Attacks

Part I
Hacking in C 2018–2019
Thom Wiggers

iCIS | Digital Security
Radboud University

Notes:

Based on slides by Peter Schwabe.

Demos:

- `printf.c`
- `buffer.c`
- `buffer_vuln.c`
- `print_buf.c`

$ whoami

- Thom Wiggers

Notes:

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  - Please give me feedback

Notes:

Recap of last week

Programs are partitioned into different segments

- The code segment `.text` for program code
- `.data` and `.bss` for global and static variables
- These segments are usually found at the low addresses.

Notes:

Recap of last week (Stack)

Stack stores local function variables

- Starts at high addresses, grows towards lower addresses
- Typically addresses start with `0x7ff` on 64-bit Linux.
- Contains return addresses, function arguments, frame pointer
- Stack is automatically managed (via stack pointer), data is gone when function returns
- Stack overflow: exceed the maximum stack size (often via recursion)

Notes:

Recap of last week (Heap)

Heap for persistent or large data

- `char *x = malloc(sizeof(char));`
- Resize with `realloc()`
- Always, always check if the returned pointer is `NULL`!
- Return used memory with `free()`
- Programmer manages heap memory

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  - Use-after-`free()`
  - Memory leaks
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- Use `calloc()` to non-lazily allocate zeroed memory.

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Program arguments

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  `./prog bla -foo ...`

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Overview

Everything is in memory

Breaking stuff with printf

Buffer overflows

Why?
- Why does it work
- Why do we care

Homework

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Von Neumann Architecture

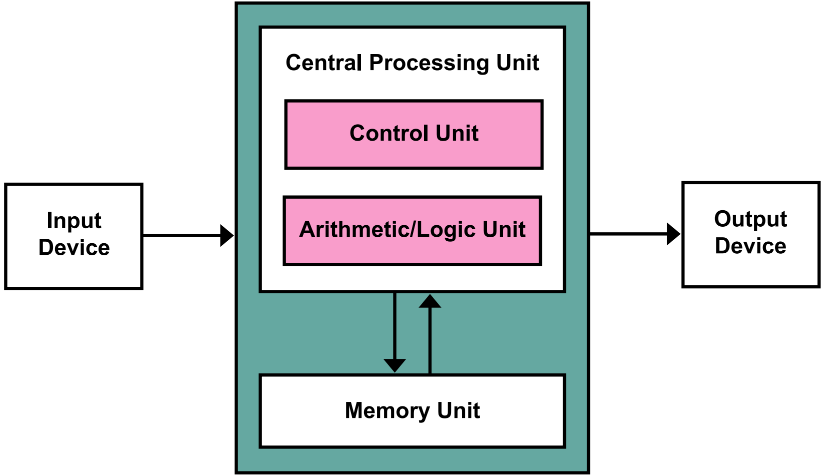

Figure: Von Neumann Architecture

Notes:

The Von Neumann Architecture is the theoretical model behind most, if not all, modern computers. It is easy to see that this model applies to your pc. It is nice and simple, and "cheap" hardware-wise.

Everything is data

- The Von Neumann architecture doesn't treat programs any different from program data!
- This means that the memory unit is shared between the code of the program and whatever the program does in memory.
- Control data such as return addresses are stored in between your program data.
- The memory bookkeeping is not just about the data of your program, but also the program itself.

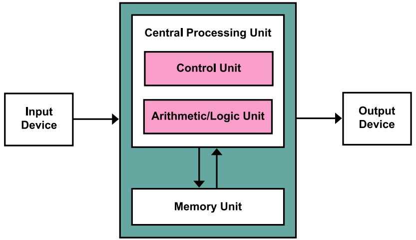

Figure: Von Neumann Architecture

Notes:

Don't yet mention self-modifying code, that's for the next slide.

Programs are data

So we now know that programs are controlled by what is in the same memory as the variables that we are reading and writing. . .

Notes:

- The foundation of the course is that if we can abuse what's happening when we modify memory in bad ways, we can then redirect the program.
- Sometimes that modifying the flow by overwriting parts of the program is a feature that is desired (and then people call it self-modifying code), but often it's a bug.
- We can even put our own code into memory, code that's not even part of the program, which we will talk about in the next lecture.
- Obviously, there are some protection mechanisms because this is all too silly, but we can turn those off.

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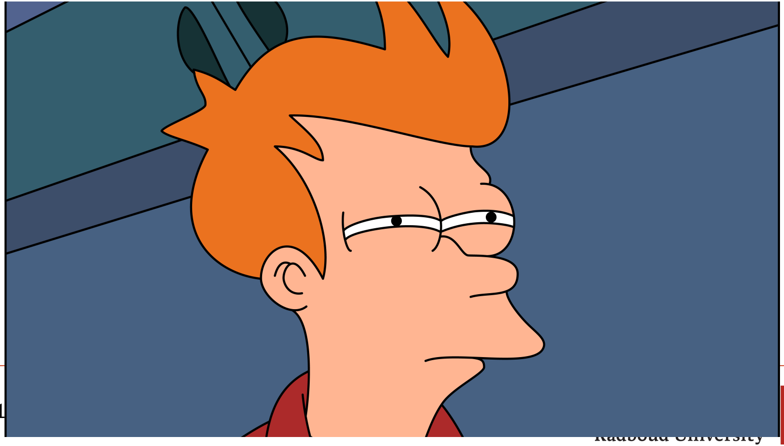

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MUST READ: I like Windows 7: Why should I pay to move to Windows 10?

Microsoft: 70 percent of all security bugs are memory safety issues

Percentage of memory safety issues has been hovering at 70 percent for the past 12 years.

By Catalin Cimpanu for Zero Day | February 11, 2019 -- 15:48 GMT (15:48 GMT) | Topic: Security

Image: Matt Miller

Around 70 percent of all the vulnerabilities in Microsoft products addressed through a security update each year are memory safety issues; a Microsoft engineer revealed last week at a security conference.

MORE FROM CATALIN CIMPANU

Security
New macOS security flaw lets malicious apps steal your Safari browsing history

Security
Dirty Sock vulnerability lets attackers gain root access on Linux systems

Security
Microsoft February Patch Tuesday fixes 77 security flaws, including IE zero-day

Security
Researchers hide malware in Intel SGX enclaves

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Your weekly update on security around the globe, featuring research, threats, and more.

Notes:

- The "dirty sock" Linux vulnerability in the side bar is *not* a memory safety issue. The program was written in Go, a memory-safe language. Instead, they messed up how they parse strings, allowing an attacker to inject "I am root". (https://shenaniganslabs.io/2019/02/13/Dirty-Sock.html)
- Article: https://www.zdnet.com/article/microsoft-70-percent-of-all-security-bugs-are-memory-safety-
- Nice follow-up blog post: https://medium.com/@sgrif/no-the-problem-isnt-bad-coders-ed4347810270.

Things we will be doing at in the next weeks

- Read data from memory that we shouldn't be able to see

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The last exercise you also have extra time for.

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Notes:

Recall: printf

*int printf(const char *format, ...);*
[printf] writes the output under the control of a ***format string*** *that specifies how subsequent arguments are converted for output.* *src: man 3 printf*

Remember:

%d	Print int as decimal
%u	Print unsigned int as decimal
%x	Print int as hexadecimal
%ld	Print long int as decimal
%hu	Print short int as unsigned decimal
%p	Print variable as pointer (void*)
%s	Print string from char* (ie. characters until we run into NULL)
%0Nx	Print as hexadecimal integer such that it's at least *N* characters wide. Fill with zeros.
%N$x	Print the *N*th argument of printf as hexadecimal integer.

Notes:

- The %0Nx syntax can be very helpful: %02x will for example make sure that 0xC is printed as 0x0C.
- The length modifiers, used for example as %ld or %hu can be used to print larger or smaller integers: e.g.
  - hh for char integers
  - h for short integers
  - l for long integers
  - ll for long long integers

Having fun with printf

What does the following program do?

```
// program.c
int main(int argc, char* argv[]) {

    printf(argv[1]);
}
```

```
~$ gcc -Wall -Wextra -Wpedantic -o program program.c
(gcc8 complains **only** about unused variable argc)
~$ ./program hi
hi
```


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Having fun with printf

What does the following program do *wrongly*?

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What does the following program do *wrongly*?

```
// program.c
int main(int argc, char* argv[]) {
    // should have been printf("%s", argv[1]);
    printf(argv[1]);
}
```

How do we make this program misbehave?

Notes:

Having fun with printf

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// program.c
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What happens if we run `./program %x`?

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int main(int argc, char* argv[]) {
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    printf(argv[1]);
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What happens if we run `./program %x`?
It will print the second argument of `printf`, even if it's not there!

Notes:

Recall: printf

*int printf(const char *format, ...);*
*[printf] writes the output under the control of a **format string** that specifies how subsequent arguments are converted for output.* *src: man 3 printf*

If the attacker controls format, they can do a lot of nasty things.
Remember:

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Format string attacks

- Reading data known since 1989
- First attack that broke something in 1999
- Remember, C is from 1972!
- Allows to read data from the stack and heap.
- Easy to spot: if there is no `"` after `printf(`, it's suspicious
- If we want compiler warnings from `gcc`, we need to use `-Wformat=2`, because of course why switch this on by default.
- The clang compiler *does* report these by default.

Notes:

Side-step: calling a function on x86_64

If we want to call a function `func(a, b, c, d, e, f, g, h)`, your computer does the following:

Notes:

- To understand what is printed, we need to look at what is happening when you call a function.
- The frame pointer may be left out (`-fomit-frame-pointer`).

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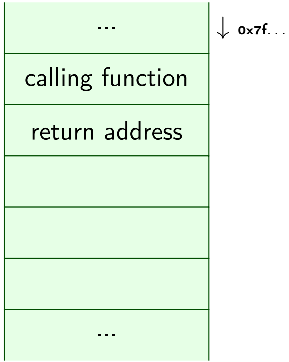

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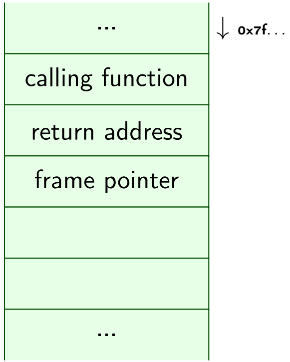

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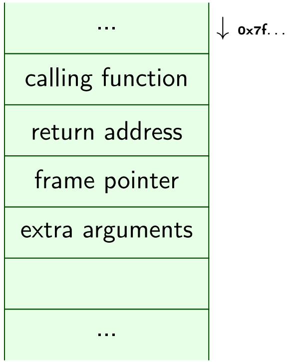

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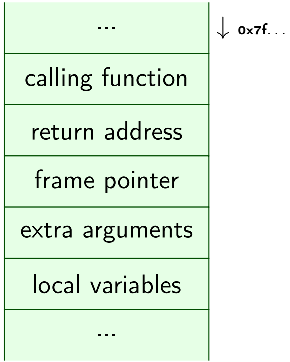

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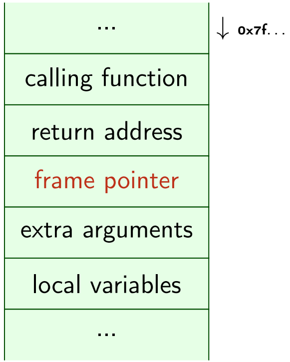

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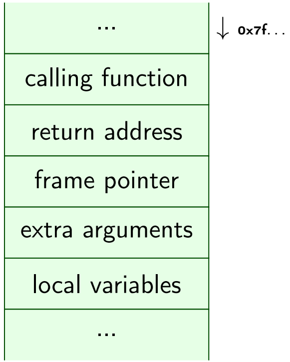

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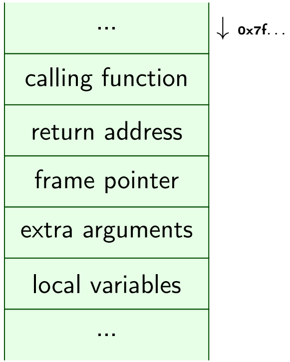

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Putting the first few arguments in registers saves a lot of time waiting for memory.

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So what do we see?

- So if we run `./printf %p`, we will print the value of the second register that would contain an argument.
- If we print `./printf '%7$p'`, we will print the first 8 bytes on the stack.

Notes:

- The `%N$` syntax starts counting at 1.
- Make sure to escape or properly quote (single quotes) the $ on the shell!

printf is a powerful debugger

```c
#include <stdio.h>
void do_print(char* string)
  { printf(string); }

int main(int argc, char** argv) {
  long bla = 0xDEADC0DECAFEF00D;
  do_print(argv[1]);
}
```


Notes:

- Demo time!
- You can see the value of `bla` clearly in the output of the command on the slide.
- The return address is also in the output. One of the more significant ways to recognise this, is the fact that it doesn't start with `0x7f`, like the stack addresses.
- Demo that we can confirm this by using `gdb`.
  - `gdb -q printf.c`
  - `break do_print`
  - `run`
  - `info frame`

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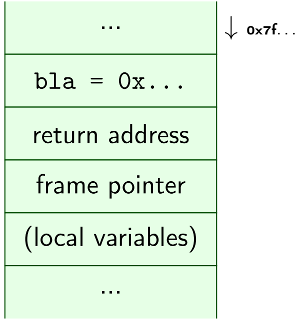


```
./printf "$(perl -e 'print "%p "x14')"
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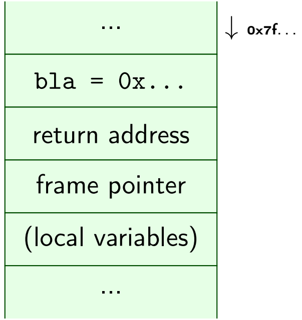


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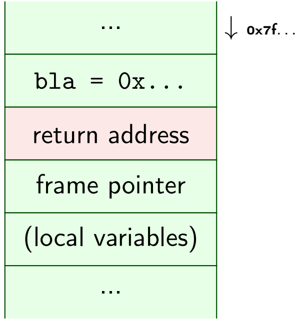
Notes:

- Demo time!
- You can see the value of `bla` clearly in the output of the command on the slide.
- The return address is also in the output. One of the more significant ways to recognise this, is the fact that it doesn't start with `0x7f`, like the stack addresses.
- Demo that we can confirm this by using `gdb`.
  - `gdb -q printf.c`
  - `break do_print`
  - `run`
  - `info frame`

printf is a powerful debugger

```
#include <stdio.h>
void do_print(char* string)
  { printf(string); }

int main(int argc, char** argv) {
  long bla = 0xDEADC0DECAFEF00D;
  do_print(argv[1]);
}
```

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Demo time again
The 9th argument was the right one.

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- If we put an address in the place where `printf` will read the argument from, we control where `printf` reads!

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More on `printf`

Q: So know we know how to read stuff, but `printf` only displays things!
We can't modify the program if we can only read things!

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> *%n The number of characters written so far is stored into the integer pointed to by the corresponding argument. That argument shall be an `int *`, or variant whose size matches the (optionally) supplied integer length modifier.* *man 3 printf*

Notes:

More on `printf`

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%n The … *red into*
the integer … *t. That*
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Figure: C standard library designers

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  – Writing $\pm 2^{47}$ characters to write a 48-bit (Linux, amd64) address is *impractical* ($\pm$16 TiB).
  – **Solution:** Instead use length modifiers and write in parts: `%hn` writes 16 bits instead.

Notes:

First format string exploit

```
Exploit for proftpd 1.2.0pre6

From: tymm () COE MISSOURI EDU (Tymm Twillman)
Date: Mon, 20 Sep 1999 14:31:51 -0500

Tested on Linux with standard RedHat 6.0 install (w/glibc 2.0
compatability), proftpd installed with configure/make/make install...

- ftp to host
- login (anonymous or no)

(this should be all on one line, no spaces)

ftp> ls aaaXXXX%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u
%u%u%u%u%u%u%u%u%u%653300u%n

(replace the X's with the characters with ascii values 0xdc,0x4f,0x07,0x08
consecutively)
```

https://seclists.org/bugtraq/1999/Sep/328

Notes:

- Ask students to figure out why 653300 + stuff.‘
- This attack writes zero (because of integer overflow) to some place in memory, where the current user id happens to be stored. . .

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In a more perfect world

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Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
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Notes:

- Example is in Python, because that was just easier.
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Remember the last time you spent hours debugging some `segmentation error`?
If you ever face a decision to choose a programming language, please think about if you really need C(++) or if you can use a safer language such as Rust (good alternative for C), Go (good with concurrency) or Python (if you can take the performance hit).

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Buffers on the stack

```
void func() {
    char buf[20];
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Notes:

- Let's take a look at the memory layout, see where `buf` is located
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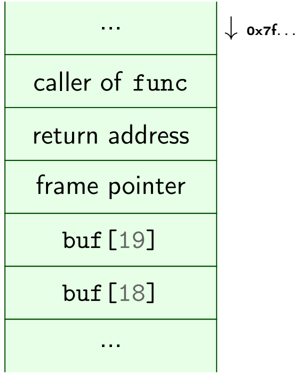

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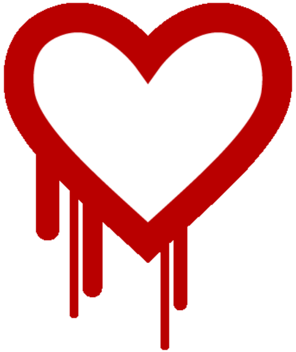

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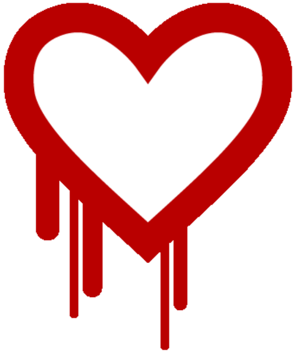

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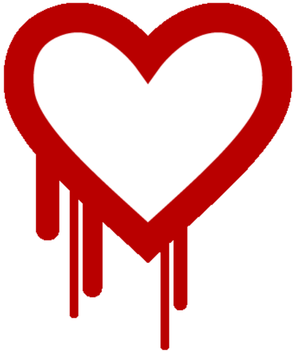

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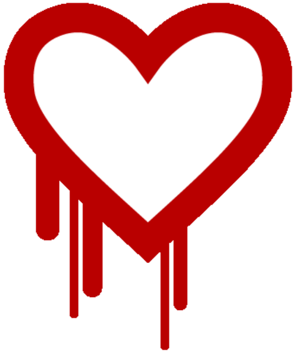

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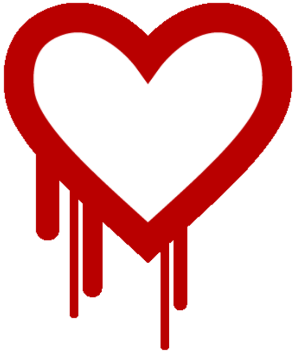

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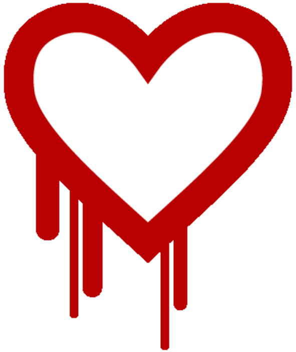

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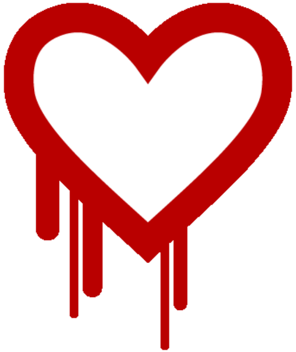

Underlying problem: Out of bounds array access in OpenSSL

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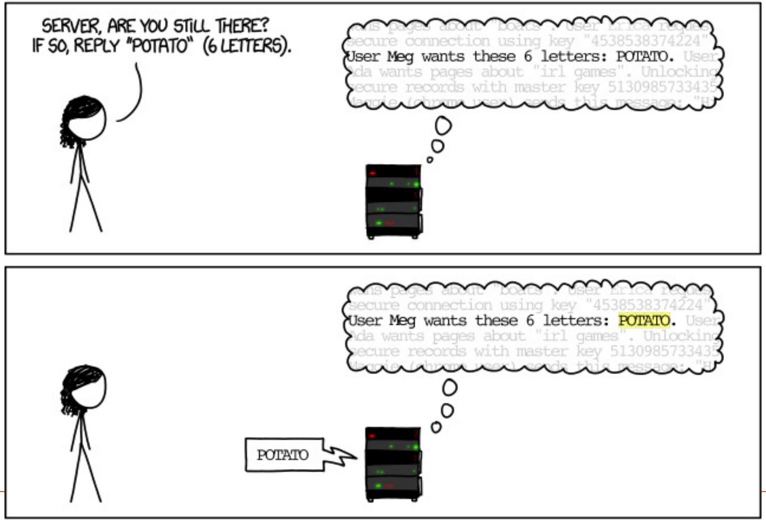
How Heartbleed works



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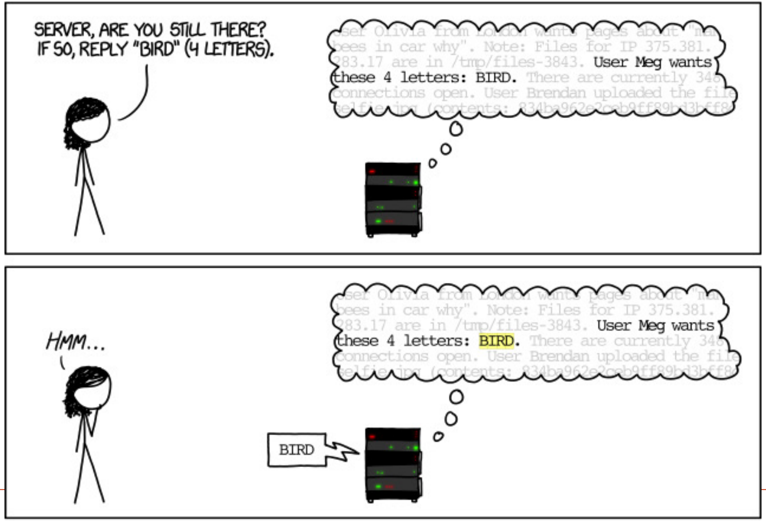

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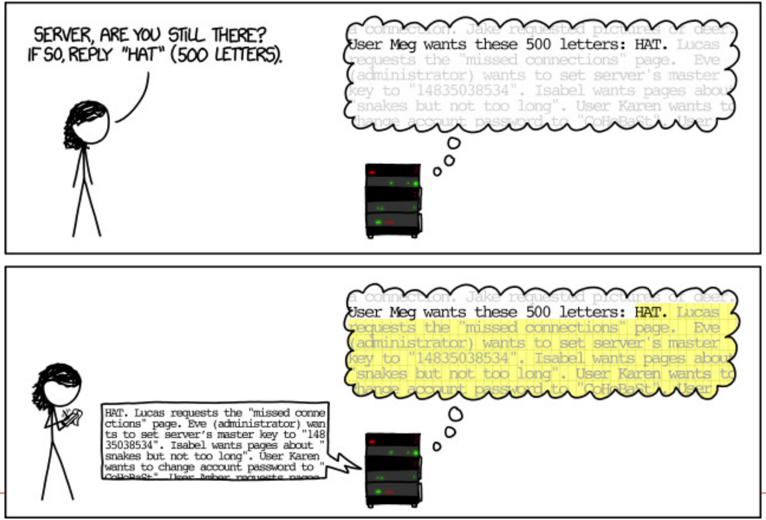

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Ping

- ping is a protocol that lets you check if a server is online and what the round-trip latency is.

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- Sends an icmp packet to the server, server sends the same thing back.

```
~ $ ping -c2 10.8.0.1
PING 10.8.0.1 (10.8.0.1) 56(84) bytes of data.
64 bytes from 10.8.0.1: icmp_seq=1 ttl=64 time=15.4 ms
64 bytes from 10.8.0.1: icmp_seq=2 ttl=64 time=14.10 ms

--- 10.8.0.1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 3ms
rtt min/avg/max/mdev = 14.992/15.213/15.435/0.253 ms
```


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  - Check if `fragment offset + packet size` < 65536

Notes:

- https://en.wikipedia.org/wiki/Ping_of_death

IPv6

- Late 90s, early 2000s: introduction of IPv6.
- You see where this is going...
  - CVE-2013-3183: IPv6 ping of death against Windows Vista SP2, Windows Server 2008 SP2 and R2 SP1, Windows 7 SP1, Windows 8, Windows Server 2012, and Windows RT
  - CVE-2016-1409: IPv6 ping of death against Cisco's IOS, IOS XR, IOS XE, and NX-OS software

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Why does this even work?

- The C specification contains descriptions of how things should behave
  - e.g. `i++` gives the value of `i` and increments it afterwards.
- It also defines that the behaviour of some things is undefined

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  - e.g. `i++` gives the value of `i` and increments it afterwards.
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Undefined behavior – behavior, upon use of a nonportable or erroneous program construct, ... for which the standard imposes no requirements. Permissible undefined behavior ranges from ignoring the situation completely with unpredictable results, to having demons fly out of your nose."
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Signed integer overflow Compilers may assume that `x` will never be smaller than `INT_MAX` and remove the `if` block, but `func(1)` will *probably* return a large negative number.

```
#include <limits.h>
void func(unsigned int foo) {
    int x = INT_MAX;
    x += foo;
    // probably removed:
    if (x < INT_MAX) bar();
    return value;
}
```


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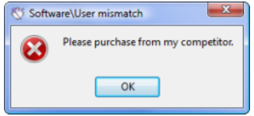

Figure: PEBKAC

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Remember when your mom installed all those toolbars?

printf-filename.c:

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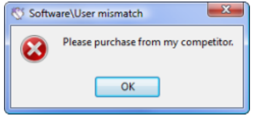

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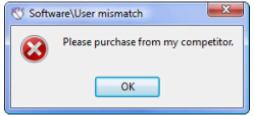

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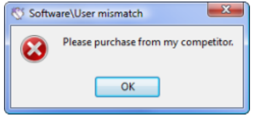

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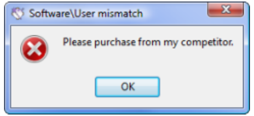

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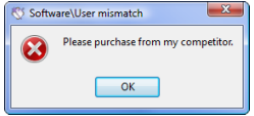

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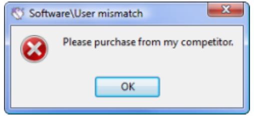

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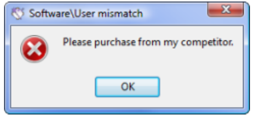

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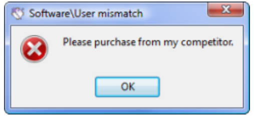

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How do we fix this?

- Use memory-safe languages

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- Why do we care

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- Redirect a program to call a function that it shouldn't have called.

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Hint about last week's homework

For the `magic_function.c` exercise:

- Draw some pictures about what's going on on the stack when you call `magic_function()`
- Make sure that the compiler doesn't remove unused variables!
  - For example, print the result to make it 'used'
  - You could try to mark a buffer as `volatile`

```
volatile char bla[1000];
```


Notes: