Buffer Overflow

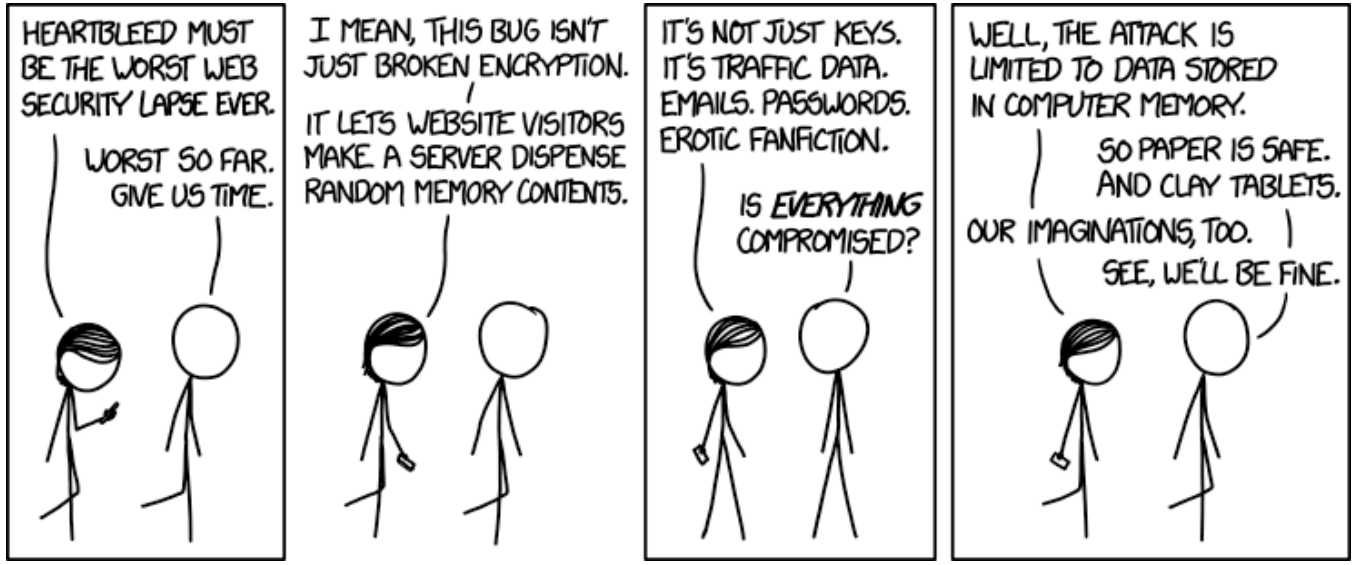
CSE 351 Winter 2024

Instructor:

Justin Hsia

Teaching Assistants:

Adithi Raghavan
Aman Mohammed
Connie Chen
Eyoel Gebre
Jiawei Huang
Malak Zaki
Naama Amiel
Nathan Khuat
Nikolas McNamee
Pedro Amarante
Will Robertson



Alt text: I looked at some of the data dumps from vulnerable sites, and it was ... bad. I saw emails, passwords, password hints. SSL keys and session cookies. Important servers brimming with visitor IPs. Attack ships on fire off the shoulder of Orion, c-beams glittering in the dark near the Tannhäuser Gate. I should probably patch OpenSSL.

http://xkcd.com/1353/

Relevant Course Information

- Mid-quarter survey due tonight!
- HW12 due tonight, HW13 due Wednesday, HW14 due Monday (2/12)

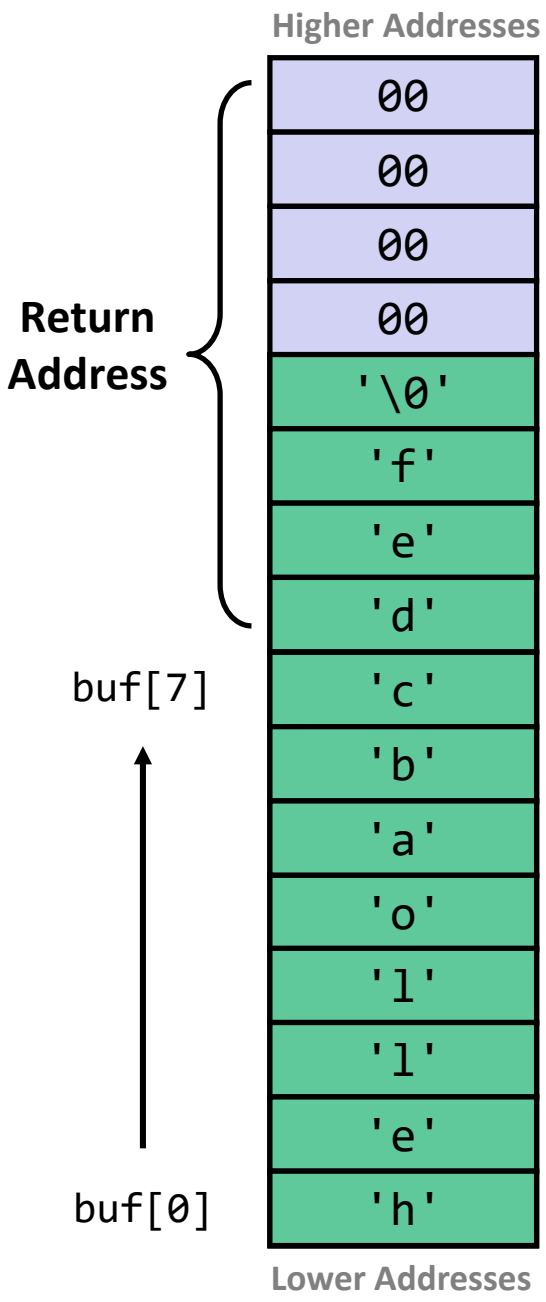
- Lab 3 released today, due next Friday (2/16)
  - You will have everything you need by the end of this lecture

- Midterm starts Thursday (Friday lecture is extra support hour)
  - Instructions will be posted on Ed Discussion
  - Gilligan's Island Rule: discuss high-level concepts and give hints, but not solving the problems together
  - Ed Discussion (private posts) and support hours to answer clarifying questions

Buffer Overflow

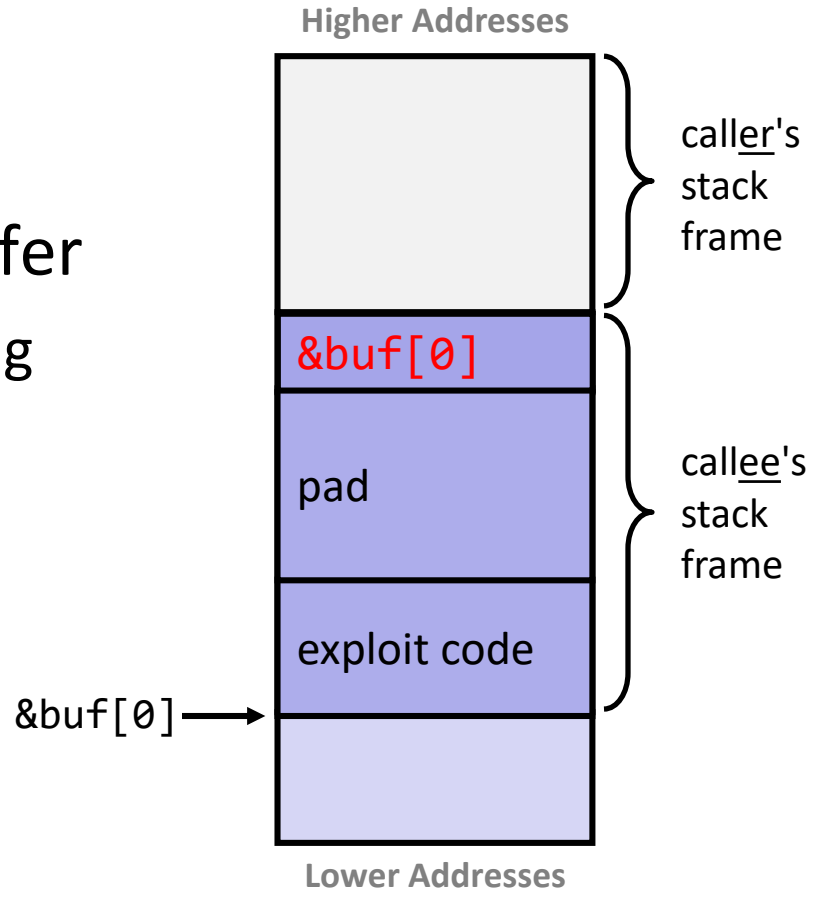
Lesson Summary (1/3)

- A **buffer** is an array that holds temporary data (*e.g.*, user/file/network input)
- **Buffer overflow** is writing past the end of the buffer
  - Common in C/Unix/Linux due to lack of bounds checking
  - Vulnerable functions include `gets`, `strcpy`, `scanf`, `fscanf`, `sscanf`
- Buffer overflow exploit: **stack smashing**
  - Overflow local array to alter stack contents
  - Commonly used to alter procedure return address



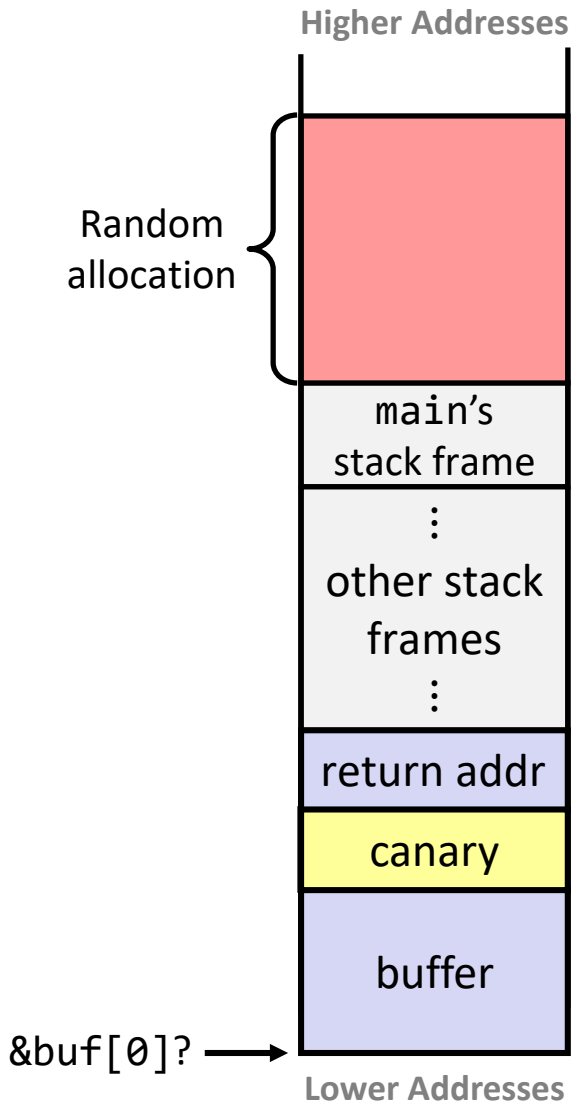
Lesson Summary (2/3)

- A **buffer** is an array that holds temporary data (*e.g.*, user/file/network input)
- **Buffer overflow** is writing past the end of the buffer
  - Common in C/Unix/Linux due to lack of bounds checking
  - Vulnerable functions include `gets`, `strcpy`, `scanf`, `fscanf`, `sscanf`
- Buffer overflow exploit: **code injection**
  1) Put exploit/machine code in buffer
  2) Pad to reach stack frame's return address
  3) Replace return address with address of the buffer



Lesson Summary (3/3)

- Dealing with buffer overflow attacks
  - Use array bounds checking
    - Manually (*i.e.*, implement yourself) or automatically (*e.g.*, use safe functions or non-C language)
  - Add a stack canary after the buffer
    - Secret value (changes on each execution) that shouldn't change
  - Randomized stack offsets
    - Makes finding the address of exploit code more difficult
  - Non-executable memory regions (*e.g.*, the stack)
    - Prevent exploit code from being placed and executed there



Lesson Q&A

- Learning Objectives:
  - Define buffer overflow and explain how it occurs.
  - Identify elements of C programs that make them vulnerable to buffer overflow.
  - Identify methods of protecting against buffer overflow.
  - Perform stack smashing and code injection exploits.

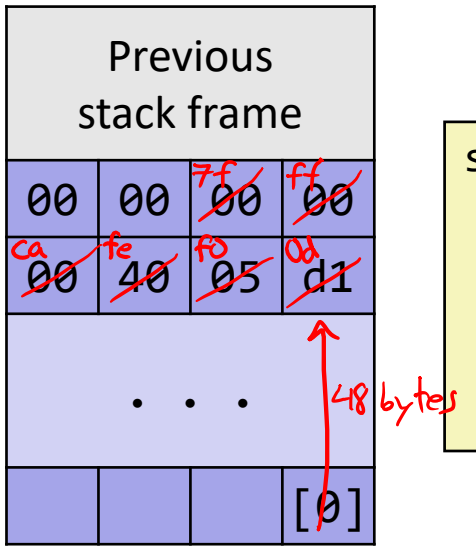
- What lingering questions do you have from the lesson?
  - Chat with your neighbors about the lesson for a few minutes to come up with questions

Buffer Overflow – Practice

Polling Question

- `smash_me` is vulnerable to stack smashing!
- What is the minimum number of characters that `gets` must read in order for us to change the return address to a stack address?
  - For example: (`0x 00 00 7f ff ca fe f0 0d`)

always 0's 6 bytes of data




```
smash_me:
  subq  $0x40, %rsp
   ...
  leaq  16(%rsp), %rdi
  call  gets
   ...
```

get to ret addr: 64 bytes − 16 + 6 (overwrite ret addr)

A. 27
B. 30
C. 51
D. 54
E. We're lost…

Lab Setup/Demo

- Printable vs. nonprintable characters (asciitable.com)
  - Input from terminal generally restricted to printable characters (~ 0x20 – 0x7E)
  - Need full range of 1-byte character values (0x00 – 0xFF) for exploits

- Lab 3 workflow:
  - Design exploit string for task
  - Type out exploit string as printable characters in `.txt` file
  - Use `sendstring` to convert `.txt` → `.bytes` file
  - Pass `.bytes` file into `bufbomb` to be read by `Gets()` when called by `getbuf()`
  - Use GDB to verify that stack is modified as desired (`x /<#>gx $rsp`)

Buffer Overflow – Context

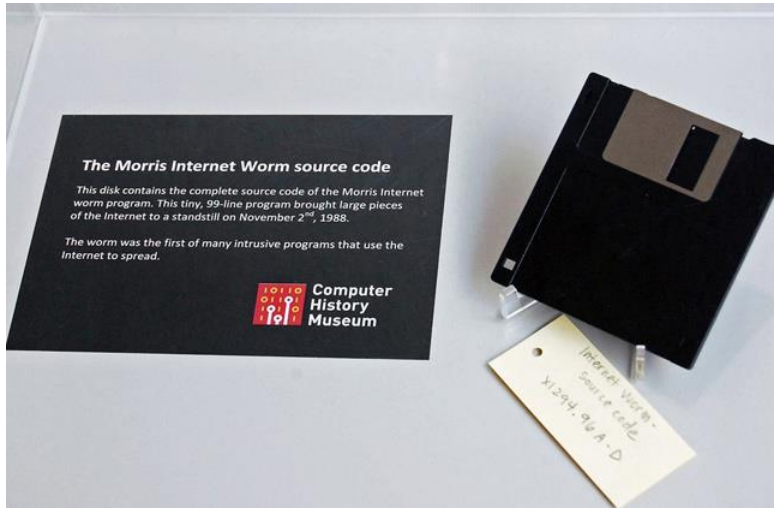
Exploits Based on Buffer Overflows

- ⚠ Buffer overflow bugs can allow attackers to execute arbitrary code on victim machines ☠
  - Most commonly executing a "root shell" – terminal with elevated privileges

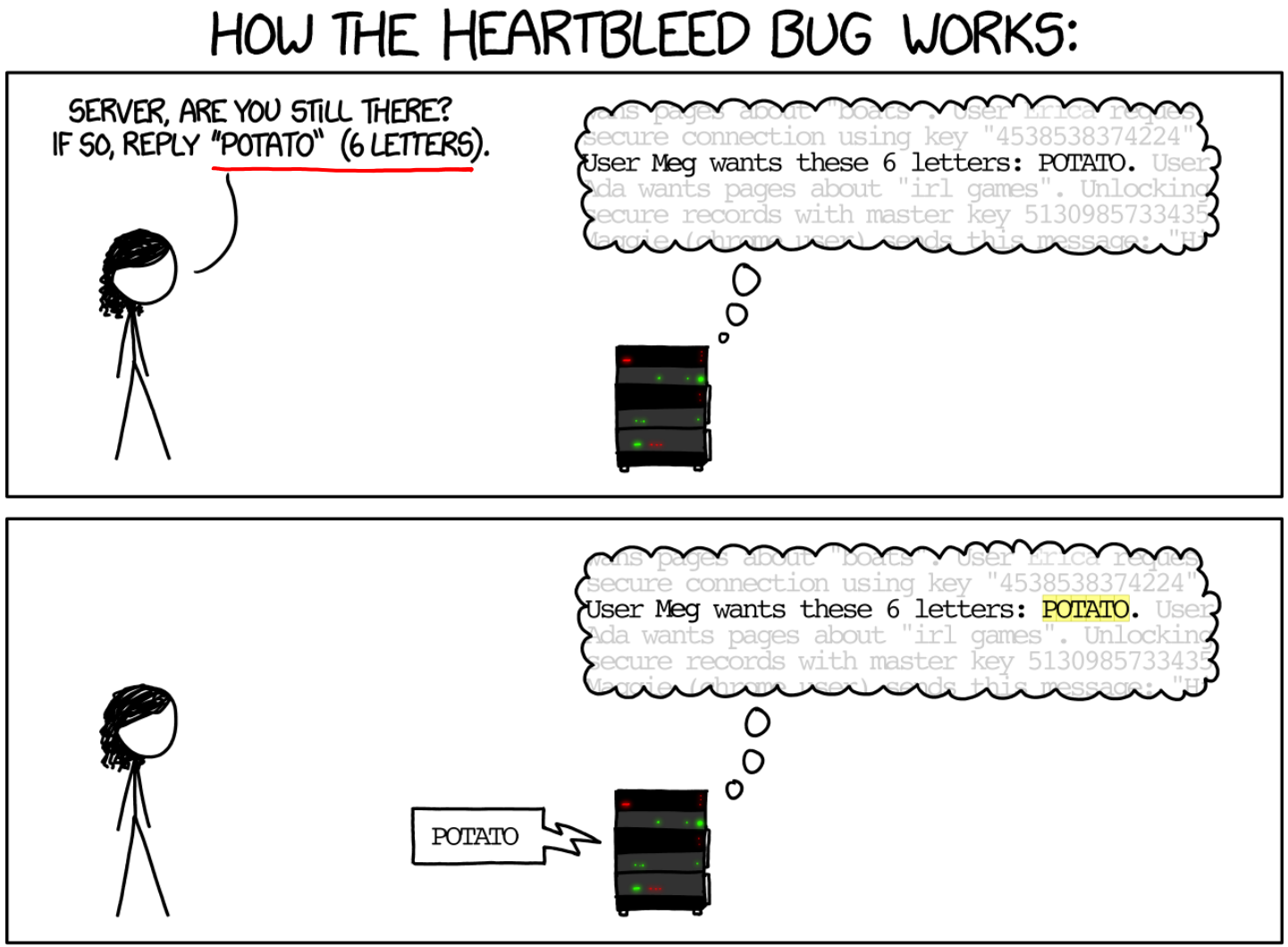
- Distressingly common in real programs
  - Original "Internet worm" (1988)
  - Heartbleed (2014, affected 17% of servers) & Cloudbleed (2017)
  - Hacking embedded devices (*e.g.*, cars, smart home devices, Internet of Things)

The Morris Worm (1988)

- Early versions of the finger server (`fingerd`) used `gets` to read the argument sent by the client
  - *e.g.*, `finger droh@cs.cmu.edu`
- The Morris Worm attacked `fingerd` server with phony argument:
  - `finger "exploit-code padding new-return-addr"`
  - Exploit code executed a root shell on the victim machine, then scanned for other machines to attack
- Fallout/legacy (1989 article)
  - Invaded ~6000 computers in hours (10% of the Internet)
  - The author, Robert Morris, was prosecuted
    - First conviction under 1986 Computer Fraud and Abuse Act
    - Now an MIT professor



Heartbleed (2014)



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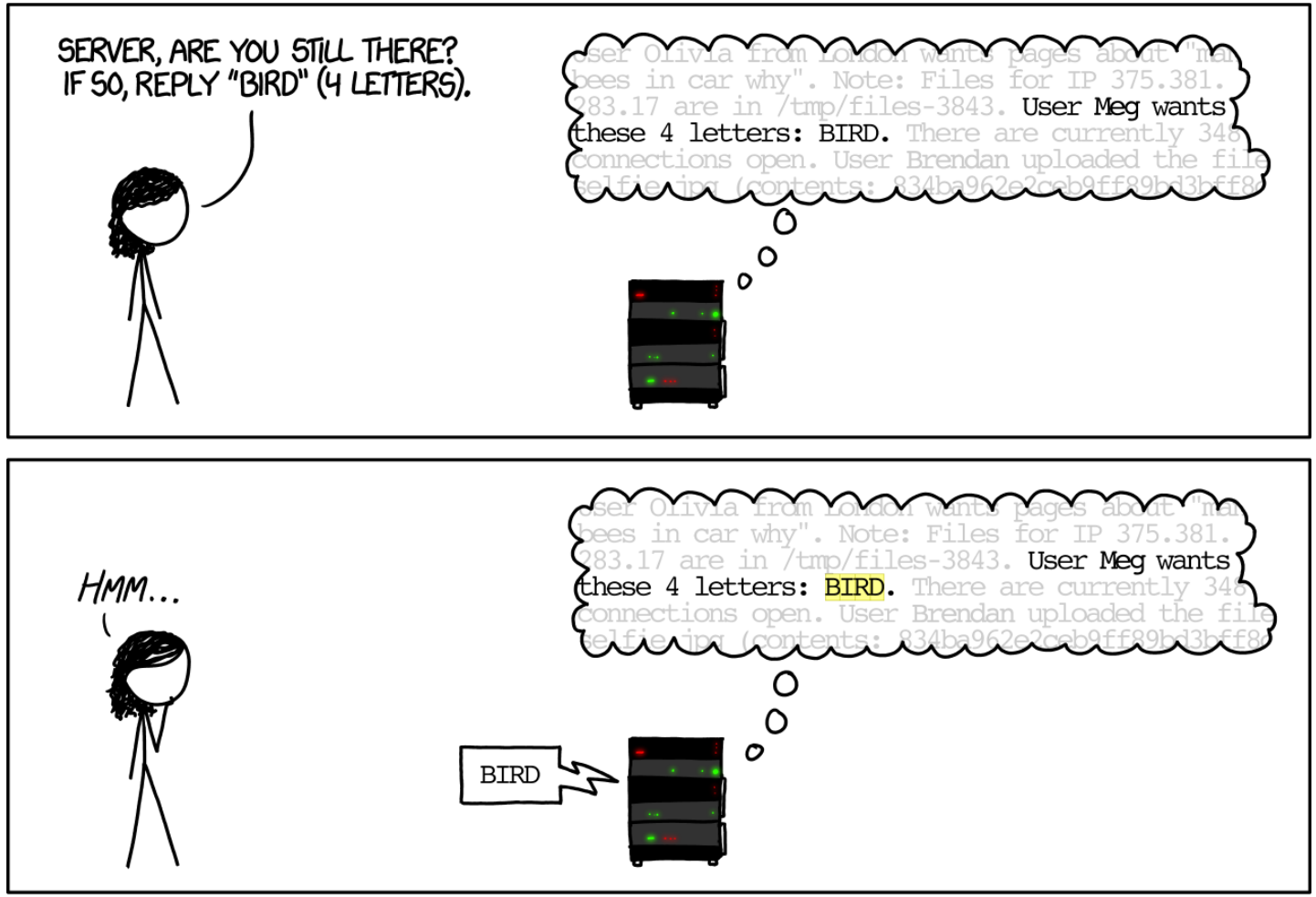
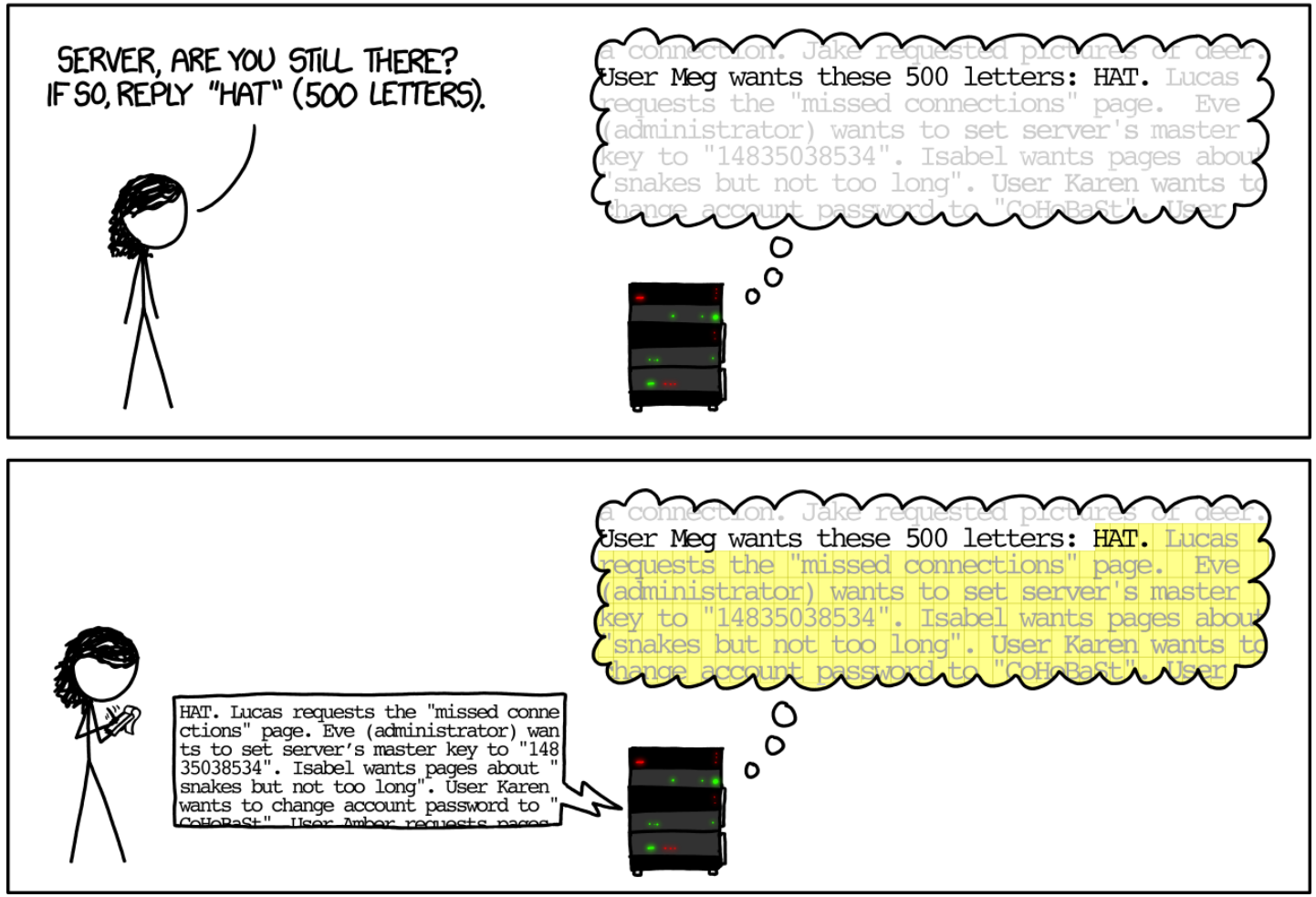
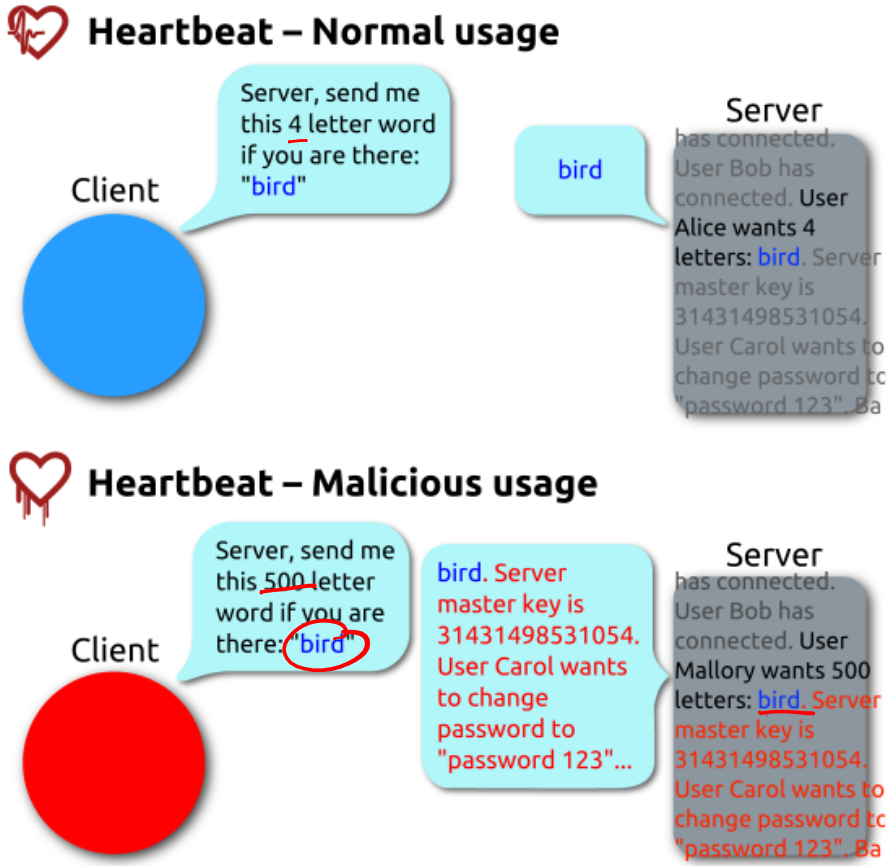


Heartbleed (2014)



Heartbleed Details

- Buffer over-read in OpenSSL
  - Open source security library
  - Bug in a small range of versions
- "Heartbeat" packet: message & length
  - Server echoes back data to match length
  - Allowed attackers to read contents of memory
- ~17% of Internet affected
  - *e.g.*, Github, Yahoo, Stack Overflow, Amazon Web Services

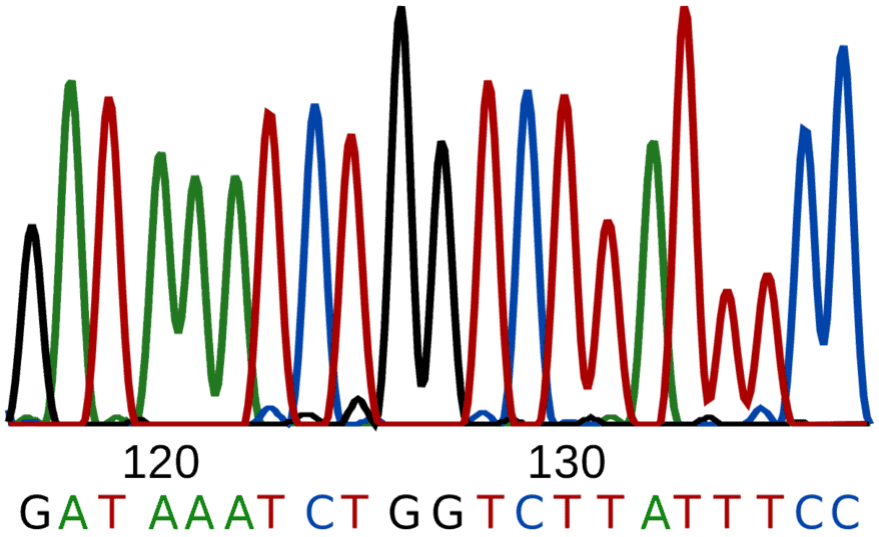


Hacking Cars (2010)

- UW CSE research demonstrated wirelessly hacking a car using buffer overflow
  - http://www.autosec.org/pubs/cars-oakland2010.pdf
- Overwrote the onboard control system's code
  - Disable brakes, unlock doors, turn engine on/off

Hacking DNA Sequencing Tech (2017)

- UW CSE project: Computer Security and Privacy in DNA Sequencing
  Ney et al. (2017): https://dnasec.cs.washington.edu/
  - Potential for malicious code to be encoded in DNA!
  - Attacker can gain control of DNA sequencing machine when malicious DNA is read



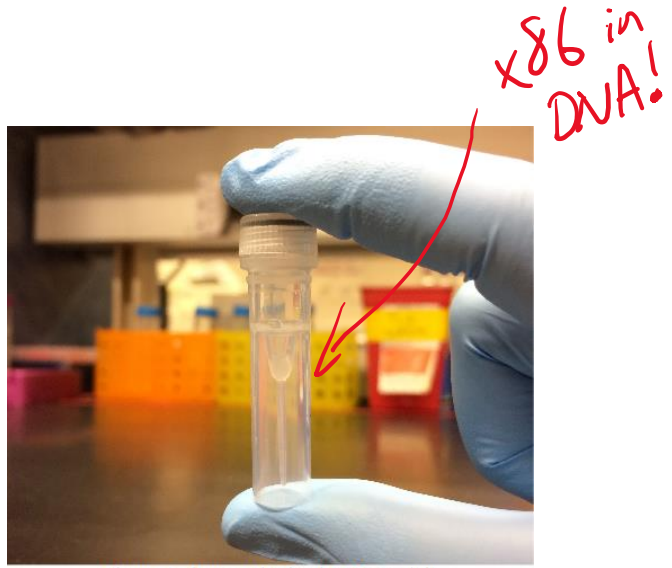


Figure 1: Our synthesized DNA exploit

Think this is cool?

- Take CSE 484 (Security)
  - Several different kinds of buffer overflow exploits
  - Many ways to counter them
- Nintendo fun!
  - Using glitches to rewrite code: https://www.youtube.com/watch?v=TqK-2jUQBUY
  - Flappy Bird in Mario: https://www.youtube.com/watch?v=hB6eY73sLV0

Discussion Questions

- Discuss the following question(s) in groups of 3-4 students
  - I will call on a few groups afterwards so please be prepared to share out
  - Be respectful of others' opinions and experiences

- Code injection attacks are a form of "*hacking*" that takes advantage of a *security vulnerability* (*e.g.*, buffer overflow). "Hacking" is now commonplace in society and media.
  - What are some of the possible <u>consequences</u> & <u>objectives</u> of hacking (*i.e.*, to what ends might someone engage in hacking)?
  - What are some reasons why vulnerable systems keep getting connected to the Internet?