Security bug of the week (in iOS and OS X)

```
 1  static OSStatus
 2  SSLVerifySignedServerKeyExchange(SSLContext *ctx, bool isRsa, SSLBuffer
 3                                   uint8_t *signature, UInt16 signatureLen
 4  {
 5      OSStatus        err;
 6      ...
 7
 8      if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
 9          goto fail;
10      if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
11          goto fail;
12          goto fail;
13      if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
14          goto fail;
15      ...
16
17  fail:
18      SSLFreeBuffer(&signedHashes);
19      SSLFreeBuffer(&hashCtx);
20      return err;
21  }
```

Attacking the stack

Thanks to SysSec and Int. Secure Systems Labs
at Vienna University of Technology for some of these slides

Attacking the stack

We have seen how the stack works.

Now: let's see how we can abuse this.

We have already seen how malicious code can *deliberately* do "strange things" , and manipulate memory *anywhere* on the heap and stack.

Now: let's see how benign, but buggy code can be *manipulated* into doing strange things using malicious input

We'll use two techniques for this

1. buffer overflows
2. format strings attacks

Abusing the stack

Goals for an attacker

1. leaking data
2. corrupting data
3. corrupting program execution

   This can be

   3a) crashing

   3b) doing something more interesting

In CIA terminology: breaking

1. confidentiality of data
2. integrity of data
3. integrity of program execution
4. availability (if data is destroyed or program is crashed)

Format string attacks

Format strings attacks

- Format strings were discovered (invented?) in 2000
- They provide a way for an attacker to leak or corrupt memory.
- Not such a big problem as buffer overflows, as possibilities for format string attacks are easy to spot and remove
- Still, a great example of how some harmless looking code can turn out to be vulnerable, and exploitable by an attacker who supplies malicious input

Leaking data

```
int main( int argc,  char** argv)
    int pincode = 1234;
    printf(argv[1]);
}
```

This program echoes the first program argument.

Aside on **`main(int argc, char** argv)`**

`argc` is the numbers of arguments, **`argv`** are the argument values.

`argv` has type is a **`char**,`** so

`*argv` has type **`char*`** (ie a string)

`**argv` has type **`char`**

and using pointer arithmetic

`argv[i]` has type **`char*`**, ie a strings

`argv[i][j]` has type **`char`**,

so effectively **`argv`** is an array of strings, or a 2-dimensional array of **`char`**'s

Note

- **`argv[0]`** is the name of the executable,
  so **`argv[1]`** is the first real argument
- **`char** argv`** can also be written as **`char **argv`**

format strings for printf

```
printf( "j is %i.\n" , j);
     // %i to print integer value
printf( "j is %x in hex.\n" , j);
     // %x to print 4-byte hexadecimal value
```

"j is %i " is called a format string

Other printing functions, eg **snprintf**, also accept format strings.

Any guess what

```
    printf("j is %x in hex");
```

does**?**

It will print the top 4 bytes of the stack

Leaking data with format string attack

```
int main( int argc,  char** argv)
    int pincode = 1234;
    printf(argv[1]);
}
```

This program may leak information from the stack when given *malicious input*, namely an argument that contains *special control characters*, which are *interpreted* by **`printf`**

Eg supplying **`%x%x%x`** as input will dump top 12 bytes of the stack

Leaking data from memory

```
printf( ”j is %s.\n” , str);
     // %s to print a string, ie a char*
```

Any guess what

```
    printf(”j is %s in hex”);
```

does**?**

It will interpret the top of the stack as a pointer (an address)
and will print the string allocated in memory at that address

Of course, there might not be a string allocated at that address, and
printf simply prints whatever is in memory up to the next null terminator

Corrupting data with format string attack

```
int j;
char* msg; ...
printf( ”how long is %s anyway %n” , msg, &j);
```

%n causes the number of characters printed to be written to j,

here it will write **20+length(msg)**

Any guess what

```
printf(”how long is this %n”);
```

does**?**

It interprets the top of the stack as an address, and writes a value there

Example malicious format strings

Interesting inputs for the string **`str`** to attack **`printf(str)`**

- **%x%x%x%x%x%x%x%x**

  will print bytes from the top of the stack

- **%s**

  will interpret the top bytes of the stack as an address X, and then prints the string starting at that address A in memory, ie. it dumps all memory from A up to the next null terminator

- **%n**

  will interpret the top bytes of the stack as an address X, and then *writes* the number of characters output so far to that address

Example *really* malicious format strings

An attacker can try to control which address X is used for reading from memory using **%s** or for writing to memory using **%n** with specially crafted format strings of the form

- **\xEF\xCD\xCD\xAB %x %x ... %x %s**
  With the right number of **%x** characters, this will print the string located at address **ABCDCDEF**

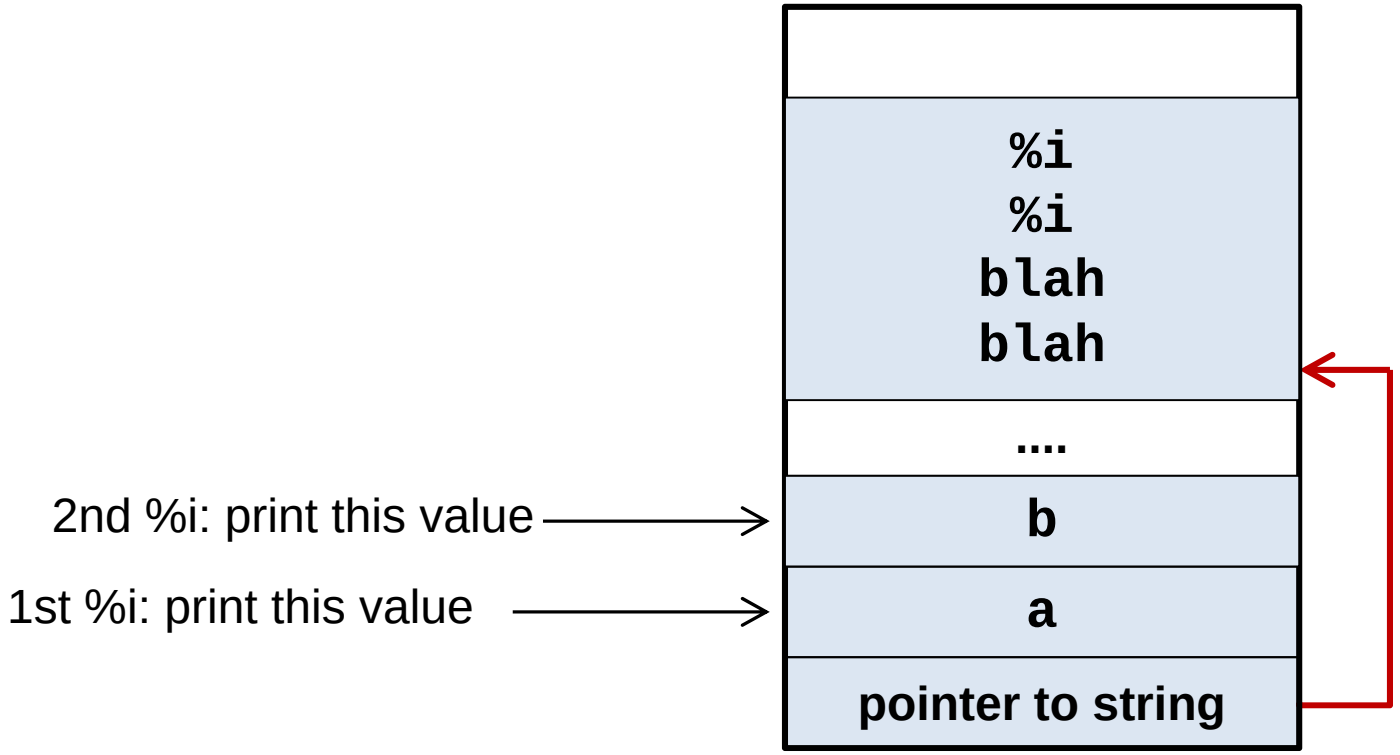
- **\xEF\xCD\xCD\xAB %x %x ... %x %n**
  With the right number of **%x** characters, this will write the number of characters printed so far to location **ABCDCDEF**

The tricky things are inserting the right number of **%x**, and choosing an interesting address

stack layout for printf

`printf(”blah blah %i %i”,  a, b)`

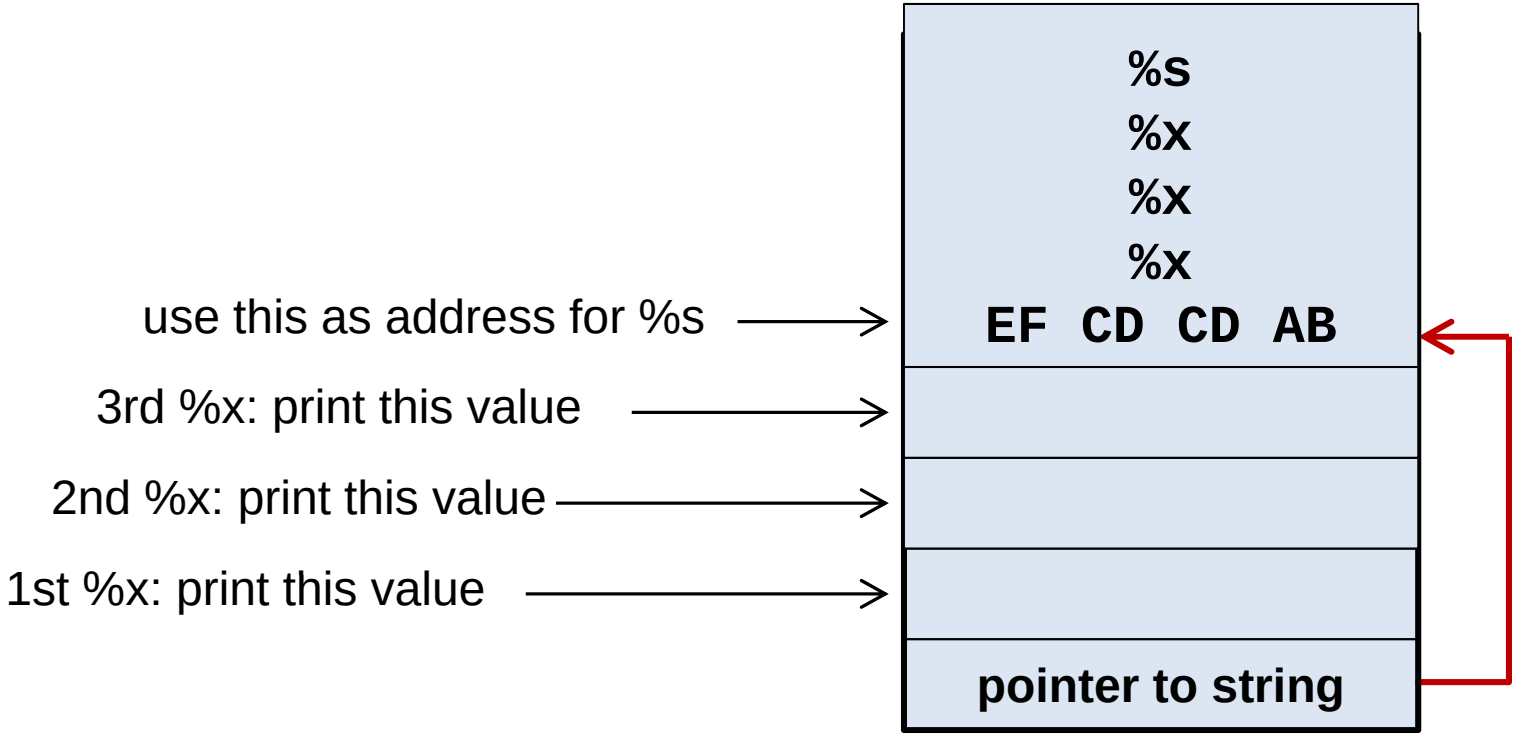
Recall: string is written upwards



stack layout for really malicious strings

`printf("\xEF\xCD\xCD\xAB %x %x  ... %x %s");`

With the right number of **%x** characters, this will print the string located at address **ABCDCDEF**



buffer overflows

Buffer overflows

It is easy to make mistakes using arrays or strings

- when using array indices we can go outside the array bounds,
  eg in

```
buffer[i]= c;
```

- when copying strings into arrays this can also happen

```
char buf[8];
sprintf(buf, ”password”);
// Does this fit?
// Not including the implicit null terminator!
```

Buffer overflows

```
void vulnerable(char *s){
 char msg[10] = "hello";
 char buffer[10];
 strcpy(buffer, s); // copy s into buffer
}

void main( int argc,  char** argv) {
  vulnerable(argv[1]);
        // argv[1] is first command line argument
}
```

What can go wrong here?

Buffer overflows to corrupt data or crash

By supplying a long argument, the buffer overflows, which can

- corrupt data

  `buffer` will overflow into other variables on the stack if is too long

- crash the program

  Why and when exactly does the program crash?

  The buffer overrun corrupts administration on the stack, esp.

  - the return address
  - the stored frame pointer

  Returning from **`vulnerable`** causes a segmentation fault if these values point to places outside the correct data segment.

Buffer overflow to change a program

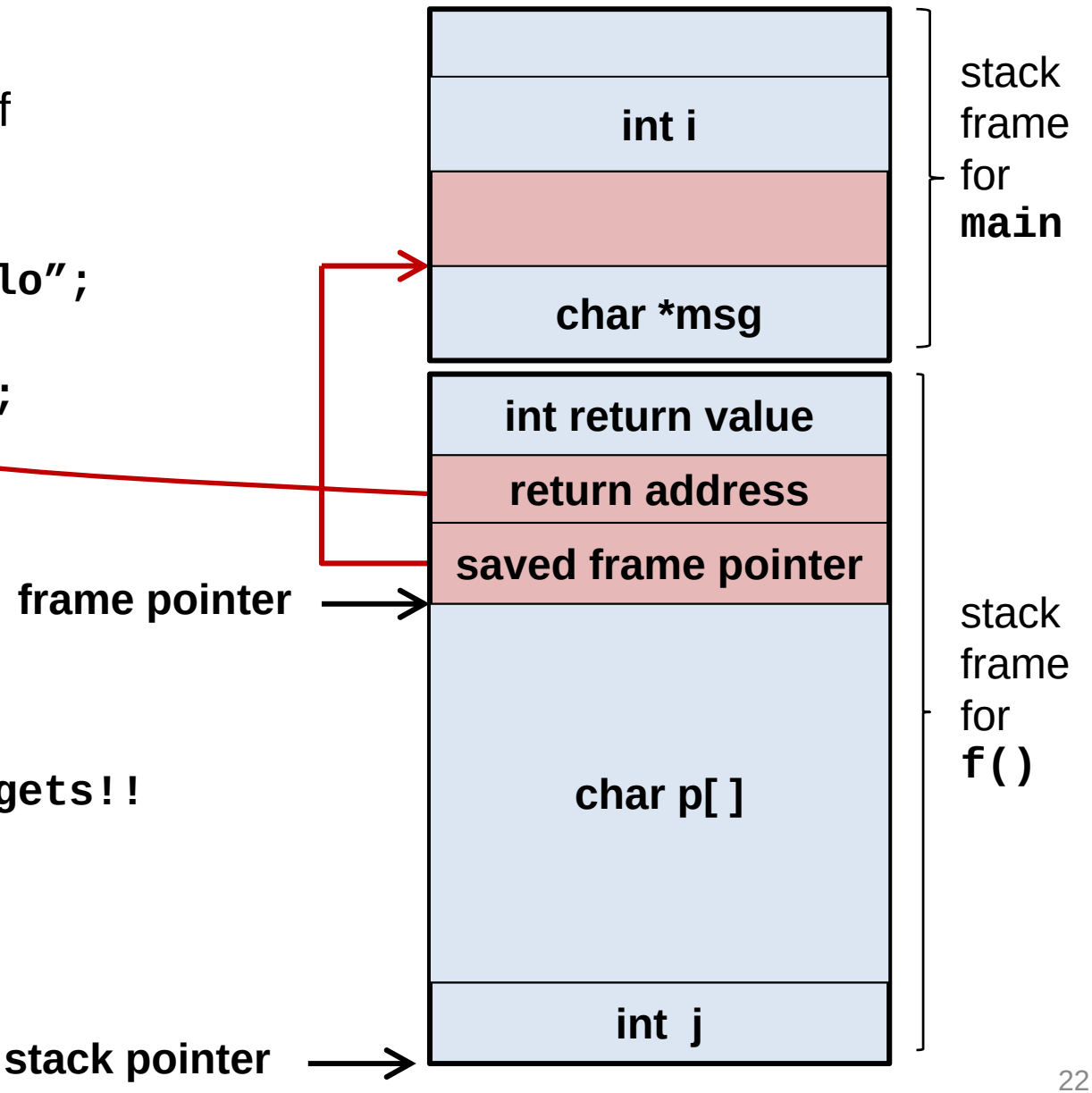
Can attacker do something more interesting than crashing?

Yes, supplying a value for ret which will do something interesting

recall: the stack

Stack during call to f

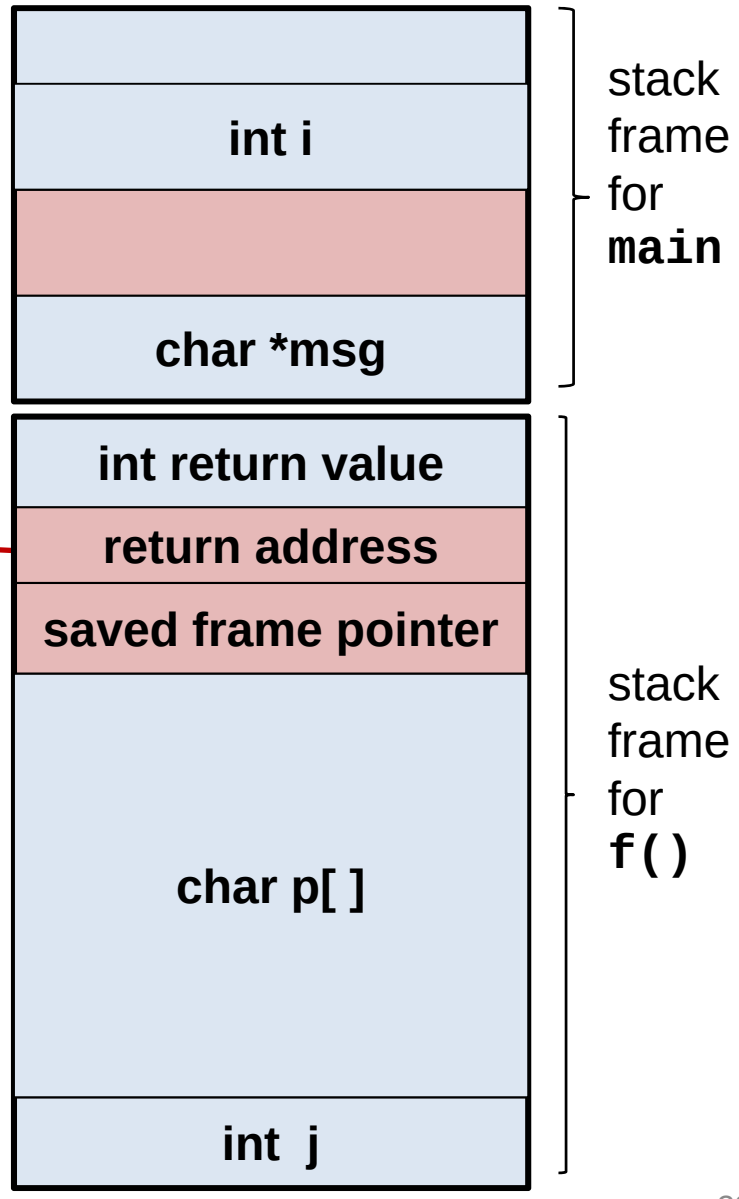
```
main(int i){
 char *msg =”hello”;
 f();
 print (“%i”, i);
}

int f(){
  char p[20];
  int j;
  gets(p);
   // NEVER USE gets!!
  return 1;
}
```



recall: the stack

Stack during call to f

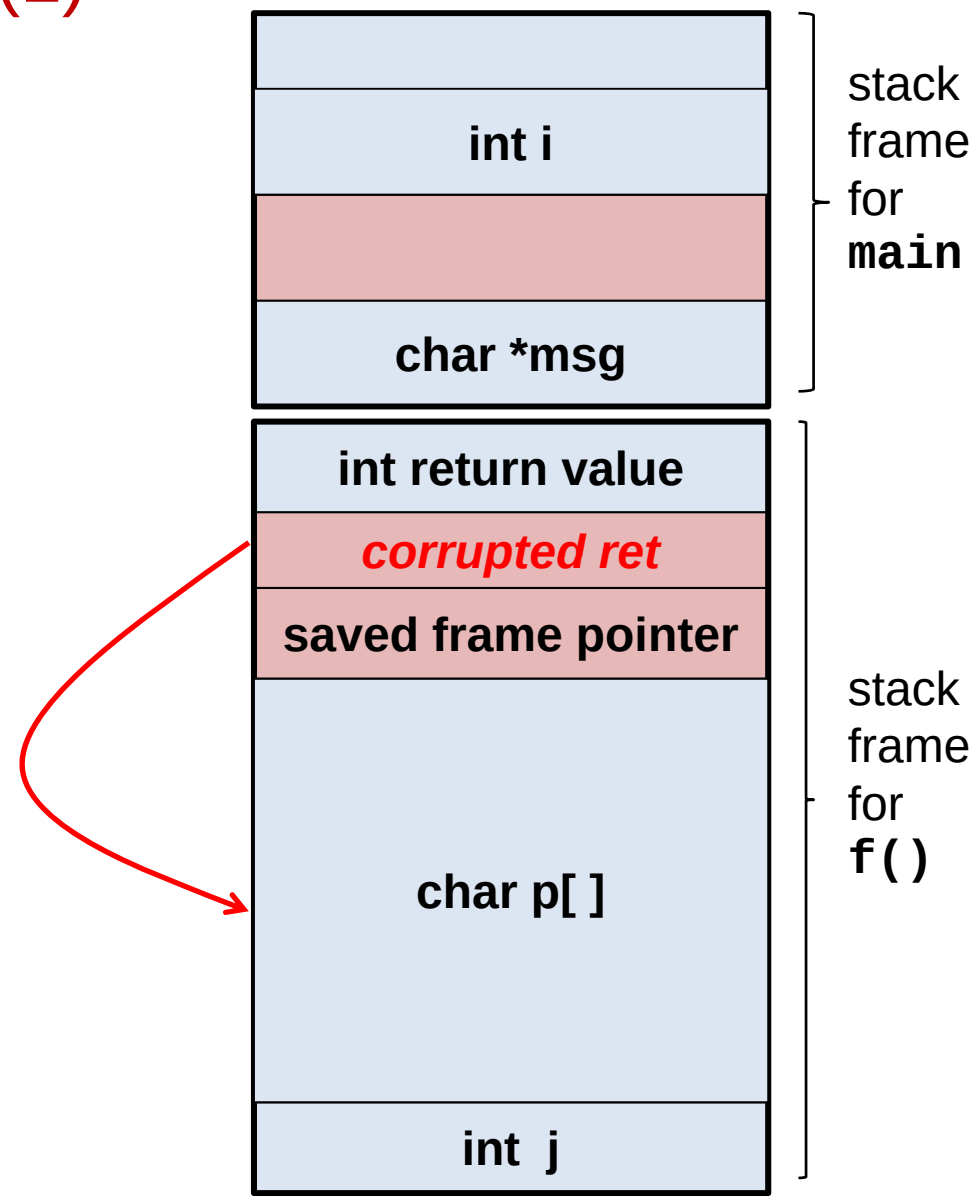
```
main(int i){
 char *msg =”hello”;
 f();
 print (“%i”, i);
}

int f(){
  char p[20];
  int j;
  gets(p);
   // NEVER USE gets!!
  return 1;
}
```



Corrupting the stack (1)

What if we overrun ***p*** *to set return address to point inside p?*

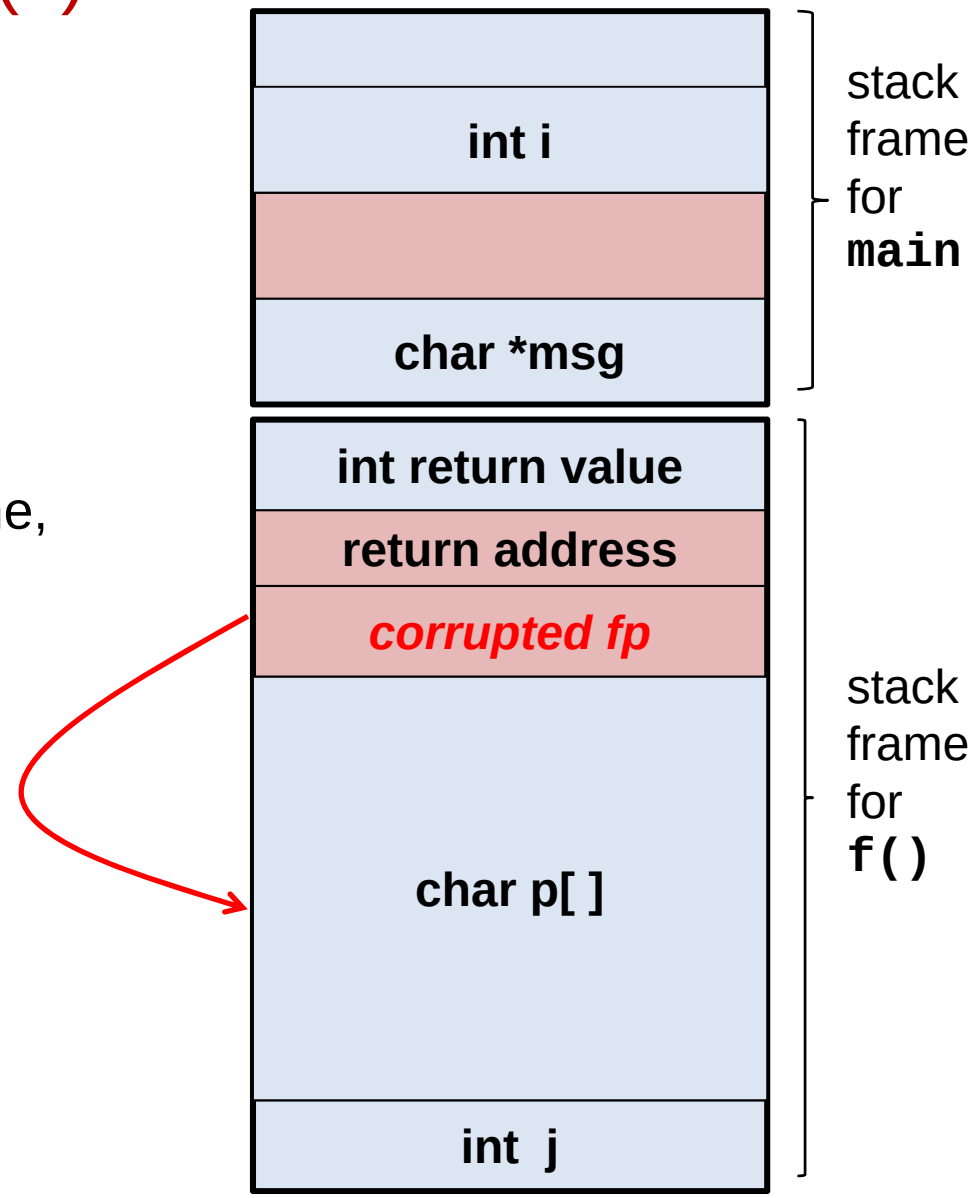
When **`f`** returns, execution will resume with what is written in **p**, interpreted as machine code



Corrupting the stack (2)

What if we overrun ***p***
to set save frame pointer
to point inside p?

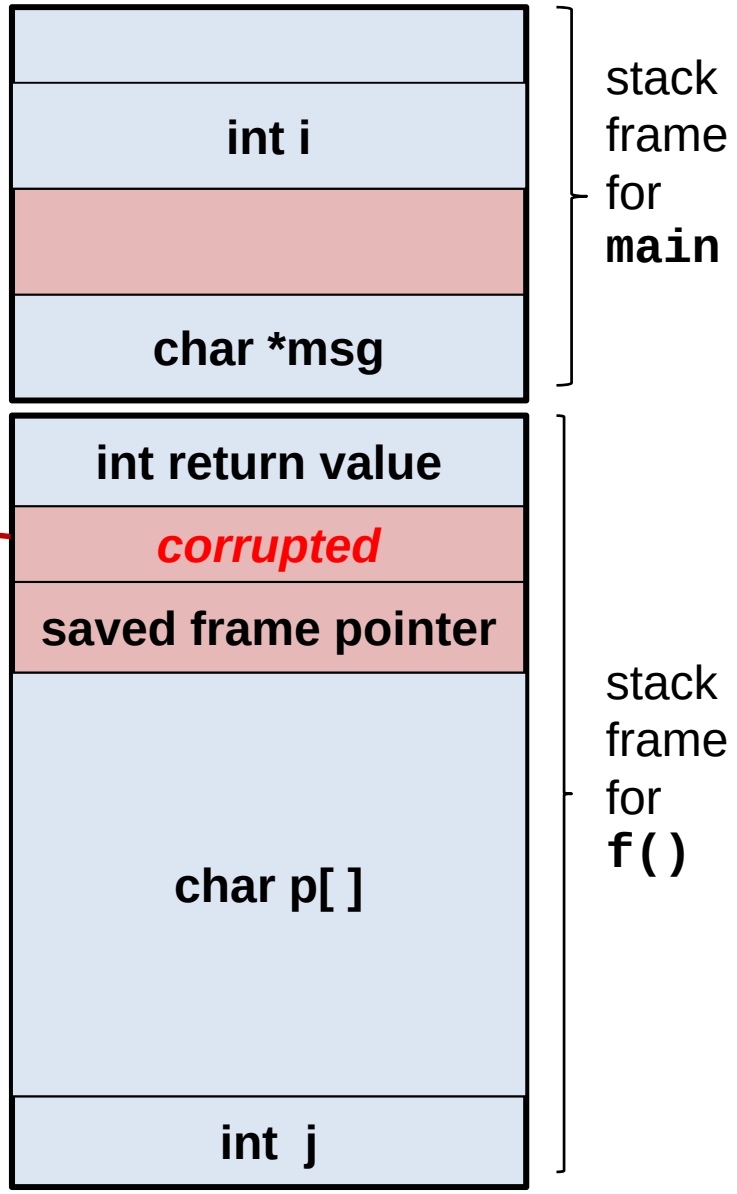
When **`f`** returns,
execution of **`main`** will resume,
but interpreting wrong part
of the stack as stack frame
for **`main`**



Corrupting the stack (3)

What if we overrun ***p***
and to set return address
to point to some existing code,
say inside a function ***g()****?*

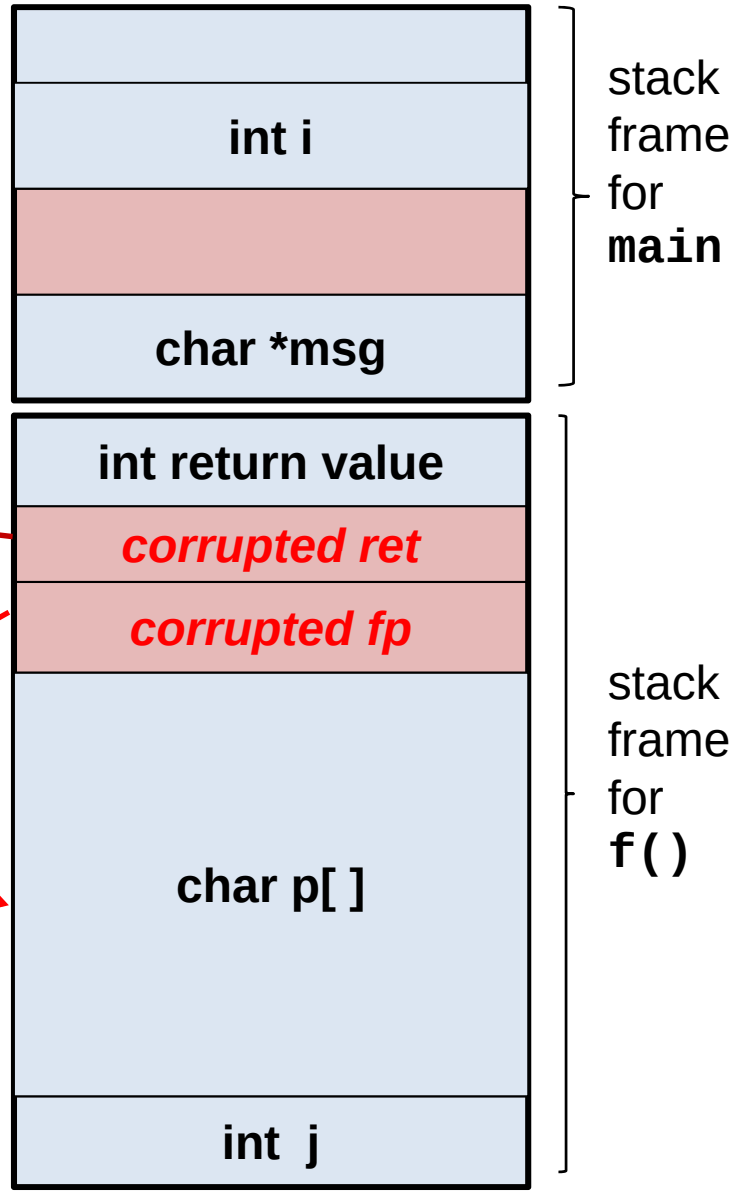
When **f** returns,
execution will resume
with executing **g** instead
of **main** and
interpreting **main**'s frame
as a stack frame for ***g***



Corrupting the stack (4)

What if we overrun ***p***
and to set return address
to point to some existing code,
say inside a function ***g(),***
and *to set save frame*
pointer to point inside p?

When **f** returns,
execution will resume
with executing **g** instead
of **main** and
interpreting stack starting
at **p** as a stack frame for ***g***



Buffer overflow to change a program

Can attacker do something more interesting than crashing?

Yes, supplying a value for ret which will do something interesting

There are two possibilities for the attacker:

1. jumping to his own attack code (aka shell code)

   The attacker writes some program code into a buffer,

   and sets the return address to point to this code

2. jumping to some existing code, but with malicious stack frame

   The attacker writes a fake stack frame into a buffer,

   and sets the return address to point to some existing code,

   and sets the saved frame pointer to point to this fake stack frame

NB lots of tricky details to get right!

pros & cons of where to jump

1. Jumping to own attack code (the original form of buffer overflow)
   - CON: the attacker needs to know the address of the buffer
   - CON: the memory page containing the buffer must be executable; on many modern systems the stack is not executable

2. Jumping to existing function inside the program with a manipulated stack frame
   - PRO: does not require an executable stack,or, access to executable memory somewhere else
   - CON: need to find the right code, and one or more fake frames must be put on the stack

   Often attacker will jump to functions in standard libc library, in so-called return-to-libc attack.

Both require the attacker to control the content of some buffers and corrupt the return address and frame pointer on the stack.

Other options on where to jump include using environment variables.

Shell code

Shell code

- If attacker manipulates the return address on the stack to jump to his own code, he needs some interesting code to jump to.

- This code is known as shell code. It is sequence of machine instructions that is executed when the attack is successful.
  - Traditionally, the goal was to spawn a shell, hence the name “shell code”)

- The actual attack will involve
  1. somehow getting this shell code somewhere in memory
  2. overwriting the return address on the stack to this place where the shell code is

- The attacker can then do practically anything, within the rights & permissions of the program that was attacked.

How to spawn a shell

```
void main(int argc, char **argv) {
   char *name[2];
   name[0] = “/bin/sh“;
   name[1] = NULL;

   execve(name[0], name, NULL);
}
```

How to spawn a shell

```
void main(int argc, char **argv) {
   char *name[2];
   name[0] = “/bin/sh“;
   name[1] = NULL;

   execve(name[0], name, NULL);
}
```

```
(gdb) disas execve
  ....
 mov    0x8(%ebp),%ebx
 mov    0xc(%ebp),%ecx
 mov    0x10(%ebp),%edx
 mov    $0xb,%eax
 int    $0x80
  ....
```

How to spawn a shell

```
int execve(char *file, char *argv[], char *env[])
```

```
(gdb) disas execve
  ....
 mov    0x8(%ebp),%ebx
 mov    0xc(%ebp),%ecx
 mov    0x10(%ebp),%edx
 mov    $0xb,%eax
 int    $0x80
  ....
```

copy **file* to ebx

copy **argv[]* to ecx

copy **env[]* to edx

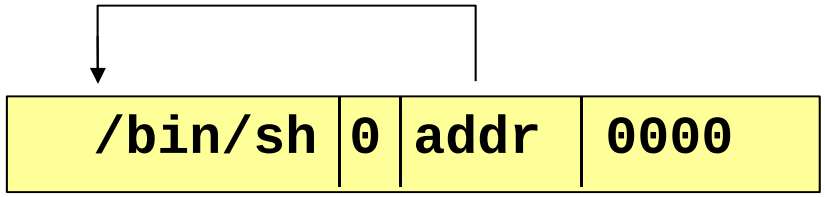
put the syscall number in eax
(execve is **0xb**)

invoke the syscall

How to spawn a shell

Three parameters are needed

- **`*file`**: put the zero-terminated string **`\bin\sh`** somewhere in memory
- **`*argv[]`**: put somewhere in memory the address of the string **`\bin\sh`** followed by NULL (0x00000000)
- **`*env[]`**: put somewhere in memory a NULL



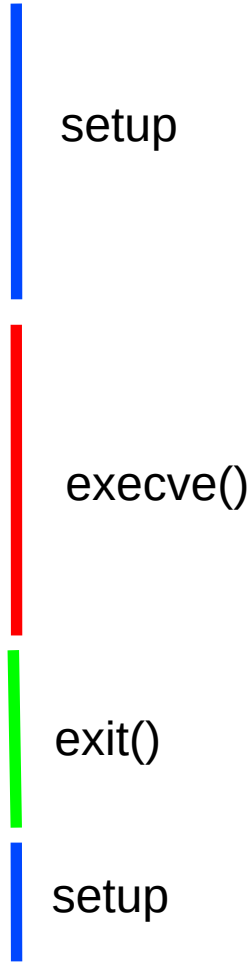
The address problem: where am I?

- How can we put in memory the address of the string **`\bin\sh`** if we do not even know where the position of the shellcode is?

- Solution...
  - the CALL instruction puts the return address on the stack
  - if we put a CALL instruction just before the string **`\bin\sh`**, when it is executed it will push the address of the string onto the stack

The Shellcode (almost ready)

```
jmp     0x26                    # 2 bytes
popl    %esi                    # 1 byte
movl    %esi,0x8(%esi)          # 3 bytes
movb    $0x0,0x7(%esi)          # 4 bytes
movl    $0x0,0xc(%esi)          # 7 bytes
movl    $0xb,%eax               # 5 bytes
movl    %esi,%ebx               # 2 bytes
leal    0x8(%esi),%ecx          # 3 bytes
leal    0xc(%esi),%edx          # 3 bytes
int     $0x80                   # 2 bytes
movl    $0x1, %eax              # 5 bytes
movl    $0x0, %ebx              # 5 bytes
int     $0x80                   # 2 bytes
call    -0x2b                   # 5 bytes
.string \"/bin/sh\"             # 8 bytes
```



The zeros problem

The shellcode is usually copied into a string buffer

```
char shellcode[] =
"\xeb\x2a\x5e\x89\x76\x08\xc6\x46\x07\x00\xc7\x46\x0c\x00\x00\x00
\x00\xb8\x0b\x00\x00\x00\x89\xf3\x8d\x4e\x08\x8d\x56\x0c\xcd\x80
\xb8\x01\x00\x00\x00\xbb\x00\x00\x00\x00\xcd\x80\xe8\xd1\xff\xff
\xff\x2f\x62\x69\x6e\x2f\x73\x68\x00\x89\xec\x5d\xc3";
```

- Problem: the null byte \x00 is the string terminator character
  which will stop any copying
- Solution: substitute any instruction containing zeros, with an alternative instruction

```
mov 0x0, reg --> xor reg, reg
mov 0x1, reg --> xor reg, reg
                 inc reg
```

The zeros problem

- Some tools provide this functionality automatically:
  e.g., **`msfencode`** (metasploit framework)

Jumping into the buffer

- The buffer that we are overflowing is usually a good place to put the code (shellcode) that we want to execute

- The buffer is somewhere on the stack, but in most cases the exact address is unknown
  - the address must be precise: jumping one byte before or after would just make the application crash
  - on the local system it is possible to calculate the address with a debugger, but it is very unlikely to be the same address on a different machine
  - any change to the environment variables affect the stack position

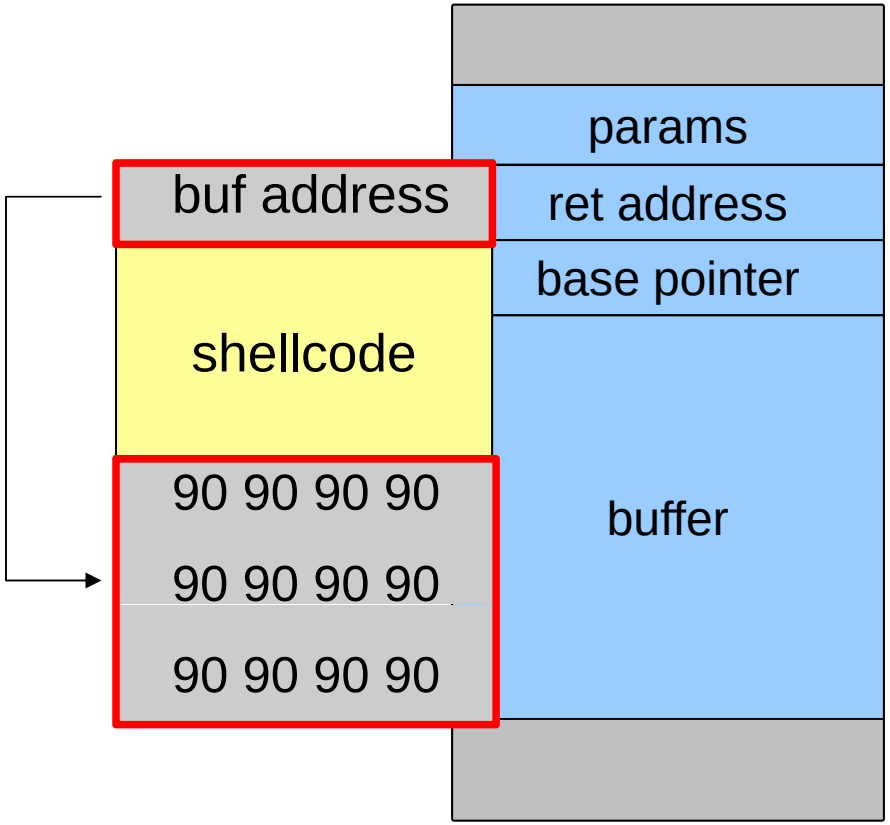
Solution 1: the NOP sled

- A sled is a “landing area” that is put in front of the shellcode
- Must be created in a way such that wherever the program jump into it..
  - .. it always finds a valid instruction
  - .. it always reaches the end of the sled and the beginning of the shellcode

- The simplest sled is a sequence of no operation (NOP) instructions
  - Single byte instruction (0x90) that does not do anything

- It mitigates the problem of finding the exact address to the buffer by increasing the size of the target area

Assembling the malicious buffer



Solution 2: jump using a register

- Find a register that points to the buffer (or somewhere into it)
  - ESP
  - EAX (return value of a function call)
- Locate an instruction that jumps/calls using that register
  - can also be in one of the libraries
  - does not even need to be a real instruction, just look for the right sequence of bytes
- Overwrite the return address with the address of that instruction

Recap

Recap

An attacker feeding malicious input to insecure code can

1. leak data
2. corrupt data
3. change program execution entirely

This can happen due to buffer overflows or format string attacks

When using buffer overflows to change program behaviour
an attacker can

1. inject his own code or
2. jump to existing code with a fake stack frame

More general trends

Format string problems are easy to fix,

eg replacing **`printf(msg)`**

by **`printf("%s", msg)`**

(for all functions of the **`*printf`** family!)

and are then no longer a threat.

Still, they are a representative of many examples where some small feature in one function can be a source of security vulnerabilities

- Such vulnerabilities typically involve *special characters* which are *interpreted* in a special way at runtime
- Note that this means that such characters are effectively more like *program code* than just *data*

Common theme: mixing channels

Remember phone phreaking!

The root cause of the problem there was:

signals to control the telephone switchboards (beeps at certain frequencies) are sent over the same channel as untrusted user data (the phone calls) .

This allowed the user to interfere with control of the phone network

Here we see the same issue:

control data for program execution is stored in the same place (namely, the stack) as user data, which introduces the possibility for the user to interfere with program execution