Practical Assembly

From the Ground Up

John Cunniff
OSIRIS Lab Hack Night

Overview - Rev 2

- Overview
  - Who is this for?
  - Whats assembly?
  - Why should we learn it?
  - Required Mindset
- Basic Assembly topics
  - Memory
  - Registers
  - Basic instructions
- Advanced Topics
  - Registers (again)
  - Memory layout
  - Stack Frame
- Helpful tools!
  - objdump
  - Binary Ninja
  - godbolt.org

Overview

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  - We're going to start with very abstract concepts
  - Build up to what it actually looks like

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  - The answer is “machine code”
  - Machine code is translated from Assembly
- Machine code is what your cpu is able to actually interpret and run
- The instructions can let you modify the cpu, memory and other physical devices *directly*

Why should we learn assembly?

Why should we care at all?

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- Bugs at this low level lead to vulnerabilities
- Better our understanding of how computers work!
  - Everything that runs has to be in one way or another translated back to assembly
  - There is no avoiding it!
  - The computer you're viewing this lecture from, the stream your watching it on, the servers all that data is passing through, all assembly

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    - That application will be a compiled program of "machine code"
    - Using special tools we can figure out how the application works!
    - This is called "reverse engineering"

Required Mindset

Going into assembly

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        - C is easily readable and can be basically directly connected back to assembly

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- This lecture will focus on 32bit x86
  - Almost all modern computers are 64bit now
  - Only small differences!

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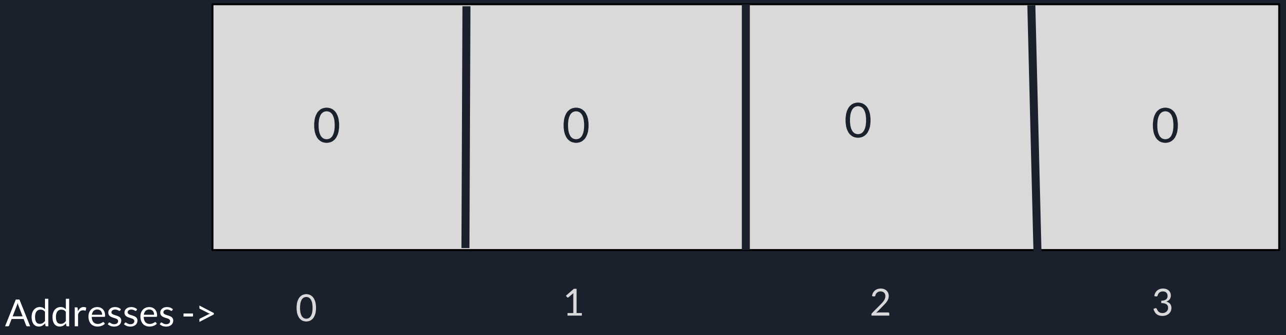
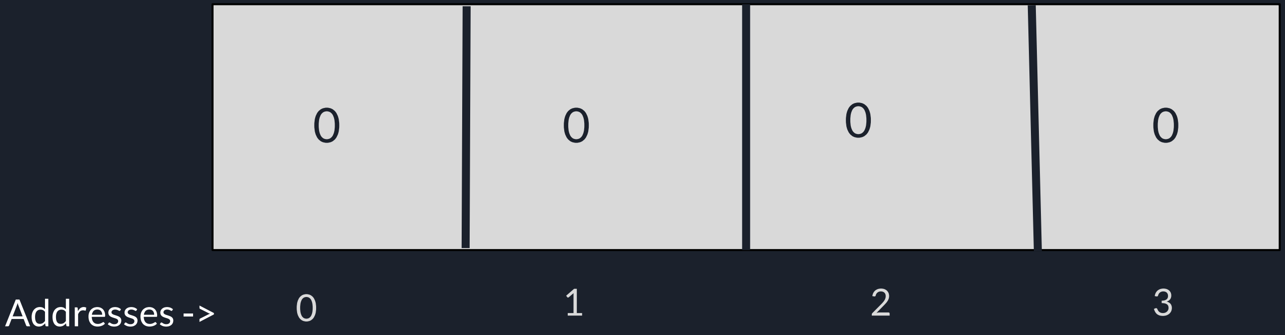


The basics - Memory

- In assembly we move values in and out of memory one at a time



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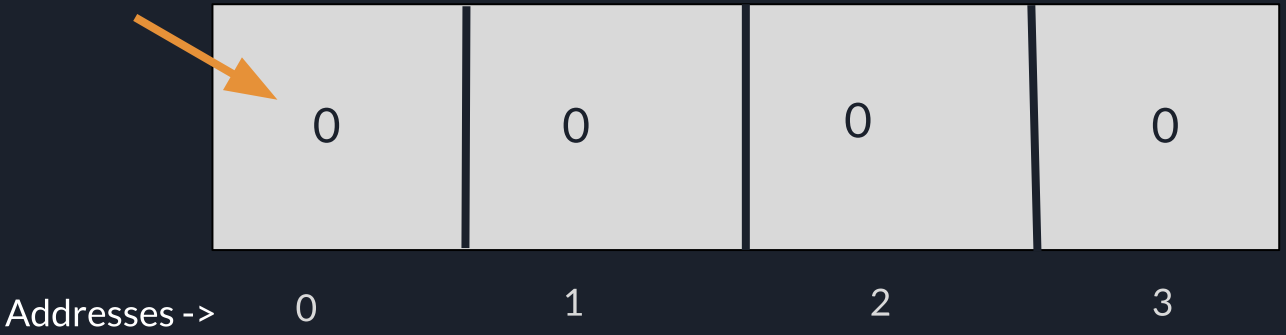

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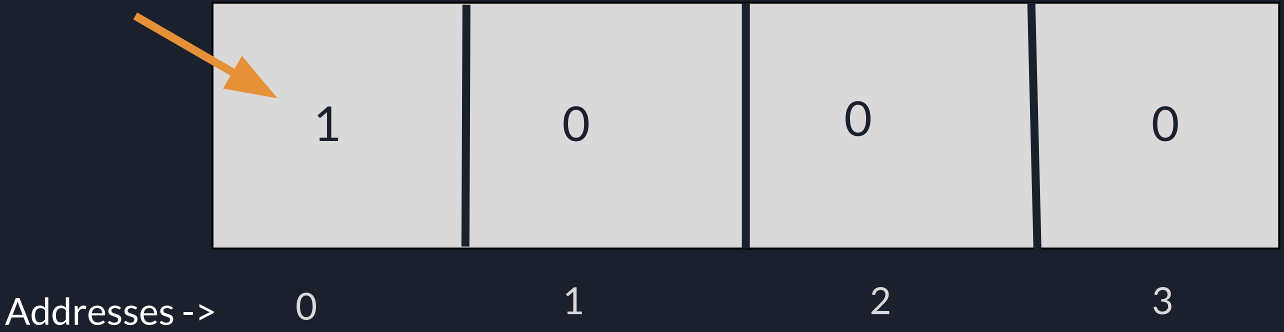

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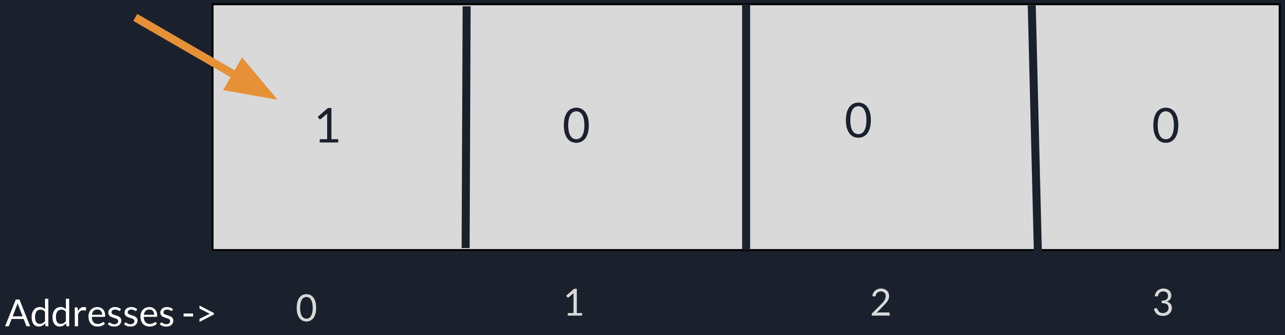
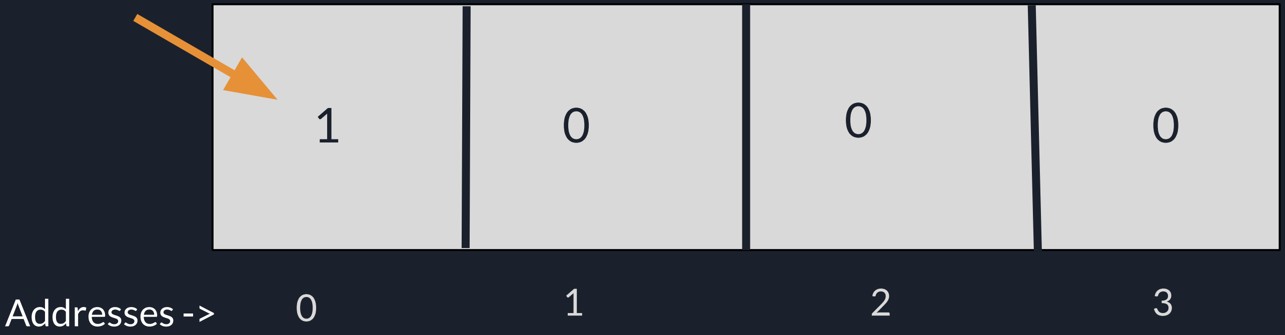
- In assembly this would be: mov [0], 1



The basics - Memory

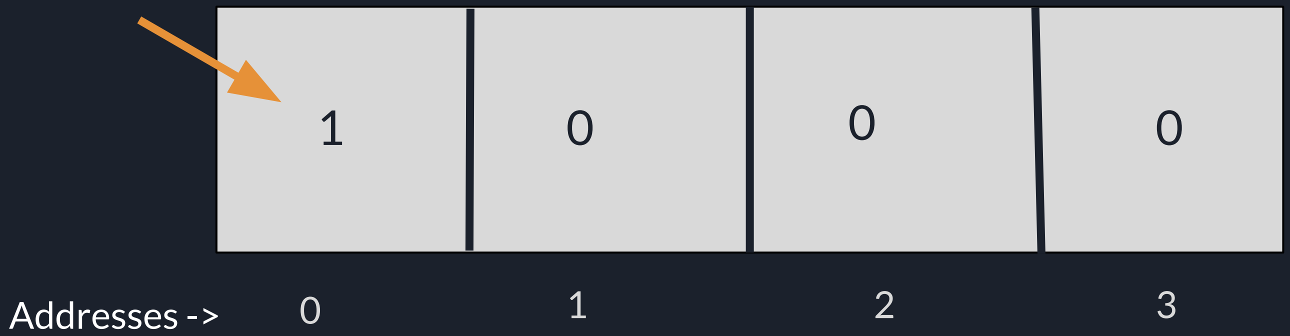
The brackets mean "dereference"

- mov [destination address], source



The basics - Memory

- mov [destination address], source
- Where destination address is the index (0) and source is the value of the new number (1)



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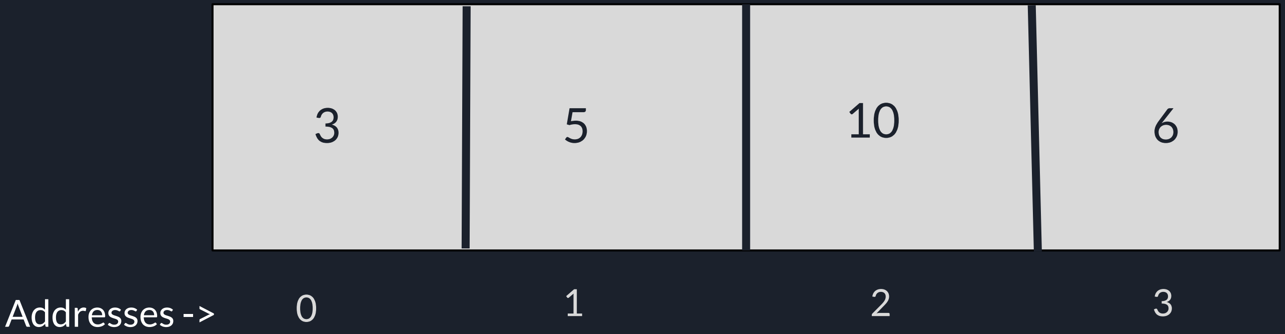
- So what will “mov [2], 3” do?



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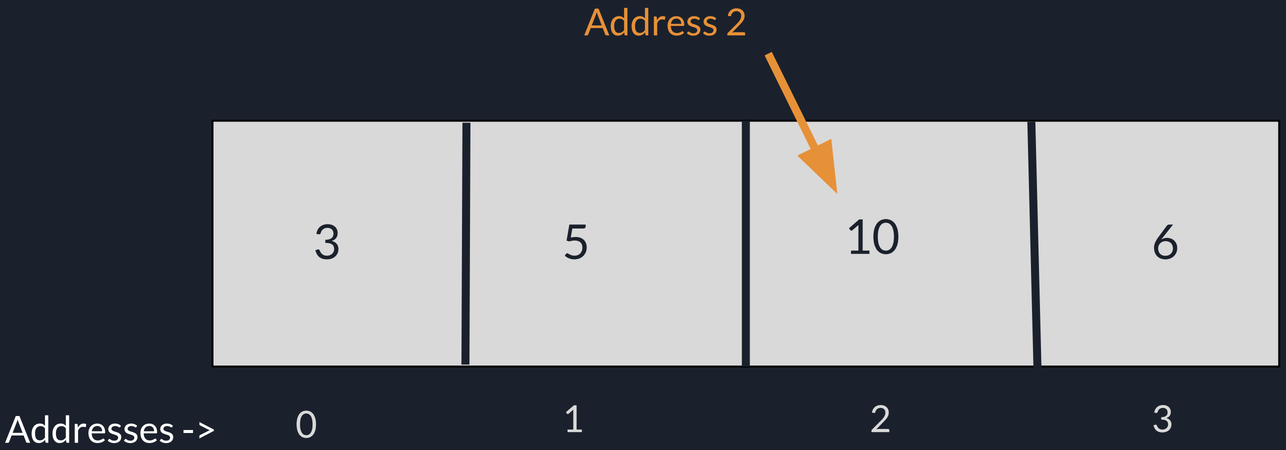

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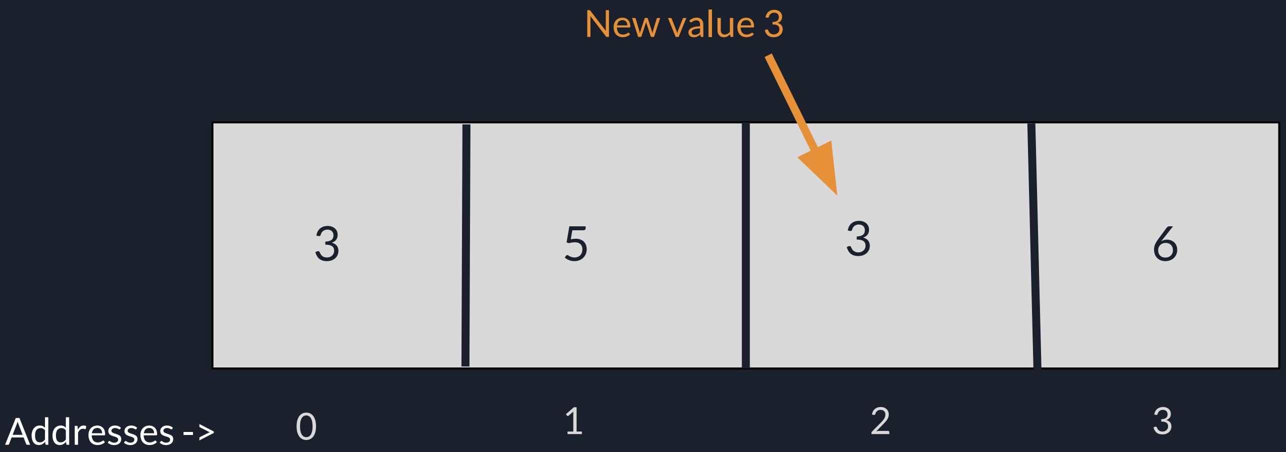

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- Hold small amounts of data
- Perform super fast operations
  - Much faster than memory

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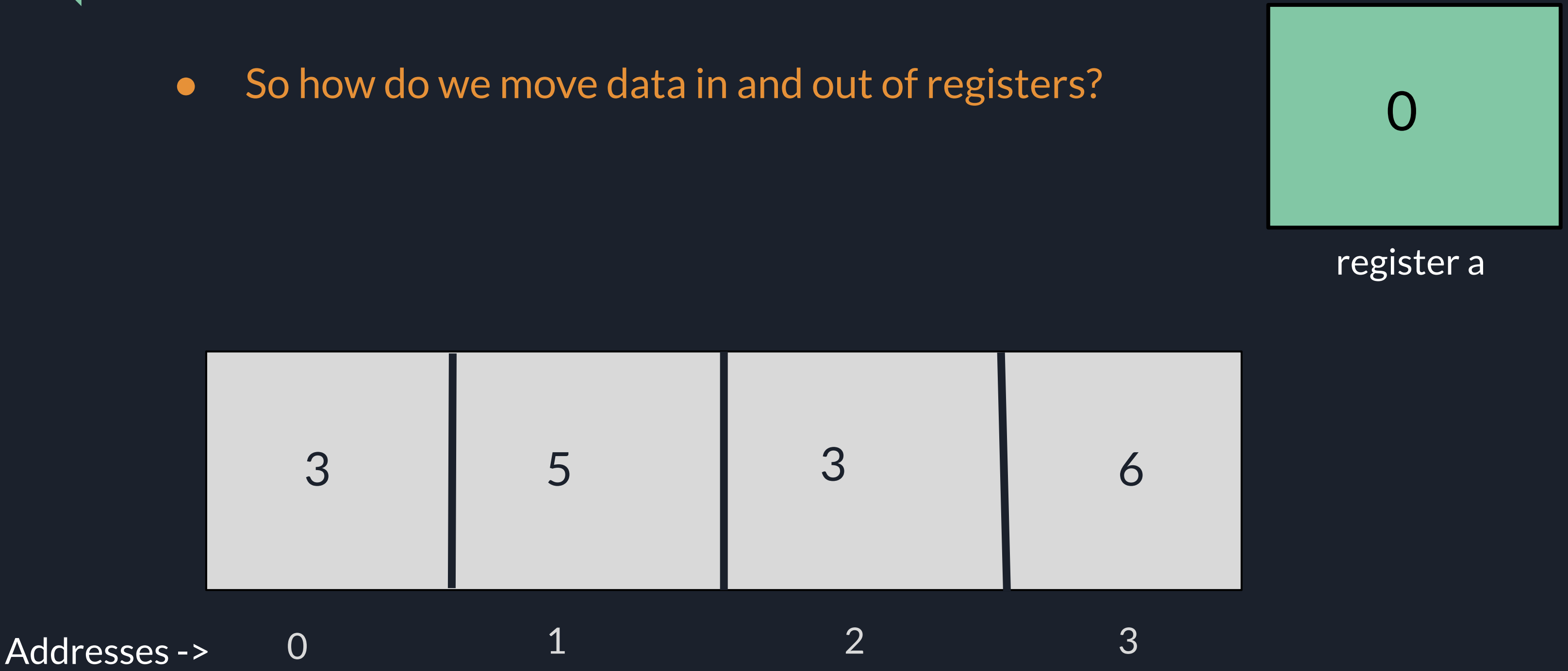

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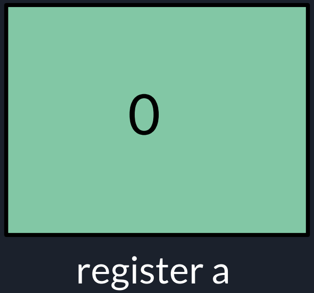
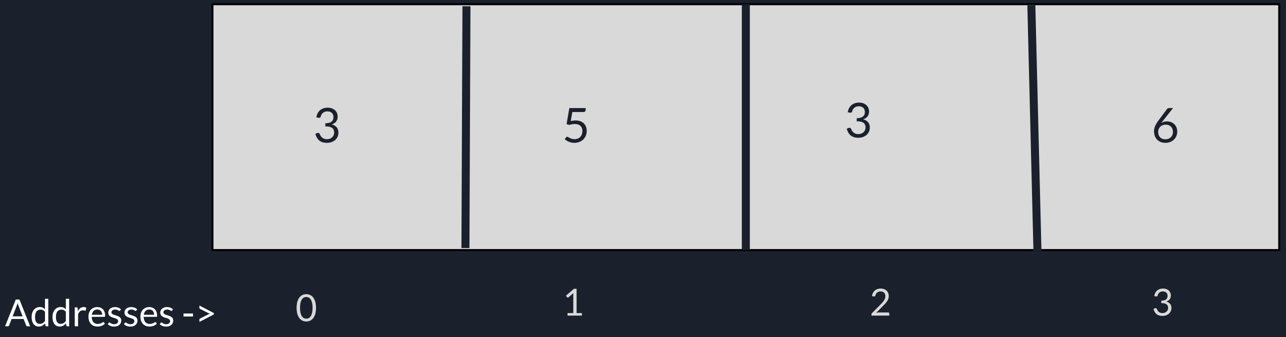
Remember its:
mov dst, src

- So how do we move data in and out of registers?
- mov a, 10





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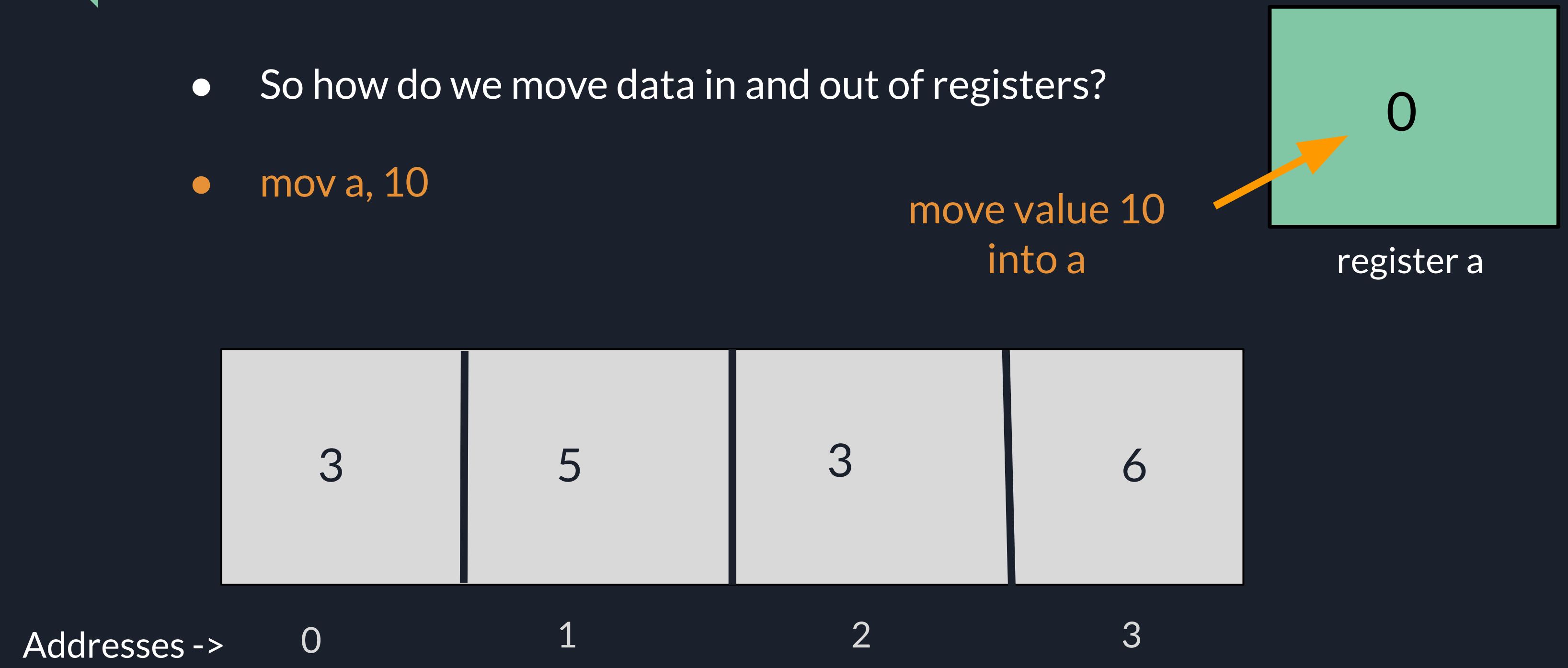

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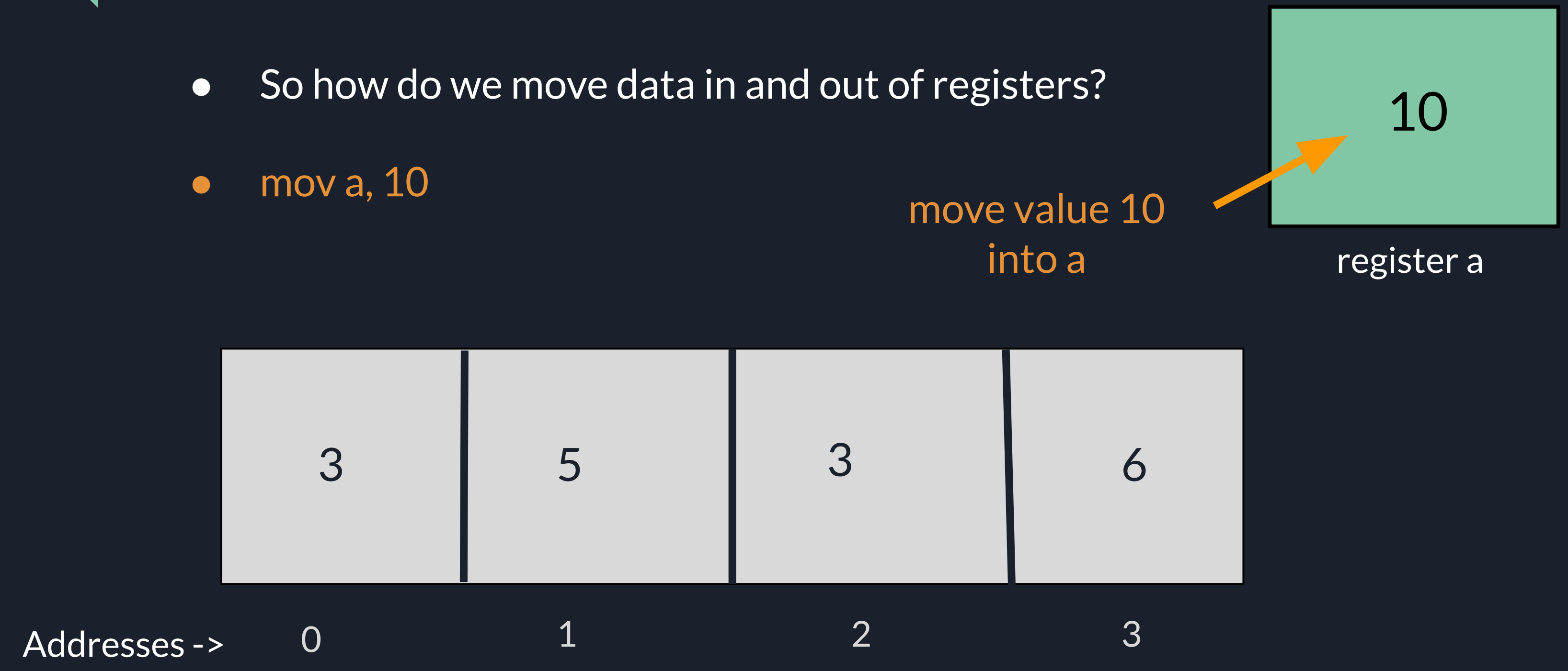

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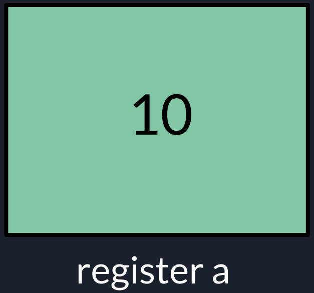

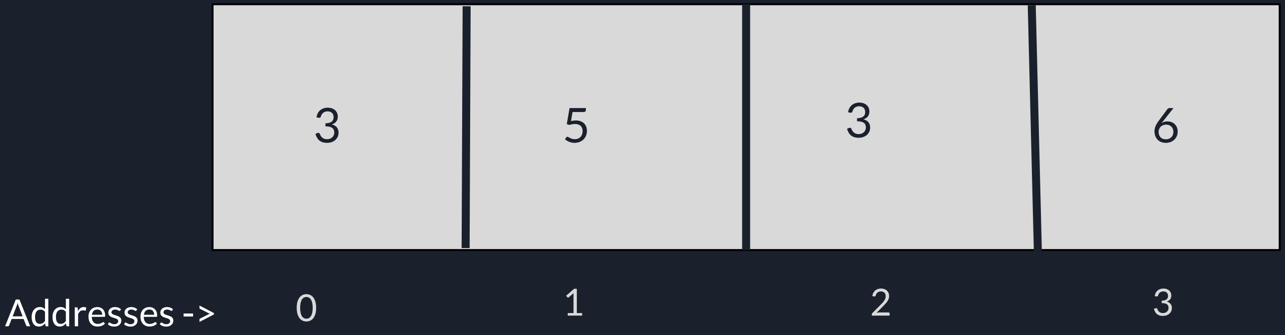

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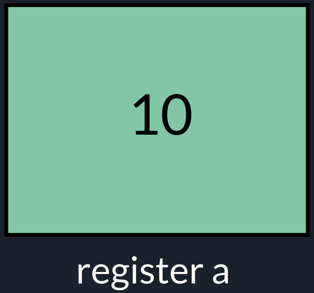

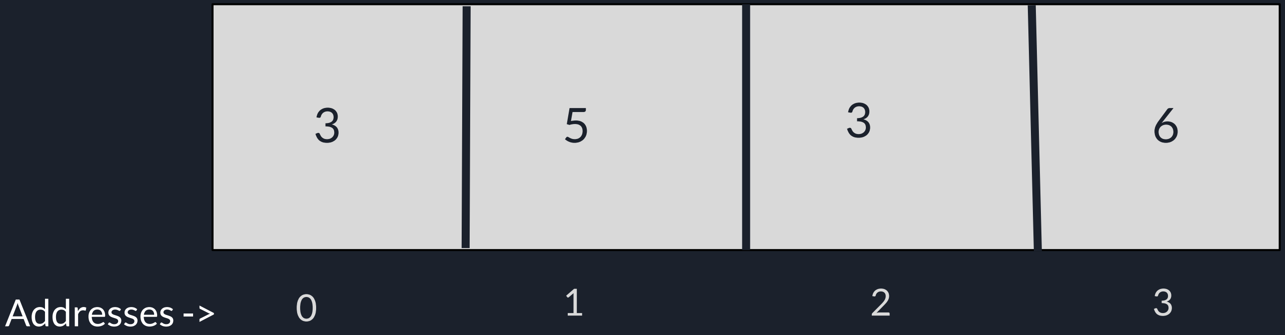

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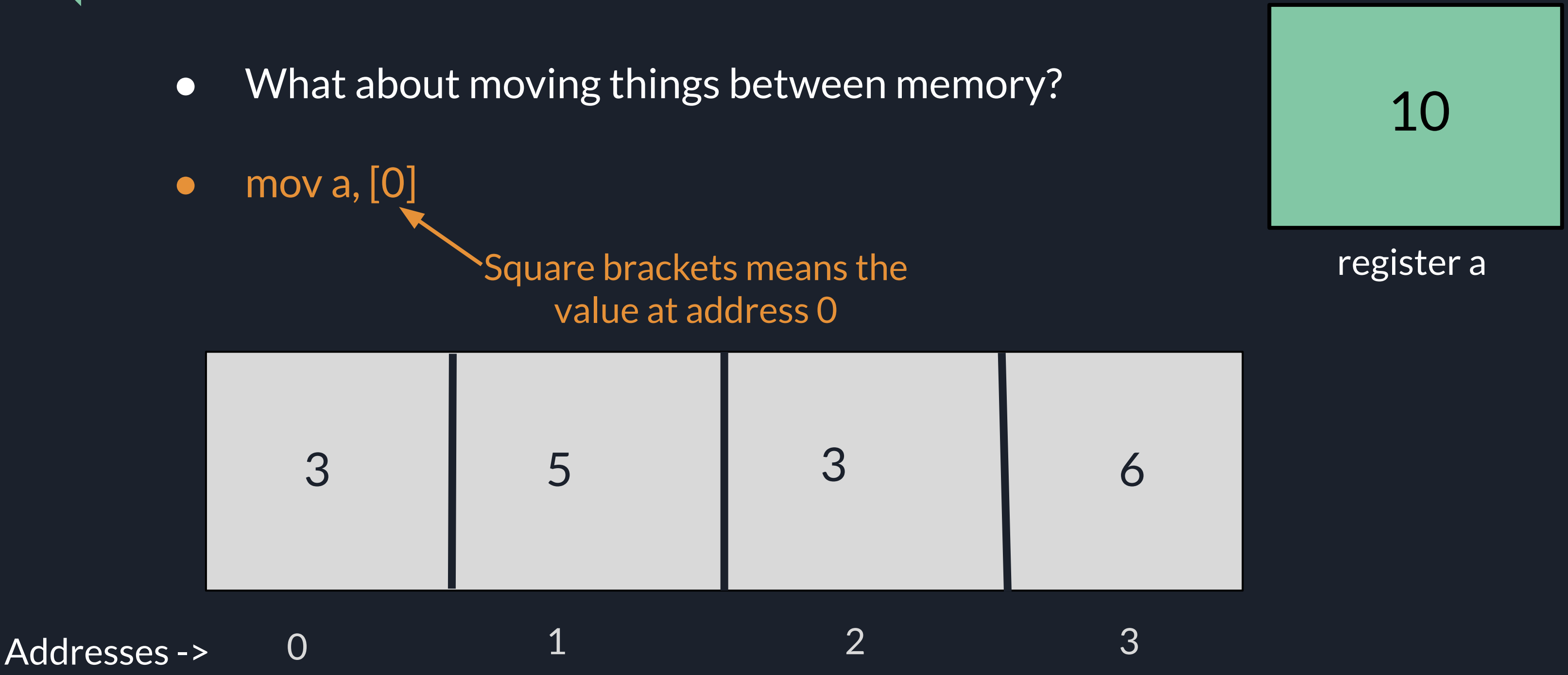
Square brackets means the value at address 0



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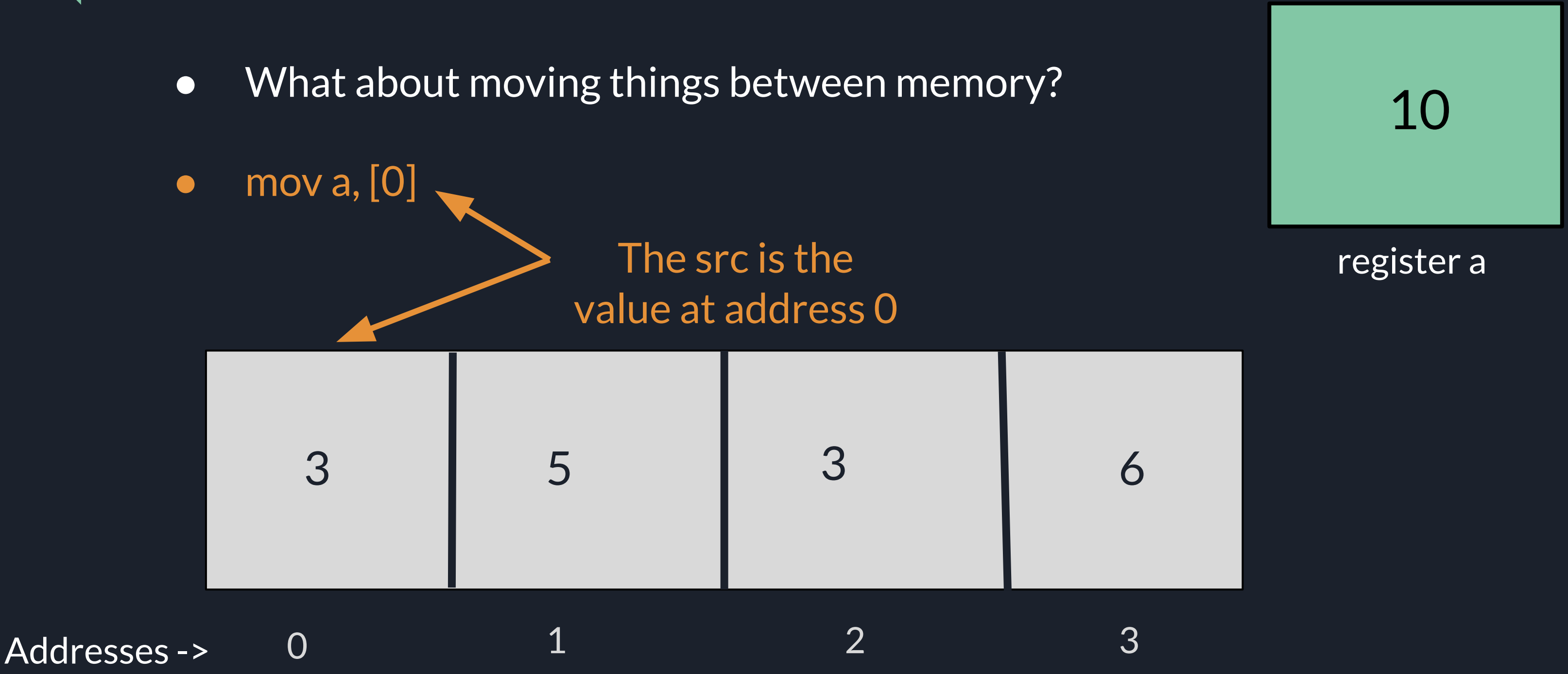
The src is the value at address 0



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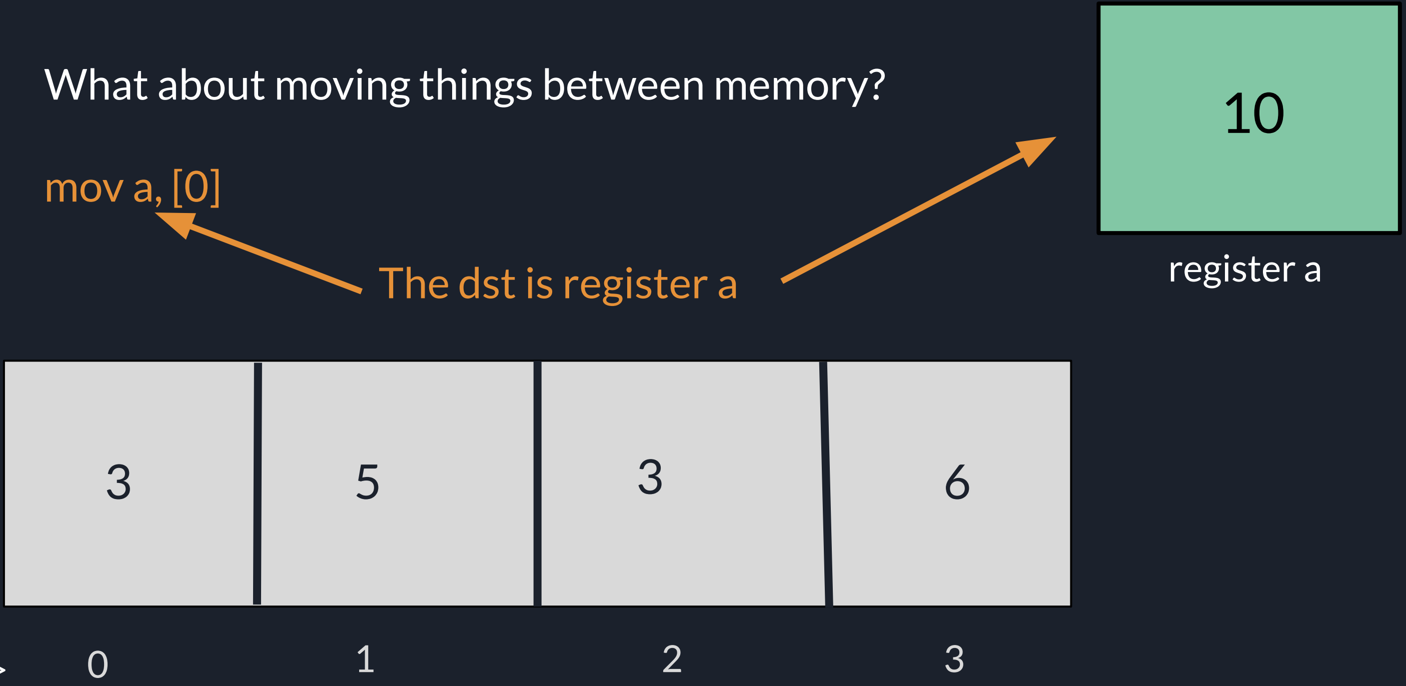

Addresses ->

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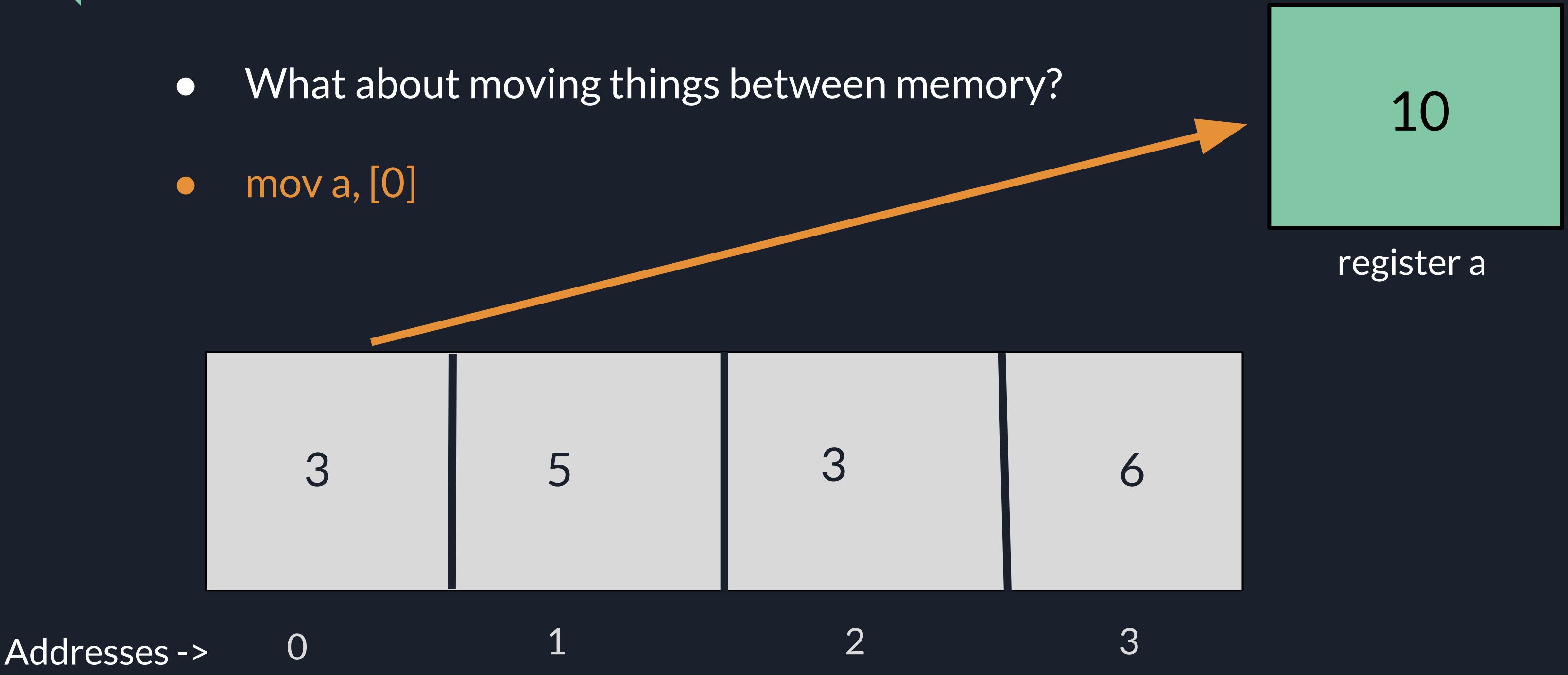

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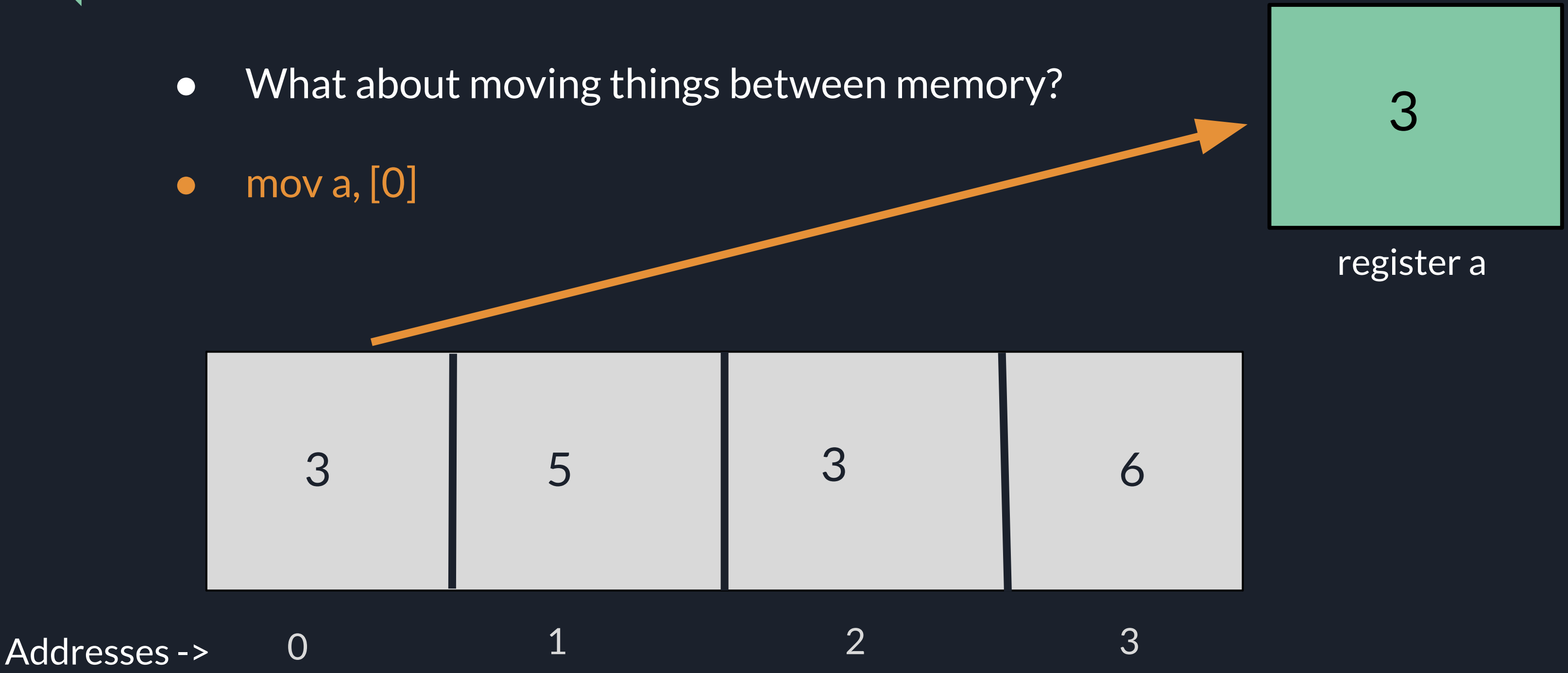

The basics - Registers

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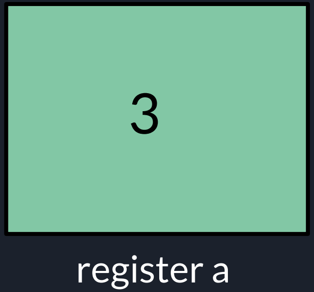

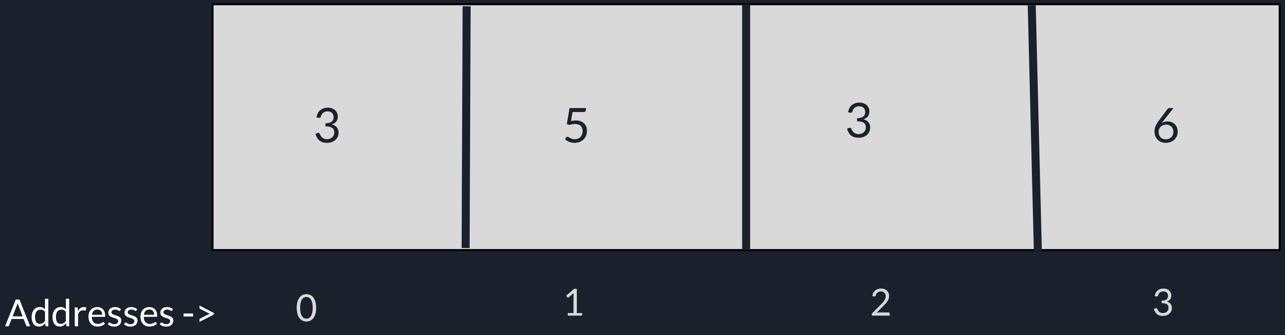

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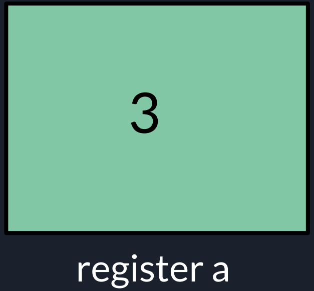
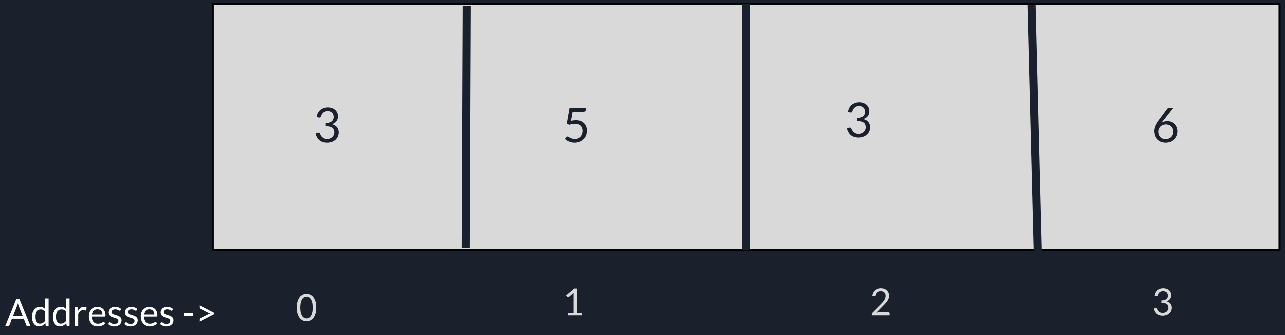
add dst, src

- Ok now let's change the value…
- add a, 10





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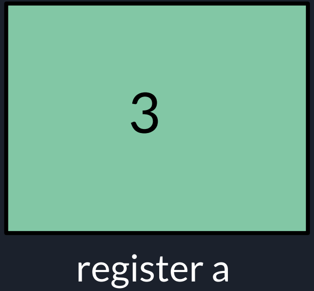
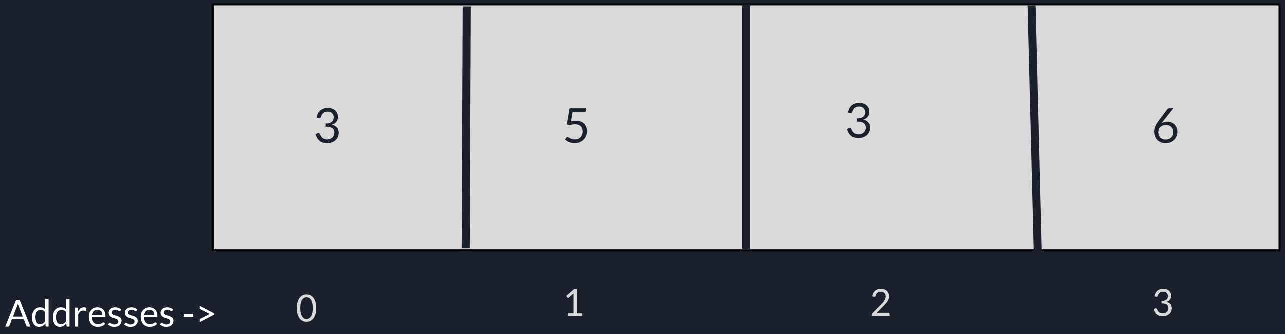
Add 10 and the value in a





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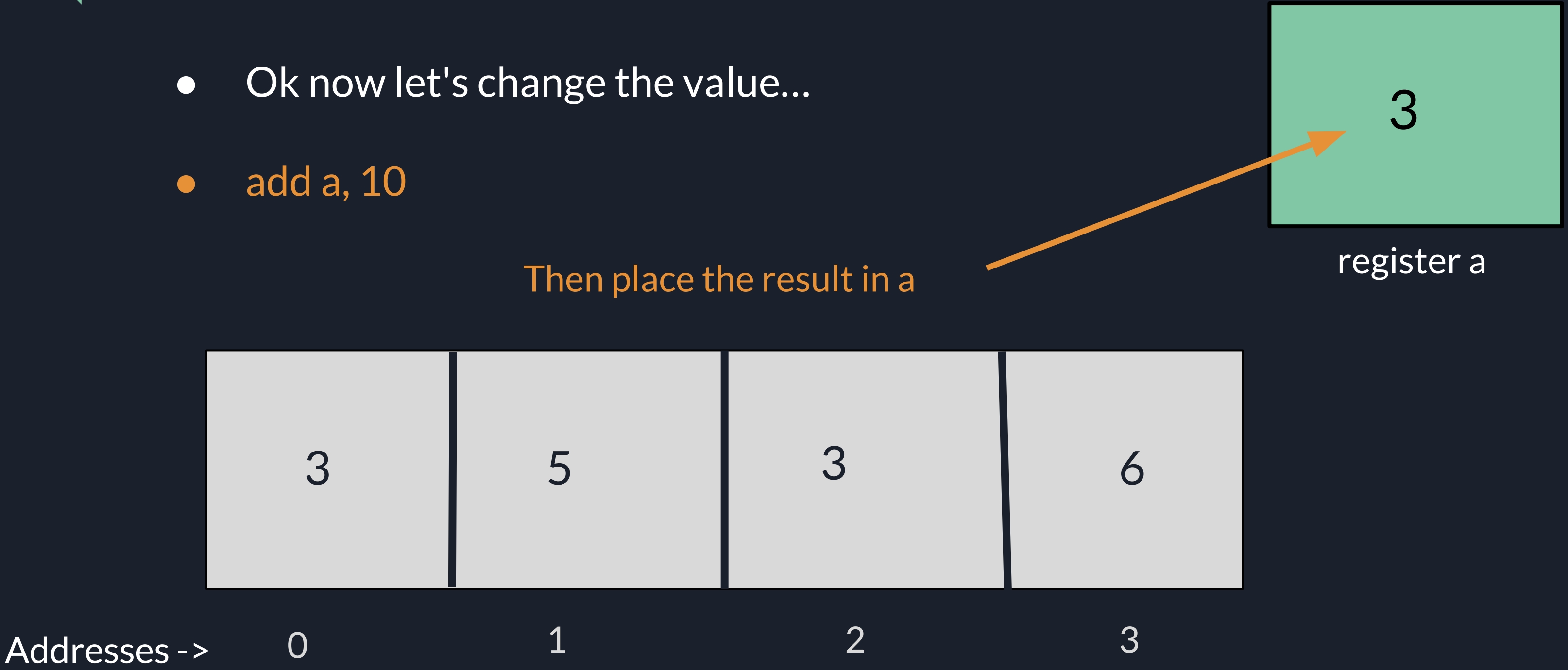

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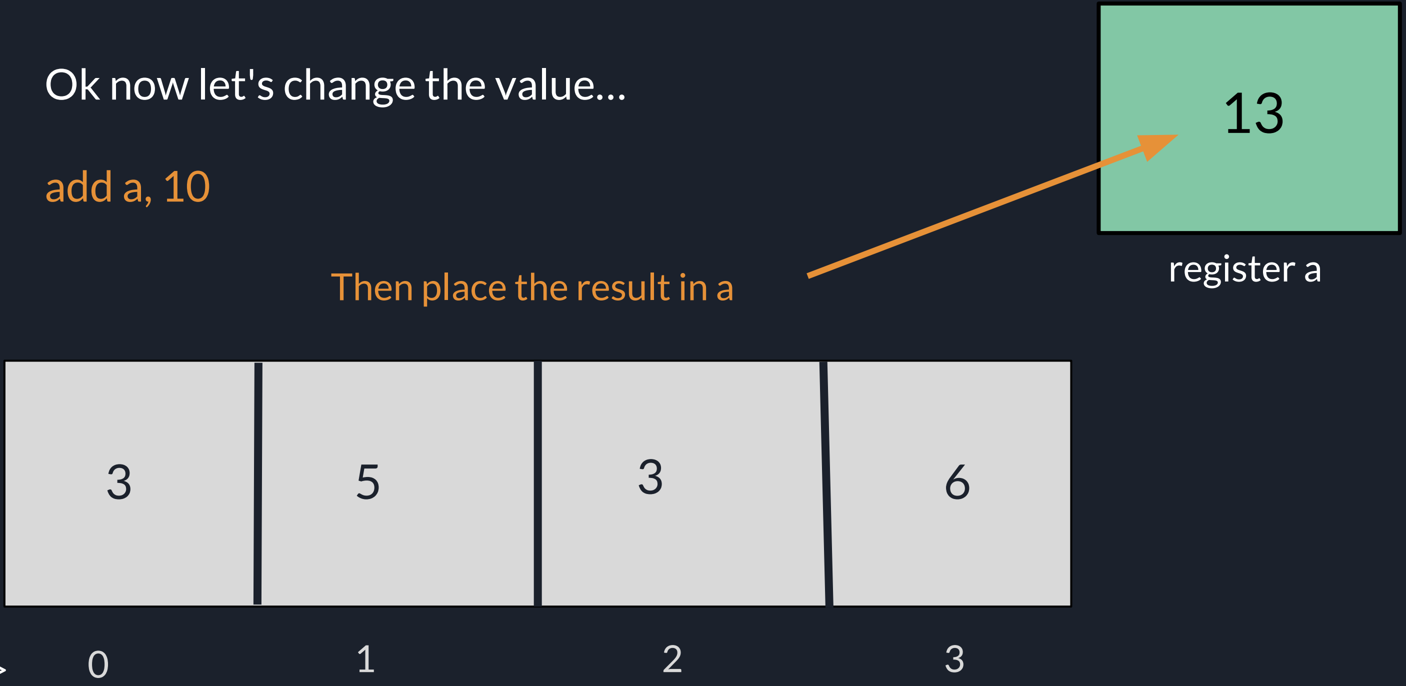

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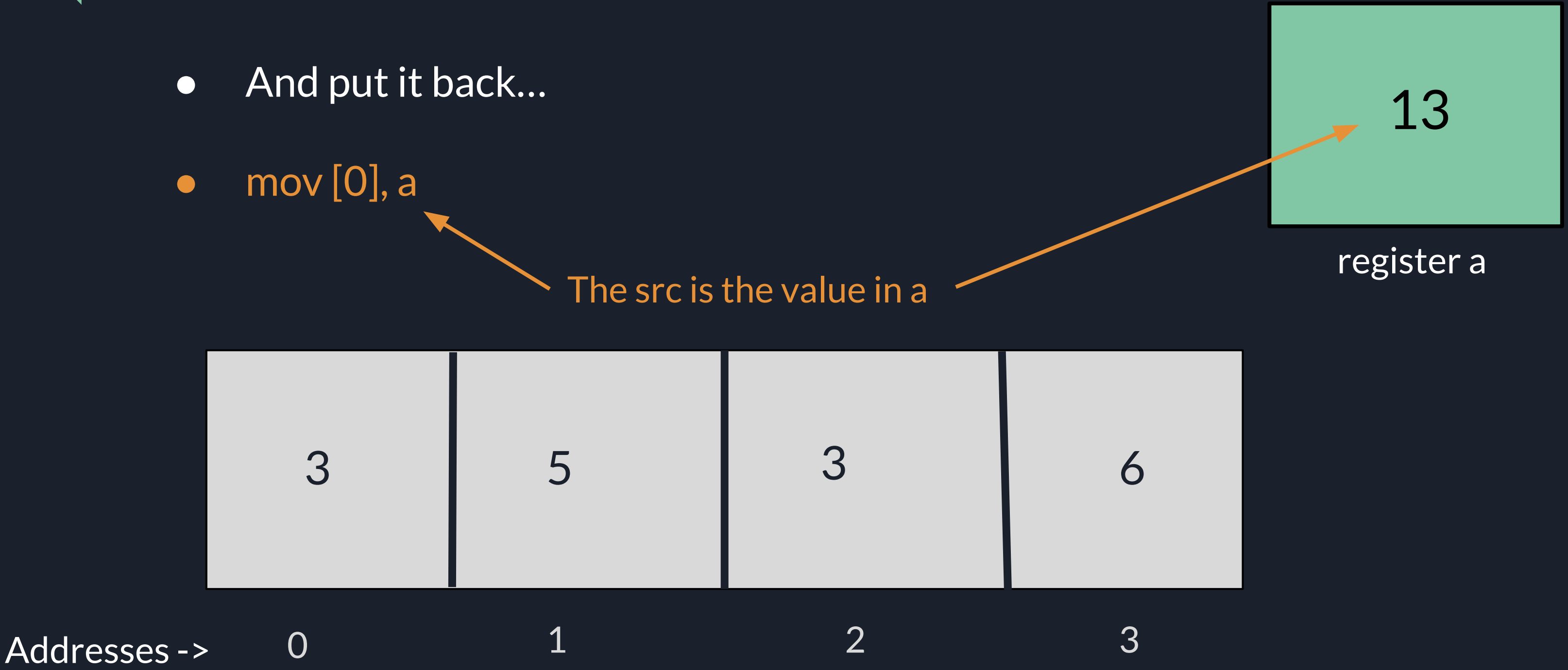

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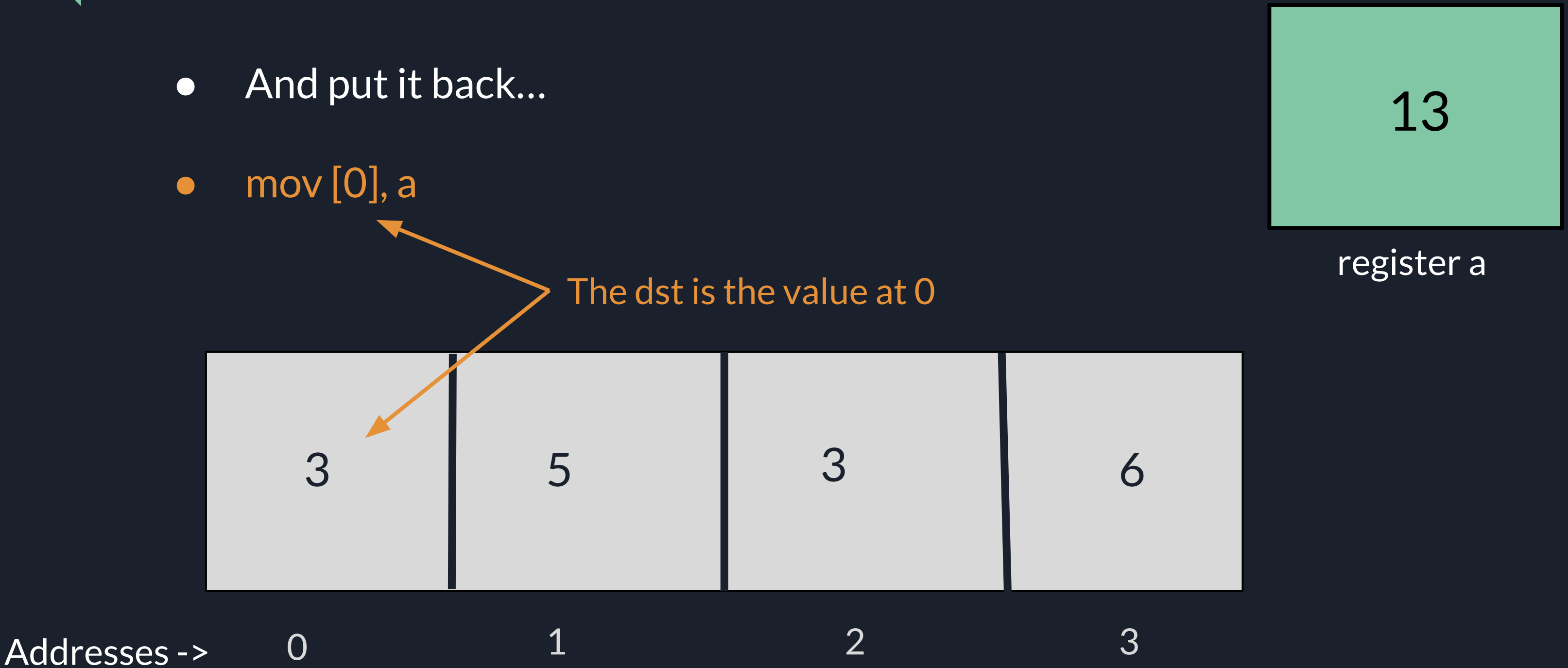
The dst is the value at 0



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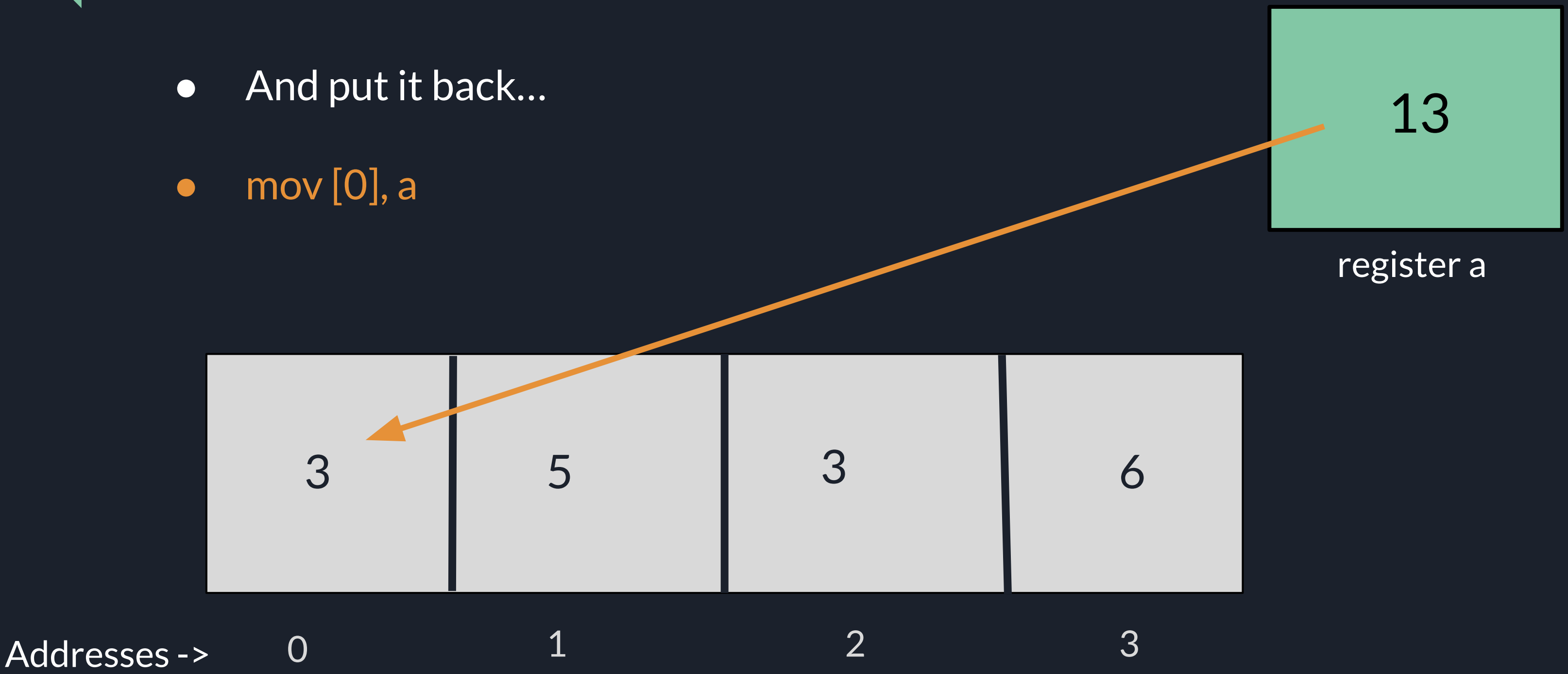

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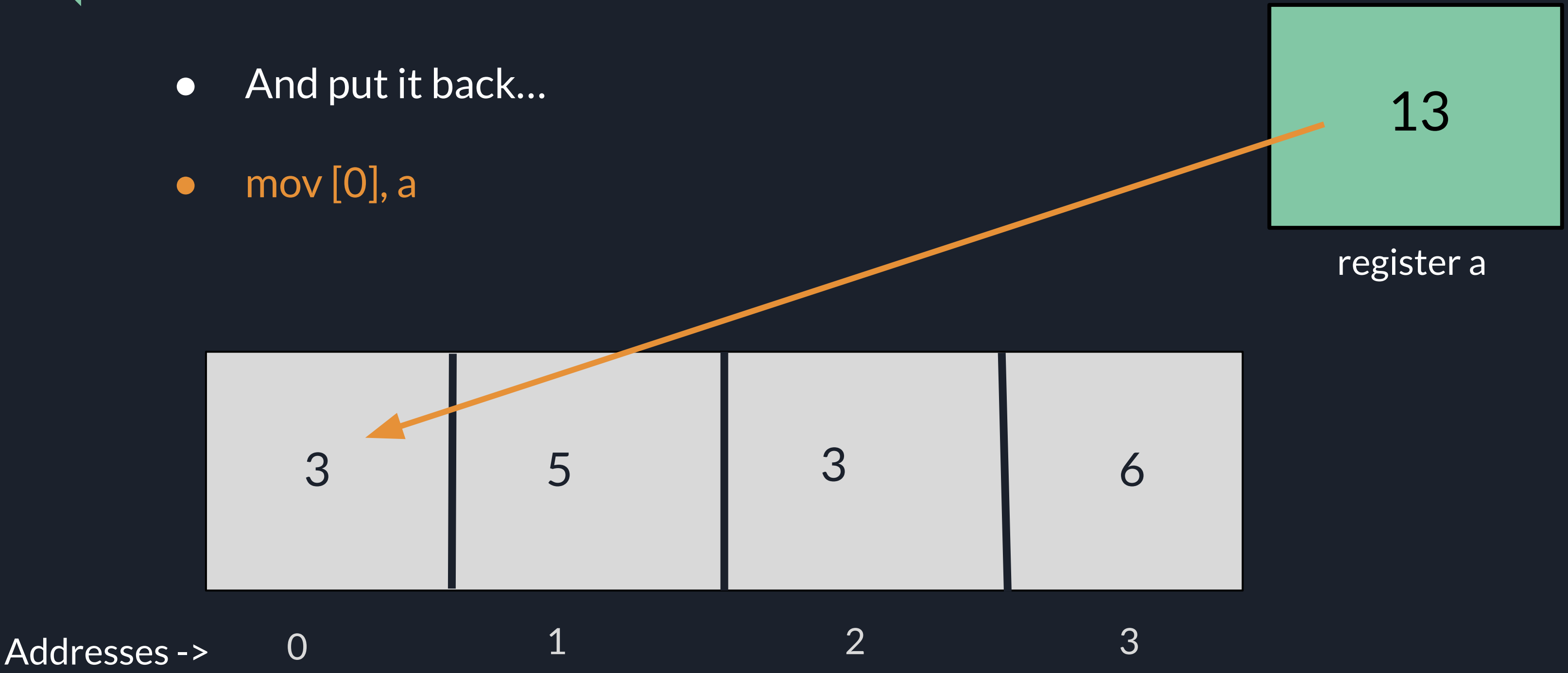

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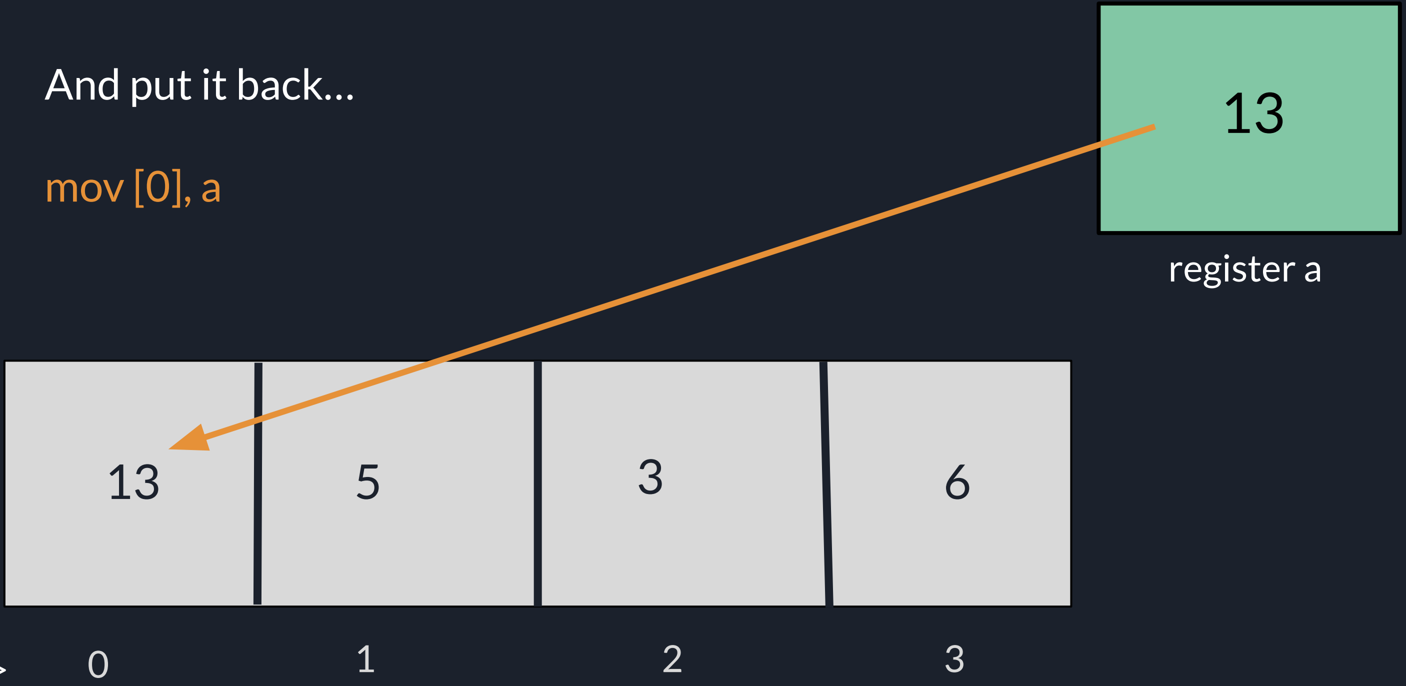

That was a lot of steps!

I promise it gets easier…

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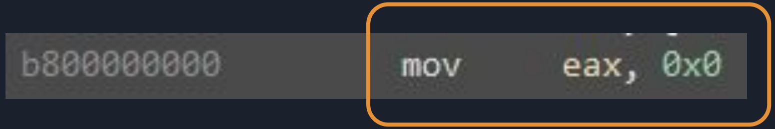

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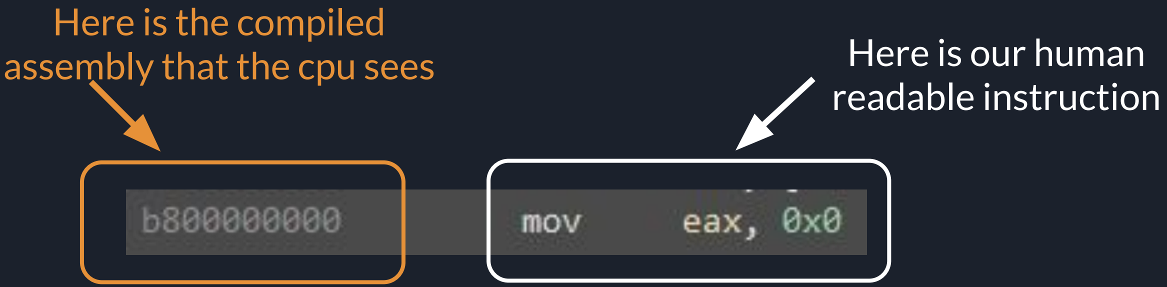
Here is the compiled assembly that the cpu sees
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- add dst, src - Adds dst and src, stores result in dst
- [address] - Dereference (says the value in brackets is an address)
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- cmp value1, value2 - Sets flags in EFLAGS
- je, jne, jz, jnz - Conditional jumps (look them up there are a lot)

Instructions - Some you know...

- Any time you see an instruction you don’t know...

Instructions - Some you know...

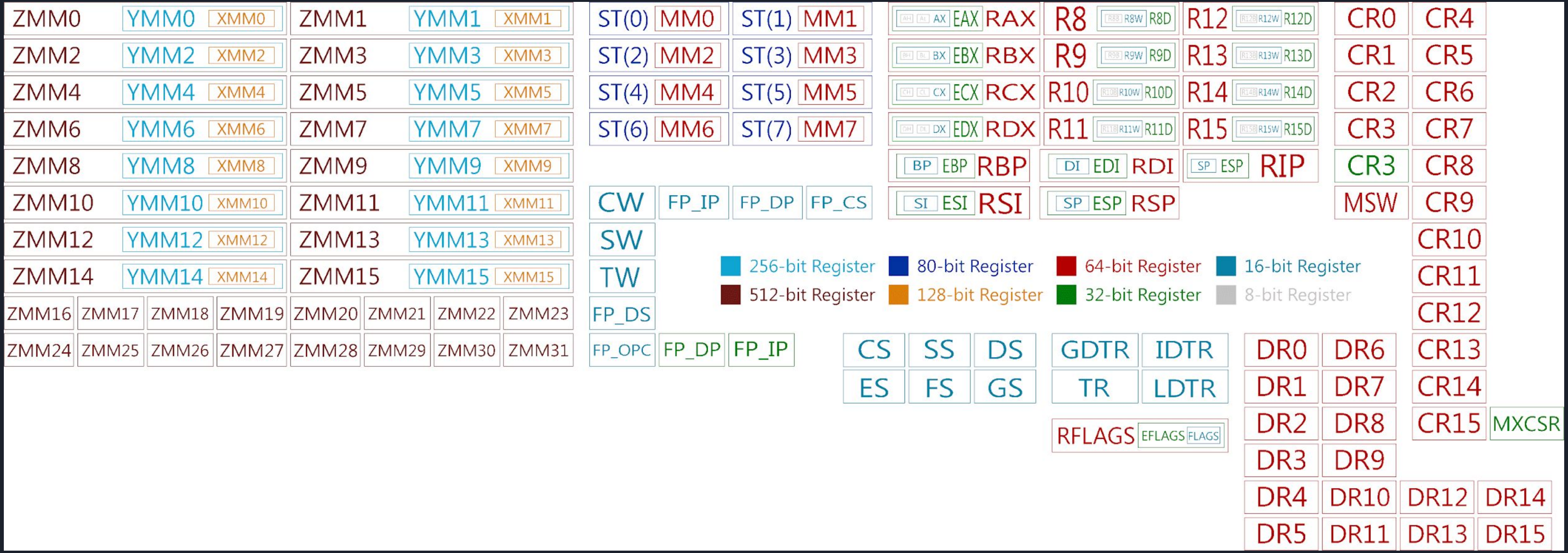
- Any time you see an instruction you don't know...
  - Look it up!

Instructions - Some you know...

- Any time you see an instruction you don't know...
  - Look it up!
  - There are decades of forum questions on any and all assembly problems

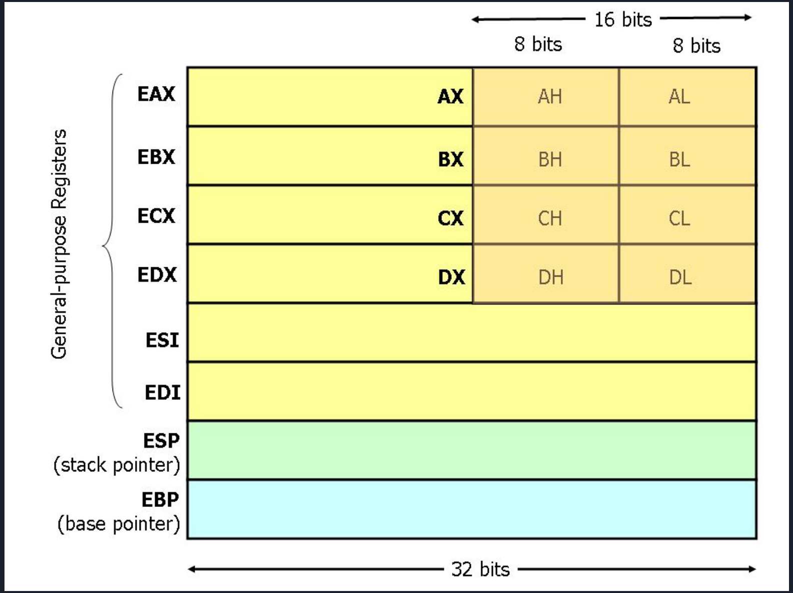
Again but advanced…

Registers (there's a lot of them)



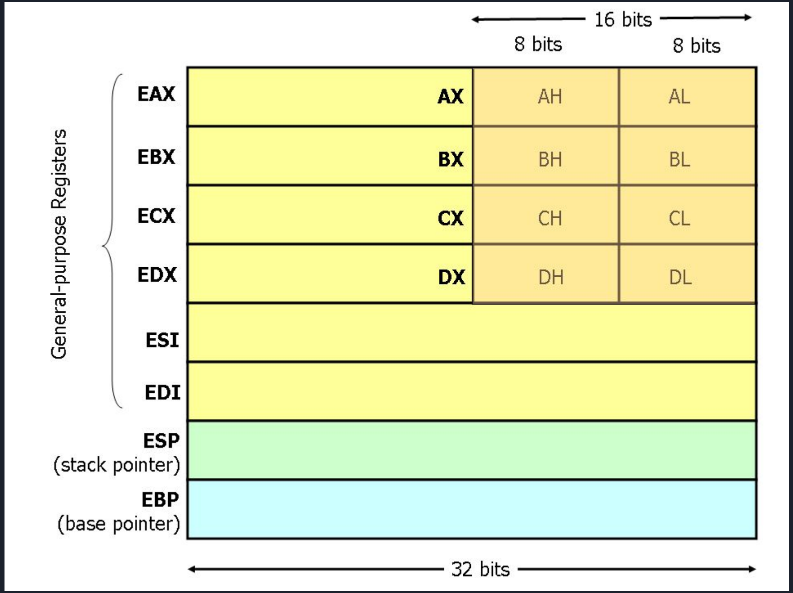
Registers

- Here are the ones we care about…



Registers

- Here are the ones we care about…
- You can refer to different sections of the same space...



Registers

- Here are the ones we care about…
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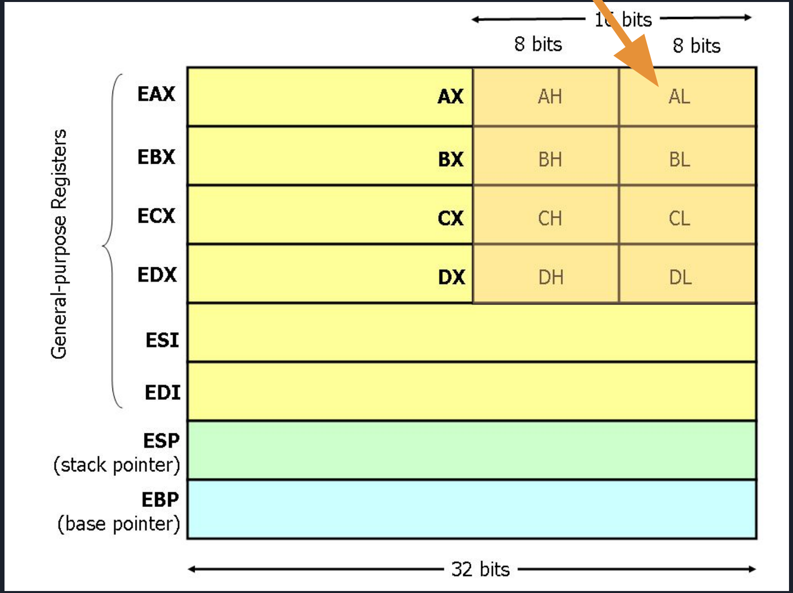
al refers to the lowest byte of the eax register



Registers

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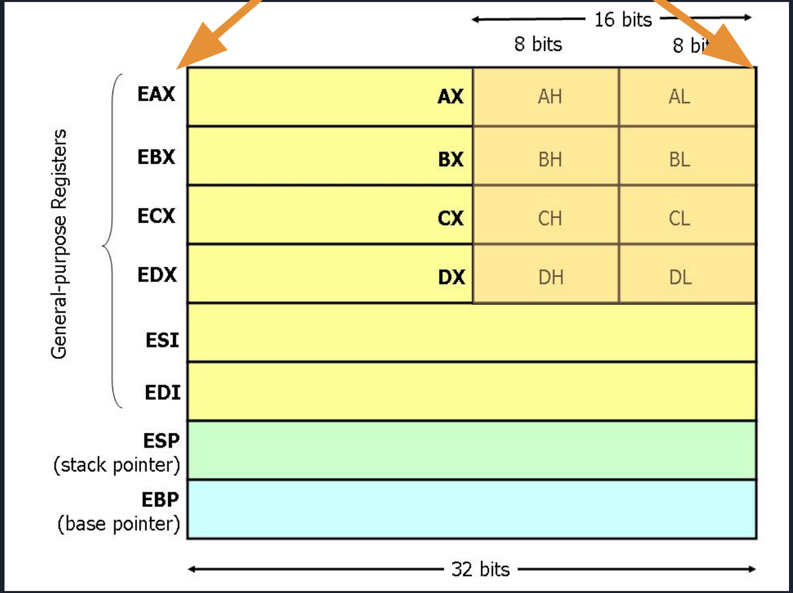
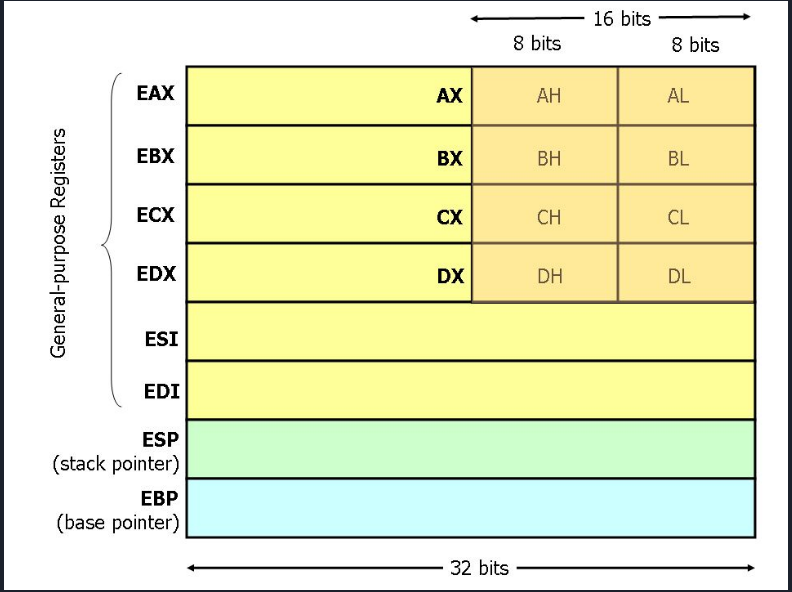
eax refers to the full 4 bytes



Registers

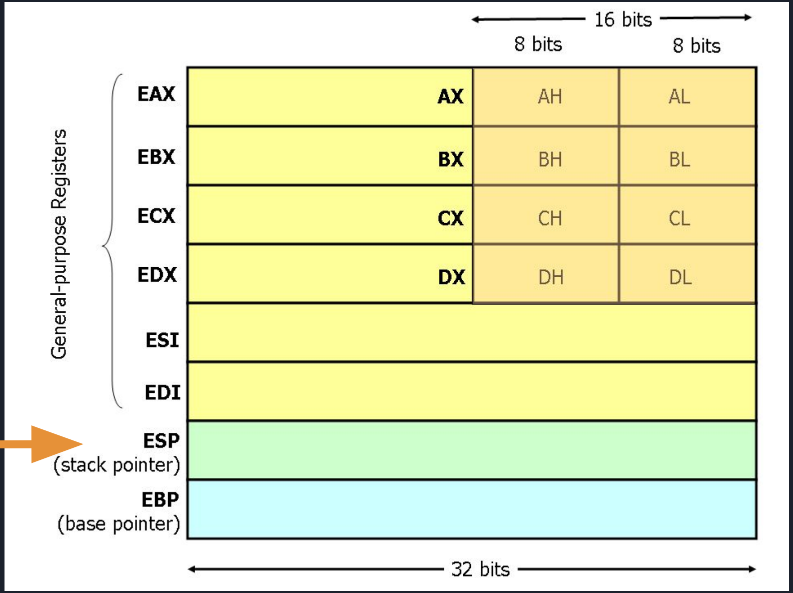
- Here are the ones we care about…
- You can refer to different sections of the same space…
- There are some registers we can use for anything, some are reserved



Registers

- Here are the ones we care about…
- You can refer to different sections of the same space…
- There are some registers we can use for anything, some are reserved

esp is reserved for the stack pointer



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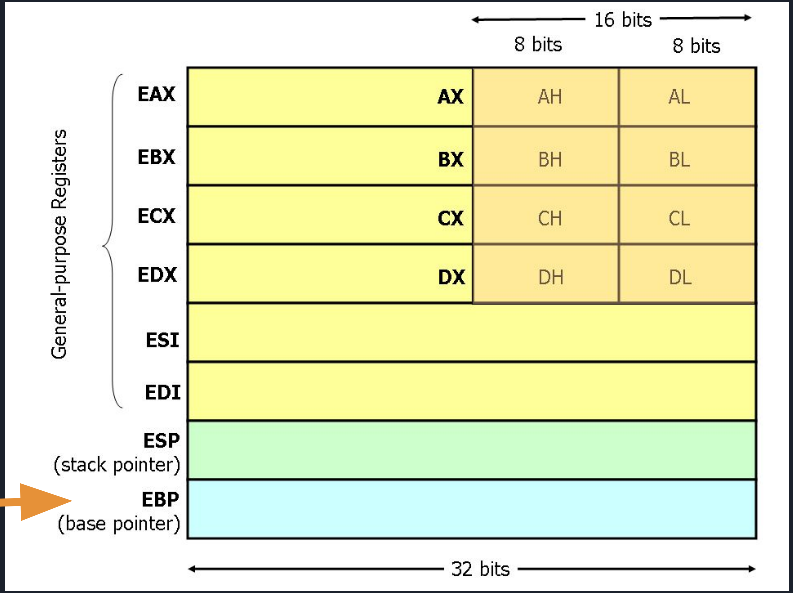
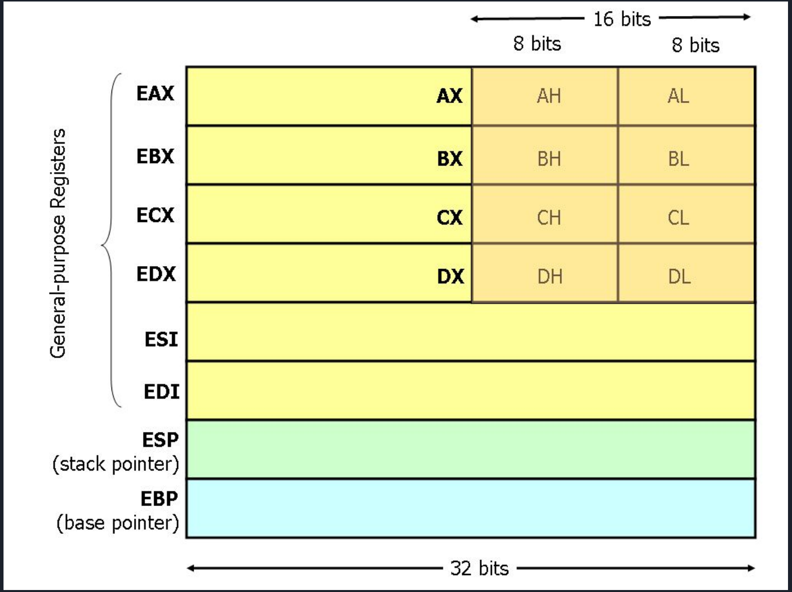


ebp is reserved for the stack base pointer

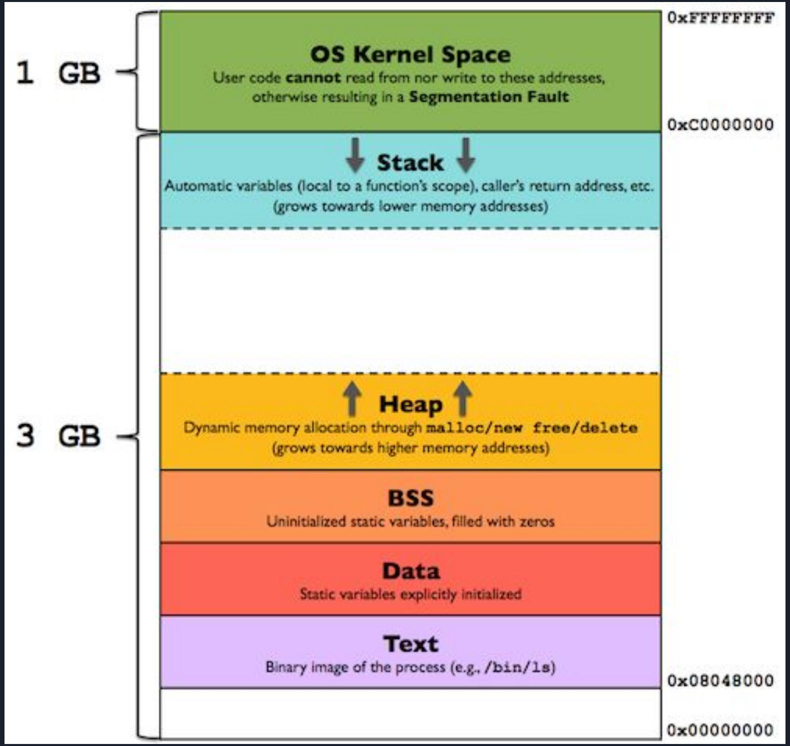
Registers

- Here are the ones we care about…
- You can refer to different sections of the same space…
- There are some registers we can use for anything, some are reserved
- More on that later...



Memory Layout

Some will draw the stack growing up, some growing down.


0xFFFFFFFF
1 GB
OS Kernel Space
User code **cannot** read from nor write to these addresses, otherwise resulting in a **Segmentation Fault**
0xC0000000
Stack
Automatic variables (local to a function's scope), caller's return address, etc. (grows towards lower memory addresses)
3 GB
Heap
Dynamic memory allocation through malloc/new free/delete (grows towards higher memory addresses)
BSS
Uninitialized static variables, filled with zeros
Data
Static variables explicitly initialized
Text
Binary image of the process (e.g., /bin/ls)
0x08048000
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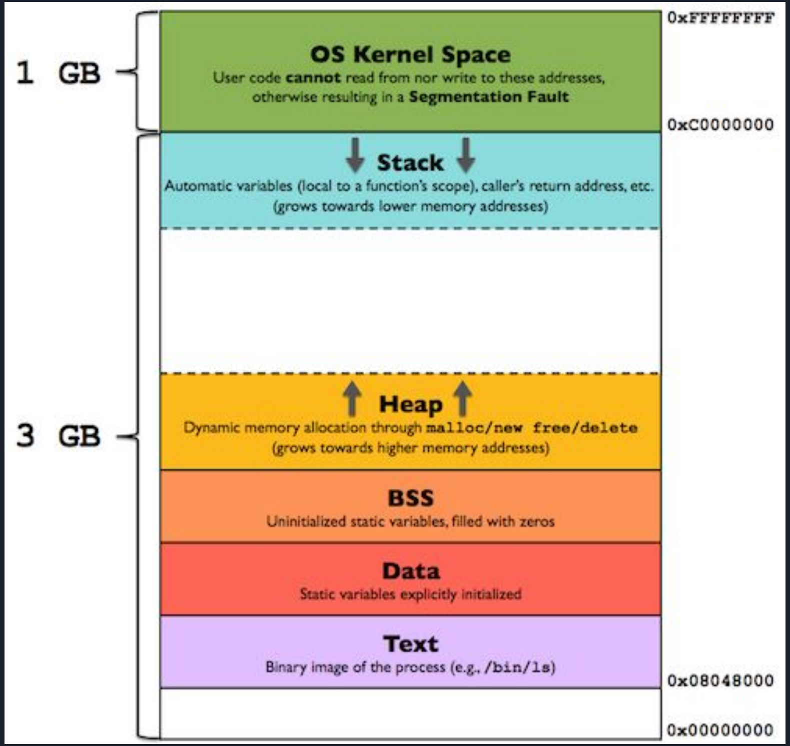
Memory Layout

Some will draw the stack growing up, some growing down.

It doesn't matter which model you adopt, they are exactly the same!



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Memory Layout

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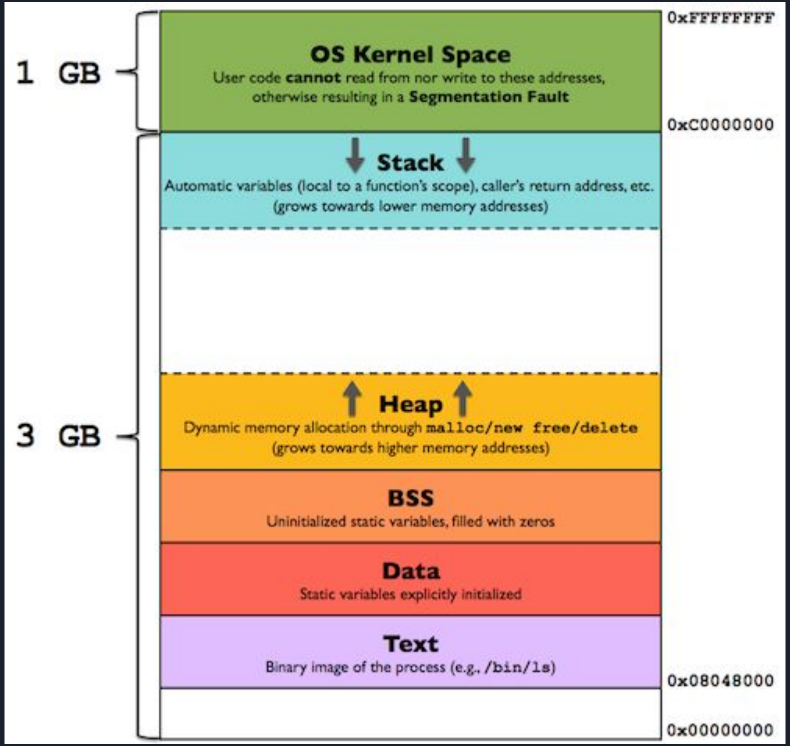
Programs have "sections" of memory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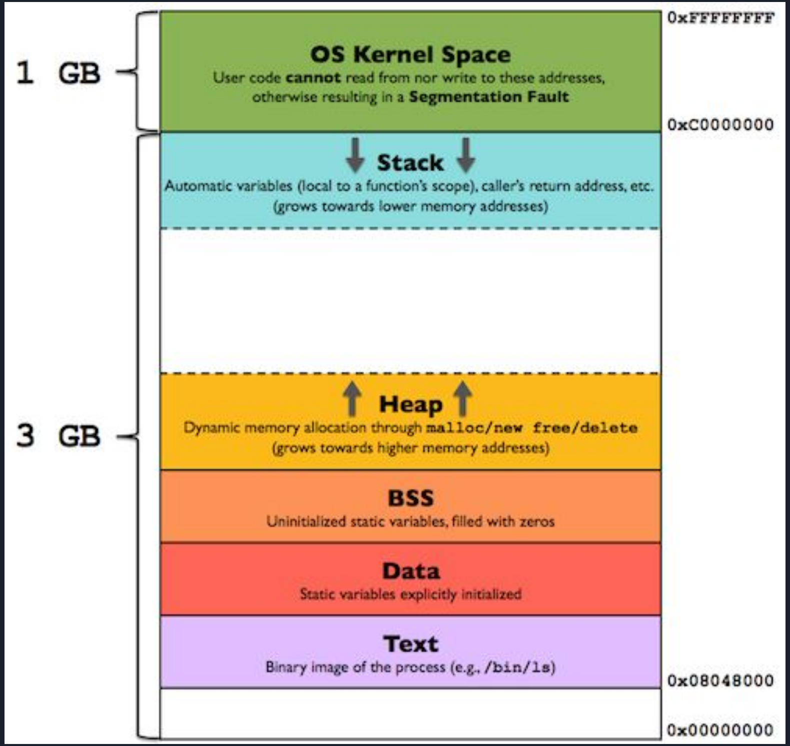
Memory Layout

Something important:
All of this is just data! We as programmers give purpose to this data in the way we treat it!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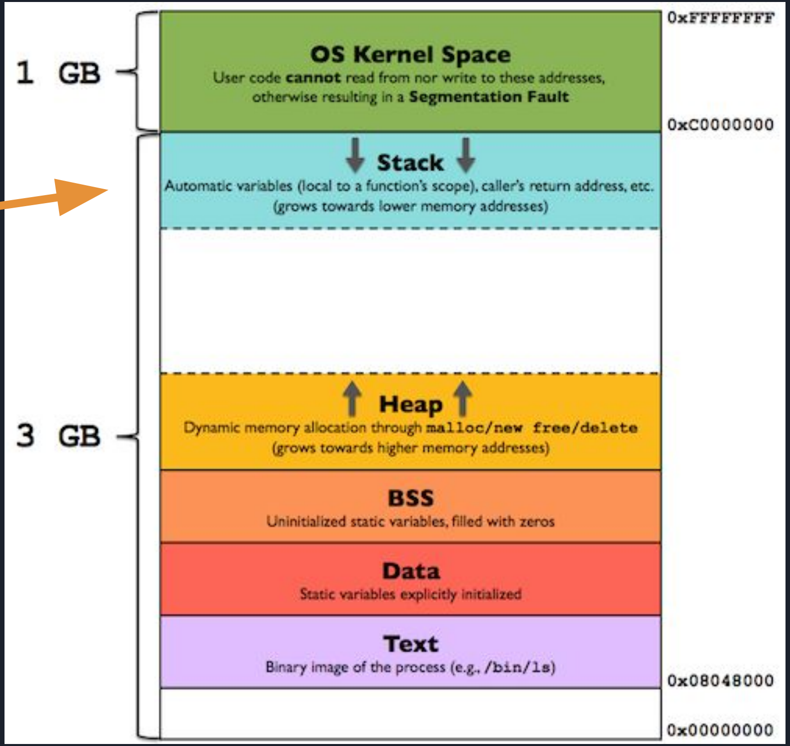
Memory Layout

Stack is where the local variables for functions live



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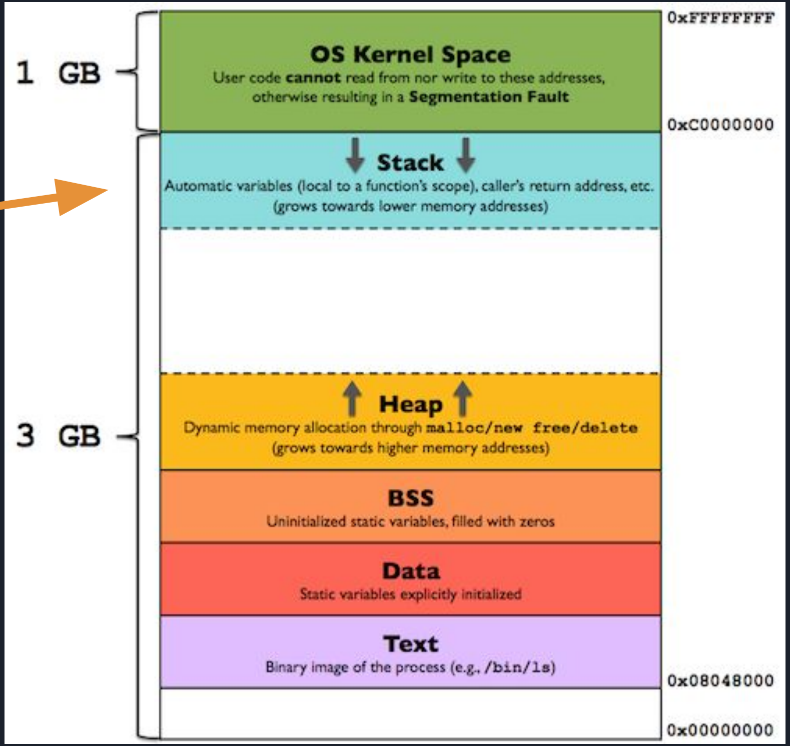
Memory Layout

As you call functions, the stack grows down



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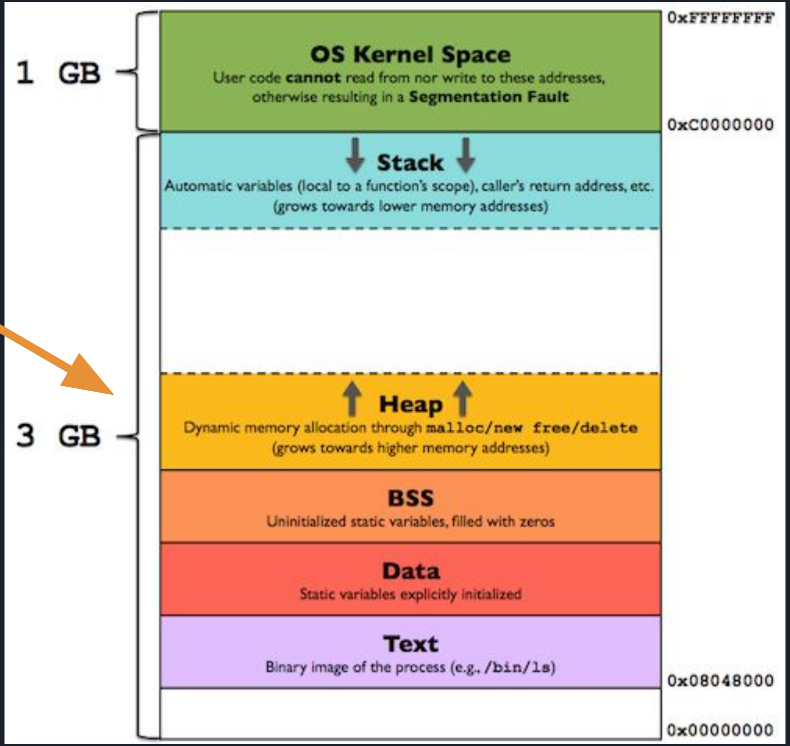
Memory Layout

The heap is where dynamically allocated data lives



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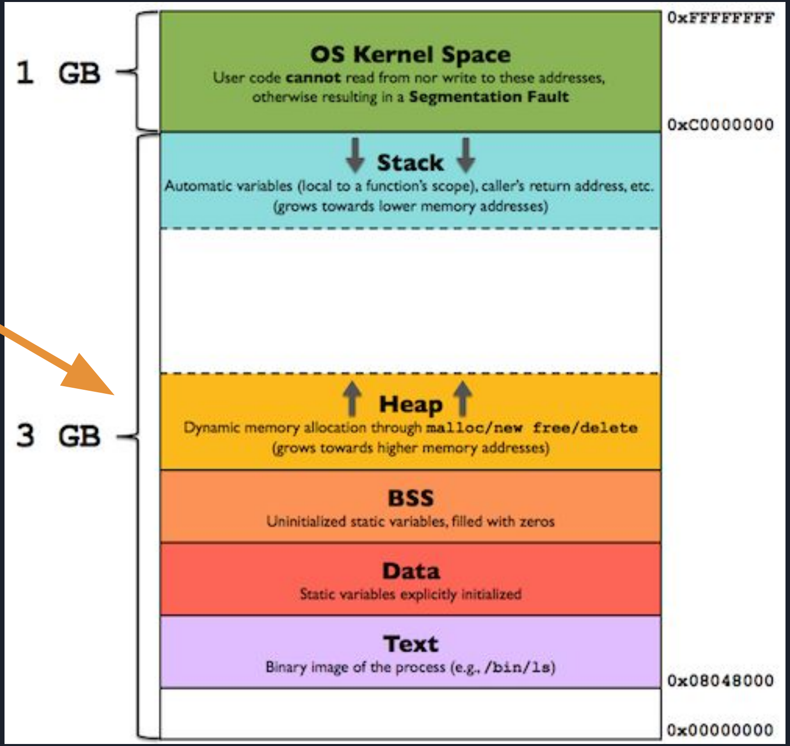
Memory Layout

As you allocate more data, the heap grows up



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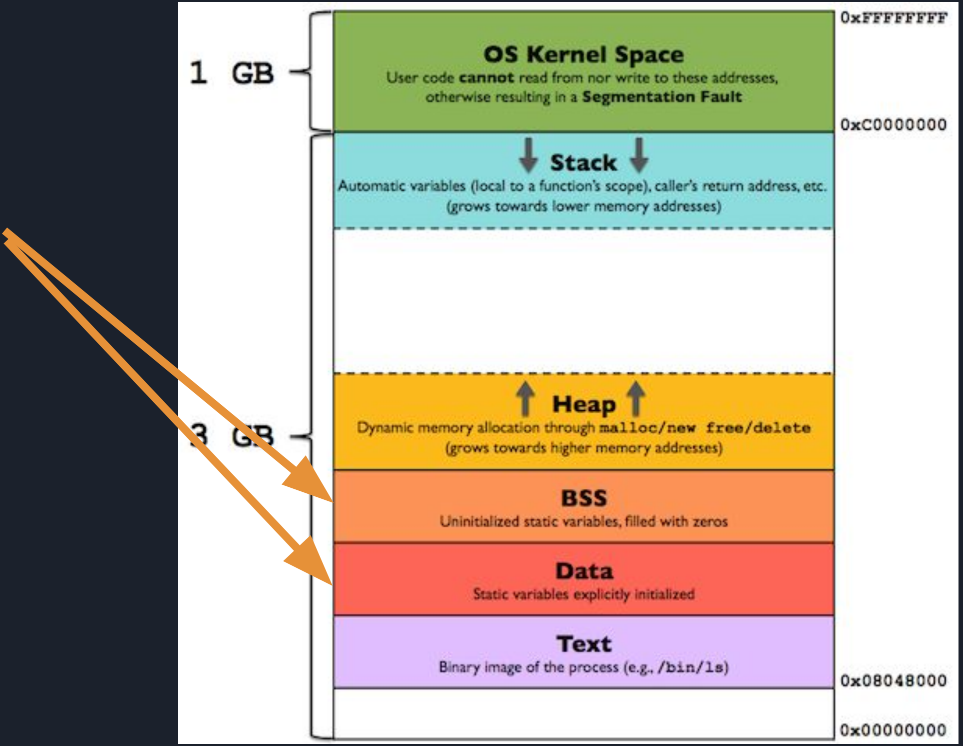
Memory Layout

The bss and data sections are where global variables live



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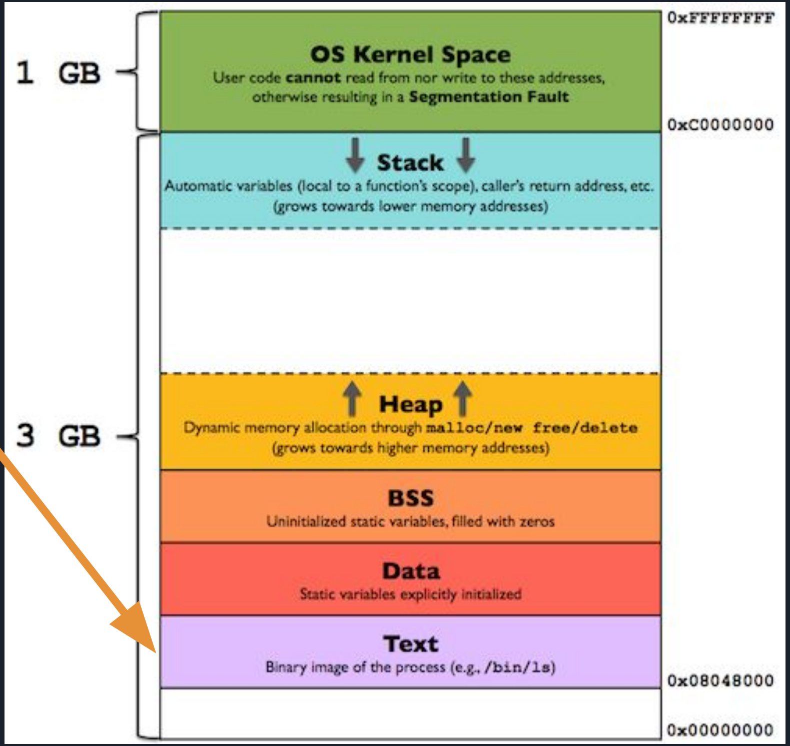
Memory Layout

The “text” section holds the assembly code of the program



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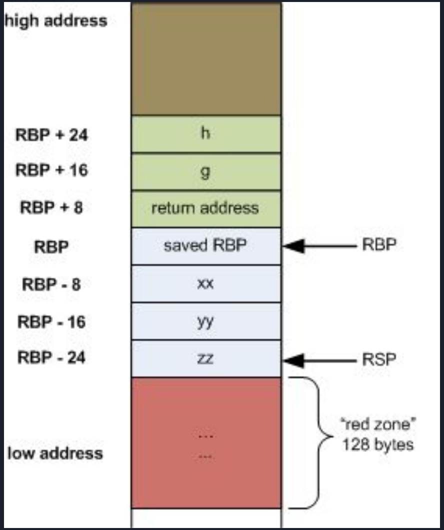
Ok now we have a problem...

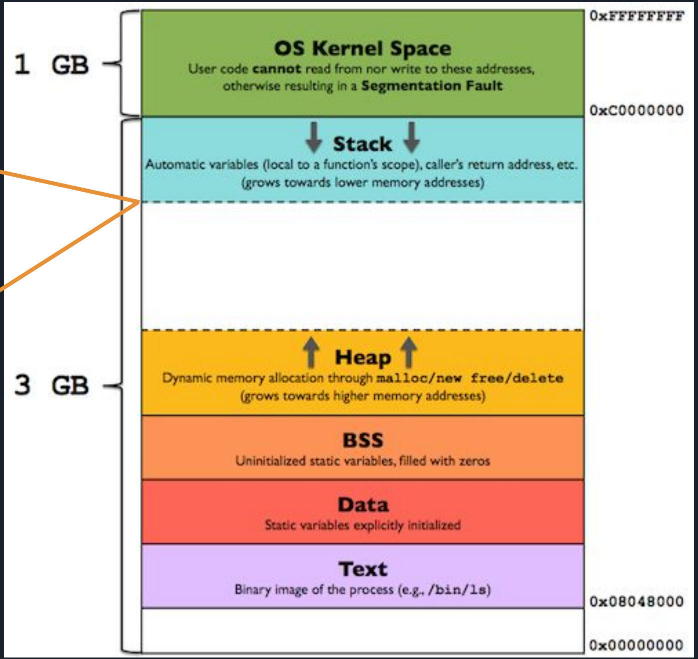
- How exactly do we organize memory?
- At this level there are basically no rules right?
- So how do we keep things straight?

The organization solution

The Stack Frame

Stack Frame


high address
RBP + 24
h
RBP + 16
g
RBP + 8
return address
RBP
saved RBP
RBP
RBP - 8
xx
RBP - 16
yy
RBP - 24
zz
RSP
low address
...
...
"red zone"
128 bytes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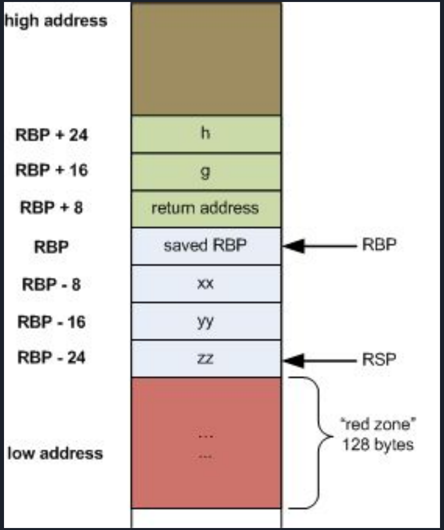
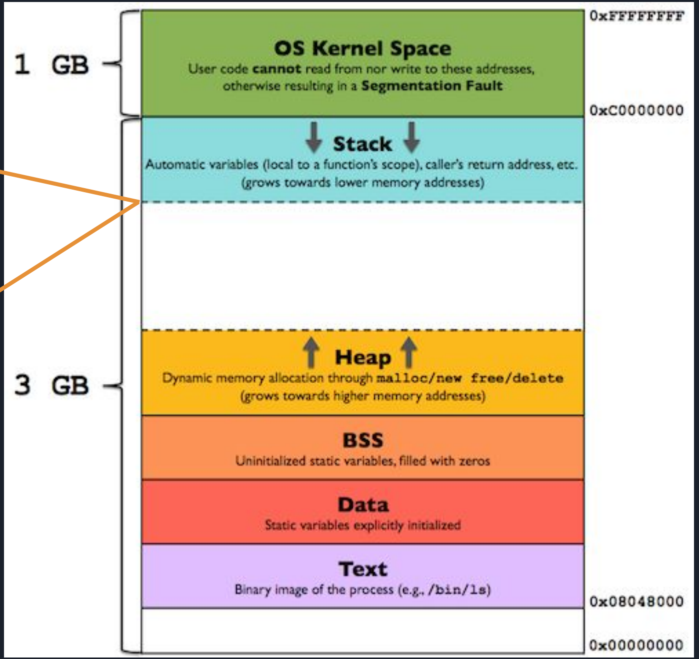
Stack Frame

The stack is made up of many "frames" for each function call





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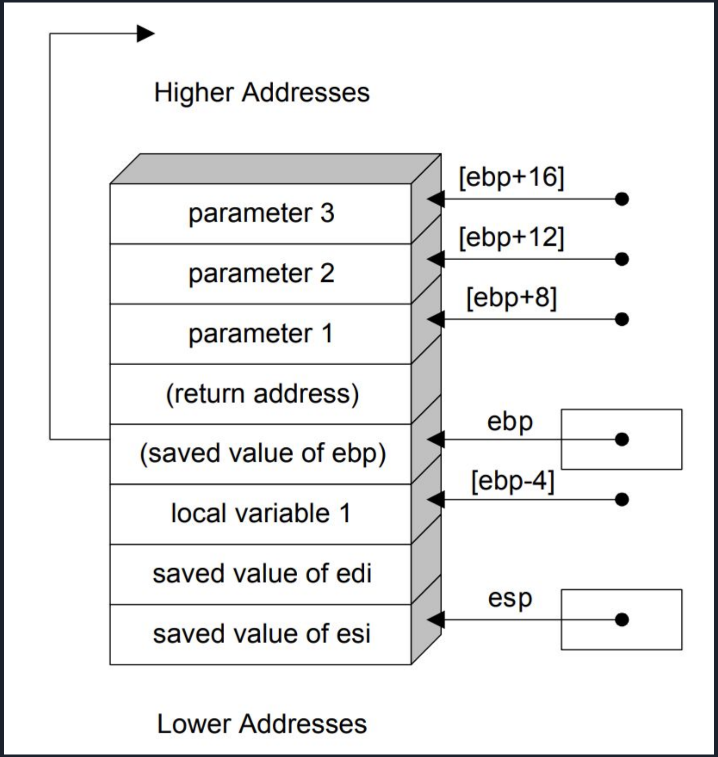
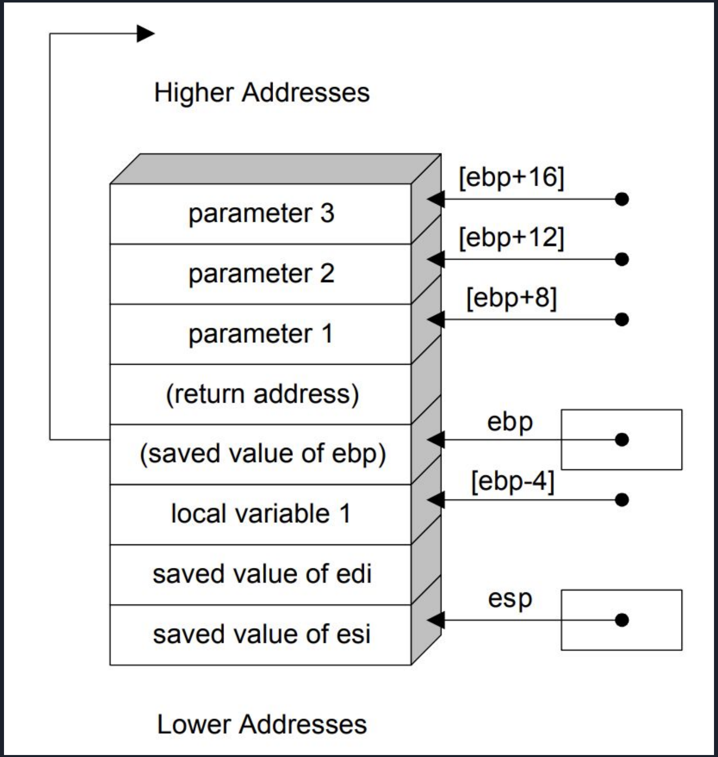
Stack Frame

- Let's talk instructions
  - call address - pushes the address of the next instruction then jmp



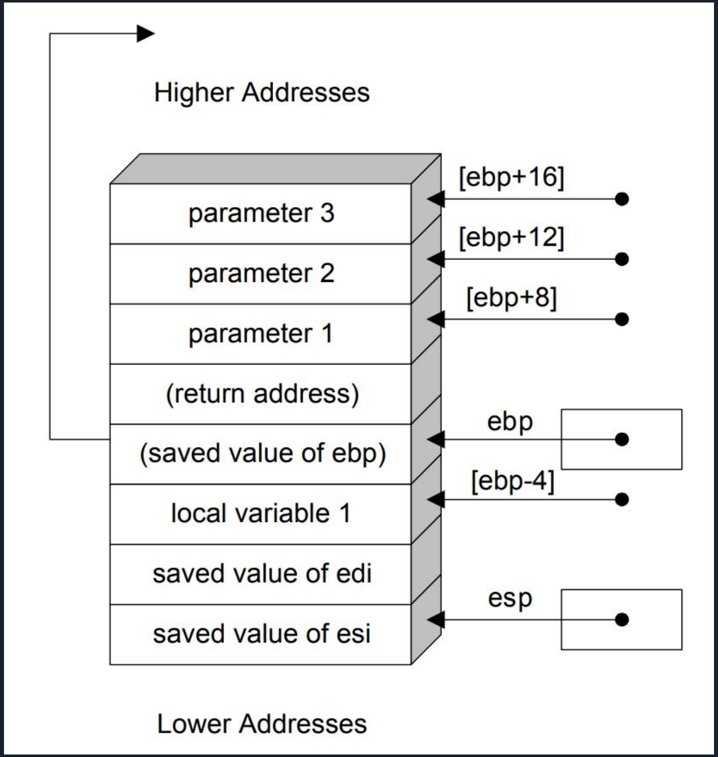
Stack Frame

- Let’s talk instructions
  - call address - pushes the address of the next instruction then jmp
  - ret - pop’s top value off the stack into eip



Stack Frame

- Let’s talk instructions
  - call address - pushes the address of the next instruction then jmp
  - ret - pop’s top value off the stack into eip
- When a new function is called, it will run a prolog and epilog
  - The prolog sets up the frame
  - The epilog cleans it up and ret’s



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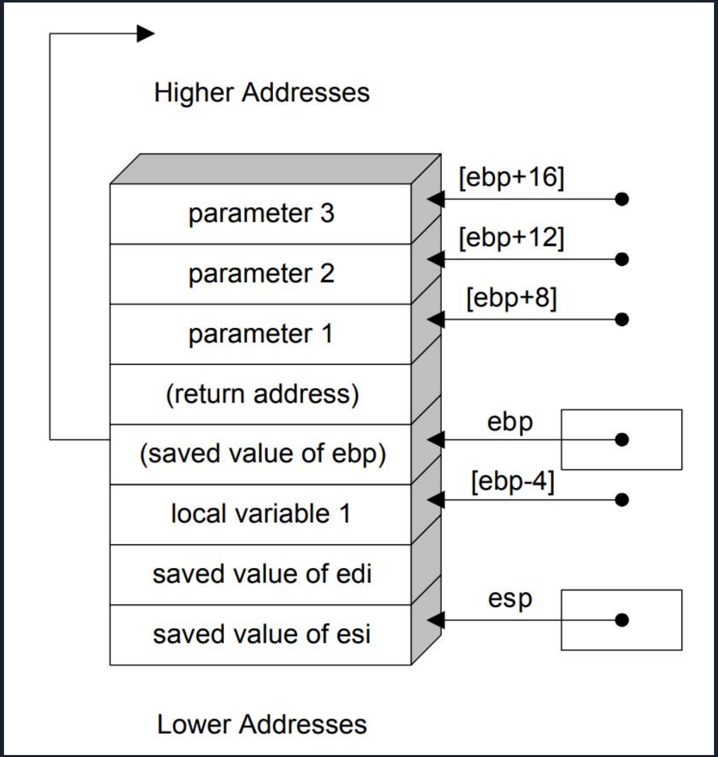

Stack Frame

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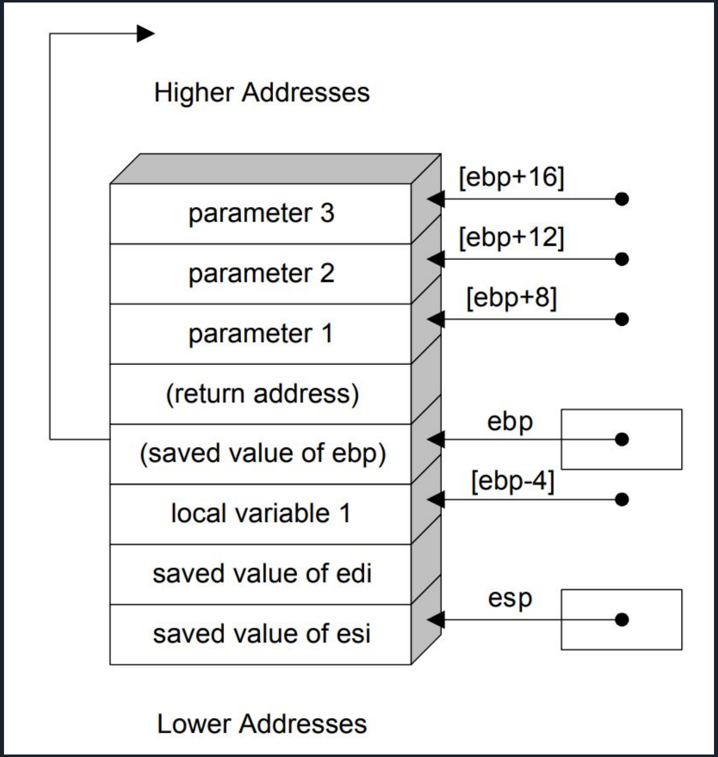
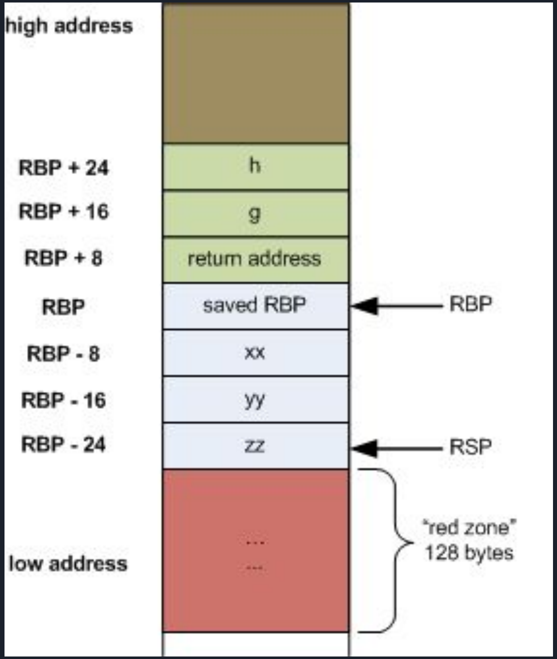


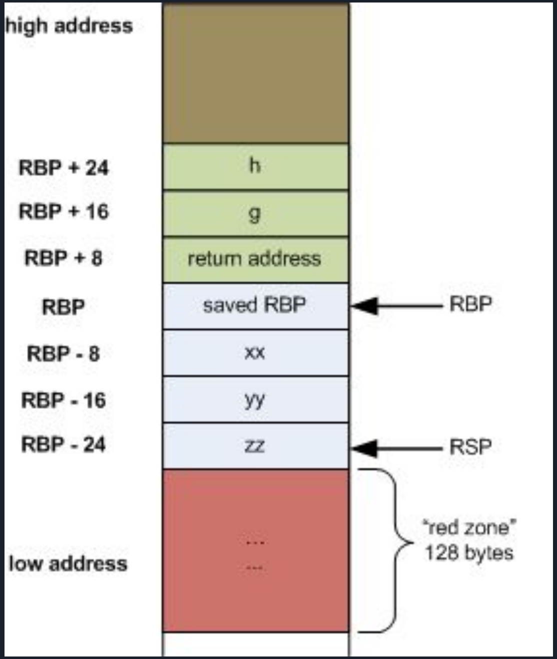
Stack Frame

- Every function will make a new stack frame, then clean it up before returning



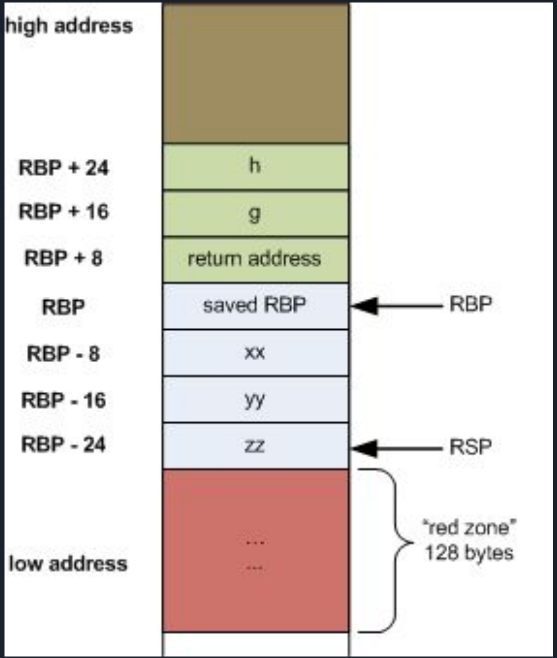
Stack Frame

- Every function will make a new stack frame, then clean it up before returning
- The stack frame is where local variables are stored



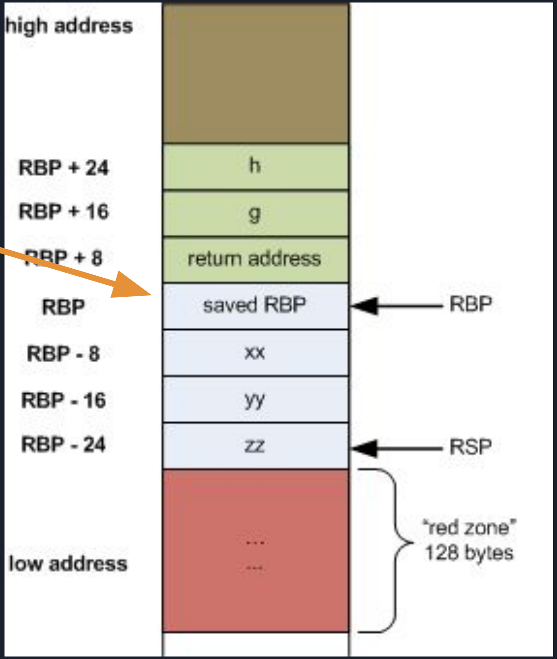
Stack Frame

Remember ebp and esp from before?



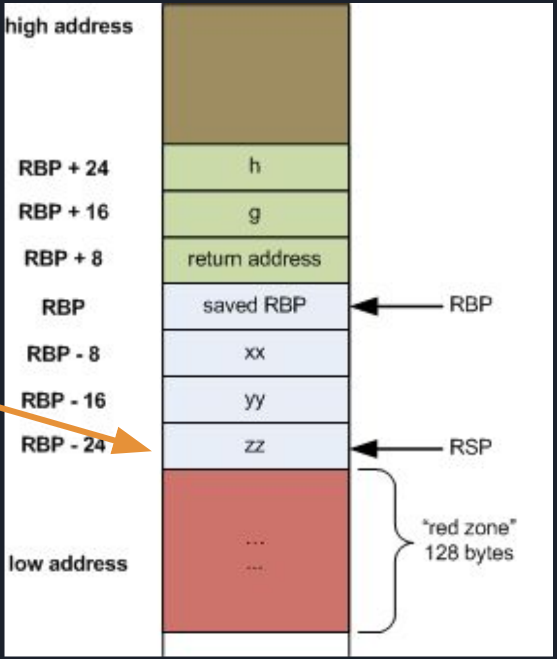
Stack Frame

ebp holds the address of the "base" of the stack frame



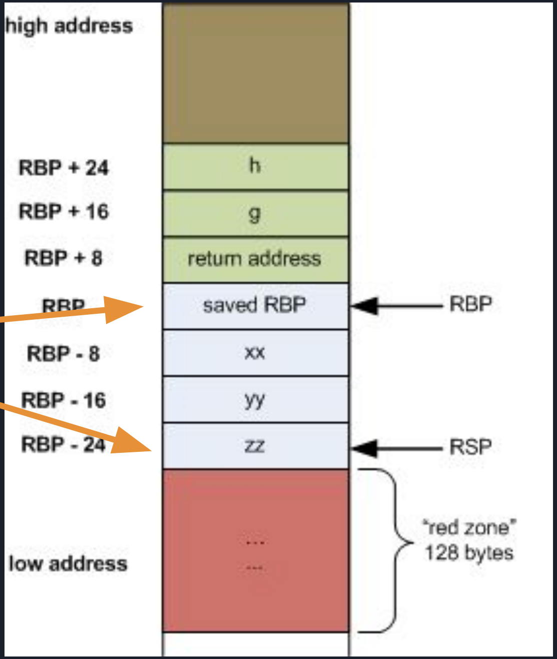
Stack Frame

esp holds the address of the bottom of the stack



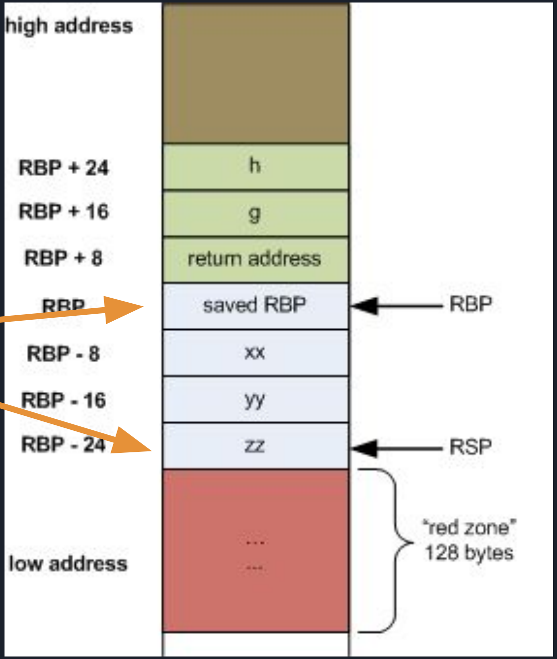
Stack Frame

Everything in between is space for the local variables!



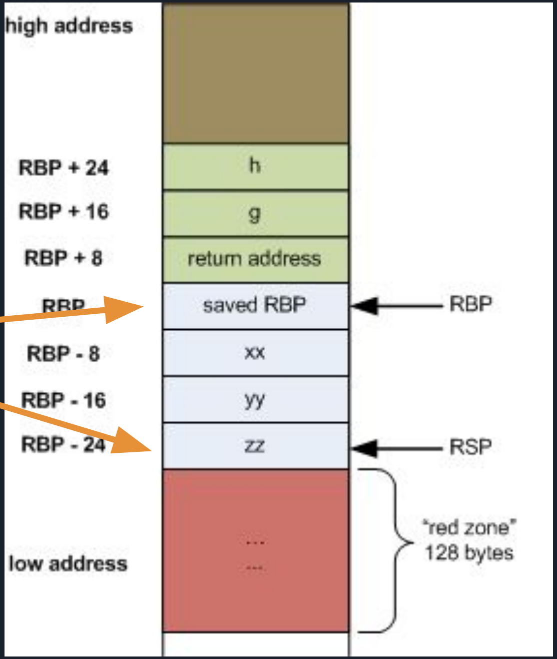
Stack Frame

Different functions will need different amounts of space for locals



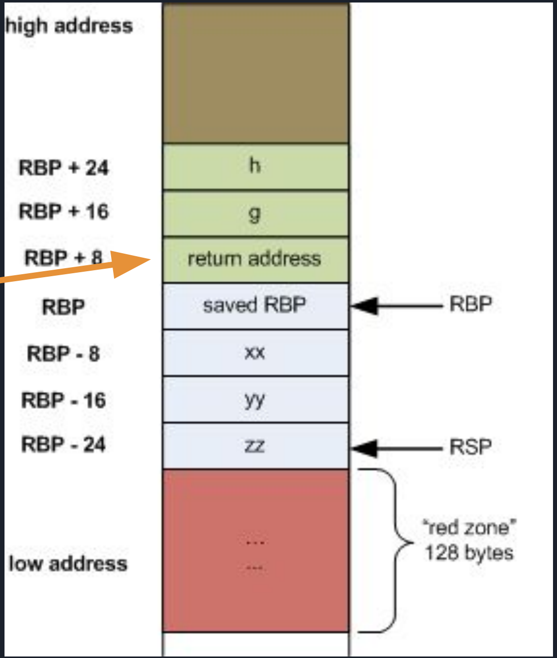
Stack Frame

It's up to each function to set up the space they need

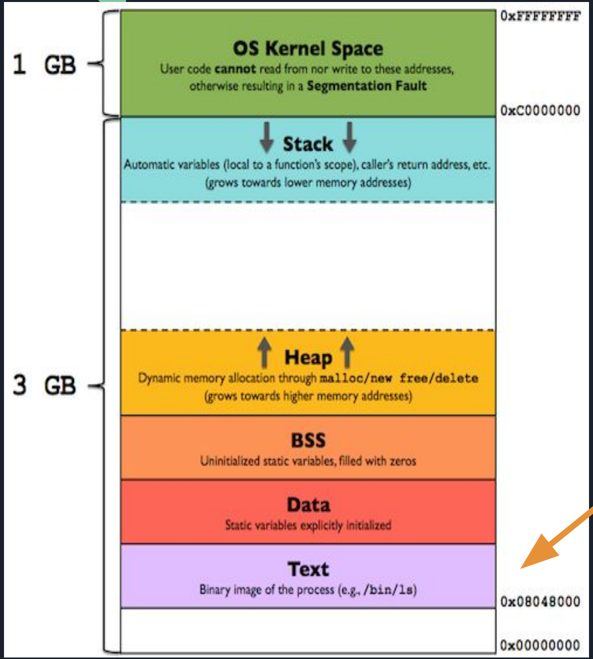


Stack Frame

To understand the return address, let's remember how the program layout looks



Stack Frame



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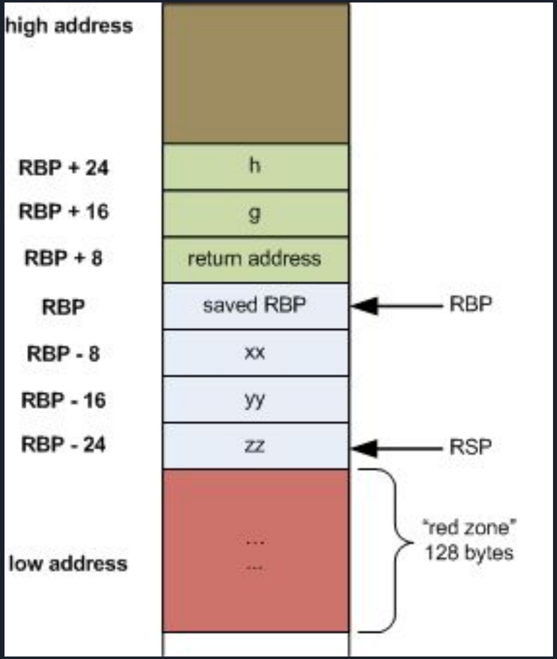
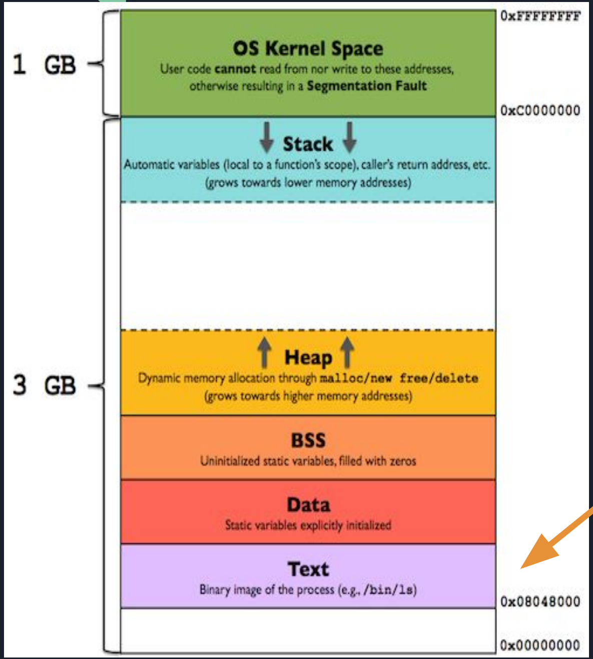
The compiled assembly lives in memory



Stack Frame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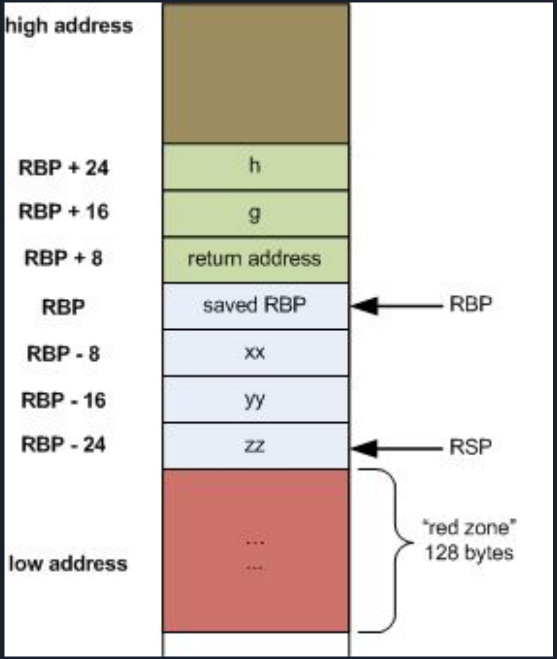
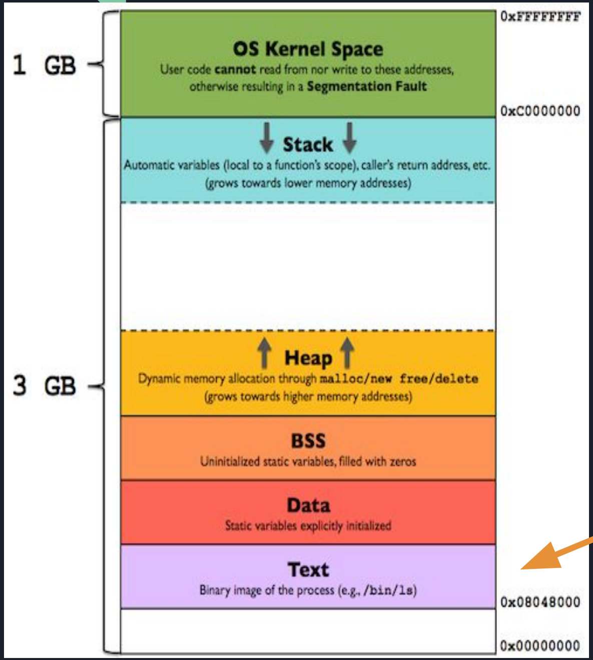
That means it has addresses!



Stack Frame



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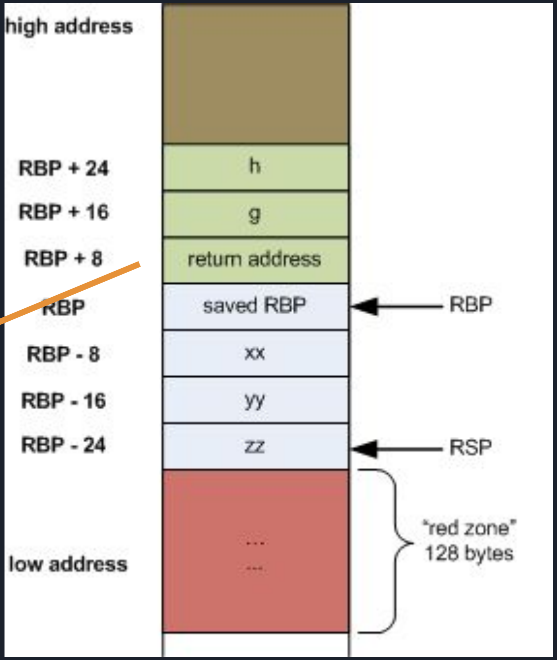
0x00000000

So the value in the return address is the address of where the function should return to



32 vs 64 bit

Calling conventions are the main difference.

- 32 bit uses stack
- 64 bit uses registers
    - Don’t memorize, just look them up!

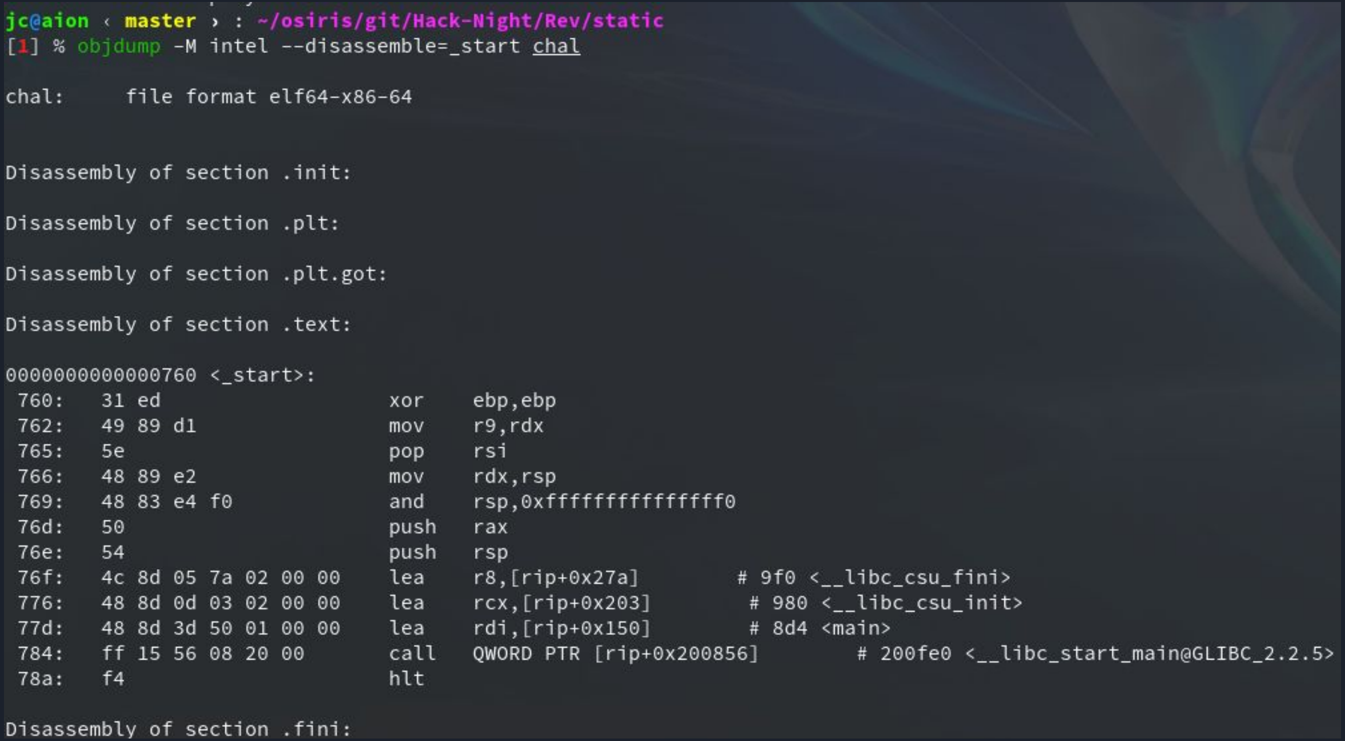
Tools

We'll take all the help we can get….

Objdump

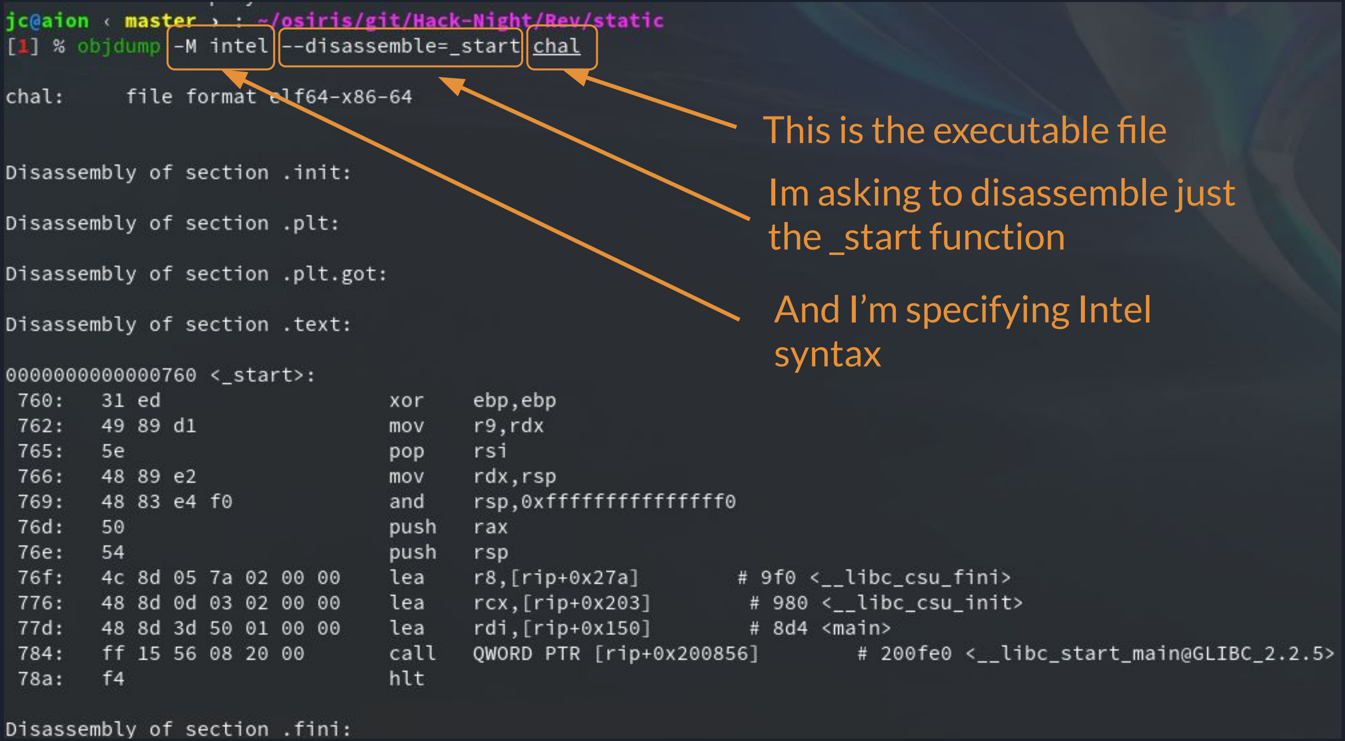
For when you have no other option…

Objdump - As basic as it gets



```
jc@aion ‹ master › : ~/osiris/git/Hack-Night/Rev/static
[1] % objdump -M intel --disassemble=_start chal

chal:     file format elf64-x86-64


Disassembly of section .init:

Disassembly of section .plt:

Disassembly of section .plt.got:

Disassembly of section .text:

0000000000000760 <_start>:
 760:   31 ed                   xor    ebp,ebp
 762:   49 89 d1                mov    r9,rdx
 765:   5e                      pop    rsi
 766:   48 89 e2                mov    rdx,rsp
 769:   48 83 e4 f0             and    rsp,0xfffffffffffffff0
 76d:   50                      push   rax
 76e:   54                      push   rsp
 76f:   4c 8d 05 7a 02 00 00    lea    r8,[rip+0x27a]        # 9f0 <__libc_csu_fini>
 776:   48 8d 0d 03 02 00 00    lea    rcx,[rip+0x203]        # 980 <__libc_csu_init>
 77d:   48 8d 3d 50 01 00 00    lea    rdi,[rip+0x150]        # 8d4 <main>
 784:   ff 15 56 08 20 00       call   QWORD PTR [rip+0x200856]        # 200fe0 <__libc_start_main@GLIBC_2.2.5>
 78a:   f4                      hlt

Disassembly of section .fini:
```

Objdump - As basic as it gets



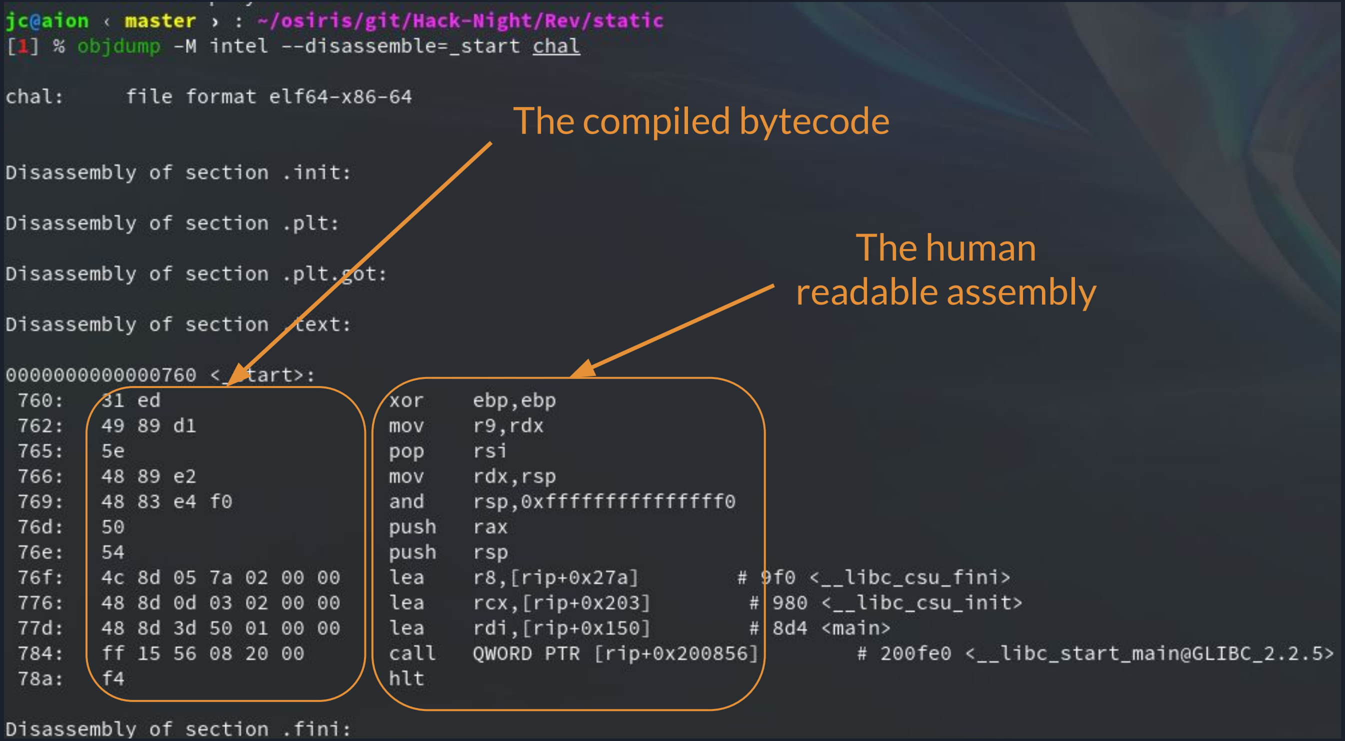
```
jc@aion ‹ master › : ~/osiris/git/Hack-Night/Rev/static
[1] % objdump -M intel --disassemble=_start chal

chal:     file format elf64-x86-64


Disassembly of section .init:

Disassembly of section .plt:

Disassembly of section .plt.got:

Disassembly of section .text:

0000000000000760 <_start>:
 760:   31 ed                   xor    ebp,ebp
 762:   49 89 d1                mov    r9,rdx
 765:   5e                      pop    rsi
 766:   48 89 e2                mov    rdx,rsp
 769:   48 83 e4 f0             and    rsp,0xfffffffffffffff0
 76d:   50                      push   rax
 76e:   54                      push   rsp
 76f:   4c 8d 05 7a 02 00 00    lea    r8,[rip+0x27a]        # 9f0 <__libc_csu_fini>
 776:   48 8d 0d 03 02 00 00    lea    rcx,[rip+0x203]        # 980 <__libc_csu_init>
 77d:   48 8d 3d 50 01 00 00    lea    rdi,[rip+0x150]        # 8d4 <main>
 784:   ff 15 56 08 20 00       call   QWORD PTR [rip+0x200856]        # 200fe0 <__libc_start_main@GLIBC_2.2.5>
 78a:   f4                      hlt

Disassembly of section .fini:
```

This is the executable file

Im asking to disassemble just the _start function

And I'm specifying Intel syntax

Objdump - As basic as it gets

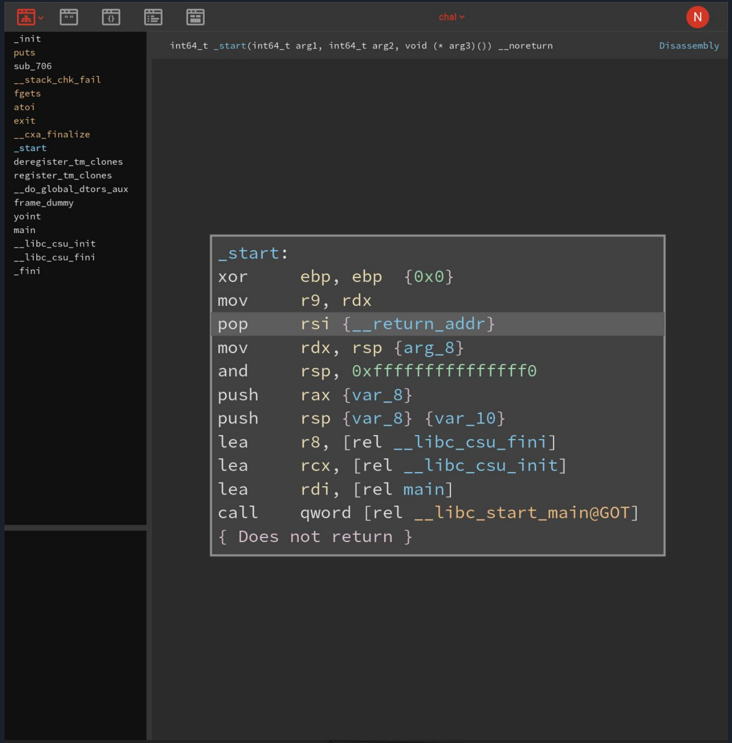


```
jc@aion ‹ master › : ~/osiris/git/Hack-Night/Rev/static
[1] % objdump -M intel --disassemble=_start chal

chal:     file format elf64-x86-64


Disassembly of section .init:

Disassembly of section .plt:

Disassembly of section .plt.got:

Disassembly of section .text:

0000000000000760 <_start>:
 760:	31 ed                	xor    ebp,ebp
 762:	49 89 d1             	mov    r9,rdx
 765:	5e                   	pop    rsi
 766:	48 89 e2             	mov    rdx,rsp
 769:	48 83 e4 f0          	and    rsp,0xfffffffffffffff0
 76d:	50                   	push   rax
 76e:	54                   	push   rsp
 76f:	4c 8d 05 7a 02 00 00 	lea    r8,[rip+0x27a]        # 9f0 <__libc_csu_fini>
 776:	48 8d 0d 03 02 00 00 	lea    rcx,[rip+0x203]        # 980 <__libc_csu_init>
 77d:	48 8d 3d 50 01 00 00 	lea    rdi,[rip+0x150]        # 8d4 <main>
 784:	ff 15 56 08 20 00    	call   QWORD PTR [rip+0x200856]        # 200fe0 <__libc_start_main@GLIBC_2.2.5>
 78a:	f4                   	hlt

Disassembly of section .fini:
```

Binary Ninja

cloud.binary.ninja

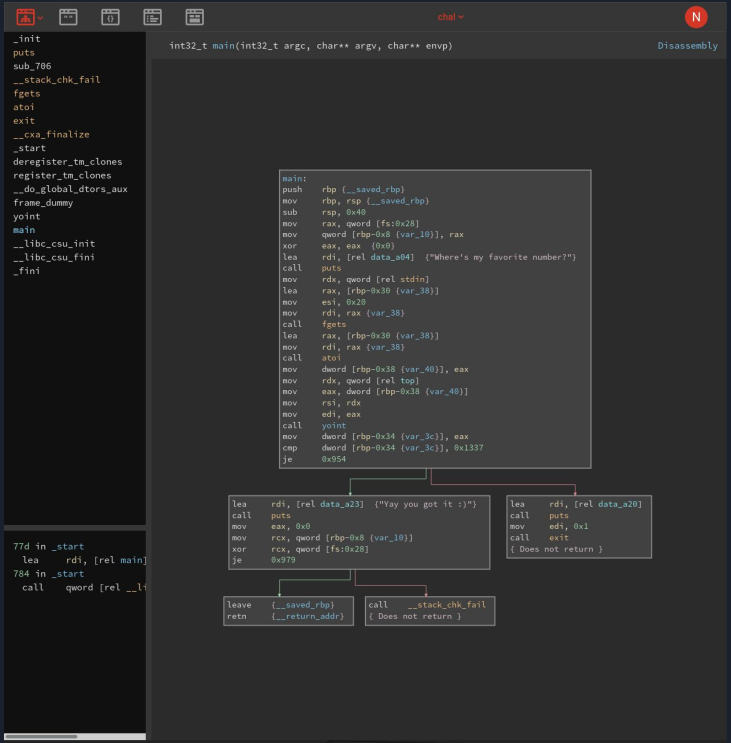
Binary Ninja - cloud



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
int64_t _start(int64_t arg1, int64_t arg2, void (* arg3)()) __noreturn
```

```
_start:
xor     ebp, ebp  {0x0}
mov     r9, rdx
pop     rsi {__return_addr}
mov     rdx, rsp {arg_8}
and     rsp, 0xfffffffffffffff0
push    rax {var_8}
push    rsp {var_8} {var_10}
lea     r8, [rel __libc_csu_fini]
lea     rcx, [rel __libc_csu_init]
lea     rdi, [rel main]
call    qword [rel __libc_start_main@GOT]
{ Does not return }
```



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

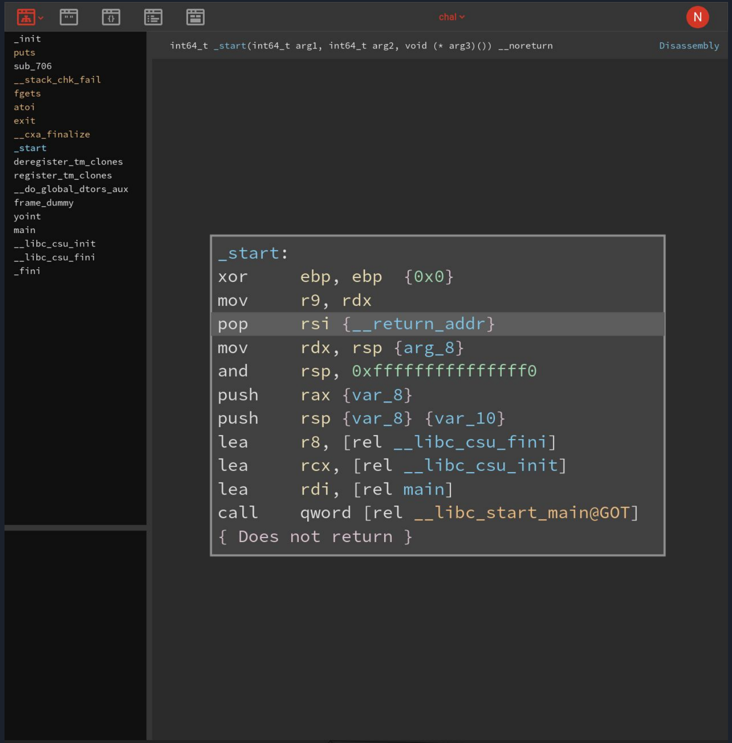
```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

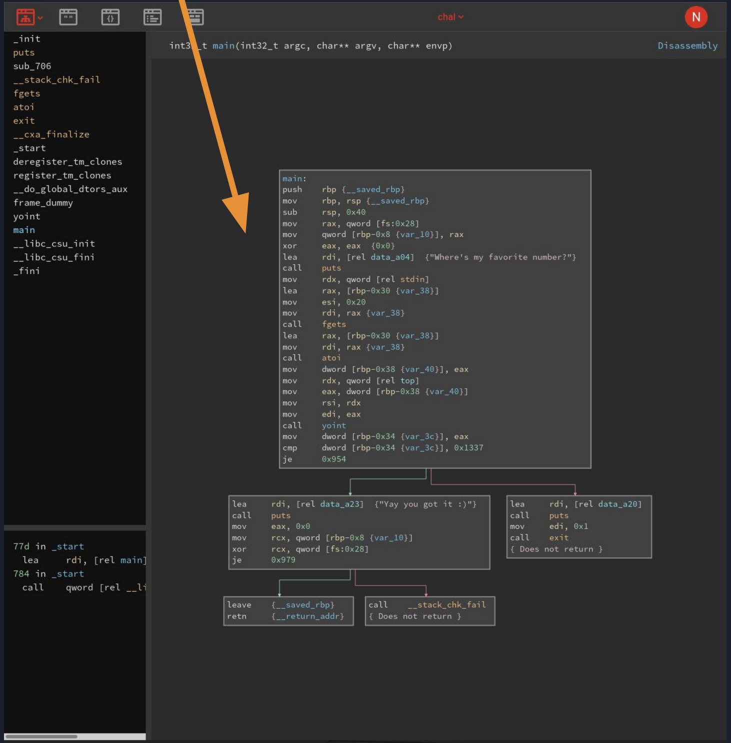
Graphs!



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
int64_t _start(int64_t arg1, int64_t arg2, void (* arg3)()) __noreturn
```

```
_start:
xor     ebp, ebp  {0x0}
mov     r9, rdx
pop     rsi {__return_addr}
mov     rdx, rsp {arg_8}
and     rsp, 0xfffffffffffffff0
push    rax {var_8}
push    rsp {var_8} {var_10}
lea     r8, [rel __libc_csu_fini]
lea     rcx, [rel __libc_csu_init]
lea     rdi, [rel main]
call    qword [rel __libc_start_main@GOT]
{ Does not return }
```



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

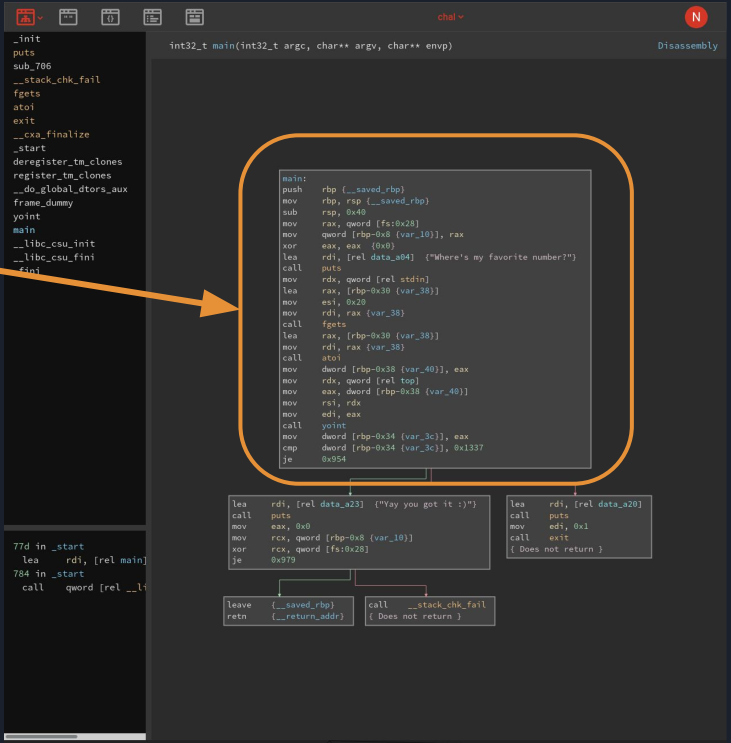
```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

We call these chunks of code in between jumps "Basic Blocks"



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

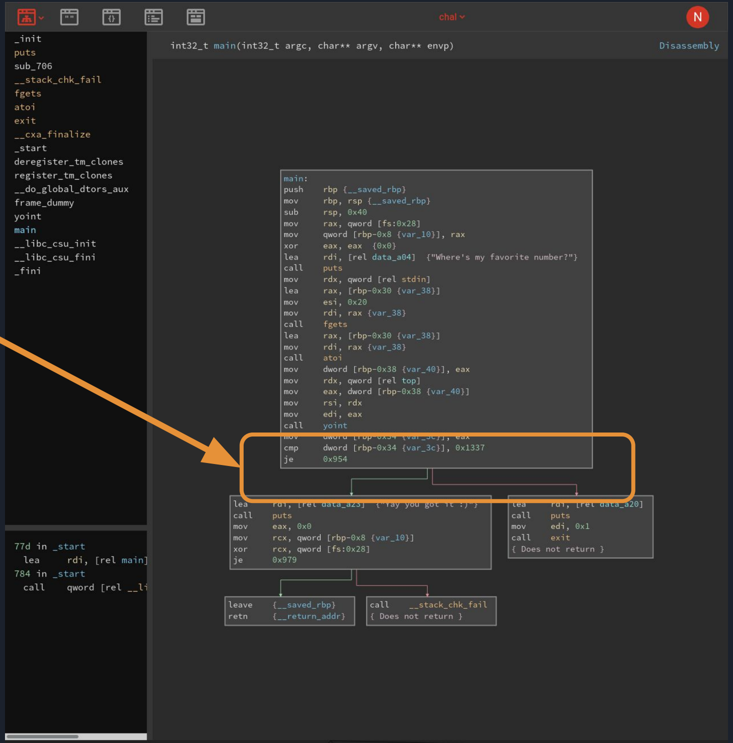
```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

Down at the bottom there is a cmp, then je



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

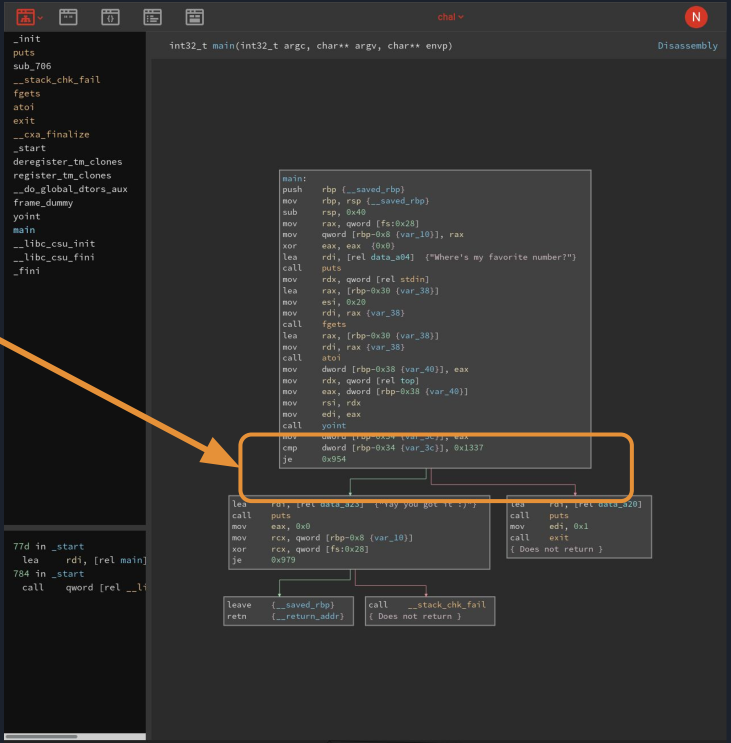
```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

This is a “conditional jump”



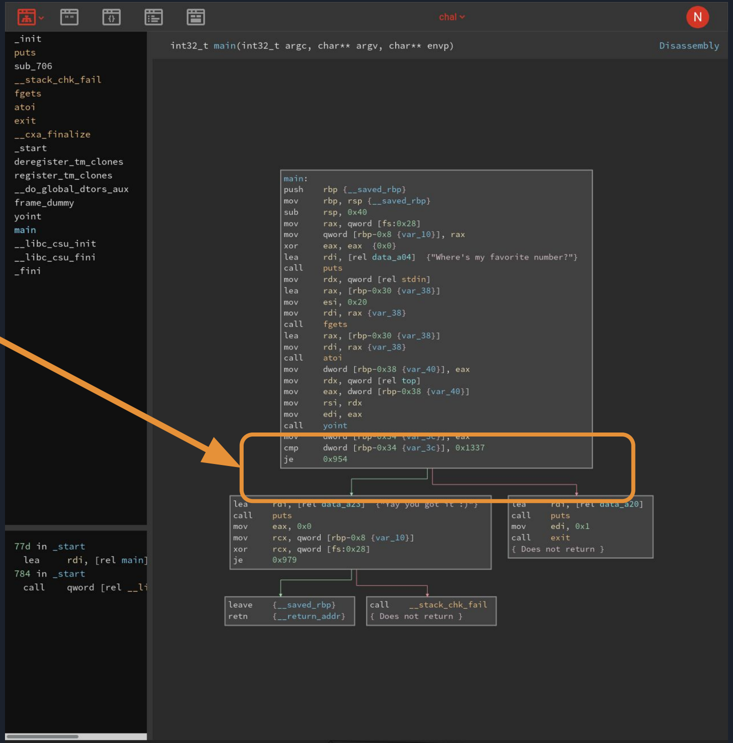
```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)

main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954

lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979

lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }

leave   {__saved_rbp}
retn    {__return_addr}

call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

Think of this as an if statement



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

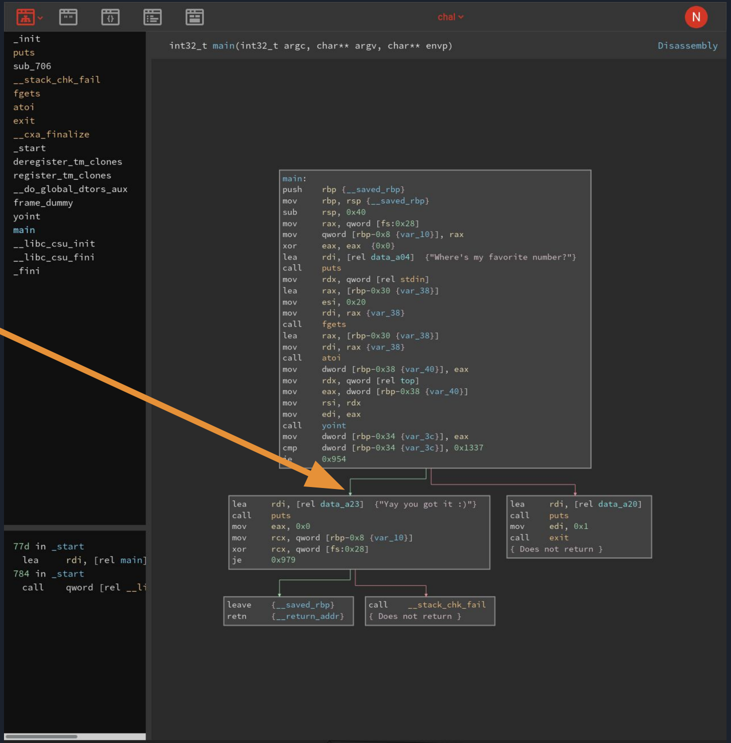
```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

If true, jump to this block



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

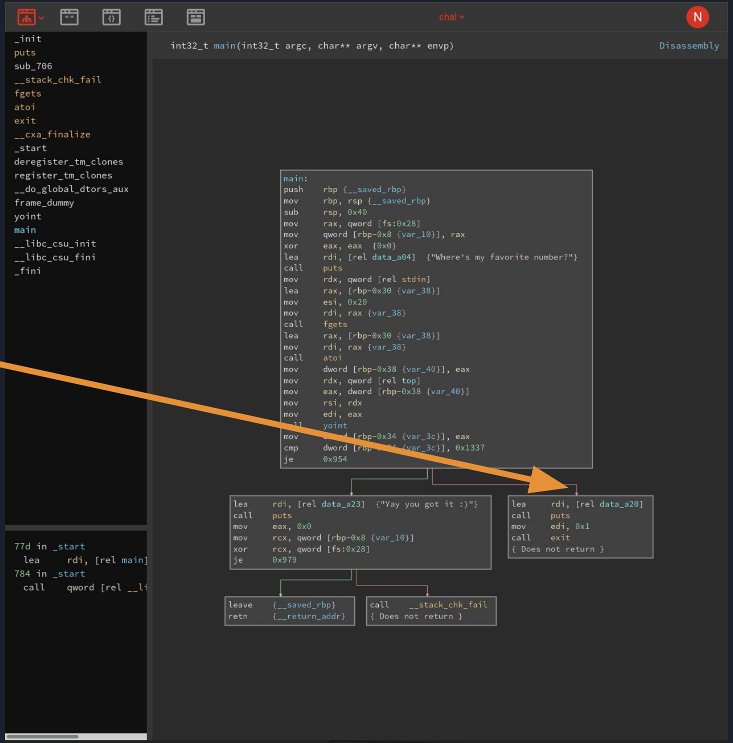
```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

Else, jump to this block



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

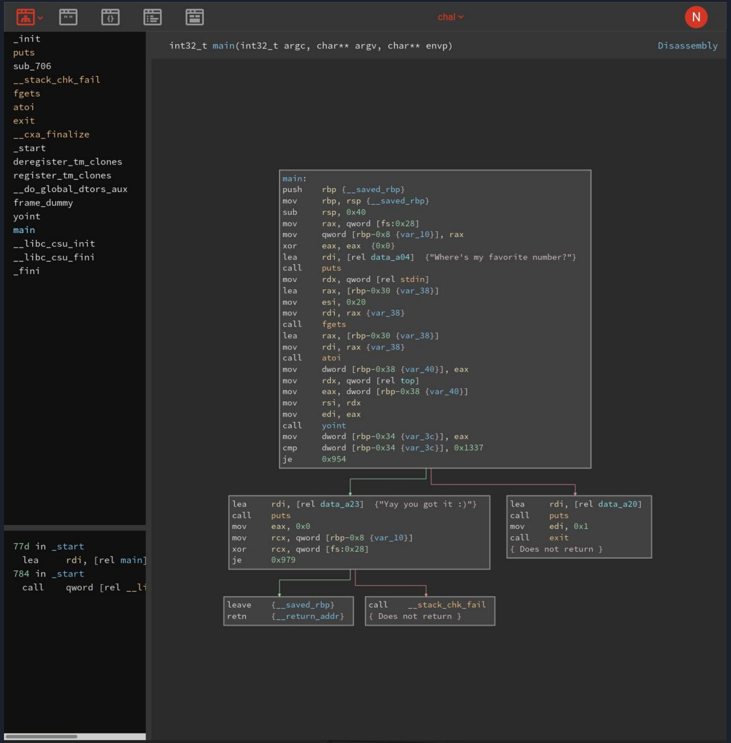
```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

Binary Ninja - cloud

This type of “graph” view is the most peoples prefered way to read assembly



```
_init
puts
sub_706
__stack_chk_fail
fgets
atoi
exit
__cxa_finalize
_start
deregister_tm_clones
register_tm_clones
__do_global_dtors_aux
frame_dummy
yoint
main
__libc_csu_init
__libc_csu_fini
_fini
```

```
77d in _start
  lea     rdi, [rel main]
784 in _start
  call    qword [rel __li
```

```
int32_t main(int32_t argc, char** argv, char** envp)
```

```
main:
push    rbp {__saved_rbp}
mov     rbp, rsp {__saved_rbp}
sub     rsp, 0x40
mov     rax, qword [fs:0x28]
mov     qword [rbp-0x8 {var_10}], rax
xor     eax, eax  {0x0}
lea     rdi, [rel data_a04]  {"Where's my favorite number?"}
call    puts
mov     rdx, qword [rel stdin]
lea     rax, [rbp-0x30 {var_38}]
mov     esi, 0x20
mov     rdi, rax {var_38}
call    fgets
lea     rax, [rbp-0x30 {var_38}]
mov     rdi, rax {var_38}
call    atoi
mov     dword [rbp-0x38 {var_40}], eax
mov     rdx, qword [rel top]
mov     eax, dword [rbp-0x38 {var_40}]
mov     rsi, rdx
mov     edi, eax
call    yoint
mov     dword [rbp-0x34 {var_3c}], eax
cmp     dword [rbp-0x34 {var_3c}], 0x1337
je      0x954
```

```
lea     rdi, [rel data_a23]  {"Yay you got it :)"}
call    puts
mov     eax, 0x0
mov     rcx, qword [rbp-0x8 {var_10}]
xor     rcx, qword [fs:0x28]
je      0x979
```

```
lea     rdi, [rel data_a20]
call    puts
mov     edi, 0x1
call    exit
{ Does not return }
```

```
leave   {__saved_rbp}
retn    {__return_addr}
```

```
call    __stack_chk_fail
{ Does not return }
```

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Connecting it back to C / C++

Questions?