Engineering Robust Server Software

Vulnerabilities

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Common/Famous Vulnerabilities: Do Not Do!

- Common vulnerabilities
  - Buffer overflow
  - Failure to sanitize
    - SQL
    - Command injection
    - Cross-site Scripting (XSS)
  - Cross Site Request Forgery
  - Privilege Escalation
  - Time of check to time of use (TOCTTOU)
- Famous vulnerabilities: Dirty COW, Heartbleed, Apple goto

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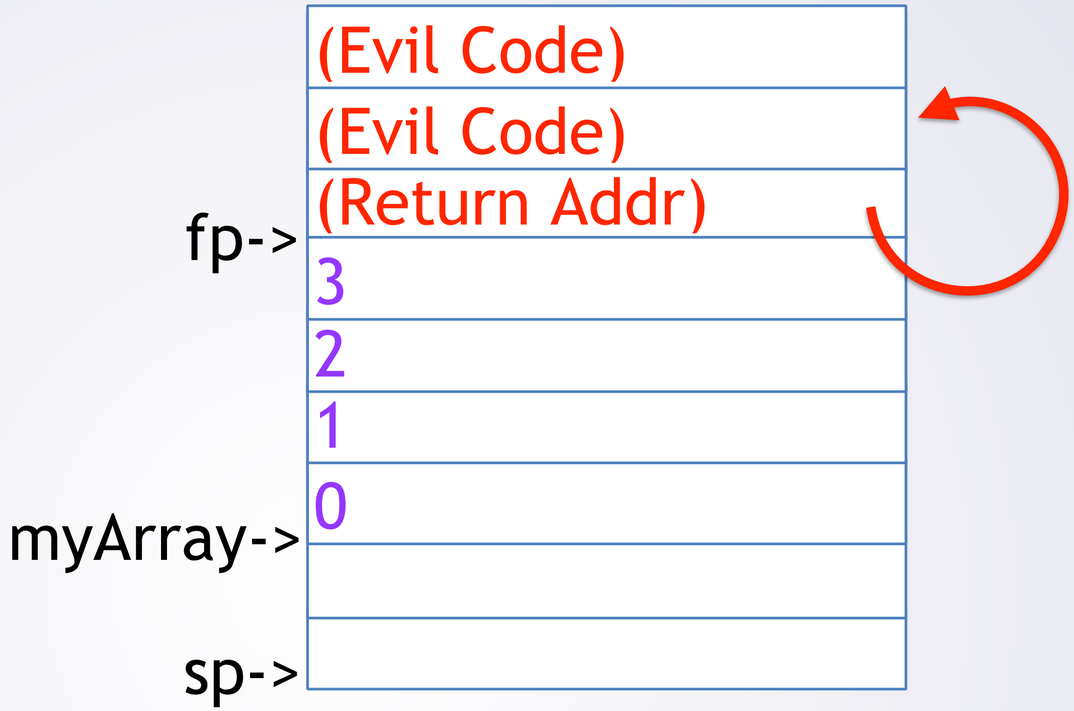
Buffer Overflow

- Common security vulnerability: buffer overflow
  - Allow more data to be read into an array than space in that array
- Why is this so bad problem?

Buffer Overflow



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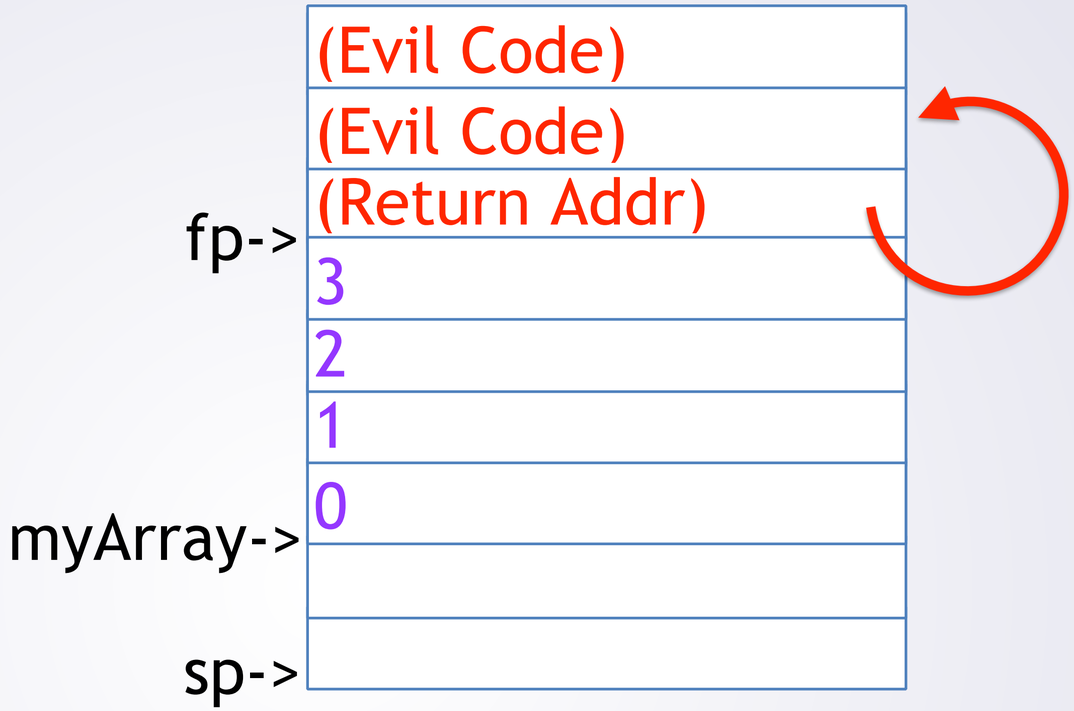
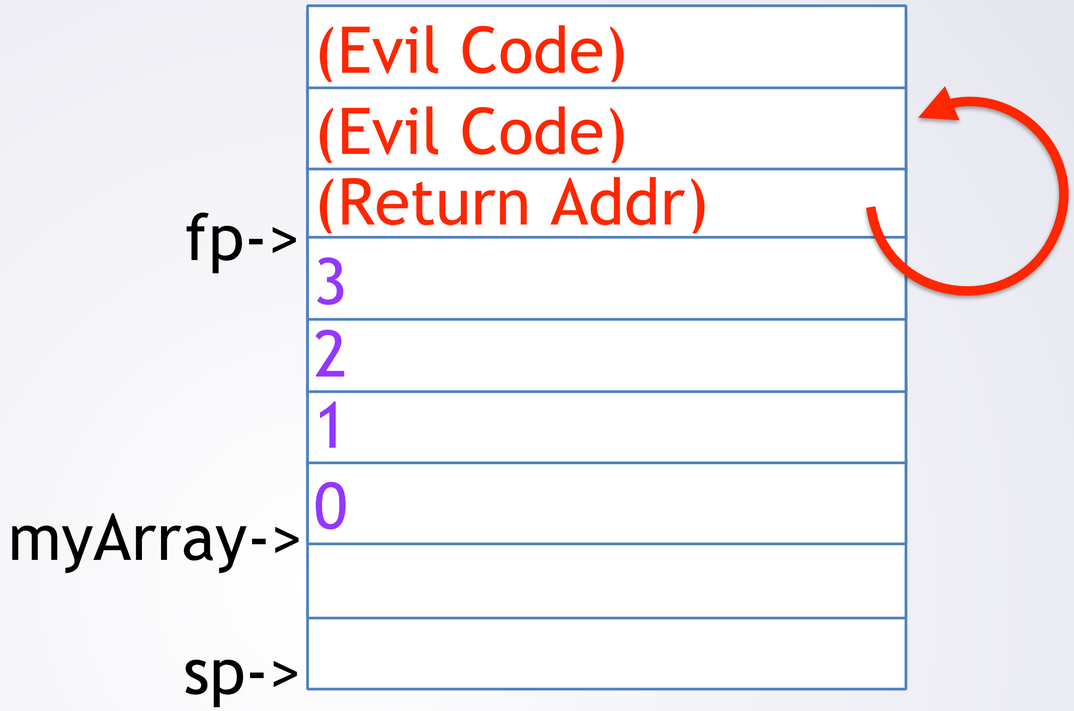


- What happens when the function returns?

Buffer Overflow



- What happens when the function returns?
  - Begins executing instructions that were delivered by attacker!
  - Runs with same permission as whatever program
    - Running as root? Completed compromised.

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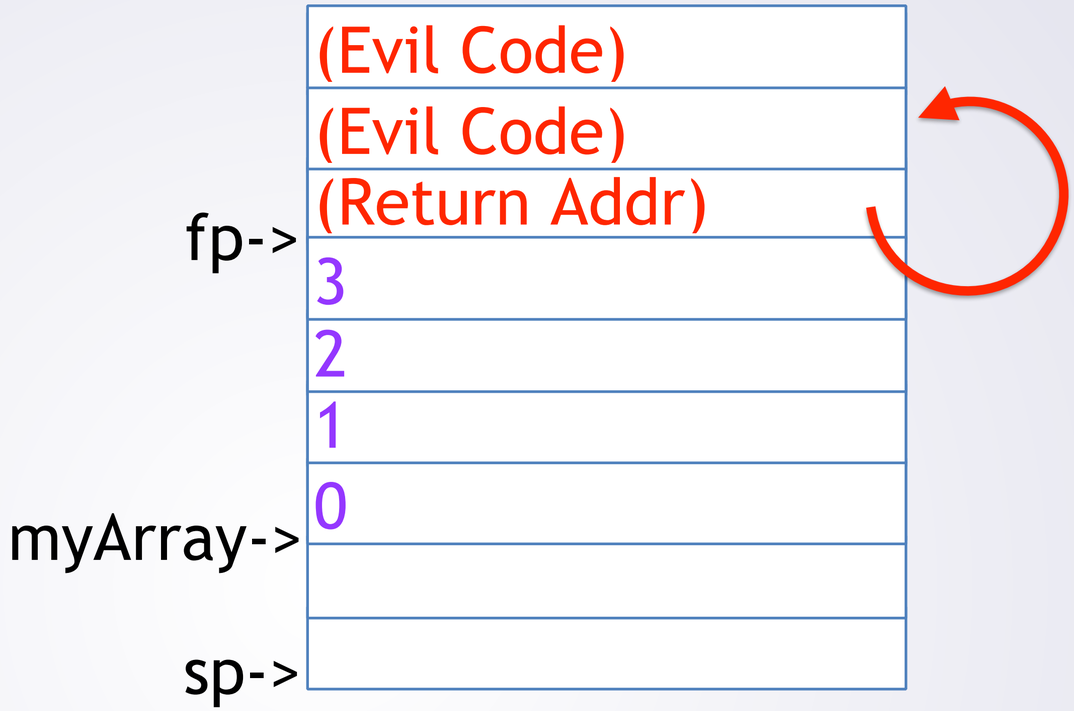
Buffer Overflows

- Buffer Overflows result from programmer carelessness
  - Use of terrible functions (e.g., gets())
  - Assuming the user will not input more than a certain size
  - Not ensuring that space allocated matches size limit read
- Memory safe languages (Java, python, sml,…)
  - Not an issue: receive array index out of bounds exception (or similar)

No Execute Protection

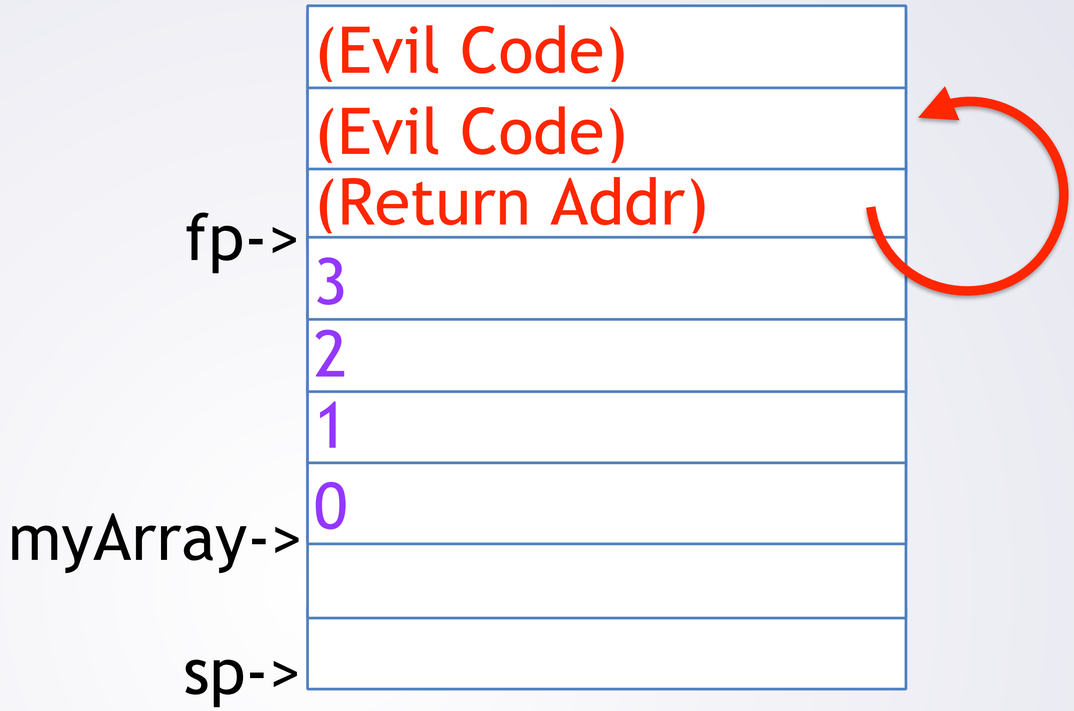
- Hardware defense: No Execute Protection (NX bit)
  - Mark stack pages as Read/Write/Non-executable
  - Available in Intel/AMD processors since early 2000s
- How does this help?

Buffer Overflow



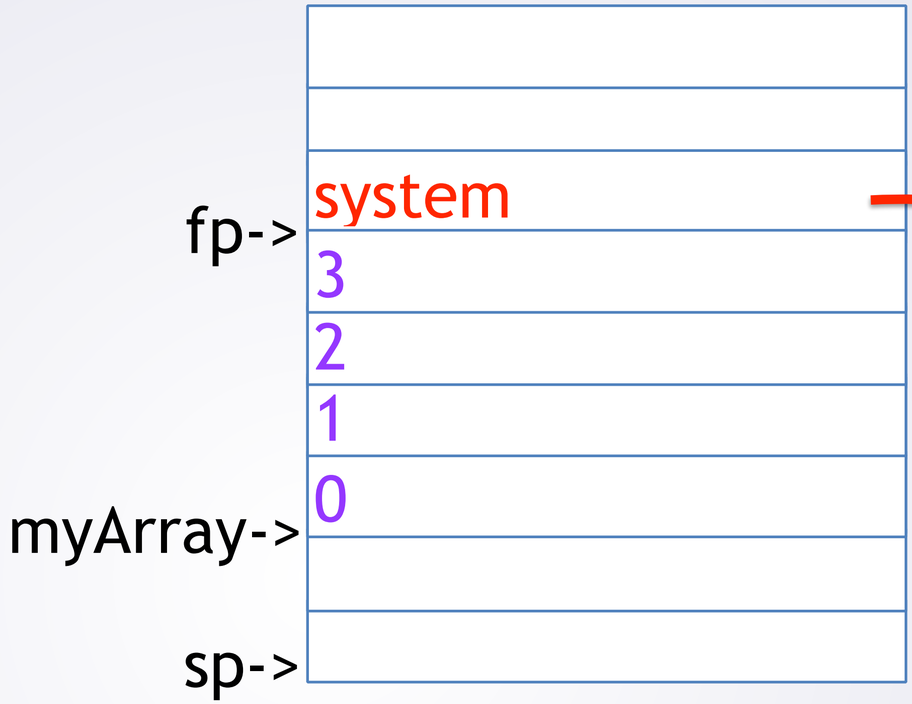
- If stack is not executable, returning to it -> segfault

Buffer Overflow



- If stack is not executable, returning to it -> segfault
  - Is this a perfect defense?

Return To libc Attacks



- Instead of returning to custom crafted code on stack
  - Return to existing code (often found in libc)
  - E.g., make the return address the system() library call…
  - Need to arrange for useful arguments

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Operating System Defense: ASLR

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

int main(void) {
  int x = 3;
  printf("%p\n", &x);
  return EXIT_SUCCESS;
}
```

```
brian@erss:~$ ./a.out
0x7fff67605974
brian@erss:~$ ./a.out
0x7fffa5689c44
brian@erss:~$ ./a.out
0x7ffc0adf03b4
brian@erss:~$ ./a.out
0x7ffdce2d1904
```

- Address Space Randomization
  - Loader randomly adjusts address layout

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ASLR: Weaknesses

- ASLR is not perfect either
  - NOP slide: attack code starts with many NOPs
  - Attacker can succeed by guessing any location in NOP slide
- Similar ideas can be applied to other data
  - //bin/bash
- Attacker may be able to learn information about layout
  - Format string injection
  - Timing attacks against branch predictor:
    - http://www.cs.ucr.edu/~nael/pubs/micro16.pdf

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Format String Injection

%p %p %p %p %p %p %p %p %p %p %p %p %p %p %p %p %p %p %p %p

```
char * str = NULL;
size_t sz = 0;
if(getline(&str,&sz, stdin) > 0) {
    printf(str);
}
```

0x6020d2
0x7ffff7dd3790
0xa70
0x2070252070252070
0x7025207025207025
0xff00000000
0x602010 str
0x78 sz
0xac2dc1a8e1744800
0x7fffffffe470 Saved FP
0x400692 Saved RA
0x4006a0
0x7ffff7a2e830

- How dangerous is this code
  - VERY

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%n conversions: most dangerous

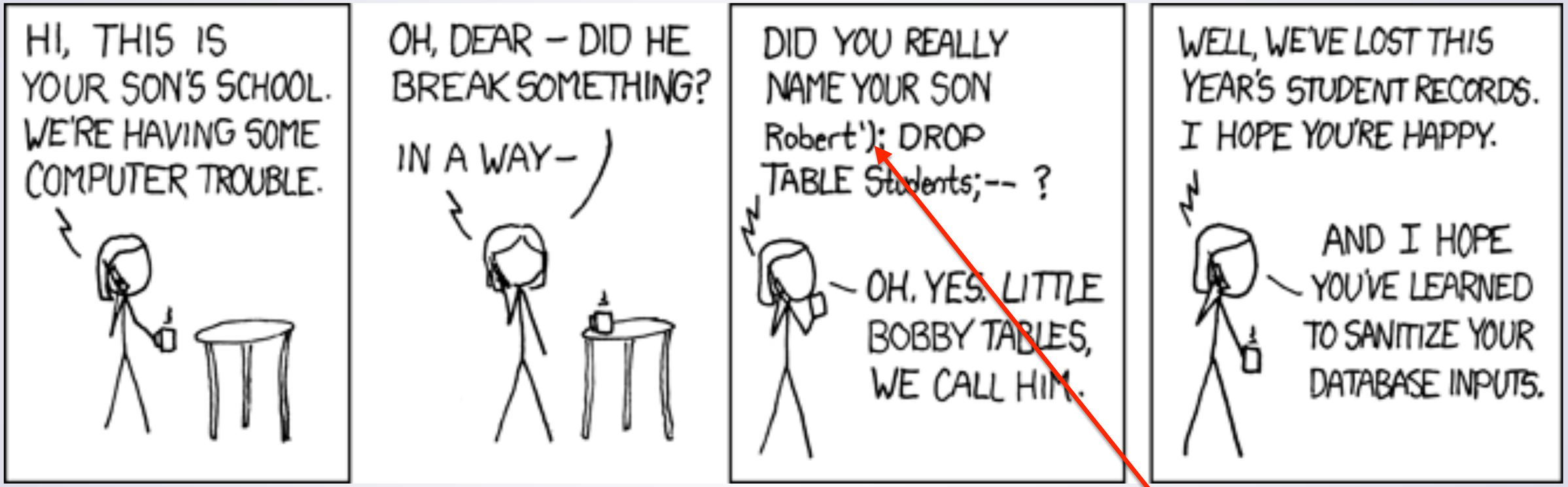
- Even more potential danger: %n conversions!
- From the man page for printf:

> 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. No argument is converted. The behavior is undefined if the conversion specification includes any flags, a field width, or a pre-cision.

Failure To Sanitize Inputs

- Format strings:
  - Example of data with special meaning (%)
  - We don't want the special meaning, but end up with it anyways :(
- For printf format strings best choice is to just
  - printf("%s", theString);
  - or use **puts** which does not format output
- Other situations: **sanitize** input
  - Remove, or escape special characters

SQL Injection



SELECT * FROM students WHERE name = '*student*';

SELECT * FROM students WHERE name = '*Robert'); DROP TABLE Students;—*';

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Guarding Against SQL Injection

- Django:
  - Using built in model operations will sanitize vs SQL Injection
  - If you write RAW query strings, use an appropriate library
- Java:
  - Use PreparedStatements
- C++:
  - Use quote function in pqxx::work to embed string value in SQL safely
  - Or use prepared statements

```
void prepare_find(pqxx::connection_base &c)
{
  // Prepare a statement called "find" that looks for employees with a given
  // name (parameter 1) whose salary exceeds a given number (parameter 2).
  const std::string sql =
    "SELECT * FROM Employee WHERE name = $1 AND salary > $2";

  c.prepare("find", sql)()();
}
```

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Command Injection

- Danger: using shell to execute command with user-input argument
  - some-command blah blah *userinput*
- What is the danger here?

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Command Injection

- Danger: using shell to execute command with user-input argument
  - some-command blah blah *userinput*
- What is the danger here?
  - `some command`
  - xyz && another command
  - xyz || another command
  - | some command
  - ; another command

Cross Site Scripting

https://bobsrecipes.com/contest/enter

Welcome to Bob's recipe website!
We are hosting a contest for the best recipes. Enter yours below to win!

Submit

I'll host a contest and let users type in their favorite recipes!

Cross Site Scripting

https://bobsrecipes.com/contest/viewAndVote

Recent entries in the recipe contest. Vote

Halloumi with Date/Walnut Paste
Put 1 cup dates, 1/2 cup walnuts
1 tsp balsamic vinegar and 1 tbsp
warm water in the food processor.
Blend until it forms a thick paste.

Chocolate Chip Cookies
Cream together 1/2 cup butter
3/4 cup brown sugar, and 3/4
cup sugar.

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Homemade Pitas
<script type="text/javascript">***(evil code)***
</script>
Dissolve 1 tbsp yeast in 1 cup warm water
Let sit for 5 minutes, until foamy

Submit

I'd love to participate in this "contest"

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Homemade Pitas

Dissolve 1 tbsp yeast in 1
cup warm water
Let sit for 5 minutes, until foamy
Mix in 1 tbsp sugar and 1/3 cup olive oil

Halloumi with Date/Walnut Paste

Put 1 cup dates, 1/2 cup walnuts
1 tsp balsamic vinegar and 1 tbsp
warm water in the food processor.

Let's see how my recipe is doing..

Ohh pitas!

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Homemade Pitas

Dissolve 1 tbsp yeast in 1 cup warm water
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Halloumi with Date/Walnut Paste

Put 1 cup dates, 1/2 cup walnuts 1 tsp balsamic vinegar and 1 tbsp warm water in the food processor.

<script type="text/javascript">***(evil code)*** </script>

More like

Ohh **pwn3d**!

Cross-Site Scripting

- Eve injects a <script> into HTML that will be viewed by other users
  - Alice's browser will run Eve's code
- Two main types
  - Persistent (what we saw): injected code stored on server
  - Reflected: injected code stored in URL that user will click
- Vulnerable anytime you take un-sanitized data and display back to user
- Not to be confused with Cross Site Request Forgery (CSRF)

CSRF

- Cross Site Request Forgery:
  - Eve crafts a requests to change something
  - Gets Alice's browser to send that request while Alice is logged in
    - Alice's browser sends her authentication cookie
    - Site believes Eve's request

CSRF GETs (which shouldn't be a thing..)

- If site allows modification with GET requests
  - Bad! GET should be for reads only. Use POST!
  - Eve injects something like

<img src = "https://bobssite.com/api/sendMoney?amt=100&dstAct=456789">

  - When Alice's browser loads this, it will try to GET that image..
  - If Bob's site allows this modification with GET, it will perform the action
- Note that Eve does not get to (nor need to) see the response

CSRF POST

- Ok, so Bob's site doesn't allow modifications with GET. Safe?
- No: Eve can still craft malicious POST requests
  - E.g., she can make a <form> and have a <script> submit it
- How to defend?
  - Generate random token which must be in POST data
  - Eve has a hard time guessing
- Django requires this by default for POSTs:
  - Put {% csrf_token %} inside <form> that will be sent back to YOUR site
    - Do not leak token to other sites!
  - Django handles the rest

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Consider The Following Psuedo-Code

```
File f = openFile(inputCommands);

for each line in f
  if(!checkUserCanExecute(line, currentUser))
     return false;

rewind(f);

for each line in f
  execute(line);

close(f);
return true;
```

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I have a plan… Anyone see it?

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commands.txt:

```
change Eve's password to xyzzy42
print Eve's Account Balance
print Eve's Last Action
```

I have permission to execute all these commands….

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commands.txt:

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change Eve's password to xyzzy42
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Let's run this program..

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commands.txt:

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While this runs…
One quick change to input file…

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```

commands.txt:

```
change Alice's password to xyzzy42
print Eve's Account Balance
print Eve's Last Action
```

Bwahahaha!
While this runs…
One quick change to input file…

Example of TOCTTOU Attack

- Time of Check To Time Of Use
  - Race condition between **validation** and **use** of data
  - Attacker can present valid data
  - Then change the data before it is used
- Defense:
  - Ensure that data cannot be changed between validation and used
  - Previous example, either:
    - Execute each command as read
    - Read file into memory, then validate/execute from memory

Privilege Escalation

```
[eve@linux] $ cat ~alice/secret.txt
ls: /home/alice/secret.txt : Permission denied
[eve@linux] $
```

I wish I were root..

What Might Eve Do?

- Find bug in setuid binary (or service running as root)?
  - "trick" it into doing privileged actions for her
- Find files with wrong permissions
  - Shouldn't be suid but is?
  - Is writeable but shouldn't be?
- Exploit kernel bug?
  - Dirty COW: up next

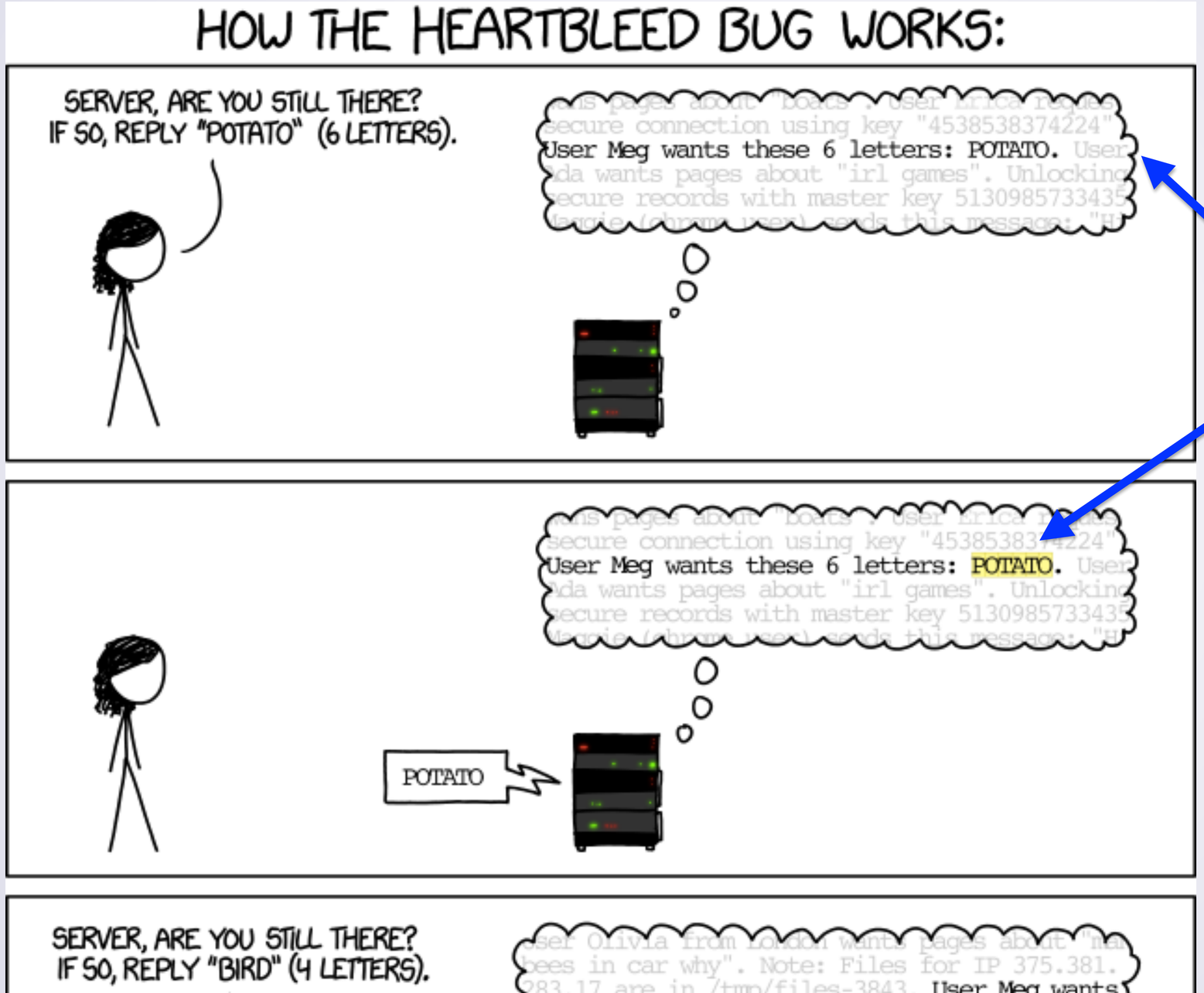
Privilege Escalation: Not Just Shell

- Can have privilege escalation bugs in other settings
- Webapp:
  - Can Eve alter her permissions?
    - E.g, Admin functionality w/o proper checks?

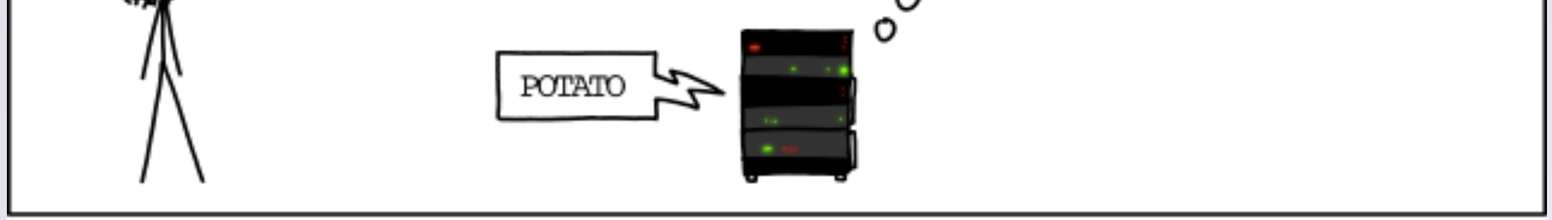
Dirty COW

- Serious Linux kernel vulnerability (fixed 2016)
  - Race condition in COW handling
  - Could allow writing read-only data
    - mmap file read only
    - End up writing to file!
  - Allowed privilege escalation:
    - User could become root
- https://www.theregister.co.uk/2016/10/21/linux_privilege_escalation_hole/
- Linux includes Android
  - Could be used to "root" Android devices
- https://raw.githubusercontent.com/dirtycow/dirtycow.github.io/master/dirtyc0w.c

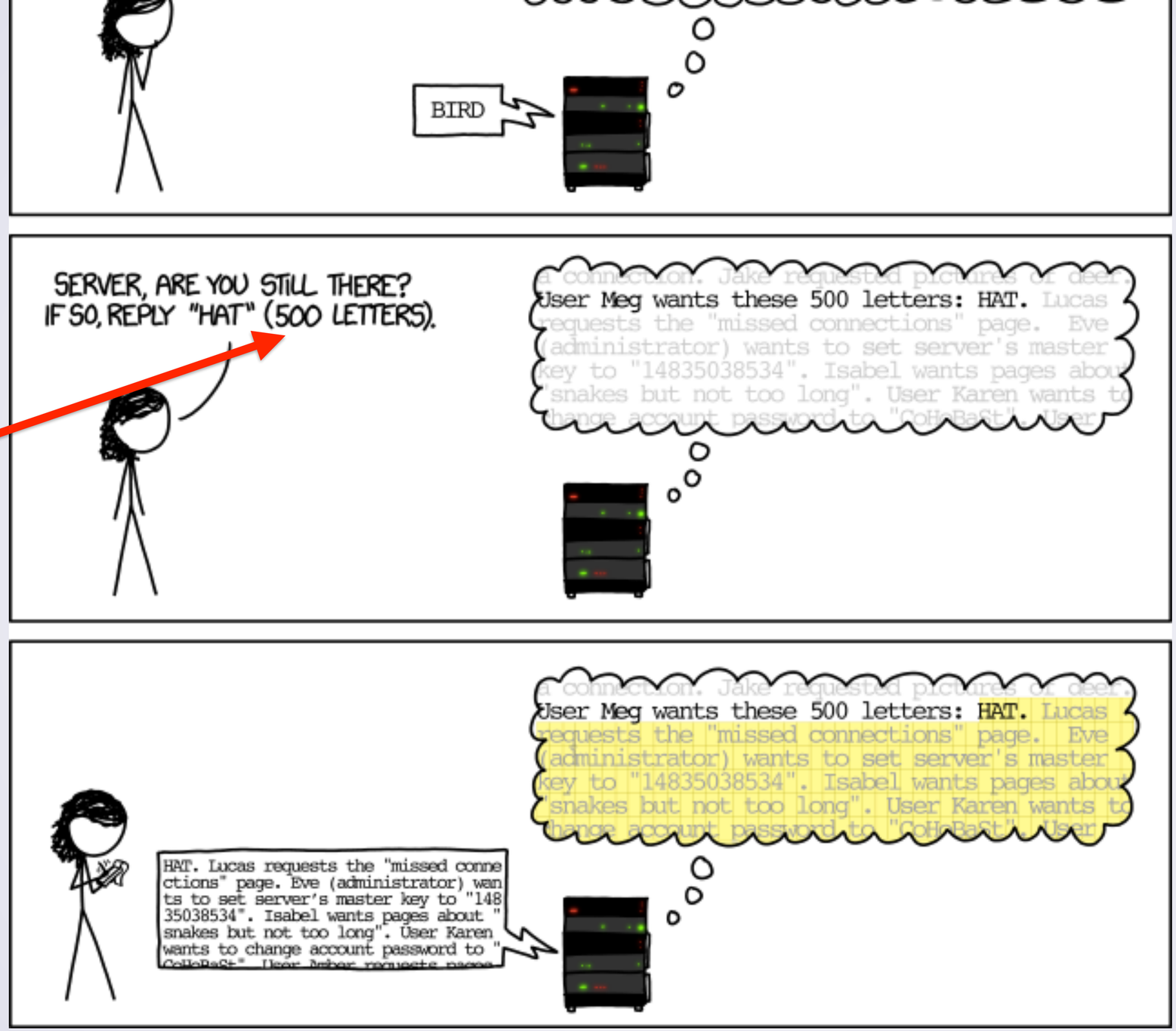
Heartbleed (Explained by xkcd)



TLS Heartbeat



TLS Heartbeat


BIRD
SERVER, ARE YOU STILL THERE? IF SO, REPLY "HAT" (500 LETTERS).
User Meg wants these 500 letters: HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to change account password to "CoHeRaSt". User
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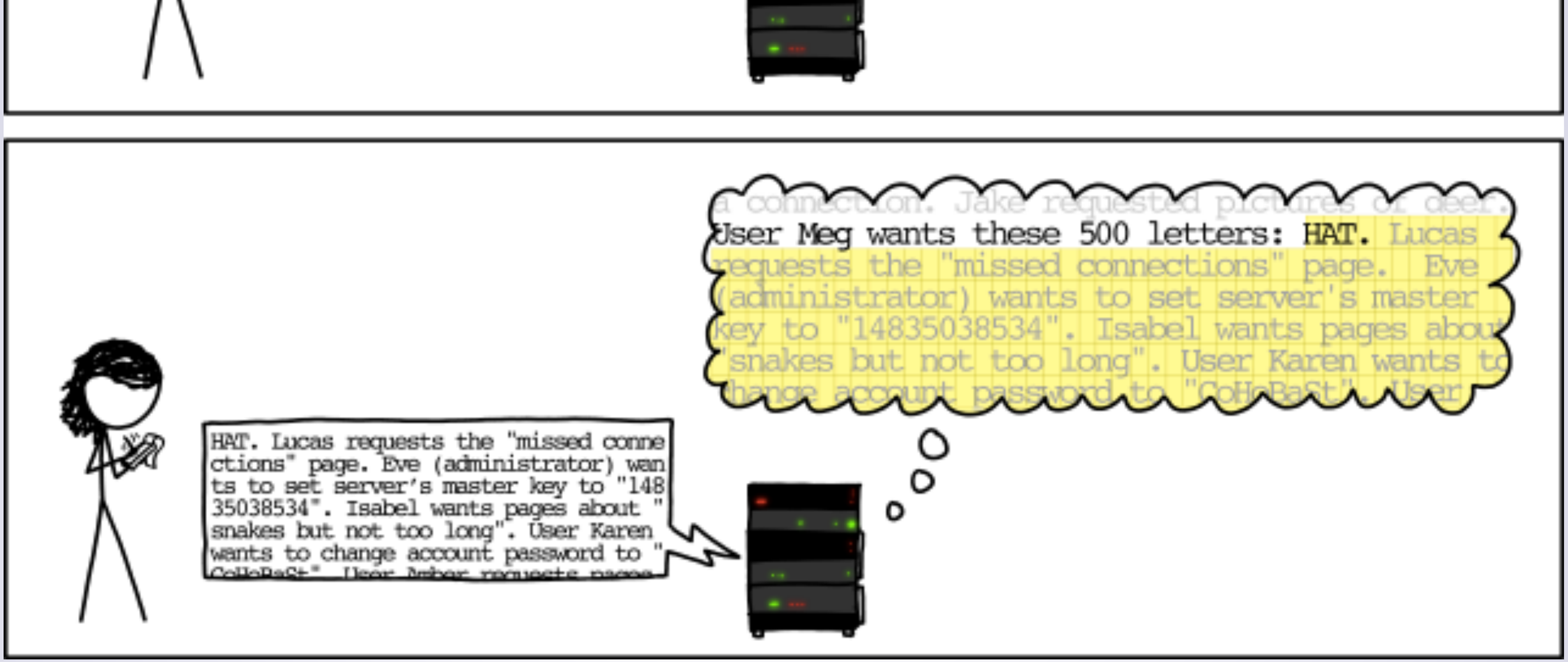
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Apple Goto

```
…
if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
    goto fail;
    goto fail;
if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
    goto fail;

err = sslRawVerify(…);

…
fail:
  //free memory, etc
  return err;
```

TLS Verification code in iOS/OSX, 2014

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Apple Goto

```
…
if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0){
    goto fail;
  }goto fail;
if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
    goto fail;

err = sslRawVerify(…);

…
fail:
  //free memory, etc
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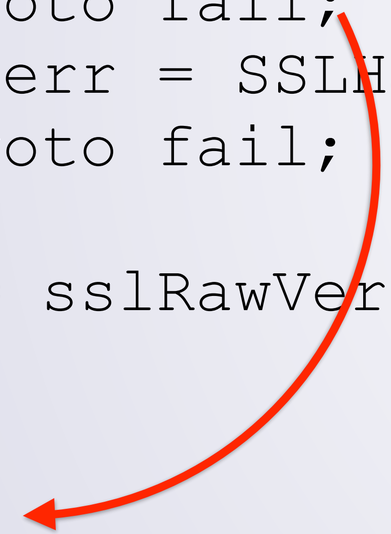

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Apple Goto

- Always use { } for bodies of anything (if, while, for, do)
- Test test test test!
  - There should have been a test case for this…
  - There should have been a test case for every one of those failing!

Barely Scratched The Surface..

- Cyber security experts?
  - We've barely scratched the surface!
- Covered the basics (most important/common things)
  - Use encryption (AES + RSA)
  - Hashes? Use SHA-256 or SHA-512 [and PBKDF2]
  - Variety of exploits:
    - Code carefully!
    - Think like a hacker

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