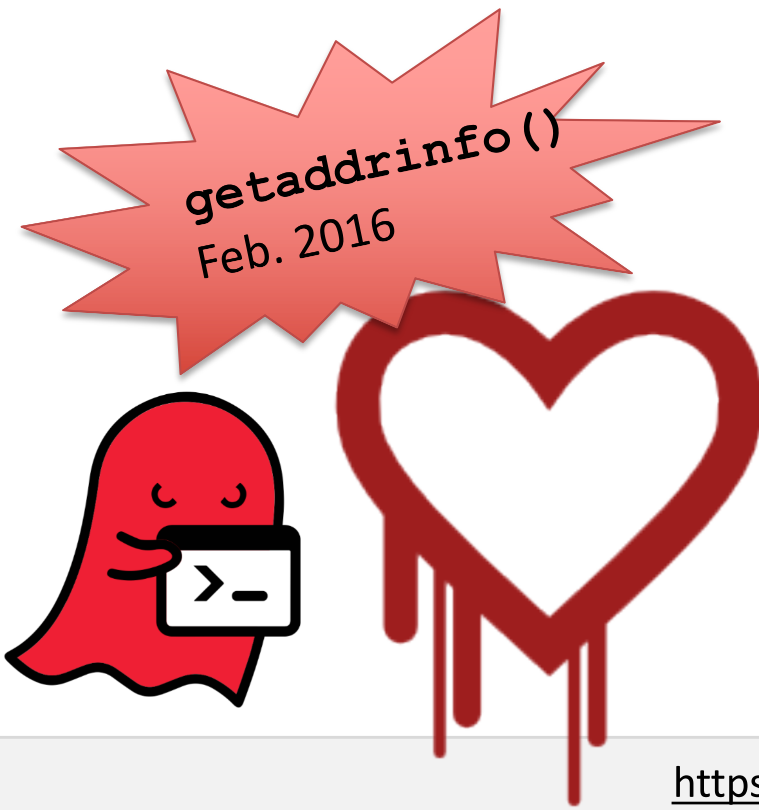
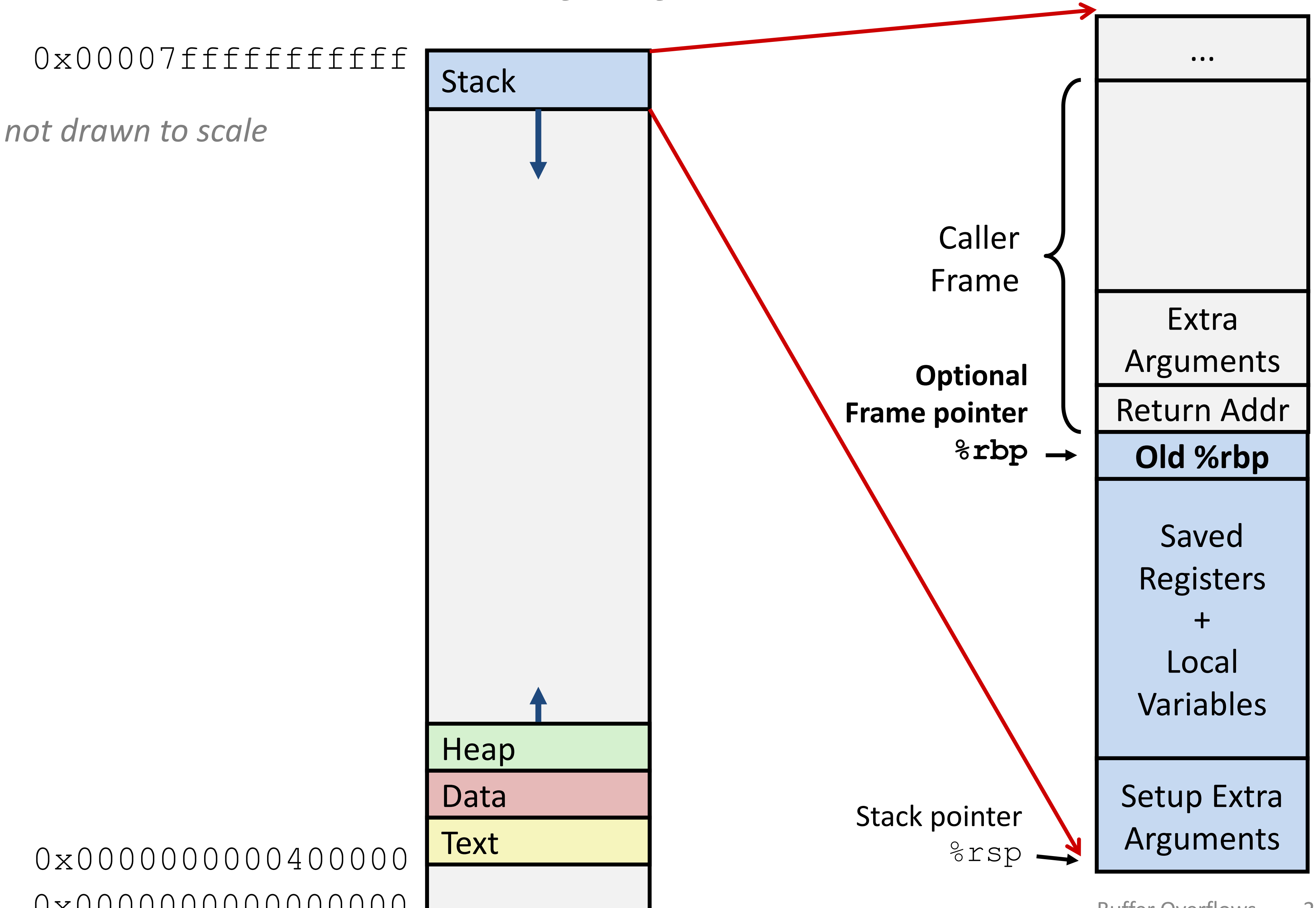
WELLESLEY

Buffer Overflows



Address space layout
the stack discipline
+ C's lack of bounds-checking
HUGE PROBLEM

x86-64 Linux **memory layout**



String library code

C standard library function `gets()`

```
/* Get string from stdin */
char* gets(char* dest) {
    int c = getchar();
    char* p = dest;
    while (c != EOF && c != '\n') {
        *p++ = c;
        c = getchar();
    }
    *p = '\0';
    return dest;
}
```

pointer to start of an array

same as:
```
*p = c;
p = p + 1;
```

What could go wrong in this code?

Same problem in many functions:

- **`strcpy`**: Copies string of arbitrary length
- **`scanf`, `fscanf`, `sscanf`**, when given **`%s`** conversion specification

Vulnerable buffer code: C

```
/* Echo Line */
void echo() {
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
int main() {
  printf("Type a string:");
  echo();
  return 0;
}
```

```
$ ./bufdemo
Type a string:123
123
```

```
$ ./bufdemo
Type a string: 0123456789012345678901234
Segmentation Fault
```

```
$ ./bufdemo
Type a string: 012345678901234567890123
012345678901234567890123
```

Vulnerable buffer code: disassembled x86

echo code

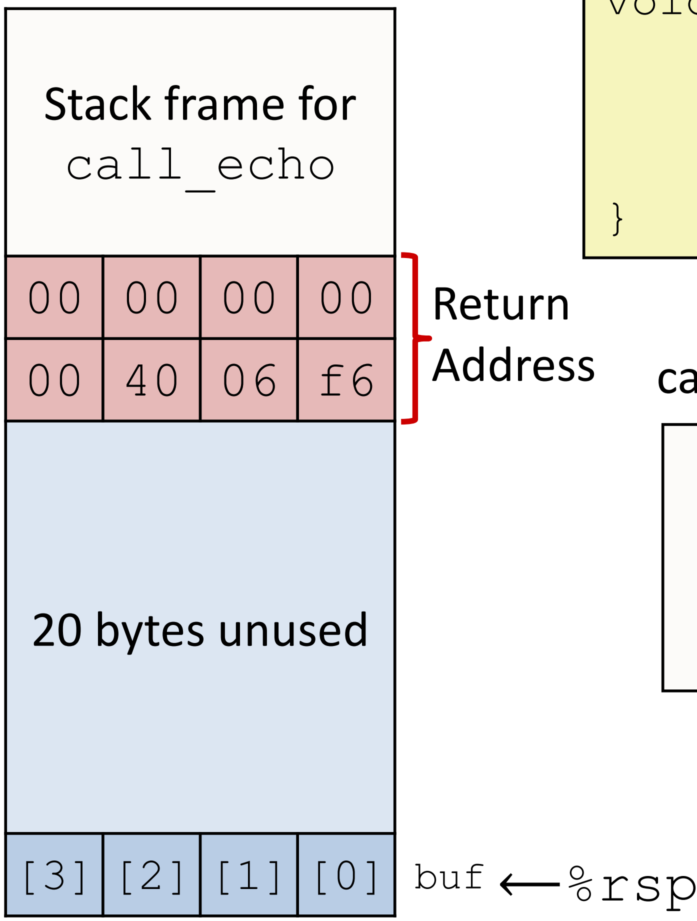
```
0000000004006cf <echo>:
 4006cf:  48 83 ec 18                sub    $24,%rsp
 4006d3:  48 89 e7                   mov    %rsp,%rdi
 4006d6:  e8 a5 ff ff ff             callq  400680 <gets>
 4006db:  48 89 e7                   mov    %rsp,%rdi
 4006de:  e8 3d fe ff ff             callq  400520 <puts@plt>
 4006e3:  48 83 c4 18                add    $24,%rsp
 4006e7:  c3                         retq
```

caller code

```
4006e8:   48 83 ec 08                sub    $0x8,%rsp
 4006ec:  b8 00 00 00 00             mov    $0x0,%eax
 4006f1:  e8 d9 ff ff ff             callq  4006cf <echo>
 4006f6:  48 83 c4 08                add    $0x8,%rsp
 4006fa:  c3                         retq
```

Buffer overflow example: before input

Before call to gets



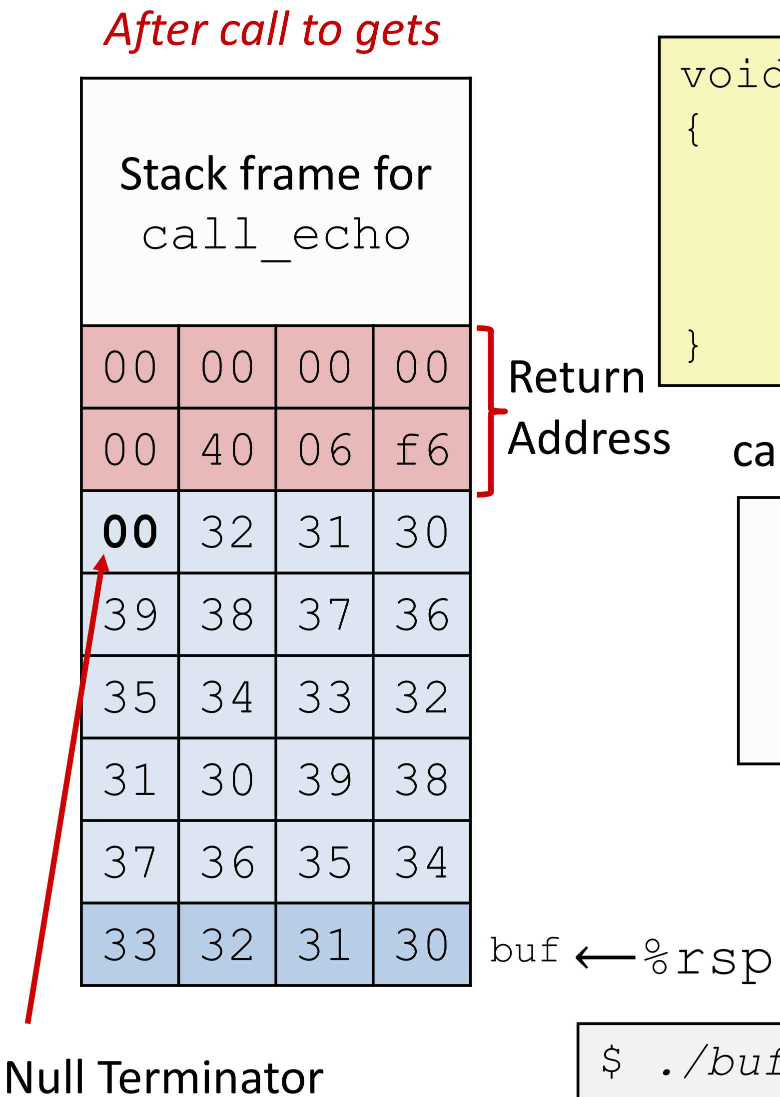

```
void echo() {
    char buf[4];
    gets(buf);
    . . .
}
```

```
echo:
  subq  $24, %rsp
  movq  %rsp, %rdi
  call  gets
  . . .
```

call_echo:

```
  . . .
  4006f1:  callq  4006cf <echo>
  4006f6:  add    $0x8,%rsp
  . . .
```

Buffer overflow example: input #1




```
void echo()
{
     char buf[4];
     gets(buf);
     . . .
}
```

```
echo:
  subq   $24, %rsp
  movq   %rsp, %rdi
  call   gets
  . . .
```

call_echo:

```
   . . .
   4006f1:  callq   4006cf <echo>
   4006f6:  add     $0x8,%rsp
   . . .
```

```
$ ./bufdemo
Type a string: 01234567890123456789012
01234567890123456789012
```

Overflowed buffer, but did not corrupt state

Buffer overflow example: input #2

After call to gets

Stack frame for call_echo				
00	00	00	00	Return Address
00	40	**00**	**34**	
33	32	31	30	
39	38	37	36	
35	34	33	32	
31	30	39	38	
37	36	35	34	
33	32	31	30	buf ⟵%rsp

```
void echo()
{
    char buf[4];
    gets(buf);
    . . .
}
```

```
echo:
  subq   $24, %rsp
  movq   %rsp, %rdi
  call   gets
  . . .
```

call_echo:

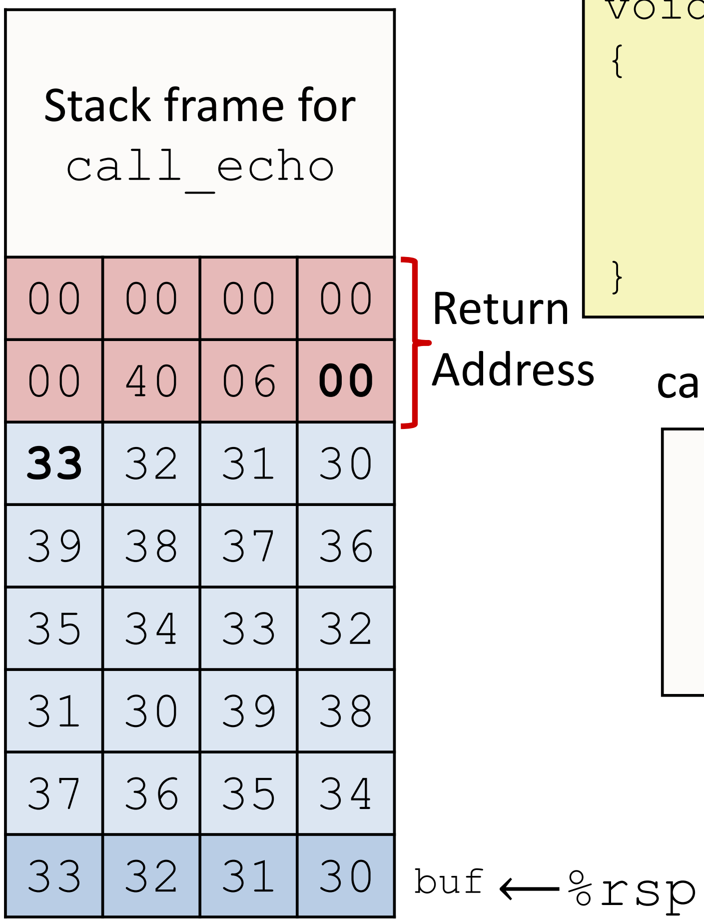
```
  . . .
  4006f1:  callq   4006cf <echo>
  4006f6:  add     $0x8,%rsp
  . . .
```

```
unix> ./bufdemo
Type a string: 01234567890123456789012**34**
Segmentation Fault
```

Overflowed buffer and corrupted return pointer

Buffer overflow example: input #3

After call to gets




```
void echo()
{
     char buf[4];
     gets(buf);
     . . .
}
```

```
echo:
  subq   $24, %rsp
  movq   %rsp, %rdi
  call   gets
  . . .
```

call_echo:

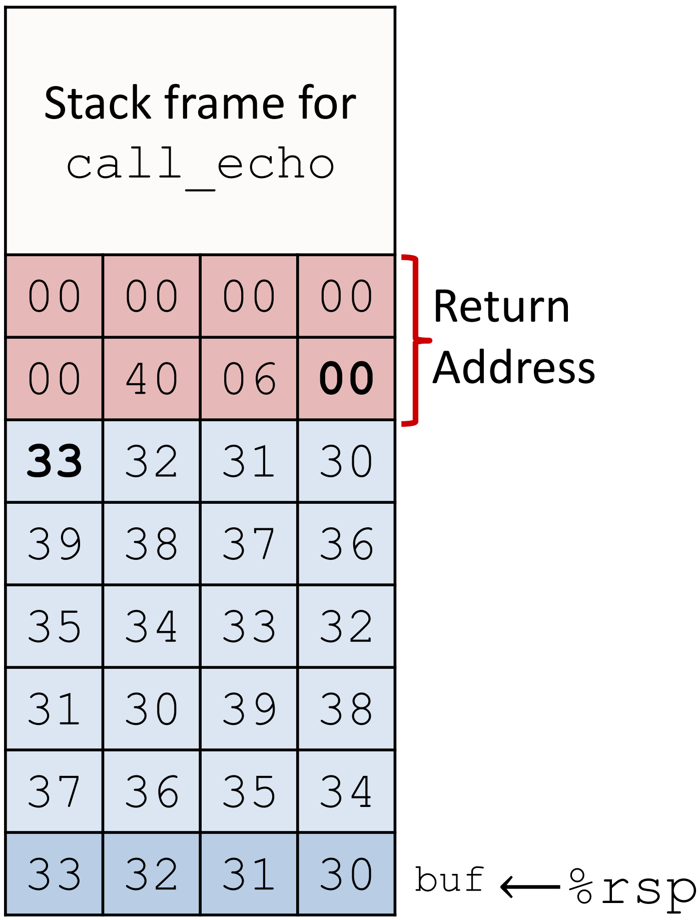
```
  . . .
  4006f1:  callq  4006cf <echo>
  4006f6:  add    $0x8,%rsp
  . . .
```

```
unix> ./bufdemo-nsp
Type a string: 012345678901234567890123
012345678901234567890123
```

Overflowed buffer, corrupted return pointer, but program seems to work!

Buffer overflow example: input #3

After call to gets



Some other place in .text

```
  . . .
  400600:  mov     %rsp,%rbp
  400603:  mov     %rax,%rdx
  400606:  shr     $0x3f,%rdx
  40060a:  add     %rdx,%rax
  40060d:  sar     %rax
  400610:  jne     400614
  400612:  pop     %rbp
  400613:  retq
```

"Returns" to unrelated code

Lots of things happen, without modifying critical state

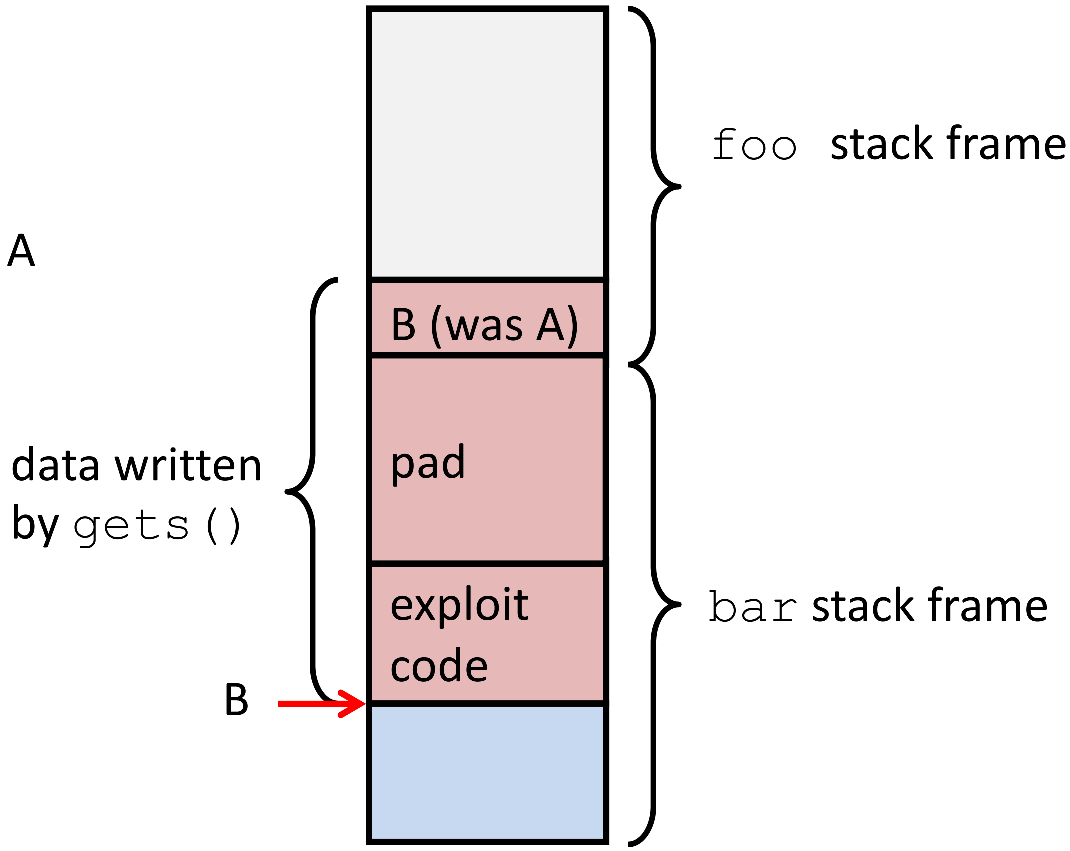
Eventually executes `retq` back to `main`

Exploiting buffer overflows

```
void foo(){
  bar();
  ...          <- return address A
}
```

```
int bar() {
  char buf[64];
  gets(buf);
  ...
  return ...;
}
```

Stack after call to gets()



Input string contains byte representation of executable code

Overwrite return address A with address of buffer (need to know B)

When `bar()` executes `ret`, will jump to exploit code (instead of A)

Exploits in the wild

Buffer overflow bugs allow remote attackers to execute arbitrary code on machines running vulnerable software.

1988: Internet worm

Early versions of the finger server daemon (fingerd) used **`gets()`** to read the argument sent by the client:

```
finger somebody@cs.wellesley.edu
```

commandline facebook of the 80s!

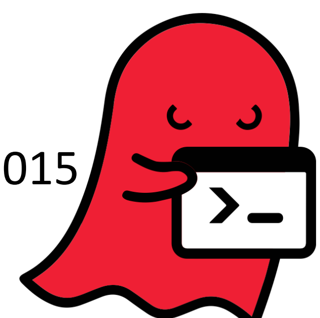
Attack by sending phony argument:

`finger` ***`“exploit-code padding new-return-address”`***

...

Still happening

"Ghost:" 2015



`gethostname()`

`getaddrinfo()`
Feb. 2016

Heartbleed (2014)

optional

Buffer over-read in OpenSSL

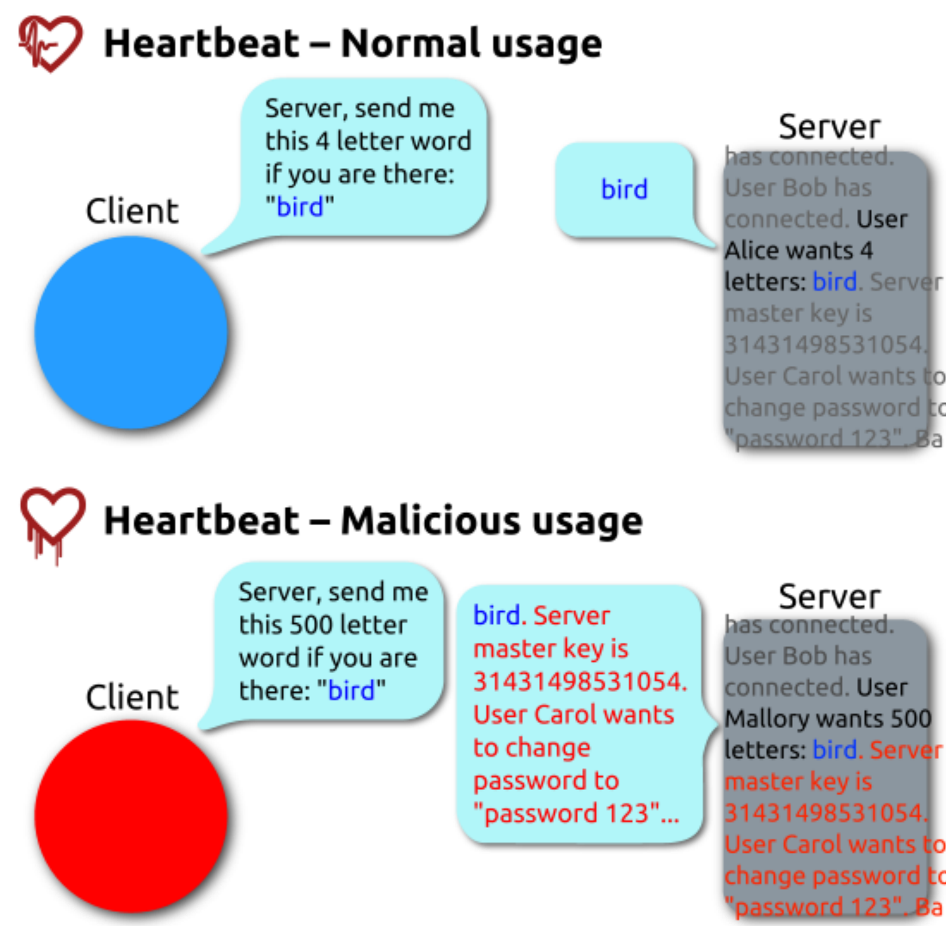
- Widely used encryption library (https)

"Heartbeat" packet

- Specifies length of message
- Server echoes that much back
- Library just "trusted" this length
- Allowed attackers to read contents of memory anywhere they wanted

~17% of Internet affected

- "Catastrophic"
- Github, Yahoo, Stack Overflow, Amazon AWS, ...



Avoiding overrun vulnerabilities

1. Use a memory-safe language (not C)!

2. If you have to use C, use library functions that limit string lengths.
   `fgets` instead of **`gets`**

```
/* Echo Line */
void echo() {
    char buf[4];  /* Way too small! */
    fgets(buf, 4, stdin);
    puts(buf);
}
```

   `strncpy` instead of **`strcpy`**
   Don't use **`scanf`** with **`%s`** conversion specification
      Use **`fgets`** to read the string
      Or use **`%ns`** where **`n`** is a suitable integer

Other ideas?

System-level protections

Available in modern OSs/compilers/hardware

(We disabled these for buffer assignment.)

1. Randomize stack base, maybe frame padding

2. Detect stack corruption

   save and check stack "canary" values

3. Non-executable memory segments

   stack, heap, data, … everything except text

   hardware support

Helpful, not foolproof!

Return-oriented programming, over-reads, etc.

not drawn to scale