

CSC 252: Computer Organization

Spring 2023: Lecture 7

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Announcement

- Programming assignment 2 is out. It's in x86 assembly language. Details at: <https://www.cs.rochester.edu/courses/252/spring2023/labs/assignment2.html>.

22	23	24	25	26	27	28
29	30	31	Feb 1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18

Today

Due

Announcement

- You might still have three slip days.
- 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.
- Logics and arithmetics problem set: <https://www.cs.rochester.edu/courses/252/spring2023/handouts.html>.
 - Not to be turned in.

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...`)

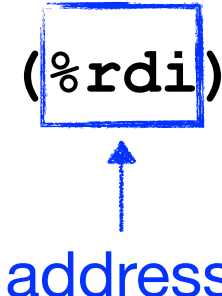
Data Movement Instruction Example

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

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

Data Movement Instruction Example

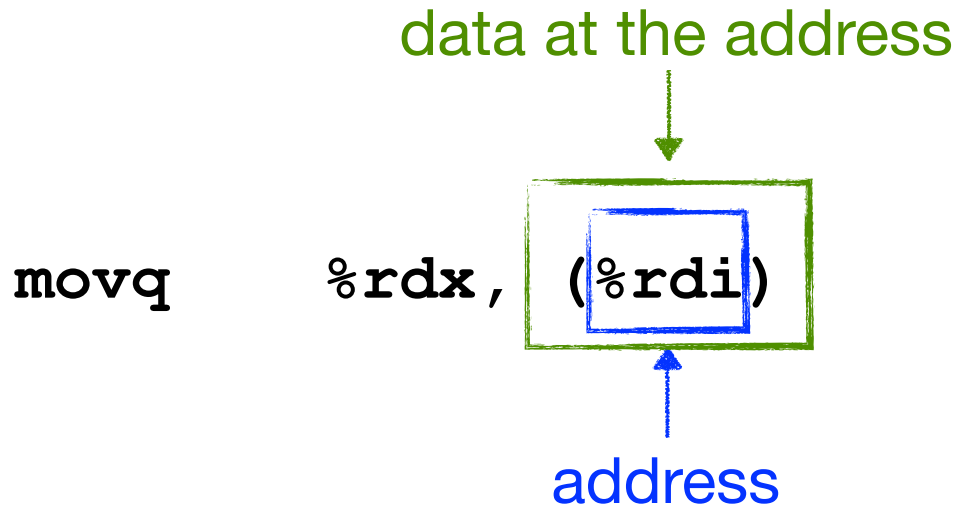
`movq %rdx, (%rdi)`



address

- Semantics:
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 - Pointer dereferencing

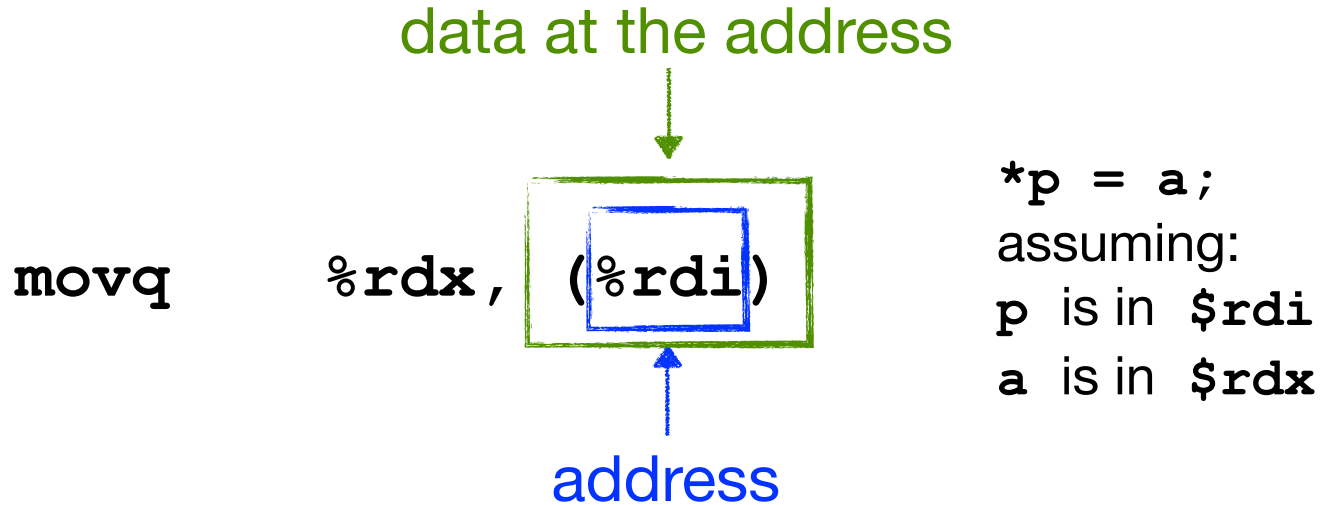
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Memory Addressing Modes

- An addressing mode specifies:
 - how to calculate the effective memory address of an operand
 - by using information held in registers and/or constants

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- **Normal: (R)**
 - Memory address: content of Register R (**Reg[R]**)
 - Pointer dereferencing in C

```
movq (%rcx), %rax; // address = %rcx
```

Memory Addressing Modes

- An addressing mode specifies:
 - how to calculate the effective memory address of an operand
 - by using information held in registers and/or constants

- **Normal:** (R)

- Memory address: content of Register R (**Reg[R]**)
- Pointer dereferencing in C

```
movq (%rcx), %rax; // address = %rcx
```

- **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*

Data Movement Instructions

`movq` *Source, Dest*

Operator Operands

Data Movement Instructions

`movq` *Source, Dest*

Operator Operands

- **Memory:**
 - Simplest example: (`%rax`)
 - How to obtain the address is called “addressing mode”

Data Movement Instructions

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- **Register:**
 - Example: `%rax, %r13`
 - But `%rsp` reserved for special use

Data Movement Instructions

`movq` *Source, Dest*

Operator Operands

- **Memory:**
 - Simplest example: (`%rax`)
 - 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

	Source	Dest	Example	C Analog
movq	Imm	Reg	movq \$0x4, %rax	
		Mem		
	Reg	Reg		
Mem				
Mem	Reg			

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movq Operand Combinations

	Source	Dest	Example	C Analog
movq	Imm	Reg	movq \$0x4, %rax	temp = 0x4;
		Mem		
	Reg	Reg		
Mem				
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movq Operand Combinations

	Source	Dest	Example	C Analog
movq	Imm	Reg	movq \$0x4, %rax	temp = 0x4;
		Mem	movq \$-147, (%rax)	
	Reg	Reg		
		Mem		
	Mem	Reg		

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movq Operand Combinations

	Source	Dest	Example	C Analog
movq	Imm	Reg	movq \$0x4, %rax	temp = 0x4;
		Mem	movq \$-147, (%rax)	*p = -147;
	Reg	Reg		
		Mem		
	Mem	Reg		

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movq Operand Combinations

	Source	Dest	Example	C Analog
movq	Imm	Reg	movq \$0x4, %rax	temp = 0x4;
		Mem	movq \$-147, (%rax)	*p = -147;
	Reg	Reg	movq %rax, %rdx	
		Mem		
	Mem	Reg		

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movq Operand Combinations

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movq	Imm	Reg	movq \$0x4, %rax	temp = 0x4;
		Mem	movq \$-147, (%rax)	*p = -147;
	Reg	Reg	movq %rax, %rdx	temp2 = temp1;
		Mem		
	Mem	Reg		

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movq Operand Combinations

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movq	Imm	Reg	movq \$0x4, %rax	temp = 0x4;
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		Mem	movq %rax, (%rdx)	
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		Mem	movq %rax, (%rdx)	*p = temp;
	Mem	Reg	movq (%rax), %rdx	

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		Mem	movq %rax, (%rdx)	*p = temp;
	Mem	Reg	movq (%rax), %rdx	temp = *p;

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Example of Simple Addressing Modes

```
void swap
  (long *xp, long *yp)
{
  long t0 = *xp;
  long t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

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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  *xp = t1;
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}
```

Registers

%rdi	xp
%rsi	yp
%rax	
%rdx	

Memory Addr

*xp	xp
*yp	yp

Example of Simple Addressing Modes

```
void swap
(long *xp, long *yp)
{
    long t0 = *xp;
    long t1 = *yp;
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Registers

%rdi	xp
%rsi	yp
%rax	
%rdx	

Memory Addr

*xp	xp
*yp	yp

swap:

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

Understanding `Swap()`

Registers

<code>%rdi</code>	<code>0x120</code>
<code>%rsi</code>	<code>0x100</code>
<code>%rax</code>	
<code>%rdx</code>	

Memory

Memory	Addr
123	<code>0x120</code> <code>xp</code>
	<code>0x118</code>
	<code>0x110</code>
	<code>0x108</code>
456	<code>0x100</code> <code>yp</code>

`swap:`

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

123
456

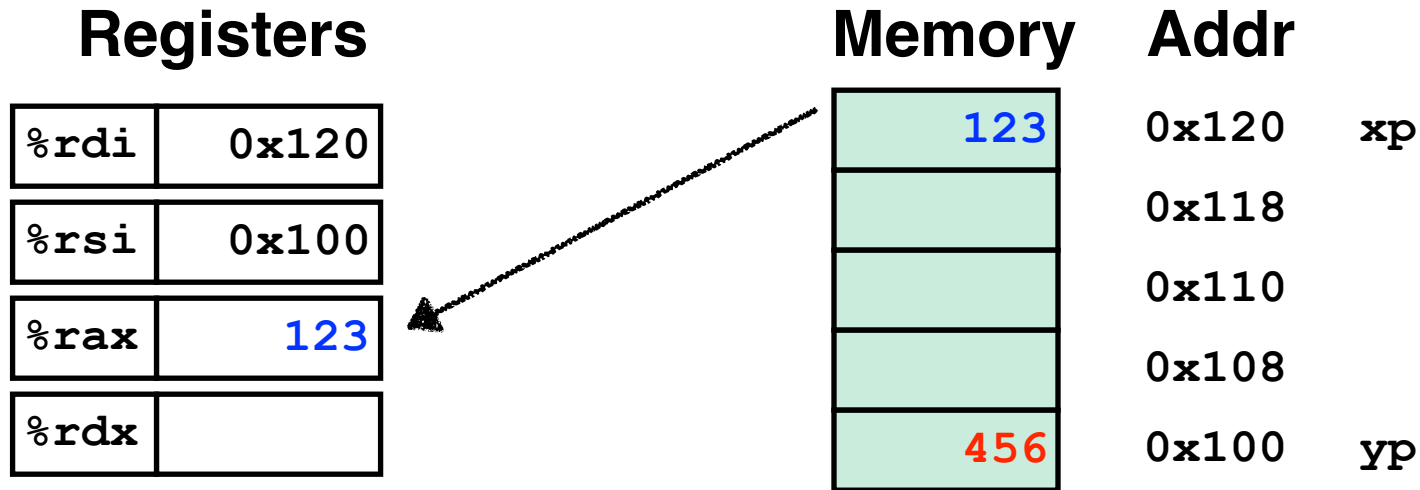
Addr

<code>0x120</code>	<code>xp</code>
<code>0x118</code>	
<code>0x110</code>	
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`swap:`

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movq    (%rdi), %rax    # t0 = *xp
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swap:

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movq    (%rdi), %rax    # t0 = *xp
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<code>%rax</code>	<code>123</code>
<code>%rdx</code>	

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<code>123</code>
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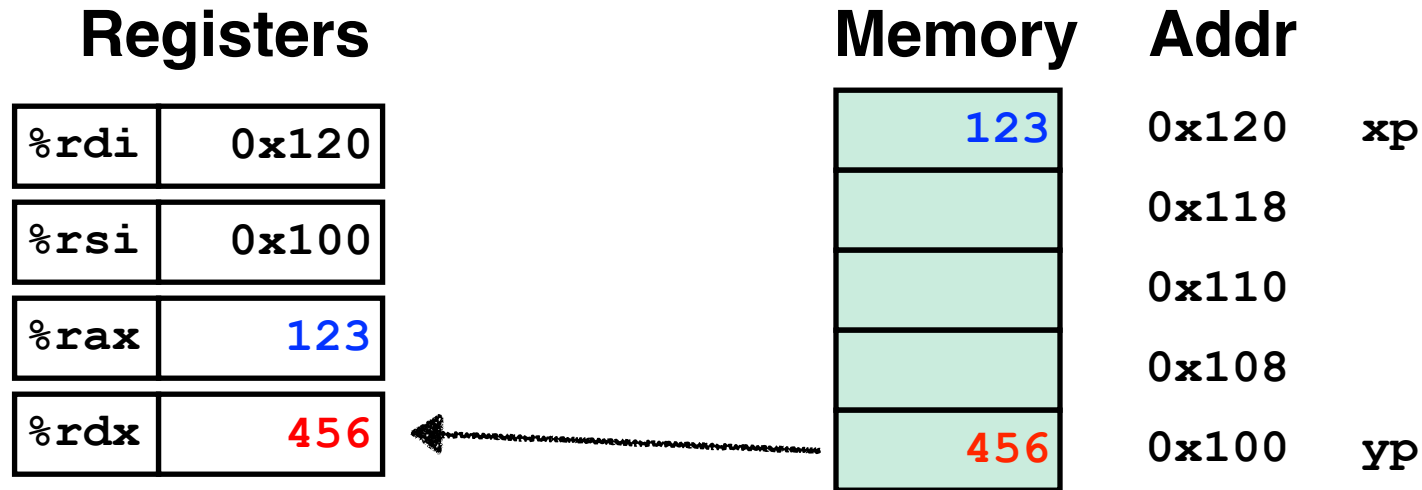
Addr

<code>0x120</code>	<code>xp</code>
<code>0x118</code>	
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movq    (%rdi), %rax    # t0 = *xp
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movq    %rdx, (%rdi)   # *xp = t1
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ret
```

Understanding `Swap()`



`swap:`

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movq    (%rdi), %rax    # t0 = *xp
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Understanding `Swap()`

Registers

<code>%rdi</code>	<code>0x120</code>
<code>%rsi</code>	<code>0x100</code>
<code>%rax</code>	<code>123</code>
<code>%rdx</code>	<code>456</code>

Memory

Memory	Addr
<code>123</code>	<code>0x120 xp</code>
	<code>0x118</code>
	<code>0x110</code>
	<code>0x108</code>
<code>456</code>	<code>0x100 yp</code>

`swap:`

```
movq    (%rdi), %rax    # t0 = *xp
```

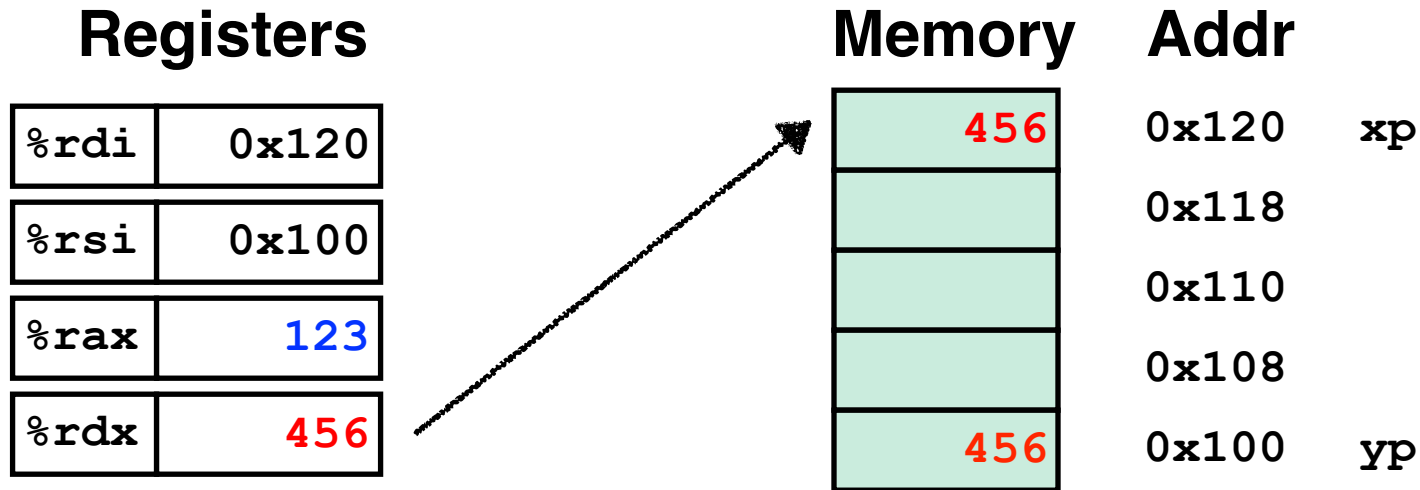
```
movq    (%rsi), %rdx    # t1 = *yp
```

```
movq    %rdx, (%rdi)    # *xp = t1
```

```
movq    %rax, (%rsi)    # *yp = t0
```

```
ret
```

Understanding `Swap()`



`swap:`

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movq    (%rdi), %rax    # t0 = *xp
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Understanding `Swap()`

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`swap:`

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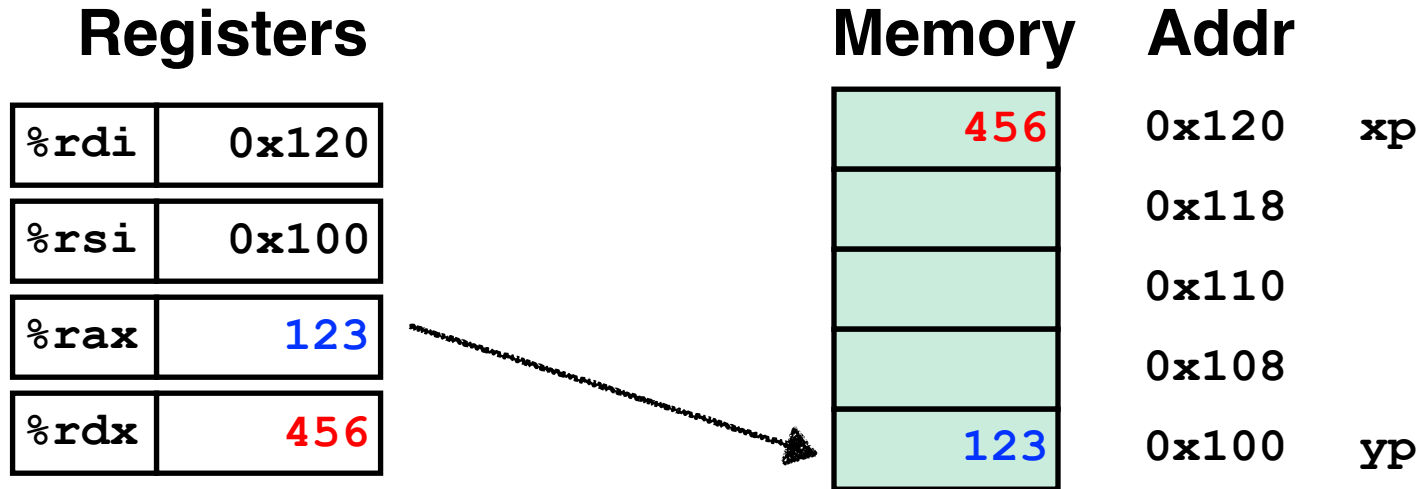
```
movq    (%rsi), %rdx    # t1 = *yp
```

```
movq    %rdx, (%rdi)    # *xp = t1
```

```
movq    %rax, (%rsi)    # *yp = t0
```

```
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```

Understanding `Swap()`



`swap:`

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movq    (%rdi), %rax    # t0 = *xp
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```
movq    %rdx, (%rdi)    # *xp = t1
```

```
movq    %rax, (%rsi)    # *yp = t0
```

```
ret
```

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`
 - S: Scale: 1, 2, 4, or 8

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- What is `8(%eax, %ebx, 4)` used for?

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- 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

<code>%rdx</code>	<code>0xf000</code>
<code>%rcx</code>	<code>0x0100</code>

Expression	Address Computation	Address
<code>0x8(%rdx)</code>		
<code>(%rdx,%rcx)</code>		
<code>(%rdx,%rcx,4)</code>		
<code>0x80(,%rdx,2)</code>		

Address Computation Examples

<code>%rdx</code>	<code>0xf000</code>
<code>%rcx</code>	<code>0x0100</code>

Expression	Address Computation	Address
<code>0x8(%rdx)</code>	<code>0xf000 + 0x8</code>	<code>0xf008</code>
<code>(%rdx,%rcx)</code>		
<code>(%rdx,%rcx,4)</code>		
<code>0x80(,%rdx,2)</code>		

Address Computation Examples

<code>%rdx</code>	<code>0xf000</code>
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<code>0x8(%rdx)</code>	<code>0xf000 + 0x8</code>	<code>0xf008</code>
<code>(%rdx,%rcx)</code>	<code>0xf000 + 0x100</code>	<code>0xf100</code>
<code>(%rdx,%rcx,4)</code>		
<code>0x80(,%rdx,2)</code>		

Address Computation Examples

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<code>(%rdx,%rcx)</code>	<code>0xf000 + 0x100</code>	<code>0xf100</code>
<code>(%rdx,%rcx,4)</code>	<code>0xf000 + 4*0x100</code>	<code>0xf400</code>
<code>0x80(,%rdx,2)</code>		

Address Computation Examples

<code>%rdx</code>	<code>0xf000</code>
<code>%rcx</code>	<code>0x0100</code>

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<code>0x8 (%rdx)</code>	<code>0xf000 + 0x8</code>	<code>0xf008</code>
<code>(%rdx, %rcx)</code>	<code>0xf000 + 0x100</code>	<code>0xf100</code>
<code>(%rdx, %rcx, 4)</code>	<code>0xf000 + 4*0x100</code>	<code>0xf400</code>
<code>0x80 (, %rdx, 2)</code>	<code>2*0xf000 + 0x80</code>	<code>0x1e080</code>

Address Computation Instruction

```
leaq 4(%rsi,%rdi,2), %rax
```


Address Computation Instruction

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leaq 4(%rsi,%rdi,2), %rax
```



$$\%rax = \%rsi + \%rdi * 2 + 4$$

Address Computation Instruction

```
leaq 4(%rsi,%rdi,2), %rax
```



$$\%rax = \%rsi + \%rdi * 2 + 4$$

- **leaq** *Src*, *Dst*
 - *Src* is address mode expression
 - Set *Dst* to address denoted by expression
 - No actual memory reference is made

Address Computation Instruction

```
leaq 4(%rsi,%rdi,2), %rax
```



$$\%rax = \%rsi + \%rdi * 2 + 4$$

- **leaq Src, Dst**

- *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];`

Data Movement Recap

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

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

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movq    %rdx, (%rdi)
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```
movq    8(%rdi), %rdx
```

Data Movement Recap

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```

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

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movq    %rdx, (%rdi)
```

```
movq    8(%rdi), %rdx
```

```
addq    8(%rdi), %rdx
```

Data Movement Recap

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

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

```
movq    8(%rdi), %rdx
```

```
addq    8(%rdi), %rdx
```

Accessing memory and doing computation in one instruction. Allowed in x86, but not all ISAs allow that (e.g., MIPS).

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```

- Semantics:

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

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```
movq    8(%rdi), %rdx
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```
addq    8(%rdi), %rdx
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Data Movement Recap

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

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movq    %rdx, (%rdi)
```

```
movq    8(%rdi), %rdx
```

```
addq    8(%rdi), %rdx
```

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

Illegal in x86 (and almost all other ISAs). Could make microarchitecture implementation inefficient/inelegant.

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
<code>addq src, dest</code>	$\text{Dest} = \text{Dest} + \text{Src}$	

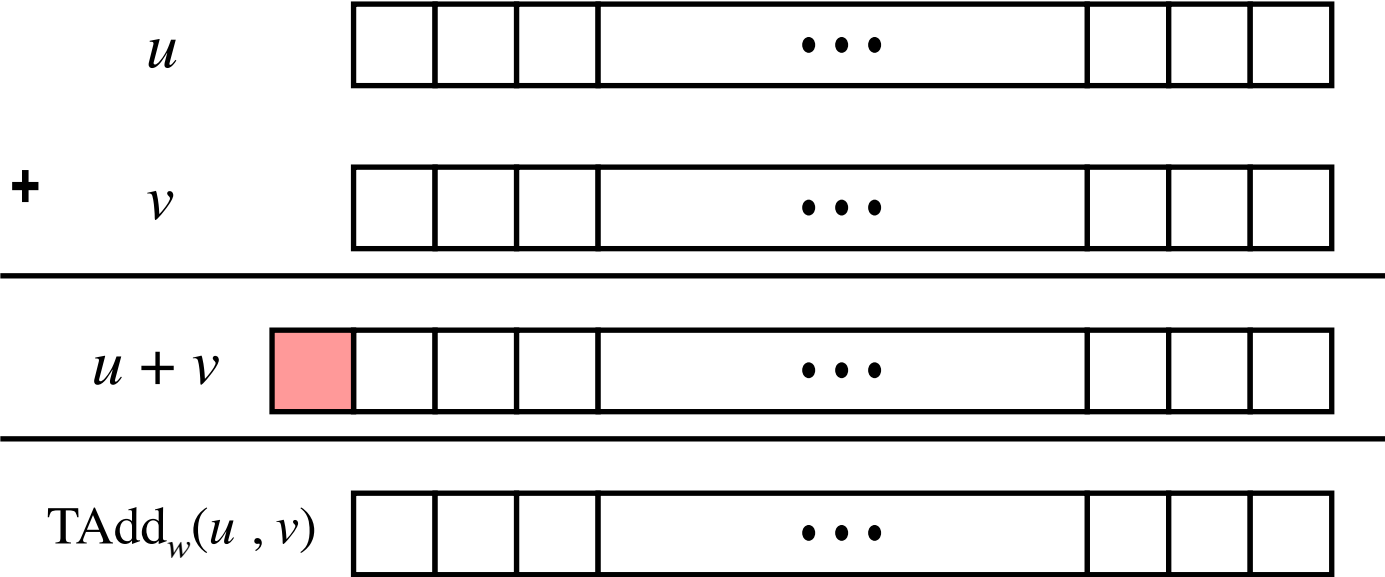
Some Arithmetic Operations (2 Operands)

Format	Computation	Notes
<code>addq src, dest</code>	$\text{Dest} = \text{Dest} + \text{Src}$	

```
addq %rax, %rbx
```

Some Arithmetic Operations (2 Operands)

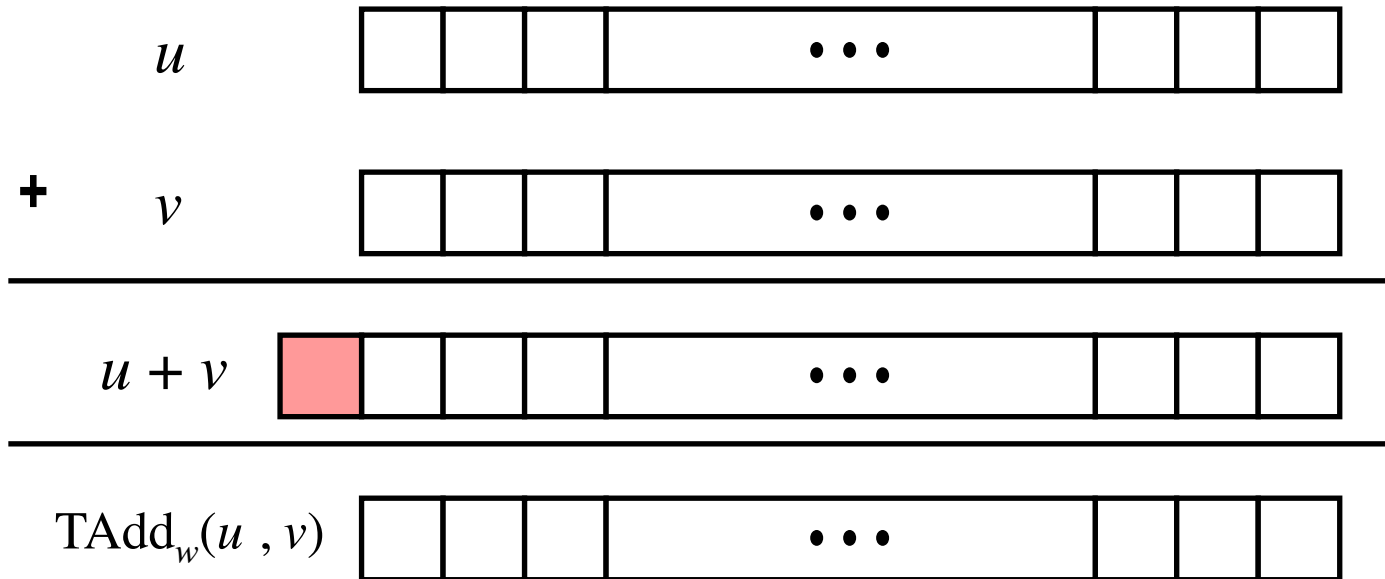
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<code>addq src, dest</code>	$\text{Dest} = \text{Dest} + \text{Src}$	



```
addq %rax, %rbx
```

Some Arithmetic Operations (2 Operands)

Format	Computation	Notes
<code>addq src, dest</code>	$\text{Dest} = \text{Dest} + \text{Src}$	



`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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 - Bit level behaviors for signed and unsigned arithmetic are exactly the same — assuming truncation

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long signed_add
(long x, long y)
{
    long res = x + y;
    return res;
}
```

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

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addq    %rdx, %rax
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```
long unsigned_add  
(unsigned long x, unsigned long y)  
{  
    unsigned long res = x + y;  
    return res;  
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#x in %rdx, y in %rax  
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Some Arithmetic Operations (2 Operands)

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Bit-level

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

```
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(long x, long y)
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(unsigned long x, unsigned long y)
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Bit-level
010
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111

Signed
2
+) -3

-1

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- No distinction between signed and unsigned (why?)
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$$\begin{array}{r} \text{Bit-level} \\ 010 \\ +) 101 \\ \hline 111 \end{array}$$

$$\begin{array}{r} \text{Signed} \\ 2 \\ +) -3 \\ \hline -1 \end{array}$$

$$\begin{array}{r} \text{Unsigned} \\ 2 \\ +) 5 \\ \hline 7 \end{array}$$

```
long signed_add
(long x, long y)
{
    long res = x + y;
    return res;
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long unsigned_add
(unsigned long x, unsigned long y)
{
    unsigned long res = x + y;
    return res;
}
```

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

```
#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

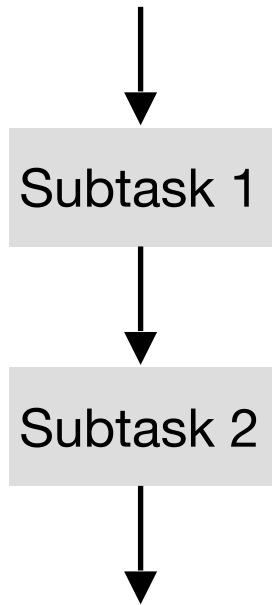
Today: Compute and Control Instructions

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

Three Basic Programming Constructs

Three Basic Programming Constructs

Sequential



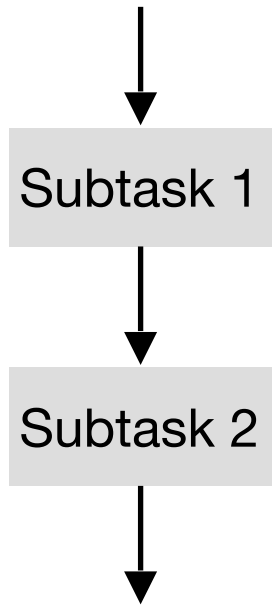
```
a = x + y;
```

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

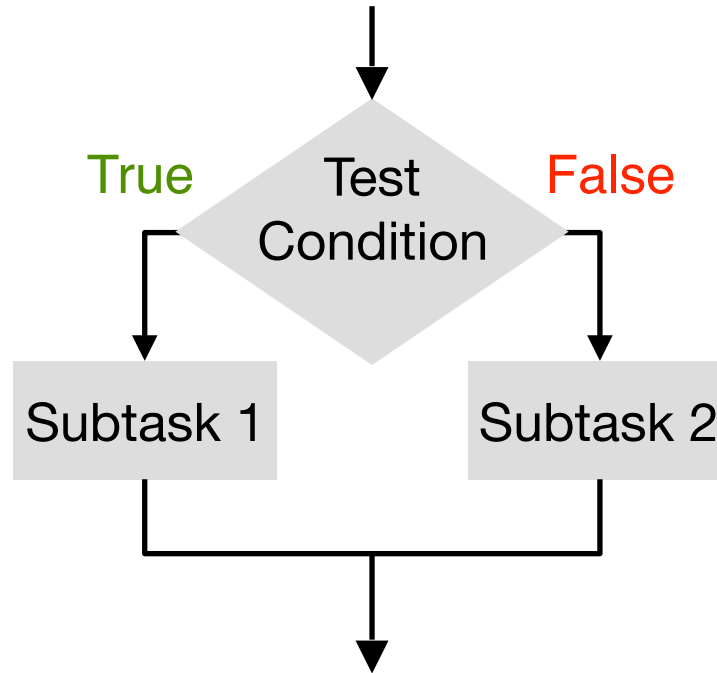
```
...
```

Three Basic Programming Constructs

Sequential



Conditional



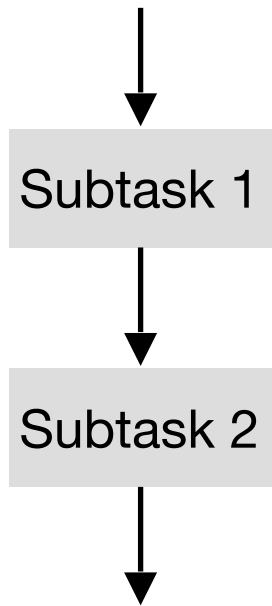
```
a = x + y;  
y = a - c;
```

...

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

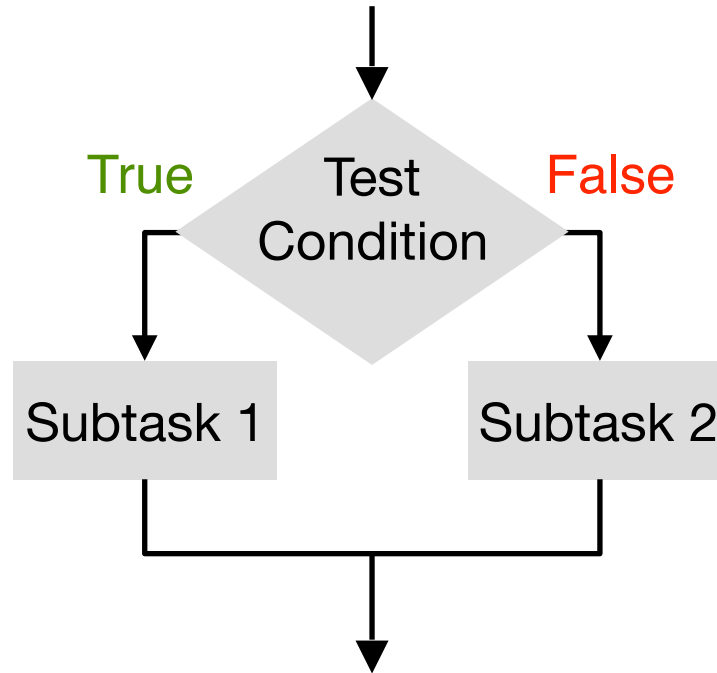
Three Basic Programming Constructs

Sequential



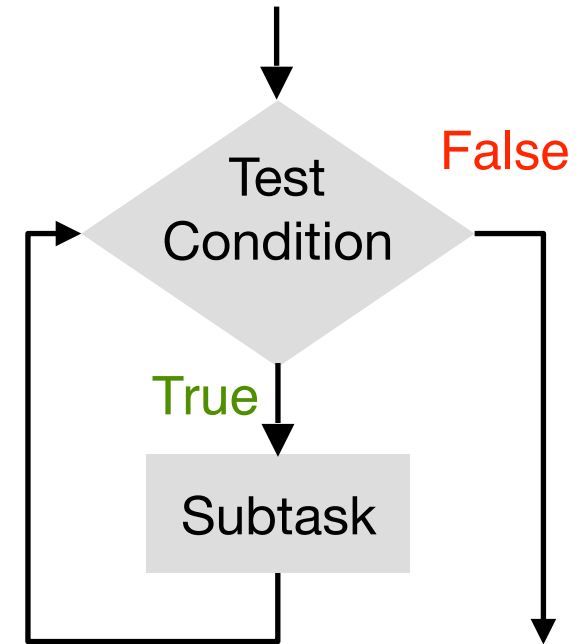
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a = x + y;  
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```

Conditional



```
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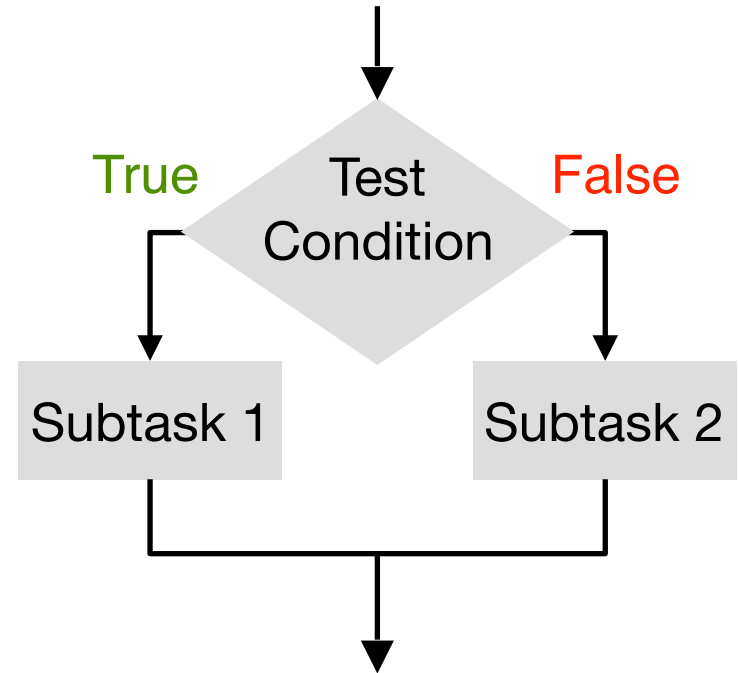
Iterative



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

Three Basic Programming Constructs

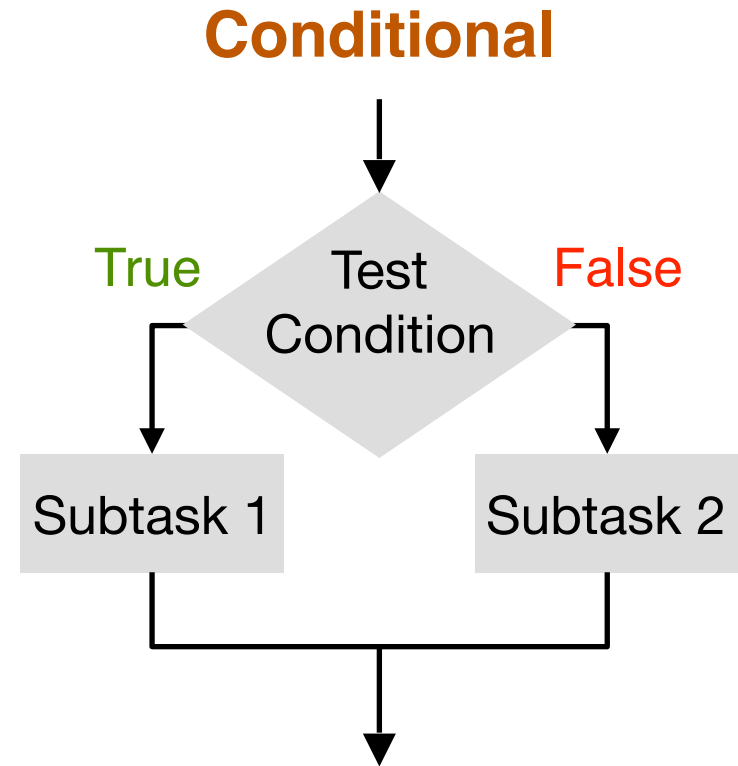
Conditional



```
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```

Three Basic Programming Constructs

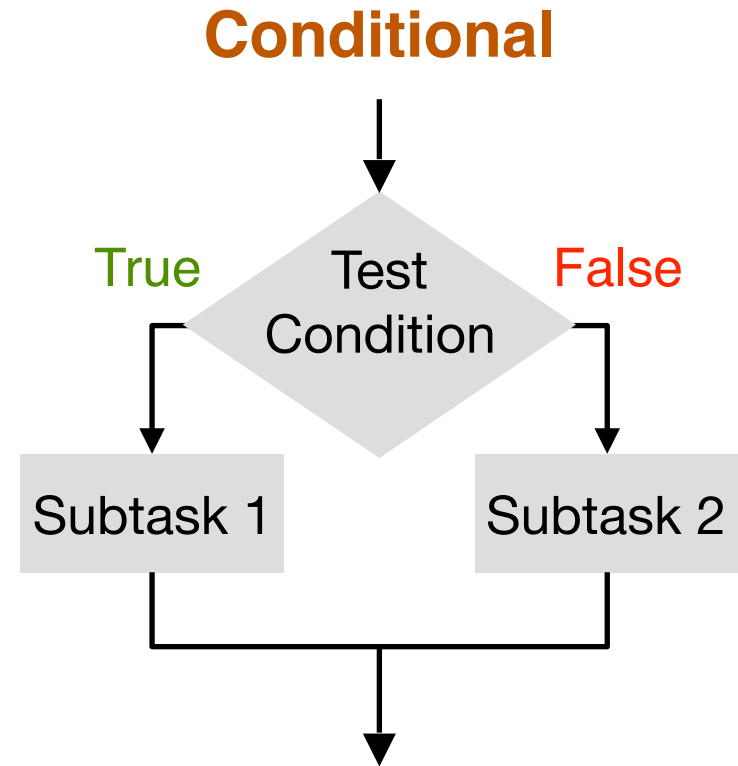
- Both conditional and iterative programming requires altering the sequence of instructions (control flow)



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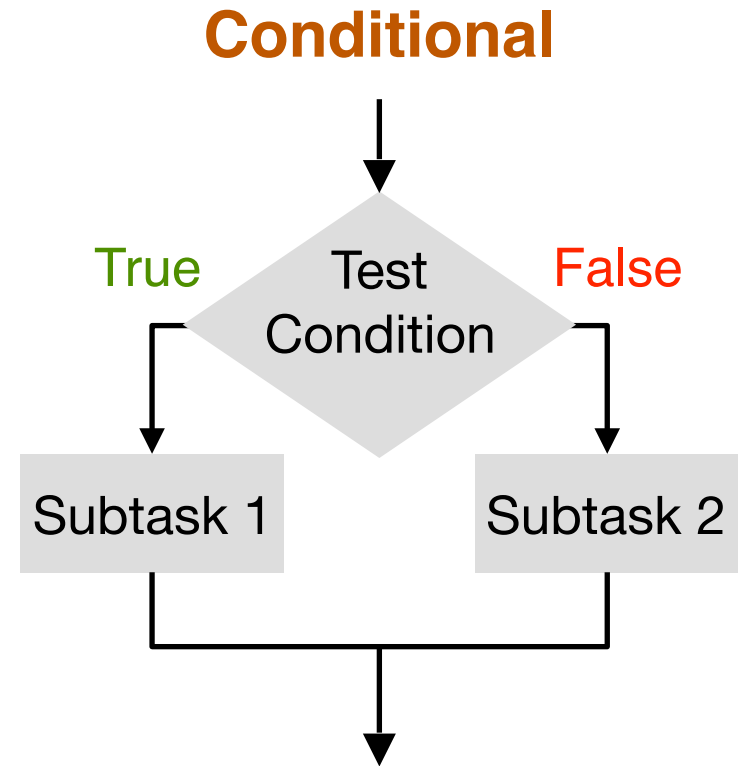
- Both conditional and iterative programming requires altering the sequence of instructions (control flow)
- We need a set of *control instructions* to do so



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



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


Conditional Branch Example

Conditional Branch Example

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

```
absdiff:  
  cmpq    %rsi,%rdi # x:y  
  jle    .L4  
  movq   %rdi,%rax  
  subq   %rsi,%rax  
  ret  
.L4:  
  # x <= y  
  movq   %rsi,%rax  
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Register	Use(s)
%rdi	x
%rsi	y
%rax	Return value

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Labels are symbolic names used to refer to instruction addresses.

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%rdi	x
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Conditional Jump Instruction

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cmpq    %rsi, %rdi  
jle     .L4
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jle     .L4
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Jump to label if less
than or equal to

- Semantics:
 - If `%rdi` is less than or equal to `%rsi` (both interpreted as **signed value**), jump to the part of the code with a label `.L4`

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- `cmpq` instruction sets the condition codes

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 - `jle` reads and checks the **condition codes**

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- Under the hood:
 - `cmpq` instruction sets the condition codes
 - `jle` reads and checks the **condition codes**
 - If condition met, modify the Program Counter to point to the address of the instruction with a label `.L4`

How Should `cmpq` Set Condition Codes?

```
cmpq    %rsi, %rdi
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- Essentially, how do we know `%rdi <= %rsi`?

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ZF Zero Flag (result is zero)



ZF

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No
Overflow

$$\begin{array}{r} 001 \\ -) 010 \\ \hline 111 \end{array} \qquad \begin{array}{r} 1 \\ -) 2 \\ \hline -1 \end{array}$$

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ZF

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No Overflow	001	1
	-) 010	-) 2
	<hr/>	<hr/>
	111	-1
Overflow	101	-3
	-) 011	-) 3
	<hr/>	<hr/>
	010	-6

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How Should `cmpq` Set Condition Codes?

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	-) 010	-) 2
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	<u>010</u>	<u>-6</u>

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How Should `cmpq` Set Condition Codes?

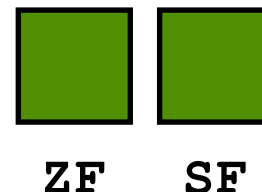
`cmpq` `%rsi, %rdi`

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No Overflow	$\begin{array}{r} 001 \\ -) 010 \\ \hline 111 \end{array}$	$\begin{array}{r} 1 \\ -) 2 \\ \hline -1 \end{array}$
	$\begin{array}{r} 101 \\ -) 011 \\ \hline 010 \end{array}$	$\begin{array}{r} -3 \\ -) 3 \\ \hline -6 \end{array}$

ZF Zero Flag (result is zero)

SF Sign Flag (result is negative)



How Should `cmpq` Set Condition Codes?

`cmpq` `%rsi, %rdi`

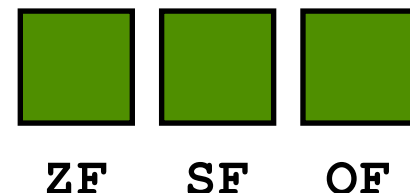
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No Overflow	001	1
	-) 010	-) 2
	<hr/>	<hr/>
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	-) 011	-) 3
	<hr/>	<hr/>
	010	-6

ZF Zero Flag (result is zero)

SF Sign Flag (result is negative)

OF Overflow Flag (result overflow)



How Should `cmpq` Set Condition Codes?

`cmpq` `%rsi, %rdi`

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11111111 10000000
`cmpq 0xFF, 0x80`

- ZF** Zero Flag (result is zero)
- SF** Sign Flag (result is negative)
- OF** Overflow Flag (result overflow)

0	0	0
ZF	SF	OF

How Should `cmpq` Set Condition Codes?

`cmpq %rsi, %rdi`

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10000000	-128
-) 11111111	-) -1
<hr/>	<hr/>
10000001	-127

ZF Zero Flag (result is zero)
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OF Overflow Flag (result overflow)

0	0	0
ZF	SF	OF

How Should `cmpq` Set Condition Codes?

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- `%rdi < %rsi` if and only if: ~~`%rdi - %rsi < 0` (is it correct??)~~
 - `%rdi - %rsi < 0` and the result doesn't overflow, or
 - `%rdi - %rsi > 0` and the result does overflow

- `%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)**

ZF Zero Flag (result is zero)

SF Sign Flag (result is negative)

OF Overflow Flag (result overflow)

0	1	0
ZF	SF	OF

Conditional Branch Example

```
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
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.L4:
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    movq   %rsi,%rax
    subq   %rdi,%rax
    ret
```

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

0 **0** **0**
ZF SF OF

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

cmpq sets ZF, SF, OF

jle checks ZF | (SF ^ OF)

0	0	0
ZF	SF	OF

How Does the Hardware Check Overflow?

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 - So again, just have to check the bits

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Conditional Branch Example

```
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
    movq    %rsi,%rax
    subq    %rdi,%rax
    ret
```

cmpq sets ZF, SF, OF

jle checks ZF | (SF ^ OF)

0	0	0
ZF	SF	OF

Register	Use(s)
%rdi	x
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Conditional Branch Example

```
unsigned long absdiff
(unsigned long x, unsigned
long y)
{
    unsigned 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
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.L4:     # x <= y
    movq   %rsi,%rax
    subq   %rdi,%rax
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```

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

0 **0** **0**
ZF SF OF

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    unsigned long result;
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        result = x-y;
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```
absdiff:
    cmpq    %rsi,%rdi # x:y
    jbe    .L4
    movq   %rdi,%rax
    subq   %rsi,%rax
    ret
.L4:     # x <= y
    movq   %rsi,%rax
    subq   %rdi,%rax
    ret
```

Register	Use(s)
%rdi	x
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ZF SF OF

Conditional Jump Instruction

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cmpq    %rsi, %rdi  
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Jump to label if
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- Semantics of **jbe**:
 - Treat the data in **%rdi** and **%rsi** as **unsigned values**.
 - If **%rdi** is less than or equal to **%rsi**, jump to the part of the code with a label **.L4**

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- Under the hood:

Conditional Jump Instruction

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- Under the hood:
 - `cmpq` instruction sets the condition codes

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 - **cmpq** instruction sets the condition codes
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- Under the hood:
 - **cmpq** instruction sets the condition codes
 - **jbe** reads and checks the condition codes
 - If condition met, modify the Program Counter to point to the address of the instruction with a label **.L4**