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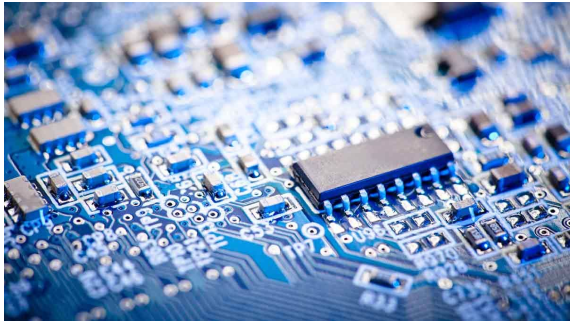
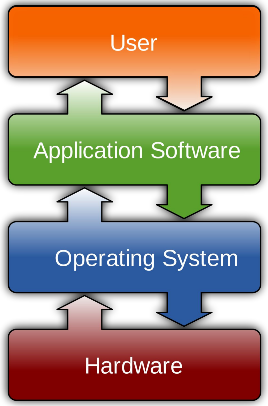


CS 3650 Computer Systems

Alden Jackson / Ferdinand Vesley



Intro	Virtualization		Concurrency	Persistence	Appendices
Preface	3 *Dialogue*	12 *Dialogue*	25 *Dialogue*	35 *Dialogue*	*Dialogue*
TOC	4 Processes	13 Address Spaces	26 Concurrency and Threads code	36 I/O Devices	Virtual Machines
1 *Dialogue*	5 Process API code	14 Memory API	27 Thread API	37 Hard Disk Drives	*Dialogue*
2 Introduction code	6 Direct Execution	15 Address Translation	28 Locks	38 Redundant Disk Arrays (RAID)	Monitors
	7 CPU Scheduling	16 Segmentation	29 Locked Data Structures	39 Files and Directories	*Dialogue*
	8 Multi-level Feedback	17 Free Space Management	30 Condition Variables	40 File System Implementation	Lab Tutorial
	9 Lottery Scheduling code	18 Introduction to Paging	31 Semaphores	41 Fast File System (FFS)	Systems Labs
	10 Multi-CPU Scheduling	19 Translation Lookaside Buffers	32 Concurrency Bugs	42 FSCK and Journaling	xv6 Labs
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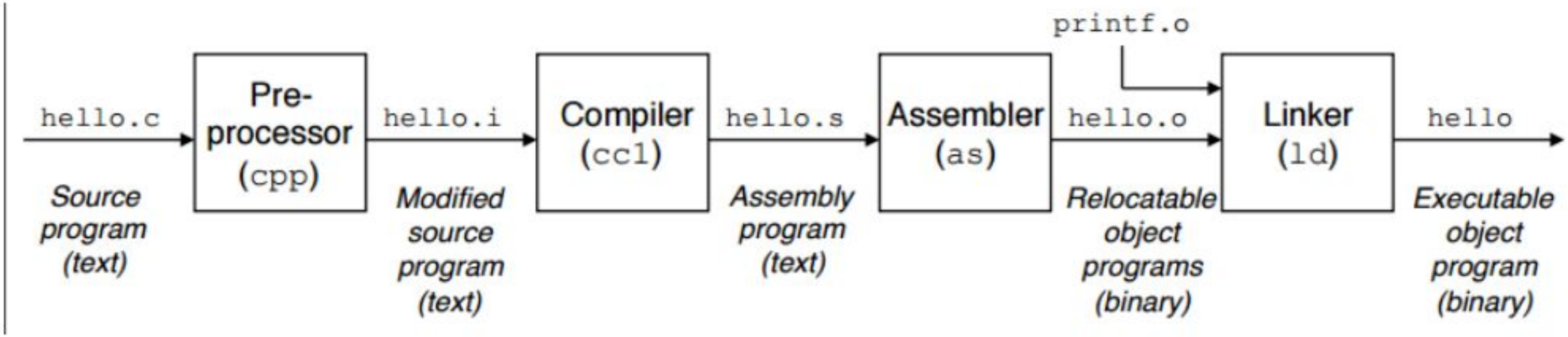
Lecture 2 - Assembly in a Day

Recall the C toolchain pipeline

- All C programs go through this transformation of C --> Assembly --> Machine Code



So we have gone back in time in a way!

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

1948	Curry notation system	Haskell Curry
1948	Plankalkül (concept published)	Konrad Zuse
1949	Short Code	John Mauchly and William F. Schmitt
Year	**Name**	**Chief developer, company**

1950s [edit]

Year	Name	Chief developer, company	Predecessor(s)
1950	Short Code	William F Schmidt, Albert B. Tonik,[3] J.R. Logan	Brief Code
1950	Birkbeck Assembler	Kathleen Booth	ARC
1951	Superplan	Heinz Rutishauser	Plankalkül
1951	ALGAE	Edward A Voorhees and Karl Balke	none (unique language)
1951	Intermediate Programming Language	Arthur Burks	Short Code
1951	Regional Assembly Language	Maurice Wilkes	EDSAC
1951	Boehm unnamed coding system	Corrado Böhm	CPC Coding scheme
1951	Klammerausdrücke	Konrad Zuse	Plankalkül
1951	OMNIBAC Symbolic Assembler	Charles Katz	Short Code
1951	Stanislaus (Notation)	Fritz Bauer	none (unique language)
1951	Whirlwind assembler	Charles Adams and Jack Gilmore at MIT Project Whirlwind	EDSAC
1951	Rochester assembler	Nat Rochester	EDSAC

So we have gone back in time!

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Year	Name
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Year	Name

1950s [edit]

Year	Name		
1950	Short Code		
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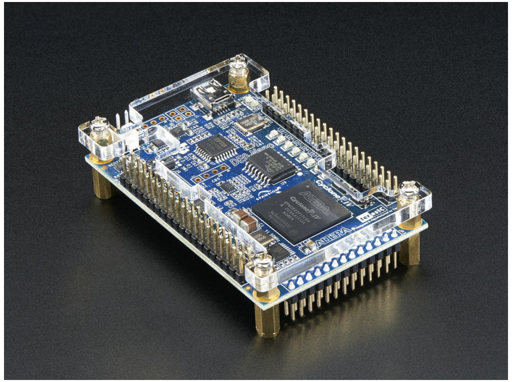
1951	Rochester assembler	Nat Rochester	EDSAC

Look at all of these assembly languages over 60 years old!

This was the family of languages folks programmed in.

Modern Day Assembly is of course still in use

- Still used in games (console games specifically)
  - In hot loops where code must run fast
- Still used on embedded systems
- Useful for debugging any compiled language
- Useful for even non-compiled or Just-In-Time Compiled languages
  - Python has its own bytecode
  - Java's bytecode (which is eventually compiled) is assembly-like
- Being used on the web
  - webassembly
- Still relevant after 60+ years!



Aside: Java(left) and Python(right) bytecode examples

```
 0 aload_0
 1 new #3 <acceptanceTests/treeset_personOK/Main$A>
 4 dup
 5 new #8 <java/lang/Object>
 8 dup
 9 invokespecial #10 <java/lang/Object.<init>>
12 new #12 <java/lang/Integer>
15 dup
16 iconst_2
17 invokespecial #14 <java/lang/Integer.<init>>
20 invokespecial #17 <acceptanceTests/treeset_personOK/Main$A.<init>>
23 new #12 <java/lang/Integer>
26 dup
27 iconst_1
28 invokespecial #14 <java/lang/Integer.<init>>
31 invokespecial #17 <acceptanceTests/treeset_personOK/Main$A.<init>>
34 getstatic #20 <java/lang/System.out>
37 new #3 <acceptanceTests/treeset_personOK/Main$A>
40 dup
41 new #8 <java/lang/Object>
44 dup
45 invokespecial #10 <java/lang/Object.<init>>
48 new #12 <java/lang/Integer>
51 dup
52 iconst_2
53 invokespecial #14 <java/lang/Integer.<init>>
56 invokespecial #17 <acceptanceTests/treeset_personOK/Main$A.<init>>
59 invokevirtual #26 <java/io/PrintStream.println>
62 return
```

```
def f(n, accum):
  if n <= 1:
    return accum
  else:
    return f(n-1, accum*n)
```

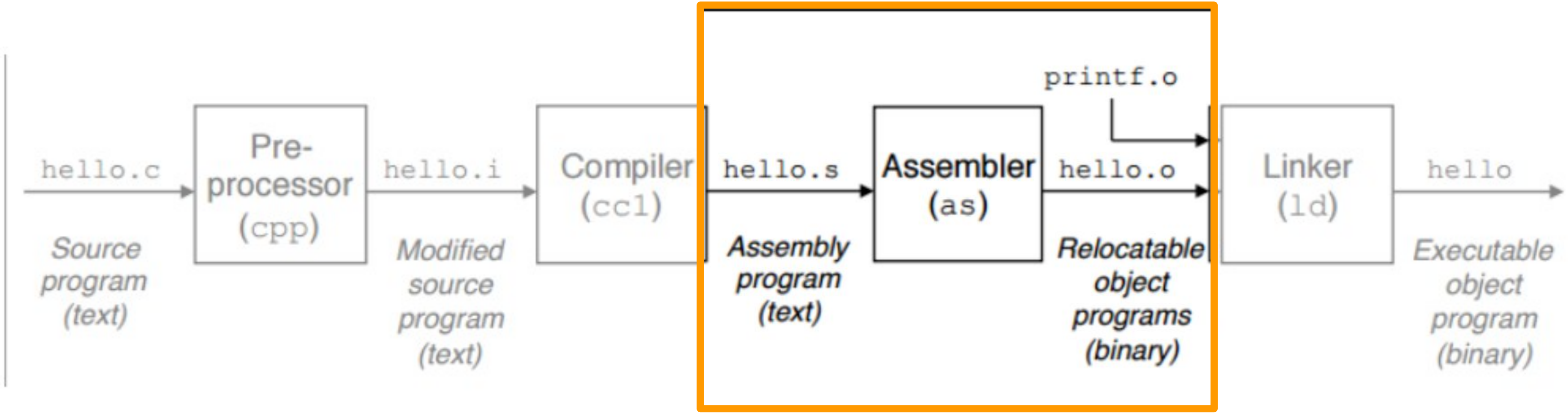
```
>>> import dis
>>> dis.dis(f)
  2           0 LOAD_FAST                0 (n)
              3 LOAD_CONST               1 (1)
              6 COMPARE_OP               1 (<=)
              9 POP_JUMP_IF_FALSE       16

  3          12 LOAD_FAST                1 (accum)
             15 RETURN_VALUE

  5     >>   16 LOAD_GLOBAL              0 (f)
             19 LOAD_FAST                0 (n)
             22 LOAD_CONST               1 (1)
             25 BINARY_SUBTRACT
             26 LOAD_FAST                1 (accum)
             29 LOAD_FAST                0 (n)
             32 BINARY_MULTIPLY
             33 CALL_FUNCTION            2
             36 RETURN_VALUE
             37 LOAD_CONST               0 (None)
             40 RETURN_VALUE
```

Assembly is important in our toolchain

- Even if the step is often hidden from us!



Intel and x86 Instruction set

- In order to program these chips, there is a specific instruction set we will use
- Popularized by Intel
- Other companies have contributed.
  - AMD has been the main competitor
- (AMD was first to really nail 64 bit architecture around 2001)
- Intel followed up a few years later (2004)
- Intel remains the dominant architecture
- x86 is a CISC architecture
  - (CISC pronounced /ˈsɪsk/)

Introduction to Assembly

How are programs created?

- Compile a program to an executable
  - `gcc main.c -o program`
- Compile a program to assembly
  - `gcc main.c -S -o main.s`
- Compile a program to an object file (.o file)
  - `gcc -c main.c`
- Linker (A program called ld) then takes all of your object files and makes a binary executable.

Focus on this step today -- pretend C does not exist

- ~~Compile a program to an executable~~
  - ~~`gcc main.c -o program`~~
- **Compile a program to assembly**
  - `gcc main.c -S -o main.s`
- ~~Compile a program to an object file (.o file)~~
  - ~~`gcc -c main.c`~~
- Linker (A program called ld) then takes all of your object files and makes a binary executable.

Layers of Abstraction

1. As a C programmer you worry about C code
    a. You work with variables, do some memory management using malloc and free, etc.
2. As an assembly programmer, you worry about assembly
    a. You also maintain the registers, condition codes, and memory
3. As a hardware engineer (programmer)
    a. You worry about cache levels, layout, clocks, etc.

Assembly Abstraction layer

- With Assembly, we lose some of the information we have in C
- In higher-order languages we have many different data types which help protect us from errors.
  - For example: int, long, boolean, char, string, float, double, complex, …
  - In C there are custom data types (structs for example)
  - Type systems help us avoid inconsistencies in how we pass data around.
- In Assembly we lose unsigned/signed information as well!
  - However, we do have two data types
  - Types for integers (1,2,4,8 bytes) and floats (4,8, or 10 bytes) [byte = 8 bits]

Sizes of data types (C to assembly)

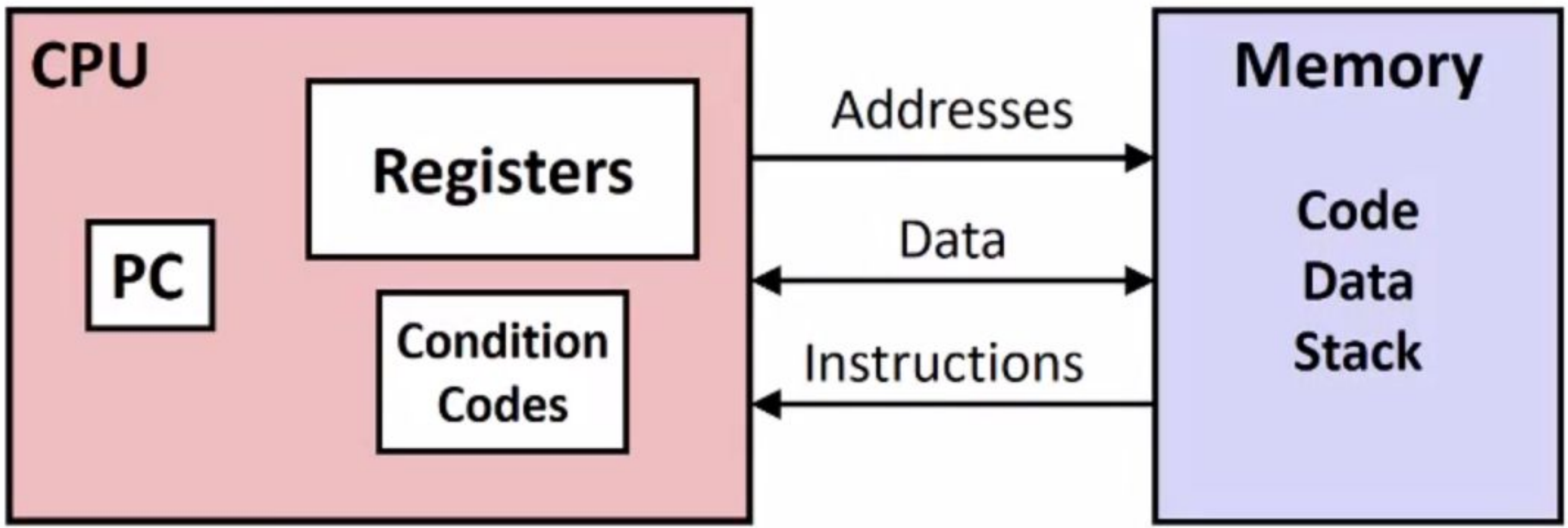
C Declaration	Intel Data Type	Assembly-code suffix	Size (bytes)
char	Byte	b	1
short	Word	w	2
int	Double word	l	4
long	Quad word	q	8
char *	Quad word	q	8
float	Single precision	s	4
double	Double Precision	l	8

Sizes of data types (C to assembly)

C Declaration	Intel Data Type	Assembly-code suffix	Size (bytes)
char	Byte	b	1
short	Word		2
int	Double word		
long	Quad word		
char *	Quad word		
float	Single precision		4
double	Double Precision	l	8

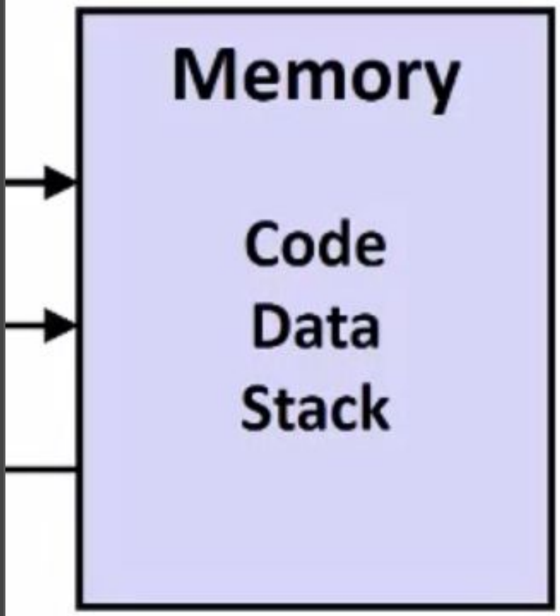
For us, one word of data is 64 bits [8 bytes] but may vary on other hardware

View as an assembly programmer



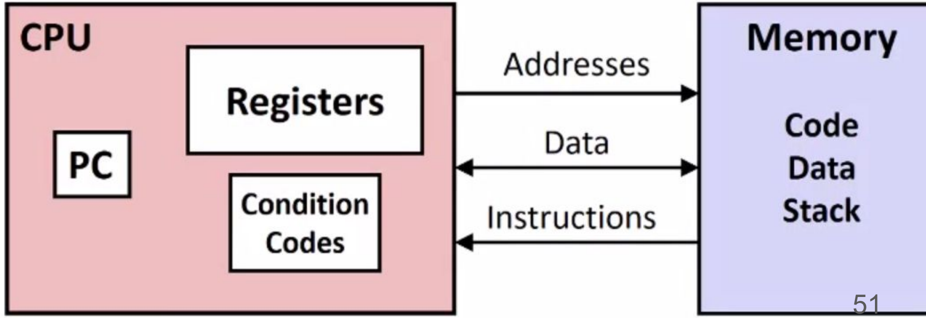
Memory Addresses

- Note that we are looking at virtual addresses in our assembly when we see addresses.
- This makes us think of the program as a large byte array.
  - The operating system takes care of managing this for us with virtual memory.
  - This is one of the key jobs of the operating system



Assembly Operations (i.e. Our instruction set)

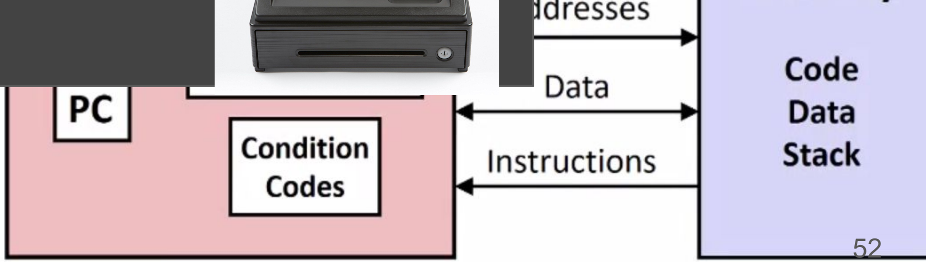
- Things we can do with assembly (and that's about it!)
  - Transfer data between memory and register
    - Load data from memory to register
    - Store register data back into memory
  - Perform arithmetic/logical operations on registers and memory
  - Transfer Control
    - Jumps
    - Branches (conditional statements)



Assembly Operations (i.e. Our instruction set)

- Things we can do with assembly (and that's about it!)
  - Transfer da
    - Load
    - Store
  - Perform ari
  - Transfer Co
    - Jump
    - Branc

Let's look at registers next!



x86-64 Registers

- Focus on the 64-bit column.
- These are 16 general purpose registers for storing bytes
  - (Note sometimes we do not always have access to all 16 registers)
- Registers are *similar* to variables where we store values

Not modified for 8-bit operands

Not modified for 16-bit operands

Register encoding	Zero-extended for 32-bit operands			Low 8-bit	16-bit	32-bit	64-bit
0			AH†	AL	AX	EAX	RAX
3			BH†	BL	BX	EBX	RBX
1			CH†	CL	CX	ECX	RCX
2			DH†	DL	DX	EDX	RDX
6				SIL‡	SI	ESI	RSI
7				DIL‡	DI	EDI	RDI
5				BPL‡	BP	EBP	RBP
4				SPL‡	SP	ESP	RSP
8				R8B	R8W	R8D	R8
9				R9B	R9W	R9D	R9
10				R10B	R10W	R10D	R10
11				R11B	R11W	R11D	R11
12				R12B	R12W	R12D	R12
13				R13B	R13W	R13D	R13
14				R14B	R14W	R14D	R14
15				R15B	R15W	R15D	R15

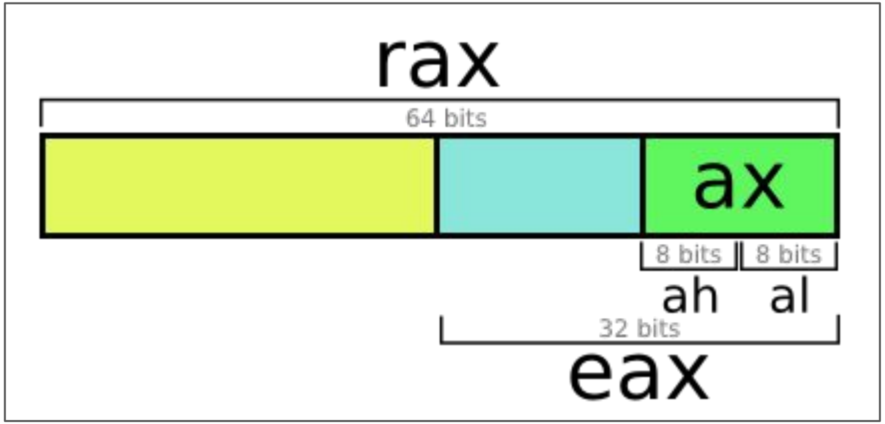
63 32 31 16 15 8 7 0

† Not legal with REX prefix

‡ Requires REX prefix

x86-64 Register (zooming in)

- Note register eax addresses the lower 32 bits of rax
- Note register ax addresses the lower 16 bits of eax
- Note register ah addresses the high 8 bits of ax
- Note register al (lowercase L) addresses the low 8 bits of ax



Some registers are reserved for special use (More to come)

- This can be dependent on the instruction being used
  - %rsp - keeps track of where the stack pointer is
  - (We will do an example with the stack and what this means soon)

A First Assembly Instruction

Moving data around | mov instruction

- (Remember moving data is all machines do!)
- mov**q** - moves a quad word of data
- mov**d** - move a double word (dword) of data

```
movq Source, Dest
```

Moving data around | mov instruction

- (Remember moving data is all machines do!)
- mov**q** - moves a quad word of data
- mov**d** - move a double word (dword) of data

`movq` *`Source, Dest`*

Order matters
“source to
destination”
“left to right”

Moving data around | mov instruction

- (Remember moving data is all machines do!)
- mov**q** - moves a quad word of data
- mov**d** - move a double word (dword) of data

`movq` *`Source, Dest`* (Keep in mind the order here)

- Source or Dest Operands can have different addressing modes
  - Immediate - some address $0x333 or $-900
  - Memory - (%rax) dereferences what is in the register and gets the value
  - Register - Just %rax

Full List of Memory Addressing Modes

Mode	Example
Global Symbol	MOVQ x, %rax
Immediate	MOVQ $56, %rax
Register	MOVQ %rbx, %rax
Indirect	MOVQ (%rsp), %rax
Base-Relative	MOVQ -8(%rbp), %rax
Offset-Scaled-Base-Relative	MOVQ -16(%rbx, %rcx, 8), %rax

C equivalent of movq instructions | movq src, dest

`movq $0x4, %rax`	**`%rax`** `= 0x4;` (Moving in literal value into register)
`movq $-150, (%rax)`	use value of rax as memory location and set that location to -150 (`*p = -150`)
`movq %rax, %rdx`	`%rdx = %rax` (copy src into dest)
`movq %rax, (%rdx)`	use value of rdx as memory location and set that location to value stored in rax`(*p = %rax)`
`movq (%rax), %rdx`	Set value of rdx to value of rax as memory location `(%rdx = *p)`

Some registers are reserved for special use (More to come)

- This can be dependent on the instruction being used
- %rsp - keeps track of where the stack is for example
- **%rdi - the first program argument in a function**
- **%rsi - The second argument in a function**
- **%rdx - the third argument of a function**

These conventions are especially useful for functions known as system calls.

1	write	sys_write	fs/read_write.c
%rdi	%rsi	%rdx	
unsigned int fd	**const char __user** * buf	**size_t** count	

https://filippo.io/linux-syscall-table/

Some registers are reserved for special use (More to come)

- This can be dependent on the instruction being used
- %rsp - keeps track of where the stack is for example
- %rdi - the first program argument in a function
- %rsi - The second argument in a function
- %rdx - the third argument of a function
- **%rip - the Program Counter**

Some registers are reserved for special use

- This can be dependent on the instruction being used
- %rsp - keeps track of where the stack is for example
- %rdi - the first program argument in a function
- %rsi - The second argument in a function
- %rdx - the third argument of a function
- %rip - the Program Counter
- **%r8-%r15 -** These eight registers are general purpose registers

A little example

What does this function do? (take a few moments to think)

```
void mystery(<type> a, <type> b){
}
```

```
mystery:
        movq (%rdi), %rax
        movq (%rsi), %rdx
        movq %rdx, (%rdi)
        movq %rax, (%rsi)
        ret
```

Cheat Sheet

(Note: This can be dependent on the instruction being used)
%rsp - keeps track of where the stack is for example
%rdi - the first program argument in a function
%rsi - The second argument in a function
%rdx - the third argument of a function
%rip - the Program Counter
%r8-%r15 - These ones are actually the general purpose registers

swap of long

```
void mystery(long *a, long *b){
        long t0 = *a;
        long t1 = *b;
        *a = t1;
        *b = t0;

}
```

```
mystery:
        movq (%rdi), %rax
        movq (%rsi), %rdx
        movq %rdx, (%rdi)
        movq %rax, (%rsi)
        ret
```

Cheat Sheet

(Note: This can be dependent on the instruction being used)
%rsp - keeps track of where the stack is for example
%rdi - the first program argument in a function
%rsi - The second argument in a function
%rdx - the third argument of a function
%rip - the Program Counter
%r8-%r15 - These ones are actually the general purpose registers

More assembly instructions

addq Src, Dest   Dest=Dest+Src
subq Src, Dest   Dest=Dest-Src
imulq Src, Dest   Dest=Dest*Src
salq Src, Dest   Dest=Dest << Src
sarq Src, Dest   Dest=Dest >> Src
shrq Src, Dest   Dest=Dest >> Src
xorq Src, Dest   Dest=Dest ^ Src
andq Src, Dest   Dest=Dest & Src
orq Src, Dest   Dest=Dest | Src

Note on order (Intel documentation uses op Dest, Src)

More assembly instructions

addq	Src, Dest	Dest=Dest+Src
subq	Src, Dest	Dest=Dest-Src
imulq	Src, Dest	Dest=Dest*Src
salq	Src, Dest	Dest=Dest << Src
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xorq	Src, Dest	Dest=Dest ^ Src
andq	Src, Dest	Dest=Dest & Src
orq	Src, Dest	Dest=Dest | Src

Note on order (Intel documentation uses op Dest, Src)

Note there is a difference with these two shift and rotate instructions shrq and sarq!

sarq is an arithmetic shift, that will carry the signed bit.

E.g. of sarq below

	Value 1	Value 2
x	0110 0011	1001 0101
x>>4 (logical)	**0000** 0110	**1111** 1001

Exercise

If I have the expression

c = b*(b+a)

How might I store this computation into c?

addq	Src, Dest	Dest=Dest+Src
subq	Src, Dest	Dest=Dest-Src
imulq	Src, Dest	Dest=Dest*Src
salq	Src, Dest	Dest=Dest << Src
sarq	Src, Dest	Dest=Dest >> Src
shrq	Src, Dest	Dest=Dest >> Src
xorq	Src, Dest	Dest=Dest ^ Src
andq	Src, Dest	Dest=Dest & Src
orq	Src, Dest	Dest=Dest | Src

One Possible Solution

If I have the expression

c = b*(b+a)

How might I store this computation into c?

```
MOVQ a, %rax
MOVQ b, %rbx
ADDQ %rbx, %rax
IMULQ %rbx
MOVQ %rax, c
```

addq	Src, Dest	Dest=Dest+Src
subq	Src, Dest	Dest=Dest-Src
imulq	Src, Dest	Dest=Dest*Src
salq	Src, Dest	Dest=Dest << Src
sarq	Src, Dest	Dest=Dest >> Src
shrq	Src, Dest	Dest=Dest >> Src
xorq	Src, Dest	Dest=Dest ^ Src
andq	Src, Dest	Dest=Dest & Src
orq	Src, Dest	Dest=Dest | Src

Description

Performs a signed multiplication of two operands. This instruction has three forms, depending on the number of operands.

- **One-operand form** — This form is identical to that used by the MUL instruction. Here, the source operand (in a general-purpose register or memory location) is multiplied by the value in the AL, AX, EAX, or RAX register (depending on the operand size) and the product (twice the size of the input operand) is stored in the AX, DX:AX, EDX:EAX, or RDX:RAX registers, respectively.
- **Two-operand form** — With this form the destination operand (the first operand) is multiplied by the source operand (second operand). The destination operand is a general-purpose register and the source operand is an immediate value, a general-purpose register, or a memory location. The intermediate product (twice the size of the input operand) is truncated and stored in the destination operand location.
- **Three-operand form** — This form requires a destination operand (the first operand) and two source operands (the second and the third operands). Here, the first source operand (which can be a general-purpose register or a memory location) is multiplied by the second source operand (an immediate value). The intermediate product (twice the size of the first source operand) is truncated and stored in the destination operand (a general-purpose register).

One Possible Solution

If I have the expression

c = b*(b+a)

How might I store this computation into c?

```
MOVQ a, %rax
MOVQ b, %rbx
ADDQ %rbx, %rax
IMULQ %rbx
MOVQ %rax, c
```

IMULQ has a variant with one operand which multiplies by whatever is in %rax and stores result in %rax

Description

Performs a signed multiplicati ... on has three forms, depending on the number of operands.

- One-operand form ... UL instruction. Here, the source operand (in a general-purpos ... value in the AL, AX, EAX, or RAX register (depending on ... input operand) is stored in the AX, DX:AX, EDX:EAX, or RDX:R...
- Two-operand form — With ... erand (the first operand) is multiplied by the source operand (second operand). ... eneral-purpose register and the source operand is an immediate value, a general- ... location. The intermediate product (twice the size of the input operand) is trunca ... ion operand location.
- Three-operand form — Th ... operand (the first operand) and two source operands (the second and the third op ... e operand (which can be a general-purpose register or a memory location) is mu ... operand (an immediate value). The intermediate product (twice the size of th ... cated and stored in the destination operand (a general-purpose register).

Some common operations with one-operand

incq Dest	Dest = Dest + 1
decq Dest	Dest = Dest - 1
negq Dest	Dest = -Dest
notq Dest	Dest = ~Dest

More Anatomy of Assembly Programs

Assembly output of hello

- Lines that start with "." are compiler directives.
  - This tells the assembler something about the program
  - .text is where the actual code starts.
- Lines that end with ":" are labels
  - Useful for control flow
  - Lines that start with . and end with : are usually temporary locals generated by the compiler.
- Reminder that lines that start with % are registers
- (.cfi stands for call frame information)

```
        .file   "hello.c"
        .text
        .globl  main
        .align  16, 0x90
        .type   main,@function
main:                                   # @main
        .cfi_startproc
# BB#0:
        pushq   %rbp
.Ltmp2:
        .cfi_def_cfa_offset 16
.Ltmp3:
        .cfi_offset %rbp, -16
        movq    %rsp, %rbp
.Ltmp4:
        .cfi_def_cfa_register %rbp
        subq    $16, %rsp
        leaq    .L.str, %rdi
        movl    $0, -4(%rbp)
        movb    $0, %al
        callq   printf
        movl    $0, %ecx
        movl    %eax, -8(%rbp)          # 4-byte Spill
        movl    %ecx, %eax
        addq    $16, %rsp
        popq    %rbp
        ret
.Ltmp5:
        .size   main, .Ltmp5-main
        .cfi_endproc

        .type   .L.str,@object          # @.str
        .section        .rodata.str1.1,"aMS",@progbits,1
.L.str:
        .asciz  "Hello\n"
        .size   .L.str, 7


        .ident  "clang version 3.4.2 (tags/RELEASE_34/dot2-final)"
        .section        ".note.GNU-stack","",@progbits
```

Where to Learn more?

Intel® 64 and IA-32 Architectures Software Developer Manuals

Document	Description
Intel® 64 and IA-32 architectures software developer's manual combined volumes: 1, 2A, 2B, 2C, 2D, 3A, 3B, 3C, 3D, and 4	This document contains the following: **Volume 1:** Describes the architecture and programming environment of processors supporting IA-32 and Intel® 64 architectures. **Volume 2:** Includes the full instruction set reference, A-Z. Describes the format of the instruction and provides reference pages for instructions. **Volume 3:** Includes the full system programming guide, parts 1, 2, 3, and 4. Describes the operating-system support environment of Intel® 64 and IA-32 architectures, including: memory management, protection, task management, interrupt and exception handling, multi-processor support, thermal and power management features, debugging, performance monitoring, system management mode, virtual machine extensions (VMX) instructions, Intel® Virtualization Technology (Intel® VT), and Intel® Software Guard Extensions (Intel® SGX). **Volume 4:** Describes the model-specific registers of processors supporting IA-32 and Intel® 64 architectures.

(Volume 2 Instruction set reference)

Bookmarks

- Volume 1:Basic Architecture
- Volume 2 (2A, 2B, 2C & 2D):Instruction Set Reference, A-Z
  - Chapter 1 About This Manual
  - Chapter 2 Instruction Format
  - Chapter 3 Instruction Set Reference, A-L
    - 3.1 Interpreting the Instruction Reference Pages
    - 3.2 Instructions (A-L)
  - Chapter 4 Instruction

INC—Increment by 1

Opcode	Instruction	Op/ En	64-Bit Mode	Compat/ Leg Mode	Description
FE /0	INC *r/m8*	M	Valid	Valid	Increment *r/m* byte by 1.
REX + FE /0	INC *r/m8**	M	Valid	N.E.	Increment *r/m* byte by 1.
FF /0	INC *r/m16*	M	Valid	Valid	Increment *r/m* word by 1.
FF /0	INC *r/m32*	M	Valid	Valid	Increment *r/m* doubleword by 1.
REX.W + FF /0	INC *r/m64*	M	Valid	N.E.	Increment *r/m* quadword by 1.
40+ *rw***	INC *r16*	O	N.E.	Valid	Increment word register by 1.
40+ *rd*	INC *r32*	O	N.E.	Valid	Increment doubleword register by 1.

NOTES:

* In 64-bit mode, r/m8 can not be encoded to access the following byte registers if a REX prefix is used: AH, BH, CH, DH.

** 40H through 47H are REX prefixes in 64-bit mode.

Instruction Operand Encoding

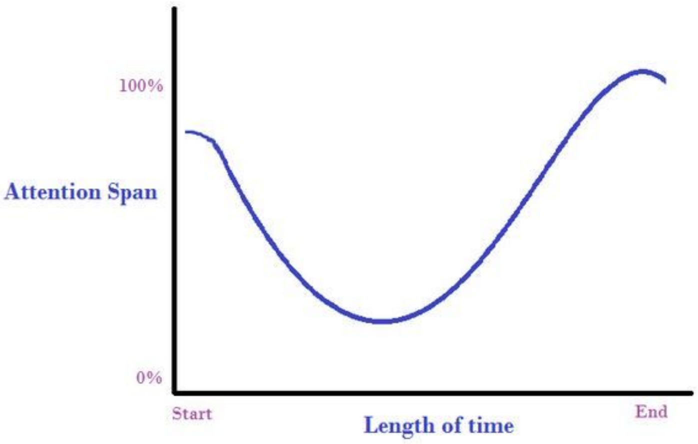
Op/En	Operand 1	Operand 2	Operand 3	Operand 4
M	ModRM:r/m (r, w)	NA	NA	NA
O	opcode + rd (r, w)	NA	NA	NA

Description

Adds 1 to the destination operand, while preserving the state of the CF flag. The destination operand can be a

Short 5 minute break

- 1 hour 40 minutes is a long time.
- I will try to never lecture for more than half of that time without some sort of ‘break’ or transition to an in-class activity/lab.
- Use this time to stretch, check your phones, eat/drink something, etc.



Comparisons

Compare operands: **cmp_, set__**

- Often we want to compare the values of two registers
  - Think if, then, else constructs or loop exit or switch conditions

- cmpq Src2, Src1
  - **cmpq Src2, Src1** is equivalent to computing **Src1-Src2** (but there is no destination register)

- Now we need a method to use the result of compare, but there is not destination to find the result…what do we do?

Using the result from cmp => SET instructions

- In order to read result from cmp, we use SET
  - SET makes the low-order byte of a destination 0 or 1 depending on the condition codes
  - Does not alter remaining 7 bytes
    - Remember (64 bits = 8 bytes)

00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

	Condition	Description
SETE	ZF	Equal to zero
SETNE	~ZF	Not equal to zero
SETS	SF	Negative
SETNS	~SF	Nonnegative
SETG	~(SF^OF) & ~SF	Greater (signed)
SETGE	~(SF^OF)	Greater or equal (signed)
SETL	(SF^OF)	Less (Signed)
SETLE	(SF^OF) | ZF	Less than or equal (Signed)

Code Example 1

```
int greaterThan(long x, long y){
        return x > y;
}
```

```
cmpq %rsi, %rdi        # compare x and y
setg %al               # Set condition
code when >
movzbl %al, %eax       #zero rest of %rax
ret
```

Some reminders:

%rdi = argument x (first argument)
%rsi = argument y (second argument)
%rax = return value

SETG	~(SF^OF) & ~SF	Greater (signed)

1. CF - (Carry Flag for unsigned)
2. SF - (Carry Flag for signed)
3. OF - Overflow Flag (For signed)
4. ZF - Zero Flag

Code Example 1

```
int greaterThan(long x, long y){
        return x > y;
}
```

cmpq %rsi, %rdi # compare x and y
setg %al # Set condition code when >
movzbl %al, %eax #zero rest of %rax

What is `movzbl`?

`movzbl %al, %eax` # 'AL' is an 8-bit register

Zeroes out first 32 bits of register automatically
Command zeroes out all but the last bit.

Why then not movzb**q**

Some remin

%rdi = argun
%rsi = argument y (second argument)
%rax = return value

ter (signed)

3. OF - Overflow Flag (For signed)
4. ZF - Zero Flag

Conditional Branches (jumps)

Jump instructions | Typically used after a compare

	Condition	Description
jmp	1	unconditional
je	ZF	jump if equal to 0
jne	~ZF	jump if not equal to 0
js	SF	Negative
jns	~SF	non-negative
jg	~(SF^OF) & ~ZF	Greater (Signed)
jge	~(SF^OF)	Greater or Equal
jl	(SF^OF)	Less (Signed)
jle	(SF ^ OF) | ZF	Less or Equal
ja	~CF & ~ZF	Above (unsigned)
jb	CF	Below (unsigned)

Conditional Branch | if-else

```
long absoluteDifference (long x, long y){
        long result;
        if (x > y)
                result = x-y;
        else
                result = y-x;
}
```

```
absoluteDifference:
        cmpq    %rsi, %rdi
        jle     .else
        movq    %rdi, %rax
        subq    %rsi, %rax
        ret
.else
        movq    %rsi, %rax
        subq    %rdi, %rax
        ret
```

Some reminders:

%rdi = argument x (first argument)
%rsi = argument y (second argument)
%rax = return value

Code Exercise (Take a moment to think what this assembly does)

```
    MOVQ $0, %rax
mystery:
    INCQ %rax
    CMPQ $5, %rax
    JL  mystery
```

Code Exercise | Annotated (while loop example)

```
    MOVQ $0, %rax
mystery:
    INCQ %rax
    CMPQ $5, %rax
    JL  mystery
```

Move the value 0 into %rax (temp = 0)

Increment %rax (temp = temp + 1;)
Is %rax equal to 5?
Jump to ‘mystery’ if it is not

Equivalent C Code

```
long temp = 0;

do{
    temp = temp + 1;
}while(temp < 5);
```

Vocabulary

- **Machine Code**
  - 1’s and 0’s represented as bytes that the machine understands
- **Object File**
  - Machine code with some symbols in it. This allows a ‘linker’ to put machine code from different parts of system together
- **Assembly**
  - The text representation of machine code that is human readable
- **Instruction Set Architecture (ISA)**
  - The architecture being built on, what the hardware understands as a language (x86 for example).
  - There exist other ISA’s like RISC-V which is an open source ISA gaining popularity!

Vocabulary

- **Program Counter (PC)**
  - Holds the address in memory of the next instruction that will be executed
- **Registers**
  - 16 named locations that store (64-bit values in our case, x86-64) values
  - Some hold important values regarding the program state (like the PC)
- **Condition codes**
  - Holds information about the most recent executed arithmetic or logic instruction
  - Useful for if/while statements
- **Vector Registers**
  - Can hold more than one value (execute multiple items at once)
  - (We will talk about these registers later in reference to SIMD)