CSE509: (Intro to) Systems Security

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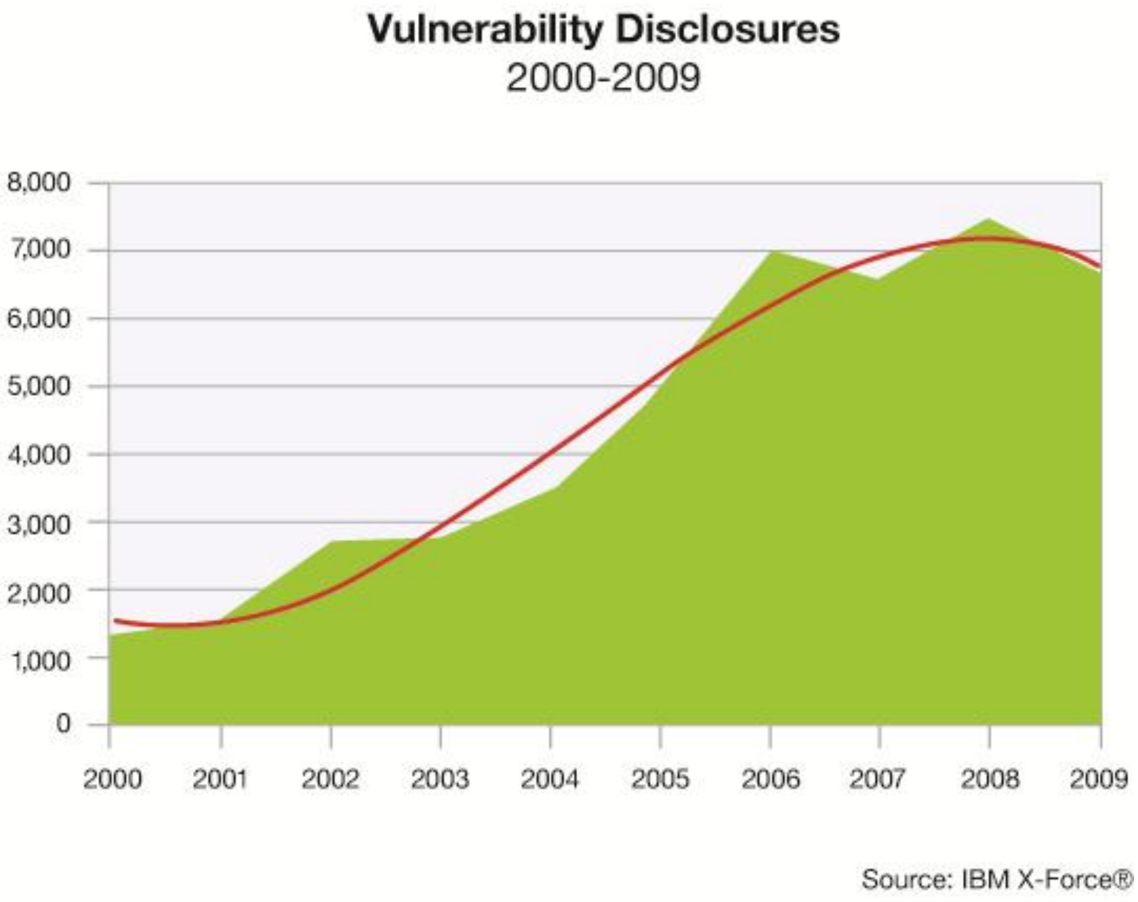
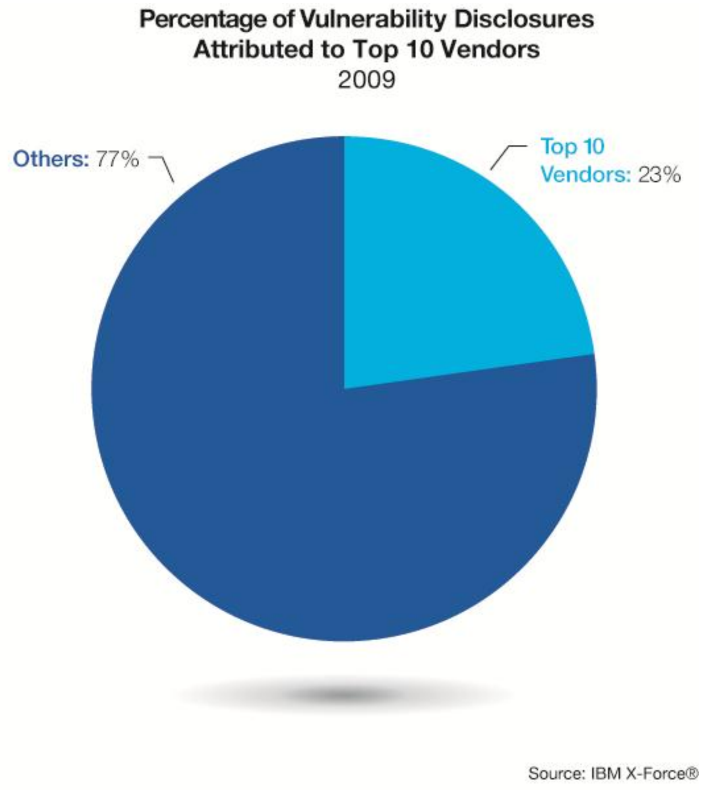
Program Errors
Buffer Overflow
TOCTTOU

Why Do We Have Security Vulnerabilities?

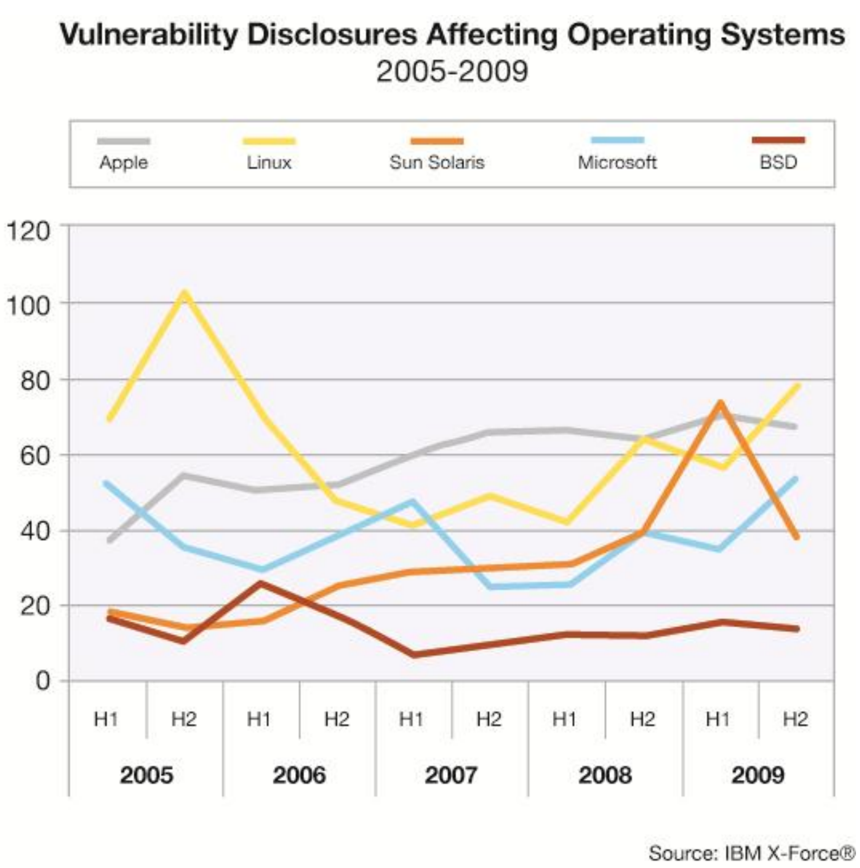
- Some contributing factors
  - Few courses in computer security ☺
  - Programming text books do not emphasize security
  - Few security audits
  - *C is an unsafe language*
  - Programmers have many other things to worry about
  - Consumers do not care about security
  - Security is expensive and takes time

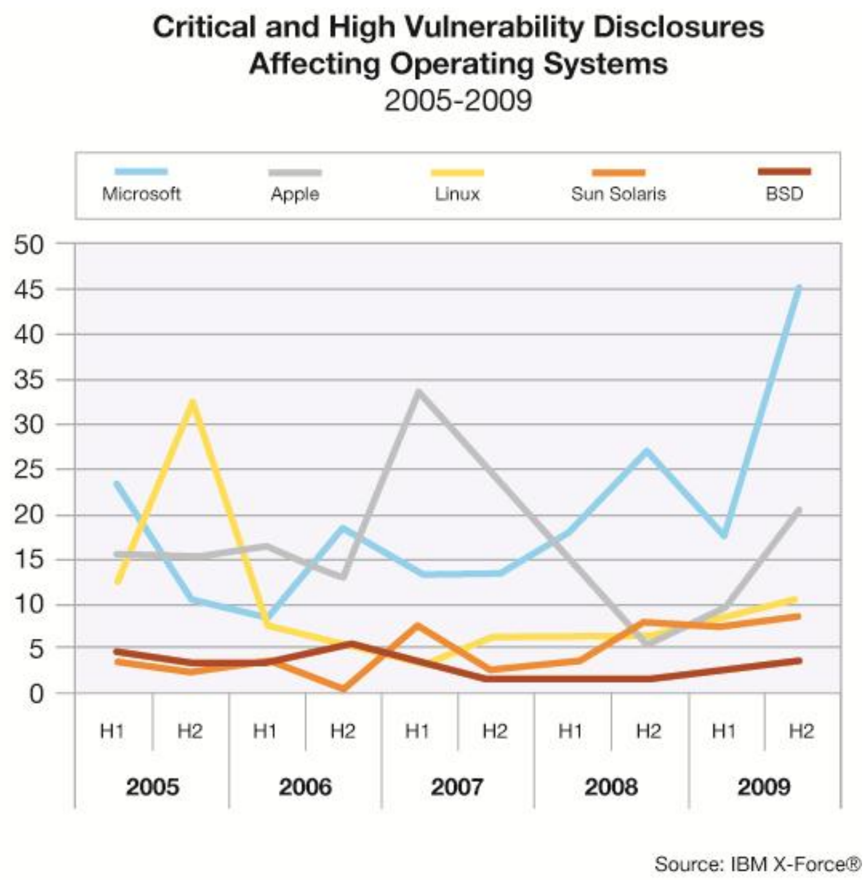
Trends


Vulnerability Disclosures
2000-2009
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Source: IBM X-Force®


Percentage of Vulnerability Disclosures
Attributed to Top 10 Vendors
2009
Others: 77%
Top 10
Vendors: 23%
Source: IBM X-Force®

OS Vulnerabilities





Non-malicious Errors

- How to determine *quality* of program ?
  - Testing …
  - Number of faults in requirements, design and code inspections
- Example
  - Module A had 100 faults discovered and fixed
  - Module B had only 20
  - Which one is better ?
  - Software testing result: software with more faults is likely to have even more !!!

Fixing Faults

- Penetrate and Patch
  - Special teams test programs and find faults
  - If no attack found, the program was OK
  - Otherwise, not – More frequently
  - Then fix faults
- Problem: *The system became less secure !*
  - Focus on fixing the fault and not its context
  - Fault had side effects in other places
  - Fixing fault generated faults somewhere else
  - Fixing fault would affect functionality or performance

Buffer Overflows Hall of Fame

- Morris worm (1988): overflow in fingerd
  - *6,000 machines infected (10% of existing Internet)*
- CodeRed (2001): overflow in MS-IIS web server
  - **Internet Information Services (IIS)**
  - Web server application
  - The most used web server after Apache HTTP Server
  - *300,000 machines infected in 14 hours*
- SQL Slammer(2003): overflow in MS-SQL server
  - *75,000 machines infected in* ***10 minutes*** *(!!)*

Buffer Overflows Hall of Fame (2)

- Sasser (2004): overflow in Windows LSASS
  - **Local Security Authority Subsystem Service**
    - Process in Windows OS
    - Responsible for enforcing the security policy on the system.
    - Verifies users logging on to a Windows computer or server, handles password changes, and creates access tokens
  - *Around 500,000 machines infected*

- Conficker (2008-09): overflow in Windows Server
  - *~10 million machines infected*

Memory Exploits

- Buffer is a data storage area inside computer memory (stack or heap)
  - Intended to hold pre-defined amount of data
- If executable code is supplied as "data", victim's machine may be fooled into executing it
- Code will give attacker control over machine

Stack Buffers

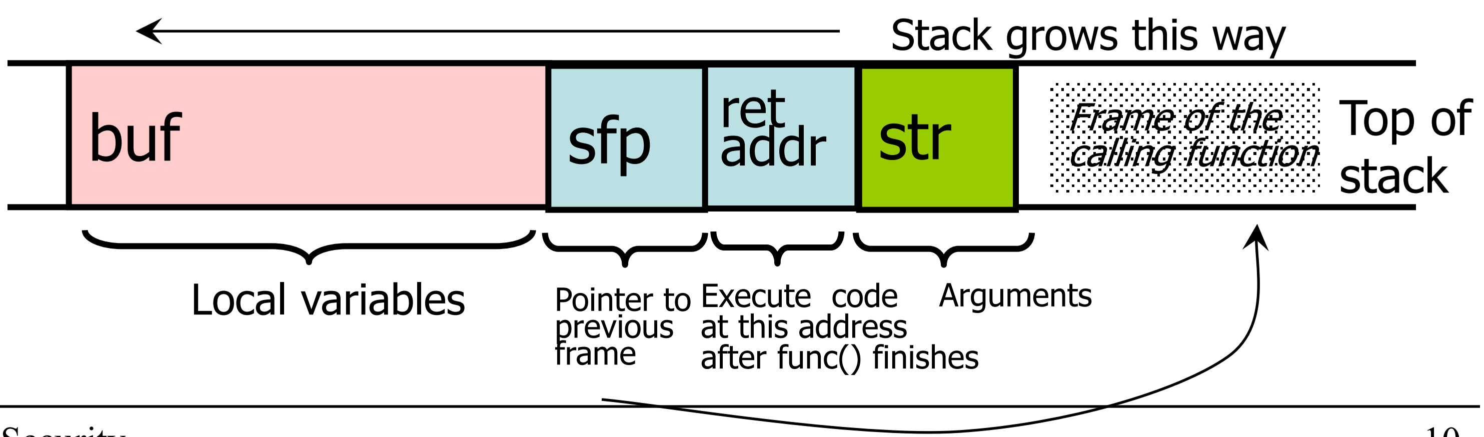
- Suppose Web server contains this function

```
void func(char *str) {
        char buf[126];
        strcpy(buf,str);
}
```

Allocate local buffer (126 bytes reserved on stack)

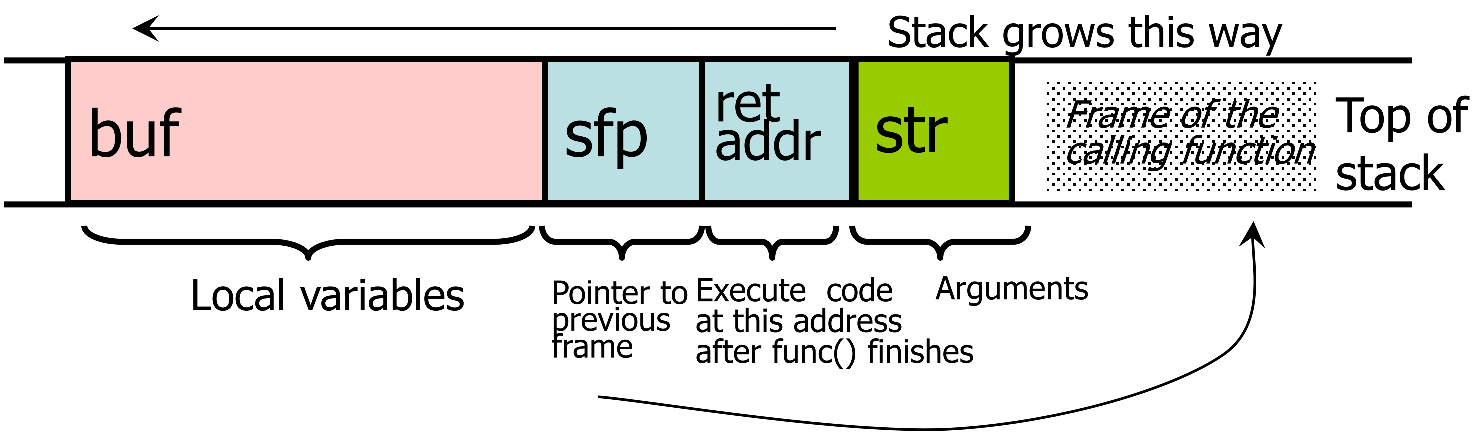
Copy argument into local buffer

- When this function is invoked, a new frame with local variables is pushed onto the stack



Stack Buffers (2)

- When func returns
  - The local variables are popped from the stack
  - The old value of the stack frame pointer (sfp) is recovered
  - The return address is retrieved
  - The stack frame is popped
  - Execution continues from return address (calling function)



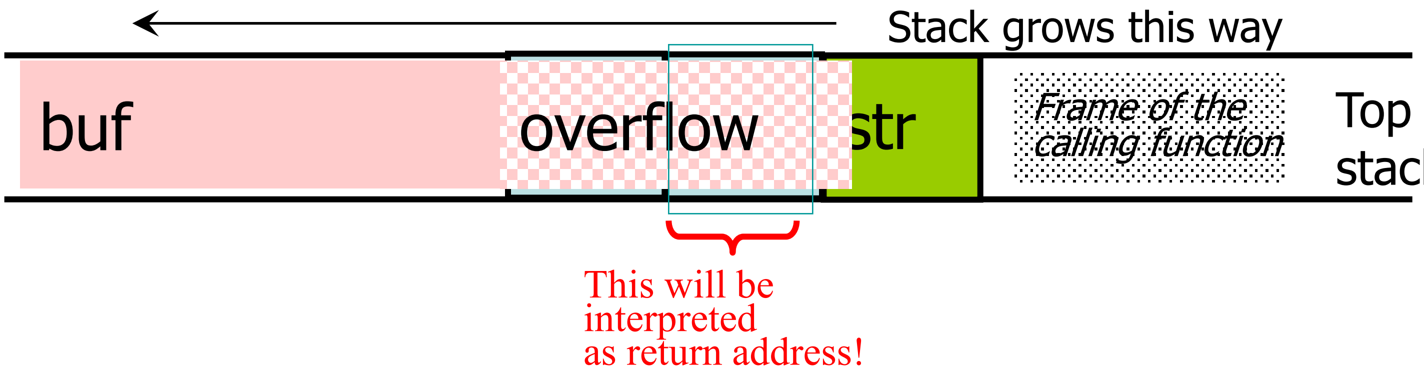
What if Buffer is Over-stuffed?

- Memory pointed to by str is copied onto stack…

```
void func(char *str) {
        char buf[126];
        strcpy(buf,str);
}
```

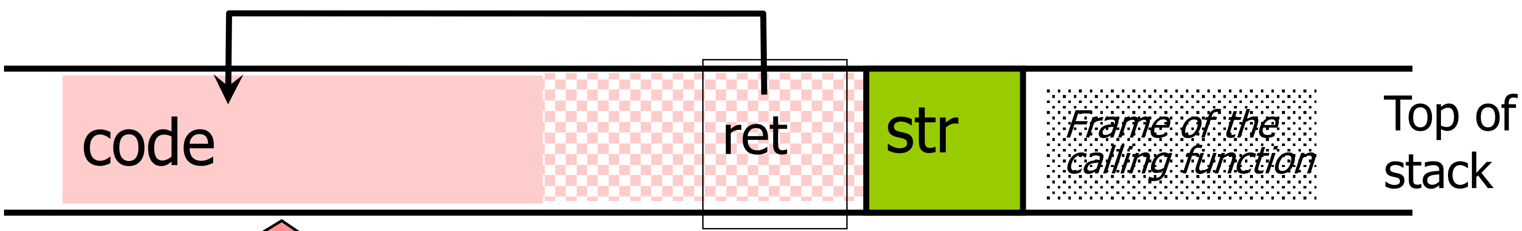
strcpy does NOT check whether the string at *str contains fewer than 126 characters

- If a string longer than 126 bytes is copied into buffer, it will overwrite adjacent stack locations



Attack 1: Smashing the Stack

- Suppose buffer contains attacker-created string
  - For example, *str contains a string received from the network as input to some network service daemon



Attacker puts actual assembly instructions into his input string, e.g., binary code of execve("/bin/sh")

In the overflow, a pointer back into the buffer appears in the location where the system expects to find return address

When function exits, code in the buffer will be executed, giving attacker a shell

Root shell if the victim program is setuid root

Buffer Overflow Difficulties

- Executable attack code is stored on stack, inside the buffer containing attacker's string
  - Stack memory is supposed to contain only data, but…
- For the basic attack, overflow portion of the buffer must contain *correct address of attack code* in the RET position
  - The value in the RET position must point to the beginning of attack assembly code in the buffer
  - Otherwise application will give segmentation violation
  - Attacker must correctly guess in which stack position his buffer will be when the function is called

Problem: No Range Checking

- strcpy does not check input size
  - strcpy(buf, str) simply copies memory contents into buf starting from *str until "\0" is encountered, ignoring the size of area allocated to buf
- Many C library functions are unsafe
  - strcpy(char *dest, const char *src)
  - strcat(char *dest, const char *src)
  - gets(char *s)
  - scanf(const char *format, …)
  - printf(const char *format, …)

Does Range Checking Help?

- strncpy(char *dest, const char *src, size_t n)
  - If strncpy is used instead of strcpy, no more than n characters will be copied from *src to *dest
  - Programmer has to supply the right value of n
- Potential overflow in htpasswd.c (Apache 1.3):

```
… strcpy(record, user);
  strcat(record, ”:”);
  strcat(record, cpw); …
```

Copies username (“user”) into buffer (“record”), then appends “:” and hashed password (“cpw”)

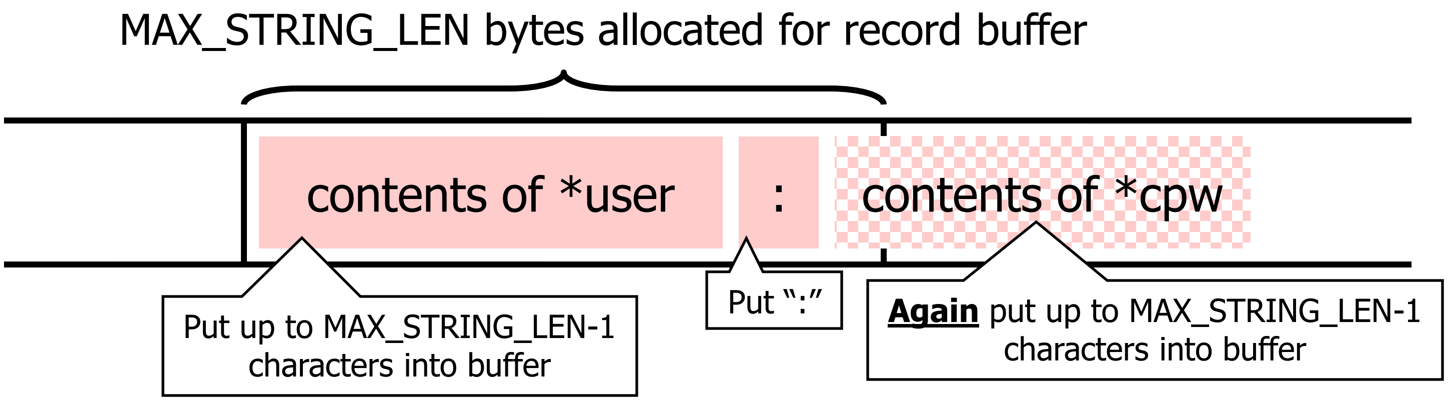
- Published “fix” (do you see the problem?):

```
… strncpy(record,user, MAX_STRING_LEN-1);
  strcat(record,”:”);
  strncat(record,cpw, MAX_STRING_LEN-1); …
```

strncpy missuse in htpasswd “fix”

Published “fix” for Apache htpasswd overflow:

```
… strncpy(record,user, MAX_STRING_LEN-1);
  strcat(record, ”:”);
  strncat(record,cpw, MAX_STRING_LEN-1); …
```

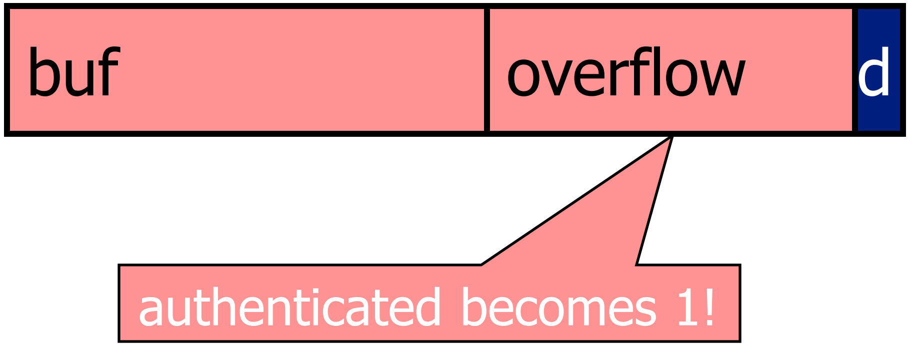


Attack 2: Variable Overflow

Somewhere in the code authenticated is set only if login procedure is successful

- Other parts of the code test authenticated to provide special access

```
char buf[80];
int authenticated = 0;
void vulnerable() {
  gets(buf);
}
```



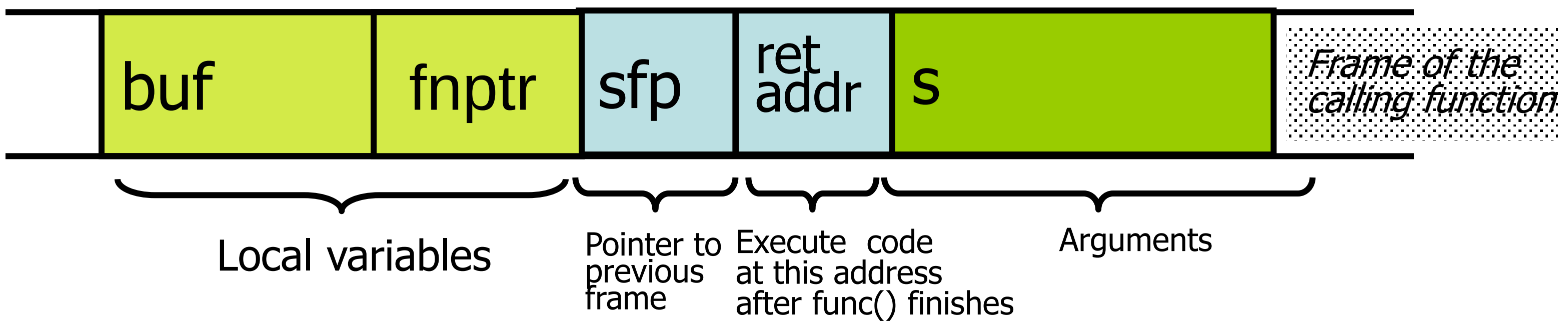
Attacker passes 81 bytes as input to buf

Attack 3: Pointer Variables

fnptr is invoked somewhere else in the program

This is only the definition

```
void func(char *s){
   char buf[80];
   int (*fnptr)();
   gets(buf);
}
```



Attack 3: Pointer Variables (2)

Send malicious code in s

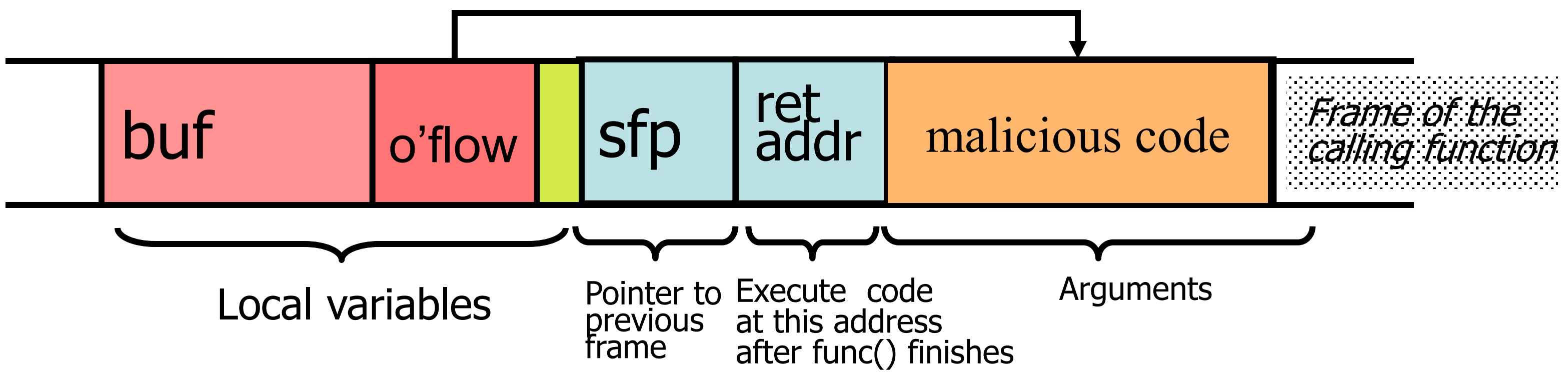
Overflow fnptr

Pass more than 80 bytes in gets

fnptr now points to malicious code

When fnptr is executed, malicious code is executed !

```
void func(char *s){
  char buf[80];
  int (*fnptr)();
  gets(buf);
}
```



Attack 4: Frame Pointer

```
void func(char *s){
   char buf[80];
   gets(buf);
}
```

Send malicious code in s

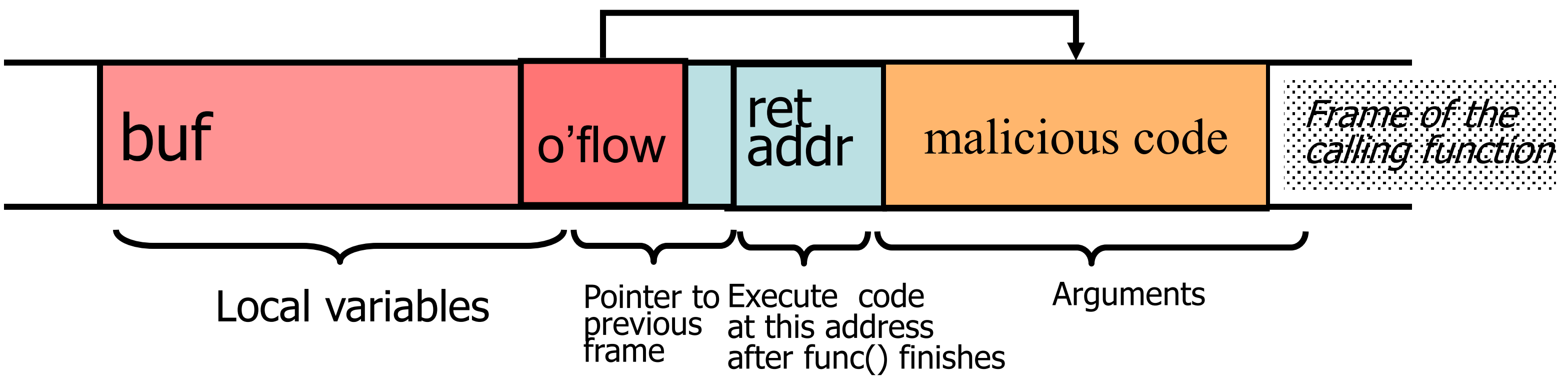
Change the caller's *saved frame ptr.*

Pass more than 80 bytes in gets

sfp now points to malicious code

Caller's return address read from sfp

When func returns, mal. code runs !



Attack 5: Integer Overflow

```
static int getpeername1(p, uap, compat) {
// In FreeBSD kernel, retrieves address of peer to which a socket is connected
    …
    struct sockaddr *sa;
     …
    len = MIN(len, sa->sa_len);
    … copyout(sa, (caddr_t)uap->asa, (u_int)len);
    …
}
```

Checks that "len" is not too big

Negative "len" will always pass this check…

… interpreted as a huge unsigned integer here

Copies "len" bytes from kernel memory to user space

… will copy up to 4G of kernel memory

Time of Check to Time of Use (TOCTTOU) Errors

- Concurrency issue
  - Successive instructions may not execute serially
  - Other processes may be given control
- TOCTTOU: control is given to other process *between* access control check and access operation

TOCTTOU Example

```
int openfile(char *path) {
    struct stat s;
    if (stat(path, &s) < 0)
        return -1;
    if (!S_ISRREG(s.st_mode)) {
        error("only allowed to regular files");
        return -1;
    }
    return open(path, O_RDONLY);
}
```

Path to file

Extract file meta-data

Between check and open attacker can change path

- Initial path is regular file
- Later path is not

Adversary by-passes security

Open file

No symlink, directory, special file

TOCTTOU Prevention

1. Ensure critical parameters are not exposed during pre-emption
   - openfile "owns" path
2. Ensure serial integrity
   - openfile is atomic
   - No pre-emption during its execution
3. Validate critical parameters
   - Compute checksum of path before pre-emption
   - Compare to checksum of path after …

Combination of Flaws

- Can be used together
- Example: Attacker can
  - Use buffer overflow to disrupt code execution
  - Use TOCTTOU to add a new user to system
  - Use incomplete mediation to achieve privileged status
  - …