chips are now possible on virtually all DDR4 modules due to a new approach that neuters defenses chip manufacturers added to make their wares more resistant to such attacks.

Rowhammer attacks work by accessing—or hammering—physical rows inside vulnerable chips millions of times per second in ways that cause bits in neighboring rows to flip, meaning 1s turn to 0s and vice versa. Researchers have shown the attacks can be used to give untrusted applications nearly unfettered system privileges, bypass security sandboxes designed to keep malicious code from accessing sensitive operating system resources, and root or infect Android devices, among other things.

https://arstechnica.com/gadgets/2021/11/ddr4-memory-is-even-more-susceptible-to-rowhammer-attacks-than-anyone-thought/

Hardware Attacks: Example - Rowhammer

- **RowHammer was disclosed in 2014**
  - Exploits memory architecture to alter data by repeatedly accessing a specific row
  - This introduces random bit flips in neighboring memory rows
- **2021: new attack technique discovered**
  - Uses non-uniform patterns that access two or more rows with different frequencies
  - Bypasses all defenses built into memory hardware
  - 80% of existing devices can be hacked this way
  - Cannot be patched!
- **Sample attacks**
  - Gain unrestricted access to all physical memory by changing bits in the page table entry
  - Give untrusted applications root privileges
  - Extract encryption key from memory

Fixed? Nope – introducing ZenHammer

- **Manufacturers tried to mitigate this problem**
- **But in March, 2024…**
  - Researchers created a new variant of the attack
  - ZenHammer acts like Rowhammer but can also flip bits on DDR5 devices

The Hacker News

New ZenHammer Attack Bypasses RowHammer Defenses on AMD CPUs

Mar 28, 2024 · Ravie Lakshmanan

Cybersecurity researchers from ETH Zurich have developed a new variant of the RowHammer DRAM (dynamic random-access memory) attack that, for the first time, successfully works against AMD Zen 2 and Zen 3 systems despite mitigations such as Target Row Refresh (TRR).

"This result proves that AMD systems are equally vulnerable to Rowhammer as Intel systems, which greatly increases the attack surface, considering today's AMD market share of around 36% on x86 desktop CPUs," the researchers said.

The technique has been codenamed ZenHammer, which can also trigger RowHammer bit flips on DDR5 devices for the first time.

RowHammer, first publicly disclosed in 2014, is a well-known attack that exploits DRAM's memory cell architecture to alter data by repeatedly accessing a specific row (aka hammering) to cause the electrical charge of a cell to leak to adjacent cells.

Part 4

Integer Overflow

Minimum & maximum values for integers

Size	Unsigned	Signed
8-bit (1 byte)	0 .. 255	-128 .. +127
16-bit (2 bytes)	0 .. 65,535	-32,768 .. +32765
32-bit (4 bytes)	0 .. 4,294,967,295	-2,147,483,648 .. 2,147,483,647
64-bit (8 bytes)	0 .. 18,446,744,073,709,551,617	-9,223,372,036,854,775,808 .. +9,223,372,036854,775,807

- **Arbitrary precision libraries may be available**
  - But processors don't do arbitrary precision math, so there's a performance penalty

Overflows and underflows

Going outside the range causes an overflow or underflow

- No room for the extra bit
- These do not generate exceptions

```
   11111111
+  00000001
  100000000
```

255 + 1 = 0

Unsigned integer overflow

Bigger than the biggest?

```
int main(int argc, char **argv)
{
    unsigned short n = 65535;

    printf("n = %d\n", n);
    n = n + 1;
    printf("n+1 = %d\n", n);
}
```

max unsigned short int

What gets printed?

```
n = 65535
n+1 = 0
```

Signed integer overflow

Bigger than the biggest?

```
int main(int argc, char **argv)
{
    short n = 32767;

    printf(”n = %d\n", n);
    n = n + 1;
    printf(”n+1 = %d\n", n);
}
```

max short int

What gets printed?

```
n = 32767
n+1 = -32768
```

Also underflow

Smaller than the smallest?

```
int main(int argc, char **argv)
{
    short n = -32768;

    printf("n = %d\n", n);
    n = n - 1;
    printf("n-1 = %d\n", n);
}
```

max short int

What gets printed?

```
n = -32768
n-1 = 32767
```

Same thing for ints

Bigger than the biggest?

```
int main(int argc, char **argv)
{
    short n = 2147483647;

    printf("n = %d\n", n);
    n = n + 1;
    printf("n+1 = %d\n", n);
}
```

max int

What gets printed?

```
n = 2147483647
n+1 = -2147483648
```

Integer overflow - casts

Casting from unsigned to signed

```
int main(int argc, char **argv)
{
    unsigned short n = 65535;
    short i = n;

    printf("n = %d\n", n);
    printf("i = %d\n", i);
}
```

What gets printed?

```
n = 65535
i = -1
```

So what?

You might not detect a buffer overflow because of an integer overflow

- **If working with money:**
  - Negative account can become positive
  - Positive account can become negative

If *packet_get_int* returns 1073741824 and **`sizeof(char*)`** = 4,
we allocate 0 bytes for response!

Version 3.3 of OpenSSH

```
nresp = packet_get_int();
if (nresp > 0) {
 response = xmalloc(nresp*sizeof(char*));
 for (i = 0; i < nresp; i++)
  response[i] = packet_get_string(NULL);
}
```

But we have 64-bit architectures!

- **Even 64-bit values can overflow**
  - If users can set a field to any value somewhere, they can set it to a huge value and overflows can occur
- **Default int size in C on Linux, macOS = 32 bits**

Some values are constrained

A lot of data fields in network messages use smaller values

- **IP header**
  - time-to-live field = 8 bits, fragment offset = 16 bits, length = 16 bits
- **TCP header**
  - Sequence #, Ack # = 32 bits, Window size = 16 bits
- **GPS week # = 10 bits**

Python 3 has no size limit

- **Actual type is hidden from the user**
  - Internally, an integer (32 or 64 bit, depending on the CPU) is used and is converted to an arbitrary-length integer object when needed
- **But there's a cost!**
  - 10B iterations of incrementing an int on an M2 Mac
    - C: 4.44 seconds
    - Java: 28.8 seconds – 6.4x slower
    - Python 237 seconds – 53x slower

By the way, do you trust Python's math?

```
$ python3 -q
>>> 0.1 + 0.2
0.30000000000000004
>>> 0.1 + 0.2 - 0.3
5.551115123125783e-17
```

SOPHOS

Patch now! Microsoft releases fixes for the serious SMB bug CVE-2020-0796

March 12, 2020

…
The SMBv3 vulnerability fixed this month is a doozy: A potentially network-based attack that can bring down Windows servers and clients, or could allow an attacker to run code remotely simply by connecting to a Windows machine over the SMB network port of 445/tcp. The connection can happen in a variety of ways we describe below, some of which can be exploited without any user interaction.
…
Microsoft fixes 116 vulnerabilities with this month's patches, and considers 25 of them critical, and 89 important. All the critical vulnerabilities could be used by an attacker to execute remote code and perform local privilege elevation.

https://news.sophos.com/en-us/2020/03/12/patch-tuesday-for-march-2020-fixes-the-serious-smb-bug-cve-2020-0796/

2020 SMB Bug: CVE-2020-0796 (SMBGhost)

"The vulnerability involves an integer overflow and underflow in one of the kernel drivers. The attacker could craft a malicious packet to trigger the underflow and have an arbitrary read inside the kernel, or trigger the overflow and overwrite a pointer inside the kernel. The pointer is then used as destination to write data. Therefore, it is possible to get a write-what-where primitive in the kernel address space."

Bug in the compression mechanism of SMB in Windows 10

Attacker can control two fields

- `OriginalCompressedSegmentSize` and `Offset`
- Use a huge value for `OriginalCompressedSegmentSize` to cause overflow
  - This will cause the system to allocate fewer bytes than necessary
  - Decompress will cause an overflow

https://blog.zecops.com/research/exploiting-smbghost-cve-2020-0796-for-a-local-privilege-escalation-writeup-and-poc/

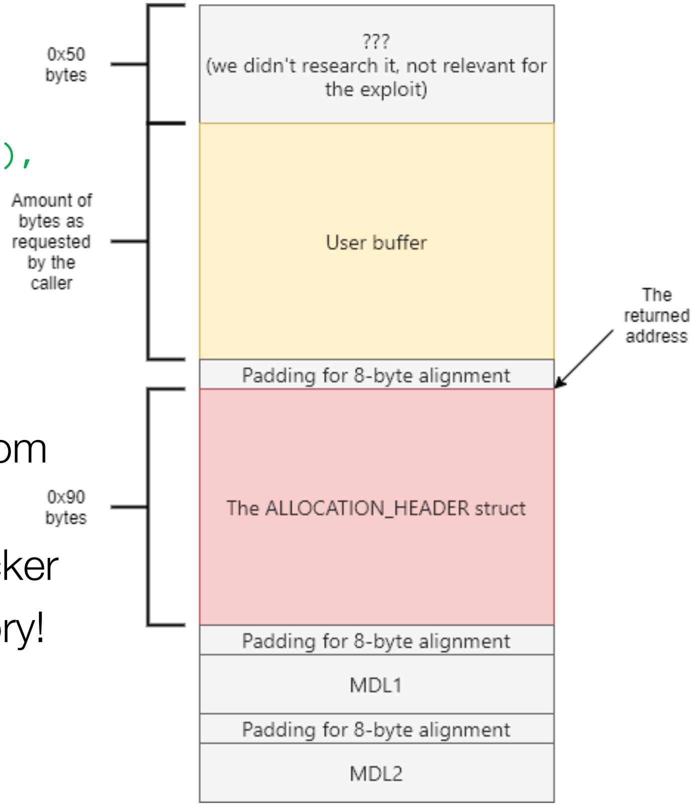
2020 SMB Bug: CVE-2020-0796 (SMBGhost)

Program does

```
memcpy( Alloc->UserBuffer,
     (PUCHAR)Header + sizeof(COMPRESSION_TRANSFORM_HEADER),
     Header->Offset);
```

Attack

- The decompression into a smaller buffer can overflow the User buffer
- The target of *memcpy* (`Alloc->UserBuffer`) is read from the allocation header, which can be overwritten
- The Header contents & offset can also be set by the attacker
- The attacker can write anything anywhere in kernel memory!



https://blog.zecops.com/research/exploiting-smbghost-cve-2020-0796-for-a-local-privilege-escalation-writeup-and-poc/

Microsoft Exchange year 2022 bug in FIP-FS breaks email delivery

BLEEPINGCOMPUTER

Lawrence Abrams • January 1, 2022

Microsoft Exchange on-premise servers cannot deliver email starting on January 1st, 2022, due to a "Year 2022" bug in the FIP-FS anti-malware scanning engine.

Starting with Exchange Server 2013, Microsoft enabled the FIP-FS anti-spam and anti-malware scanning engine by default to protect users from malicious email.

Microsoft Exchange Y2K22 bug

According to numerous reports from Microsoft Exchange admins worldwide, a bug in the FIP-FS engine is blocking email delivery with on-premise servers starting at midnight on January 1st, 2022.

> **Joseph Roosen**
> @JRoosen
>
> According to additional research on this issue, this is happening because Microsoft is using a signed int32 for the date and the new date value of 2,201,010,001 is over the max value of "long" int32 being 2,147,483,647. @MSFTExchange - Not sure why it was structured this way??
>
> 4:00 AM · Jan 1, 2022 · Twitter Web App

https://www.bleepingcomputer.com/news/microsoft/microsoft-exchange-year-2022-bug-in-fip-fs-breaks-email-delivery/

Is .gif a GIF file? Assumptions about file formats

- **iOS Messages app**
  - Any embedded file with a `.gif` extension will be decoded before the message is shown
    - Sent to the *IMTranscoderAgent* process that uses the ImageIO library
    - The ImageIO library ignores the file name and tries to guess the format to parse it
  - Allows attackers to send files in over 20 formats, increasing the attack surface
- **This was used in NSO's Pegasus malware on the iPhone**
  - Zero-click install via iMessages
  - Sent a PDF file with a `.gif` file name
  - Contents were compressed with JBIG2 compression

See https://googleprojectzero.blogspot.com/2021/12/a-deep-dive-into-nso-zero-click.html

PDF – JBIG2 Compression – Integer Overflow

- **JBIG2 compression**
  - Extreme compression format for black & white images
  - Breaks images into segments
  - Contains table with pointers to similar bitmaps
- **This attack exploited an integer overflow bug**
  - With carefully crafted segments, the count of detected symbols could overflow
  - This results in the allocated buffer being too small
  - Bitmaps are then written into this buffer
  - Enables attacker to control what gets written into arbitrary memory

PDF – JBIG2 Compression – Integer Overflow

```
Guint numSyms; // (1)
numSyms = 0;
for (i = 0; i < nRefSegs; ++i) {
   if ((seg = findSegment(refSegs[i]))) {
      if (seg->getType() == jbig2SegSymbolDict) {
        numSyms += ((JBIG2SymbolDict *)seg)->getSize();  // (2)
      } else if (seg->getType() == jbig2SegCodeTable) {
        codeTables->append(seg);
      }
   } else {
      ...
...
// get the symbol bitmaps
  syms = (JBIG2Bitmap **)gmallocn(numSyms, sizeof(JBIG2Bitmap *)); // (3)
  kk = 0;
  for (i = 0; i < nRefSegs; ++i) {
    if ((seg = findSegment(refSegs[i]))) {
      if (seg->getType() == jbig2SegSymbolDict) {
        symbolDict = (JBIG2SymbolDict *)seg;
        for (k = 0; k < symbolDict->getSize(); ++k) {
          syms[kk++] = symbolDict->getBitmap(k); // (4)
        }
...
```

32-bit symbol count

Symbol count can overflow with too many segments. `numSyms` becomes a small #

Allocated buffer becomes too small

The end

Top Known Exploited Vulnerabilities – 2023

MITRE, a non-profit organization that manages federally-funded research & development centers, publishes a list of top security weaknesses

Rank	Name
1	Use After Free
2	Heap-based Buffer Overflow
3	Out-of-bounds Write
4	Improper Input Validation
5	Improper Neutralization of Special Elements used in an OS Command (OS Command Injection)
6	Deserialization of Untrusted Data
7	Server-Side Request Forgery (SSRF)
8	Access of Resource Using Incompatible Type ('Type Confusion')
9	Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')
10	Missing Authentication for Critical Function

https://cwe.mitre.org/top25/archive/2023/2023_kev_list.html

The End