



# x86 Crash Course

With a focus on Linux and a glance to x86\_64

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# The x86 Architecture

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# Instruction Set Architecture (ISA)



- “Logical” specification of a computer architecture
- Concerned with programming concepts
  - instructions, registers, interrupts, memory architecture, ...
- May differ (widely) from the actual microarchitecture
- Examples:
  - x86 (IA-32 and x86\_64)
  - ARM (mobile devices)
  - MIPS (embedded devices, e.g., consumer routers)
  - AVR, SPARC, Power, RISC V, ...

# The x86 ISA

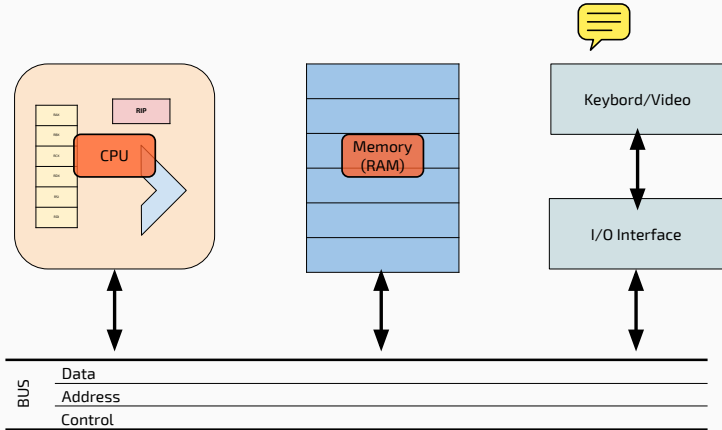
- Born in 1978, 16-bit ISA (Intel 8086)
- Evolved to a 32-bit ISA (1985, Intel 80386)
- Evolved to a 64-bit ISA (2003, AMD Opteron)
- CISC design (e.g., string operations)
- Many legacy features (e.g, segmentation)
- We'll see the basics of the “core” ISA
  - There is also the floating point unit, processor-specific features, and extensions such as SIMD (MMX, SSE, SSE2) with their own instructions and registers<sup>1</sup>



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<sup>1</sup>Complete reference: Intel Software Developer's Manual, about 5,000 pages (<https://software.intel.com/en-us/articles/intel-sdm>)

# Von Neumann Architecture

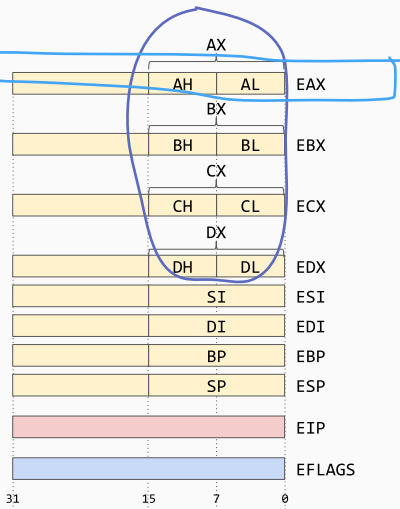


# Memory



	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0x8040204...	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
0x8040203...	E8	FF	FF	FF	E0	FF	FF	FF	D8	FF	FF	FF	D0	FF	FF	FF
0x8040202...	50	20	40	80	60	20	40	80	70	20	40	80	80	20	40	80
0x8040201...	48	65	6C	6C	6F	20	77	6F	72	6C	64	00	00	00	00	00
0x8040200...	'H'	'e'	'l'	'l'	'o'	' '	'w'	'o'	'r'	'l'	'd'	00	00	00	00	00

# IA-32: Registers



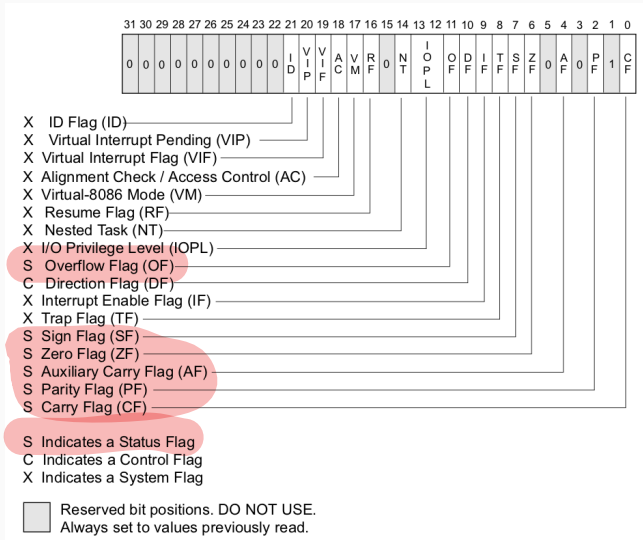
- General-purpose registers
  - EAX, EBX, ECX, EDX
  - ESI, EDI (source and destination index for string operations)
  - EBP (base pointer)
  - ESP (stack pointer)
- Instruction pointer: EIP
  - No explicit access
  - Modified by `jmp`, `call`, `ret`
  - Read through the stack (saved IP)
- Program status and control: EFLAGS
- ~~(segment registers)~~

## IA-32: EFLAGS register

- 32-bits register, boolean flags
- **Program status:** overflow, sign, zero, auxiliary carry (BCD), parity, carry
  - Indicate the result of arithmetic instructions
  - Extremely important for control flow
- **Program control:** direction flag
  - controls string instructions (auto-increment or auto-decrement)
- **System:** control operating-system operations



## IA-32: EFLAGS register



# Fundamental data types



**byte** 8 bits

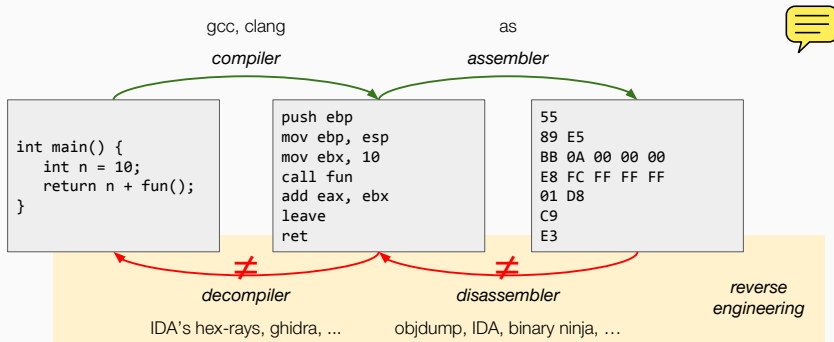
**word** 2 bytes

**dword** Doubleword, 4 bytes (32 bits)

**qword** Quadword, 8 bytes (64 bits)

# Assembly and Machine Code

Assembly language: specific to each ISA, mapped to binary code



For simplicity, we don't deal with the *linking* process.

# Assembly: Syntax

Two main syntaxes:

- **Intel**: default in most Windows programs (e.g., IDA)
- **AT&T**: default in most UNIX tools (e.g., gdb, objdump)

Beware: The order of the operands is **different**

We will use the Intel syntax

*move the value 0 to EAX*

**Intel**

```
mov eax, 0h
```

**AT&T**

```
movl $0x0,%eax
```

*move the value 0 to the address contained in EBX+4*

**Intel**

```
mov [ebx+4h],0h
```

**AT&T**

```
movl $0x0,0x4(%ebx)
```

## x86: data movement

### Examples

Immediate to register:

`mov eax, 4h`  $EAX = 4$

Register to register:

`mov eax, ebx`  $EAX = EBX$

Memory to register (and register to memory):

`mov eax, [ebx]`  $EAX = *EBX$

`mov eax, [ebx + 4h]`  $EAX = *(EBX + 4)$

`mov eax, [edx + ebx*4 + 8]`  $EAX = *(EDX + EBX * 4 + 8)$

Note: memory to memory is an **invalid** combination<sup>2</sup>

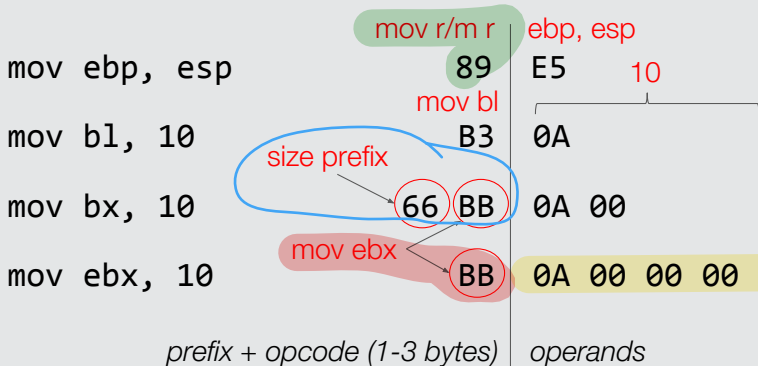
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<sup>2</sup>Except in some instructions, such as `movs` (move from string to string).

# x86 Assembly and Machine Code

Instruction = opcode + operand

## Example



Beware: in x86, instructions have **variable length**.

# Basic instructions

- **Data Transfer:** `mov`, `push`, `pop`, `xchg`, `lea`
- **Integer Arithmetic:** `add`, `sub`, `mul`, `imul`, `div`, `idiv`, `inc`, `dec`
- **Logical:** `and`, `or`, `not`, `xor`
- **Control Transfer:** `jmp`, `jne`, `call`, `ret`
- and lots more...



# Data Transfer: `mov`

- `mov` destination, source

**source:** immediate, register, memory location

**destination:** register or memory location

- Basic load/store operations

- Register to register, register to memory, immediate to register, immediate to memory
- Memory to memory is INVALID (in every instruction)

## Examples

`MOV eax, ebx`

`MOV eax, FFFFFFFFh`

`MOV ax, bx`

`MOV [eax],ecx`

`MOV [eax],[ecx] NO!!!`

`MOV al, FFh`

# Integer Arithmetics: add and sub

add destination, source

$\text{dest} \leftarrow \text{dest} + \text{source}$

sub destination, source

$\text{dest} \leftarrow \text{dest} - \text{source}$



- Addressing:

**source:** immediate, register, memory location

**destination:** register or memory location

(the destination has to be at least as large as the source)

- Negate a value: `neg [op]`
- Bitwise operations: `and`, `or`, `xor`, `not` work similarly

## Examples

`add esp, 44h`

`add edx, cx`

`add al, dh`

`sub esp, 33h`

`sub eax, ebx`

`sub [eax], 1h`

# Integer Arithmetics: unsigned multiply (`mul`)

- `mul` source  
**source**: register or memory location
- $\text{dest} \leftarrow \text{implied\_op} \times \text{source}$
- **Implied operands** according to the size of **source**
  - First operand: AL, AX, or EAX
  - Destination: AX, DX:AX, EDX:EAX (double the size of **source**)
- Signed multiply: `imul`



## Example

- `mul ebx: EDX:EAX`  $\leftarrow \text{EAX} * \text{EBX}$ 
  - most significant bits of the result in EDX
  - least significant bits of the result in EAX
- `mul cx: DX:AX`  $\leftarrow \text{AX} * \text{CX}$
- `mul cl: AX`  $\leftarrow \text{AL} * \text{CL}$

# Integer Arithmetics: unsigned divide (div)

- `div` source  
**source**: register or a memory location
- Computes quotient and remainder
- Implied operand: EDX:EAX (according to the size of **source**)
- Signed divide: `idiv`

## Examples

- `div ebx` (4 bytes)
  - $EAX \leftarrow EDX:EAX / EBX$
  - $EDX \leftarrow EDX:EAX \% EBX$
- `div bx` (2 bytes)
  - $AX \leftarrow DX:AX / BX$        $DX = DX:AX \% BX$
- `div bl` (1 byte)
  - $AL \leftarrow AX / B\cancel{X}$        $AH = AX \% B\cancel{X}$

# Integer Arithmetics: `cmp` and `test`



`cmp` `op1`, `op2`

Computes `op1 - op2`

`test` `op1`, `op2`

Computes `op1 & op2`

- Sets the flags (ZF, CF, OF, ...)
- Discards the result

## Examples

`cmp eax, ebx`

`cmp eax, 44BBCCDDh`

`cmp al, dh`

`cmp al, 44h`

`cmp ax, FFFFh`

`cmp [eax], 4h`

# Control-Flow Instructions: conditional jumps

j<cc> address or offset

Jump to **address** if and only if a certain condition is verified

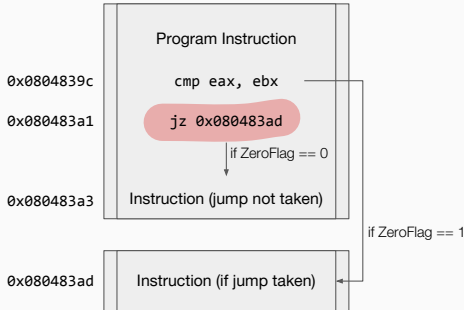
<cc>: condition

- O, NO, S, NS, E, Z, NE, ...
- based on one or more status flags of EFLAGS

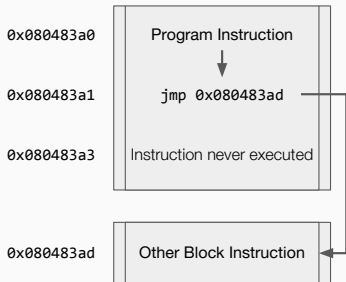
Examples:

- jz = jump if zero
- jg = jump if greater than
- jlt = jump if less than

Reference: <http://www.unixwiz.net/techtips/x86-jumps.html>



# Control-Flow Instructions: unconditional jump `jmp`



- `jmp` address or offset
- Unconditional jump: just set the **EIP** to **address**
- Can be also *relative*: increment or decrement EIP by an offset

## Exercise 1

Translate the following C code in assembly x86. Assume  $EBX \leftarrow b$ ,  $ECX \leftarrow c$ . Finally,  $a$  goes in  $EAX$ .

```
if (c == 0)
    a = b;
else
    a = -b;
```



# Solution

```
mov edx, 0
cmp ecx, edx
jne ELSE
mov eax, ebx
jmp ENDIF
ELSE:
mov eax, 0
sub eax, ebx
ENDIF:
nop
...
```

## Exercise 2

Translate the following C code in assembly x86. The variable `a` goes in EAX.

```
a = 0;
for(i = 0; i < 10; i++)
    a += i;
```

# Solution

```
    mov eax, 0
    mov ebx, 0
    mov ecx, 10
LOOP:
    cmp ebx, ecx
    jge END
    add eax, ebx
    inc ebx
    jmp LOOP
END:
    nop
    ...
```

## A very simple example (what does it do?)

Assume that the input is in registers: ECX and EDX; output: EAX

```
    mov eax, ecx
    mov ebx, edx
    cmp ebx, 0
    jz LABEL
LOOP:
    cmp ebx, 1
    jle RET
    mul ecx
    sub ebx, 1
    jmp LOOP
LABEL:
    mov eax, 1
RET:
    ...
```

# Load effective address (lea)

- lea destination, source  
**source**: memory location  
**destination**: register
- Like a mov, but it is storing the pointer, not the value
- It does NOT access memory

## Example

Registers		Memory	
EAX	0x00000000	0x7C81776F	0x00403A40
		0x7C911000	0x00403A44
EBX	0x00403A40	0x0012C140	0x00403A48
	...	0x7FFDB000	0x00403A4C

lea eax, [ebx + 8] → EAX = 0x00403A48

**N.B.:** with mov eax, [ebx+8] → EAX = 0x0012C140

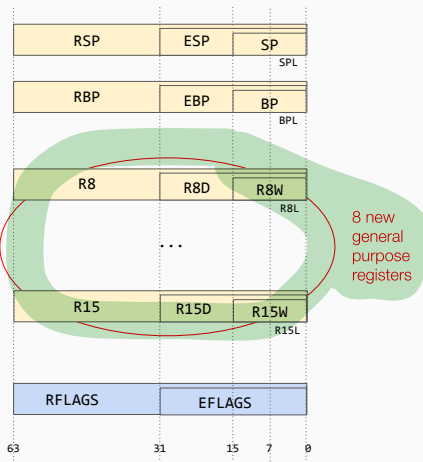
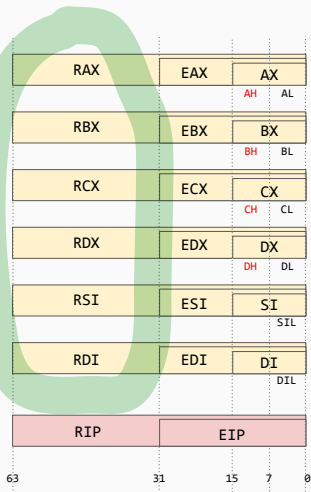
## Basic Instructions: `nop`

- `nop` = **No Operation**. Just move to next instruction.
- The opcode is pretty famous and is `0x90`
- Really useful in exploitation (we will see!)

# Interrupts and Syscalls

- `int` value
  - **value**: software interrupt number to generate (0-255)
  - Every OS has its set of interrupt numbers (e.g., 80h for Linux system calls)
- `syscall` used for Linux 64-bit
- `sysenter` used by Microsoft Windows

# The x86\_64 ISA



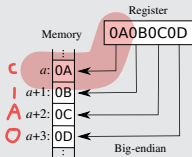


# Endianness

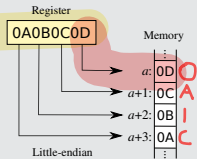
**Endianness:** convention that specifies in which order the bytes of a data word are lined up sequentially in memory.

## Big-endian (left)

Systems in which the *most significant* byte of the word is stored in the *smallest address* given.



## Little-endian



Systems in which the *least significant* byte is stored in the *smallest address*.  
IA-32 is "little endian".



# Program Layout and Functions

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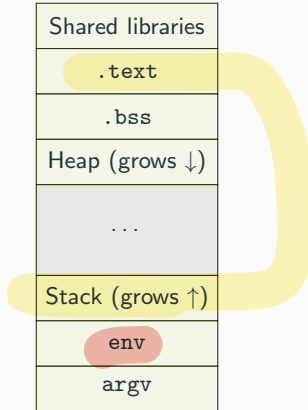
# How an executable is mapped to memory in Linux (ELF)



Executable	Description
.plt	This section holds stubs which are responsible of external functions linking.
.text	This section holds the "text," or executable instructions, of a program.
.rodata	This section holds read-only data that contribute to the program's memory image
.data	This section holds initialized data that contribute to the program's memory image
.bss	This section holds uninitialized data that contributes to the program's memory image. By definition, the system initializes the data with zeros when the program begins to run.
.debug	This section holds information symbolic debugging.
.init	This section holds executable instructions that contribute to the process initialization code. That is, when a program starts to run, the system arranges to execute the code in this section before calling the main program entry point (called main for C programs).
.got	This section holds the global offset table.

# Simplified program memory layout

Low addresses (0x80000000)



High addresses (0xbfffffff)

# The Stack

- LIFO (last in first out) data structure
- Used to manage functions
  - local variables
  - return addresses
  - ...
- Handled through the register ESP (stack pointer)
- Remember: the stack grows **toward lower addresses** (downward the address space)

# Stack Management Instructions: `push`

`push` immediate or register

Stores the immediate or register value at the top of the stack and decrements the ESP of the **operand size**

## Example

Initial condition: `EAX = 30`

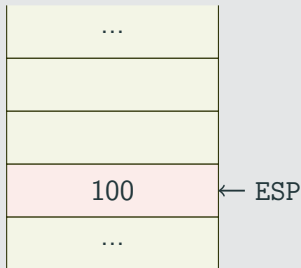
`push eax`

is equivalent to:

`sub esp, 4`

`mov DWORD PTR [esp], eax`

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High addresses (0xbfffffff)

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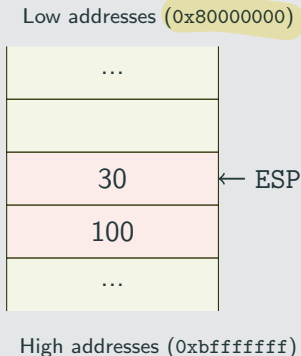
Final condition: `EAX = 30`

`push eax`

is equivalent to:

`sub esp, 4`

`mov DWORD PTR [esp], eax`





# Stack Management Instructions: pop

pop destination

Loads to the destination a word off the top of the stack, then it increases ESP of the operand's size.

## Example

Initial condition: EAX = ???

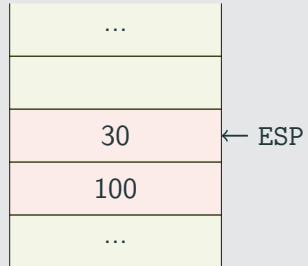
pop eax

is equivalent to:

`mov eax, DWORD PTR [esp]`

`add esp, 4`

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Stack Management Instructions: pop

pop destination

Loads to the destination a word off the top of the stack, then it increases ESP of the operand's size.

## Example

Initial condition: EAX = 30

pop eax

is equivalent to:

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mov eax, DWORD PTR [esp]
```

```
add esp, 4
```



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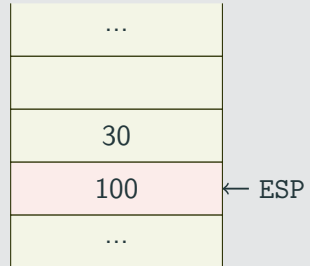
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is equivalent to:

mov eax, DWORD PTR [esp]

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Low addresses (0x80000000)



High addresses (0xbfffffff)

# Calling a function

Instruction `call`:

- Push to the stack the address of the next instruction
- Move the address of the first instruction of the callee into EIP

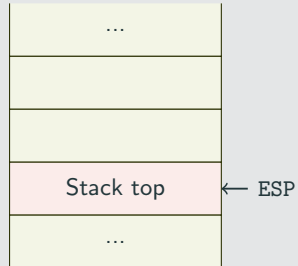
**Example: Let's call `func`, located at `0x800bff00`**

Equivalent to:

- `push address(of the instruction after the call!)`
- `jmp func`

(reminder: we can't read or set EIP directly!)

Low addresses (`0x80000000`)



High addresses (`0xbfffffff`)

EIP = `0x8001020`

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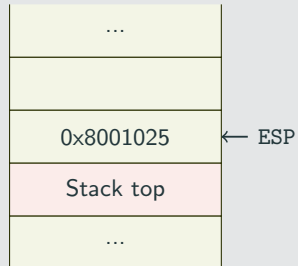
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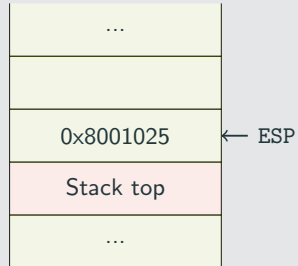
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EIP = `0x800bff00`

# Returning from a function

Instruction `ret`:

- Restores the return address saved by `call` from the top of the stack

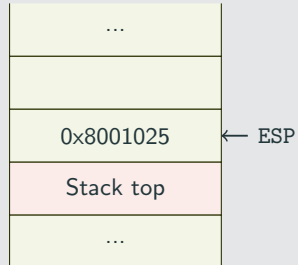
**Example: let's return from `func`**

Equivalent to:

- `pop eip`

(remind: we can't read or set EIP directly!)

Low addresses (0x80000000)



High addresses (0xbfffffff)

EIP = 0x800bff00

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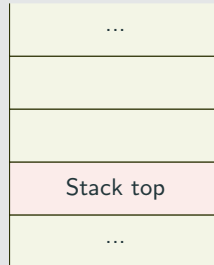
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Equivalent to:

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(reminds: we can't read or set EIP directly!)

Low addresses (0x80000000)



← ESP

High addresses (0xbfffffff)

EIP = 0x8001025

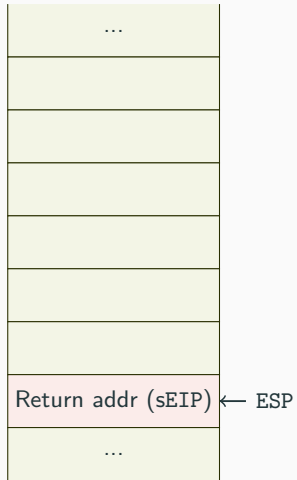


# Functions and Stack Frames

At the beginning of a function, the function itself must reserve space for its local variables.

```
void foo() {  
    int a;  
    int b;  
    int c;  
  
    b = 0;  
}
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

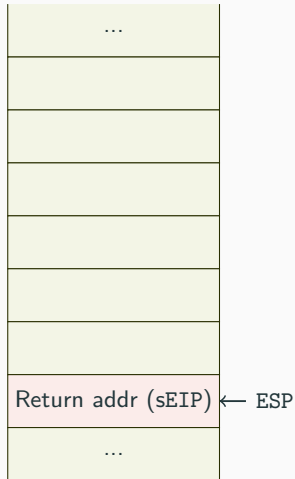
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F00:

```
mov ebp, esp
sub esp, 0xc
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

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High addresses (0xbfffffff)

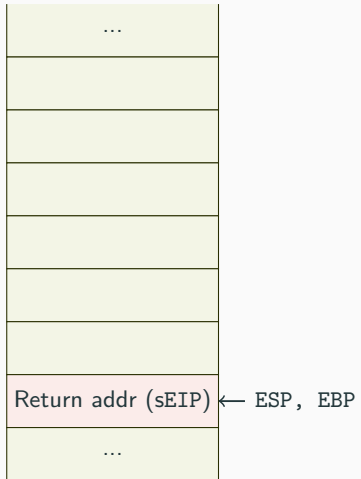
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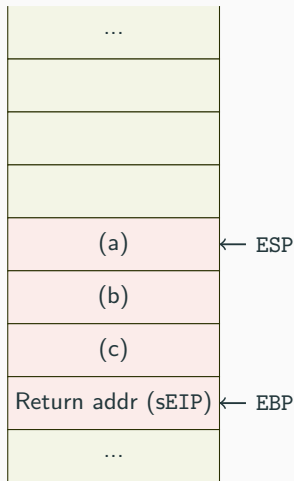
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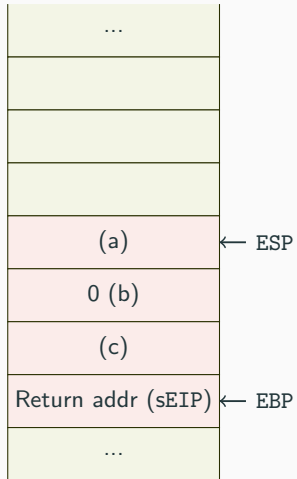
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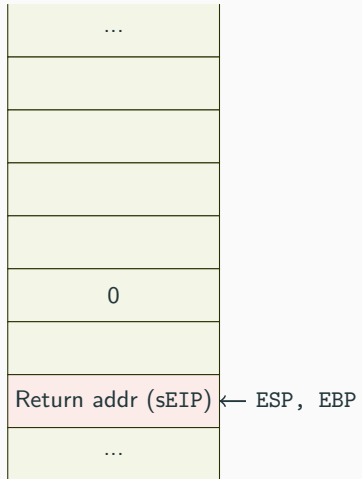
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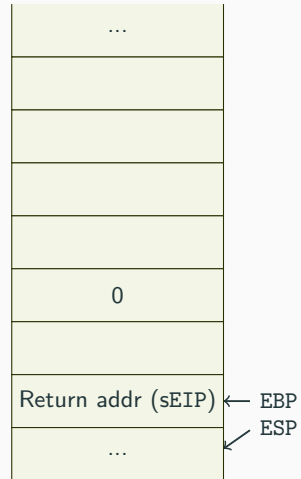
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mov ebp, esp
sub esp, 0xc
mov [ebp - 0x8], 0x0
add esp, 0xc
ret ←
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

That works!!! But what if foo calls bar.

```
void foo() {  
    int a;  
    int b;  
    int c;  
  
    bar();  
    b = 0;  
}  
  
void bar() {  
    int d;  
  
    d = 1;  
}
```



# Functions and Stack Frames

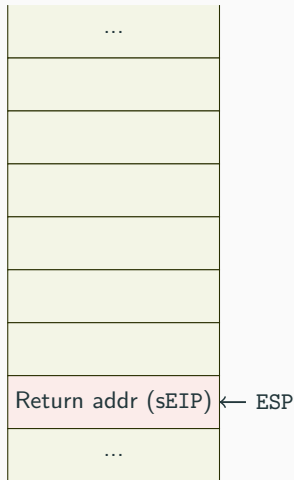
F00:

```
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1
add esp, 0xc
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

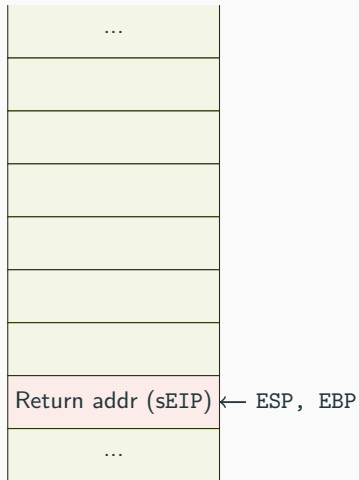
F00:

```
mov ebp, esp ←  
sub esp, 0xc  
call BAR  
mov [ebp - 0x8], 0x0  
add esp, 0xc  
ret
```

BAR:

```
mov ebp, esp  
sub esp, 0x4  
mov [ebp - 0x4], 0x1  
add esp, 0xc  
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

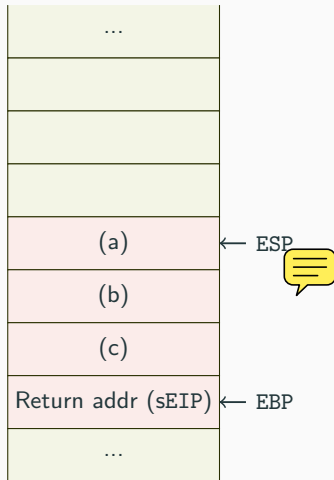
F00:

```
mov ebp, esp
sub esp, 0xc ←
call BAR
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1
add esp, 0xc
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

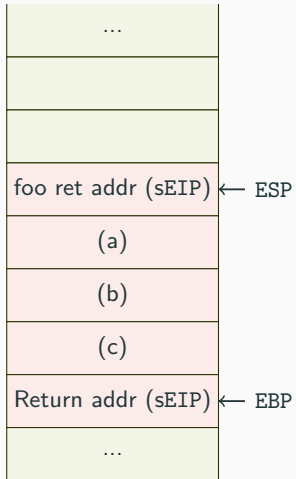
F00:

```
mov ebp, esp
sub esp, 0xc
call BAR ←
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1
add esp, 0xc
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

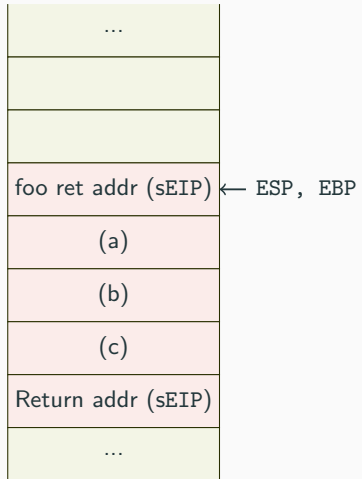
F00:

```
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp ←
sub esp, 0x4
mov [ebp - 0x4], 0x1
add esp, 0xc
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

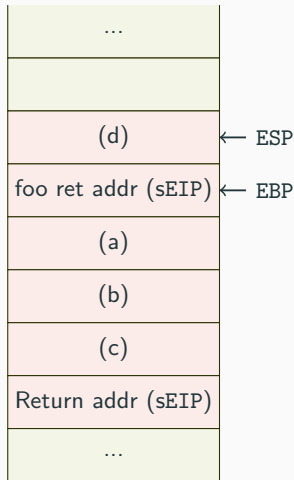
F00:

```
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4 ←
mov [ebp - 0x4], 0x1
add esp, 0xc
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

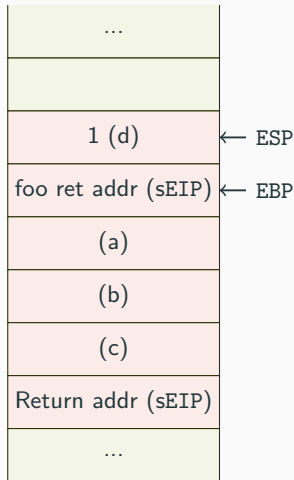
F00:

```
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1 ←
add esp, 0xc
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

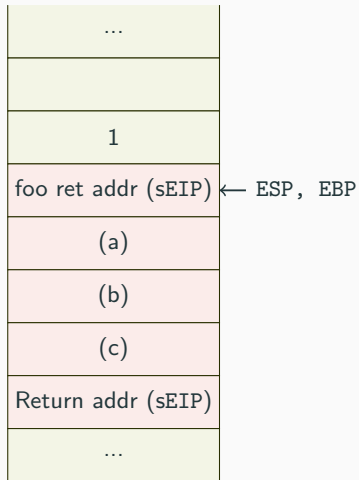
F00:

```
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1
add esp, 0xc ←
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)



# Functions and Stack Frames

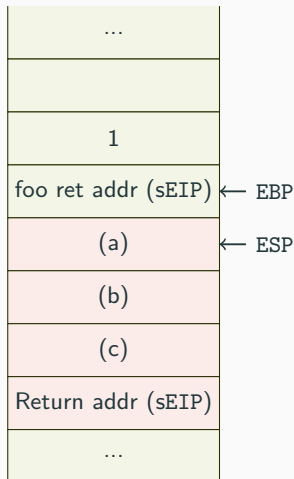
F00:

```
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1
add esp, 0xc
ret ←
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames

Wrong memory access!!! EBP changed and we lost the old value!

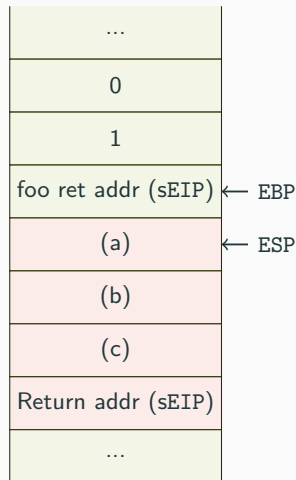
FOO:

```
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0 ←
add esp, 0xc
ret
```

BAR:

```
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1
add esp, 0xc
ret
```

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Functions and Stack Frames



Redacted!

F00:

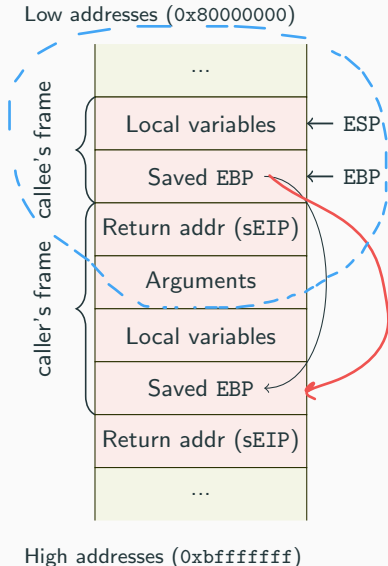
```
push ebp
mov ebp, esp
sub esp, 0xc
call BAR
mov [ebp - 0x8], 0x0
leave
ret
```

BAR:

```
push ebp
mov ebp, esp
sub esp, 0x4
mov [ebp - 0x4], 0x1
leave
ret
```

# Functions and Stack Frames

- Stack frame = stack area allocated to a function
- EBP register: pointer to the beginning (base) of a function's frame
- At the beginning of a function:
  - Save EBP to stack
  - Set EBP to the address of the function's frame



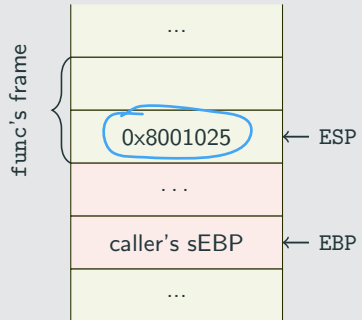
# Entering a function

**Example: We've just called `func`, located at `0x800bff00`**

Setup the stack frame

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

Low addresses (`0x80000000`)



High addresses (`0xbfffffff`)

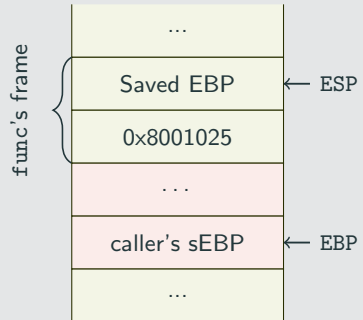
# Entering a function

**Example: We've just called `func`, located at `0x800bff00`**

Setup the stack frame

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

Low addresses (`0x80000000`)



High addresses (`0xbfffffff`)

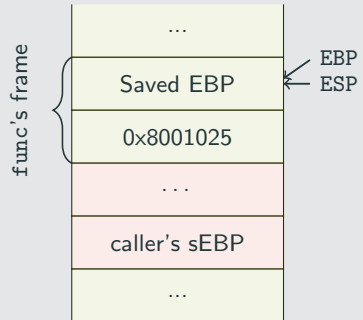
# Entering a function

**Example: We've just called `func`, located at `0x800bff00`**

Setup the stack frame

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

Low addresses (`0x80000000`)



High addresses (`0xbfffffff`)

# Leaving a function

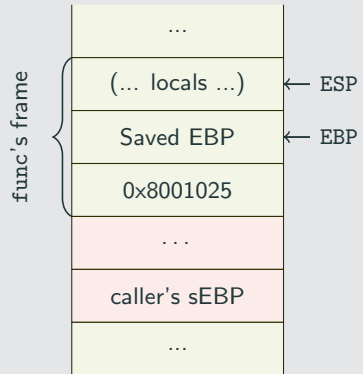
Instruction `leave`: restores the caller's base pointer

**Example: We're about to return from `func`**

Equivalent to:

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

Low addresses (0x80000000)



High addresses (0xbfffffff)



# Leaving a function

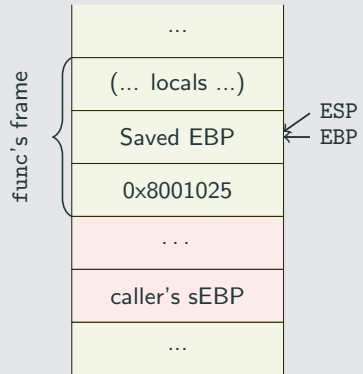
Instruction `leave`: restores the caller's base pointer

**Example: We're about to return from `func`**

Equivalent to:

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

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Leaving a function

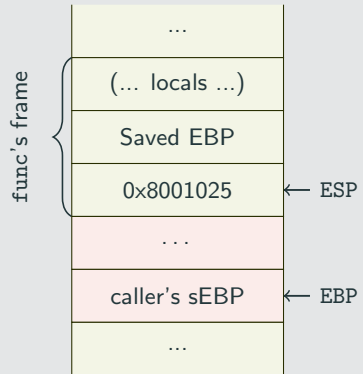
Instruction `leave`: restores the caller's base pointer

**Example: We're about to return from `func`**

Equivalent to:

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

Low addresses (0x80000000)



High addresses (0xbfffffff)

# Calling Conventions

- Defines
  - how to pass parameters (stack, registers or both, and who is responsible to clean them up)
  - how to return values
  - caller-saved or callee-saved registers
- The high-level language, the compiler, the OS, and the target architecture all together “implement” and “agree upon” a certain calling convention
  - it's part of the **ABI**, the Application Binary Interface

## Calling Conventions: cdecl (C declaration)

- Default calling convention used by most x86 C compilers
  - Can be forced with the modifier `_cdecl`
- Arguments: passed **through the stack**, right to left order
- Cleanup: the **caller removes** the parameters from the stack *after* the called function completes
- Return: register EAX
- Caller-saved registers: EAX, ECX, EDX (other are callee-saved)

## cdecl: Example

```
void demo_cdecl(int a, int b, int c, int z);
```

```
//...
```

```
demo_cdecl(1, 2, 3, 4); //calling
```

```
; ...
```

```
push 4 ; push last parameter value
```

```
push 3 ; push third parameter value
```

```
push 2 ; ...
```

```
push 1
```

```
call demo_cdecl ; call the subroutine
```

```
add esp, 16 ; clean up the stack
```

## Calling Conventions: `fastcall` (C declaration)



- Default calling convention used by most x86\_64 C compilers
  - Can be forced with the modifier `_fastcall`
- Parameters passed **in registers**: `rdi`, `rsi`, `rdx`, `rcx`, `r8`, `r9`, subsequent ones on the stack (reverse order, caller cleanup)
- Callee-saved registers: `rbx`, `rsp`, `rbp`, `r12`, `r13`, `r14`, and `r15`
- Caller-saved registers (scratch): `rax`, `rdi`, `rsi`, `rdx`, `rcx`, `r8`, `r9`, `r10`, `r11`
- Return value: `rax` (if 128-bit: `rax` and `rdx`)

# Linux x86-64 calling convention: Example

```
main:
    push rbp
    mov rbp, rsp
    sub rsp, 16
    mov DWORD PTR [rbp-4], edi
    mov QWORD PTR [rbp-16], rsi
    mov esi, 2 ; Second parameter
    mov edi, 1 ; First parameter
    call function
    mov esi, eax ; Return value -> first param
    mov edi, OFFSET FLAT:.LCO ; "The return ...
    mov eax, 0
    call printf
    leave
    ret
```

```
function:
    push rbp
    mov rbp, rsp
    mov DWORD PTR [rbp-4], edi
    mov DWORD PTR [rbp-8], esi
    mov edx, DWORD PTR [rbp-4]
    mov eax, DWORD PTR [rbp-8]
    add eax, edx
    pop rbp
    ret
```

```
int function (int a, int b) {
    return a + b;
}

int main (int argc, char** argv) {
    return printf("The return value is %d\n",
        function(1,2));
}
```

Low addresses

...
2
1
Saved RBP
Return address
...

High addresses

# Tooling

---



# Shell for Dummies<sup>3</sup>

important paths	/	#root (first) directory
	~/	#your home directory
	.	#current directory
	..	#parent directory
filesystem utils	pwd	#show current directory
	cd <i>path</i>	#change directory to <i>path</i>
	ls <i>path</i>	#list files in the directory at <i>path</i>
	cp <i>path_src path_dst</i>	#copy <i>path_src</i> to <i>path_dst</i> , -r if copying directories
basic text editor	mv <i>path_src path_dst</i>	#move <i>path_src</i> to <i>path_dst</i>
	nano <i>path/file</i>	#opens/create <i>file</i> in <i>path</i> (ctrl+x to exit)
	vim <i>path/file</i>	#opens/create <i>file</i> in <i>path</i> (i to edit; esc, :wq to save and quit)
remote actions	ssh <i>user@server_addr</i>	#ssh to <i>server_addr</i> as <i>user</i>
	scp [ <i>u@s:</i> ] <i>p_src</i> [ <i>u@s:</i> ] <i>p_dst</i>	#cp to/from remote server

<sup>3</sup>cmd --help or cmd -h to get the available options

# Shell for Dummies <sup>4</sup>

file visualization	cat <i>file</i> less <i>file</i> hexdump -Cv <i>file</i>	#print <i>file</i> to stdout #visualize <i>file</i> better, q to quit #visualize raw bytes
redirections	command > <i>file</i> command >> <i>file</i>  command < <i>file</i> cmd1   cmd2	#write stdout of command to <i>file</i> #append stdout of command to <i>file</i>  #use <i>file</i> as stdin of command #stdout of cmd1 as stdin cmd2
argv from command	cmd `cmd2`  cmd \$(cmd2)	#executes cmd2 first and uses the output to eval the next command
other useful commands	chmod +x <i>file</i> grep <i>expression</i> python -c 'cmd1;cmd2;...'	#give exec permission to <i>file</i> #search for <i>expr</i> in stdin #executes python commands

<sup>4</sup>cmd --help or cmd -h to get the available options

- `man objdump`  
objdump **displays information** about one or more **object files**.
- `-x` all-headers
- `-d` disassemble
- `-M intel` intel syntax (default is AT&T)

- **What is GDB?**

GDB is GNU Project's Debugger: allows to follow, step by step, at assembler-level granularity, a running program, or what a program was doing right before it crashed.<sup>5</sup>

---

<sup>5</sup><http://www.gnu.org/software/gdb/>

# Start, break and navigate the execution with gdb

- Suppose you have an executable binary and want run it
  - **`gdb /path/to/executable`** loads the binary in gdb
- Now you decide to start the program with two parameters
  - **`run 1 "abc"`** passes 1 via `argv[1]` and "abc" as `argv[2]`
  - **`run 'printf "AAAAAAAAAAAAAA"'`** (with the back ticks)  
we're passing the output of the print (very useful when you need to pass non printable characters such as raw bytes)
- Suppose you want to stop the execution at the address of a certain instruction
  - **`break *0xDEADBEAF`** places a break point at that address
  - **`break *main+1`** with debugging symbols this can be less painful
  - **`catch syscall`** block the execution when a syscall happens

# Start, break and navigate the execution with gdb

- Now the execution stops at our break point. Here we can do several things
- Examples:
  - **ni** allows to proceed instruction per instruction
  - **next 4** moves 4 lines ahead (if you have the line-numbers information in the binary)
  - **si** step into function
  - **finish** run until the end of current function
  - **continue** runs until the next break point (if any)
- To see info about the execution state:
  - **info registers** to inspect the content of the registers
  - **info frame** to see the values of the stack frame related to the function where we are in
  - **info file** print the information about the sections of the binary



# Navigate the stack

- Suppose we're stopped somewhere in the code and want to inspect the stack
- Some useful view of the stack is achievable with:
  - **x/100wx \$esp** prints 100 words of memory from the address found in the ESP to ESP+100 (x = hexadecimal formatting)
  - **x/10wo \$ebp-100** prints 10 words of memory from EBP-100 to EBP-100+10 (o = octal formatting)
  - **x/s \$eax** prints the elements pointed by EAX (s = string formatting)
- Do you have debug symbols? (i.e., gcc -ggdb)
  - **print args** prints info about the main parameters
  - **print a** prints the content of variable 'a'
  - **print \*b** prints the value pointed by 'b'

# Our friend gdb

- **The '~/.gdbinit' file**

Gdb is a command line tool and it supports the configuration script as almost all the \*nix software.

Some options that you may want to tune are:

- **set history save on**

To have the latest commands always available also when we re-open gdb

- **set follow-fork-mode child**

Allows you, if the process spawns children, to follow them and not only wait their end.

- **set disassembly-flavor [intel | att]**

This option sets in which predefined syntax your disassembled will be showed up. The default one is at&t

- Highly recommended to install pwndbg  
<https://github.com/pwndbg/pwndbg>



# GDB - How to Survive <sup>6</sup>

## start

`gdb -q program`

#starts gdb silently for program

## disassemble

`set disassembly-flavor intel`  
`disass *address (or f-name)`

#sets intel syntax  
#disassemble from given address

## run program

`run (r)`  
`start`  
`run arg1`  
`run <<< arg1`

#runs the program  
#runs the program and imm. stops  
#runs program with *arg1* in argv  
#runs program with *arg1* in stdin

## memory layout

`vmmap`

#show memory layout

<sup>6</sup>CTRL + C to Break and Debug

# GDB - How to Survive <sup>7</sup>

execution	stepi (si) nexti (ni) finish (f) continue (c)	#exec next inst - enters a function #exec next inst - skips the function #exec till next return statement #continue exec till next break/ watch
breakpoints	b *address b *address if \$reg==val del br_num	#set software breakp at address #set conditional breakp #remove breakpoint br_num
watchpoints	w *address rw *address	#set watch for write at address #set watch for read at address
examine	x/numF *address search string p symbol	#show num data of type F (useful Fs are bx, wx, gx, c, s, i) #search for string in memory #print address of symbol

<sup>7</sup>CTRL + D to Exit

- Intercepts and records system calls and signals
- Dumps to standard error name, argument and return value of each system call

## Useful options

- `-p <pid>` attach to existing process
- `-f` trace child process
- `-o <filename>` output to file
- `-e <expr>` modifies which events to trace (see manpage)

- Intercepts and records dynamic library calls
- Similar to strace, but at a different layer

**Questions?**