CSC 252: Computer Organization
Spring 2022: Lecture 6

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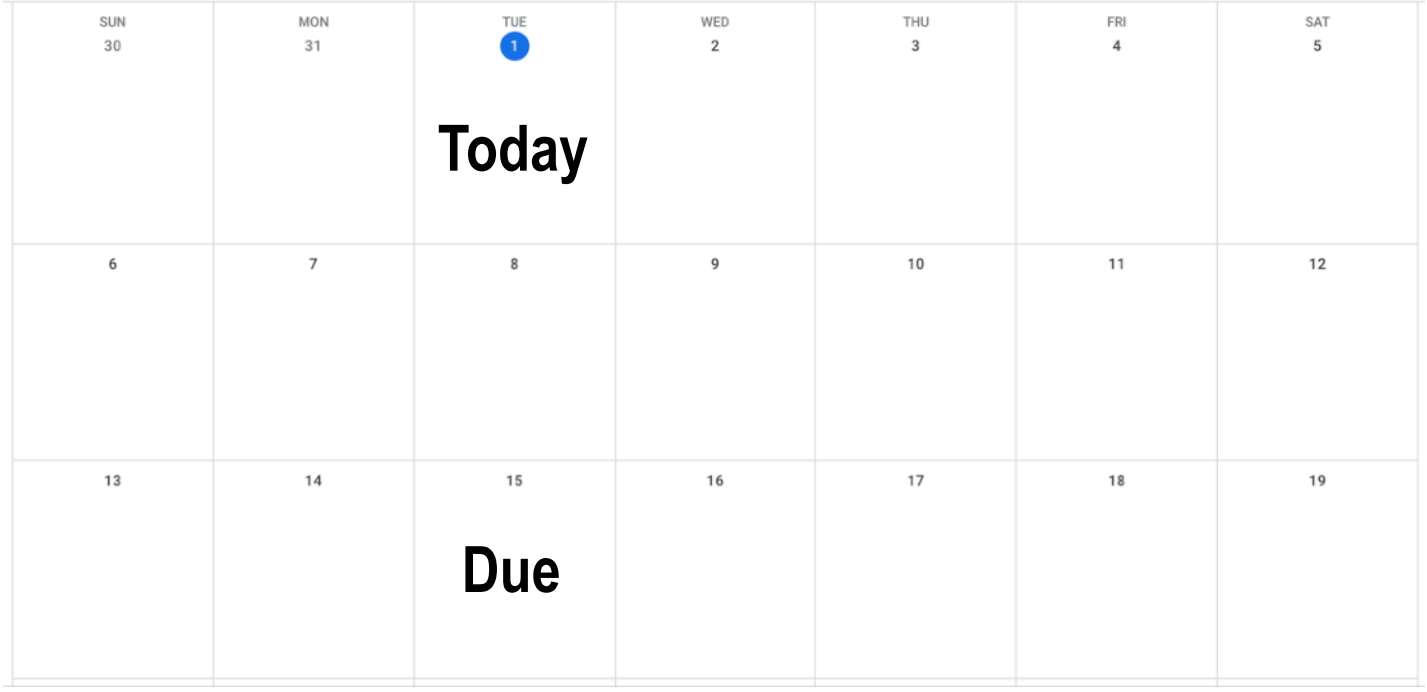
Department of Computer Science
University of Rochester

Announcement

- Programming assignment 2 is out
  - Details: https://www.cs.rochester.edu/courses/252/spring2022/labs/assignment2.html
  - Due on **Feb 15**, 11:59 PM
  - You (may still) have 3 slip days

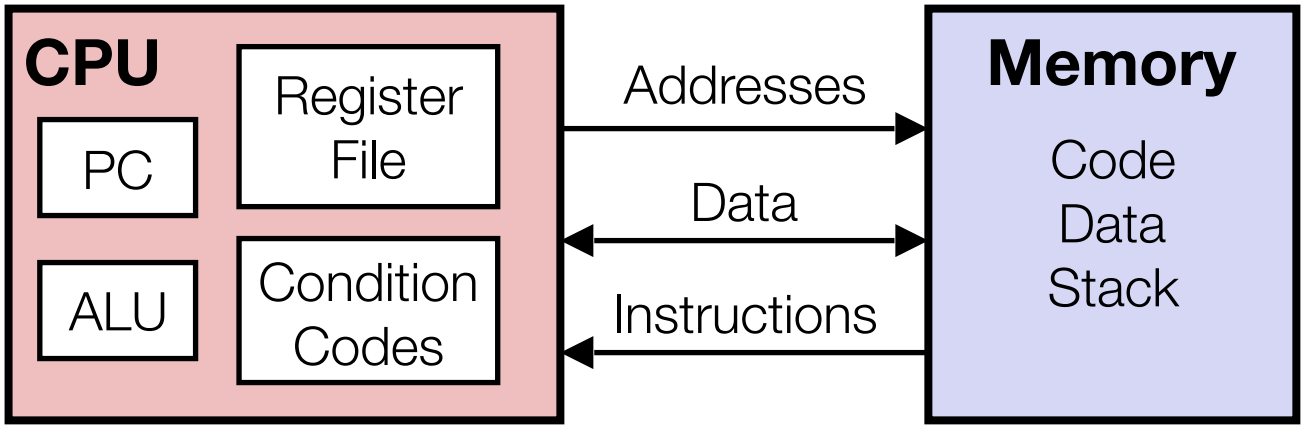


Announcement

- Programming assignment 2 is in x86 assembly language.
- Read the instructions before getting started!!!
  - You get 1/4 point off for every wrong answer
  - Maxed out at 10
- TAs are best positioned to answer your questions about programming assignments!!!
- Programming assignments do NOT repeat the lecture materials. They ask you to synthesize what you have learned from the lectures and work out something new.
- Problem set on arithmetics: https://www.cs.rochester.edu/courses/252/spring2022/handouts.html.
  - Not to be turned in.

Instruction Processing Sequence

Assembly Programmer's Perspective of a Computer



Fetch Instruction
(According to PC)

Instruction Processing Sequence

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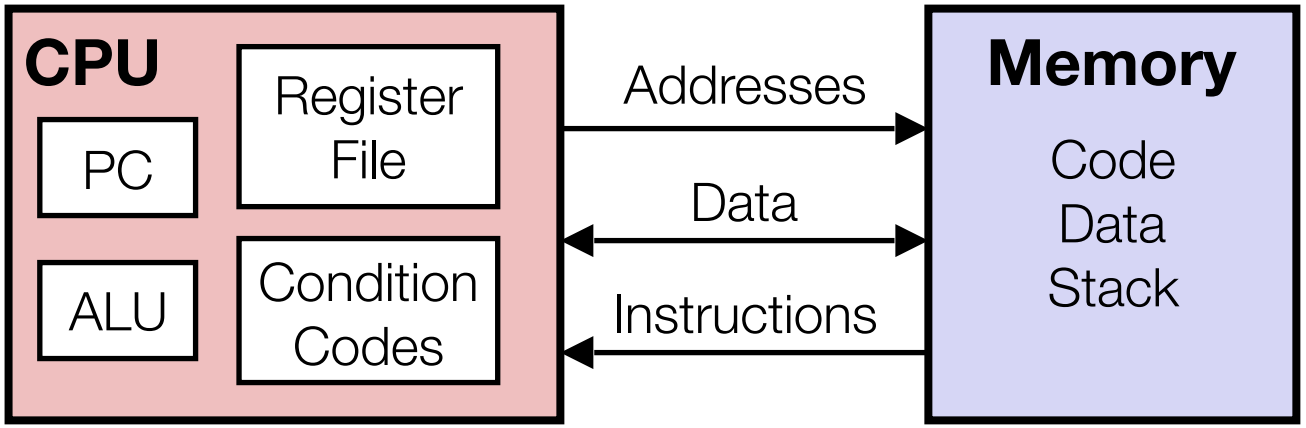

Fetch Instruction (According to PC)

`0x4801d8`

Instruction Processing Sequence

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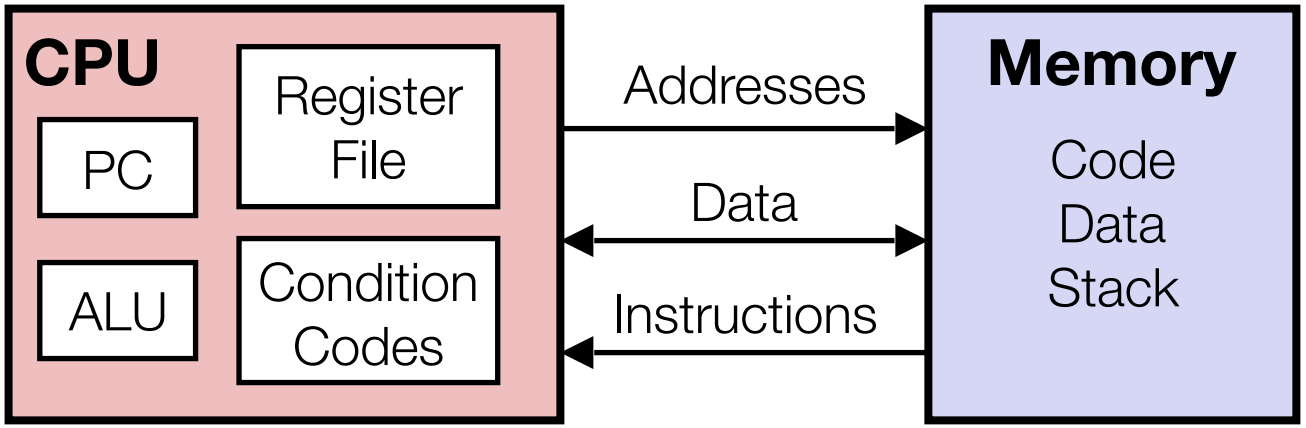

Fetch Instruction (According to PC) → Decode Instruction

```
addq %rax,(%rbx)
```

Instruction Processing Sequence

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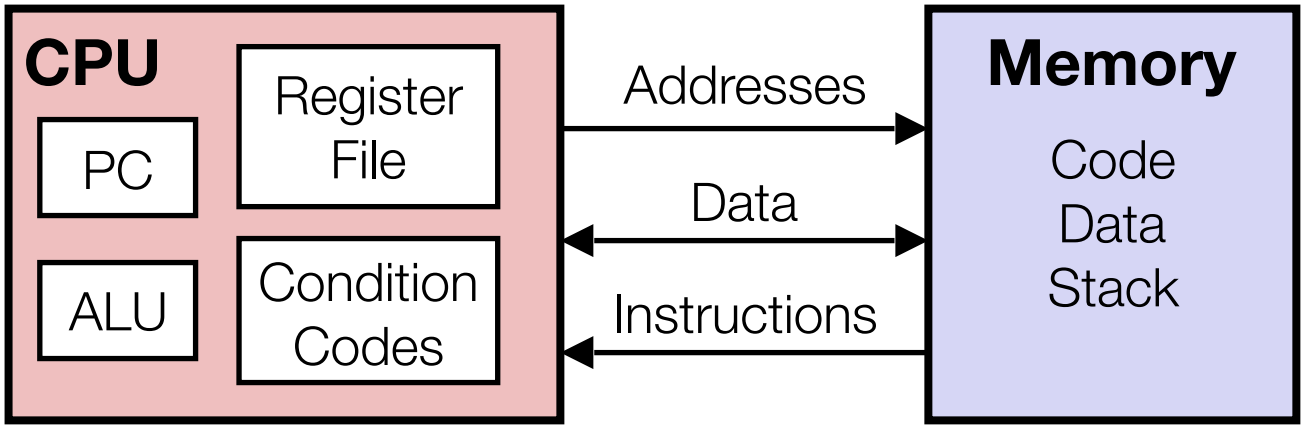

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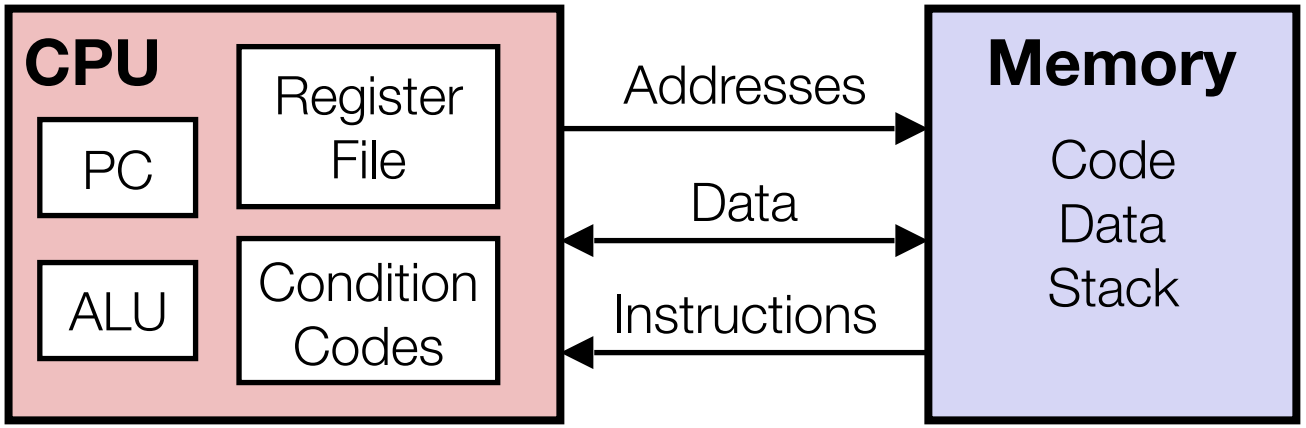

Fetch Instruction (According to PC) → Decode Instruction → Fetch Operands → Execute Instruction

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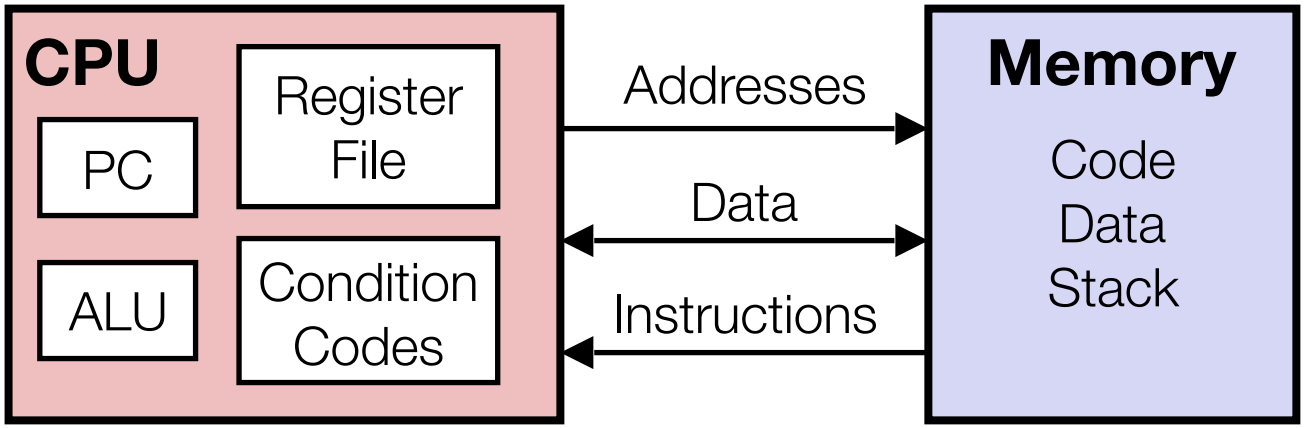

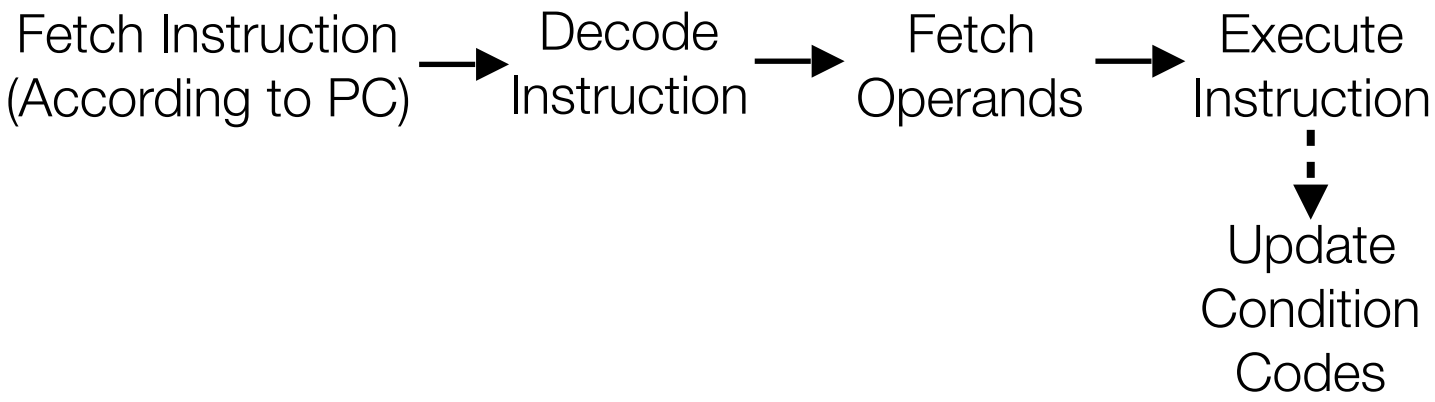

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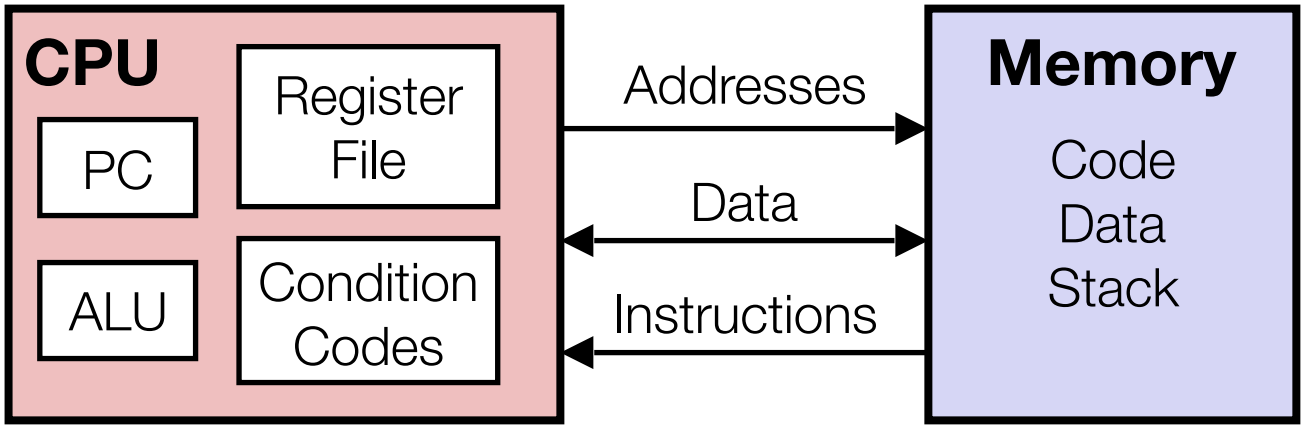

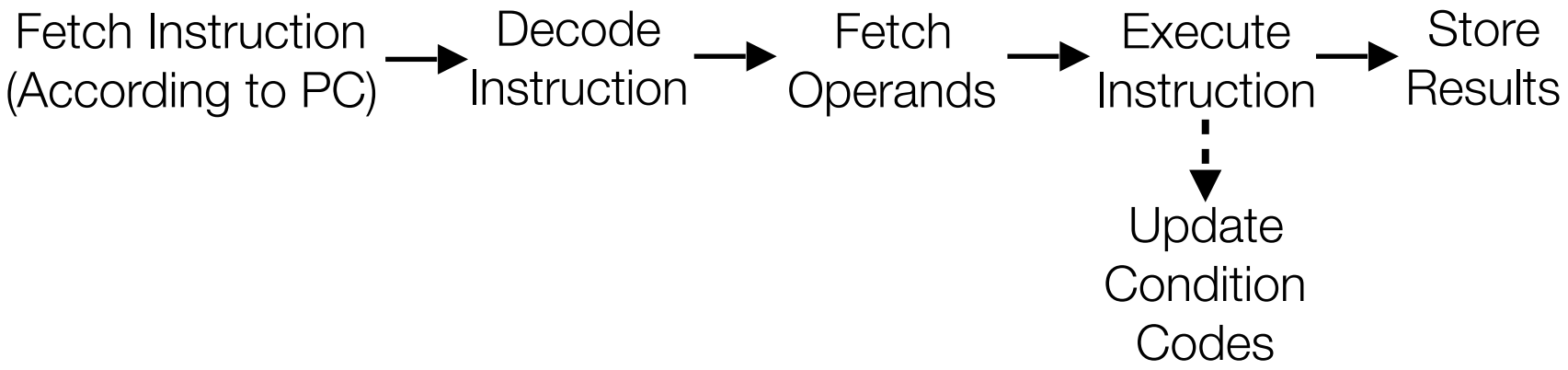

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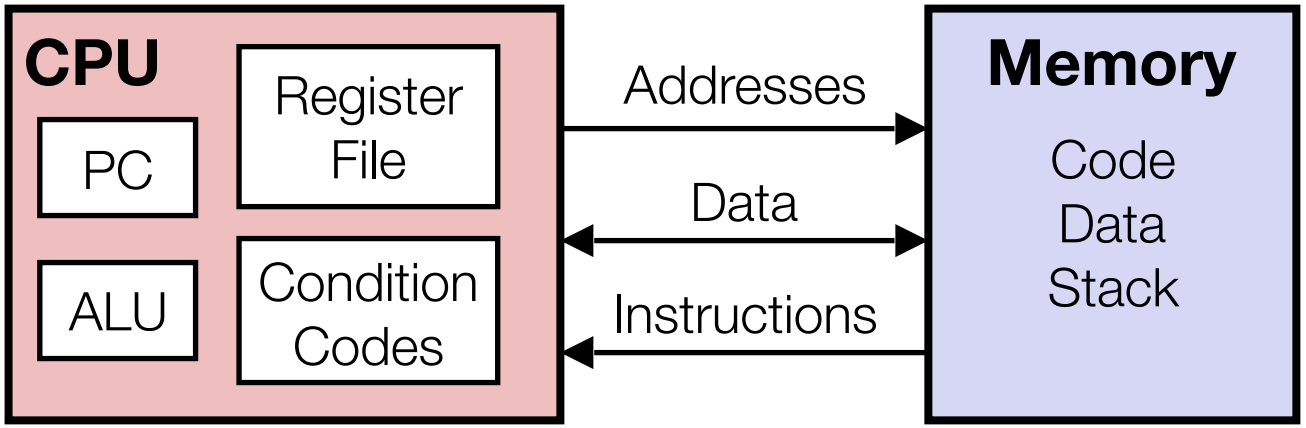

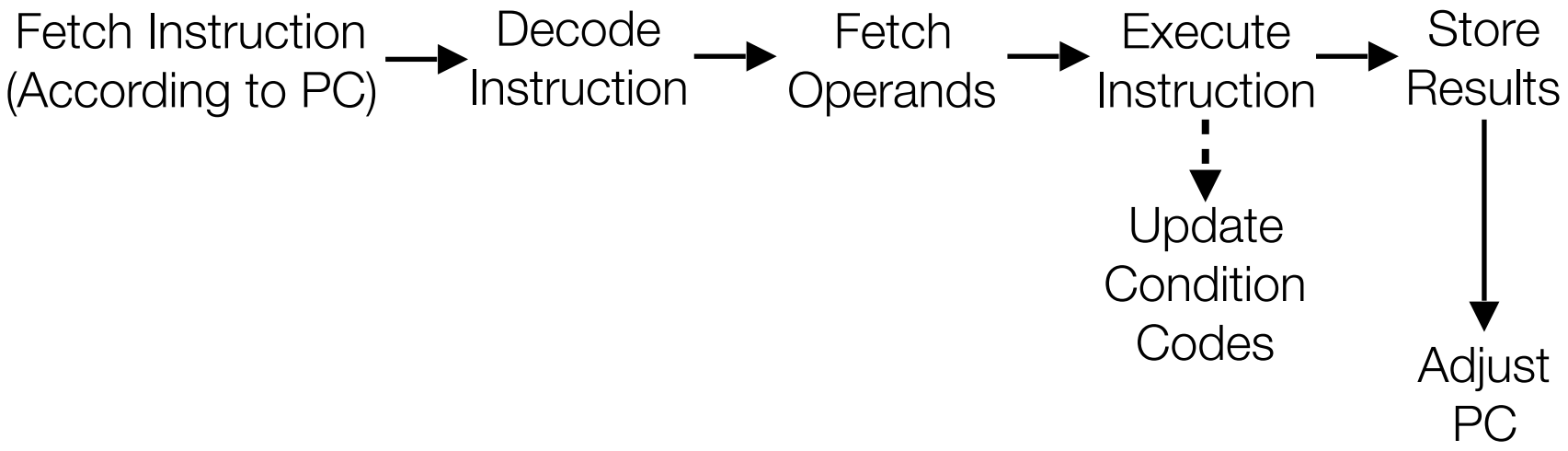

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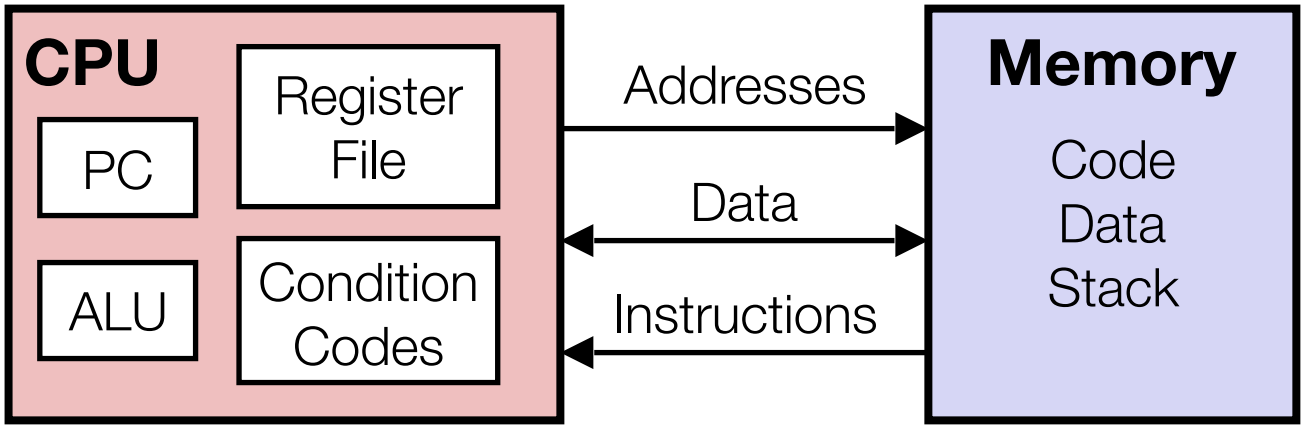

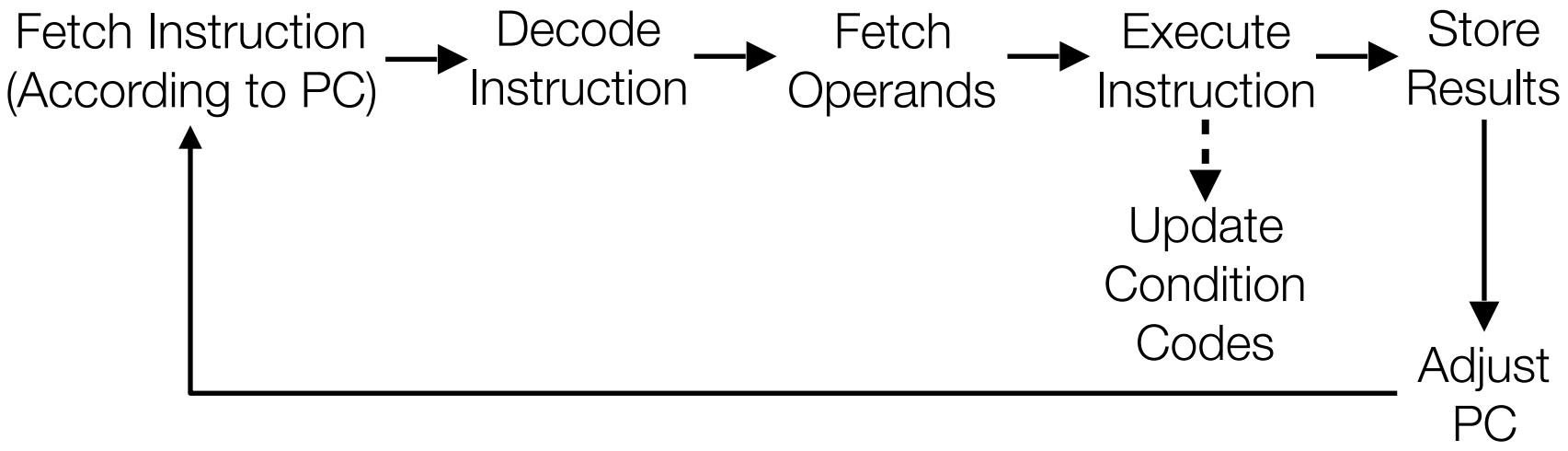

Assembly Program Instructions

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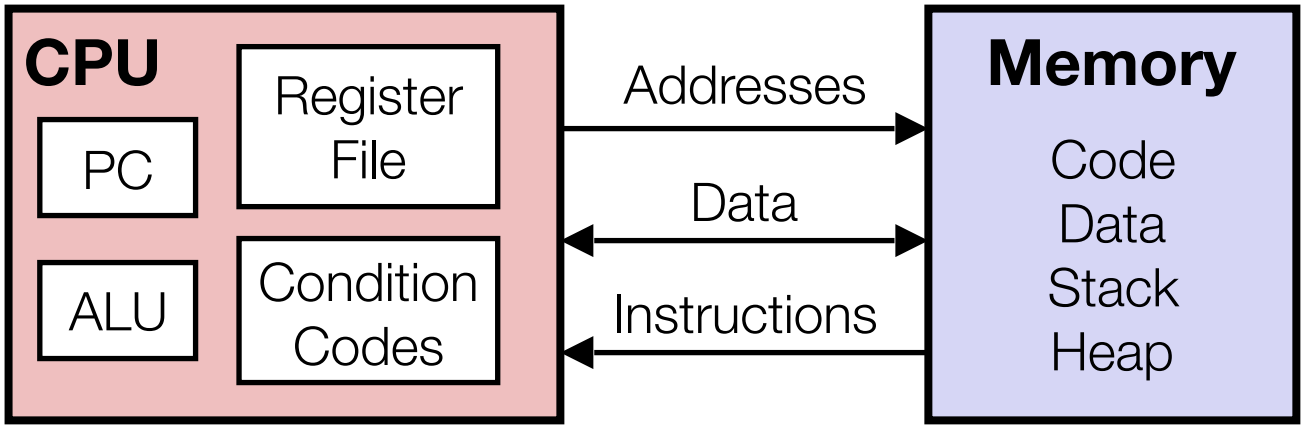

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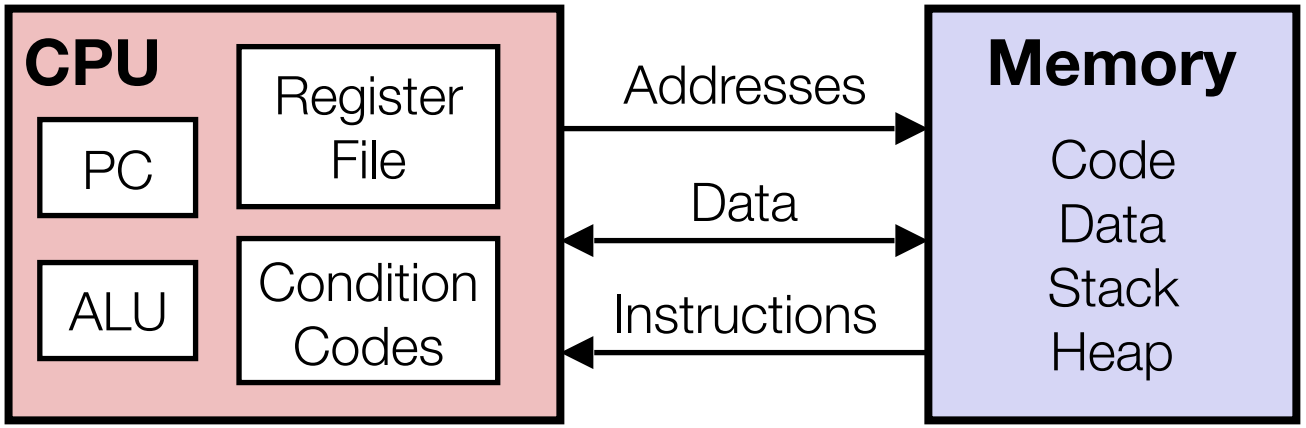

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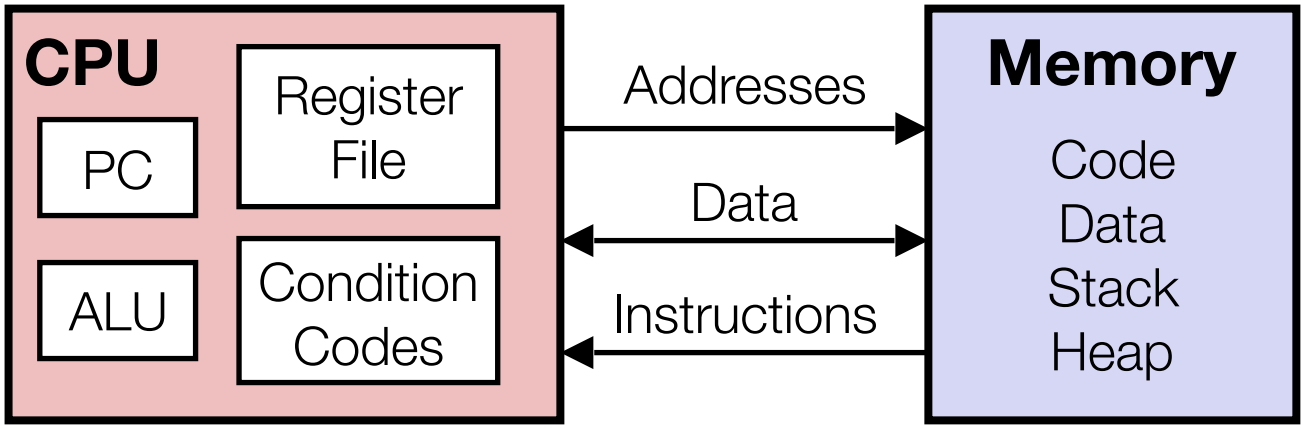

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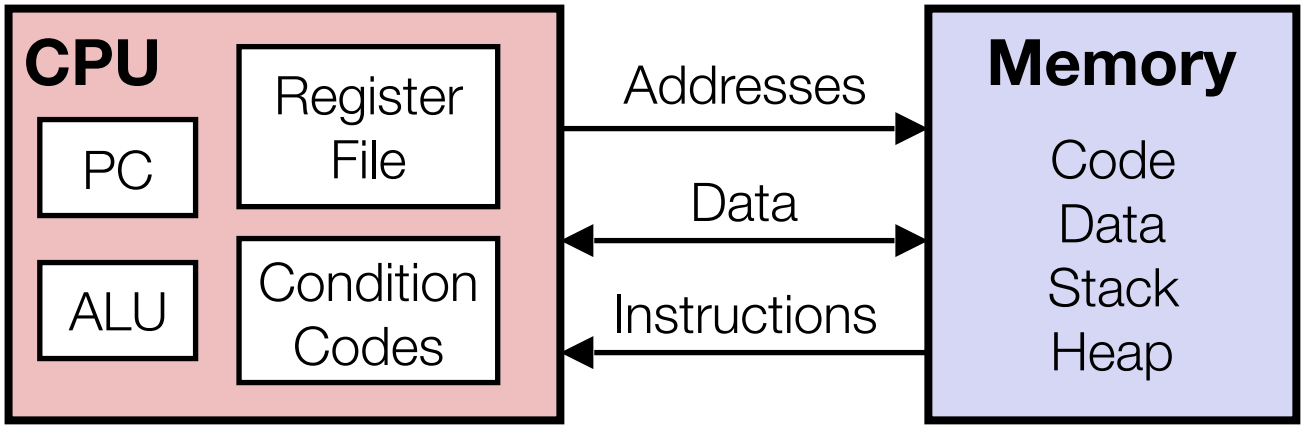

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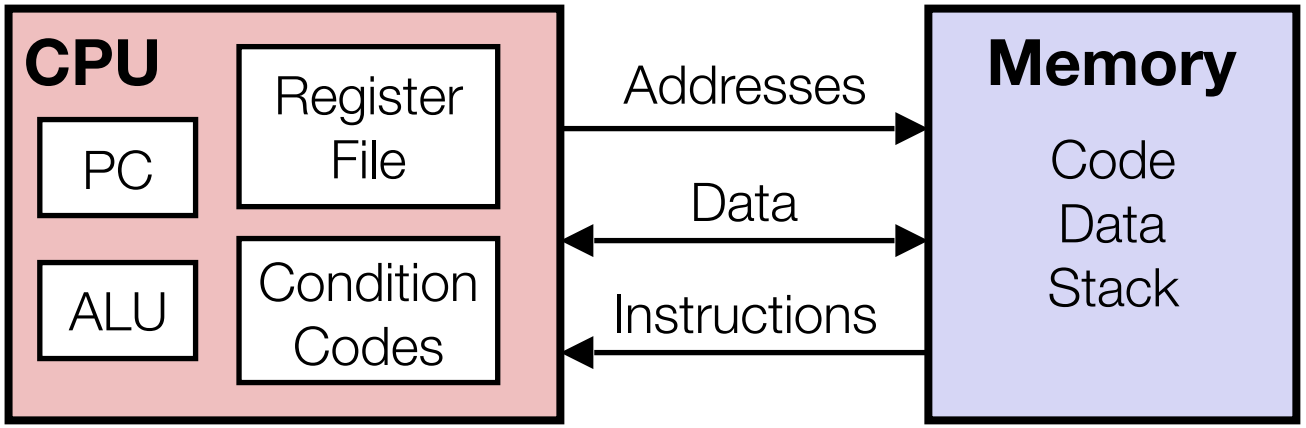
- *Data Movement Instruction*: Transfer data between memory and register
  - **`movq %eax, (%ebx)`**
- *Control Instruction*: Alter the sequence of instructions (by changing PC)
  - **`jmp`**, **`call`**
  - C constructs: **`if-else`**, **`do-while`**, function call, etc.

Today: Compute and Control Instructions

- Move operations (and addressing modes)
- Arithmetic & logical operations
- Control: Conditional branches (`if`… `else`…)
- Control: Loops (`for`, `while`)
- Control: Switch Statements (`case`… `switch`…)

Data Movement in Processors

Assembly Programmer's Perspective of a Computer



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Data Movement in Processors

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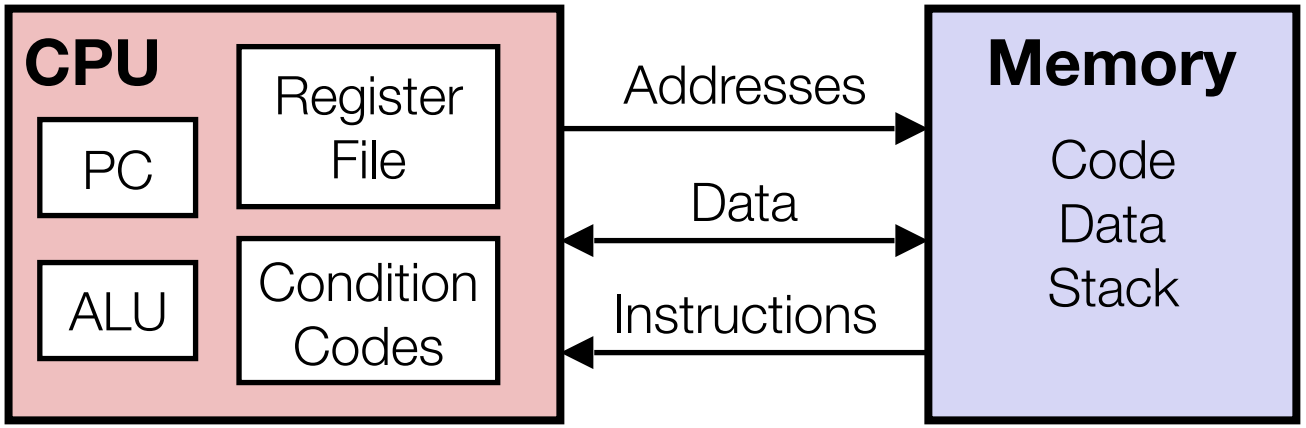

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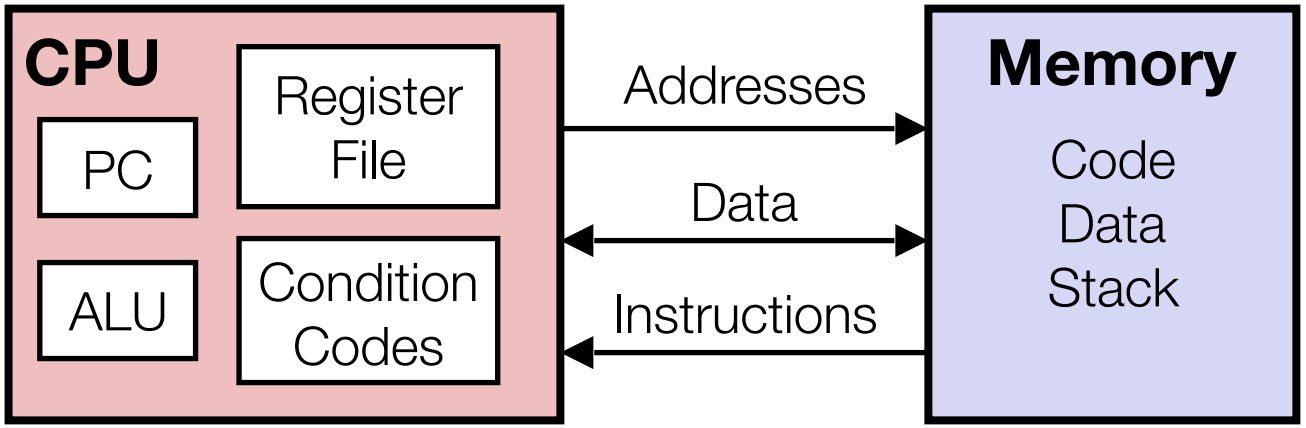

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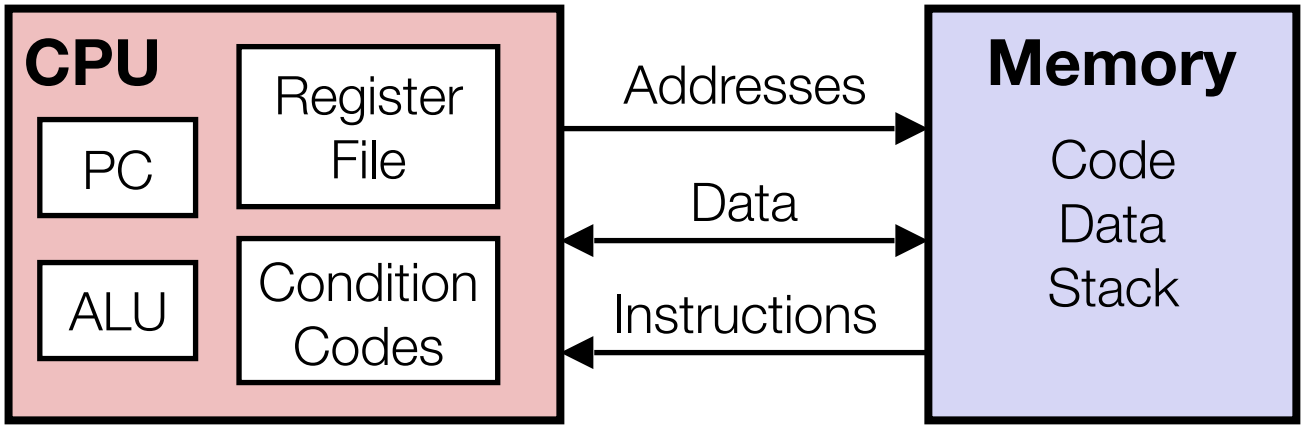

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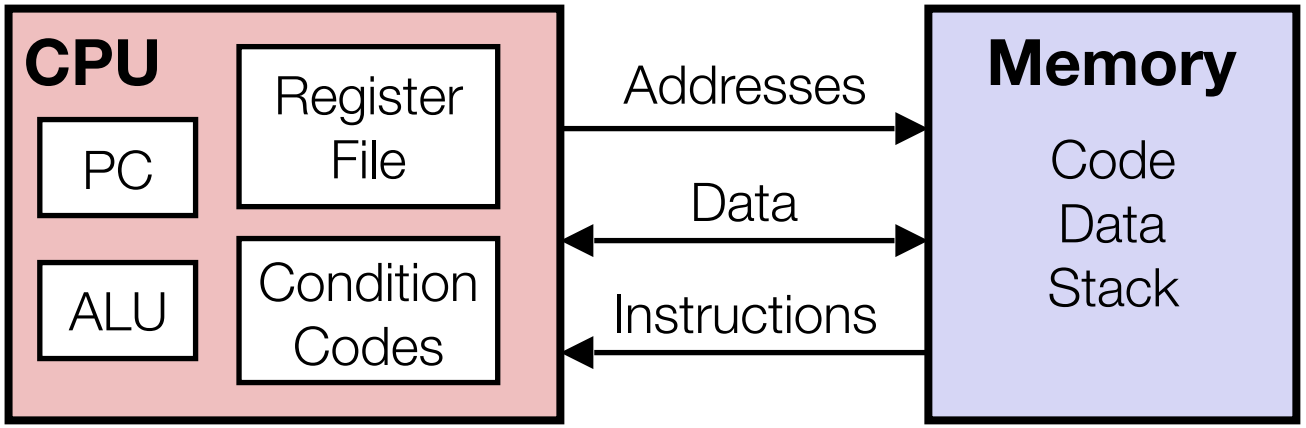

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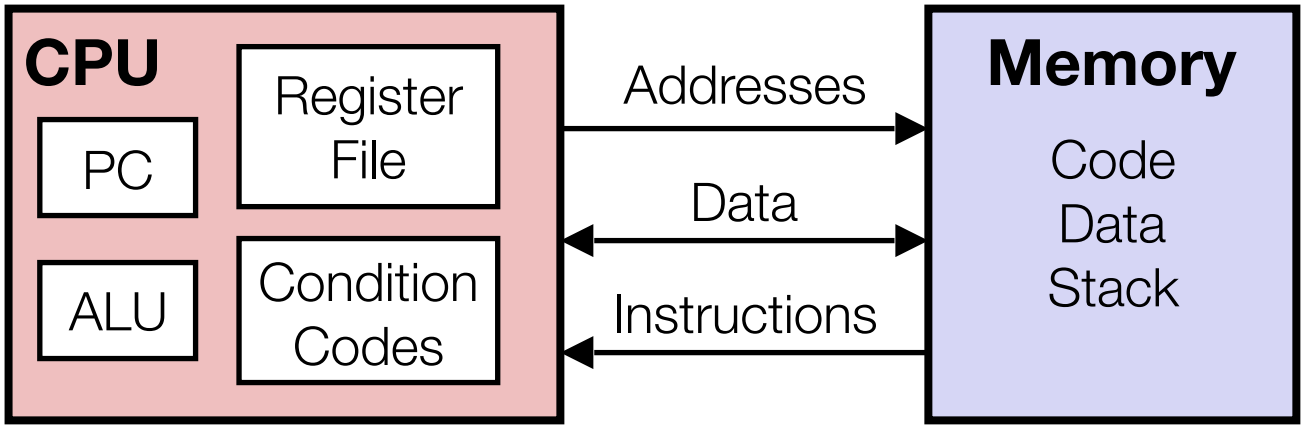

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- There are other kinds of faster memory that we will talk about later
- Key: register file is programmer visible, i.e., you could use instructions to explicitly move data between memory and register file.

Data Movement Instruction Example

```
movq    %rdx, (%rdi)
```

- Semantics:
  - Move (really, **copy**) data in register **`%rdx`** to memory location whose address is the value stored in **`%rdi`**
  - Pointer dereferencing

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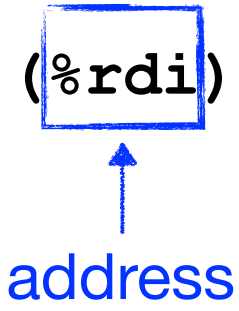

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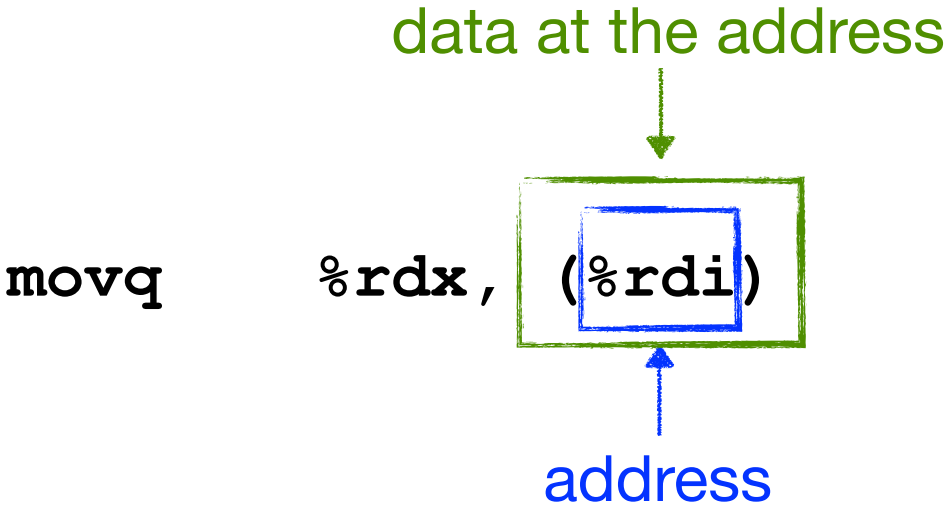

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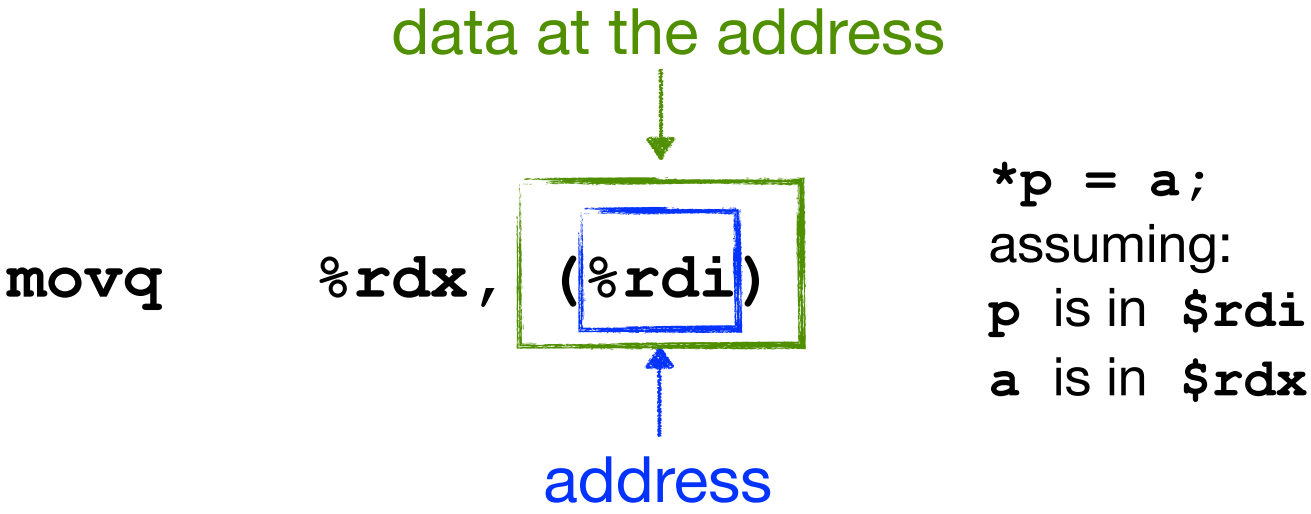

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```

- Displacement: D(R)
  - Memory address: **Reg[R]+D**
  - Register R specifies start of memory region
  - Constant displacement D specifies offset

```
movq 8(%rbp),%rdx; // address = %rbp + 8
```

Data Movement Instructions

`movq` *Source*, *Dest*

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Operator Operands

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  - But **`%rsp`** reserved for special use

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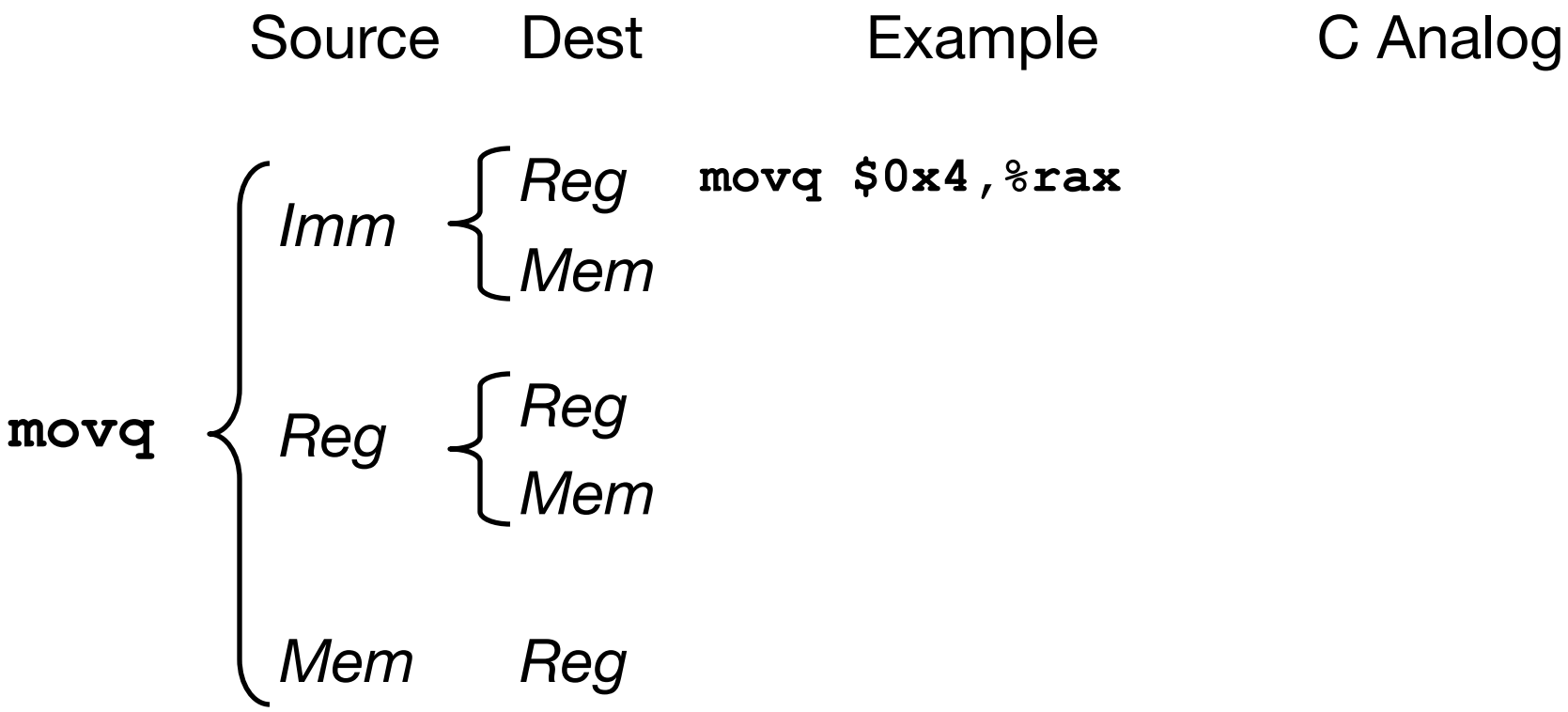
  - How to obtain the address is called “addressing mode”
- Register:
  - Example: **`%rax, %r13`**
  - But **`%rsp`** reserved for special use
- Immediate: Constant integer data
  - Example: **`$0x400`**, **`$-533;`** like C constant, but prefixed with ‘**`$`**’
  - Encoded with 1, 2, or 4 bytes; can only be source

`movq` Operand Combinations

	Source	Dest	Example	C Analog
`movq`	*Imm*	*Reg*		
		Mem		
	Reg	*Reg*		
		Mem		
	Mem	*Reg*		

Cannot do memory-memory transfer with a single instruction in x86.

`movq` Operand Combinations



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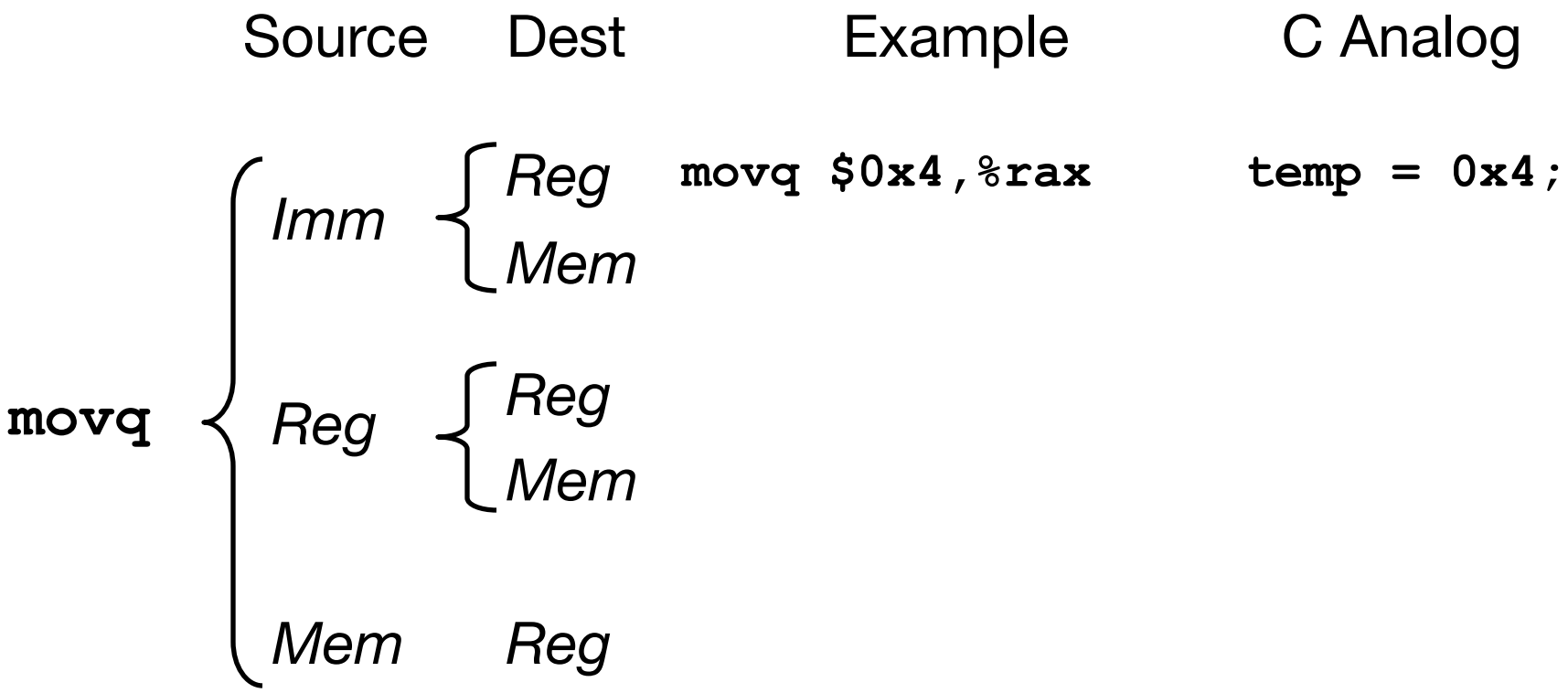

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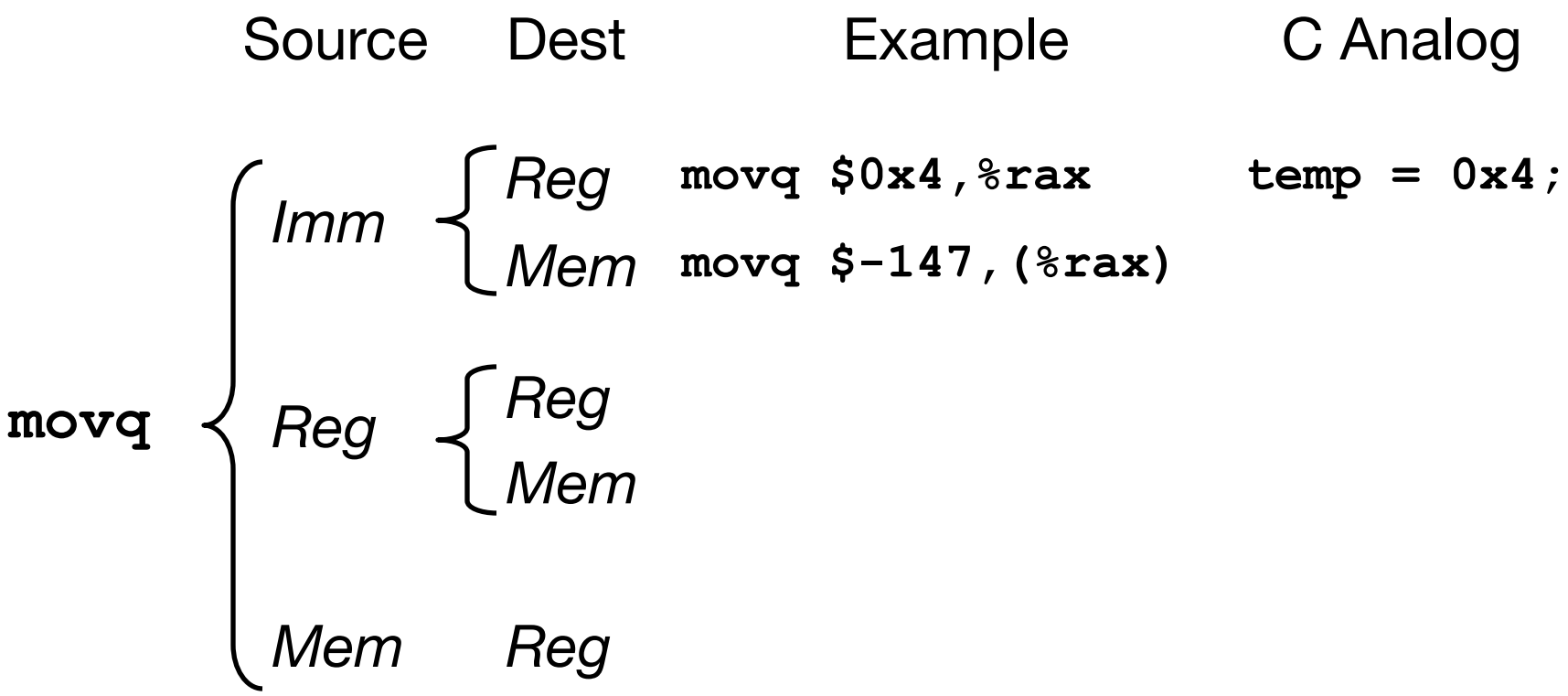

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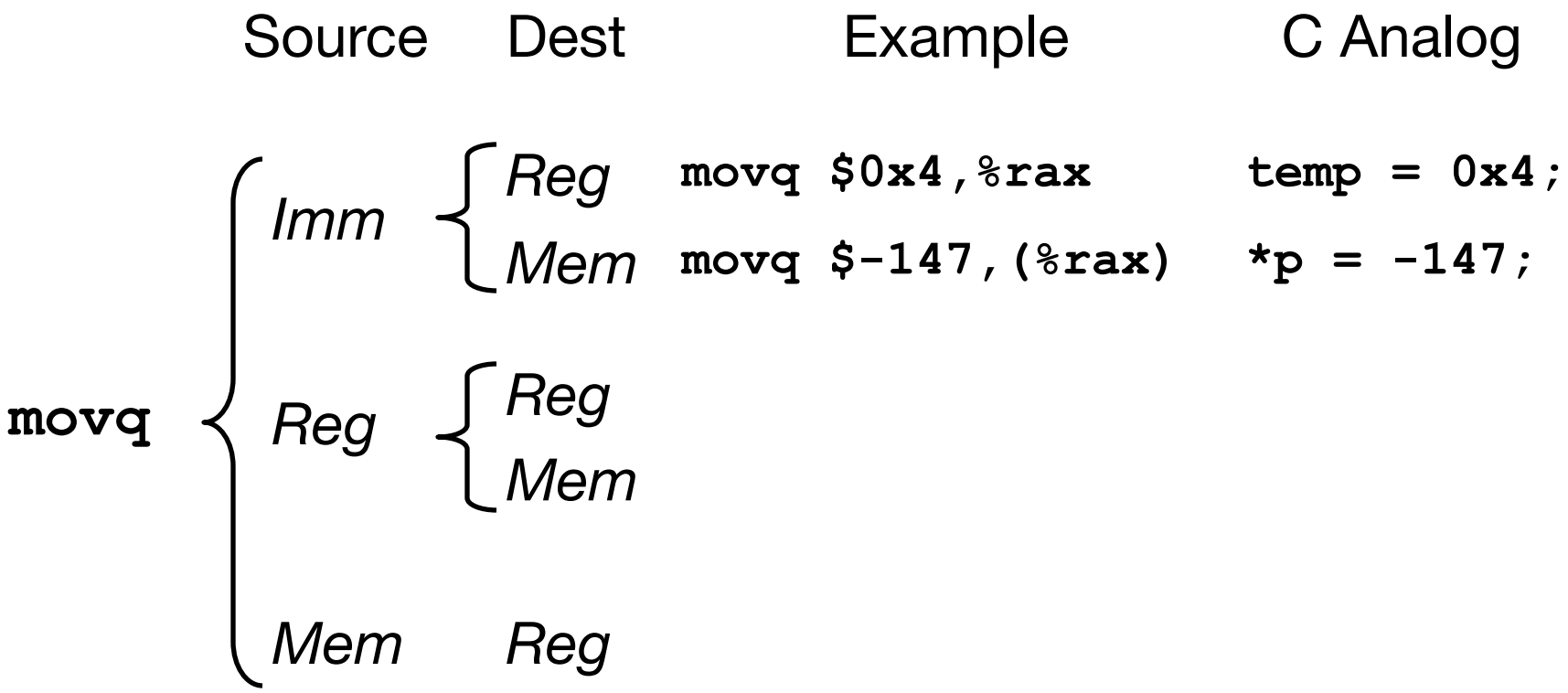

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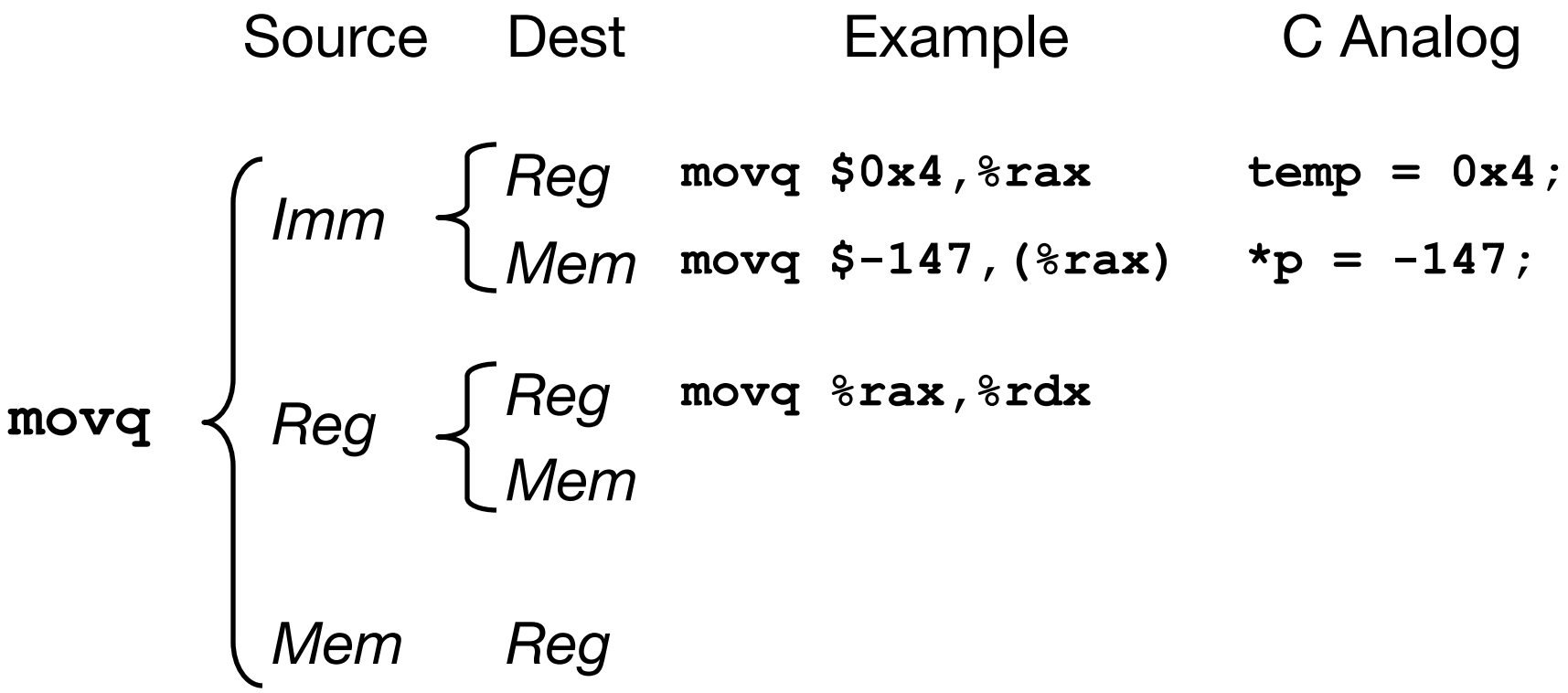

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		Mem	`movq $-147,(%rax)`	`*p = -147;`
	Reg	*Reg*	`movq %rax,%rdx`	`temp2 = temp1;`
		Mem		
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Example of Simple Addressing Modes

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void swap
    (long *xp, long *yp)
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  long t0 = *xp;
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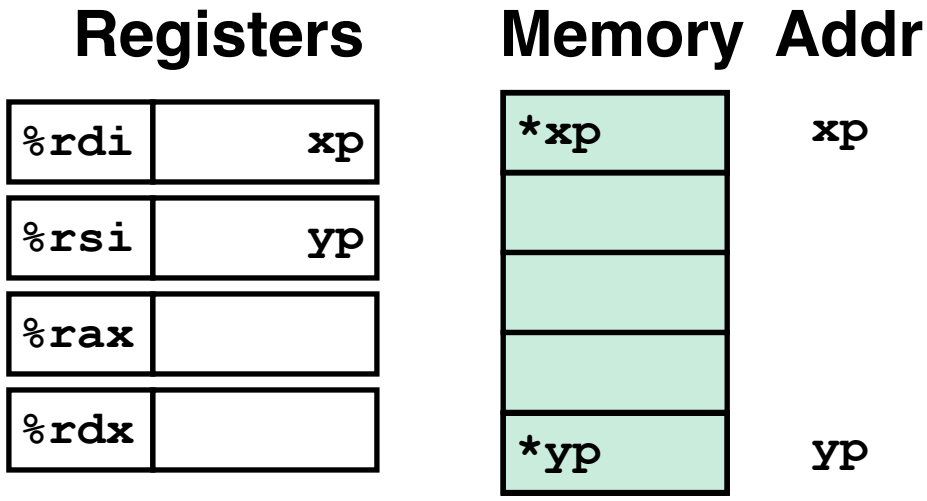

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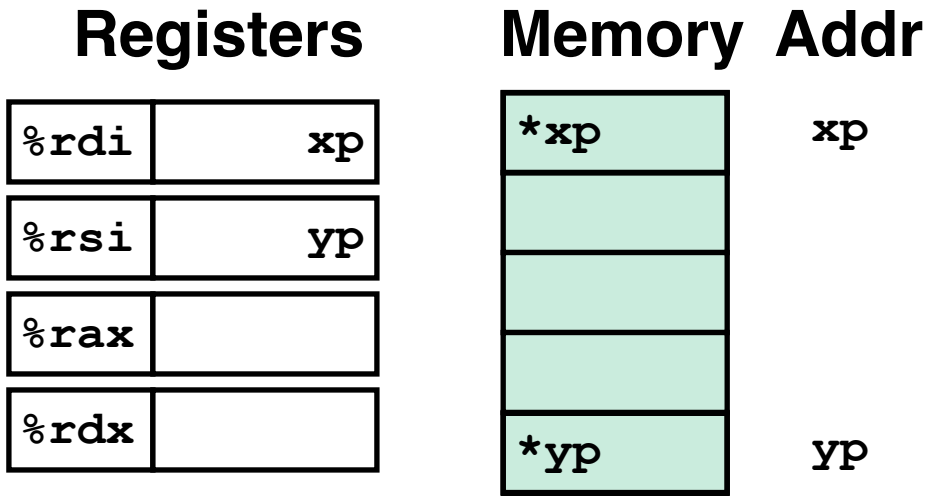
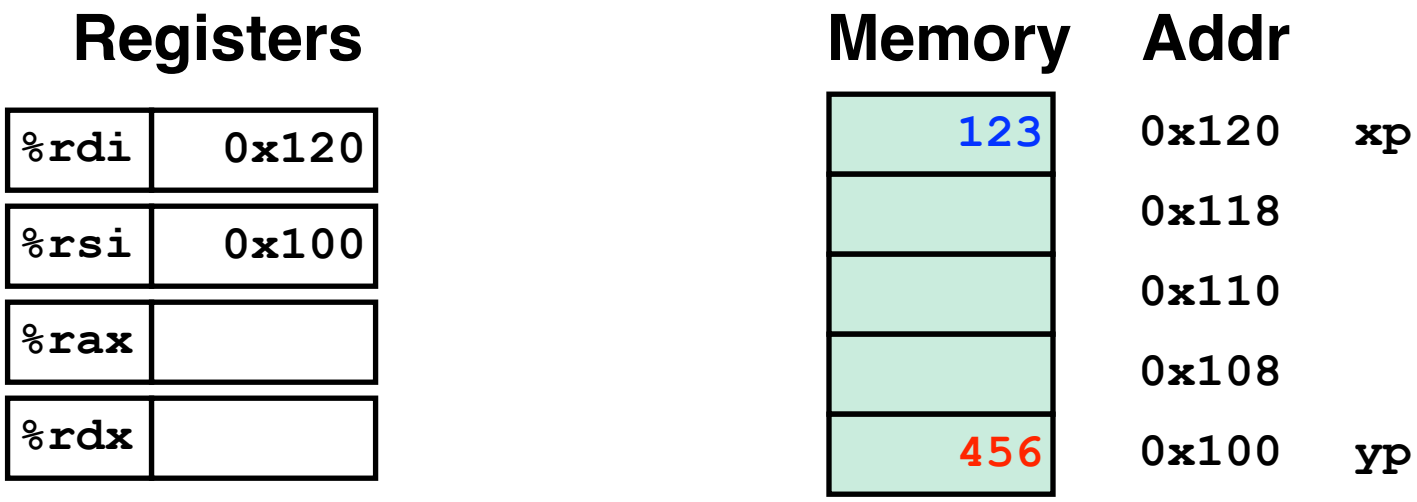



```
swap:
    movq    (%rdi), %rax  # t0 = *xp
    movq    (%rsi), %rdx  # t1 = *yp
    movq    %rdx, (%rdi)  # *xp = t1
    movq    %rax, (%rsi)  # *yp = t0
    ret
```

Understanding `Swap()`

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    ret
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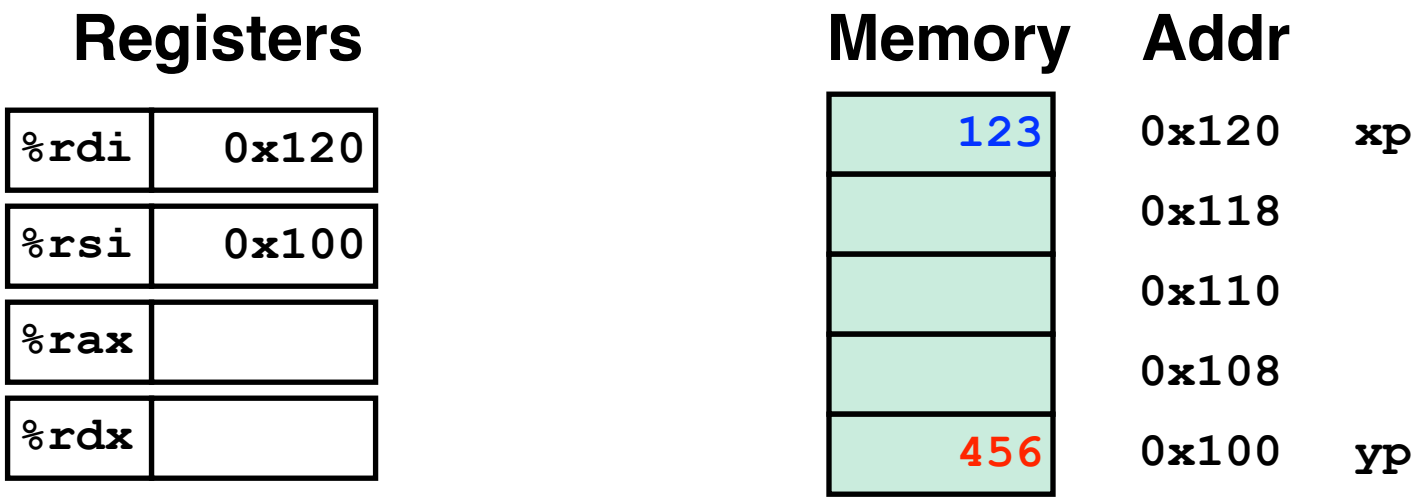
Understanding `Swap()`

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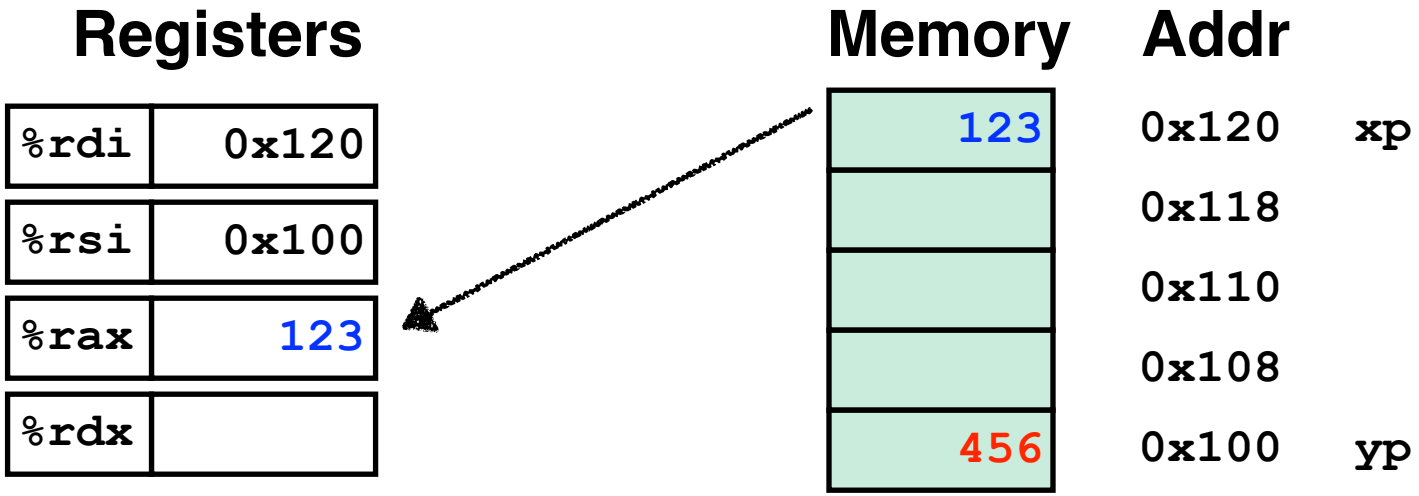


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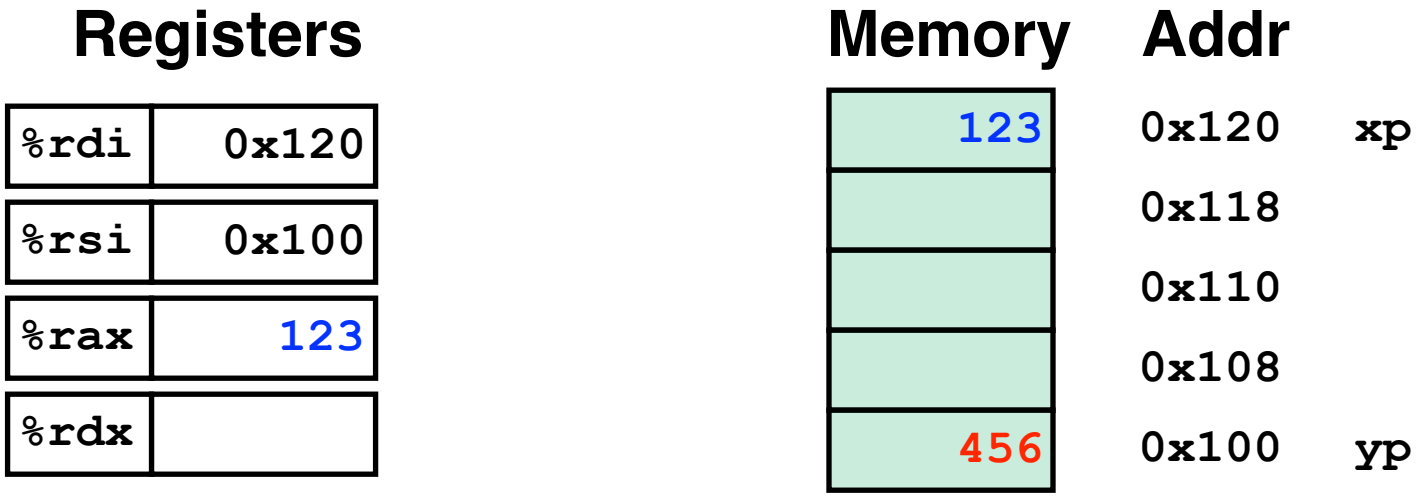


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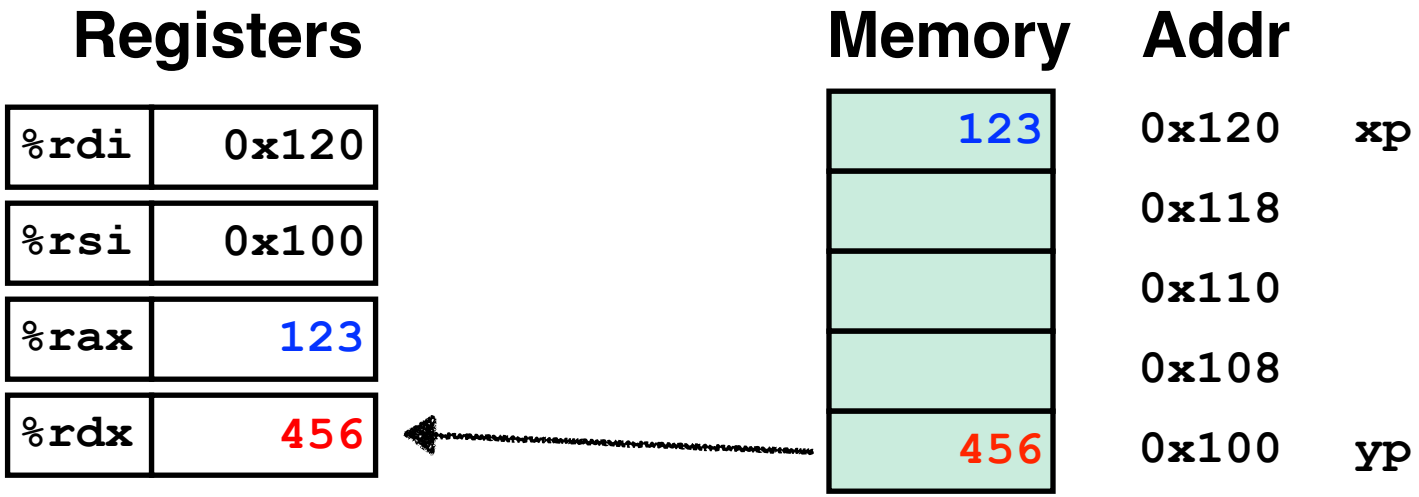


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Understanding `Swap()`

Registers

%rdi	0x120
%rsi	0x100
%rax	123
%rdx	456

Memory	Addr	
123	0x120	xp
	0x118	
	0x110	
	0x108	
456	0x100	yp

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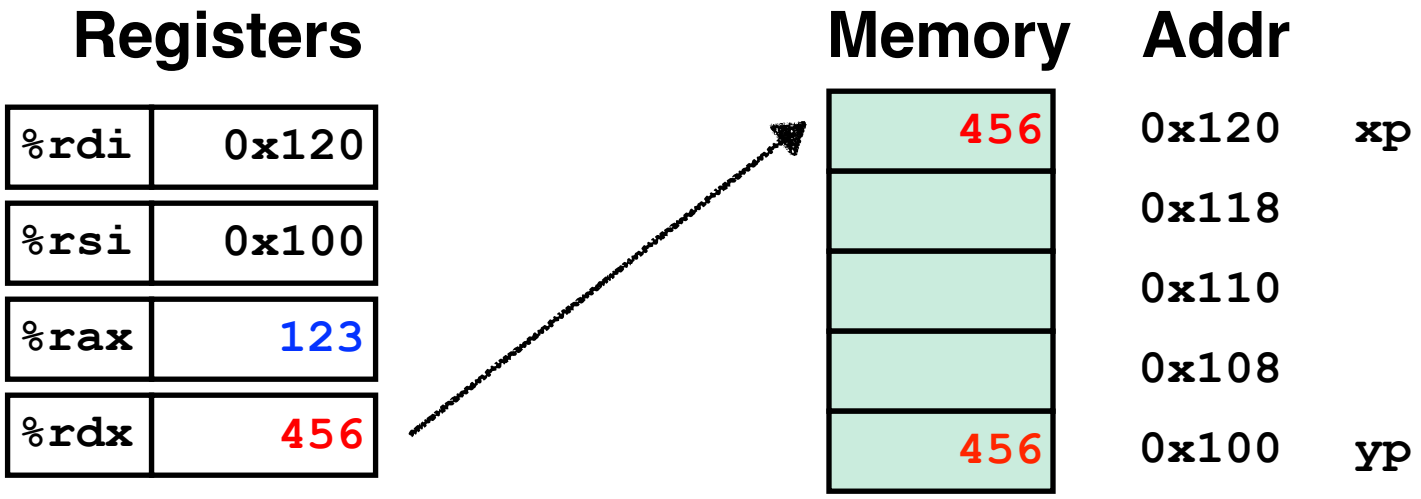


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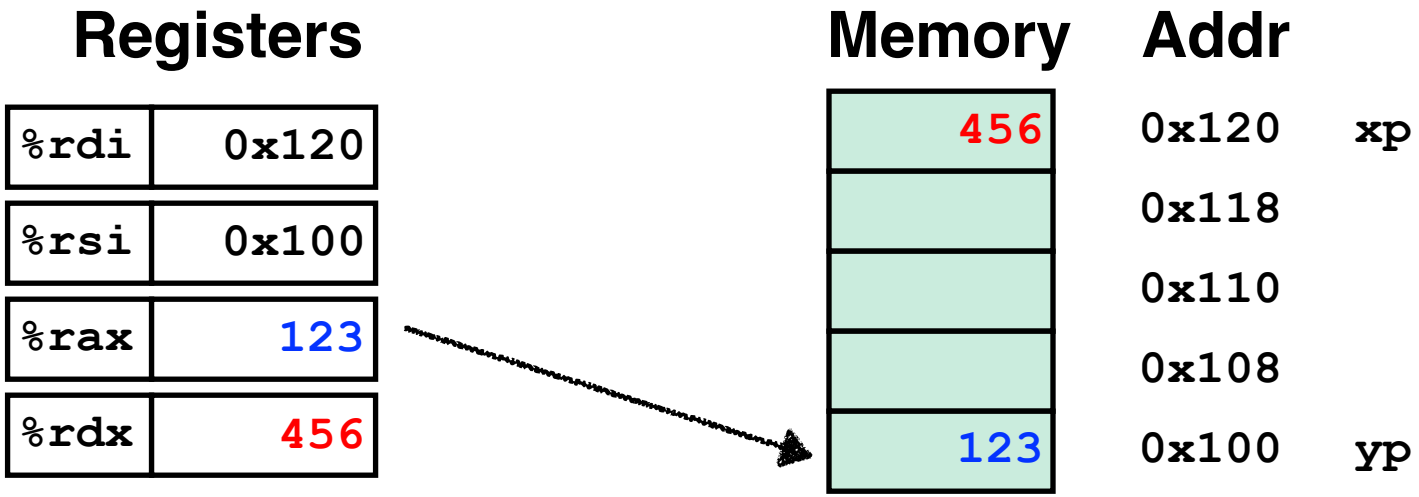


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Complete Memory Addressing Modes

- The General Form: D(Rb,Ri,S)
  - Memory address: Reg[Rb] + S * Reg[Ri] + D
  - E.g., **`8(%eax, %ebx, 4)`**; // address = **`%eax`** + 4 * **`%ebx`** + 8
  - D: Constant “displacement”
  - Rb: Base register: Any of 16 integer registers
  - Ri: Index register: Any, except for %rsp
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- What is **`8(%eax, %ebx, 4)`** used for?
- Special Cases

(Rb,Ri)	address = Reg[Rb]+Reg[Ri]
D(Rb,Ri)	address = Reg[Rb]+Reg[Ri]+D
(Rb,Ri,S)	address = Reg[Rb]+S*Reg[Ri]

Address Computation Examples

`%rdx`	`0xf000`
`%rcx`	`0x0100`

Expression	Address Computation	Address
`0x8(%rdx)`		
`(%rdx,%rcx)`		
`(%rdx,%rcx,4)`		
`0x80(,%rdx,2)`		

Address Computation Examples

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`(%rdx,%rcx,4)`	`0xf000 + 4*0x100`	`0xf400`
`0x80(,%rdx,2)`	`2*0xf000 + 0x80`	`0x1e080`

Address Computation Instruction

```
leaq 4(%rsi,%rdi,2), %rax
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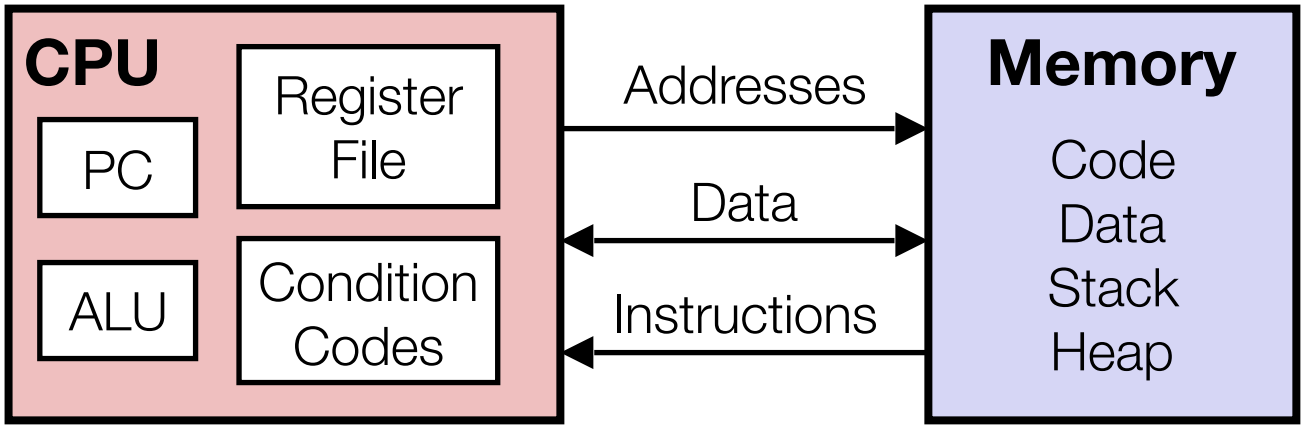
  - *Src* is address mode expression
  - Set *Dst* to address denoted by expression
  - No actual memory reference is made
- Uses
  - Computing addresses without a memory reference
    - E.g., translation of p = &x[i];

Assembly Program Instructions

Assembly Programmer's Perspective of a Computer



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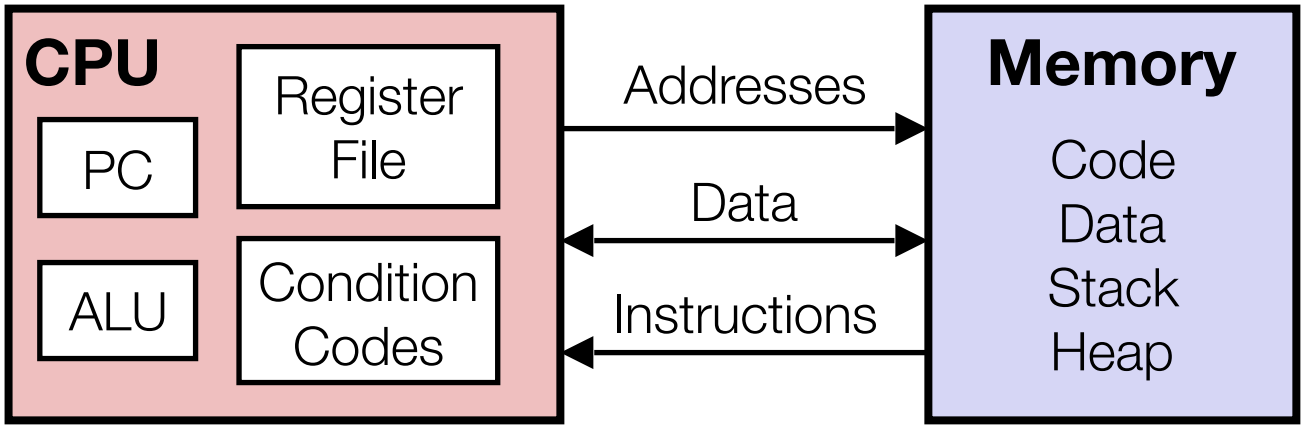

- *Data Movement Instruction*: Transfer data between memory and register
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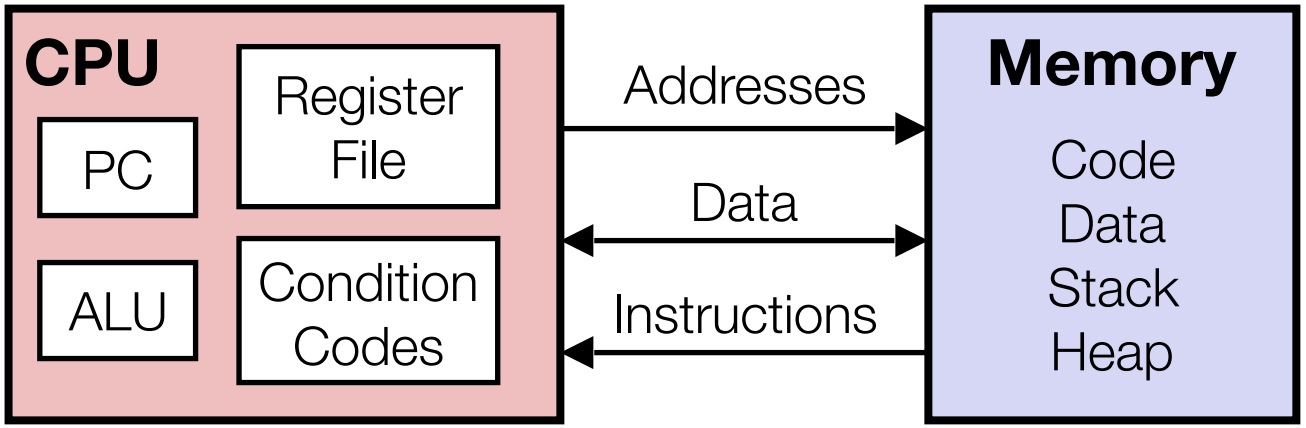

- *Data Movement Instruction*: Transfer data between memory and register
  - **`movq %eax, (%ebx)`**
- *Compute Instruction*: Perform arithmetics on register or memory data
  - **`addq %eax, %ebx`**
  - C constructs: +, -, >>, etc.
- *Control Instruction*: Alter the sequence of instructions (by changing PC)
  - **`jmp`**, **`call`**
  - C constructs: **`if-else`**, **`do-while`**, function call, etc.

Today: Compute and Control Instructions

- Move operations (and addressing modes)
- Arithmetic & logical operations
- Control: Conditional branches (`if`… `else`…)
- Control: Loops (`for`, `while`)
- Control: Switch Statements (`case`… `switch`…)

Some Arithmetic Operations (2 Operands)

Format	Computation	Notes
addq `src, dest`	Dest = Dest + Src	

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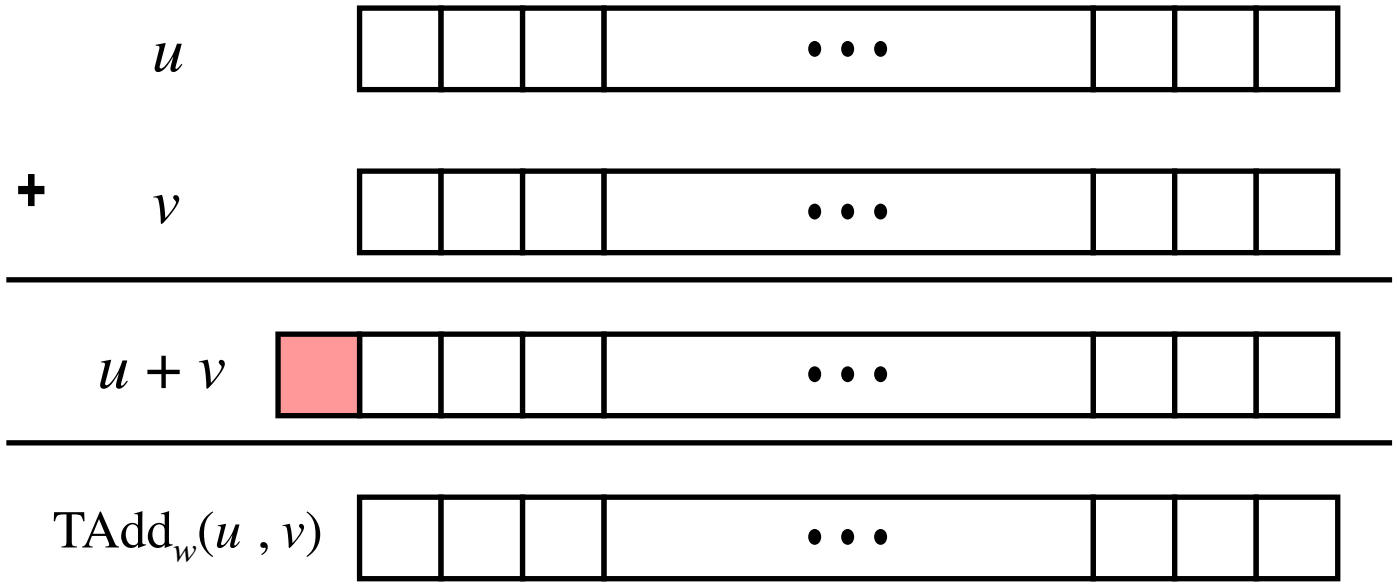

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Some Arithmetic Operations (2 Operands)

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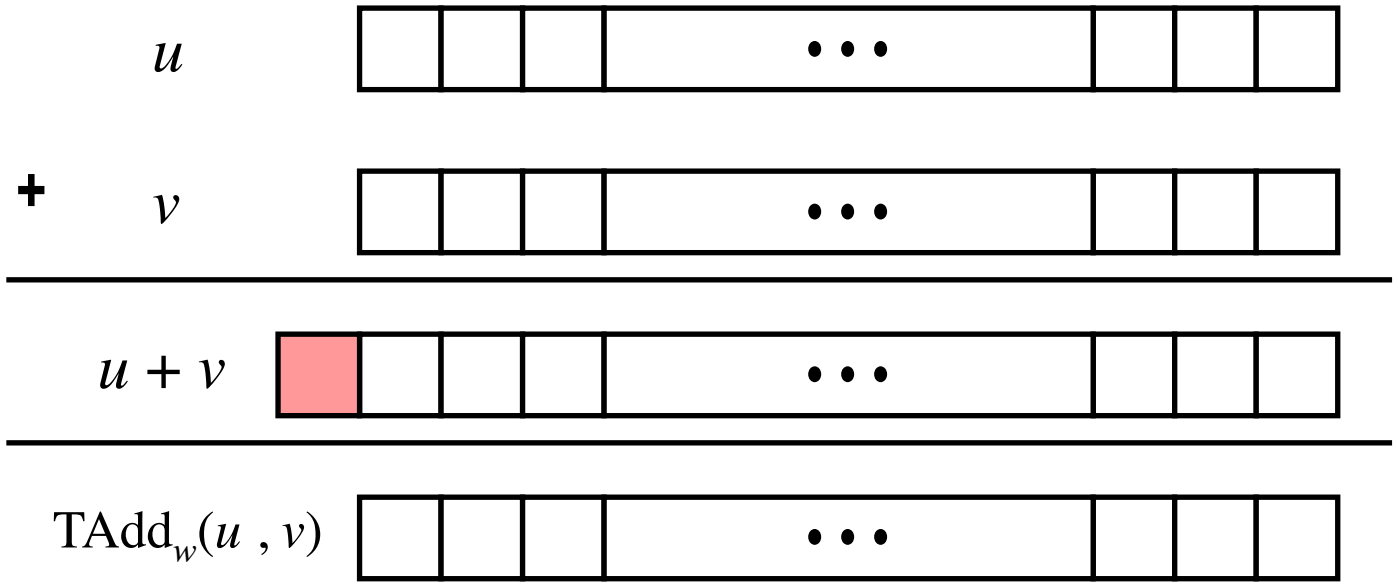

addq %rax, %rbx

%rbx = %rax + %rbx
Truncation if overflow,
set carry bit (more later…)

Some Arithmetic Operations (2 Operands)

Format	Computation	Notes
addq src, dest	Dest = Dest + Src	
subq src, dest	Dest = Dest - Src	
imulq src, dest	Dest = Dest * Src	
salq src, dest	Dest = Dest << Src	Also called **shlq**
sarq src, dest	Dest = Dest >> Src	Arithmetic shift
shrq src, dest	Dest = Dest >> Src	Logical shift
xorq src, dest	Dest = Dest ^ Src	
andq src, dest	Dest = Dest & Src	
orq src, dest	Dest = Dest | Src	

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```
long signed_add
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  return res;
}
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#x in %rdx, y in %rax
addq    %rdx, %rax
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Bit-level

```
   010
+) 101
-------
   111
```

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Bit-level

```
   010
+) 101
-----
   111
```

Signed

```
    2
+) -3
-----
   -1
```

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Bit-level	Signed	Unsigned
010	2	2
+) 101	+) -3	+) 5
111	-1	7

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long signed_add
(long x, long y)
{
  long res = x + y;
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}
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```
#x in %rdx, y in %rax
addq    %rdx, %rax
```

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long unsigned_add
(unsigned long x, unsigned long y)
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}
```

```
#x in %rdx, y in %rax
addq    %rdx, %rax
```

Some Arithmetic Operations (1 Operand)

- Unary Instructions (one operand)

Format	Computation
`incq` `dest`	Dest = Dest + 1
`decq` `dest`	Dest = Dest - 1
`negq` `dest`	Dest = -Dest
`notq` `dest`	Dest = ~Dest

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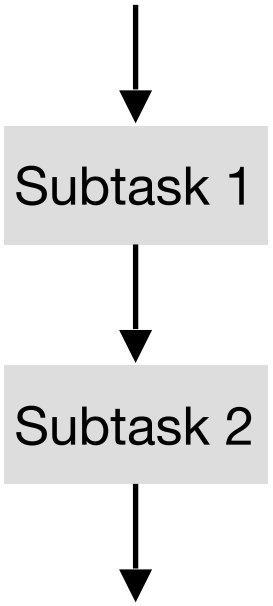
- Control: Loops (**`for`**, **`while`**)
- Control: Switch Statements (**`case`**... **`switch`**...)

Three Basic Programming Constructs

Three Basic Programming Constructs

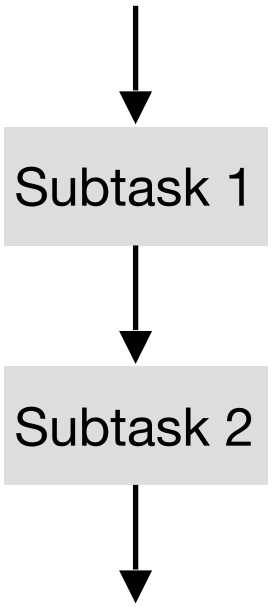
Sequential




```
a = x + y;
y = a - c;
...
```

Three Basic Programming Constructs

Sequential




```
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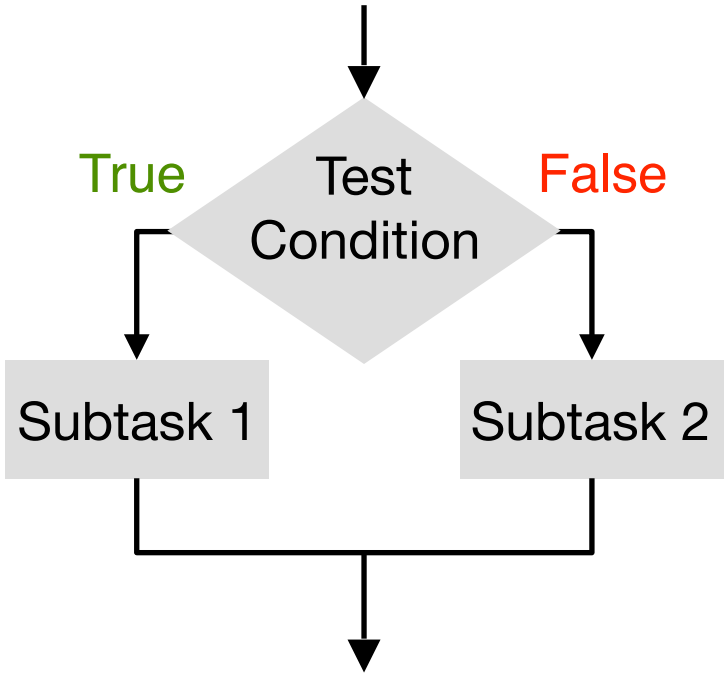
y = a - c;
...
```

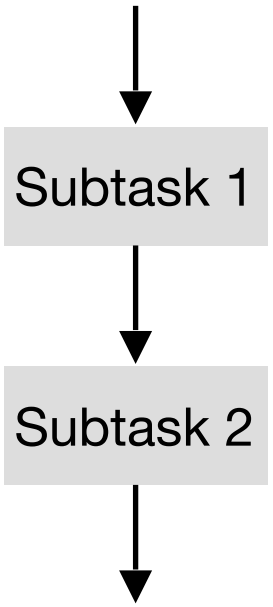
Conditional




```
if (x > y) r = x - y;
else r = y - x;
```

Three Basic Programming Constructs

Sequential

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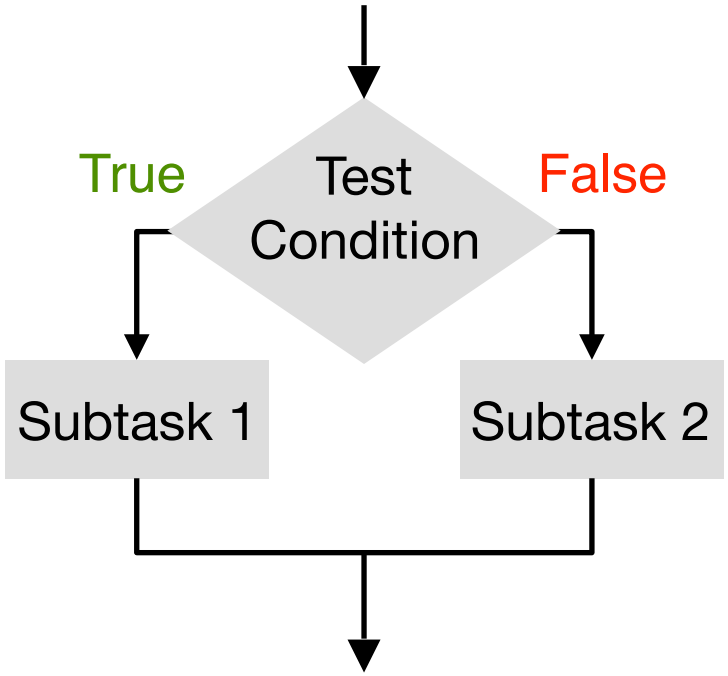
Conditional

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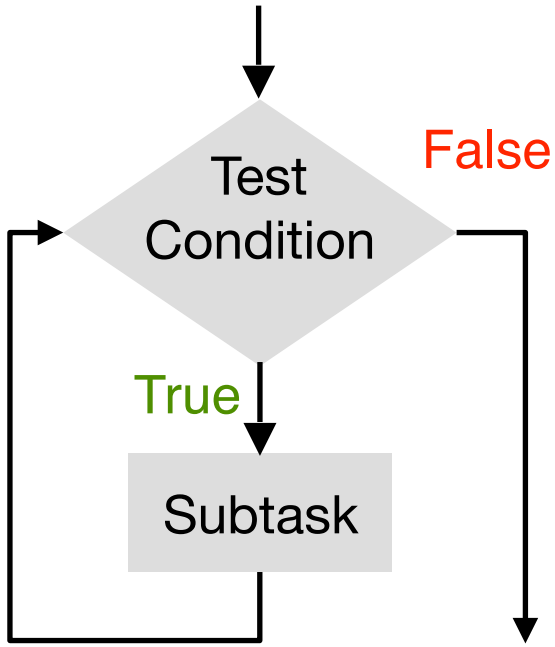
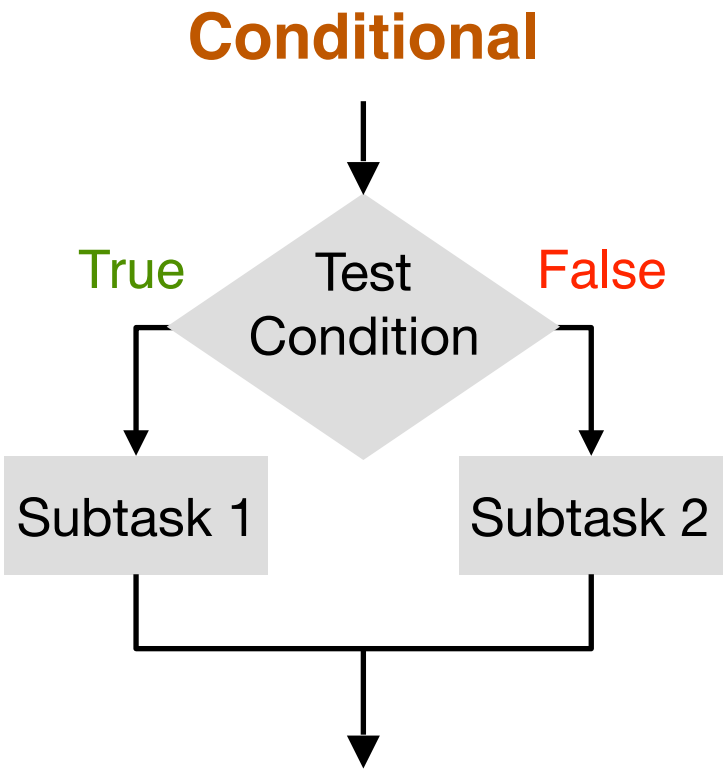
Iterative




```
while (x > 0) {
  x--;
}
```

Three Basic Programming Constructs

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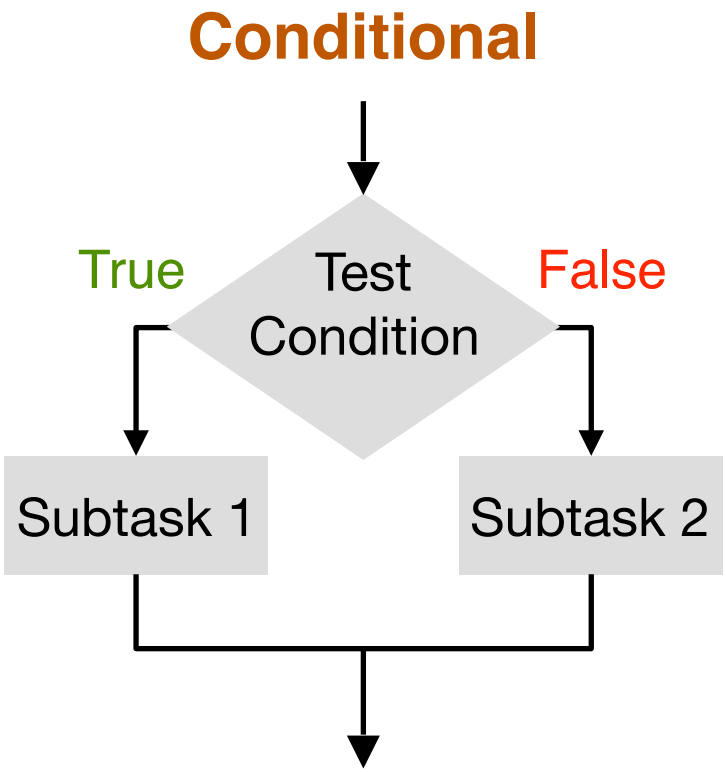
Three Basic Programming Constructs

- Both conditional and iterative programming requires altering the sequence of instructions (control flow)

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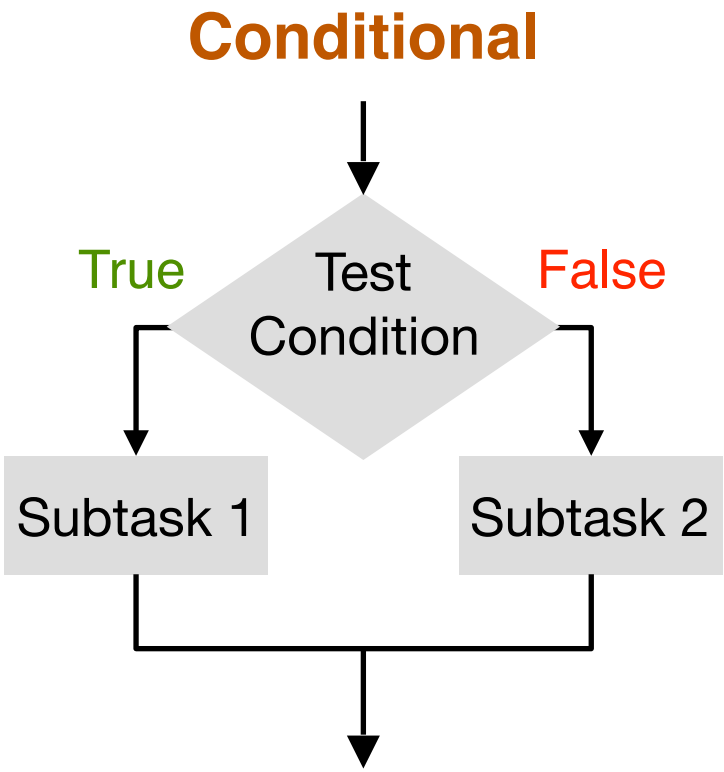


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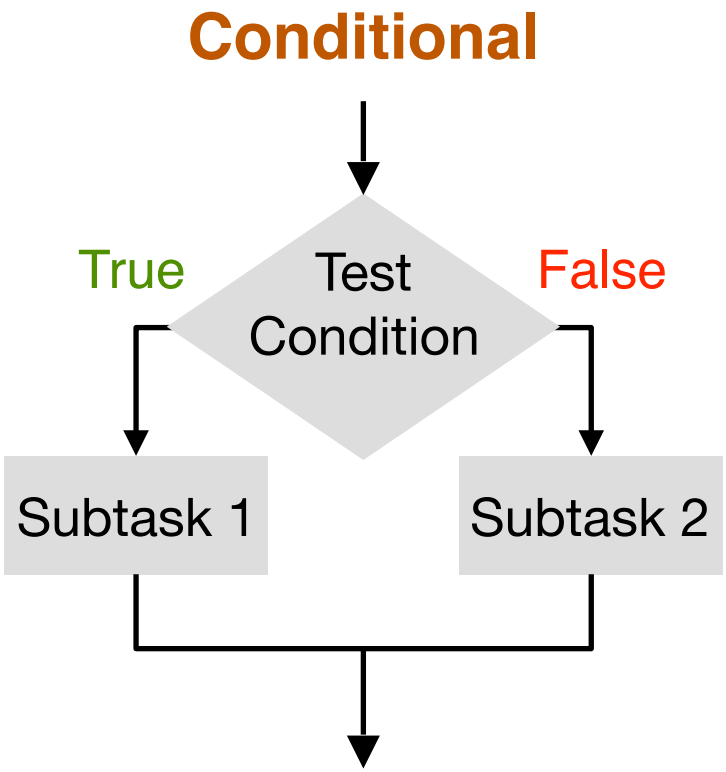
Three Basic Programming Constructs

- Both conditional and iterative programming requires altering the sequence of instructions (control flow)
- We need a set of *control instructions* to do so
- Two fundamental questions:
  - How to test condition and how to represent test results?
  - How to alter control flow according to the test results?

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Conditional Branch Example

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

Conditional Branch Example

```
gcc -Og -S -fno-if-conversion control.c
```

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```

```
absdiff:
    cmpq    %rsi,%rdi # x:y
    jle     .L4
    movq    %rdi,%rax
    subq    %rsi,%rax
    ret
.L4:                  # x <= y
    movq    %rsi,%rax
    subq    %rdi,%rax
    ret
```

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    ret
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    movq    %rsi,%rax
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```

Register	Use(s)
%rdi	x
%rsi	y
%rax	Return value

Conditional Branch Example

```
gcc -Og -S -fno-if-conversion control.c
```

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

```
absdiff:
    cmpq    %rsi,%rdi # x:y
    jle     .L4
    movq    %rdi,%rax
    subq    %rsi,%rax
    ret
.L4:                  # x <= y
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Labels are symbolic names used to refer to instruction addresses.

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unsigned long y)
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Conditional Jump Instruction

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-------    -------
   010        -6
```

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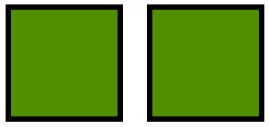

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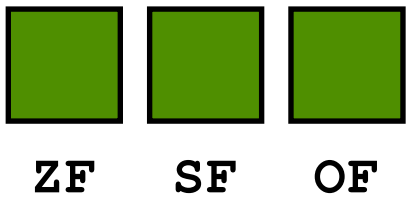

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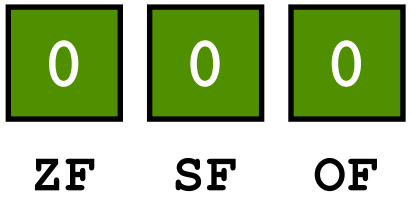

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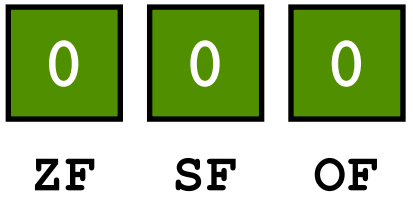

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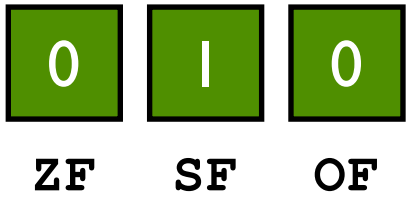

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- `%rdi <= %rsi` if and only if
  - ZF is set, or
  - SF is set but OF is not set, or
  - SF is not set, but OF is set
- or simply: ZF | (SF ^ OF)

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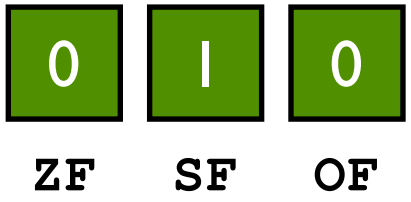

Conditional Branch Example

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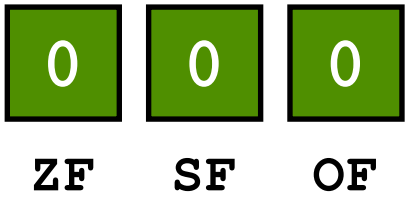

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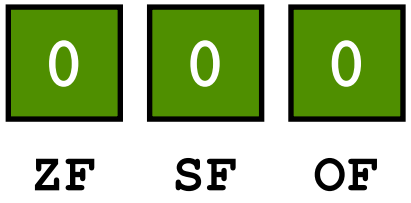
`cmpq` sets ZF, SF, OF

`jle` checks ZF | (SF ^ OF)



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-------    -------    -------     -------
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  - If A > 0 & B < 0, but the result < 0
  - So again, just have to check the bits

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   001        1
-) 010     -) 2
-------    -------
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   101        -3         011         3
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