CSC 405
Assembly

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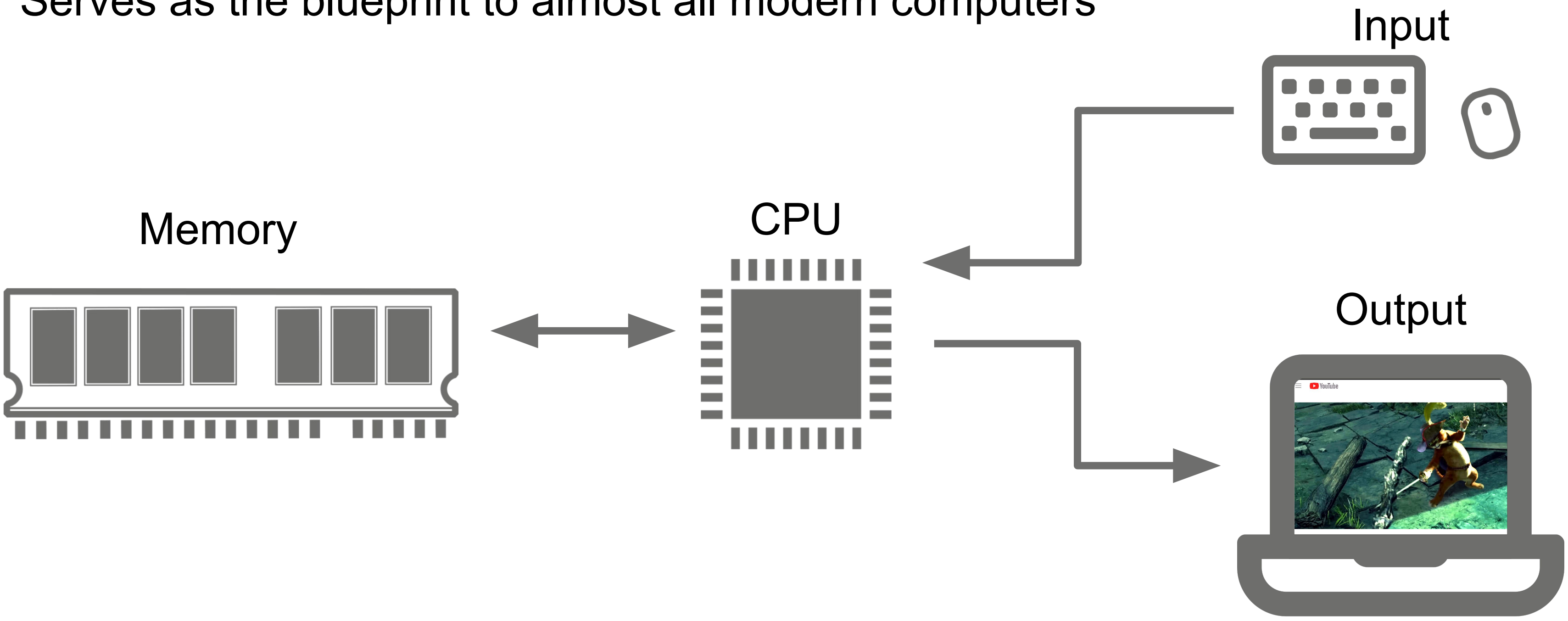
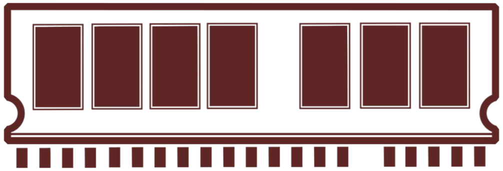
The von Neumann Architecture

Serves as the blueprint to almost all modern computers



The von Neumann Architecture

Memory



Memory holds two types of information:

Data Items

- variables, objects, etc.
- Read **from** or written **to**

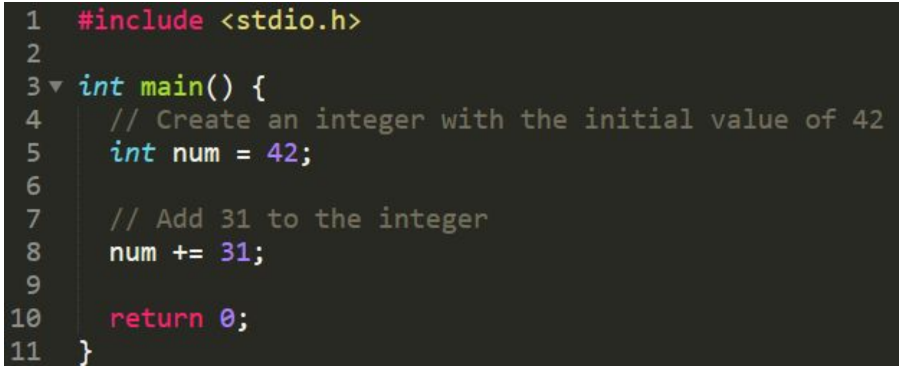
Program Instructions

- machine code
- Code, but converted into 'binary words'

Both are stored in memory as binary numbers in a continuous array of fixed width (also known as **words**) and have a unique **address**

Compiling Programs

Let's take a look at a simple C program



```c
#include <stdio.h>

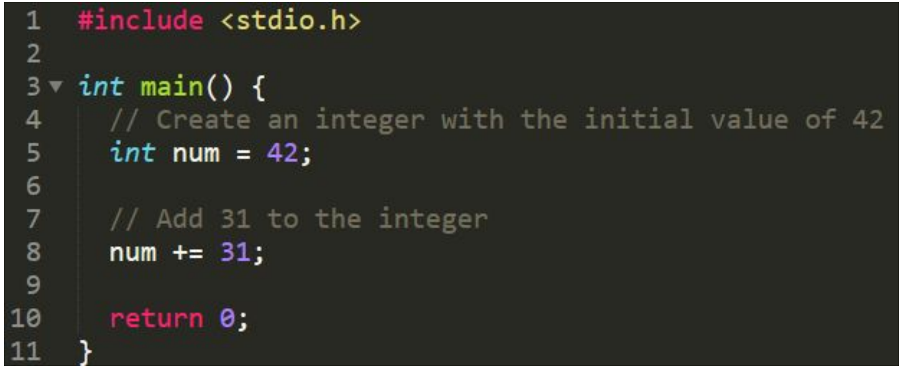
int main() {
  // Create an integer with the initial value of 42
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

Compiling Programs

We can compile C programs using **`gcc`** to generate a **binary** executable



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int main() {
    // Create an integer with the initial value of 42
    int num = 42;

    // Add 31 to the integer
    num += 31;

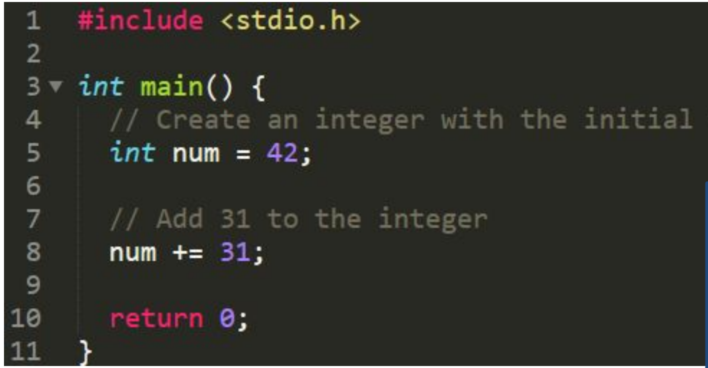
    return 0;
}
```

```
gcc simple.c -o simple
```

Using **`gcc`**, compile **`simple.c`** and output its binary as **`simple`**

Compiling Programs

We can compile C programs using **`gcc`** to generate a **binary** executable



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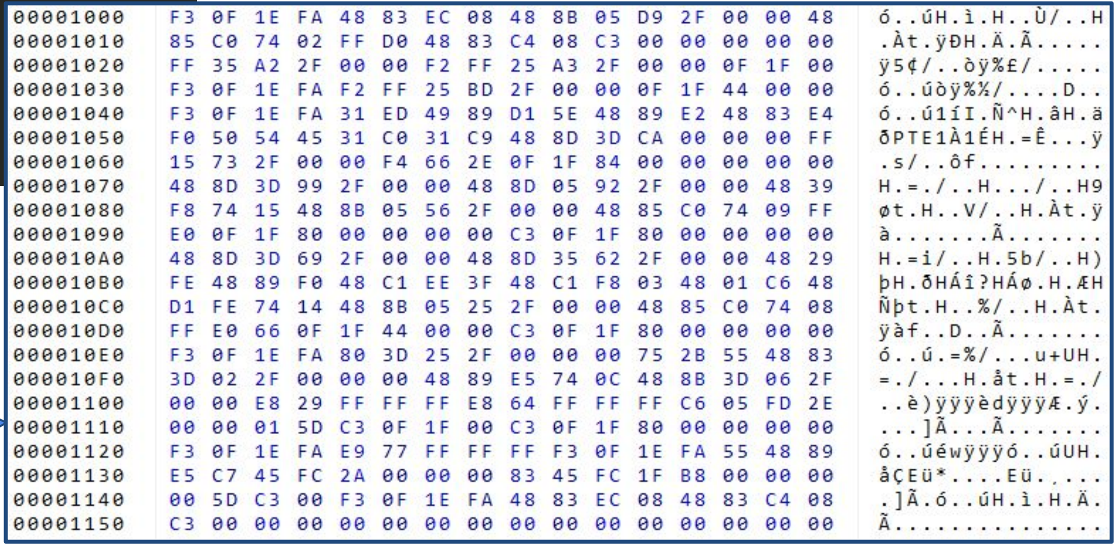
```
gcc simple.c -o simple
```

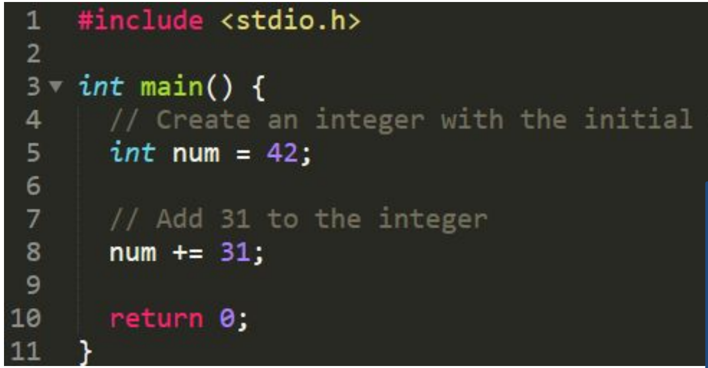
It will translate things into binary!



```
00001000   F3 0F 1E FA 48 83 EC 08 48 8B 05 D9 2F 00 00 48   ó..úH.ì.H..Ù/..H
00001010   85 C0 74 02 FF D0 48 83 C4 08 C3 00 00 00 00 00   .Àt.ÿÐH.Ä.Ã.....
00001020   FF 35 A2 2F 00 00 F2 FF 25 A3 2F 00 00 0F 1F 00   ÿ5¢/..òÿ%£/.....
00001030   F3 0F 1E FA F2 FF 25 BD 2F 00 00 0F 1F 44 00 00   ó..úòÿ%½/....D..
00001040   F3 0F 1E FA 31 ED 49 89 D1 5E 48 89 E2 48 83 E4   ó..ú1íI.Ñ^H.âH.ä
00001050   F0 50 54 45 31 C0 31 C9 48 8D 3D CA 00 00 00 FF   ðPTE1À1ÉH.=Ê...ÿ
00001060   15 73 2F 00 00 F4 66 2E 0F 1F 84 00 00 00 00 00   .s/..ôf.........
00001070   48 8D 3D 99 2F 00 00 48 8D 05 92 2F 00 00 48 39   H.=./..H.../..H9
00001080   F8 74 15 48 8B 05 56 2F 00 00 48 85 C0 74 09 FF   øt.H..V/..H.Àt.ÿ
00001090   E0 0F 1F 80 00 00 00 00 C3 0F 1F 80 00 00 00 00   à.......Ã.......
000010A0   48 8D 3D 69 2F 00 00 48 8D 35 62 2F 00 00 48 29   H.=i/..H.5b/..H)
000010B0   FE 48 89 F0 48 C1 EE 3F 48 C1 F8 03 48 01 C6 48   þH.ðHÁî?HÁø.H.ÆH
000010C0   D1 FE 74 14 48 8B 05 25 2F 00 00 48 85 C0 74 08   Ñþt.H..%/..H.Àt.
000010D0   FF E0 66 0F 1F 44 00 00 C3 0F 1F 80 00 00 00 00   ÿàf..D..Ã.......
000010E0   F3 0F 1E FA 80 3D 25 2F 00 00 00 75 2B 55 48 83   ó..ú.=%/...u+UH.
000010F0   3D 02 2F 00 00 00 48 89 E5 74 0C 48 8B 3D 06 2F   =./...H.åt.H.=./
00001100   00 00 E8 29 FF FF FF E8 64 FF FF FF C6 05 FD 2E   ..è)ÿÿÿèdÿÿÿÆ.ý.
00001110   00 00 01 5D C3 0F 1F 00 C3 0F 1F 80 00 00 00 00   ...]Ã...Ã.......
00001120   F3 0F 1E FA E9 77 FF FF FF F3 0F 1E FA 55 48 89   ó..úéwÿÿÿó..úUH.
00001130   E5 C7 45 FC 2A 00 00 00 83 45 FC 1F B8 00 00 00   åÇEü*....Eü.¸...
00001140   00 5D C3 00 F3 0F 1E FA 48 83 EC 08 48 83 C4 08   .]Ã.ó..úH.ì.H.Ä.
00001150   C3 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   Ã...............
```

Compiling Programs

We can compile C programs using **`gcc`** to generate a **binary** executable



```c
#include <stdio.h>

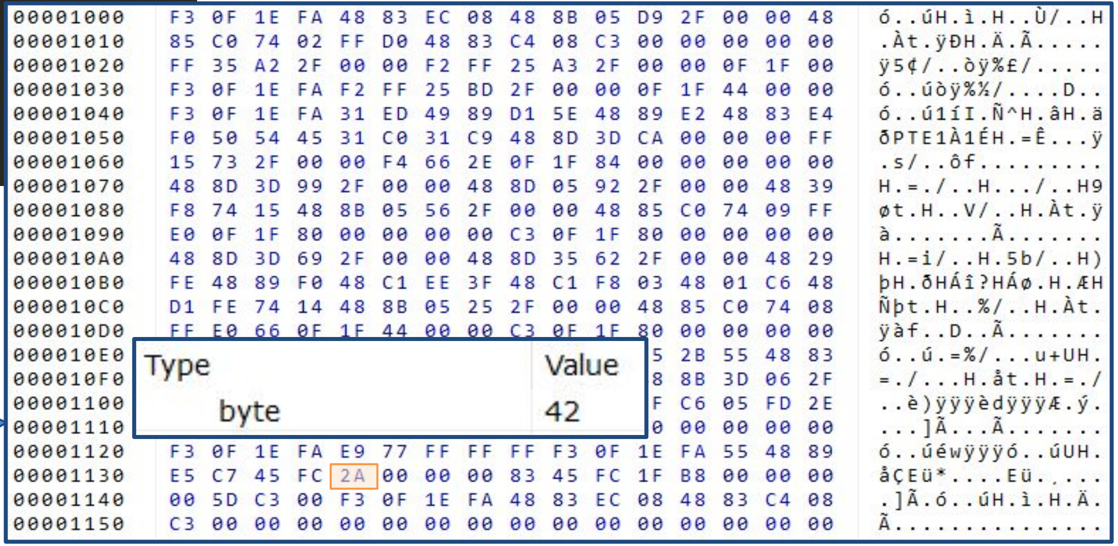
int main() {
    // Create an integer with the initial value of 42
    int num = 42;

    // Add 31 to the integer
    num += 31;

    return 0;
}
```

```
gcc simple.c -o simple
```

It will translate things into binary!



```
00001000   F3 0F 1E FA 48 83 EC 08 48 8B 05 D9 2F 00 00 48   ó..úH.ì.H..Ù/..H
00001010   85 C0 74 02 FF D0 48 83 C4 08 C3 00 00 00 00 00   .Àt.ÿÐH.Ä.Ã.....
00001020   FF 35 A2 2F 00 00 F2 FF 25 A3 2F 00 00 0F 1F 00   ÿ5¢/..òÿ%£/.....
00001030   F3 0F 1E FA F2 FF 25 BD 2F 00 00 0F 1F 44 00 00   ó..úòÿ%½/....D..
00001040   F3 0F 1E FA 31 ED 49 89 D1 5E 48 89 E2 48 83 E4   ó..ú1íI.Ñ^H.âH.ä
00001050   F0 50 54 45 31 C0 31 C9 48 8D 3D CA 00 00 00 FF   ðPTE1À1ÉH.=Ê...ÿ
00001060   15 73 2F 00 00 F4 66 2E 0F 1F 84 00 00 00 00 00   .s/..ôf.........
00001070   48 8D 3D 99 2F 00 00 48 8D 05 92 2F 00 00 48 39   H.=./..H.../..H9
00001080   F8 74 15 48 8B 05 56 2F 00 00 48 85 C0 74 09 FF   øt.H..V/..H.Àt.ÿ
00001090   E0 0F 1F 80 00 00 00 00 C3 0F 1F 80 00 00 00 00   à.......Ã.......
000010A0   48 8D 3D 69 2F 00 00 48 8D 35 62 2F 00 00 48 29   H.=i/..H.5b/..H)
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000010C0   D1 FE 74 14 48 8B 05 25 2F 00 00 48 85 C0 74 08   Ñþt.H..%/..H.Àt.
000010D0   FF E0 66 0F 1F 44 00 00 C3 0F 1F 80 00 00 00 00   ÿàf..D..Ã.......
000010E0                                     5 2B 55 48 83   ó..ú.=%/...u+UH.
000010F0                                     8 8B 3D 06 2F   =./...H.åt.H.=./
00001100                                     F C6 05 FD 2E   ..è)ÿÿÿèdÿÿÿÆ.ý.
00001110                                     0 00 00 00 00   ...]Ã...Ã.......
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00001130   E5 C7 45 FC 2A 00 00 00 83 45 FC 1F B8 00 00 00   åÇEü*....Eü.....
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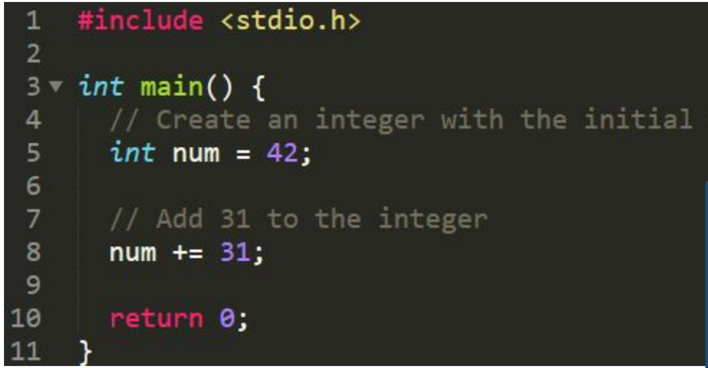
00001150   C3 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   Ã...............
```

Type	Value
byte	42

Compiling Programs

We can compile C programs using **gcc** to generate a **binary** executable



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```

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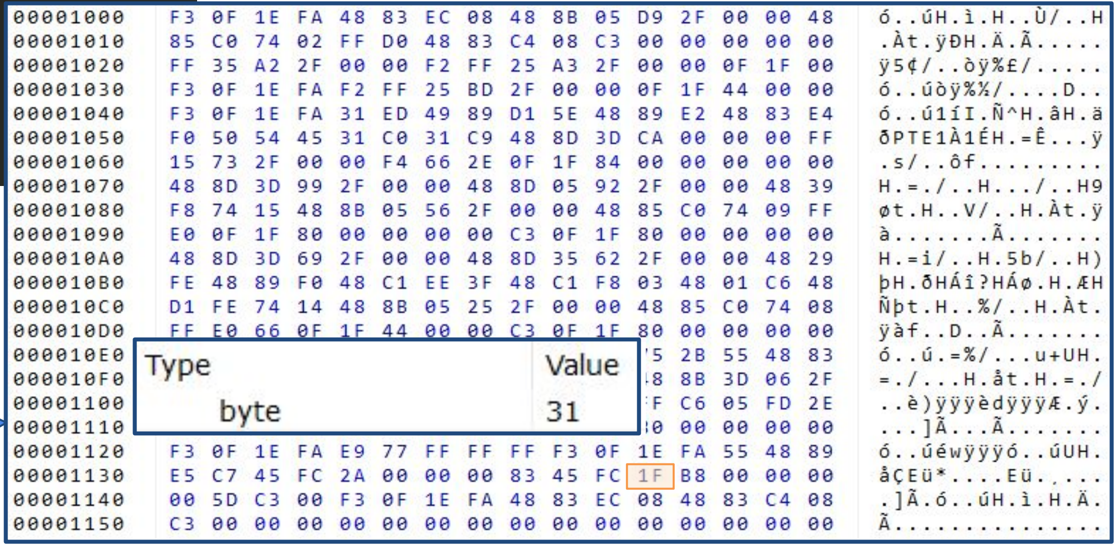

```
00001000   F3 0F 1E FA 48 83 EC 08 48 8B 05 D9 2F 00 00 48   ó..úH.ì.H..Ù/..H
00001010   85 C0 74 02 FF D0 48 83 C4 08 C3 00 00 00 00 00   .Àt.ÿÐH.Ä.Ã.....
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00001080   F8 74 15 48 8B 05 56 2F 00 00 48 85 C0 74 09 FF   øt.H..V/..H.Àt.ÿ
00001090   E0 0F 1F 80 00 00 00 00 C3 0F 1F 80 00 00 00 00   à.......Ã.......
000010A0   48 8D 3D 69 2F 00 00 48 8D 35 62 2F 00 00 48 29   H.=i/..H.5b/..H)
000010B0   FE 48 89 F0 48 C1 EE 3F 48 C1 F8 03 48 01 C6 48   þH.ðHÁî?HÁø.H.ÆH
000010C0   D1 FE 74 14 48 8B 05 25 2F 00 00 48 85 C0 74 08   Ñþt.H..%/..H.Àt.
000010D0   FF E0 66 0F 1F 44 00 00 C3 0F 1F 80 00 00 00 00   ÿàf..D..Ã.......
000010E0                                      '5 2B 55 48 83   ó..ú.=%/...u+UH.
000010F0                                      8 8B 3D 06 2F   =./...H.åt.H.=./
00001100                                      F C6 05 FD 2E   ..è)ÿÿÿèdÿÿÿÆ.ý.
00001110                                      0 00 00 00 00   ...]Ã...Ã.......
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00001150   C3 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   Ã...............
```

Type	Value
byte	31

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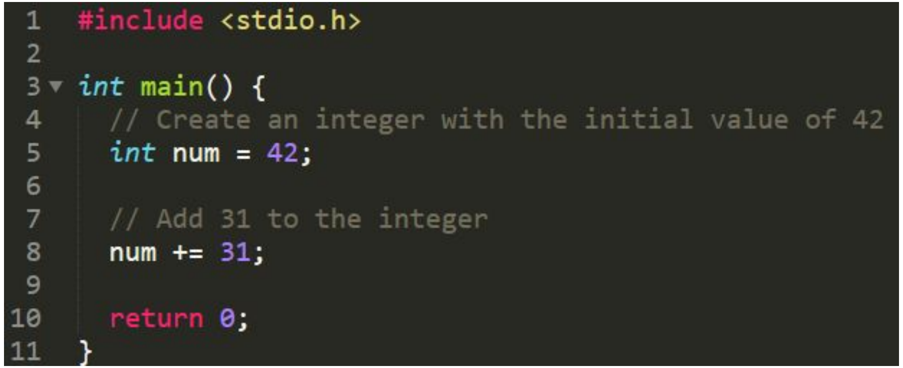
We can compile C programs using **gcc** to generate a **binary** executable



```c
#include <stdio.h>

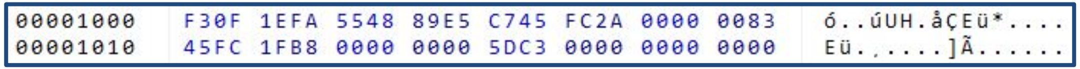
int main() {
    // Create an integer with the initial value of 42
    int num = 42;

    // Add 31 to the integer
    num += 31;

    return 0;
}
```

```
gcc -nostdlib simple.c -o simple
```

We can also exclude the standard library with -nostdlib to reduce "the code"



```
00001000    F30F 1EFA 5548 89E5 C745 FC2A 0000 0083    ó..úUH.åÇEü*....
00001010    45FC 1FB8 0000 0000 5DC3 0000 0000 0000    Eü.¸....]Ã......
```

Same code, but **only** `simple.c` and nothing else

The von Neumann Architecture

CPU

The CPU is in charge of executing the currently load program's instructions

Executes three primary tasks:

- **Arithmetic Logic Unit** (ALU)
  - Make some calculation
  - Do some comparison
- **Registers**
  - Read/Write values from/to memory
  - Stores values on the CPU rather than pushing to memory for efficiency
- **Control Unit**
  - Conditionally **jump** to execute other instructions

Memory is Slow

When the CPU retrieves contents from memory address **`i`**

- **`i`** travels from the **`CPU`** to **`RAM`**
- **`RAM`**'s logic selects the memory register whose address is **`i`**
- contents of **`RAM[i]`** travels back to the **`CPU`**

Level	**Access Time**	**Typical Size**	**Technology**	**Managed By**
Registers	`1-3 ns`	`1 KB`	CMOS	Compiler
L1 Cache	`2-8 ns`	`8KB - 128KB`	SRAM	Hardware
L2 Cache	`5-12 ns`	`0.5MB - 8MB`	SRAM	Hardware
Main Memory	`10-60 ns`	`64MB - 1GB`	DRAM	OS
Hard Disk	`0.3-1 ms`	`20GB - 100GB`	Magnetic	OS / User

Registers

Registers provide the same service but without travel and search expenses

This is because the reside inside the CPU and are much more limited in supply (allowing for shorter instructions)

Serves three purposes:

- **Data** - stores values for short term calculations
- **Addressing** - stores memory addresses for various functions
- **Program Counter** - keeps track of the next instruction to be fetched

Registers

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Serves three purposes:

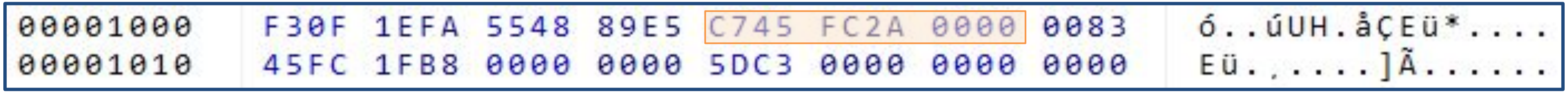
- **Data** - stores values for short term calculations
- **Addressing** - stores memory addresses for various functions
- **Program Counter** on to be fetched

As we'll see next week, this is how we can cause some damage

Machine Code

Machine code can be broken down into two categories: **binary** and **symbolic**

```
C7 45 FC 2A 00 00 00
```



```
00001000    F30F 1EFA 5548 89E5 C745 FC2A 0000 0083    ó..úUH.åÇEü*....
00001010    45FC 1FB8 0000 0000 5DC3 0000 0000 0000    Eü.¸....]Ã......
```

Machine Code

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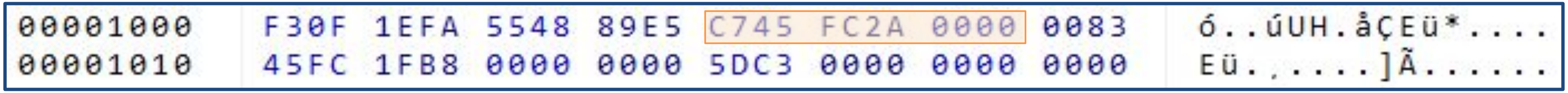
"binary"

```
C7 45 FC 2A 00 00 00
```



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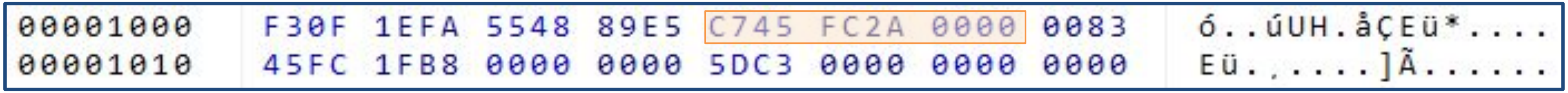
00001000    F30F 1EFA 5548 89E5 C745 FC2A 0000 0083    ó..úUH.åÇEü*....
00001010    45FC 1FB8 0000 0000 5DC3 0000 0000 0000    Eü.¸....]Ã......
```

Machine Code

Machine code can be broken down into two categories:

```
C7 45 FC 2A 00 00 00
```

Instead of
`1100 0111 0100 0101 1111`
`1100 0010 1010 0000 0000`
`0000 0000 0000 0000`,
we commonly condense it down to hexadecimal for "easier reading"



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00001000    F30F 1EFA 5548 89E5 C745 FC2A 0000 0083    ó..úUH.åÇEü*....
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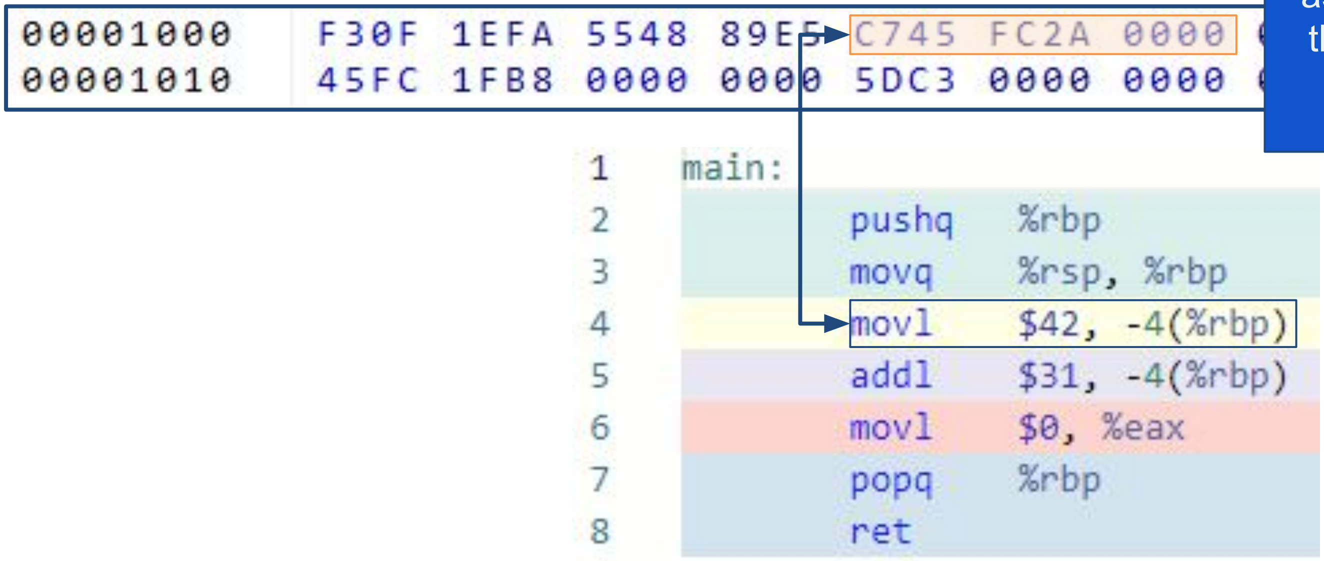


```
00001000    F30F 1EFA 5548 89E5 C745 FC2A 0000
00001010    45FC 1FB8 0000 0000 5DC3 0000 0000
```

```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

We can also use a symbolic assembly language that converts these 1's and 0's into something actually readable

Assembly Flavors

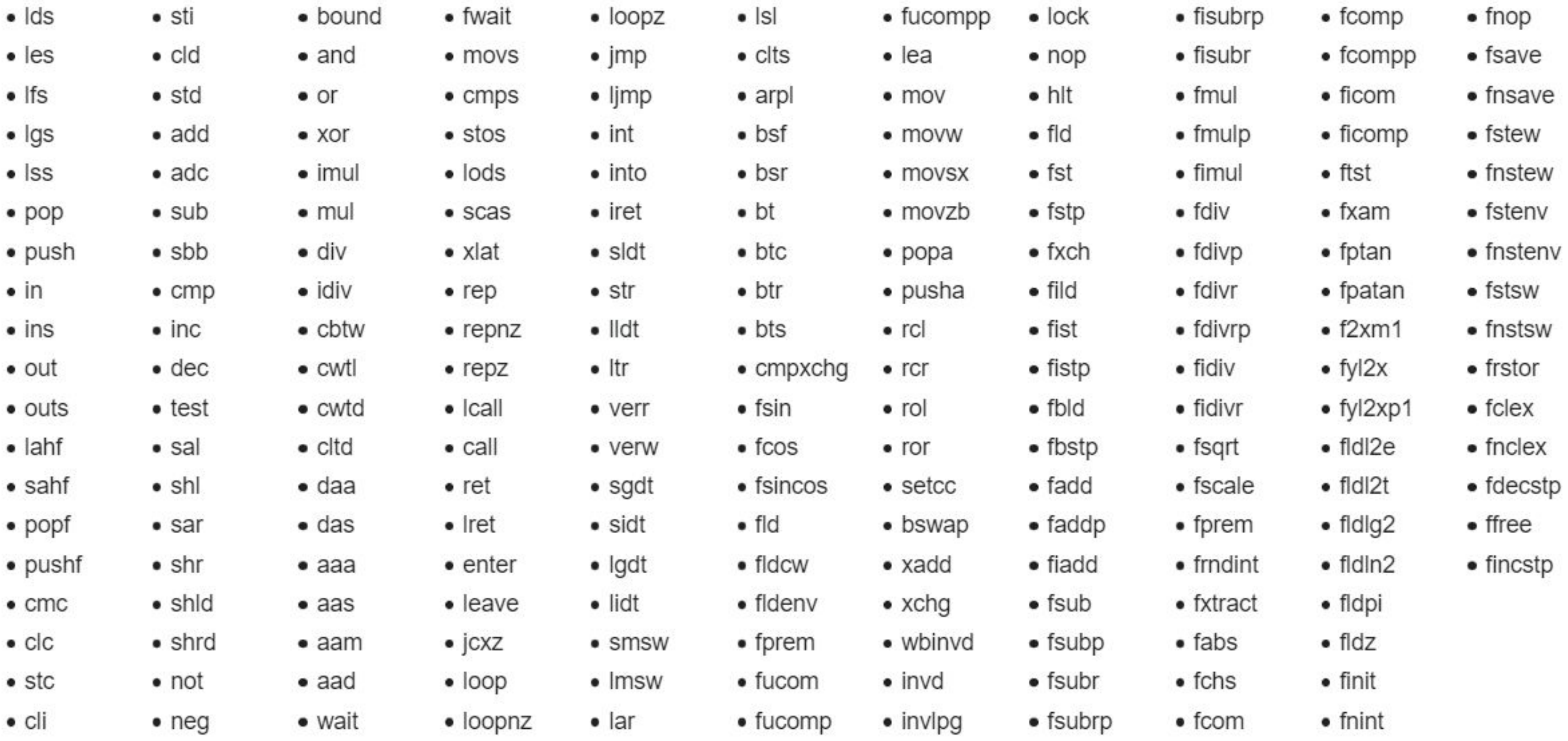
There are several Assembly languages, each written for a specific processor

In accordance with the processor's Instruction Set Architecture, or **ISA**

Three Primary Architectures

- x86
- ARM
- MIPS
- plus **many** more…

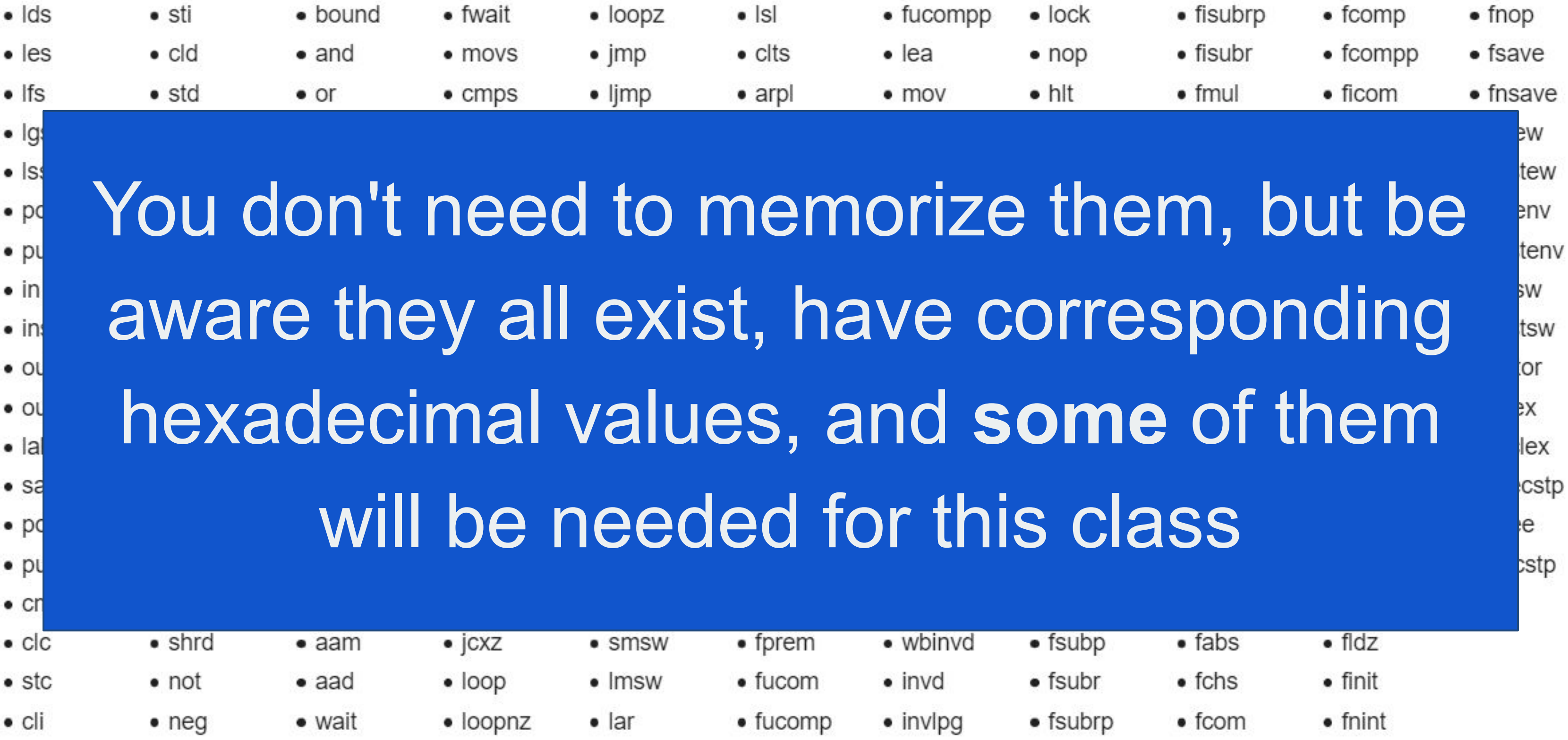
x86 Assembly Syntax - Reserved Keywords



- lds
- les
- lfs
- lgs
- lss
- pop
- push
- in
- ins
- out
- outs
- lahf
- sahf
- popf
- pushf
- cmc
- clc
- stc
- cli
- sti
- cld
- std
- add
- adc
- sub
- sbb
- cmp
- inc
- dec
- test
- sal
- shl
- sar
- shr
- shld
- shrd
- not
- neg
- bound
- and
- or
- xor
- imul
- mul
- div
- idiv
- cbtw
- cwtl
- cwtd
- cltd
- daa
- das
- aaa
- aas
- aam
- aad
- wait
- fwait
- movs
- cmps
- stos
- lods
- scas
- xlat
- rep
- repnz
- repz
- lcall
- call
- ret
- lret
- enter
- leave
- jcxz
- loop
- loopnz
- loopz
- jmp
- ljmp
- int
- into
- iret
- sldt
- str
- lldt
- ltr
- verr
- verw
- sgdt
- sidt
- lgdt
- lidt
- smsw
- lmsw
- lar
- lsl
- clts
- arpl
- bsf
- bsr
- bt
- btc
- btr
- bts
- cmpxchg
- fsin
- fcos
- fsincos
- fld
- fldcw
- fldenv
- fprem
- fucom
- fucomp
- fucompp
- lea
- mov
- movw
- movsx
- movzb
- popa
- pusha
- rcl
- rcr
- rol
- ror
- setcc
- bswap
- xadd
- xchg
- wbinvd
- invd
- invlpg
- lock
- nop
- hlt
- fld
- fst
- fstp
- fxch
- fild
- fist
- fistp
- fbld
- fbstp
- fadd
- faddp
- fiadd
- fsub
- fsubp
- fsubr
- fsubrp
- fisubrp
- fisubr
- fmul
- fmulp
- fimul
- fdiv
- fdivp
- fdivr
- fdivrp
- fidiv
- fidivr
- fsqrt
- fscale
- fprem
- frndint
- fxtract
- fabs
- fchs
- fcom
- fcomp
- fcompp
- ficom
- ficomp
- ftst
- fxam
- fptan
- fpatan
- f2xm1
- fyl2x
- fyl2xp1
- fldl2e
- fldl2t
- fldlg2
- fldln2
- fldpi
- fldz
- finit
- fnint
- fnop
- fsave
- fnsave
- fstew
- fnstew
- fstenv
- fnstenv
- fstsw
- fnstsw
- frstor
- fclex
- fnclex
- fdecstp
- ffree
- fincstp

https://en.wikipedia.org/wiki/X86_instruction_listings

x86 Assembly Syntax - Reserved Keywords



- lds
- les
- lfs
- lg
- ls
- po
- pu
- in
- in
- ou
- ou
- la
- sa
- po
- pu
- cr
- clc
- stc
- cli
- sti
- cld
- std
- shrd
- not
- neg
- bound
- and
- or
- aam
- aad
- wait
- fwait
- movs
- cmps
- jcxz
- loop
- loopnz
- loopz
- jmp
- ljmp
- smsw
- lmsw
- lar
- lsl
- clts
- arpl
- fprem
- fucom
- fucomp
- fucompp
- lea
- mov
- wbinvd
- invd
- invlpg
- lock
- nop
- hlt
- fsubp
- fsubr
- fsubrp
- fisubrp
- fisubr
- fmul
- fabs
- fchs
- fcom
- fcomp
- fcompp
- ficom
- fldz
- finit
- fnint
- fnop
- fsave
- fnsave
- ew
- tew
- env
- tenv
- sw
- tsw
- or
- ex
- lex
- cstp
- e
- cstp

You don't need to memorize them, but be aware they all exist, have corresponding hexadecimal values, and **some** of them will be needed for this class

https://en.wikipedia.org/wiki/X86_instruction_listings

Syntax Branches - Intel and AT&T

Intel

- Windows and DOS programs
- Operations follow the format
  `mnemonic destination, source`
- `mov ebx, 42`

AT&T

- Unix programs
- Operations follows the format
  `mnemonic source, destination`
- `mov $42, %ebx`

Syntax Branches - Intel and AT&T

Intel

- Windows and DOS programs
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AT&T

- Unix programs
- Operations follows the format
  `mnemonic source, destination`
- `mov $42, %ebx`

Move the value 42 into register ebx

* Slight variations between the two

Executing Programs

When a program is executed, various elements of the program are loaded into memory

Information from the program is then loaded from the address space in memory

Three Segments:

`.text` - holds program instructions (read-only)

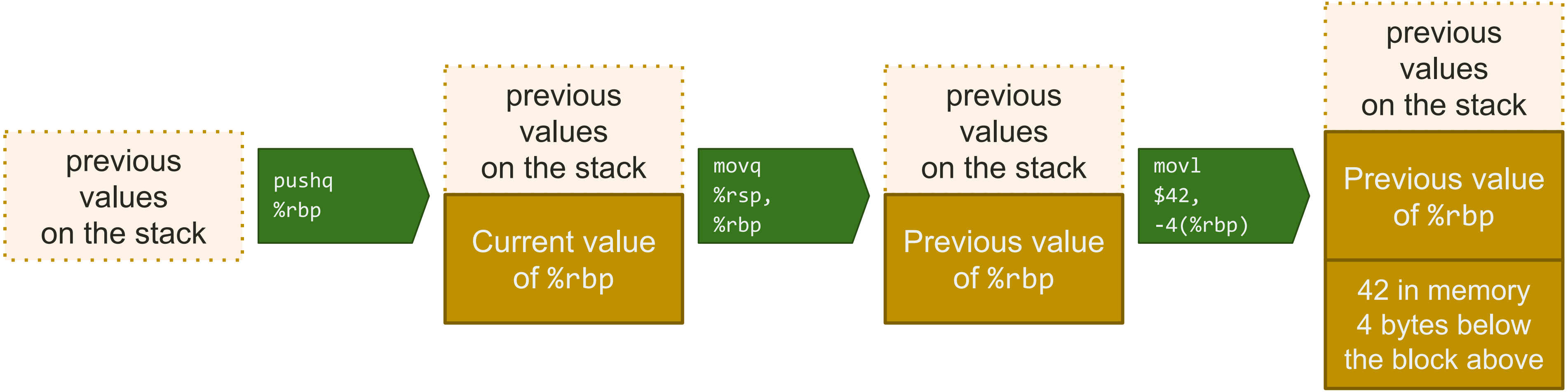
`.bss` - reserved for global variables, contains uninitialized data

`.data` - reserved for global variables, contains initialized data

Stack Machine Model

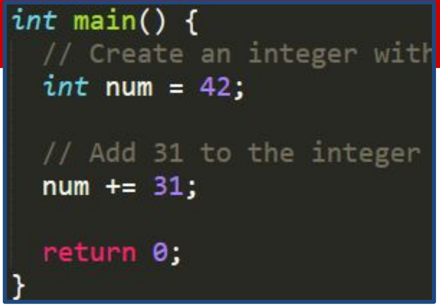
Arithmetic commands pop their operands from the top of the stack and push their results back to the stack

Since stacks are LIFO (last in first out), a stack pointer (sp) tracks the location just above the topmost element


previous values on the stack
pushq %rbp
previous values on the stack
Current value of %rbp
movq %rsp, %rbp
previous values on the stack
Previous value of %rbp
movl $42, -4(%rbp)
previous values on the stack
Previous value of %rbp
42 in memory 4 bytes below the block above

Programs in Memory

```
↑ Lower Memory Addresses (0x08000000)
  Shared Libraries
  .text
  .bss
  Heap  (grows ↓)
  Stack (grows ↑)
  env pointer
  argc
↓ Higher Memory Addresses (0xbfffffff)
```



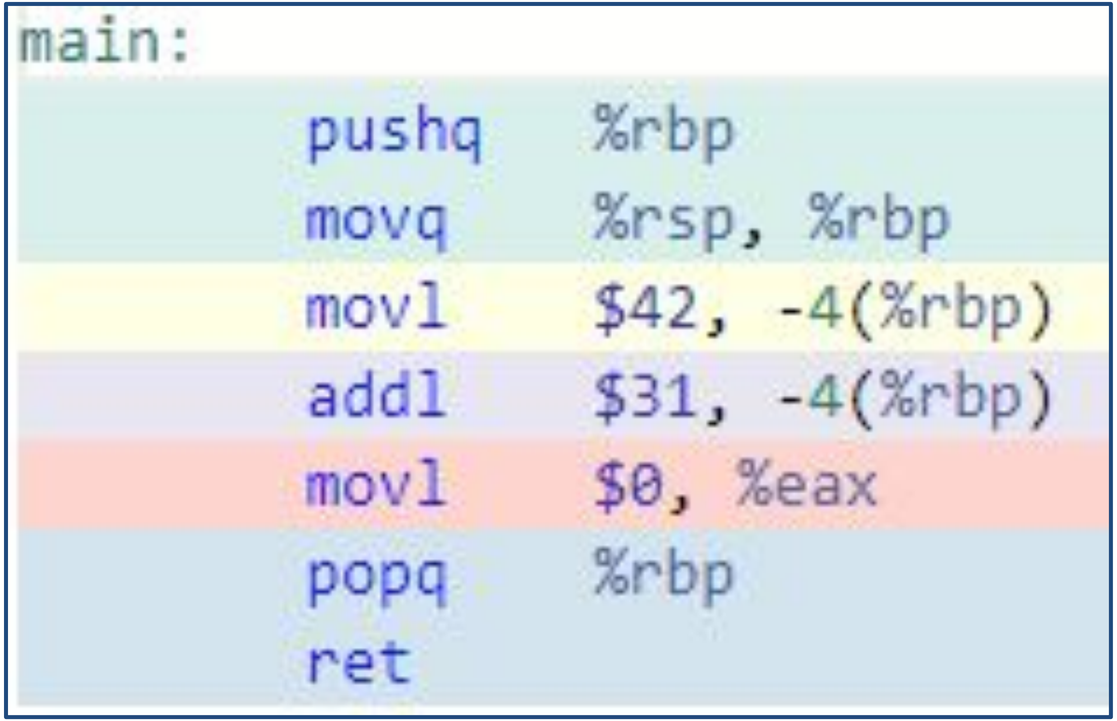
```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

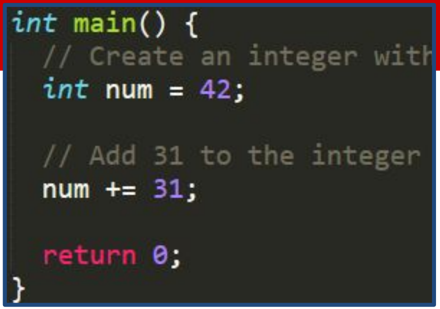
  return 0;
}
```

Machine Code

Let's break down the machine code of simple.c



```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```



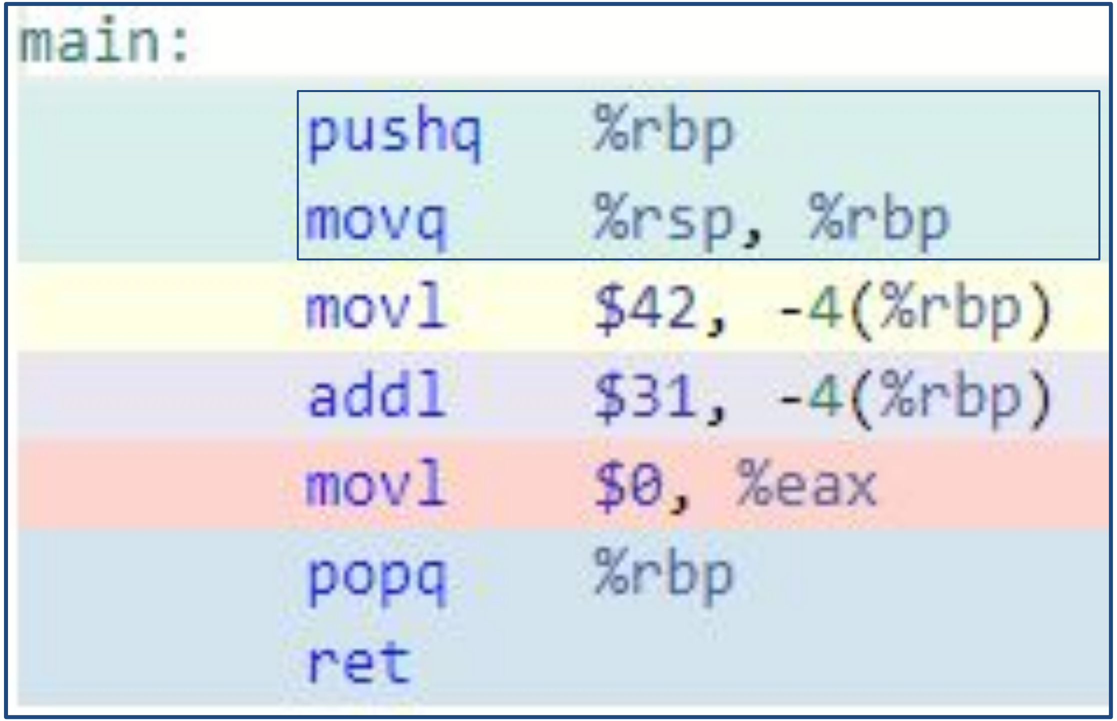
```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

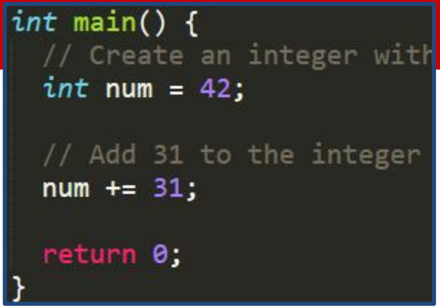
Machine Code

Let's break down the machine code of simple.c



```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

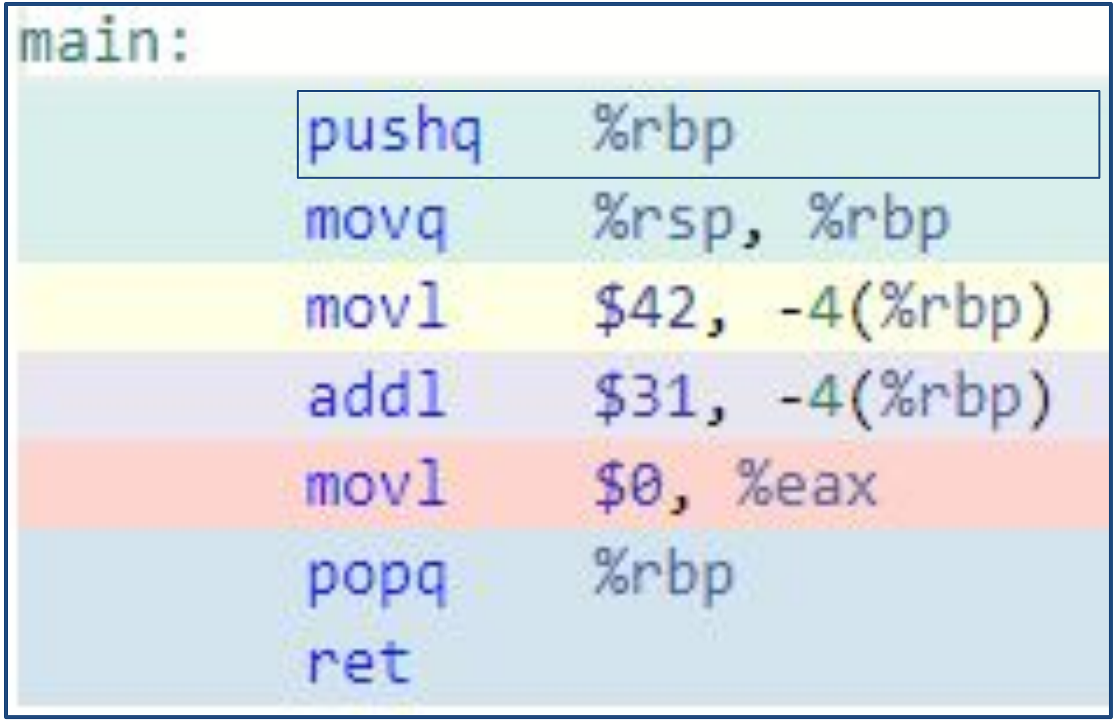
These first two instructions serve as the "function prologue"



```c
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

Machine Code

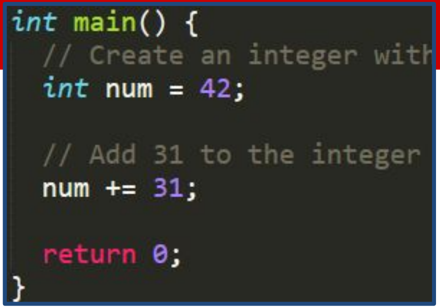
Let's break down the machine code of simple.c



```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

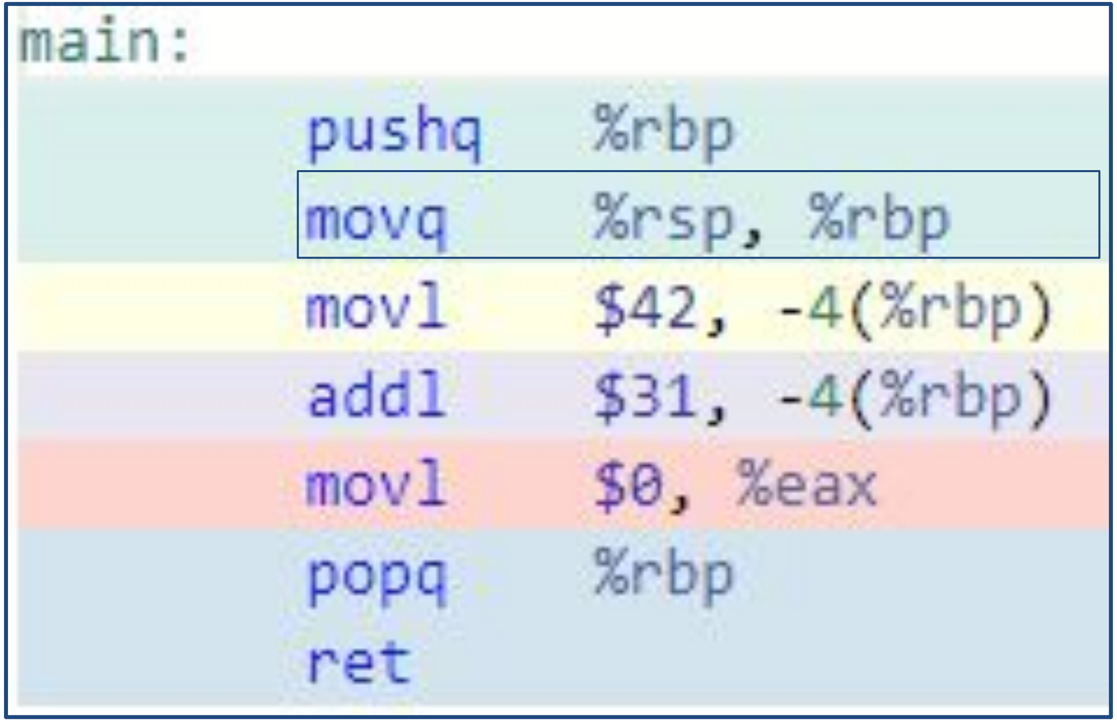
First, we **push** the **base pointer** (**%rbp**) onto the stack for later

Machine Code



```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

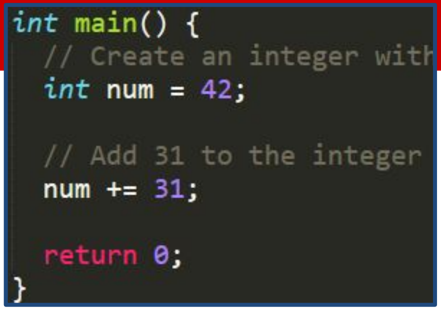
Let's break down the machine code of simple.c



```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

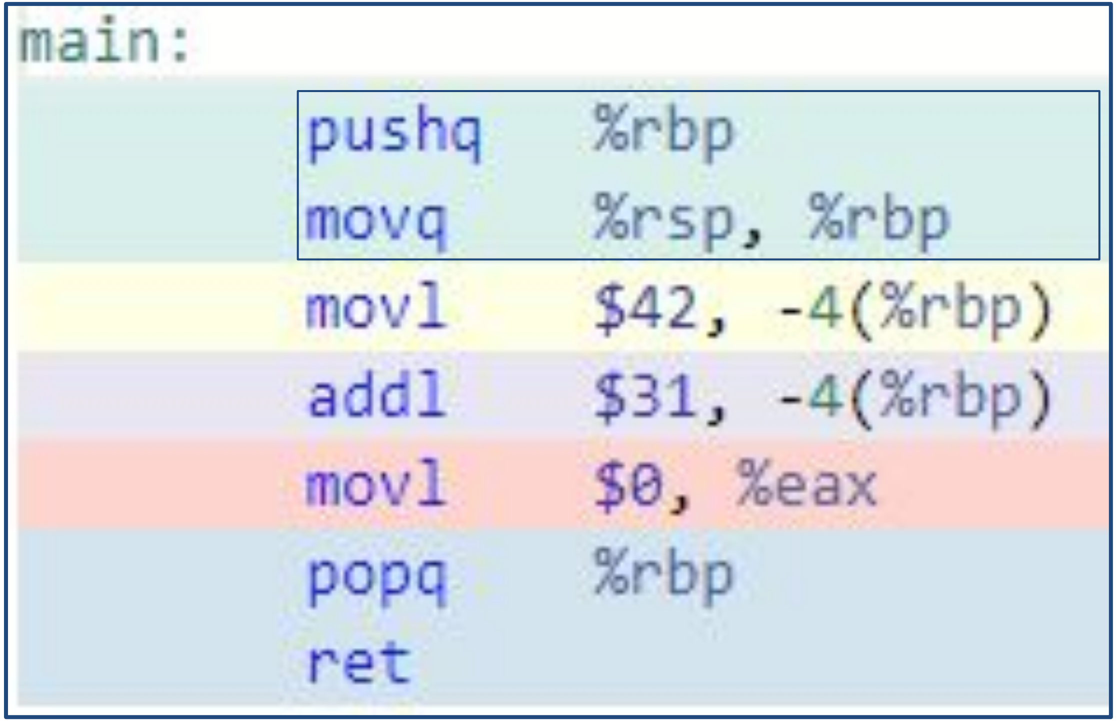
Next, we **move** (really copy) the **stack pointer** (%rsp) to the **base pointer** (%rbp)

Machine Code



```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

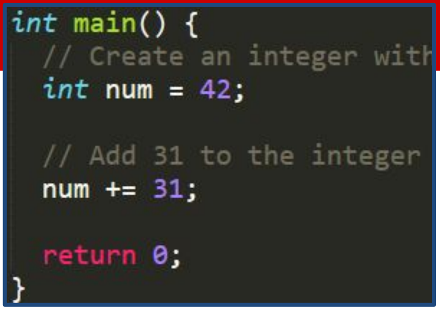
Let's break down the machine code of simple.c



```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

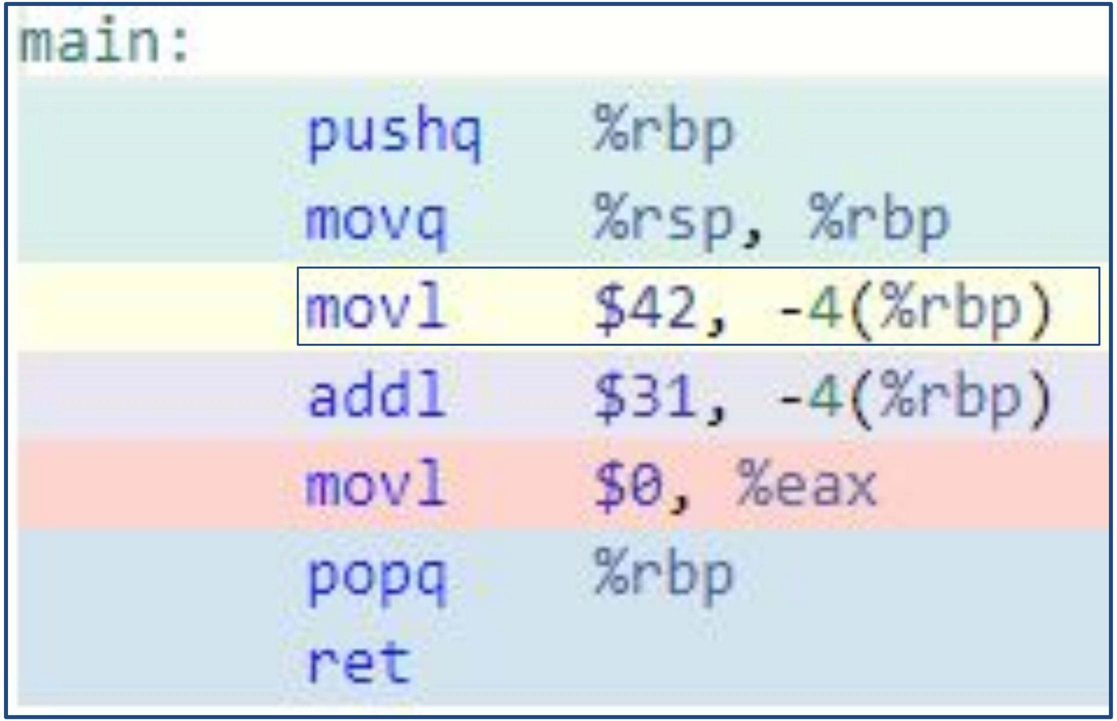
These two instructions establish the **stack frame** of the program

Machine Code



```c
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

Let's break down the machine code of simple.c

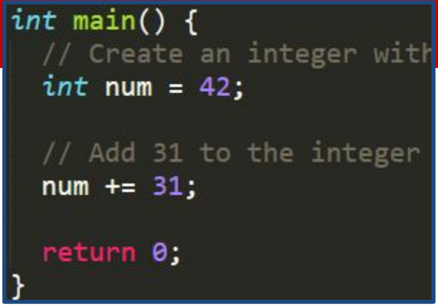


```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

Next, we're storing the constant 42 (**`$42`**) into a memory location

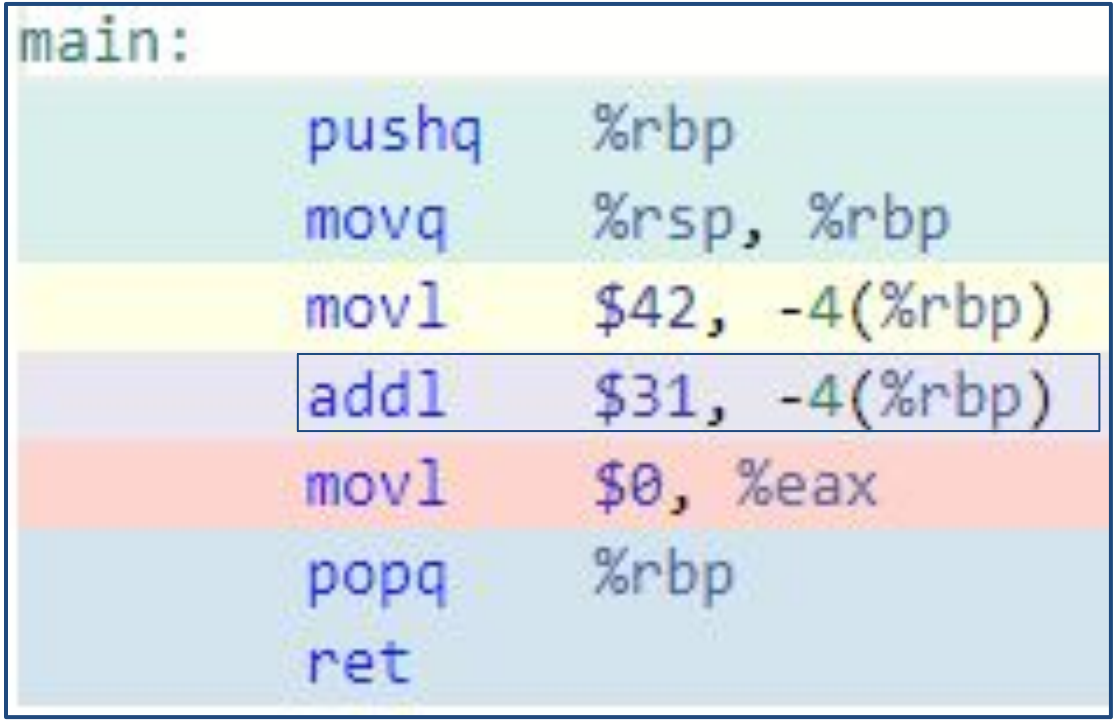
`-4(%rbp)` is pointing to a memory address that is 4 bytes before **`%rbp`**

Machine Code



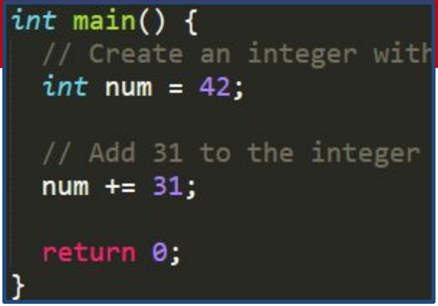
```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

Let's break down the machine code of simple.c



```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

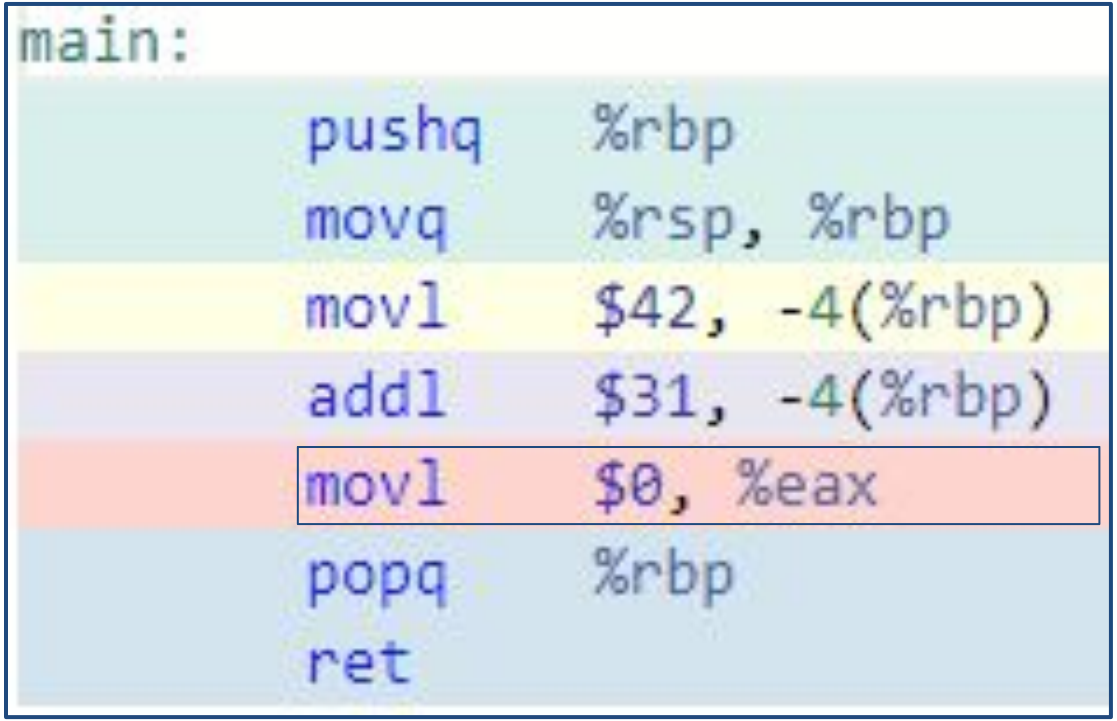
Next, add the constant 31 (**$31**) that same memory address



```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

Machine Code

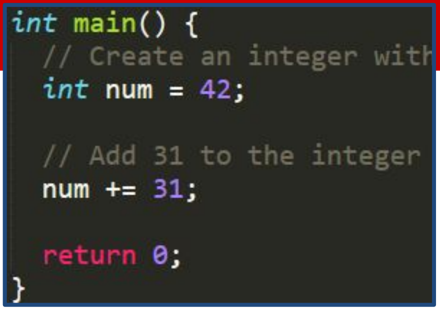
Let's break down the machine code of simple.c



```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

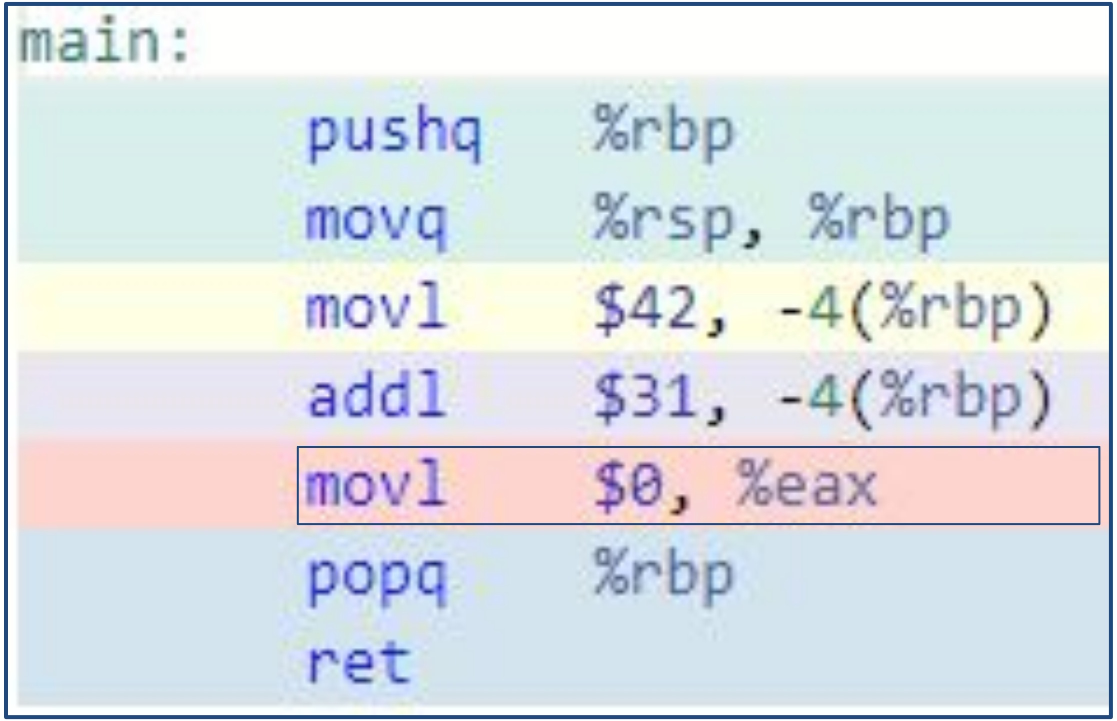
C programs need to return a value, so here we are copying the return value (0) to a general purpose register (%eax)

Machine Code



```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

Let's break down the machine code of simple.c

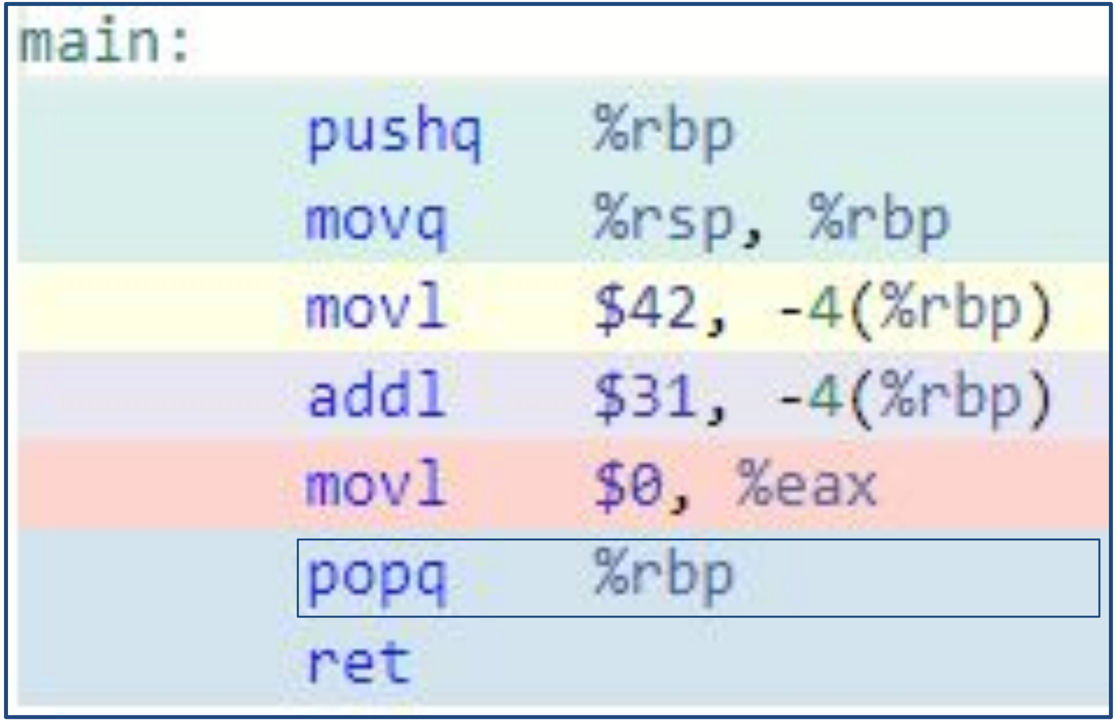


```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

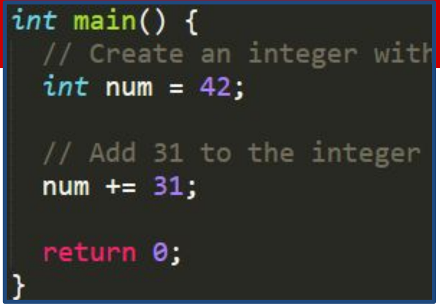
General purpose register (**%eax**)
Register relative to stack (**%rbp**)

Machine Code

Let's break down the machine code of simple.c

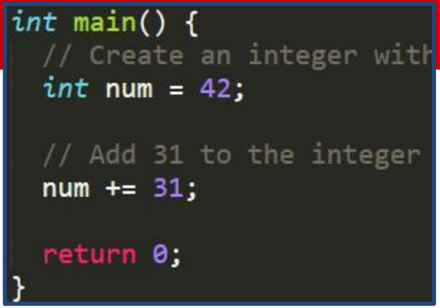


```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```



```
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

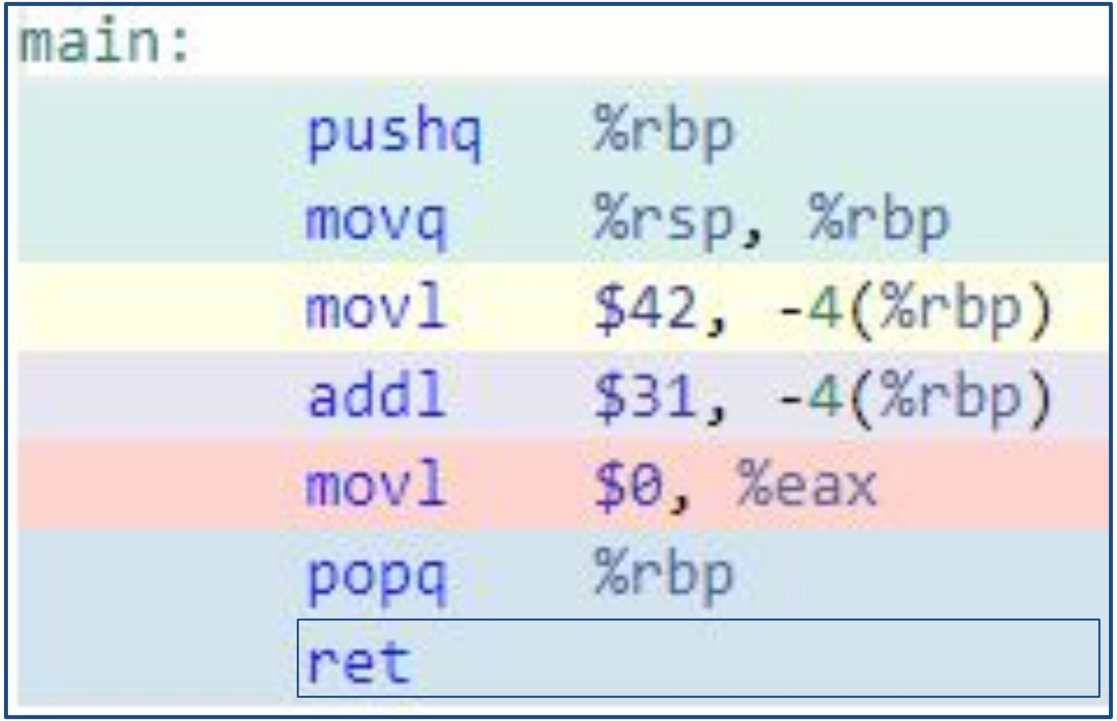
We **pop** the **base pointer** (%rbp) off the stack to return it to its original value



```c
int main() {
  // Create an integer with
  int num = 42;

  // Add 31 to the integer
  num += 31;

  return 0;
}
```

Machine Code

Let's break down the machine code of simple.c

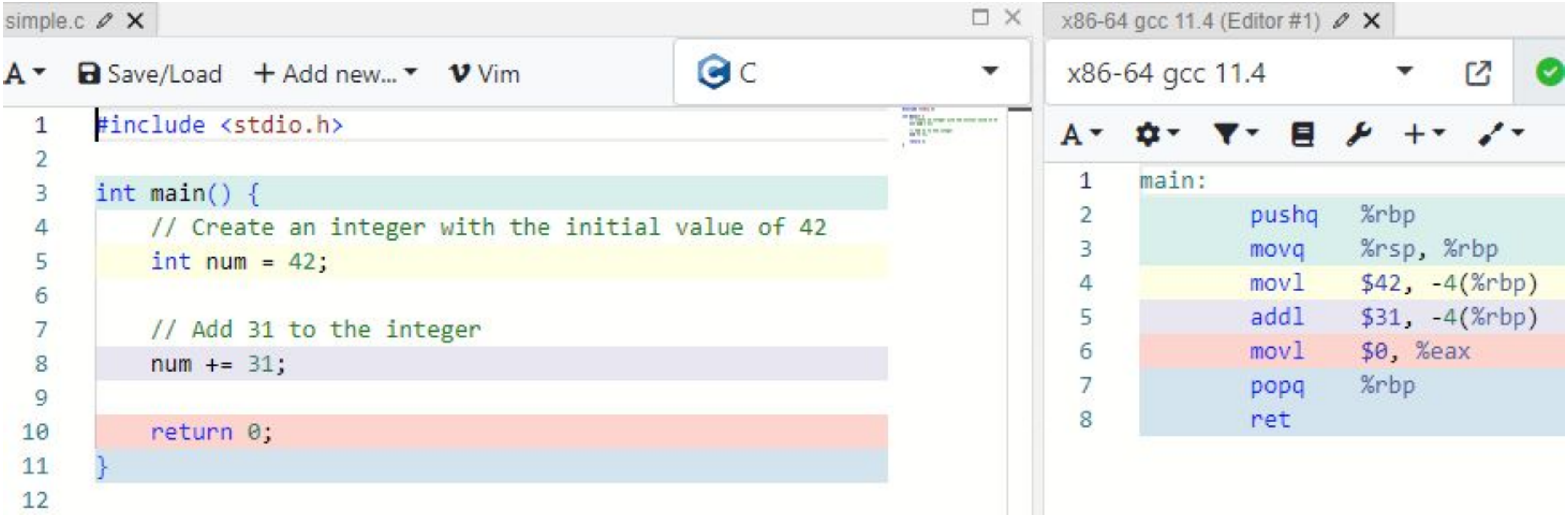


```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

Finally, we **return** from the function, where the return value (`0`) is expected to be stored in **`%eax`**

Tools to Become Familiar With

godbolt.org - You can use this site to browser the machine code for any program

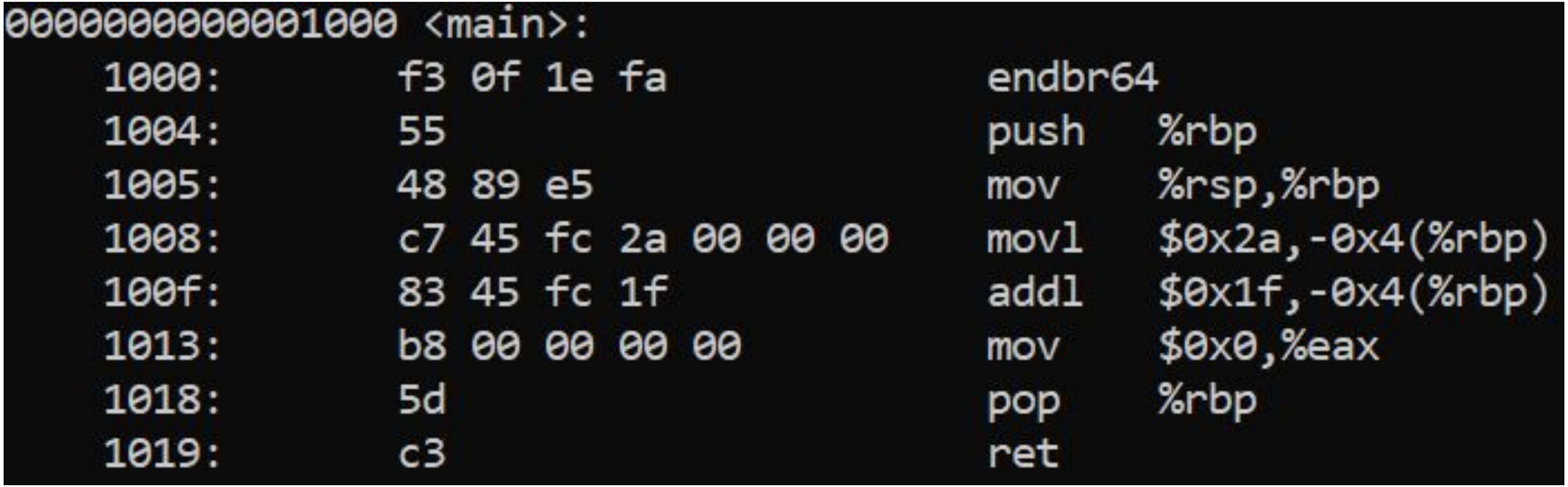


```c
#include <stdio.h>

int main() {
    // Create an integer with the initial value of 42
    int num = 42;

    // Add 31 to the integer
    num += 31;

    return 0;
}
```

```
main:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $42, -4(%rbp)
        addl    $31, -4(%rbp)
        movl    $0, %eax
        popq    %rbp
        ret
```

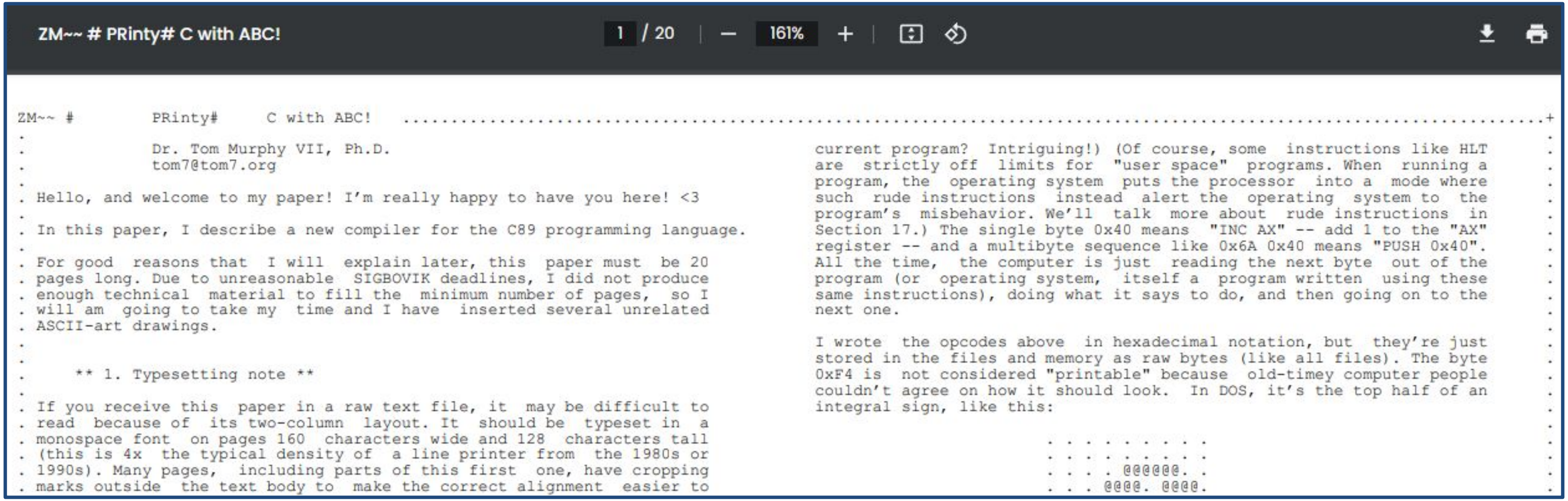
Tools to Become Familiar With

`objdump -zd <binary>` - Linux tool for producing the same results locally



```
0000000000001000 <main>:
    1000:       f3 0f 1e fa             endbr64
    1004:       55                      push   %rbp
    1005:       48 89 e5                mov    %rsp,%rbp
    1008:       c7 45 fc 2a 00 00 00    movl   $0x2a,-0x4(%rbp)
    100f:       83 45 fc 1f             addl   $0x1f,-0x4(%rbp)
    1013:       b8 00 00 00 00          mov    $0x0,%eax
    1018:       5d                      pop    %rbp
    1019:       c3                      ret
```

Security Zen - PDF that is also an executable program



ZM~~ #   PRinty#   C with ABC!

Dr. Tom Murphy VII, Ph.D.
tom7@tom7.org

Hello, and welcome to my paper! I’m really happy to have you here! <3

In this paper, I describe a new compiler for the C89 programming language.

For good reasons that I will explain later, this paper must be 20 pages long. Due to unreasonable SIGBOVIK deadlines, I did not produce enough technical material to fill the minimum number of pages, so I will am going to take my time and I have inserted several unrelated ASCII-art drawings.

** 1. Typesetting note **

If you receive this paper in a raw text file, it may be difficult to read because of its two-column layout. It should be typeset in a monospace font on pages 160 characters wide and 128 characters tall (this is 4x the typical density of a line printer from the 1980s or 1990s). Many pages, including parts of this first one, have cropping marks outside the text body to make the correct alignment easier to

current program? Intriguing!) (Of course, some instructions like HLT are strictly off limits for "user space" programs. When running a program, the operating system puts the processor into a mode where such rude instructions instead alert the operating system to the program’s misbehavior. We’ll talk more about rude instructions in Section 17.) The single byte 0x40 means "INC AX" -- add 1 to the "AX" register -- and a multibyte sequence like 0x6A 0x40 means "PUSH 0x40". All the time, the computer is just reading the next byte out of the program (or operating system, itself a program written using these same instructions), doing what it says to do, and then going on to the next one.

I wrote the opcodes above in hexadecimal notation, but they’re just stored in the files and memory as raw bytes (like all files). The byte 0xF4 is not considered "printable" because old-timey computer people couldn’t agree on how it should look. In DOS, it’s the top half of an integral sign, like this:

```
. . . . . . . . . .
. . . . . . . . . .
. . . . . @@@@@@. .
. . . . @@@@. @@@@.
```

Paper Link

YouTube Video Explaining How He Did It