CMSC 426
Principles of Computer Security

Stack Overflow Demo & Shellcode

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Last Class We Covered

- Assembly review
- Cdecl calling convention
- In-depth explanation of stack buffer overflow exploits

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Any Questions from Last Time?

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Today's Topics

- How the shellcode works
- Stack buffer overflow exploit demo (finally!)

Quick Note: Word Alignment

- Having things on the stack align along word boundaries is not automatic when we're causing a buffer overflow
  - Words are four bytes (32 bits)

- Having the return address copies in our buffer overflow input line up with the original return address needs to be managed
  - We can control our shellcode and NOP sled sizes to ensure that the final return address (and anything else) will be correctly aligned

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Breaking Down the Shellcode

Shellcode

```
XOR     EAX, EAX
PUSH    EAX
PUSH    0x2F2F7368
PUSH    0x2F62696E
MOV     EBX, ESP
PUSH    EAX
PUSH    EBX
MOV     ECX, ESP
CDQ
MOV     AL, 0xB
INT     0x80
```

Set up to put "`/bin//sh`" on the stack

Putting the arguments for `execve()` in the correct registers

System call

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Building the string `/bin/sh` on the stack

- Executing the command `/bin/sh` will open a shell
- We want to put this string on the stack and then find a way to execute it
- Actually going to build the string `/bin//sh`
  - The second forward slash doesn't do anything
  - But it keeps the length of the string a multiple of 4
  - This keeps the stack word aligned (very important!)

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Building the string `/bin/sh` on the stack

- "`/bin//sh`" needs to be pushed onto the stack in reverse

- Why?
  - Because the stack starts at higher addresses and grows down
  - But the stack is "read" from the bottom up

1. Push **`NULL`** terminator (end of string)
2. Push **`//sh`**
3. Push **`/bin`**

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Shellcode: Line by Line

`XOR EAX, EAX`

Register	Value
`EAX`	`00 00 00 00`
`EBX`	
`ECX`	
`EDX`	
`ESP`	

- Want to put a **`NULL`** terminator into **`EAX`** so we can use it later
- Can't use **`MOV EAX, 0`**, because the opcode contains NULL bytes
- Workaround: anything **`XOR`**ed with itself is 0

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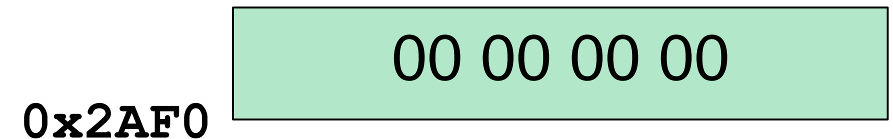
PUSH EAX

- Need to add a **NULL** pointer to the stack
  - We'll want it here later

- **PUSH EAX**
  - **SUB ESP, 4**
  - **MOV [ESP], EAX**

Register	Value
EAX	00 00 00 00
EBX	
ECX	
EDX	
ESP	00 00 2A F0



0x2AF0

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PUSH 0x2F2F7368

- Pushing the second half of the string “**/bin//sh**” onto the stack
- **0x2F2F7368** is ASCII for “**//sh**”

Register	Value
EAX	00 00 00 00
EBX	
ECX	
EDX	
ESP	00 00 2A EC

Address	Stack
	00 00 00 00
0x2AF0	
	“//sh”
0x2AEC	

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`PUSH 0x2F62696E`

- Pushing the first half of the string "`/bin//sh`" onto the stack
- `0x2F2F7368` is ASCII for "`/bin`"

Register	Value
EAX	00 00 00 00
EBX	
ECX	
EDX	
ESP	00 00 2A E8

Address	Stack
	00 00 00 00
0x2AF0	"//sh"
0x2AEC	"/bin"
0X2AE8	

Side Note: Executing `/bin//sh`

- Now that we've built the string **`/bin//sh`** on the stack, we need to find a way to execute it
- Going to use the **`execve()`** system call

```
int execve(const char *filename,
           char *const argv[],
           char *const envp[]);
```


- We will be putting each argument into a separate register

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(Unimportant) Side Note: `const`

- What is the difference between

```
const char* param
```

and

```
char* const param
```

- The first is a pointer to a constant character
  - Cannot change the value, but can make it point elsewhere
- The second is a constant pointer to a non-constant character
  - Cannot change where it points to, but can change the value there
- *(Don’t worry about it, it doesn’t matter)*

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The `execve()` arguments: `filename`

- A string that contains the name of the “file”
  - (Really a pointer to a character array, but same difference)
- For our purposes, the “file” is the command **`/bin//sh`**
- Need **`EBX`** to point to the string “**`/bin//sh`**”
  - Already built on the stack earlier

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The `execve()` arguments: `argv`

- An array of string (char*) arguments used by the program being executed
  - Last element of the array must be a NULL pointer

- The first element of the array should be the name of the program being executed

- Need **`ECX`** to point to an array **`["/bin//sh", NULL]`**
  - How handy, we've already built the pieces of this on the stack

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The `execve()` arguments: `envp`

- An array of string (char*) arguments
  - Contains any necessary environment info for the program
  - Last element of the array must be a NULL pointer
- There is no environment information for this program
  - Just need to build an array of **`[NULL]`** on the stack
- Once done, store a pointer to it in **`EDX`**

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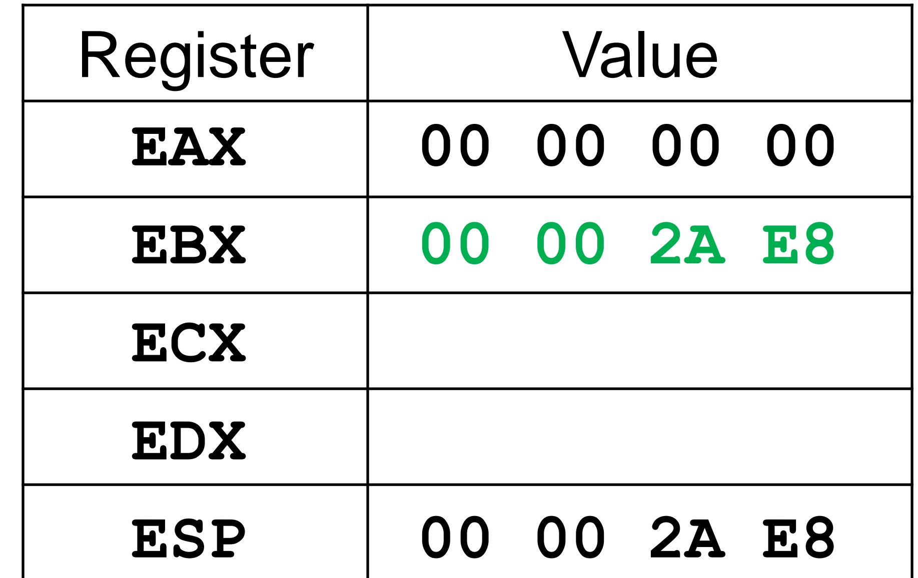
How We Left the Stack

Register	Value
EAX	00 00 00 00
EBX	
ECX	
EDX	
ESP	00 00 2A E8

Address	Stack
	00 00 00 00
0x2AF0	“//sh”
0x2AEC	“/bin”
0X2AE8	

MOV EBX, ESP

- **ESP** is already pointing to the string "**/bin//sh**"
  - Because we set it up that way
- Make **EBX** point to it as well
  - (That was easy)



Register	Value
EAX	00 00 00 00
EBX	00 00 2A E8
ECX	
EDX	
ESP	00 00 2A E8

Address	Memory
	00 00 00 00
0x2AF0	"//sh"
0x2AEC	"/bin"
0X2AE8	

PUSH EAX

- We have to build the array **`["/bin//sh", NULL]`** in reverse order on the stack
  - Because it grows down, but is read up
- Pushing a **`NULL`** terminator first
- We already have one in **`EAX`**

Register	Value
EAX	00 00 00 00
EBX	00 00 2A E8
ECX	
EDX	
ESP	00 00 2A E4

Address	Stack
	00 00 00 00
0x2AF0	“//sh”
0x2AEC	“/bin”
0X2AE8	00 00 00 00
0X2AE4	

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PUSH EBX

- We have to build the array
  `["/bin//sh", NULL]`
  in reverse order on the stack
  - Because it grows down, but is read up

- Next push a pointer to "**`/bin//sh`**" onto the stack

- We already have one in **`EBX`**

Register	Value
EAX	`00 00 00 00`
EBX	`00 00 2A E8`
ECX	
EDX	
ESP	`00 00 2A E0`

Address	Stack
	00 00 00 00
0x2AF0	"//sh"
0x2AEC	"/bin"
0X2AE8	00 00 00 00
0X2AE4	00 00 2A E8
0X2AE0	

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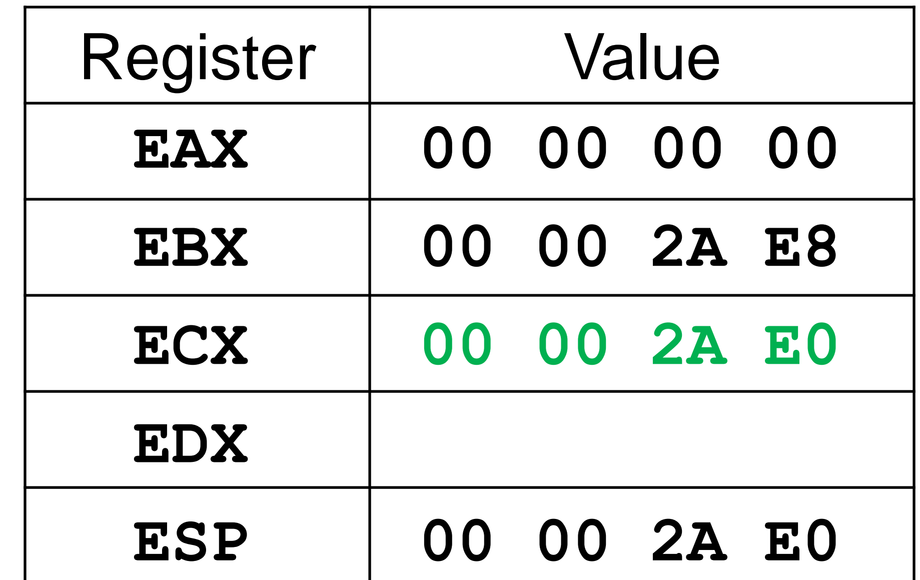
MOV ECX, ESP

- Array `["/bin//sh", NULL]` is built on the stack
- Now need to make register **ECX** point to it
- **ESP** is already pointing to it
  - Make **ECX** point to it as well



Register	Value
EAX	00 00 00 00
EBX	00 00 2A E8
ECX	00 00 2A E0
EDX	
ESP	00 00 2A E0

Address	Stack
	00 00 00 00
0x2AF0	“//sh”
0x2AEC	“/bin”
0X2AE8	00 00 00 00
0X2AE4	00 00 2A E8
0X2AE0	

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CDQ

- Need to make register **EDX** point to an array **[NULL]**
  - Can't use **MOV EDX, 0**
  - Could use **MOV EDX, EAX**

- Opcode for **CDQ** is smaller
  - Happens to make the shellcode align with word size (multiples of four)
  - Extends sign bit of **EAX** into **EDX**, which zeroes **EDX**

Register	Value
EAX	00 00 00 00
EBX	00 00 2A E8
ECX	00 00 2A E0
EDX	00 00 00 00
ESP	00 00 2A E0

Address	Memory
	00 00 00 00
0x2AF0	"//sh"
0x2AEC	"/bin"
0X2AE8	00 00 00 00
0X2AE4	00 00 2A E8
0X2AE0	

MOV AL, 0xB

- Moving the code for the **execve()** system call into the lowest byte of **EAX**
  - **0xB** is the code *because it is*
- **AL** means lowest byte in the **EAX** register
  - **L** means lowest byte
  - **H** means second lowest byte
  - **X** means lowest two bytes

Register	Value
EAX	00 00 00 0B
EBX	00 00 2A E8
ECX	00 00 2A E0
EDX	00 00 00 00
ESP	00 00 2A E0

Address	Memory
	00 00 00 00
0x2AF0	“//sh”
0x2AEC	“/bin”
0X2AE8	00 00 00 00
0X2AE4	00 00 2A E8
0X2AE0	

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INT 0X80

- Calling the interrupt with the code `0x80` means that we want to make a system call
- Interrupt whatever else was going on, and acts based on the values we gave the registers

Register	Value
EAX	00 00 00 0B
EBX	00 00 2A E8
ECX	00 00 2A E0
EDX	00 00 00 00
ESP	00 00 2A E0

Address	Value
	00 00 00 00
0x2AF0	"//sh"
0x2AEC	"/bin"
0X2AE8	00 00 00 00
0X2AE4	00 00 2A E8
0X2AE0	

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Summary of Shellcode's Execution

- **`EAX`** → **`0xB`**, the code for the **`execve()`** system call
- **`EBX`** → **`"/bin//sh"`**, the command to open a shell
- **`ECX`** → **`["/bin//sh", NULL]`**, an array of arguments
- **`EDX`** → **`[NULL]`**, an array of environment info
- We've got a shell!

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DEMO TIME!

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