x86-64 Programming II

CSE 351 Spring 2024

Instructor:

Elba Garza

Teaching Assistants:

Ellis Haker
Adithi Raghavan
Aman Mohammed
Brenden Page
Celestine Buendia
Chloe Fong
Claire Wang
Hamsa Shankar
Maggie Jiang
Malak Zaki
Naama Amiel
Nikolas McNamee
Shananda Dokka
Stephen Ying
Will Robertson

* An Amendment

Announcements, Reminders

- HW6 due tonight! (10 Apr)
  - HW7 due 15 Apr
  - HW8 due 17 Apr
  - HW 9/10 due 19 Apr
- No reading due for next class! Naama will be instructing!
- Lab 1b due 15 Apr by 11:59 PM
- Lab 2 releasing 12 Apr; due 26 Apr

Lab Extras

- All labs starting with Lab 2 have extra "components"
  - These are meant to be **fun extensions to the labs**

We're serious!

- Extra components aren't graded, nor do we expect you to do them
  - Make sure you finish the lab before even attempting any extra component

Last Time: Practice Question

- Which of the following are valid implementations of `rcx = rax + rbx`?

  - ```
    addq %rax, %rcx
    addq %rbx, %rcx
    ```
    rcx = rcx + rax + rbx

  - ```
    movq %rax, %rcx
    addq %rbx, %rcx
    ```

  - ```
    movq $0, %rcx
    addq %rbx, %rcx
    addq %rax, %rcx
    ```

  - ```
    xorq %rax, %rax
    addq %rax, %rcx
    addq %rbx, %rcx
    ```
    zero'd out!

    rcx = rcx + 0 + rbx

Arithmetic Example

Register	Use(s)
%rdi	1st argument (x)
%rsi	2nd argument (y)
%rax	return value

```
long simple_arith(long x, long y)
{
  long t1 = x + y;
  long t2 = t1 * 3;
  return t2;
}
```

```
y += x;
y *= 3;
long r = y;
return r;
```

Compiler Optimization & Generation

Bless our compiler overlords ♡

```
simple_arith:
  addq    %rdi, %rsi
  imulq     $3, %rsi
  movq    %rsi, %rax
  ret
```

Example of Basic Addressing Modes

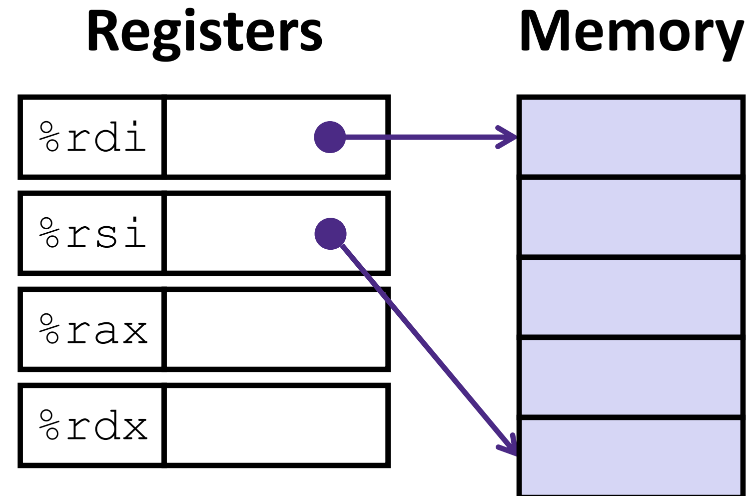
```
void swap(long* xp, long* yp)
{
  long t0 = *xp;
  long t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

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

Compiler Explorer:
https://godbolt.org/z/8sMcnasjx

Understanding `swap()`

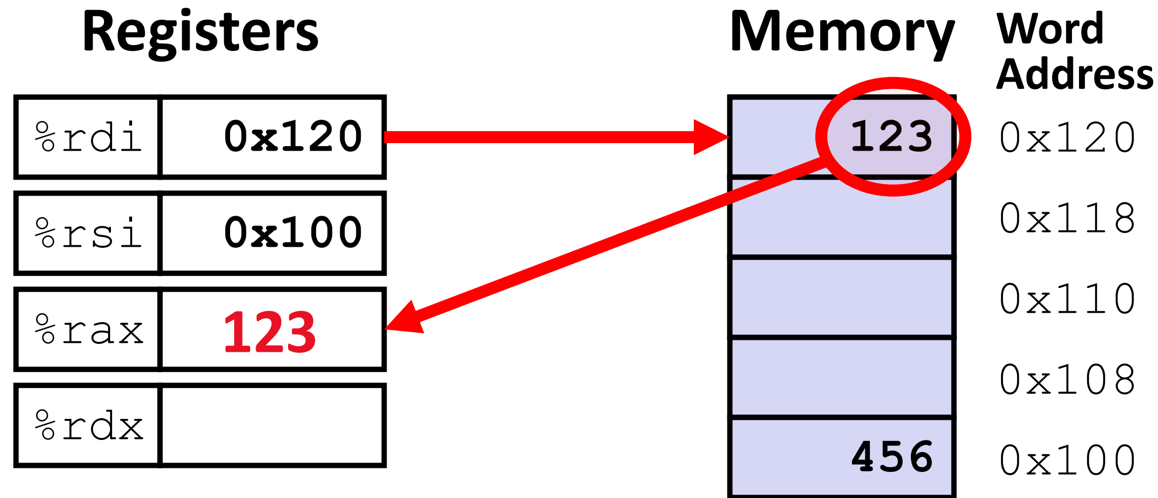
```
void swap(long* xp, long* yp)
{
  long t0 = *xp;
  long t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```




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

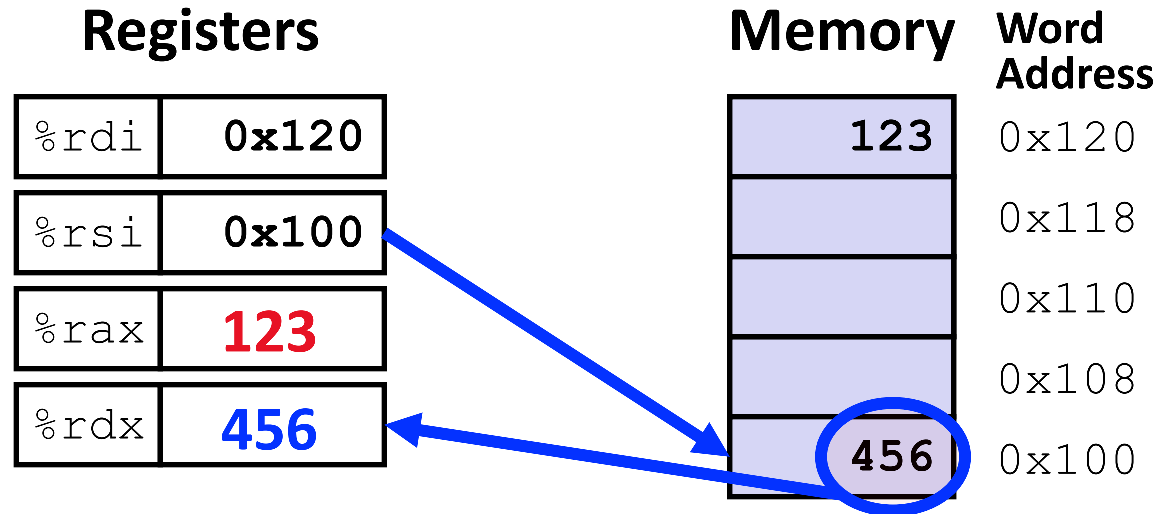
Register		Variable
%rdi	⇔	xp
%rsi	⇔	yp
%rax	⇔	t0
%rdx	⇔	t1

Understanding swap()



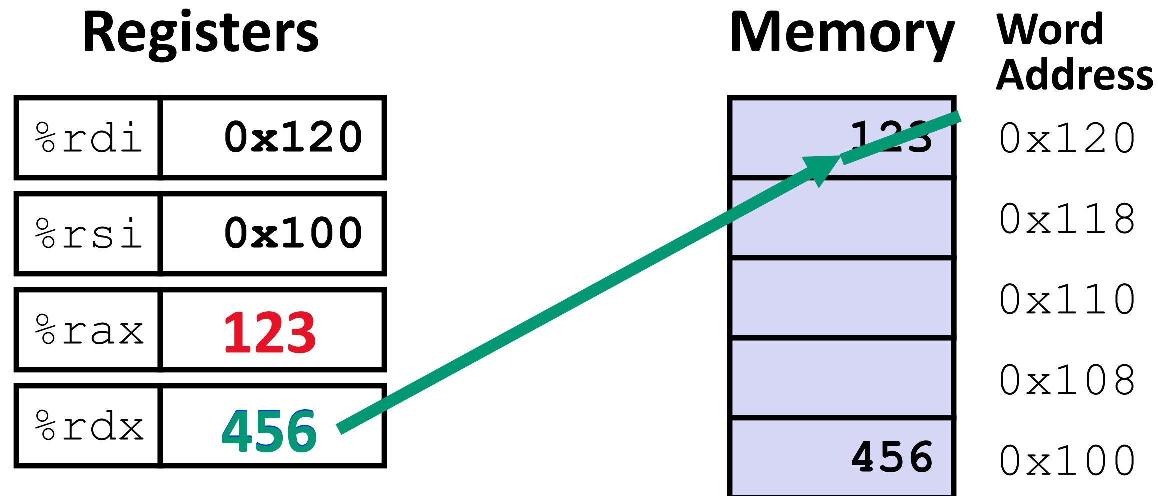

```
swap:
1 movq   (%rdi), %rax   #  t0 = *xp
  movq   (%rsi), %rdx   #  t1 = *yp
  movq   %rdx, (%rdi)   # *xp =  t1
  movq   %rax, (%rsi)   # *yp =  t0
  ret
```

Understanding `swap()`



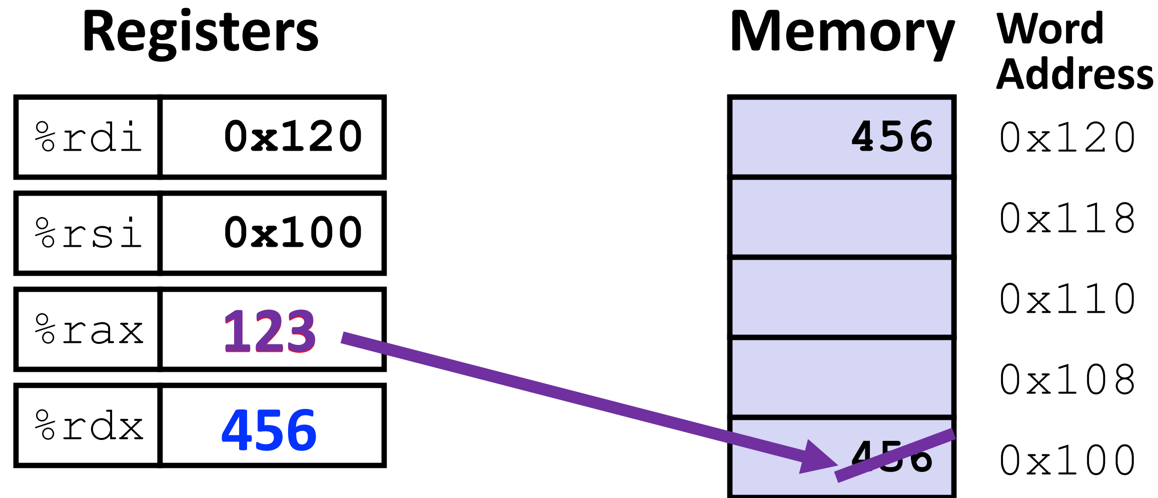

```
swap:
  1 movq   (%rdi), %rax   #  t0 = *xp
  2 movq   (%rsi), %rdx   #  t1 = *yp
    movq   %rdx, (%rdi)   # *xp =  t1
    movq   %rax, (%rsi)   # *yp =  t0
    ret
```

Understanding swap()




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

Understanding `swap()`




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

Understanding swap()

Registers

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

Memory

Memory	Word Address
456	0x120
	0x118
	0x110
	0x108
123	0x100

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

Complete Memory Addressing Modes

- **General:**

  `D(Rb,Ri,S)` ➔ Mem[Reg[Rb]+Reg[Ri]*S+D]

  - **Rb**: Base register (any register)
  - **Ri**: Index register (any register except `%rsp`)
  - **S**: Scale factor (1, 2, 4, 8) **– why these numbers?**
  - **D**: Constant displacement value (a.k.a. immediate)

- **Special cases** (see CSPP Figure 3.3 on p.181) *Implies*

		Implies
`D(Rb,Ri)`	Mem[Reg[Rb]+Reg[Ri]+D]	`(S=1)`
`(Rb,Ri,S)`	Mem[Reg[Rb]+Reg[Ri]*S]	`(D=0)`
`(Rb,Ri)`	Mem[Reg[Rb]+Reg[Ri]]	`(S=1,D=0)`
`(,Ri,S)`	Mem[Reg[Ri]*S]	`(Rb=0,D=0)`

Address Computation Examples

%rdx	0xf000
%rcx	0x0100

D(Rb,Ri,S) → Mem[Reg[Rb]+Reg[Ri]*S+D]

we'll ignore the actual memory access for now

Expression	Address Computation	Address (8 bytes wide)
0x8(%rdx)	%rdx + 0x8	0xf008
(%rdx,%rcx)	%rdx + %rcx	0xf100
(%rdx,%rcx,4)	%rdx + %rcx * 4	0xf400
0x80(,%rdx,2)	%rdx * 4 + 0x80	0x1e080

Reading Review

- Terminology:
  - Address Computation Instruction (`lea`)
  - Condition codes: Carry Flag (`CF`), Zero Flag (`ZF`), Sign Flag (`SF`), and Overflow Flag (`OF`)
  - Test (`test`) and compare (`cmp`) assembly instructions
  - Jump (`j*`) and set (`set*`) families of assembly instructions

Review Questions

D(Rb,Ri,S) ➔ Mem[Reg[Rb]+Reg[Ri]*S+D]

- Which of the following x86-64 instructions correctly calculates: `%rax=9*%rdi`

A. `leaq (,%rdi,9), %rax`
B. `movq (,%rdi,9), %rax`
C. `leaq (%rdi,%rdi,8), %rax`
D. `movq (%rdi,%rdi,8), %rax`

can't be an S value!

∴ (rdi + rdi * 8) ⟶ rax

- If `%rsi` is `0x B0BA CAFE 1EE7 F00D`, what is its value after executing **`movswl %si, %esi`**?

Address Computation Instruction

- `leaq src, dst`
  - `"lea"` stands for load effective address
  - `src` is address expression (any of the formats we've seen)
  - `dst` is a register
  - Sets `dst` to the **address** computed by the `src` expression

    Does **not** go to memory! – it just does math!
  - Example: `leaq (%rdx,%rcx,4), %rax`
- Uses:
  - Computing addresses without a memory reference
    - *e.g.*, translation of `p = &x[i];`
  - Computing arithmetic expressions of the form `x+k*i+d`
    - Though `k` can only be 1, 2, 4, or 8

Example: lea vs. mov

Registers

%rax	0x110
%rbx	
%rcx	0x4
%rdx	0x100
%rdi	
%rsi	

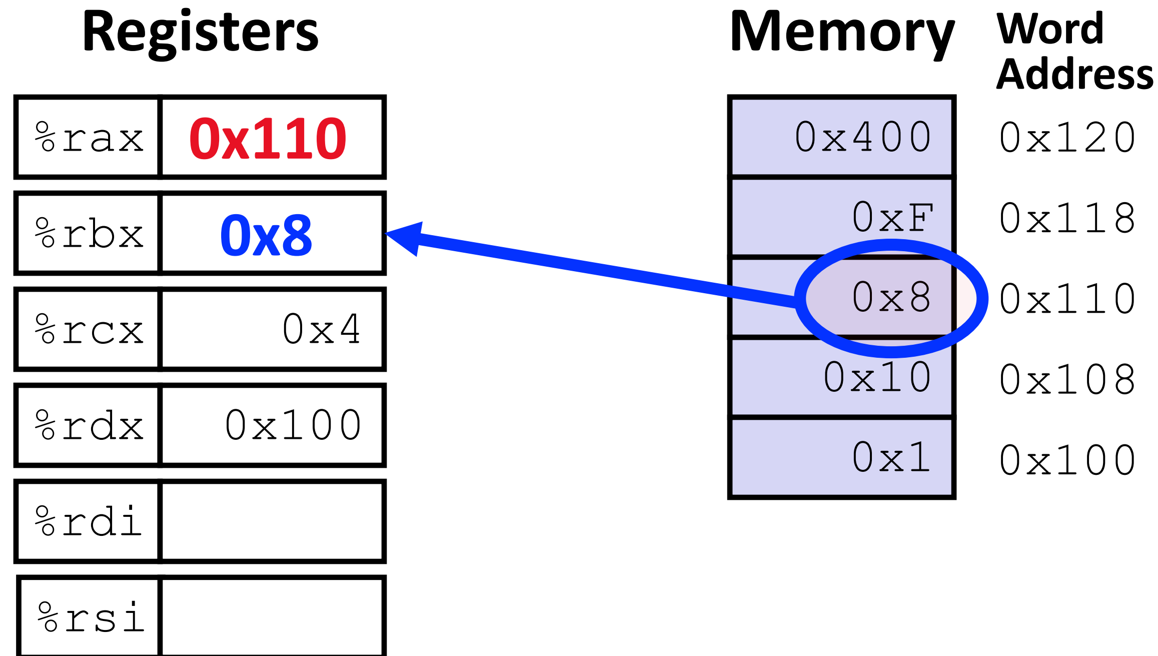
Memory	Word Address
0x400	0x120
0xF	0x118
0x8	0x110
0x10	0x108
0x1	0x100

1

```
leaq (%rdx,%rcx,4), %rax
movq (%rdx,%rcx,4), %rbx
leaq (%rdx), %rdi
movq (%rdx), %rsi
```

0x100 + 0x4 * 4 = 0x110

Example: `lea` vs. `mov`




```
1 leaq (%rdx,%rcx,4), %rax
2 movq (%rdx,%rcx,4), %rbx
  leaq (%rdx), %rdi
  movq (%rdx), %rsi
```

0x100 + 0x4 * 4 = 0x110

Example: `lea` vs. `mov`

Registers

Register	Value
%rax	0x110
%rbx	0x8
%rcx	0x4
%rdx	0x100
%rdi	
%rsi	

Memory

Memory	Word Address
0x400	0x120
0xF	0x118
0x8	0x110
0x10	0x108
0x1	0x100

```
1 leaq (%rdx,%rcx,4), %rax
2 movq (%rdx,%rcx,4), %rbx
3 leaq (%rdx), %rdi
  movq (%rdx), %rsi
```

Example: `lea` vs. `mov`

Registers

Register	Value
%rax	0x110
%rbx	0x8
%rcx	0x4
%rdx	0x100
%rdi	0x100
%rsi	0x1

Memory

Memory	Word Address
0x400	0x120
0xF	0x118
0x8	0x110
0x10	0x108
0x1	0x100

```
1 leaq (%rdx,%rcx,4), %rax
2 movq (%rdx,%rcx,4), %rbx
3 leaq (%rdx), %rdi
4 movq (%rdx), %rsi
```

Example: lea vs. mov

Registers

%rax	0x110
%rbx	0x8
%rcx	0x4
%rdx	0x100
%rdi	0x100
%rsi	0x1

Memory	Word Address
0x400	0x120
0xF	0x118
0x8	0x110
0x10	0x108
0x1	0x100

```
1 leaq (%rdx,%rcx,4), %rax
2 movq (%rdx,%rcx,4), %rbx
3 leaq (%rdx), %rdi
4 movq (%rdx), %rsi
```

lea used for Arithmetic

```
long arith(long x, long y, long z)
{
  long t1 = x + y;
  long t2 = z + t1;
  long t3 = x + 4;
  long t4 = y * 48;
  long t5 = t3 + t4;
  long rval = t2 * t5;
  return rval;
}
```

```
arith:
  leaq    (%rdi,%rsi), %rax
  addq    %rdx, %rax
  leaq    (%rsi,%rsi,2), %rdx
  salq    $4, %rdx
  leaq    4(%rdi,%rdx), %rcx
  imulq   %rcx, %rax
  ret
```

Register	Use(s)
`%rdi`	1st argument (`x`)
`%rsi`	2nd argument (`y`)
`%rdx`	3rd argument (`z`)

Rather than using multiplication, use `lea` and shifting!

- Interesting Instructions
  - `leaq`: “address” computation
  - `salq`: shift
  - `imulq`: multiplication—only used once!

lea used for Arithmetic

Register	Use(s)
%rdi	x
%rsi	y
%rdx	z, t4
%rax	t1, t2, rval
%rcx	t5

```
long arith(long x, long y, long z)
{
  long t1 = x + y;
  long t2 = z + t1;
  long t3 = x + 4;
  long t4 = y * 48;
  long t5 = t3 + t4;
  long rval = t2 * t5;
  return rval;
}
```

```
arith:
  leaq    (%rdi,%rsi), %rax     # rax/t1   = x + y
  addq    %rdx, %rax            # rax/t2   = t1 + z
  leaq    (%rsi,%rsi,2), %rdx   # rdx      = 3 * y
  salq    $4, %rdx              # rdx/t4   = (3*y) * 16
  leaq    4(%rdi,%rdx), %rcx    # rcx/t5   = x + t4 + 4
  imulq   %rcx, %rax            # rax/rval = t5 * t2
  ret
```

Move extension: movz and movs

```
movz__ src, regDest      # Move with zero extension
movs__ src, regDest      # Move with sign extension
```

- Copy from a smaller source value to a larger destination
- Source can be memory or register; but Destination must be a register
- Fill remaining bits of dest with **zero** (movz) or **sign bit** (movs)

movzsd / movssd:

s – size of source (**b** = 1 byte, **w** = 2, **l** = 4)

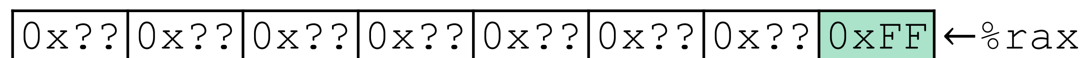
d – size of destination (**w** = 2 bytes, **l** = 4, **q** = 8)

'l' for 'lower' byte

Example:

```
movzbq %al, %rbx
```

al



Move extension: `movz` and `movs`

```
movz__  src, regDest     # Move with zero extension
movs__  src, regDest     # Move with sign extension
```

- Copy from a smaller source value to a larger destination
- Source can be memory or register; but Destination must be a register
- Fill remaining bits of dest with **zero** (`movz`) or **sign bit** (`movs`)

Note: In x86-64, any instruction that generates a 32-bit (long word) value for a register **also** sets the high-order portion of the register to 0. Also the reason why **`movzlq`** is not defined! Good example on p. 184 in the textbook.

`movzsd` / `movssd`:

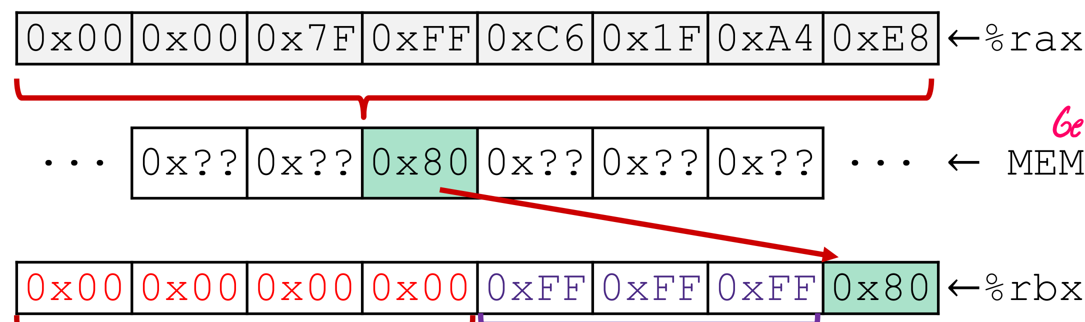
s – size of source (**b** = 1 byte, **w** = 2, **l** = 4)

d – size of destination (**w** = 2 bytes, **l** = 4, **q** = 8)

Example:

```
movsbl (%rax), %ebx
```

Copy 1 byte from memory into 8-byte register & sign extend it!



Summary

- **Memory Addressing Modes:** The addresses used for accessing memory in `mov` (and other) instructions can be computed in several different ways
  - *Base register*, *index register*, *scale factor*, and *displacement* map well to pointer arithmetic operations
- Control flow in x86 determined by Condition Codes