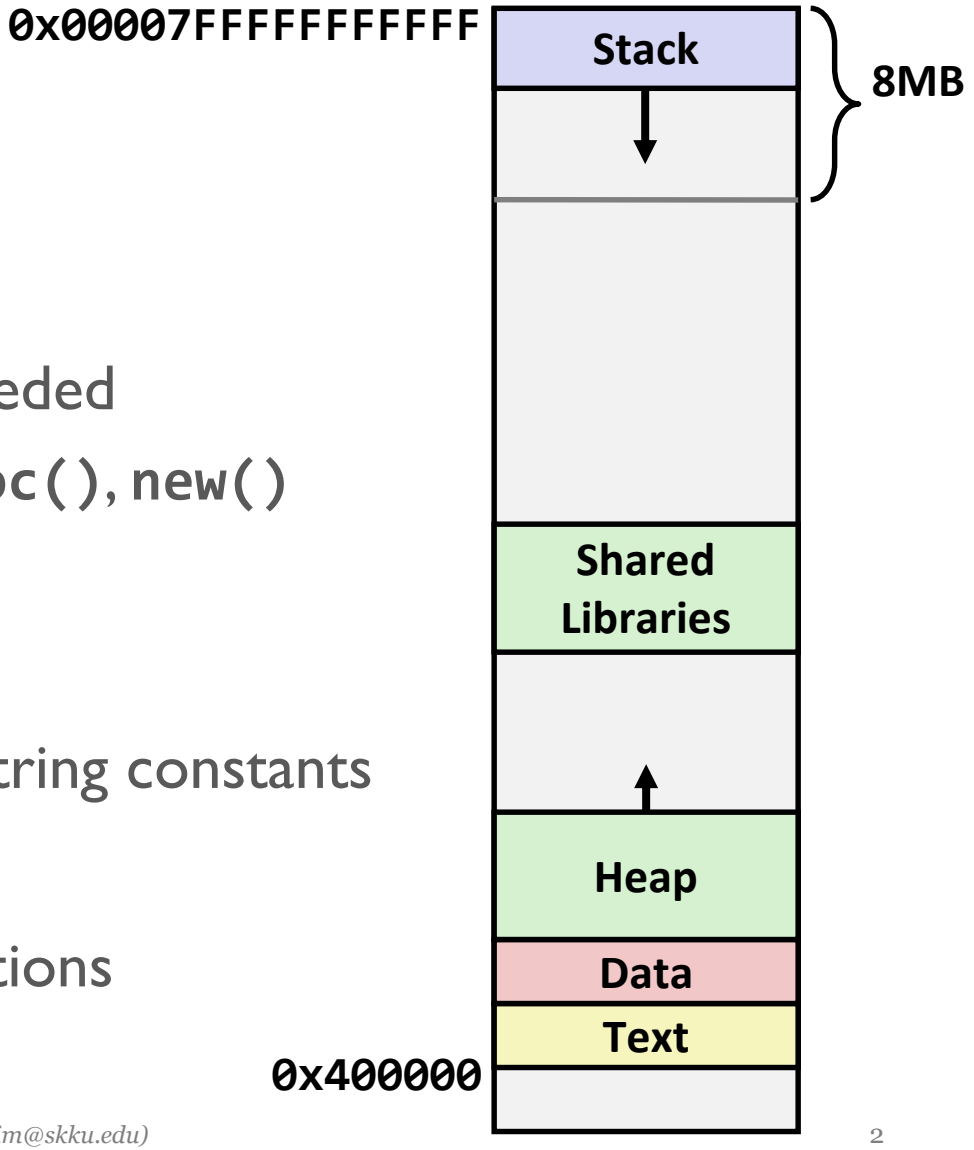
Buffer Overflow

Jin-Soo Kim (*jinsookim@skku.edu*)
Computer Systems Laboratory
Sungkyunkwan University
http://csl.skku.edu

x86-64/Linux Memory Layout

- Stack
  - Runtime stack (8MB limit)
- Heap
  - Dynamically allocated as needed
  - When call `malloc()`, `calloc()`, `new()`
- Data
  - Statically allocated data
  - e.g. global vars, static vars, string constants
- Text / Shared libraries
  - Executable machine instructions
  - Read-only

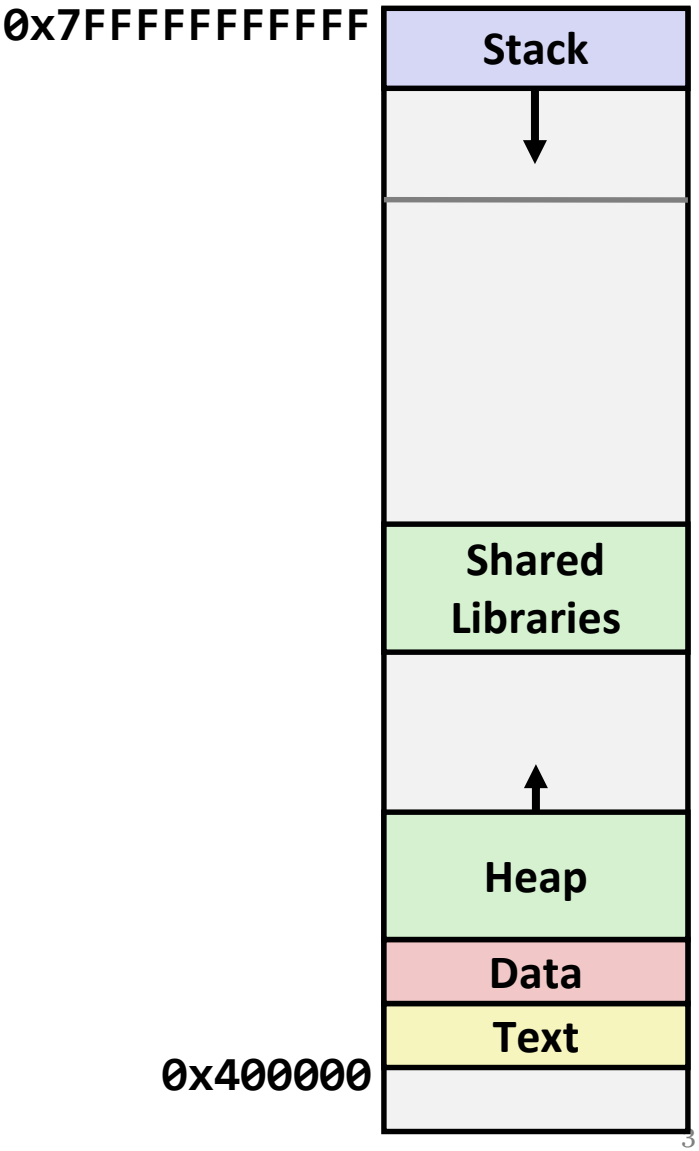


x86-64 Addresses Example

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

int g = 1;
int main(void) {
  char *p = malloc(100);
  printf("main() = %p\n", main);
  printf("&g = %p\n", &g);
  printf("&p = %p\n", &p);
  printf("p = %p\n", p);
}
```

```
$ gcc -Og -g mem.c
$ ./a.out
main() = 0x4005f6
&g = 0x601048
&p = 0x7fff07b94b70
p = 0x1ece010
```



Vulnerable Buffer Code

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

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

```
$ ./bufdemo
Type:012
012

$ ./bufdemo
Type: 0123456789012345678901
0123456789012345678901

$ ./bufdemo
Type: 012345678901234567890123
Segmentation fault (core dumped)
```

String Library Code

- Implementation of Unix function **`gets()`**
  - No way to specify limit on number of characters to read

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

  - Similar problems with other Unix functions
    - **`strcpy`**: copies string of arbitrary length
    - **`scanf`** / **`fscanf`** / **`sscanf`**, given **`%s`** conversion specification

Buffer Overflow Disassembly

- **echo()**:

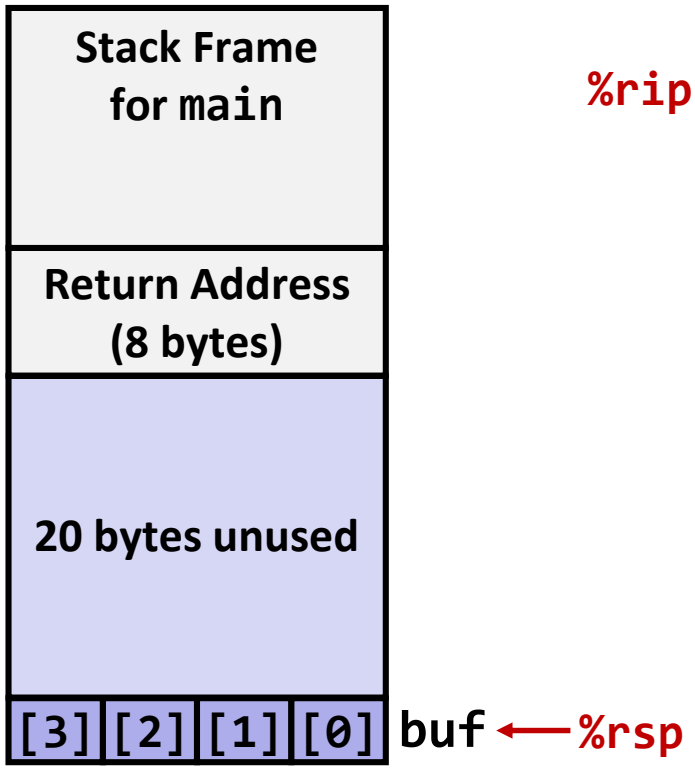
```
0000000004006cf <echo>:
 4006cf:   48 83 ec 18              sub    $0x18,%rsp
 4006d3:   48 89 e7                 mov    %rsp,%rdi
 4006d6:   e8 a5 ff ff ff           callq  400680 <gets>
 4006db:   48 89 e7                 mov    %rsp,%rdi
 4006de:   e8 3d fe ff ff           callq  400520 <puts@plt>
 4006e3:   48 83 c4 18              add    $0x18,%rsp
 4006e7:   c3                       retq
```

- **main()**:

```
           ...
 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
           ...
```

Buffer Overflow (1)

- Before call to **`gets()`**

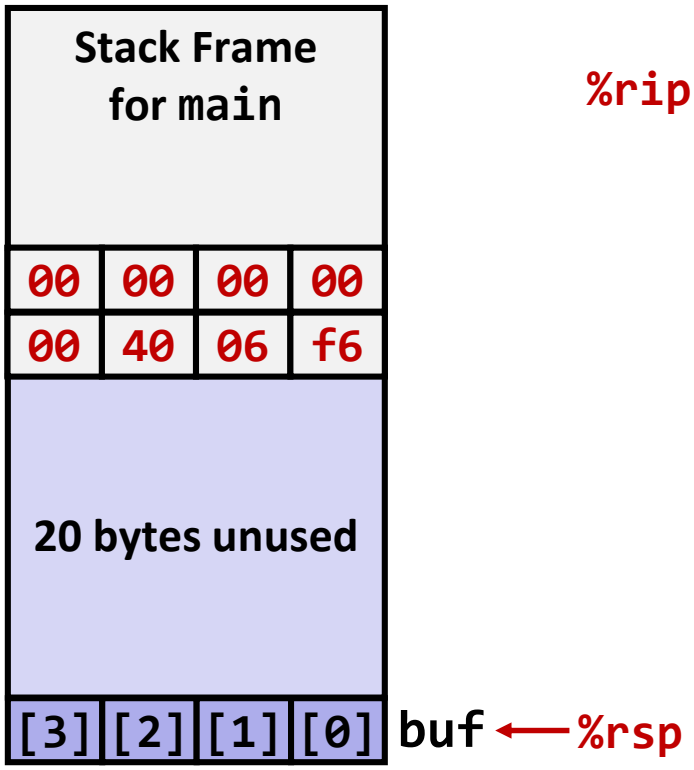



```
echo:
   4006cf:  sub    $0x18,%rsp
%rip→ 4006d3:  mov    %rsp,%rdi
   4006d6:  callq  400680 <gets>
   4006db:  mov    %rsp,%rdi
   4006de:  callq  400520 <puts@plt>
   4006e3:  add    $0x18,%rsp
   4006e7:  retq

main:
            ...
   4006ec:  mov    $0x0,%eax
   4006f1:  callq  4006cf <echo>
   4006f6:  add    $0x8,%rsp
            ...
```

Buffer Overflow (2)

- Before call to **`gets()`**

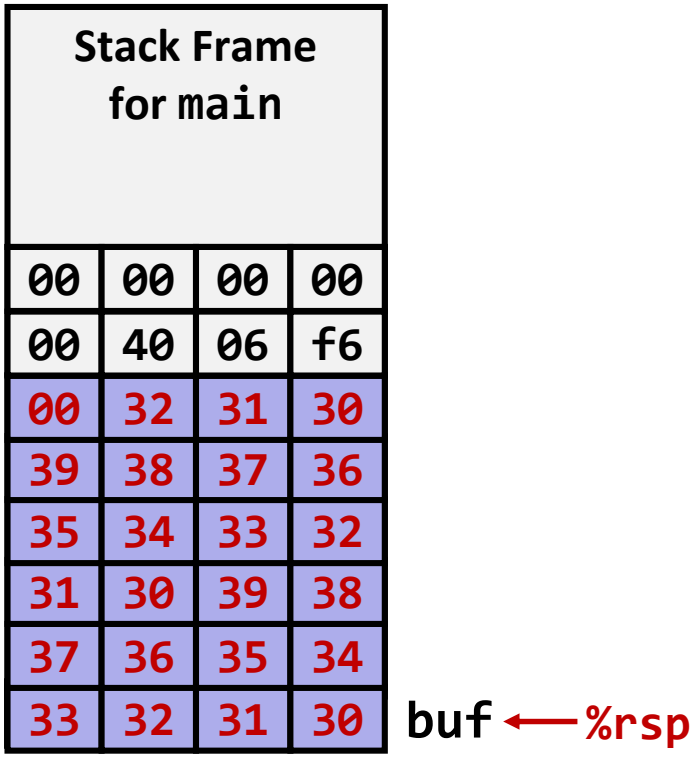



```
echo:
   4006cf:  sub    $0x18,%rsp
%rip→ 4006d3:  mov    %rsp,%rdi
   4006d6:  callq  400680 <gets>
   4006db:  mov    %rsp,%rdi
   4006de:  callq  400520 <puts@plt>
   4006e3:  add    $0x18,%rsp
   4006e7:  retq

main:
            ...
   4006ec:  mov    $0x0,%eax
   4006f1:  callq  4006cf <echo>
   4006f6:  add    $0x8,%rsp
            ...
```

Buffer Overflow (3)

- Overflowed buffer, but did not corrupt state

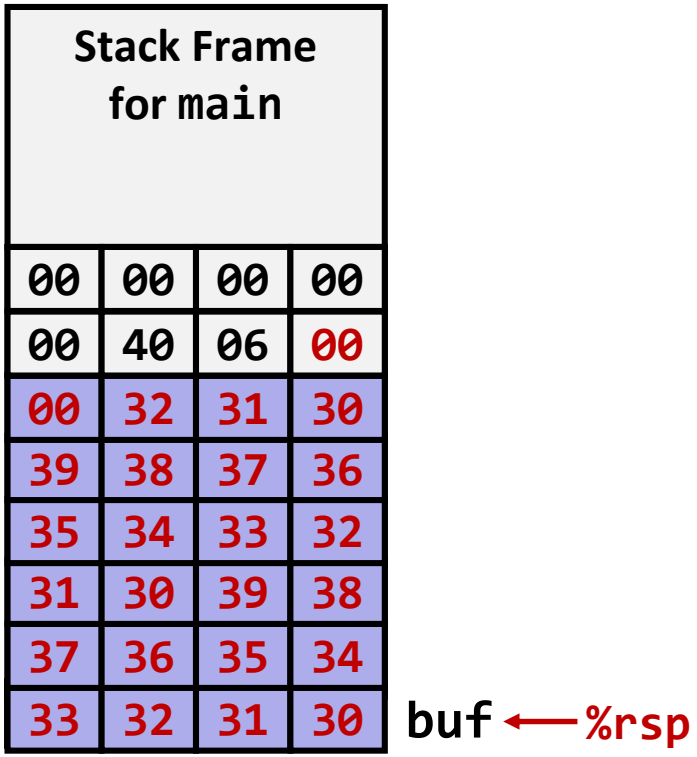



```
echo:
   4006cf:  sub    $0x18,%rsp
   4006d3:  mov    %rsp,%rdi
   4006d6:  callq  400680 <gets>
   4006db:  mov    %rsp,%rdi
   4006de:  callq  400520 <puts@plt>
   4006e3:  add    $0x18,%rsp
   4006e7:  retq
```

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

Buffer Overflow (4)

- Overflowed buffer, and corrupted return pointer

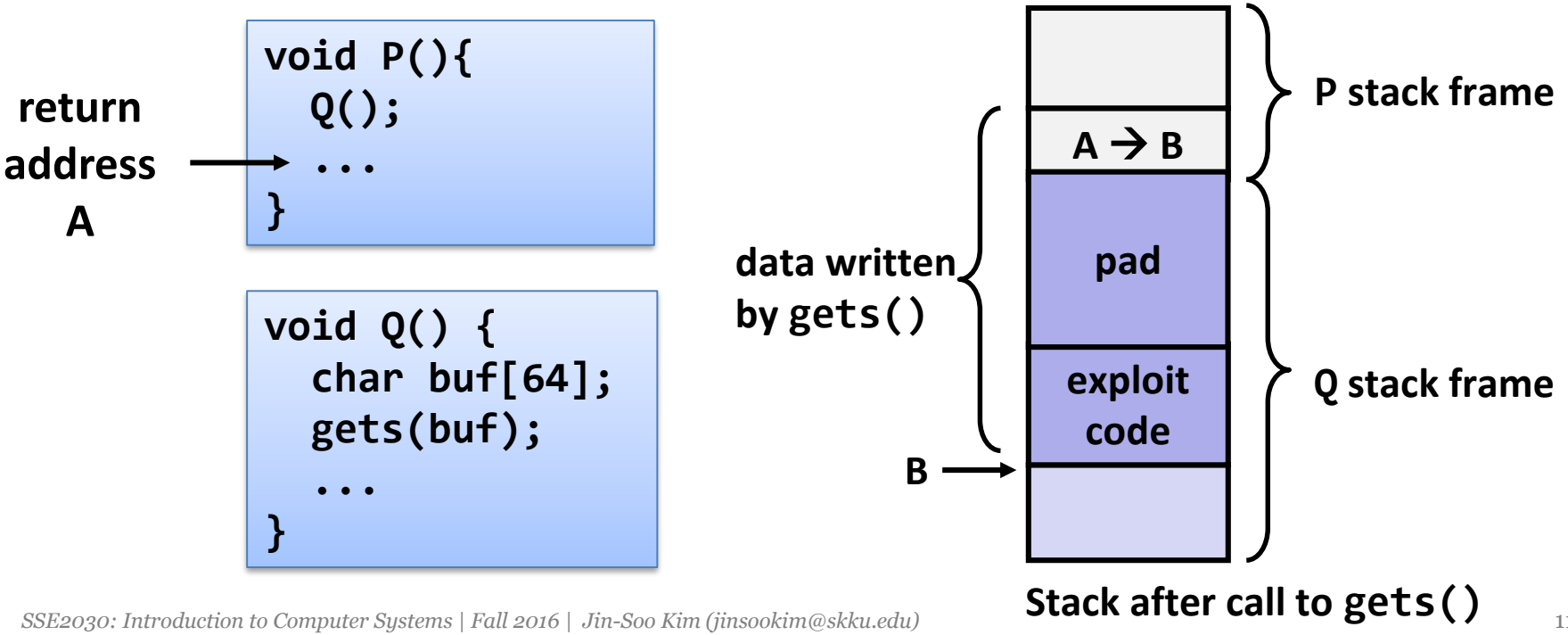



```
echo:
  4006cf:  sub    $0x18,%rsp
  4006d3:  mov    %rsp,%rdi
  4006d6:  callq  400680 <gets>
  4006db:  mov    %rsp,%rdi
  4006de:  callq  400520 <puts@plt>
  4006e3:  add    $0x18,%rsp
  4006e7:  retq
```

```
$ ./bufdemo
Type: 01234567890123456789012
Segmentation fault (core dumped)
```

Buffer Overflow Attack

- Malicious use of buffer overflow
  - Input string contains byte representation of executable code
  - Overwrite return address **A** with address of buffer **B**
  - When **P()** executes **ret**, will jump to exploit code



Exploits Using Buffer Overflows

- Buffer overflow bugs can allow remote machines to execute arbitrary code on victim machines
- Distressingly common in real programs
  - Programmers keep making the same mistakes ☹
  - Recent measures make these attacks much more difficult

Internet Worm (1988)

- Exploited a few vulnerabilities to spread
  - Early versions of the finger server (`fingerd`) used `gets()` to read the argument sent by the client:
    - `finger kildong@skku.edu`
  - Worm attacked `fingerd` server by sending phony argument:
    - `finger "exploit-code padding new-return-address"`
    - exploit code: executed a root shell on the victim machine with a direct TCP connection to the attacker
- Once on a machine, scanned other machines to attack
  - Invaded ~6000 computers in hours (10% of the Internet)
  - The young author of the worm was prosecuted
  - CERT (Computer Emergency Response Team) formed @ CMU

Worms vs. Viruses

- Worm: A program that
  - Can run by itself
  - Can propagate a fully working version of itself to other computers
- Virus: Code that
  - Adds itself to other programs
  - Does not run independently
- Both are (usually) designed to spread among computers and to wreak havoc

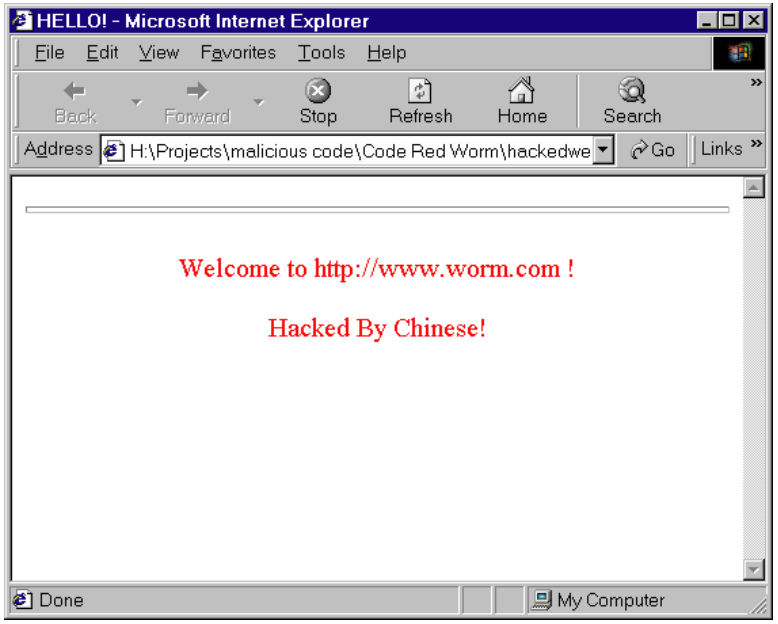
Code Red Worm (2001)

- History
  - June 18, 2001, Microsoft announces buffer overflow vulnerability in IIS Internet Server
  - July 19, 2001, Over 250,000 machines infected by new virus in 9 hours
  - White house must change its IP address. Pentagon shut down public WWW servers for day
- Received strings of form

```
GET
  /default.ida?NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN....NNN
  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN%u9090%u6858%ucbd3%u7
  801%u9090%u6858%ucbd3%u7801%u9090%u6858%ucbd3%u7801%u9090%u
  9090%u8190%u00c3%u0003%u8b00%u531b%u53ff%u0078%u0000%u00=a
HTTP/1.0" 400 325 "-" "-"
```

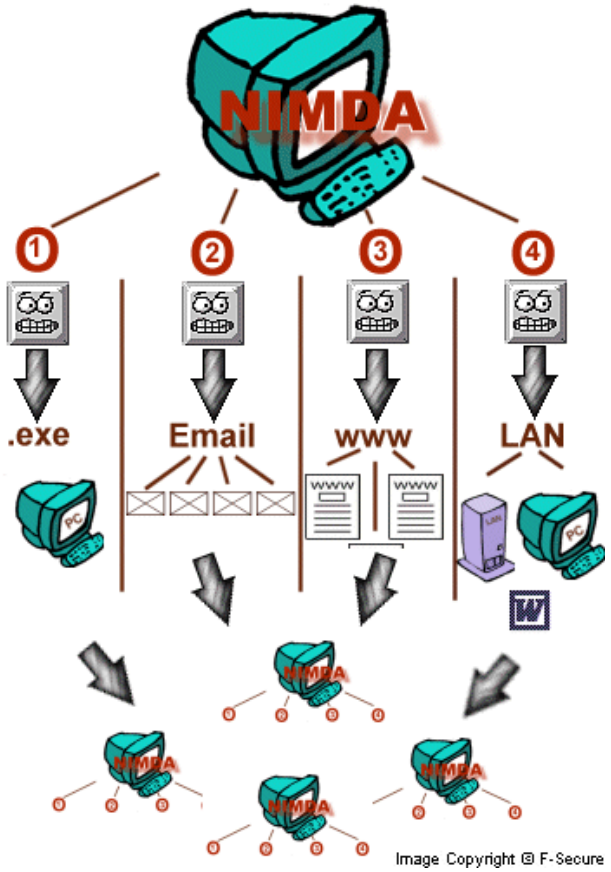
Code Red Worm (2001)

- Code Red exploit code
  - Starts 100 threads running
  - Spread self
    - Generate random IP addresses & send attack string
    - Between 1st & 19th of month
  - Denial of service attack to www.whitehouse.gov
    - Send 98,304 packets; sleep for 4-1/2 hours; repeat
    - Between 21st & 27th of month
  - Deface server's home page
    - After waiting 2 hours



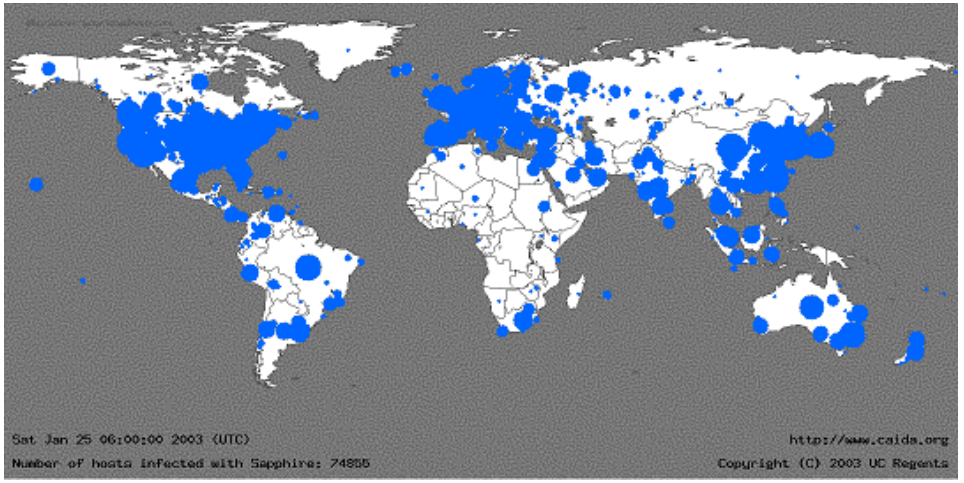
Nimda Worm (2001)

- Five different infection methods
  - Via e-mail
  - Via open network shares
  - Via browsing of compromised web sites
  - Exploitation of various Microsoft IIS 4.0/5.0 directory traversal vulnerabilities
  - Via back doors left behind by the Code Red II and Sadmind/IIS worms
- One of the most widespread virus/worm



SQL Slammer Worm (2003)

- History
  - Exploited two buffer overflow bugs in Microsoft's SQL Server and Desktop Engine
  - Infected 75,000 victims within 10 minutes
  - Generate random IP addresses and send itself out to those addresses, slowing down Internet traffic dramatically
  - Jan. 25 nationwide Internet shutdown in South Korea



30 minutes after release

Avoiding Buffer Overflow

- Use library routines that limit string lengths
  - **`fgets()`** instead of **`gets()`**
  - **`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

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

System-Level Protections

- Randomized stack offsets
  - At start of program, allocate random amount of space on stack
  - Makes it difficult for hacker to predict beginning of inserted code

- Executable space protection
  - Mark certain areas of memory as non-executable (e.g. stack)
  - Requires hardware assistance:
    x86-64 added explicit "execute" permission

Stack Canaries

- Idea
  - Place special value ("canary") on stack just beyond buffer
  - Check for corruption before exiting function
- GCC implementation
  - `-fstack-protector` (now the default)

```
$ ./bufdemo                              bufdemo with -fstack-protector
Type:01234567
01234567
$ ./bufdemo
Type: 012345678
012345678
*** stack smashing detected ***: ./bufdemo terminated
Aborted (core dumped)
```

Summary

- Memory layout
  - OS/machine dependent (including kernel version)
  - Basic partitioning:
    stack, data, text, heap, shared libraries found in most machines
- Avoiding buffer overflow vulnerability
  - Important to use library routines that limit string lengths
- Working with strange code
  - Important to analyze nonstandard cases
    - e.g. What happens when stack corrupted due to buffer overflow?
  - Helps to step through with GDB