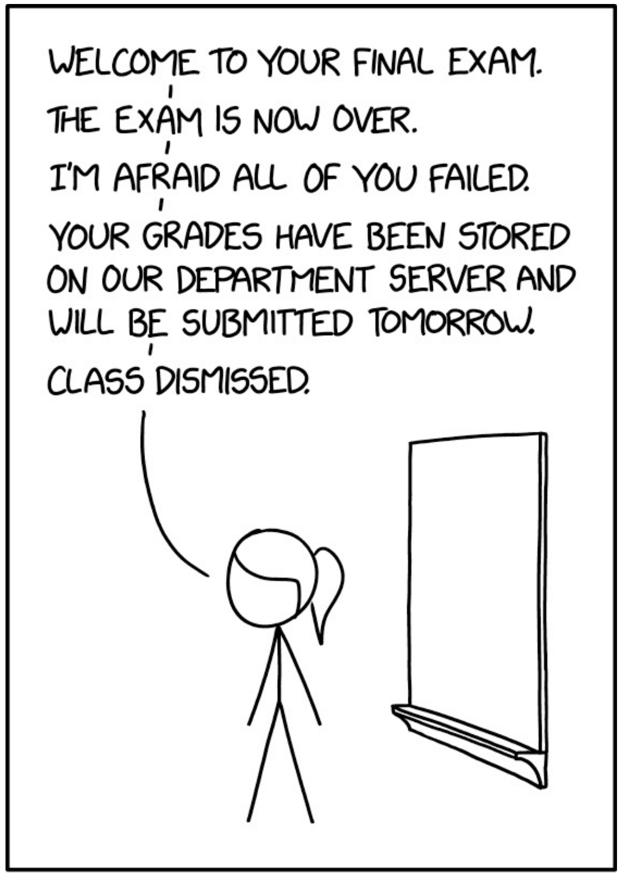
COS 217: Introduction to Programming Systems

Buffer Overrun Vulnerabilities and Assignment 6 (The ‘B’ Attack)


WELCOME TO YOUR FINAL EXAM.
THE EXAM IS NOW OVER.
I'M AFRAID ALL OF YOU FAILED.
YOUR GRADES HAVE BEEN STORED ON OUR DEPARTMENT SERVER AND WILL BE SUBMITTED TOMORROW.
CLASS DISMISSED.

CYBERSECURITY FINAL EXAMS

xkcd.com/2385

PRINCETON UNIVERSITY

A Program

```c
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

```
$ ./a.out
  What is your name?
  Aarti Gupta
  Thank you, Aarti Gupta.
  The answer to life, the universe, and everything is 42
```

A Reason Why People With Long Names Can't Have Nice Thi

```c
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

```
$ ./a.out
  What is your name?
  Christopher Moretti
  Thank you, Christopher Mor
  tti.
  The answer to life, the universe, and everything is 6911092
```

?

??? (!)

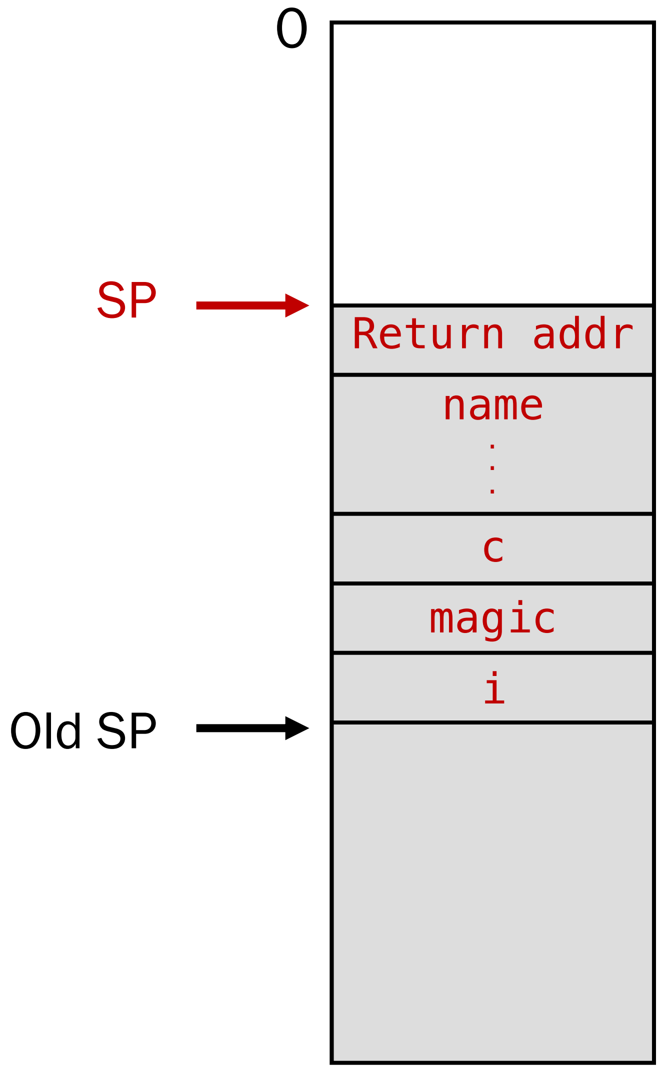
(depending on the area code, this might be an interesting phone number, but probably not one you should call for the answer to life, the universe, and everything)

Explanation: Stack Frame Layout

When there are too many characters, program carelessly writes beyond space "belonging" to name.

- Overwrites other variables
- This is a *buffer overrun*, or *stack smash*
- The program has a security bug!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```



Example Trace

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

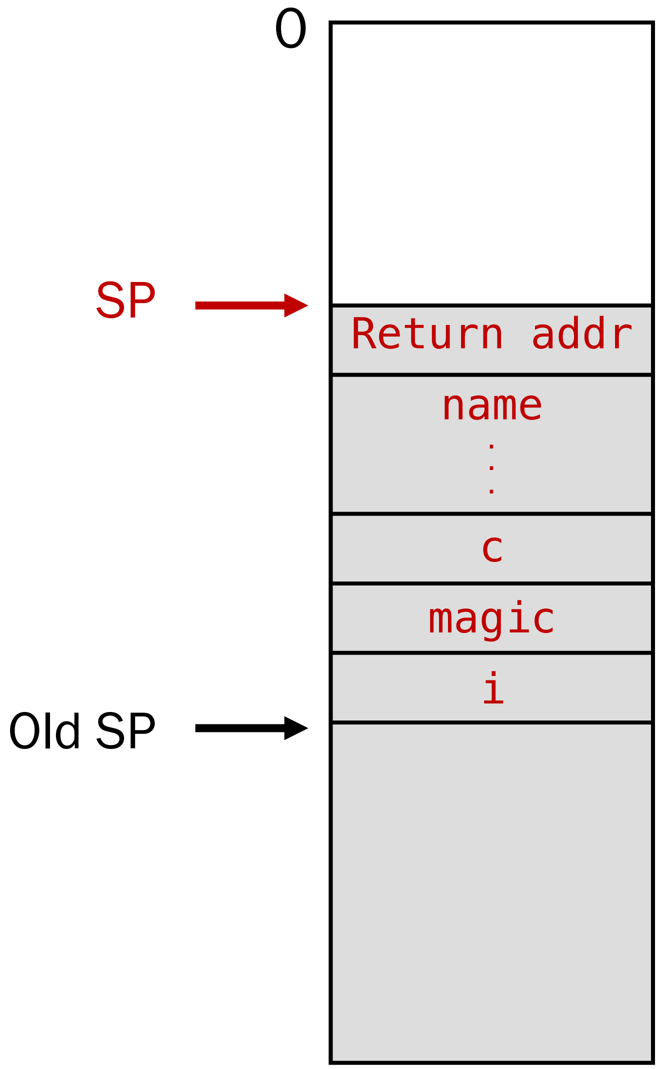
`Christopher`$_s$ (not `\0` terminated) in `name[0]`–`name[11]`
`Mor` in 3 padding bytes before `c`

Each letter from `getchar` overwrites `c` (it is also overwritten once by `name[i++] = c`, when `i` is 15 and `c` is `'e'`) until `c` becomes `'\n'` and the loop ends.

First `t` overwrites `42` with `0x74` (`'t'`) – little endian!

Second `t` makes `magic 29812` (2 high-order bytes still `0`)

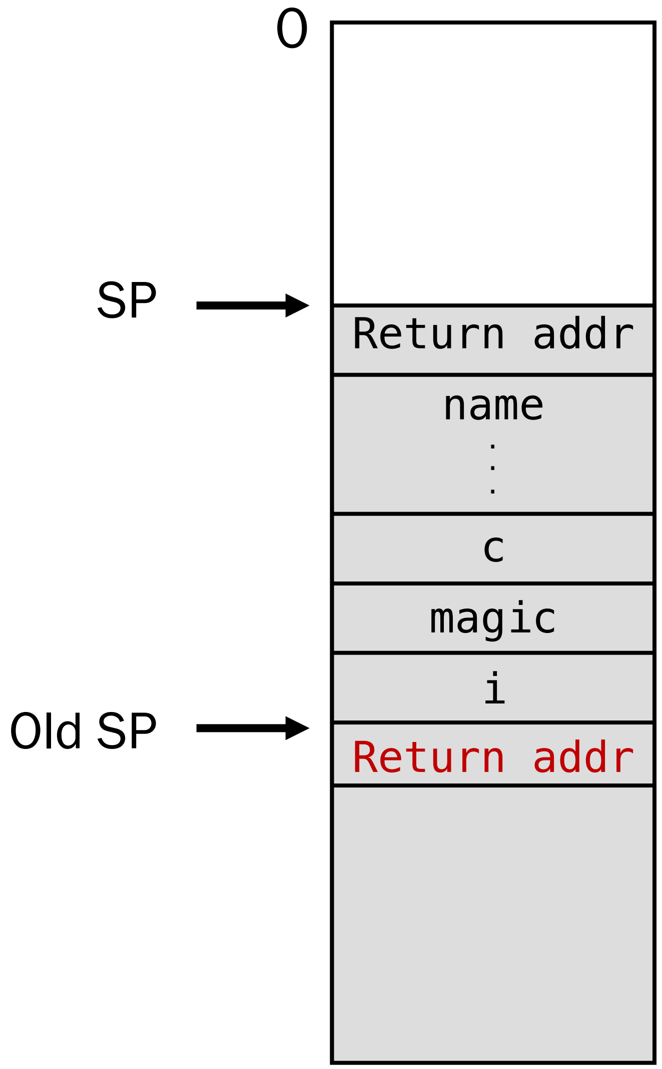
Final `i` makes `magic 6911092` (1 high-order byte still `0`)



It Gets Worse…

Buffer overrun can overwrite return address of a previous stack frame!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

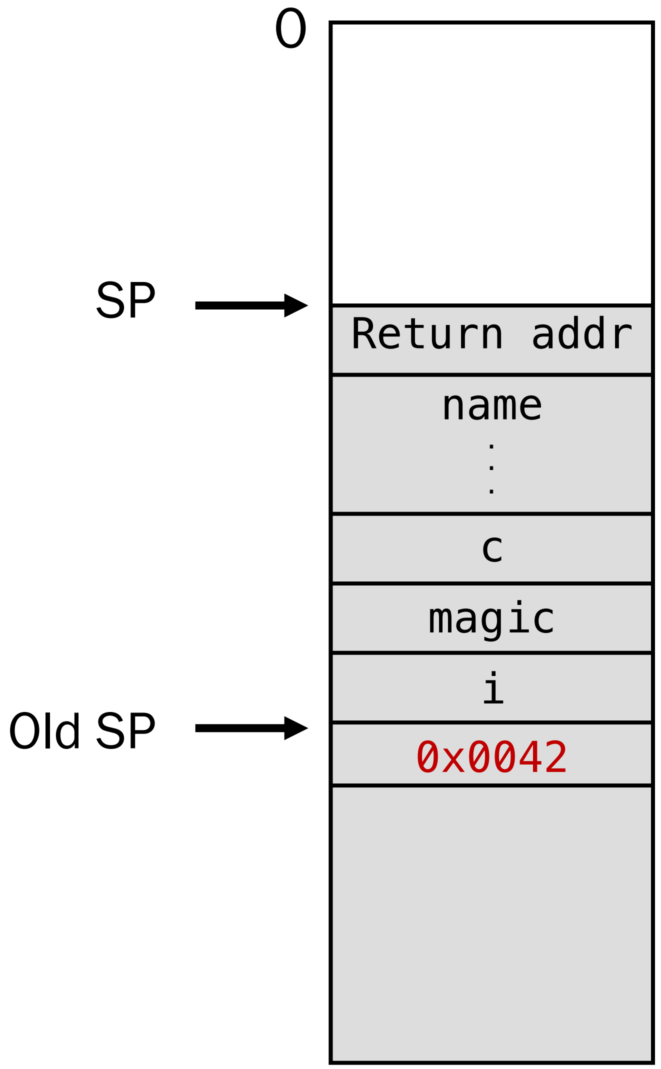


It Gets Worse…

Buffer overrun can overwrite return address of a previous stack frame!

- Value can be an invalid address, leading to a segfault, or …

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

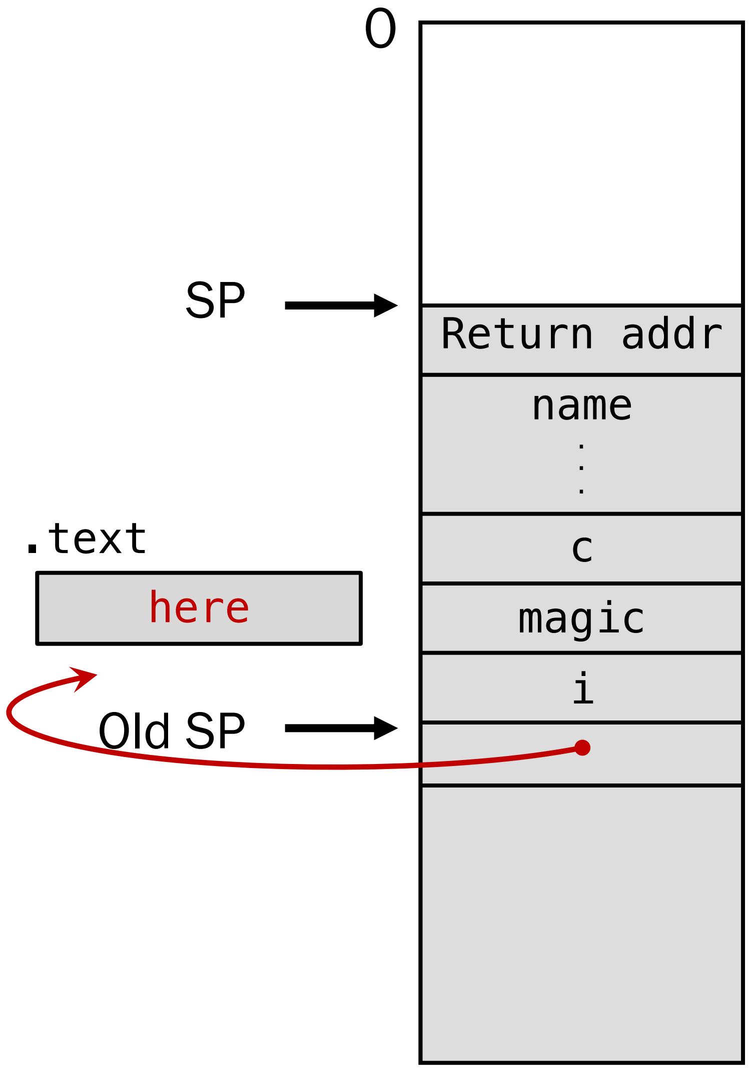


It Gets Much Worse…

Buffer overrun can overwrite return address of a previous stack frame!

- Value can be an invalid address, leading to a segfault, or it can cleverly cause unintended control flow!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

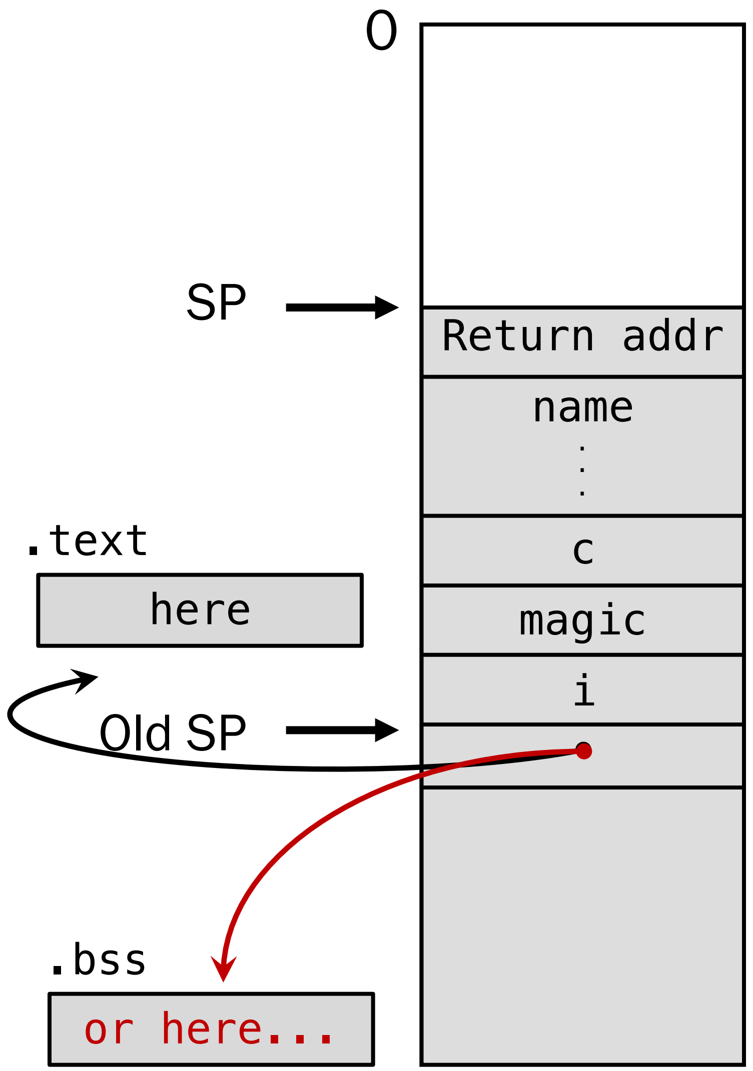


It Gets Much, Much Worse...

Buffer overrun can overwrite return address of a previous stack frame!

- Value can be an invalid address, leading to a segfault, or it can cleverly cause unintended control flow, or even cause arbitrary malicious code to execute!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```



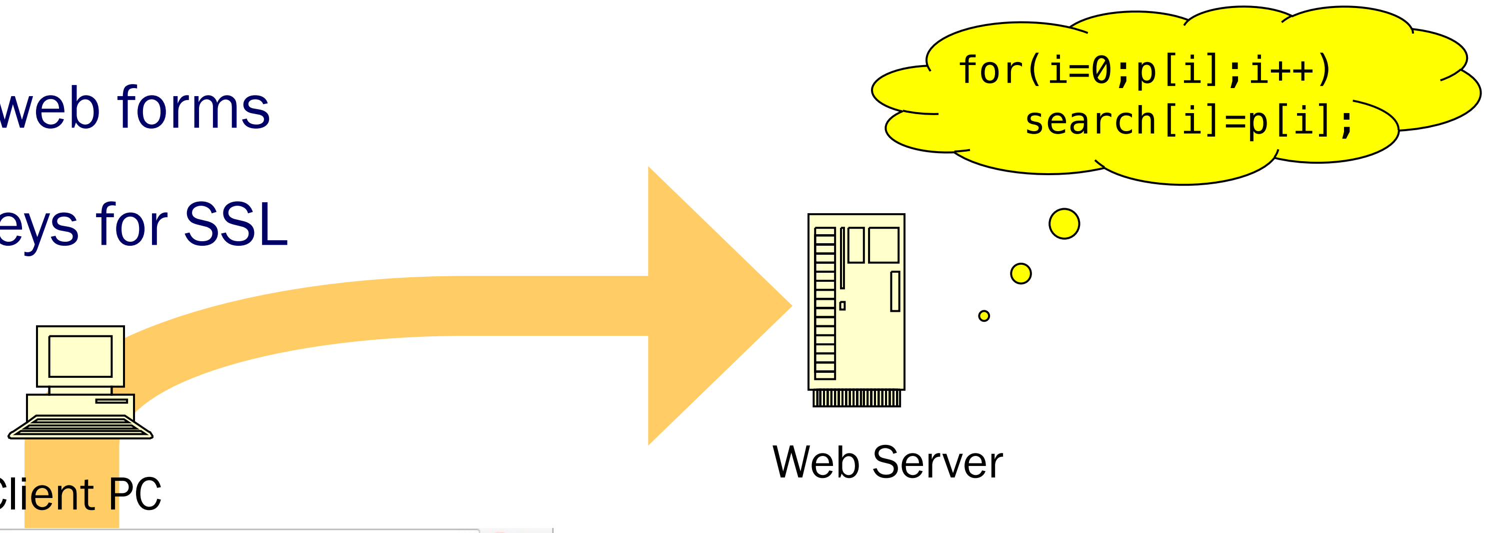
Attacking a Web Server

URLs

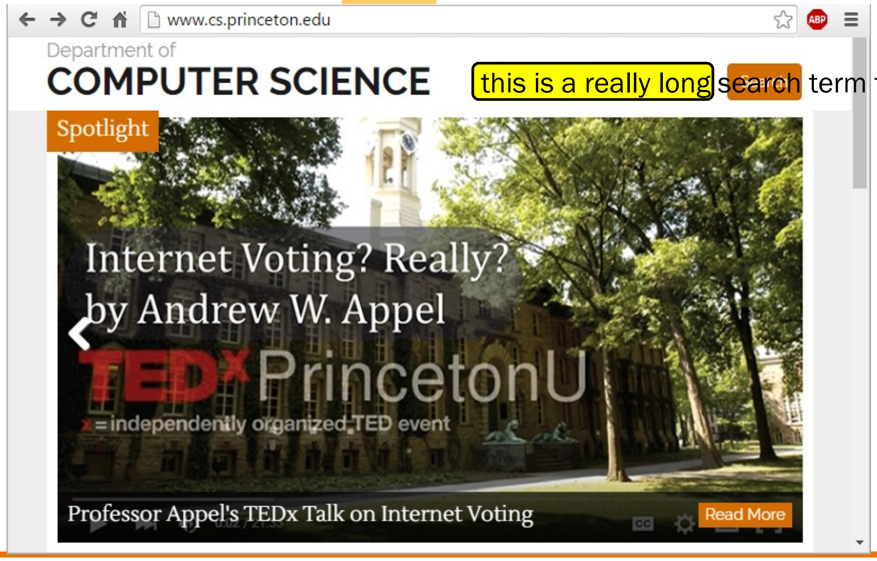
Input in web forms

Crypto keys for SSL

etc.



```
for(i=0;p[i];i++)
    search[i]=p[i];
```



this is a really long search term that overflows a buffer

Attacking a Web Browser

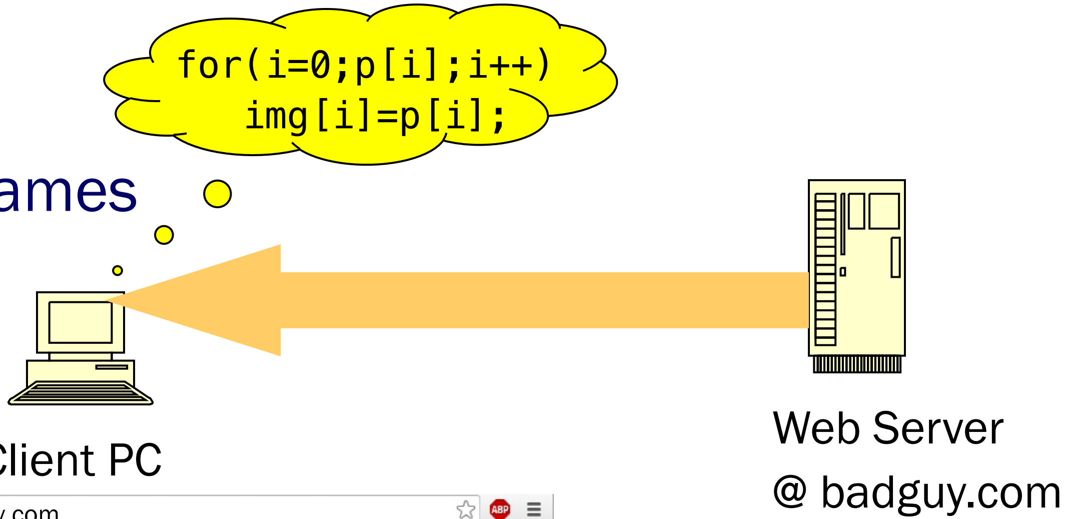
HTML keywords

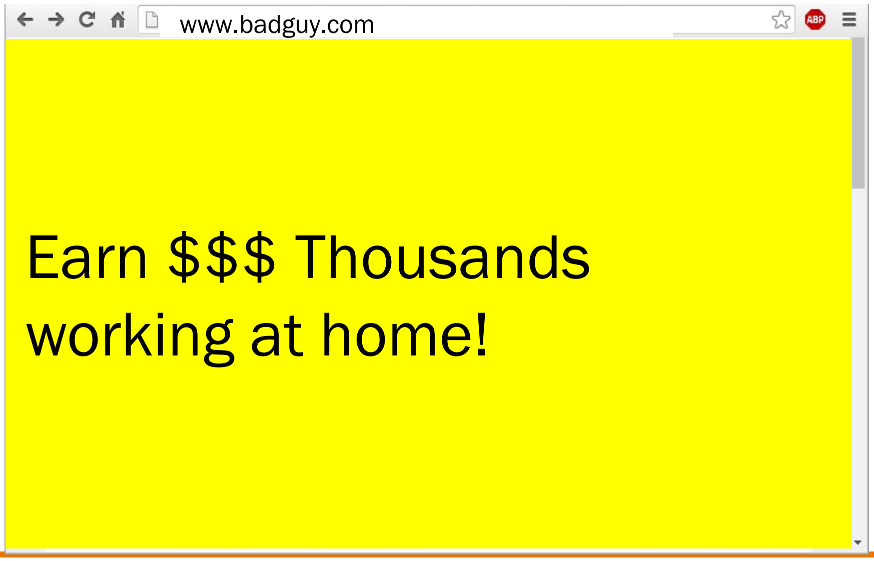
Images

Image names

URLs

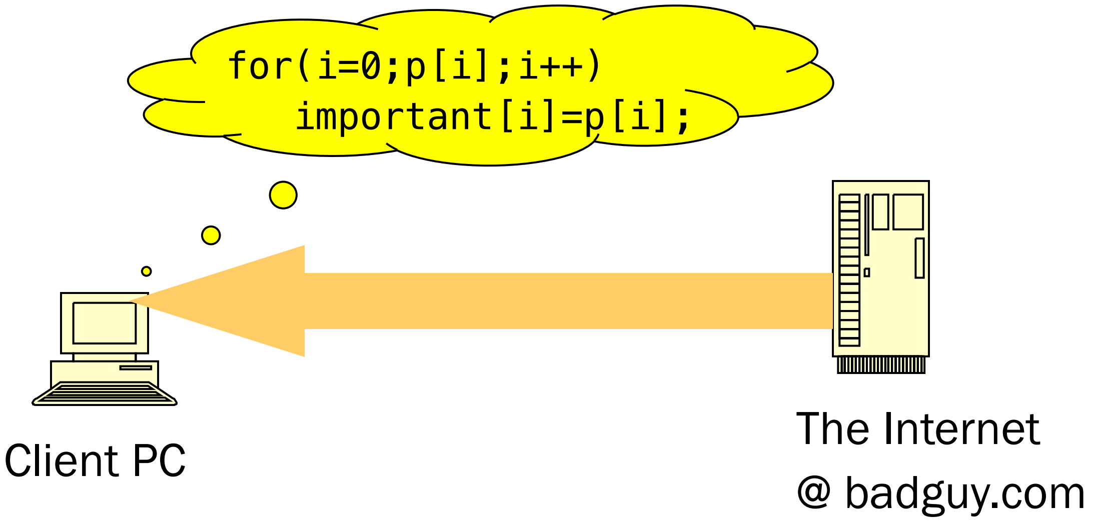
etc.





Earn $$$ Thousands
working at home!

Attacking Everything in Sight



```
for(i=0;p[i];i++)
    important[i]=p[i];
```

E-mail client

PDF viewer

Operating-system kernel

TCP/IP stack

Any application that ever sees input directly from the outside

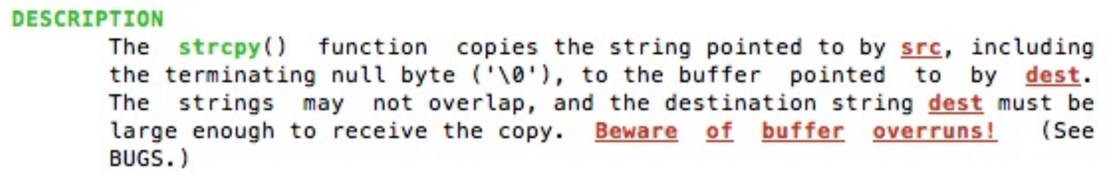
Defenses Against This Attack

Best: program in languages that make array-out-of-bounds impossible (Java, python, C#, ML, …)

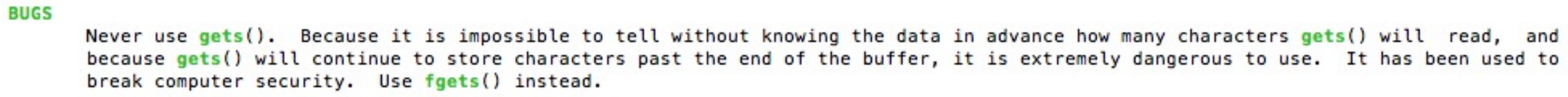
But if you need to use C…

Defenses Against This Attack

In C: use discipline and software analysis tools to check bounds of array subscripts



```
DESCRIPTION
       The  strcpy()  function  copies the string pointed to by src, including
       the terminating null byte ('\0'), to the buffer  pointed  to  by  dest.
       The  strings  may  not overlap, and the destination string dest must be
       large enough to receive the copy.  Beware  of  buffer  overruns!   (See
       BUGS.)
```



```
BUGS
       Never use gets().  Because it is impossible to tell without knowing the data in advance how many characters gets() will  read,  and
       because gets() will continue to store characters past the end of the buffer, it is extremely dangerous to use.  It has been used to
       break computer security.  Use fgets() instead.
```

Augmented by OS- or compiler-level mitigations:

- Randomize initial stack pointer
- “No-execute” memory permission for sections other than .text
- “Canaries” at end of stack frames

None of these would have prevented the “Heartbleed” attack

Assignment 6: Attack the “Grader” Program

```
enum {BUFSIZE = 48};
char grade = 'D';
char name[BUFSIZE];
...
int main(void)
{
   mprotect(...);
   getname();
   if (strcmp(name, "Andrew Appel") == 0)
      grade = 'B';
   printf("%c is your grade.\n", grade);
   printf("Thank you, %s.\n", name);
   return 0;
}
```

```
$ ./grader
What is your name?
Aarti
D is your grade.
Thank you, Aarti.
$ ./grader
What is your name?
Andrew Appel
B is your grade.
Thank you, Andrew Appel.
```

Assignment 6: Attack the “Grader” Program

```
/* Prompt for name and read it */
void getName() {
  printf("What is your name?\n");
  readString();
}
```

```
/* Read a string into name */
void readString() {
  char buf[BUFSIZE];
  int i = 0;
  int c;

  /* Read string into buf[] */
  for (;;) {
    c = fgetc(stdin);
    if (c == EOF || c == '\n')
      break;
    buf[i] = c;
    i++;
  }
  buf[i] = '\0';

  /* Copy buf[] to name[] */
  for (i = 0; i < BUFSIZE; i++)
    name[i] = buf[i];
}
```

Unchecked write to buffer!

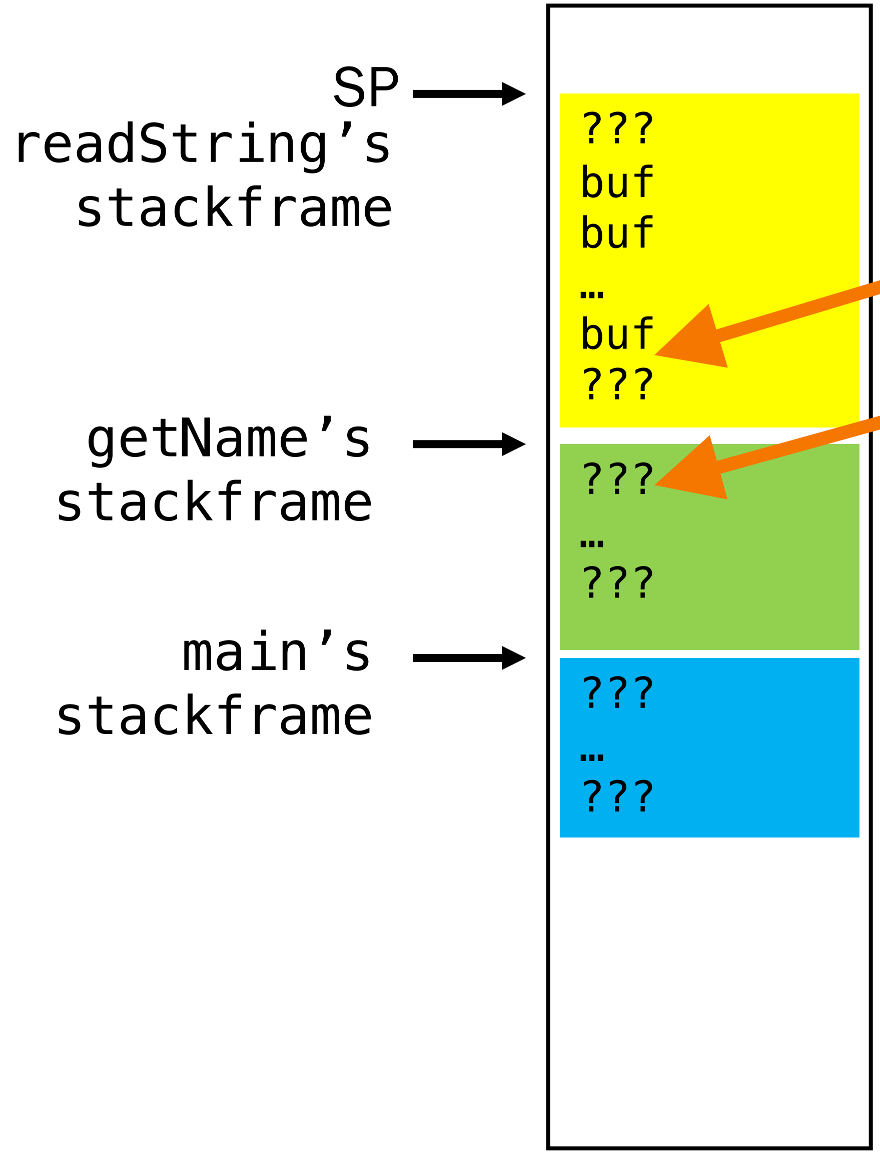
Assignment 6: Attack the "Grader" Program

```c
enum {BUFSIZE = 48};
char grade = 'D';
char name[BUFSIZE];
...
int main(void)
{
   mprotect(...);
   getname();
   if (strcmp(name, "Andrew Appel") == 0)
      grade = 'B';
   printf("%c is your grade.\n", grade);
   printf("Thank you, %s.\n", name);
   return 0;
}
```

```
$ ./grader
What is your name?
Aarti\0(#@&$%*#&(*^!@%*!!(&#$
B is your grade.
Thank you, Aarti.
```

Smash the stack!

Memory Map of STACK Section



Keep writing past end of buf

Get to getName's stackframe

What's there?

getName's saved x30!
(somewhere on stack)

Overwrite it!

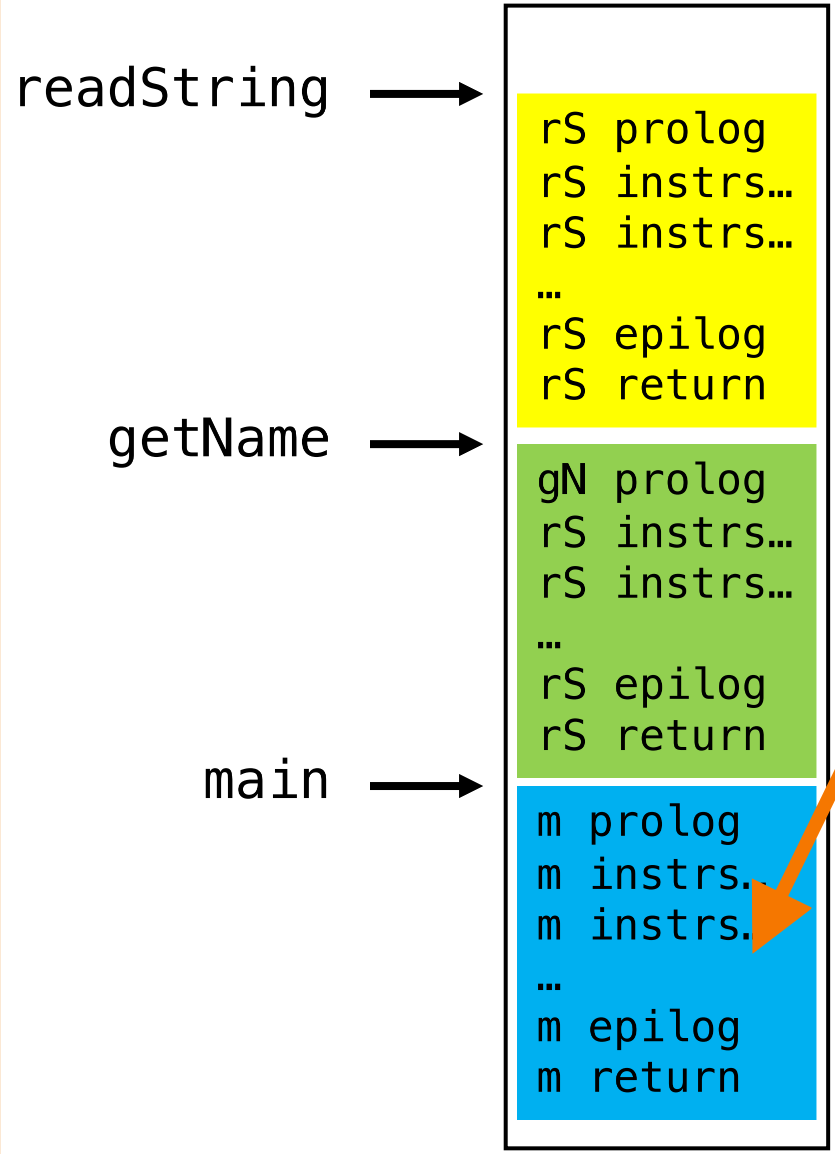
With what?

Assignment 6: Attack the “Grader” Program

```
enum {BUFSIZE = 48};
char grade = 'D';
char name[BUFSIZE];
...
int main(void)
{
   mprotect(...);
   getname();
   if (strcmp(name, "Andrew Appel") == 0)
      grade = 'B';
   printf("%c is your grade.\n", grade);
   printf("Thank you, %s.\n", name);
   return 0;
}
```

```
$ ./grader
What is your name?
Aarti\0(#@&$%*#&(*^!@%*!!(&#$
B is your grade.
Thank you, Aarti.
```

Memory Map of TEXT Section



```
...
checkappel:
   if (strcmp(name, "Andrew Appel") != 0)
      goto afterb
   grade = ‘B’ ← HERE!
afterb:
   print ...
...
```

Construct Your Exploit String (`createdataB.c`)

1. Your name.
   - After all, the `grader` program's last line of output must be: “`Thank you, [your name].`”

fopen the file `"dataB"` and write your name into that file (e.g. with `fprintf`)

2. A null byte.
   - Otherwise, the `grader` program's last line of output will be corrupted.

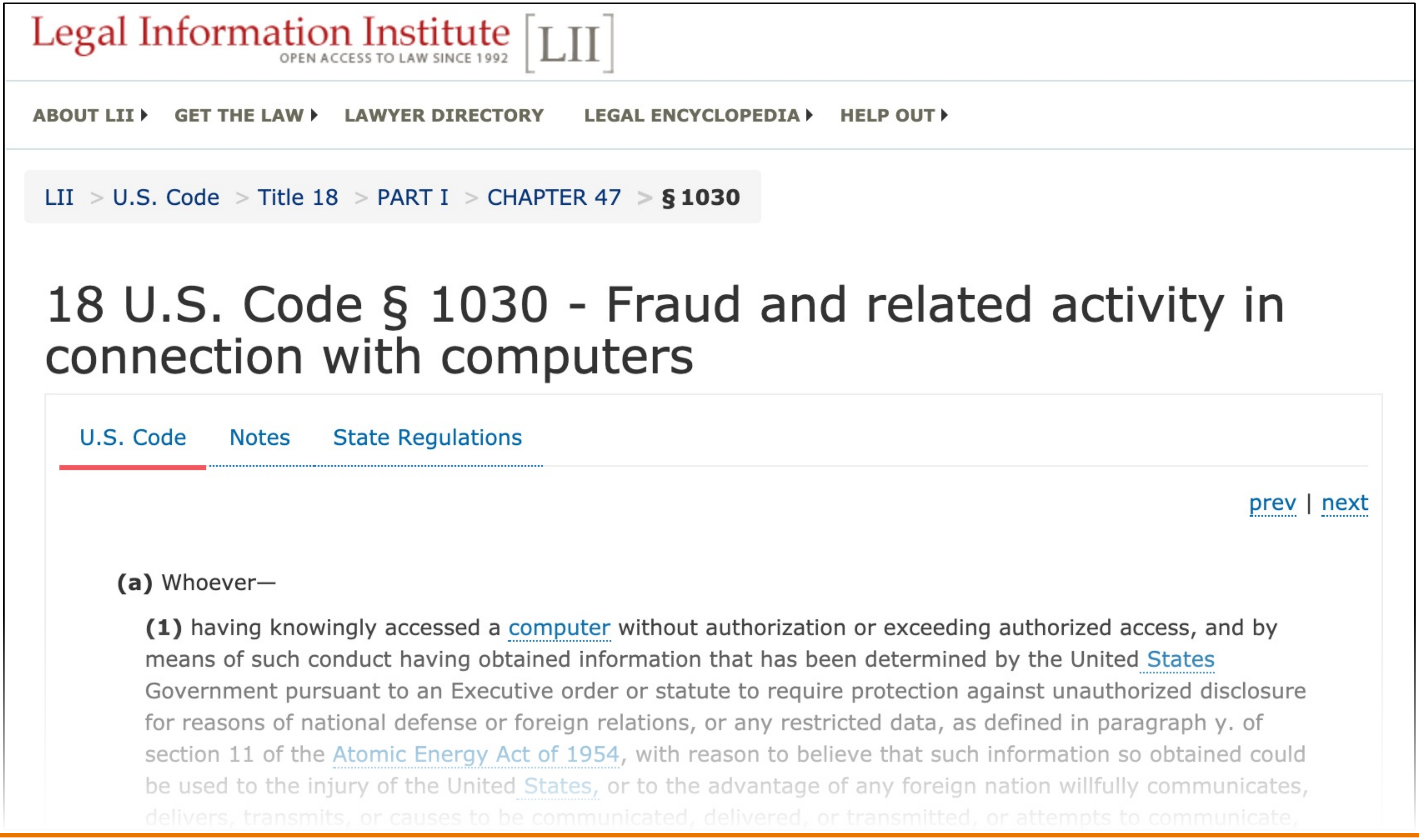
See “Writing Binary Data” precept handout. `'\0'` is just a single byte of binary data.

3. Filler to overrun until `x30`.
   - Presumably more null bytes are easiest, but easter eggs are fine.

4. The address of the target
   - The statement `grade = 'B'`.

Address is a 64-bit (little-endian) unsigned integer (which in C is spelled `unsigned long`).

Let’s Not Get Thrown in Jail, Please



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LII > U.S. Code > Title 18 > PART I > CHAPTER 47 > § 1030

18 U.S. Code § 1030 - Fraud and related activity in connection with computers

U.S. Code | Notes | State Regulations

prev | next

(a) Whoever—

(1) having knowingly accessed a computer without authorization or exceeding authorized access, and by means of such conduct having obtained information that has been determined by the United States Government pursuant to an Executive order or statute to require protection against unauthorized disclosure for reasons of national defense or foreign relations, or any restricted data, as defined in paragraph y. of section 11 of the Atomic Energy Act of 1954, with reason to believe that such information so obtained could be used to the injury of the United States, or to the advantage of any foreign nation willfully communicates, delivers, transmits, or causes to be communicated, delivered, or transmitted, or attempts to communicate,

Summary

- This lecture:
  - Buffer overrun attacks in general
  - Assignment 6 “B Attack” principles of operation
- This week’s precept:
  - Assignment 6 “B Attack” recap
  - Memory map using gdb
  - Writing binary data
- Final 2 lectures:
  - Assignment 6 “A Attack” overview
  - Machine language details needed for “A Attack”
  - *Finally* finishing the 4-stage build process: the Linker!
- Final precept next week:
  - MiniAssembler and ”A Attack” details