CSE 410/510 Special Topics: Software Security

Instructor: Dr. Ziming Zhao

Location: Norton 218
Time: Monday, 5:00 PM - 7:50 PM

HW-1 & HW-2

Why are there instructions after RET? Use *add64* as an example

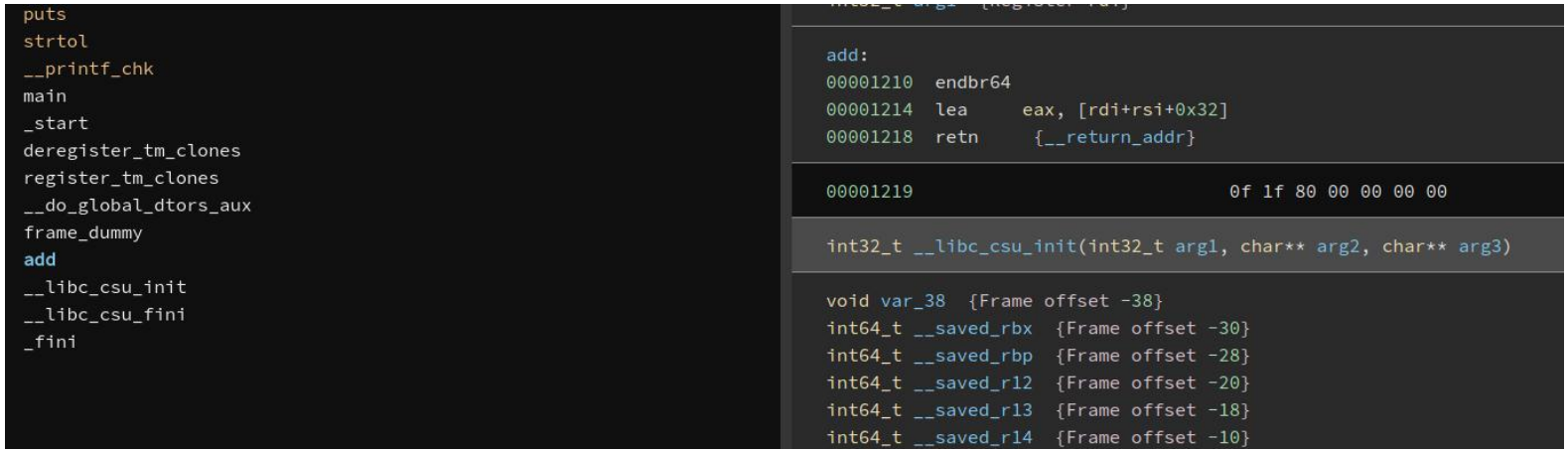
```
0000000000001210 <add>:
    1210:       f3 0f 1e fa             endbr64
    1214:       8d 44 37 32             lea    0x32(%rdi,%rsi,1),%eax
    1218:       c3                      retq
    1219:       0f 1f 80 00 00 00 00    nopl   0x0(%rax)
```

Objdump is a static disassembly tool, it uses an approach named linear disassembly.

It iterates through all code segments in a binary, decoding all bytes consecutively and parsing them into a list of instructions.

HW-1 & HW-2

Why are there instructions after RET? Use *add64* as an example



BinaryNinja uses recursive disassembly, which considers the control flow.

Last Class

1. Background knowledge
    a. Compiler, linker, loader
    b. x86 and x86-64 architectures and ISA
    c. Linux file permissions
    d. Set-UID programs
    e. Memory map of a Linux process
    f. System calls
    g. Environment and Shell variables
    h. Basic reverse engineering

This Class

1. ELF Files
    a. Executable Header
    b. Section and Section Headers
    c. Lazy Binding
    d. Program Headers

This Class

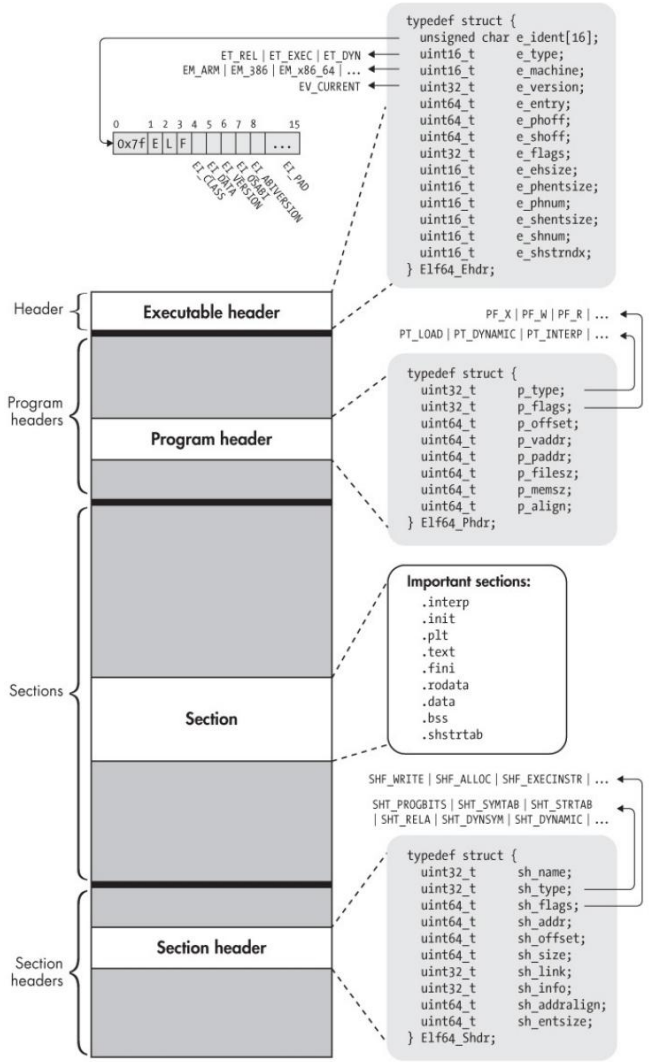
2. Stack-based buffer overflow (Sequential buffer overflow)
    a. Brief history of buffer overflow
    b. Information C function needs to run
    c. C calling conventions (x86, x86-64)
    d. Overflow local variables
    e. Overflow RET address to execute a function
    f. Overflow RET and more to execute a function with parameters

Executable and Linkable Format (ELF)

ELF Files

The **Executable** and **Linkable Format** (**ELF**) is a common standard file format for *executable files*, *object code*, *shared libraries*, and *core dumps*. Filename extension *none*, .*axf*, .*bin*, .*elf*, .*o*, .*prx*, .*puff*, .*ko*, .*mod* and .*so*

Contains the program and its data. Describes how the program should be loaded (program/segment headers). Contains metadata describing program components (section headers).



- Executable (a.out), object files (.o), shared libraries (.a), even core dumps.
- Four *types* of components: an **executable header**, a series of (optional) **program headers**, a number of **sections**, and a series of (optional) **section headers**, one per section.

Executable Header

```
typedef struct {
  unsigned char e_ident[16];   /* Magic number and other info     */ 0x7F ELF ..
  uint16_t      e_type;        /* Object file type                */ Executable, obj, dynamic lib
  uint16_t      e_machine;     /* Architecture                    */ x86-64, Arm
  uint32_t      e_version;     /* Object file version             */
  uint64_t      e_entry;       /* Entry point virtual address     */
  uint64_t      e_phoff;       /* Program header table file offset */
  uint64_t      e_shoff;       /* Section header table file offset */
  uint32_t      e_flags;       /* Processor-specific flags        */
  uint16_t      e_ehsize;      /* ELF header size in bytes        */
  uint16_t      e_phentsize;   /* Program header table entry size  */
  uint16_t      e_phnum;       /* Program header table entry count */
  uint16_t      e_shentsize;   /* Section header table entry size  */
  uint16_t      e_shnum;       /* Section header table entry count */
  uint16_t      e_shstrndx;    /* Section header string table index*/
} Elf64_Ehdr;
```

readelf -h a.out

```
➜  add readelf -h /bin/ls
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
  Class:                             ELF64
  Data:                              2's complement, little endian
  Version:                           1 (current)
  OS/ABI:                            UNIX - System V
  ABI Version:                       0
  Type:                              DYN (Shared object file)
  Machine:                           Advanced Micro Devices X86-64
  Version:                           0x1
  Entry point address:               0x67d0
  Start of program headers:          64 (bytes into file)
  Start of section headers:          140224 (bytes into file)
  Flags:                             0x0
  Size of this header:               64 (bytes)
  Size of program headers:           56 (bytes)
  Number of program headers:         13
  Size of section headers:           64 (bytes)
  Number of section headers:         30
  Section header string table index: 29
```

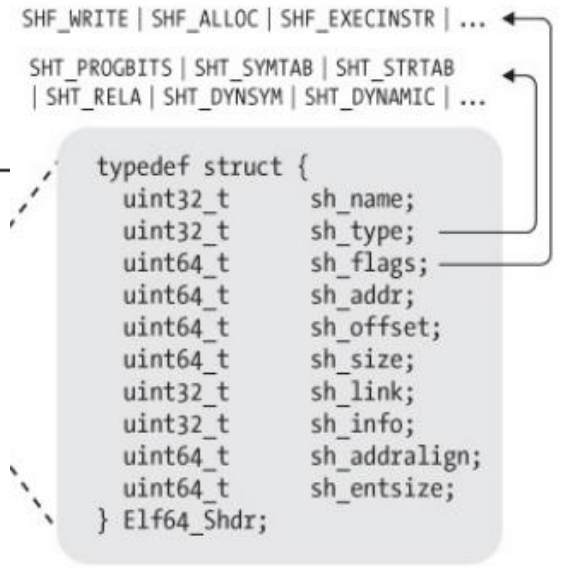
Sections

The code and data in an ELF binary are logically divided into contiguous non-overlapping chunks called sections. The structure of each section varies depending on the contents.

The division into sections is intended to provide a convenient organization for use by the ***linker***.

Section Header Format

```
typedef struct {
  uint32_t  sh_name;      /* Section name (string tbl index)   */
  uint32_t  sh_type;      /* Section type                      */
  uint64_t  sh_flags;     /* Section flags                     */
  uint64_t  sh_addr;      /* Section virtual addr at execution */
  uint64_t  sh_offset;    /* Section file offset               */
  uint64_t  sh_size;      /* Section size in bytes             */
  uint32_t  sh_link;      /* Link to another section           */
  uint32_t  sh_info;      /* Additional section information    */
  uint64_t  sh_addralign; /* Section alignment                 */
  uint64_t  sh_entsize;   /* Entry size if section holds table */
} Elf64_Shdr;
```



Each section is described by its section header.

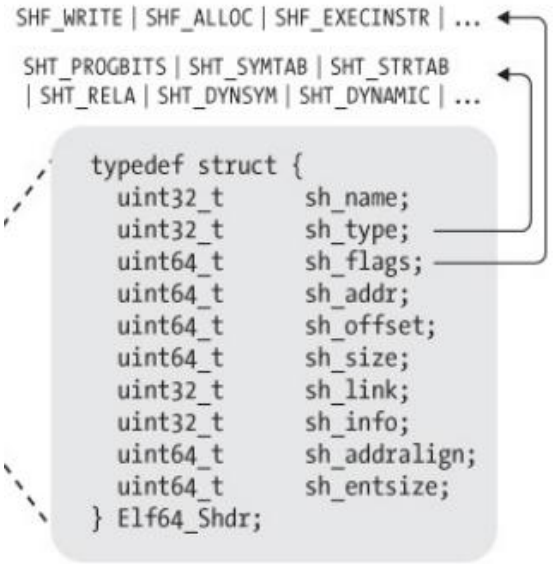
```
readelf -S a.out
```

sh_flags

SHF_WRITE: the section is writable at runtime.

SHF_ALLOC: the contents of the section are to be loaded into virtual memory when executing the binary.

SHF_EXECINSTR: the section contains executable instructions.



```
➜ add readelf -S add
There are 31 section headers, starting at offset 0x385c:

Section Headers:
  [Nr] Name              Type            Addr     Off    Size   ES Flg Lk Inf Al
  [ 0]                   NULL            00000000 000000 000000 00      0   0  0
  [ 1] .interp           PROGBITS        000001b4 0001b4 000013 00   A  0   0  1
  [ 2] .note.gnu.build-i NOTE            000001c8 0001c8 000024 00   A  0   0  4
  [ 3] .note.gnu.propert NOTE            000001ec 0001ec 00001c 00   A  0   0  4
  [ 4] .note.ABI-tag     NOTE            00000208 000208 000020 00   A  0   0  4
  [ 5] .gnu.hash         GNU_HASH        00000228 000228 000020 04   A  6   0  4
  [ 6] .dynsym           DYNSYM          00000248 000248 0000a0 10   A  7   1  4
  [ 7] .dynstr           STRTAB          000002e8 0002e8 0000bb 00   A  0   0  1
  [ 8] .gnu.version      VERSYM          000003a4 0003a4 000014 02   A  6   0  2
  [ 9] .gnu.version_r    VERNEED         000003b8 0003b8 000040 00   A  7   1  4
  [10] .rel.dyn          REL             000003f8 0003f8 000040 08   A  6   0  4
  [11] .rel.plt          REL             00000438 000438 000020 08  AI  6  24  4
  [12] .init             PROGBITS        00001000 001000 000024 00  AX  0   0  4
  [13] .plt              PROGBITS        00001030 001030 000050 04  AX  0   0 16
  [14] .plt.got          PROGBITS        00001080 001080 000010 10  AX  0   0 16
  [15] .plt.sec          PROGBITS        00001090 001090 000040 10  AX  0   0 16
  [16] .text             PROGBITS        000010d0 0010d0 000259 00  AX  0   0 16
  [17] .fini             PROGBITS        0000132c 00132c 000018 00  AX  0   0  4
  [18] .rodata           PROGBITS        00002000 002000 000025 00   A  0   0  4
  [19] .eh_frame_hdr     PROGBITS        00002028 002028 000054 00   A  0   0  4
  [20] .eh_frame         PROGBITS        0000207c 00207c 00014c 00   A  0   0  4
  [21] .init_array       INIT_ARRAY      00003ed0 002ed0 000004 04  WA  0   0  4
  [22] .fini_array       FINI_ARRAY      00003ed4 002ed4 000004 04  WA  0   0  4
  [23] .dynamic          DYNAMIC         00003ed8 002ed8 0000f8 08  WA  7   0  4
  [24] .got              PROGBITS        00003fd0 002fd0 000030 04  WA  0   0  4
  [25] .data             PROGBITS        00004000 003000 000008 00  WA  0   0  4
  [26] .bss              NOBITS          00004008 003008 000004 00  WA  0   0  1
  [27] .comment          PROGBITS        00000000 003008 00002a 01  MS  0   0  1
  [28] .symtab           SYMTAB          00000000 003034 000490 10     29  47  4
  [29] .strtab           STRTAB          00000000 0034c4 00027d 00      0   0  1
  [30] .shstrtab         STRTAB          00000000 003741 000118 00      0   0  1
Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), I (info),
  L (link order), O (extra OS processing required), G (group), T (TLS),
  C (compressed), x (unknown), o (OS specific), E (exclude),
  p (processor specific)
```

readelf -S a.out

Sections

.init: executable code that performs initialization tasks and needs to run before any other code in the binary is executed.

.fini: code that runs after the main program completes.

.text: where the main code of the program resides.

Sections

.rodata section, which stands for “read-only data,” is dedicated to storing constant values. Because it stores constant values, .rodata is not writable.

The default values of initialized variables are stored in the .data section, which is marked as writable since the values of variables may change at runtime.

the .bss section reserves space for uninitialized variables. The name historically stands for “block started by symbol,” referring to the reserving of blocks of memory for (symbolic) variables.

Lazy Binding (.plt, .got, .got.plt Sections)

Binding at Load Time: When a binary is loaded into a process for execution, the dynamic linker resolves references to functions located in shared libraries. The addresses of shared functions were not known at compile time.

In reality - Lazy Binding: many of the relocations are typically not done right away when the binary is loaded but are deferred until the first reference to the unresolved location is actually made.

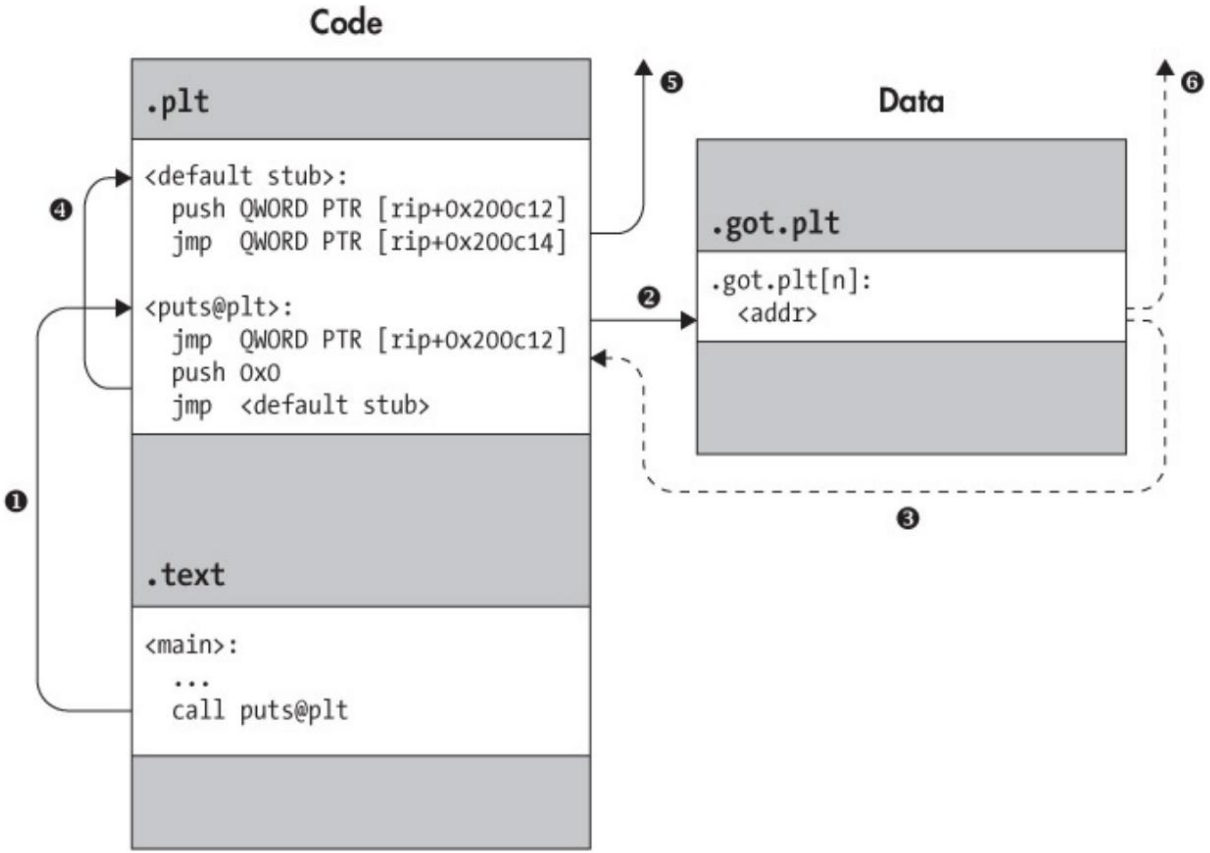
Lazy Binding (.plt, .got, .got.plt Sections)

Lazy binding in Linux ELF binaries is implemented with the help of two special sections, called the Procedure Linkage Table (.plt) and the Global Offset Table (.got).

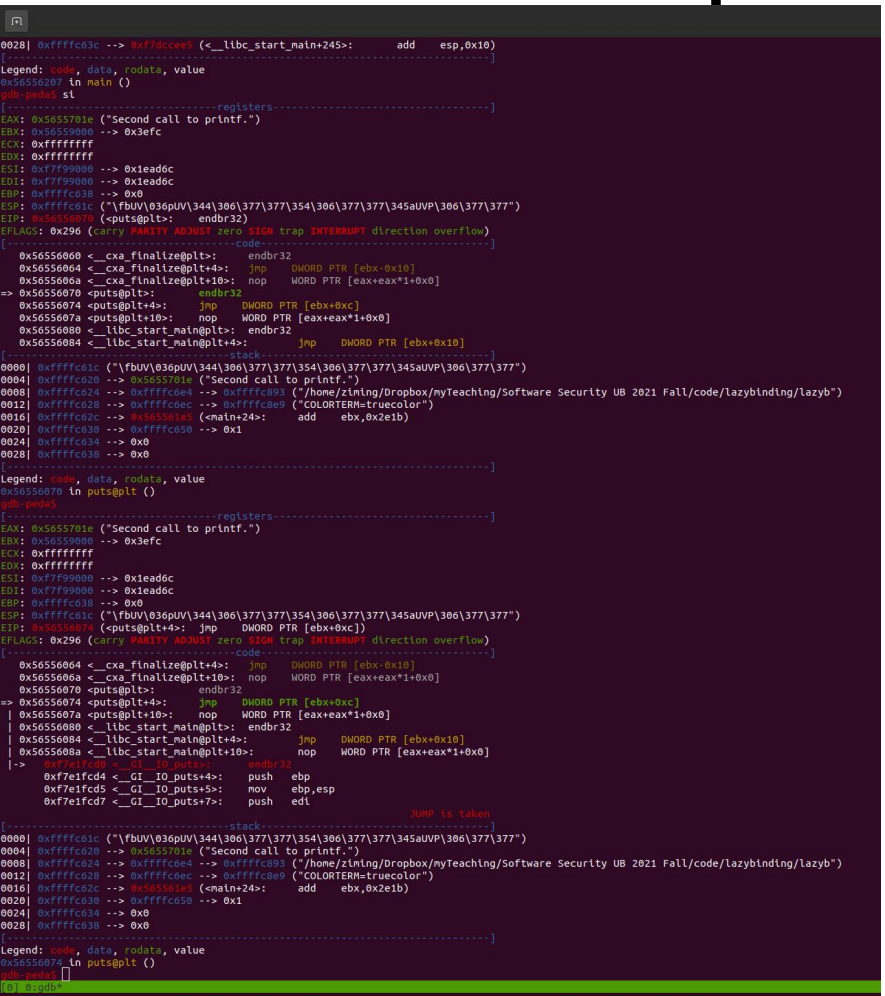
.plt is a code section that contains executable code. The PLT consists entirely of stubs of a well-defined format, dedicated to directing calls from the .text section to the appropriate library location.

.got.plt is a data section.

Dynamically Resolving a Library Function Using the PLT



Example: Debug code\lazyb



GDB Cheatsheet:

https://darkdust.net/files/GDB%20Cheat%20Sheet.pdf

Section View (Section Header)
vs.
Segment View (Program Header)

The program header table provides a segment view of the binary, as opposed to the section view provided by the section header table.

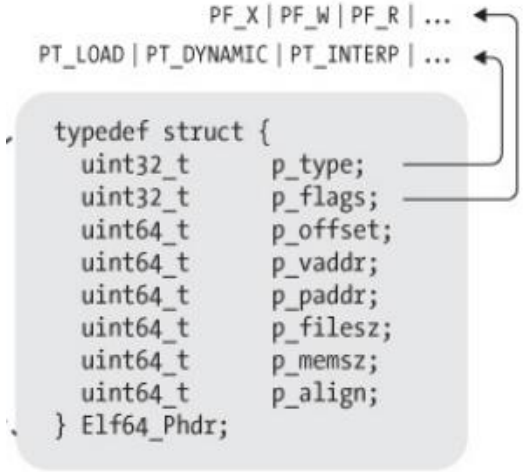
The section view of an ELF binary is meant for static linking purposes.

The segment view is used by the operating system and dynamic linker when loading an ELF into a process for execution to locate the relevant code and data and decide what to load into virtual memory.

Segments are simply a bunch of sections bundled together.

Program Header Format

```
typedef struct {
  uint32_t  p_type;   /* Segment type              */
  uint32_t  p_flags;  /* Segment flags             */
  uint64_t  p_offset; /* Segment file offset       */
  uint64_t  p_vaddr;  /* Segment virtual address   */
  uint64_t  p_paddr;  /* Segment physical address  */
  uint64_t  p_filesz; /* Segment size in file      */
  uint64_t  p_memsz;  /* Segment size in memory    */
  uint64_t  p_align;  /* Segment alignment         */
} Elf64_Phdr;
```



Each section is described by its section header.

```
readelf -l a.out
```

```
➜ add readelf -l add

Elf file type is DYN (Shared object file)
Entry point 0x1160
There are 12 program headers, starting at offset 52

Program Headers:
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  PHDR           0x000034 0x00000034 0x00000034 0x00180 0x00180 R   0x4
  INTERP         0x0001b4 0x000001b4 0x000001b4 0x00013 0x00013 R   0x1
      [Requesting program interpreter: /lib/ld-linux.so.2]
  LOAD           0x000000 0x00000000 0x00000000 0x00458 0x00458 R   0x1000
  LOAD           0x001000 0x00001000 0x00001000 0x00344 0x00344 R E 0x1000
  LOAD           0x002000 0x00002000 0x00002000 0x001c8 0x001c8 R   0x1000
  LOAD           0x002ed0 0x00003ed0 0x00003ed0 0x00138 0x0013c RW  0x1000
  DYNAMIC        0x002ed8 0x00003ed8 0x00003ed8 0x000f8 0x000f8 RW  0x4
  NOTE           0x0001c8 0x000001c8 0x000001c8 0x00060 0x00060 R   0x4
  GNU_PROPERTY   0x0001ec 0x000001ec 0x000001ec 0x0001c 0x0001c R   0x4
  GNU_EH_FRAME   0x002028 0x00002028 0x00002028 0x00054 0x00054 R   0x4
  GNU_STACK      0x000000 0x00000000 0x00000000 0x00000 0x00000 RW  0x10
  GNU_RELRO      0x002ed0 0x00003ed0 0x00003ed0 0x00130 0x00130 R   0x1

 Section to Segment mapping:
  Segment Sections...
   00
   01     .interp
   02     .interp .note.gnu.build-id .note.gnu.property .note.ABI-tag .gnu.hash .dynsym .dynstr .gnu.version .gnu.version_r .rel.dyn .rel.plt
   03     .init .plt .plt.got .plt.sec .text .fini
   04     .rodata .eh_frame_hdr .eh_frame
   05     .init_array .fini_array .dynamic .got .data .bss
   06     .dynamic
   07     .note.gnu.build-id .note.gnu.property .note.ABI-tag
   08     .note.gnu.property
   09     .eh_frame_hdr
   10
   11     .init_array .fini_array .dynamic .got
➜ add
[0] 0:zsh*
```

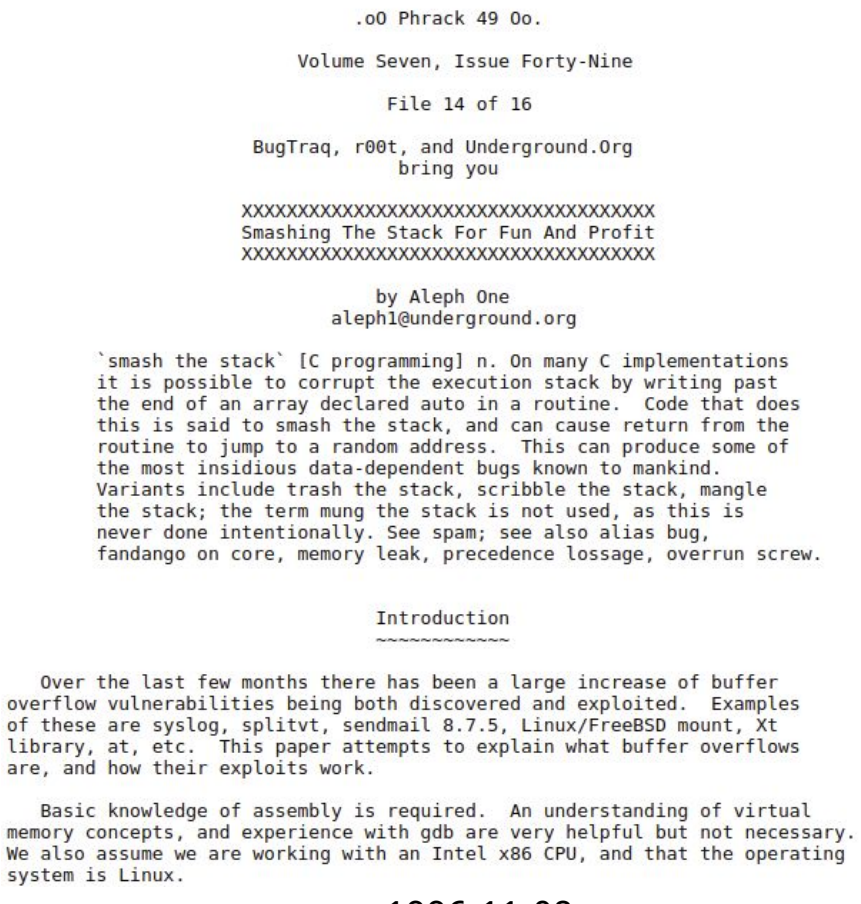
Stack-based Buffer Overflow

Objectives

1. Understand how stack works in Linux x86/amd64
2. Identify a buffer overflow in a program
3. Exploit a buffer overflow vulnerability

An Extremely Brief History of Buffer Overflow

The Morris worm (November 9, 1988), was one of the first computer worms distributed via the Internet, and the first to gain significant mainstream media attention. Morris worn used buffer overflow as one of its attack techniques.



.oO Phrack 49 Oo.

Volume Seven, Issue Forty-Nine

File 14 of 16

BugTraq, r00t, and Underground.Org
bring you

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Smashing The Stack For Fun And Profit
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

by Aleph One
aleph1@underground.org

`smash the stack` [C programming] n. On many C implementations it is possible to corrupt the execution stack by writing past the end of an array declared auto in a routine. Code that does this is said to smash the stack, and can cause return from the routine to jump to a random address. This can produce some of the most insidious data-dependent bugs known to mankind. Variants include trash the stack, scribble the stack, mangle the stack; the term mung the stack is not used, as this is never done intentionally. See spam; see also alias bug, fandango on core, memory leak, precedence lossage, overrun screw.

Introduction
~~~~~~~~~~~~

Over the last few months there has been a large increase of buffer overflow vulnerabilities being both discovered and exploited. Examples of these are syslog, splitvt, sendmail 8.7.5, Linux/FreeBSD mount, Xt library, at, etc. This paper attempts to explain what buffer overflows are, and how their exploits work.

Basic knowledge of assembly is required. An understanding of virtual memory concepts, and experience with gdb are very helpful but not necessary. We also assume we are working with an Intel x86 CPU, and that the operating system is Linux.

1996-11-08
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The CWE Top 25

2019 CWE Top 25, including the overall score of each.

Rank	ID	Name	Score
[1]	CWE-119	Improper Restriction of Operations within the Bounds of a Memory Buffer	75.56
[2]	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')	45.69
[3]	CWE-20	Improper Input Validation	43.61
[4]	CWE-200	Information Exposure	32.12
[5]	CWE-125	Out-of-bounds Read	26.53
[6]	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')	24.54
[7]	CWE-416	Use After Free	17.94
[8]	CWE-190	Integer Overflow or Wraparound	17.35
[9]	CWE-352	Cross-Site Request Forgery (CSRF)	15.54
[10]	CWE-22	Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')	14.10
[11]	CWE-78	Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')	11.47
[12]	CWE-787	Out-of-bounds Write	11.08
[13]	CWE-287	Improper Authentication	10.78
[14]	CWE-476	NULL Pointer Dereference	9.74
[15]	CWE-732	Incorrect Permission Assignment for Critical Resource	6.33
[16]	CWE-434	Unrestricted Upload of File with Dangerous Type	5.50
[17]	CWE-611	Improper Restriction of XML External Entity Reference	5.48
[18]	CWE-94	Improper Control of Generation of Code ('Code Injection')	5.36
[19]	CWE-798	Use of Hard-coded Credentials	5.12
[20]	CWE-400	Uncontrolled Resource Consumption	5.04
[21]	CWE-772	Missing Release of Resource after Effective Lifetime	5.04
[22]	CWE-426	Untrusted Search Path	4.40
[23]	CWE-502	Deserialization of Untrusted Data	4.30
[24]	CWE-269	Improper Privilege Management	4.23
[25]	CWE-295	Improper Certificate Validation	4.06

C/C++ Function in x86

What information do we need to call a function at runtime? Where are they stored?

- Code
- Parameters
- Return value
- Global variables
- Local variables
- Temporary variables
- Return address
- Function frame pointer
- Previous function Frame pointer

Global and Local Variables in C/C++

Variables that are declared inside a function or block are called **local variables**. They can be used only by statements that are inside that function or block of code. Local variables are not known to functions outside their own.

Global variables are defined outside a function. Global variables hold their values throughout the lifetime of your program and they can be accessed inside any of the functions defined for the program.

In the definition of function parameters which are called **formal parameters**. Formal parameters are similar to local variables.

Global and Local Variables (code/globallocalv)

```
char g_i[] = "I am an initialized global variable\n";
char* g_u;

int func(int p)
{
  int l_i = 10;
  int l_u;

  printf("l_i in func() is at %p\n", &l_i);
  printf("l_u in func() is at %p\n", &l_u);
  printf("p in func() is at %p\n", &p);
  return 0;
}
```

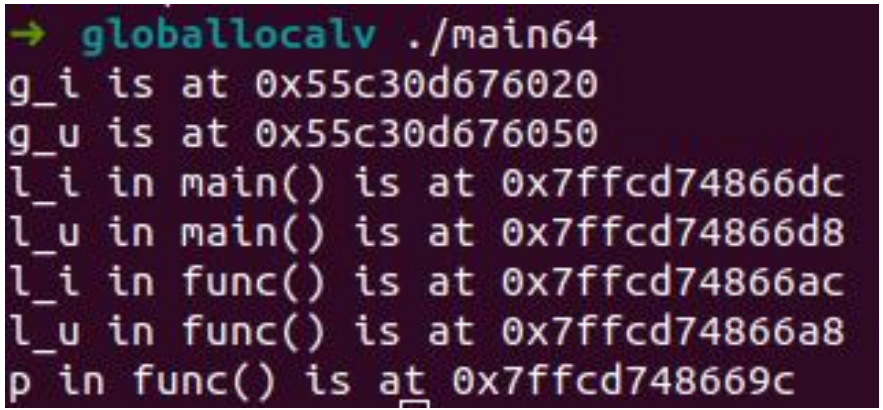
```
int main(int argc, char *argv[])
{
  int l_i = 10;
  int l_u;

  printf("g_i is at %p\n", &g_i);
  printf("g_u is at %p\n", &g_u);

  printf("l_i in main() is at %p\n", &l_i);
  printf("l_u in main() is at %p\n", &l_u);

  func(10);
}
```

Tools: readelf; nm

Global and Local Variables (code/globallocalv 32bit)

```
ziming@ziming-ThinkPad:~/Dropbox/my
g_i is at 0x56558020
g_u is at 0x5655804c
l_i in main() is at 0xfff7c6d4
l_u in main() is at 0xfff7c6d8
l_i in func() is at 0xfff7c6a4
l_u in func() is at 0xfff7c6a8
p in func() is at 0xfff7c6c0
```

Global and Local Variables (code/globallocalv 64bit)



C/C++ Function in x86/64

What information do we need to call a function at runtime? Where are they stored?

- Code [.text]
- Parameters [mainly stack (32bit); registers + stack (64bit)]
- Return value [%eax, %rax]
- Global variables [.bss, .data]
- Local variables [stack; registers]
- Temporary variables [stack; registers]
- Return address [stack]
- Function frame pointer [%ebp, %rbp]
- Previous function Frame pointer [stack]

Stack

Stack is essentially scratch memory for functions

- Used in MIPS, ARM, x86, and x86-64 processors

Starts at high memory addresses, and grows down

Functions are free to push registers or values onto the stack, or pop values from the stack into registers

The assembly language supports this on x86

- **%esp/%rsp** holds the address of the top of the stack
- push %eax/%rax 1) decrements the stack pointer (%esp/%rbp) then 2) stores the value in %eax/%rax to the location pointed to by the stack pointer
- pop %eax/%rax 1) stores the value at the location pointed to by the stack pointer into %eax/%rax, then 2) increments the stack pointer (%esp/%rsp)

x86/64 Instructions that affect Stack

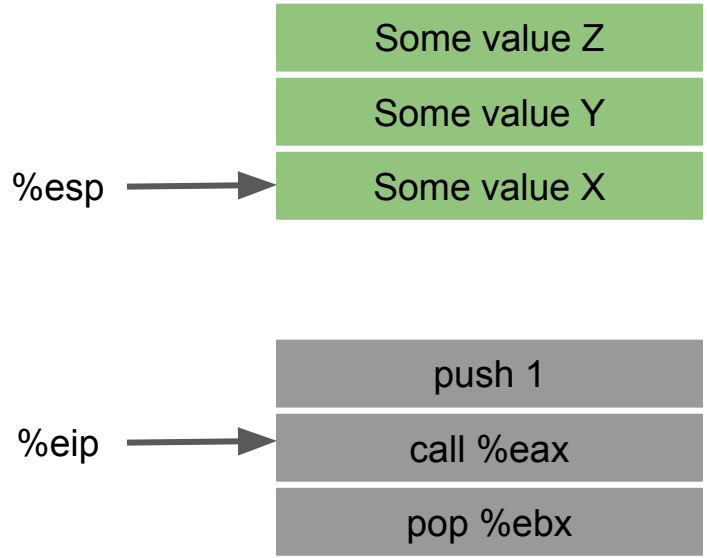
push, pop, call, ret, enter, leave

x86 Instructions that affect Stack

x86 Instructions that affect Stack

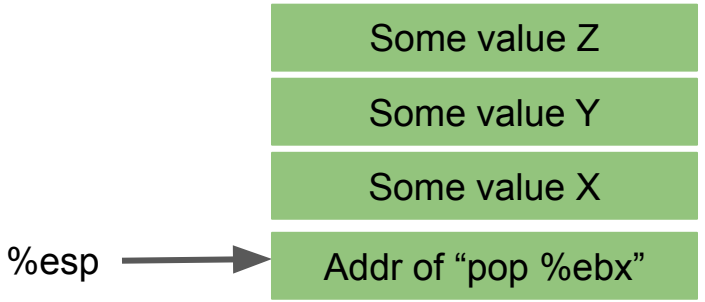
x86 Instructions that affect Stack

Before:



call %eax

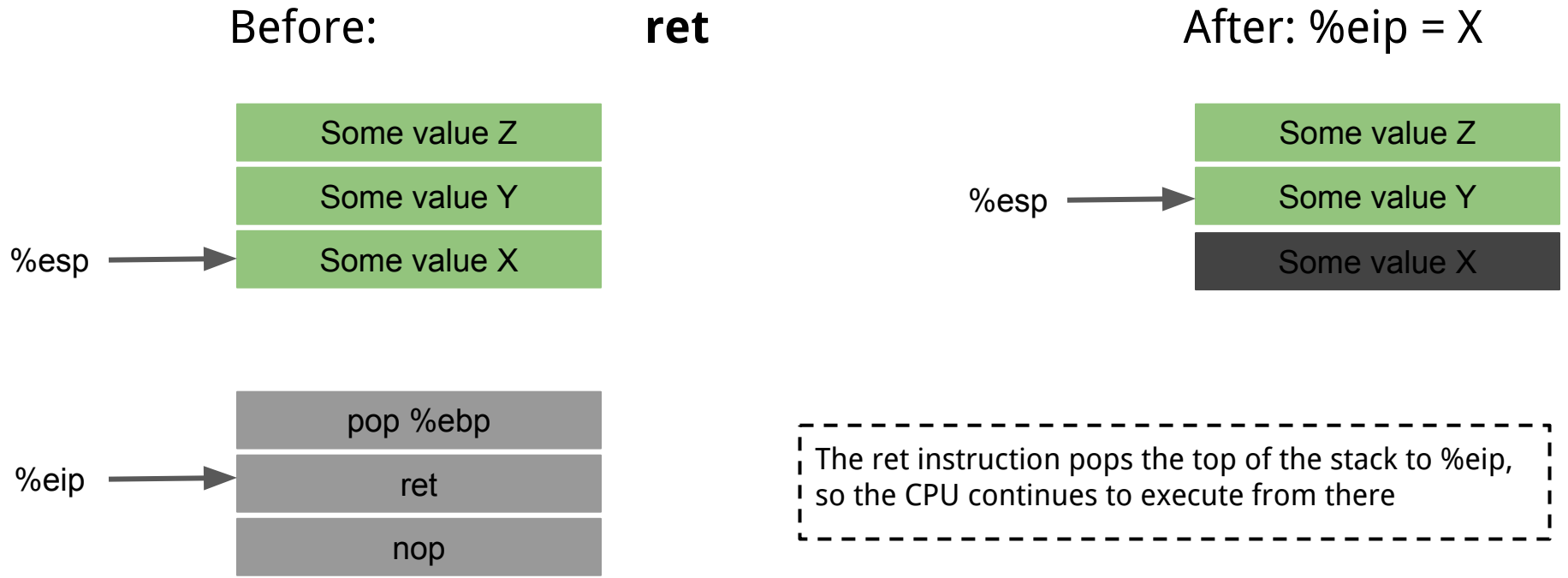
After: %eip = %eax



The call instruction does two things:

1. Push the address of next instruction to the stack
2. Move the dest address to %eip

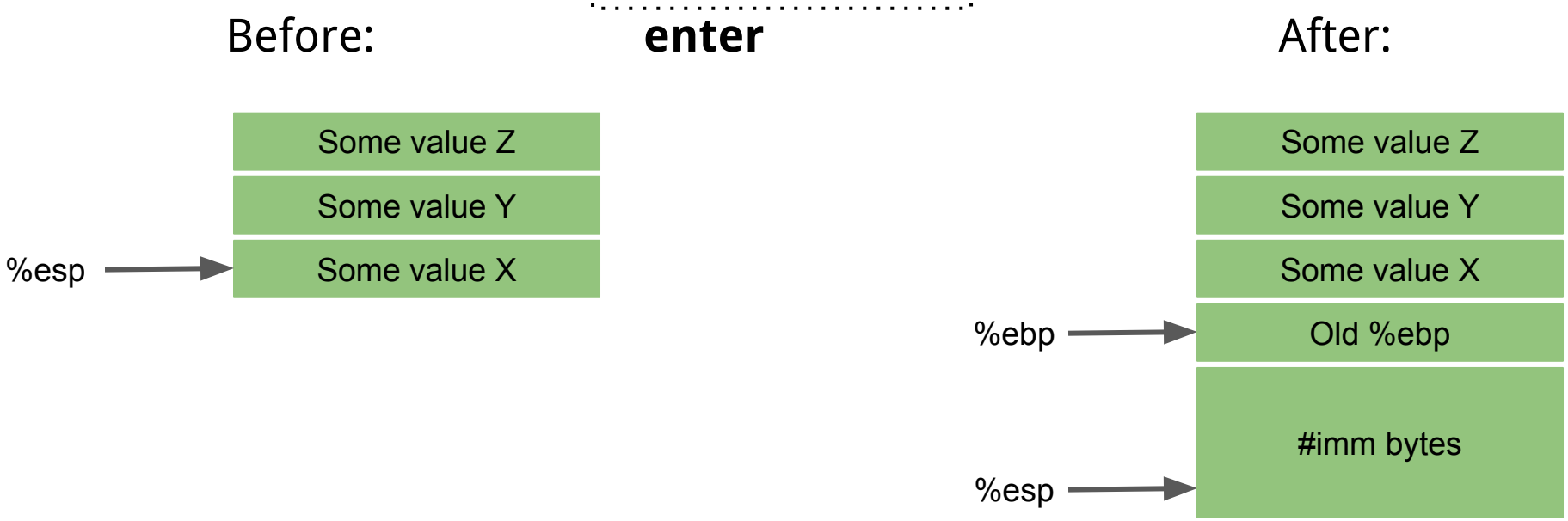
x86 Instructions that affect Stack



x86 Instructions that affect Stack

```
push %ebp
mov %esp, %ebp
Sub #imm, %esp
```

enter

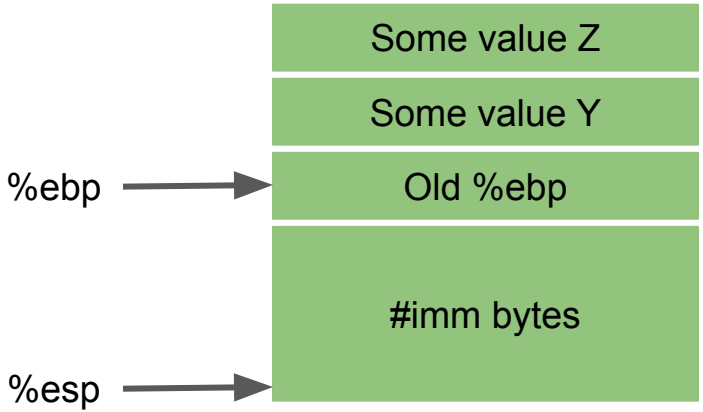


x86 Instructions that affect Stack

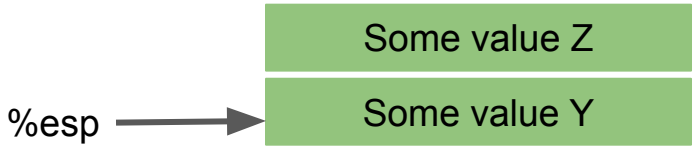
```
mov %ebp, %esp
pop %ebp
```

leave

Before:



After: %ebp = old %ebp



Function Frame

Functions would like to use the stack to allocate space for their local variables. Can we use the stack pointer (%esp) for this?

- Yes, however stack pointer can change throughout program execution

Frame pointer points to the start of the function's frame on the stack

- Each local variable will be (different) **offsets** of the frame pointer
- In x86, frame pointer is called the base pointer, and is stored in **%ebp**

Function Frame

A function’s Stack Frame
- Starts with **where %ebp points to**
- Ends with **where %esp points to**

Calling Convention

Information, such as parameters, must be stored on the stack in order to call the function. Who should store that information? Caller? Callee?

Thus, we need to define a convention of who pushes/stores what values on the stack to call a function

- Varies based on processor, operating system, compiler, or type of call

X86 Linux Calling Convention (cdecl)

Caller (in this order)

- Pushes arguments onto the stack (in right to left order)
- Execute the **call** instruction (pushes address of instruction after call, then moves dest to %eip)

Callee

- Pushes previous frame pointer onto stack (%ebp)
- Setup new frame pointer (mov %esp, %ebp)
- Creates space on stack for local variables (sub #imm, %esp)
- Ensures that stack is consistent on return
- Return value in %eax register

Callee Allocate a stack (Function prologue)

Three instructions:

push %ebp; (Pushes previous frame pointer onto stack)
mov %esp, %ebp; (change the base pointer to the stack)
sub $0x10**, %esp**; (allocating a local stack space)

Callee Deallocate a stack (Function epilogue)

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

Global and Local Variables (code/globallocalv)

```
int func(int p)
{
  int l_i = 10;
  int l_u;

  printf("l_i in func() is at %p\n", &l_i);
  printf("l_u in func() is at %p\n", &l_u);
  printf("p in func() is at %p\n", &p);
  return 0;
}
```

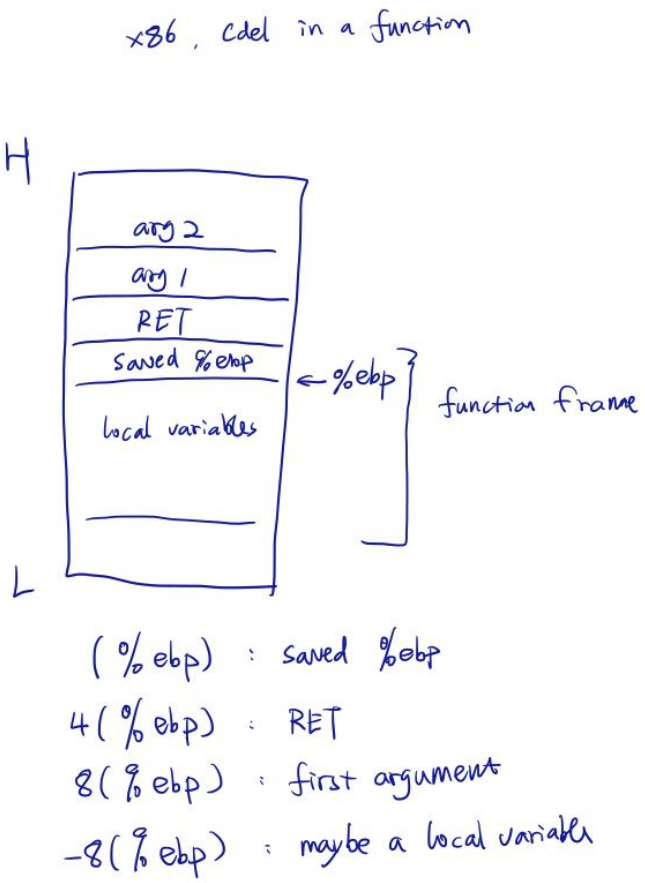
Function main()

```
657:   83 ec 0c          sub    $0xc,%esp
65a:   6a 0a             push   $0xa
65c:   e8 3c ff ff ff    call   59d <func>
661:   83 c4 10          add    $0x10,%esp
```

Function func()

```
59d:   55                push   %ebp
59e:   89 e5             mov    %esp,%ebp
5a0:   83 ec 18          sub    $0x18,%esp
5a3:   c7 45 f4 0a 00 00 00    movl   $0xa,-0xc(%ebp)
5aa:   83 ec 08          sub    $0x8,%esp
5ad:   8d 45 f4          lea    -0xc(%ebp),%eax
5b0:   50                push   %eax
5b1:   68 00 07 00 00    push   $0x700
5b6:   e8 fc ff ff ff    call   5b7 <func+0x1a>
5bb:   83 c4 10          add    $0x10,%esp
5be:   83 ec 08          sub    $0x8,%esp
5c1:   8d 45 f0          lea    -0x10(%ebp),%eax
5c4:   50                push   %eax
5c5:   68 18 07 00 00    push   $0x718
5ca:   e8 fc ff ff ff    call   5cb <func+0x2e>
5cf:   83 c4 10          add    $0x10,%esp
5ca:   e8 fc ff ff ff    call   5cb <func+0x2e>
5cf:   83 c4 10          add    $0x10,%esp
5d2:   83 ec 08          sub    $0x8,%esp
5d5:   8d 45 08          lea    0x8(%ebp),%eax
5d8:   50                push   %eax
5d9:   68 30 07 00 00    push   $0x730
5de:   e8 fc ff ff ff    call   5df <func+0x42>
5e3:   83 c4 10          add    $0x10,%esp
5e6:   b8 00 00 00 00    mov    $0x0,%eax
5eb:   c9                leave
5ec:   c3                ret
```

Draw the stack (x86 cdecl)



X86 Stack Usage

- Negative indexing over ebp

```
mov -0x8(%ebp), %eax
lea -0x24(%ebp), %eax
```

- Positive indexing over ebp

```
mov 0x8(%ebp), %eax
mov 0xc(%ebp), %eax
```

- Positive indexing over esp

X86 Stack Usage

- Accesses local variables (negative indexing over ebp)

mov -0x8(%ebp), %eax value at ebp-0x8
lea -0x24(%ebp), %eax address as ebp-0x24

- Stores function arguments from caller (positive indexing over ebp)

mov 0x8(%ebp), %eax 1st arg
mov 0xc(%ebp), %eax 2nd arg

- Positive indexing over esp

Function arguments to callee

Stack example: code/factorial

```
int fact(int n)
{
  printf("---In fact(%d)\n", n);
  printf("&n is %p\n", &n);

  if (n <= 1)
    return 1;

  return fact(n-1) * n;
}
```

```
int main(int argc, char *argv[])
{
  if (argc != 2)
  {
    printf("Usage: fact integer\n");
    return 0;
  }

  printf("The factorial of %d is %d\n.",
atoi(argv[1]), fact(atoi(argv[1])));
}
```

Stack example: code/fivepara

```
int fp(int a, int b, int c, int d, int e)
{
  return a + b + c + d + e;
}

int main(int argc, char *argv[])
{
  fp(1, 2, 3, 4, 5);
}
```

X86 disassembly

Homework Task 2: code/globallocalv - fastcall

fastcall

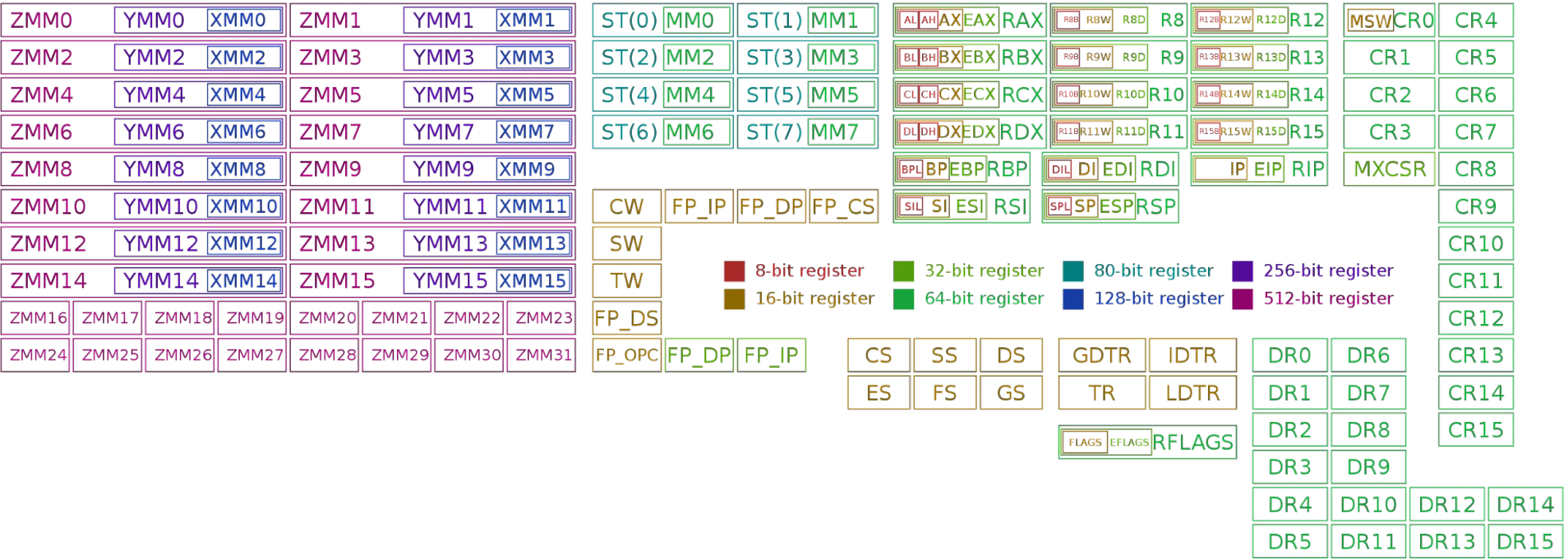
On x86-32 targets, the fastcall attribute causes the compiler to pass the first argument (if of integral type) in the register ECX and the second argument (if of integral type) in the register EDX. Subsequent and other typed arguments are passed on the stack. The called function pops the arguments off the stack. If the number of arguments is variable all arguments are pushed on the stack.

x86-64 Linux Calling Convention

Caller

- Use registers to pass arguments to callee. Register order (1st, 2nd, 3rd, 4th, 5th, 6th, etc.) %rdi, %rsi, %rdx, %rcx, %r8, %r9, ... (use stack for more arguments)

Registers on x86-64



https://en.wikipedia.org/wiki/X86

Stack example: code/fivepara

```
int fp(int a, int b, int c, int d, int e)
{
  return a + b + c + d + e;
}

int main(int argc, char *argv[])
{
  fp(1, 2, 3, 4, 5);
}
```

X86-64 disassembly

X86-64 Stack Usage

- Access local variables (negative indexing over rbp)

```
mov -0x8(%rbp), %rax
lea -0x24(%rbp), %rax
```

- Access function arguments from caller

```
mov %rdi, %rax
```

- Setup parameters for callee

```
mov %rax, %rdi
```

Overwrite Local Variables

Data-only Attack

Buffer Overflow Example: code/overflowlocal

```
char *secret = "This is a secret";

int vulfoo(int i, char* p)
{
  int j = i;
  char buf[6];

  strcpy(buf, p);

  if (j)
    printf("%s\n", secret);
  else
    printf("I pity the fool!\n");

  return 0;
}

int main(int argc, char *argv[])
{
  if (argc == 2)
    vulfoo(0, argv[1]);
}
```

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
 583:   8b 45 08                    mov    0x8(%ebp),%eax
 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                    lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                 cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00              mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00              push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00              mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

Implementations of strcpy()

```
char *strcpy(char *dest, const char *src)
{
  unsigned i;
  for (i=0; src[i] != '\0'; ++i)
    dest[i] = src[i];

  //Ensure trailing null byte is copied
  dest[i]= '\0';

  return dest;
}
```

Implementations of strcpy()

```
char *strcpy(char *dest, const char *src)
{
  unsigned i;
  for (i=0; src[i] != '\0'; ++i)
    dest[i] = src[i];

  //Ensure trailing null byte is copied
  dest[i]= '\0';

  return dest;
}
```

```
char *strcpy(char *dest, const char *src)
{
   char *save = dest;
   while(*dest++ = *src++);
   return save;
}
```

Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
 583:   8b 45 08                   mov    0x8(%ebp),%eax
 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
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 5b7:   68 a1 06 00 00             push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

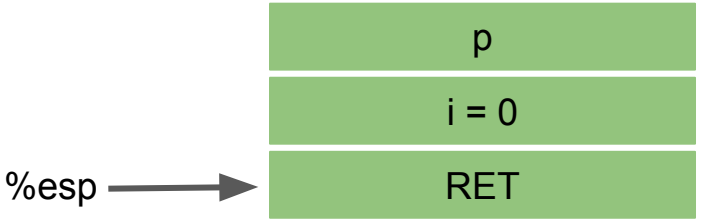

Buffer Overflow Example: code/overflowlocal

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 57e:   89 e5               mov    %esp,%ebp
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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
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 5a1:   a1 08 20 00 00             mov    0x2008,%eax
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 5c4:   b8 00 00 00 00             mov    $0x0,%eax
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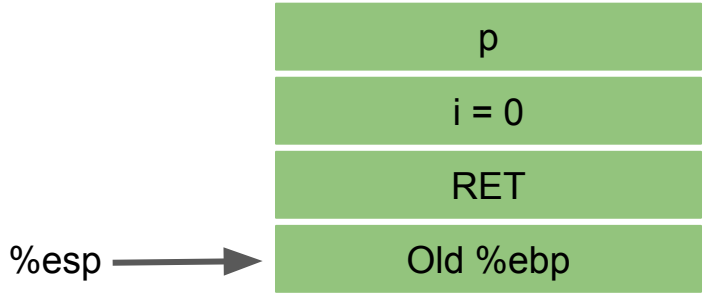
 5ca:   c3                  ret
```



Buffer Overflow Example: code/overflowlocal

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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
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 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
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 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

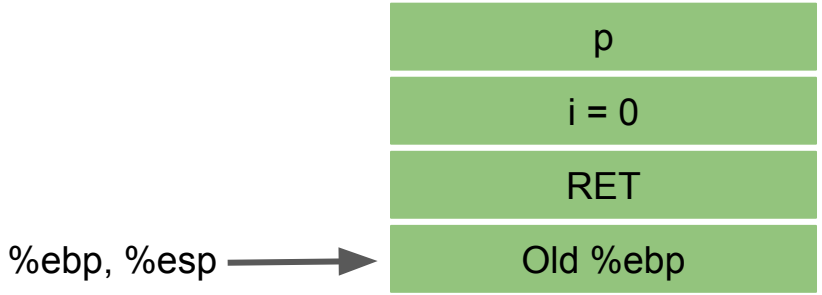

Buffer Overflow Example: code/overflowlocal

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 580:   83 ec 18            sub    $0x18,%esp
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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
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 5a1:   a1 08 20 00 00             mov    0x2008,%eax
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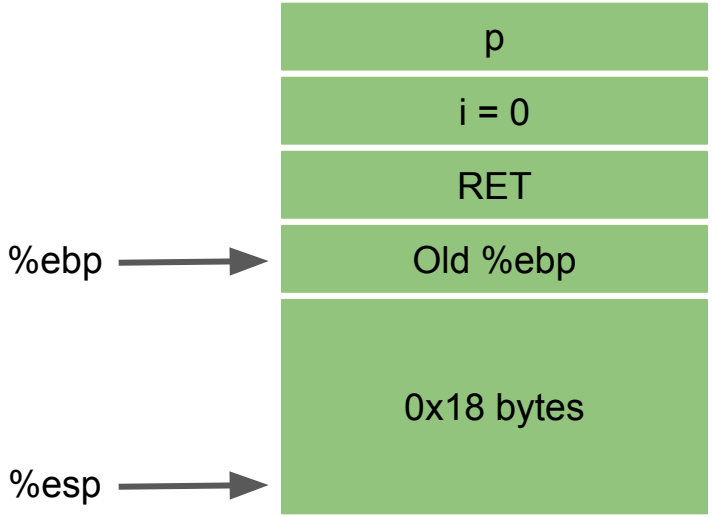
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```



Buffer Overflow Example: code/overflowlocal

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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
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 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
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 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00             push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

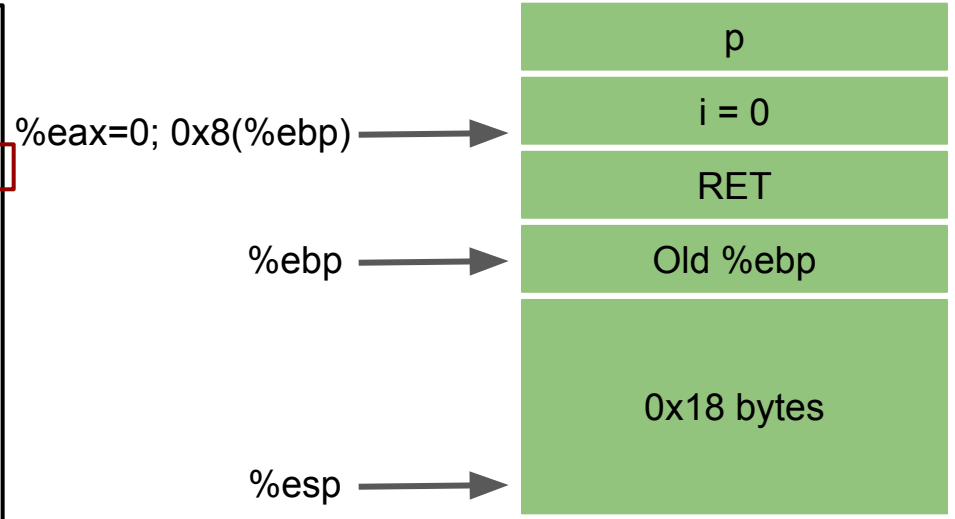

Buffer Overflow Example: code/overflowlocal

```
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 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00              mov    0x2008,%eax
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 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00              mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

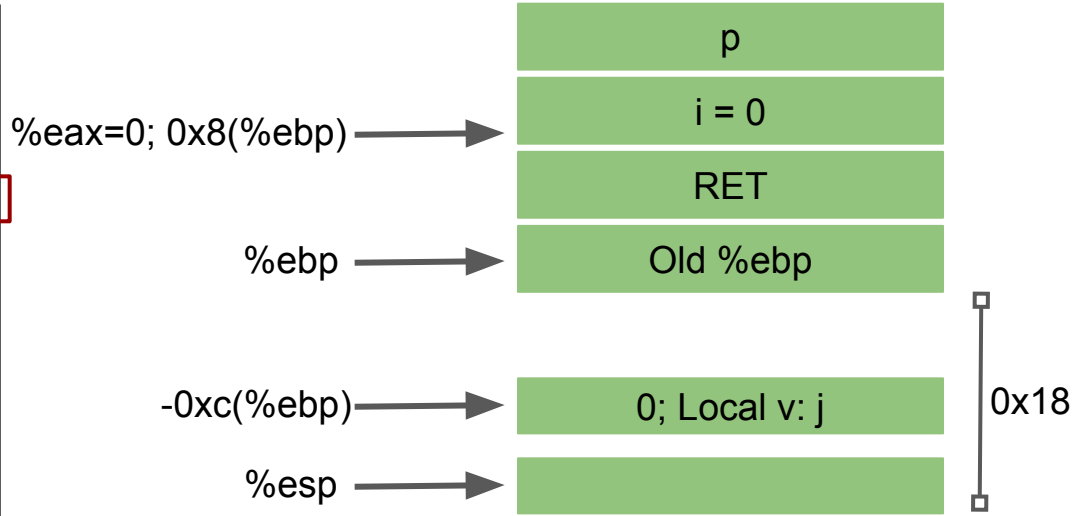

Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
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 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00             push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

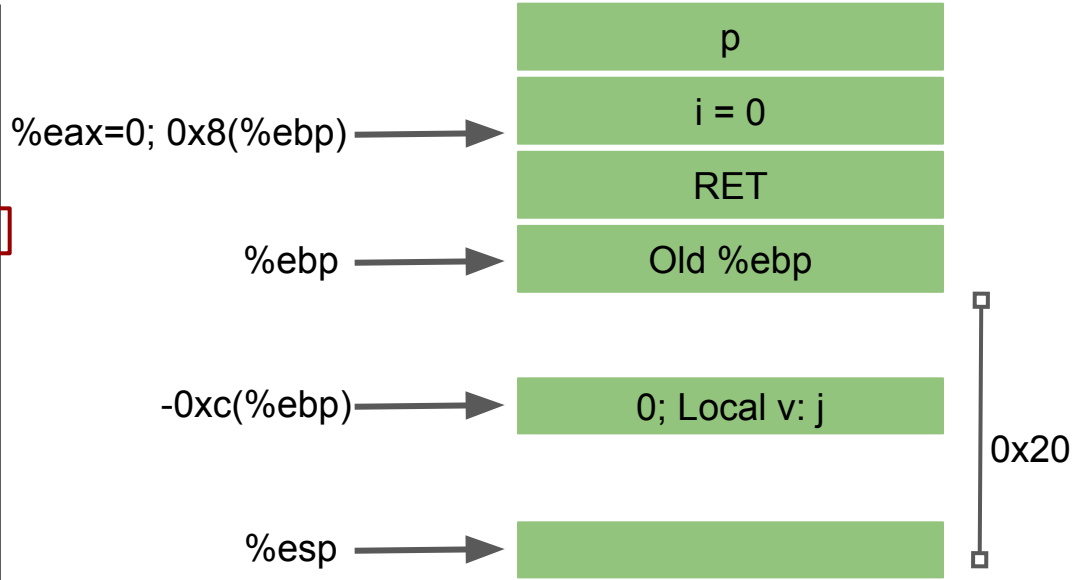

Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
 583:   8b 45 08                   mov    0x8(%ebp),%eax
 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
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 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

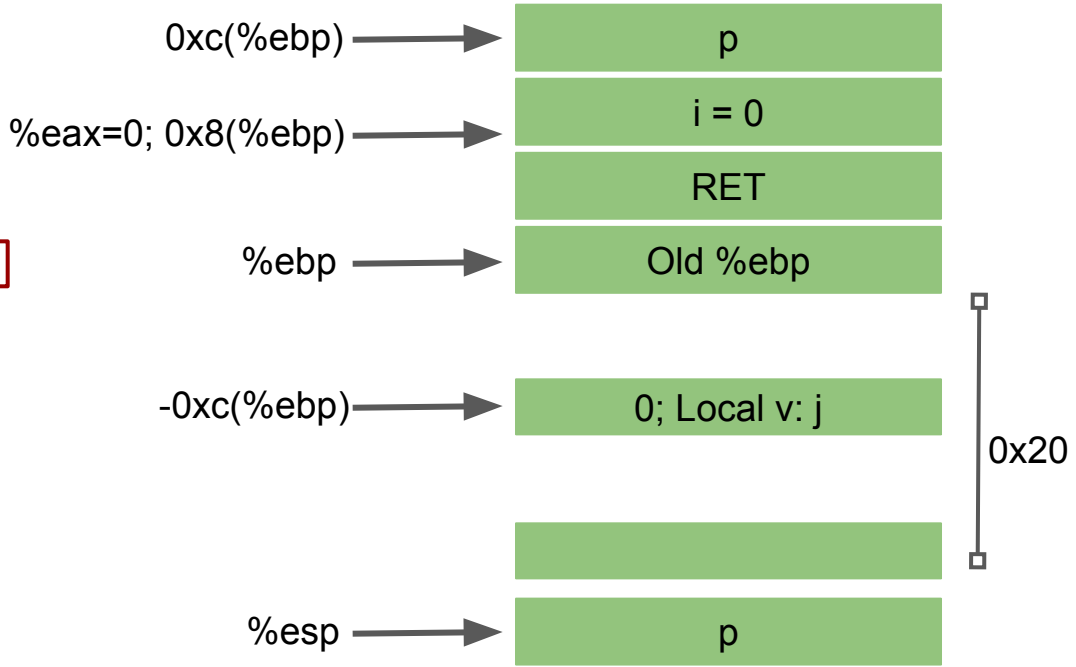

Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00             push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```
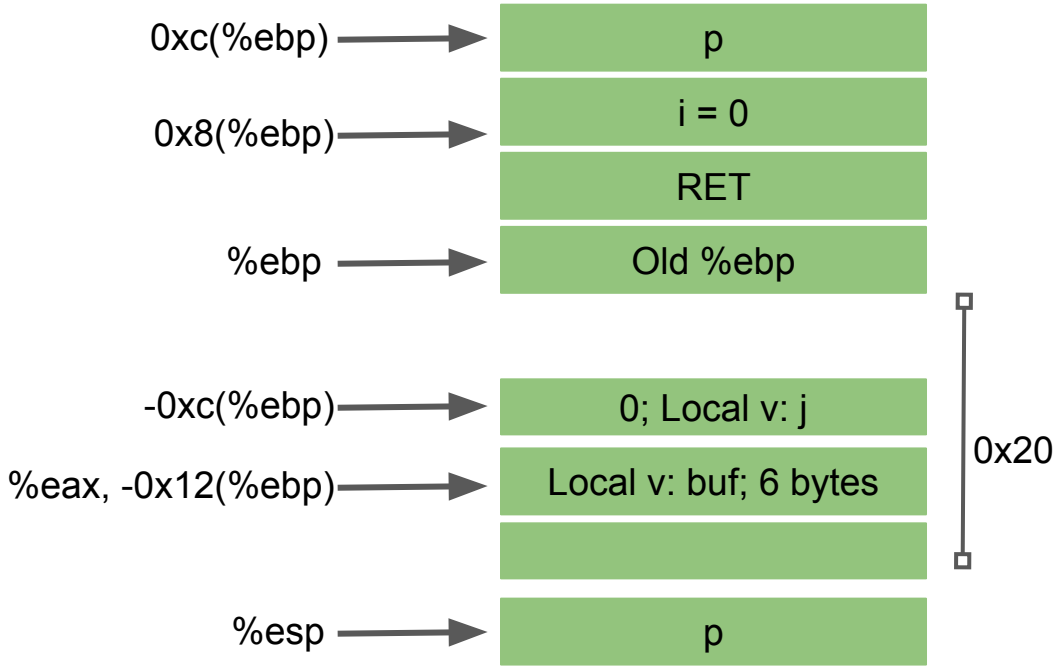
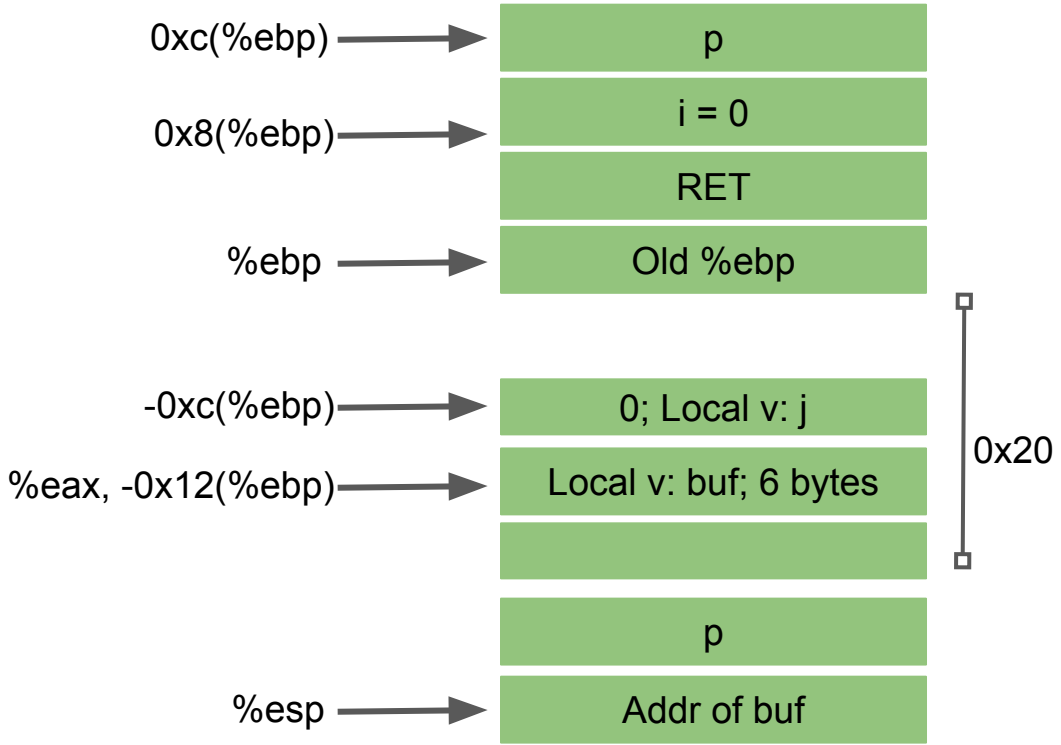



Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
 583:   8b 45 08                   mov    0x8(%ebp),%eax
 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00             push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```



Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
 583:   8b 45 08                   mov    0x8(%ebp),%eax
 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
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 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
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 5b7:   68 a1 06 00 00             push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

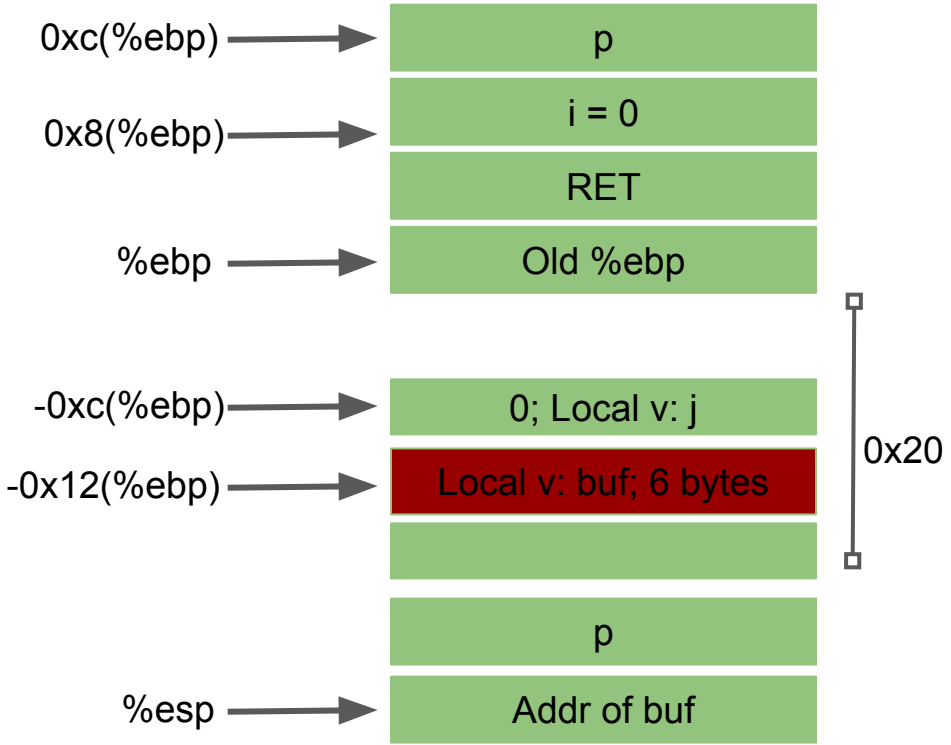

Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
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 5a9:   50                  push   %eax
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 5af:   83 c4 10            add    $0x10,%esp
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 5b7:   68 a1 06 00 00             push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

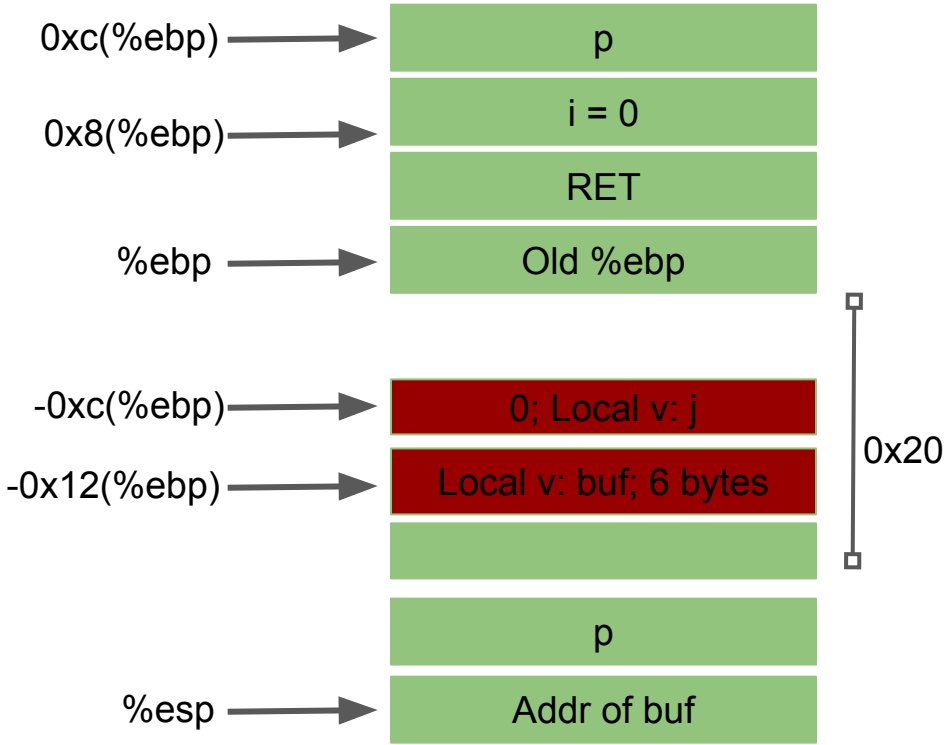

Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
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 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
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 5a1:   a1 08 20 00 00             mov    0x2008,%eax
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 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00             push   $0x6a1
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 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

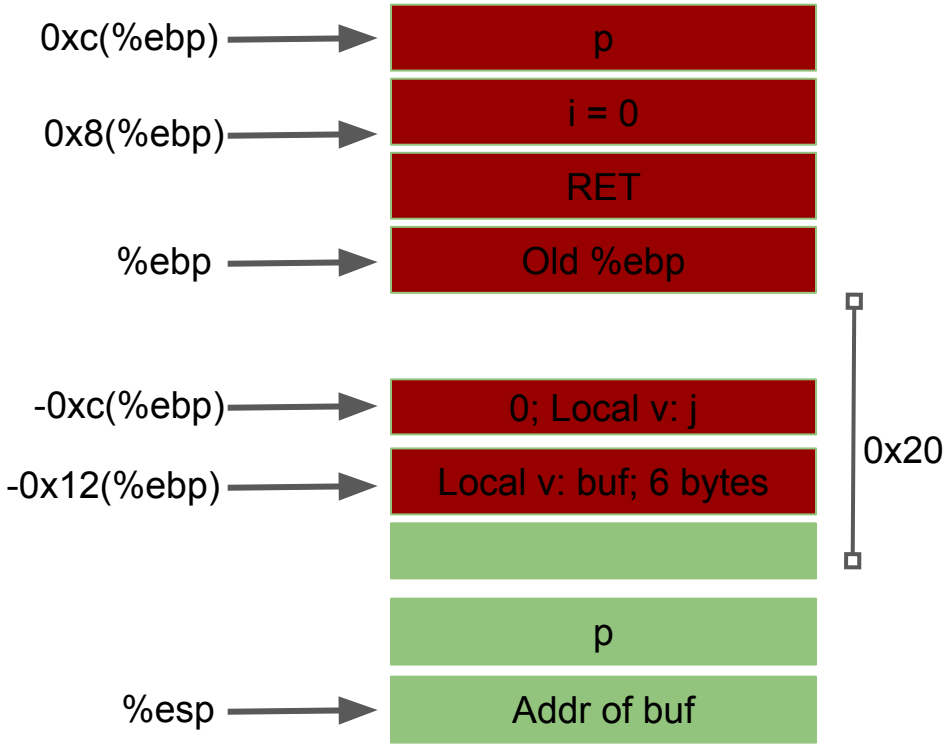

Buffer Overflow Example: code/overflowlocal

```
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 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                   lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00             mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
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 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00             mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

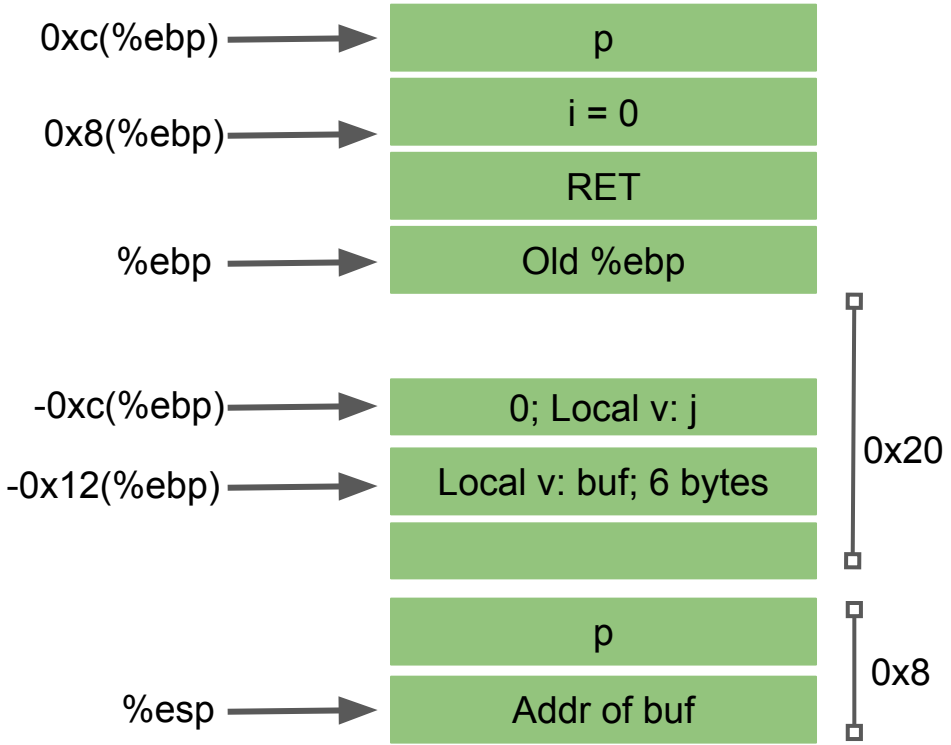

Buffer Overflow Example: code/overflowlocal

```
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 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
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 586:   89 45 f4            mov    %eax,-0xc(%ebp)
 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                    lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                 cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00              mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00              push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00              mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

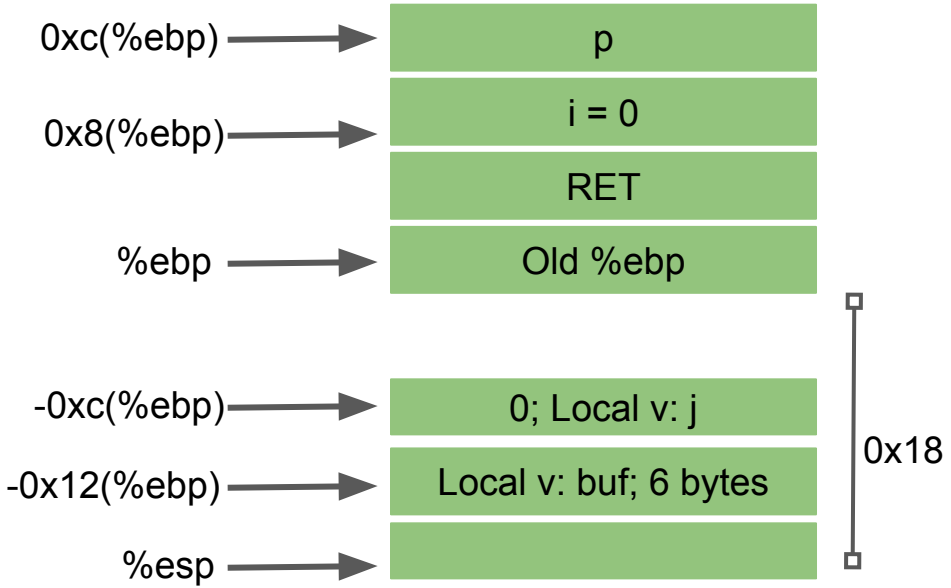

Buffer Overflow Example: code/overflowlocal

```
0000057d <vulfoo>:
 57d:   55                  push   %ebp
 57e:   89 e5               mov    %esp,%ebp
 580:   83 ec 18            sub    $0x18,%esp
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 589:   83 ec 08            sub    $0x8,%esp
 58c:   ff 75 0c            pushl  0xc(%ebp)
 58f:   8d 45 ee                    lea    -0x12(%ebp),%eax
 592:   50                  push   %eax
 593:   e8 fc ff ff ff      call   594 <vulfoo+0x17>
 598:   83 c4 10            add    $0x10,%esp
 59b:   83 7d f4 00                 cmpl   $0x0,-0xc(%ebp)
 59f:   74 13               je     5b4 <vulfoo+0x37>
 5a1:   a1 08 20 00 00              mov    0x2008,%eax
 5a6:   83 ec 0c            sub    $0xc,%esp
 5a9:   50                  push   %eax
 5aa:   e8 fc ff ff ff      call   5ab <vulfoo+0x2e>
 5af:   83 c4 10            add    $0x10,%esp
 5b2:   eb 10               jmp    5c4 <vulfoo+0x47>
 5b4:   83 ec 0c            sub    $0xc,%esp
 5b7:   68 a1 06 00 00              push   $0x6a1
 5bc:   e8 fc ff ff ff      call   5bd <vulfoo+0x40>
 5c1:   83 c4 10            add    $0x10,%esp
 5c4:   b8 00 00 00 00              mov    $0x0,%eax
 5c9:   c9                  leave
 5ca:   c3                  ret
```

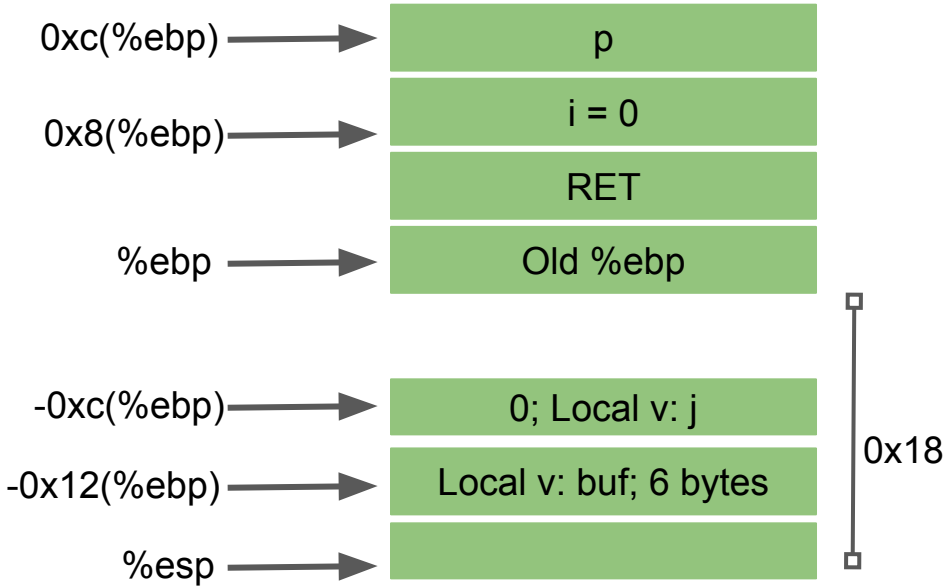

Buffer Overflow Example: code/overflowlocal 64-bit

```
char *secret = "This is a secret";

int vulfoo(int i, char* p)
{
  int j = i;
  char buf[6];

  strcpy(buf, p);

  if (j)
    printf("%s\n", secret);
  else
    printf("I pity the fool!\n");

  return 0;
}

int main(int argc, char *argv[])
{
  if (argc == 2)
    vulfoo(0, argv[1]);
}
```

```
0000000000001149 <vulfoo>:
    1149:       55                          push   %rbp
    114a:       48 89 e5                    mov    %rsp,%rbp
    114d:       48 83 ec 20                 sub    $0x20,%rsp
    1151:       89 7d ec                    mov    %edi,-0x14(%rbp)
    1154:       48 89 75 e0                 mov    %rsi,-0x20(%rbp)
    1158:       8b 45 ec                    mov    -0x14(%rbp),%eax
    115b:       89 45 fc                    mov    %eax,-0x4(%rbp)
    115e:       48 8b 55 e0                 mov    -0x20(%rbp),%rdx
    1162:       48 8d 45 f6                 lea    -0xa(%rbp),%rax
    1166:       48 89 d6                    mov    %rdx,%rsi
    1169:       48 89 c7                    mov    %rax,%rdi
    116c:       e8 bf fe ff ff              callq  1030 <strcpy@plt>
    1171:       83 7d fc 00                 cmpl   $0x0,-0x4(%rbp)
    1175:       74 11                       je     1188 <vulfoo+0x3f>
    1177:       48 8b 05 92 2e 00 00        mov    0x2e92(%rip),%rax
    117e:       48 89 c7                    mov    %rax,%rdi
    1181:       e8 ba fe ff ff              callq  1040 <puts@plt>
    1186:       eb 0c                       jmp    1194 <vulfoo+0x4b>
    1188:       48 8d 3d 86 0e 00 00        lea    0xe86(%rip),%rdi
    118f:       e8 ac fe ff ff              callq  1040 <puts@plt>
    1194:       b8 00 00 00 00              mov    $0x0,%eax
    1199:       c9                          leaveq
    119a:       c3                          retq
```

Exercise: code/overflowlocal2

```
char *secret = "This is a secret";

int vulfoo(int i, char* p)
{
  int j = i;
  char buf[6];

  strcpy(buf, p);

  if (j == 0x12345678)
    printf("%s\n", secret);
  else
    printf("I pity the fool!\n");

  return 0;
}

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

Shell Command

Run a program and use another program’s output as a parameter

```
./program $(python -c "print '\x12\x34'*5")
```

Homework-3: crackme-2

Similar to **code/overflowlocal2**, but no source code available

Shell Command

Compute some data and redirect the output to another program’s stdin

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