x86-64 Programming II

CSE 351 Spring 2020

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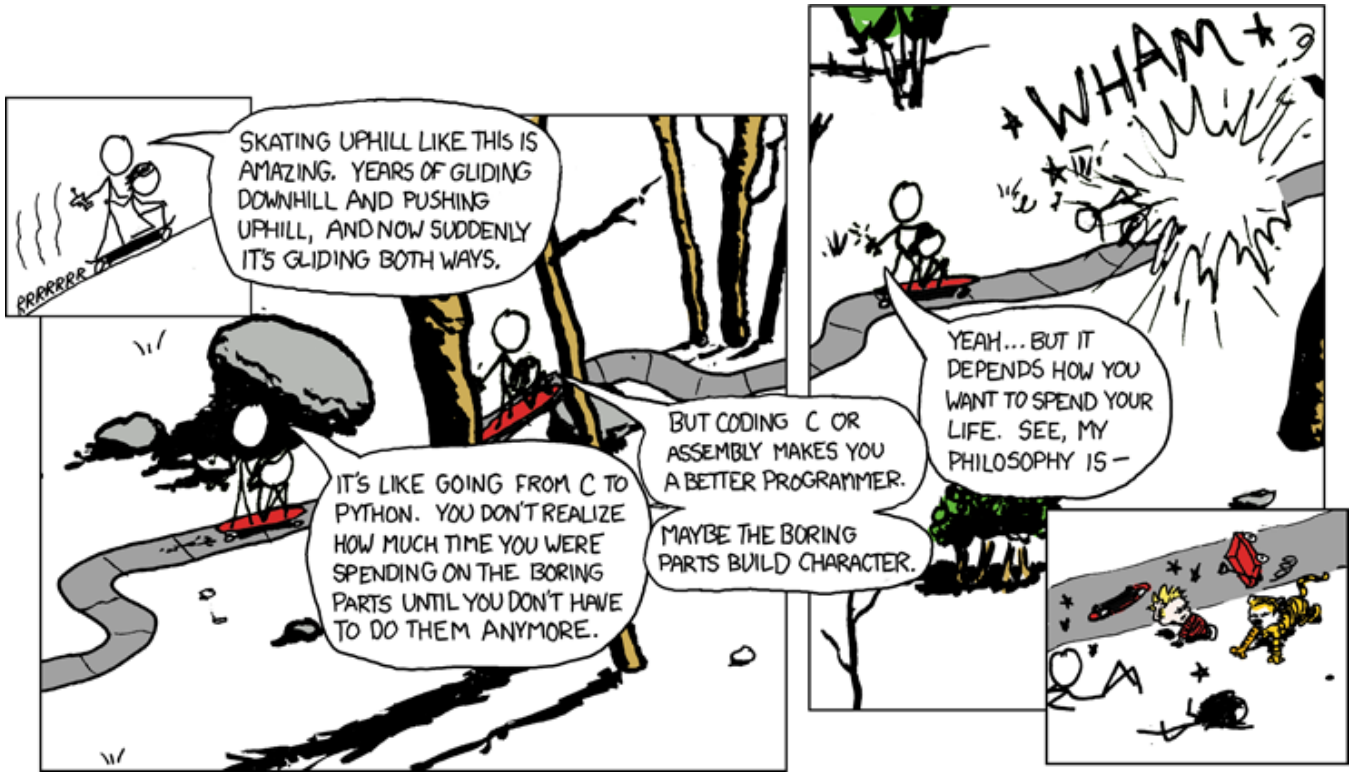


http://xkcd.com/409/

Administrivia

- hw8 due Monday – 11am
- Lab 1b due Monday (4/20)
  - Submit `bits.c` and `lab1Breflect.txt`
  - Submissions that fail the autograder get a **ZERO**
    - No excuses – make full use of tools & Gradescope's interface
- Lab 2 (x86-64) coming soon
  - Learn to read x86-64 assembly and use GDB

- **You must log on with your @uw google account to access!!**
  - **Google doc** for 11:30 Lecture: https://tinyurl.com/351-04-17A
  - **Google doc** for 2:30 Lecture: https://tinyurl.com/351-04-17B

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	0x8
%rcx	0x4
%rdx	0x100
%rdi	0x100
%rsi	0x1

Memory

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

0x110

0x10

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

`lea` – "It just does math"

Arithmetic Example

```
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;
}
```

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

```
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
```

- Interesting Instructions
  - leaq: "address" computation
  - salq: shift
  - imulq: multiplication
    - Only used once!

Arithmetic Example

```
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;
}
```

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

```
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
```

Polling Question [Asm II – a]

- Which of the following x86-64 instructions correctly calculates `%rax = 9 * %rdi`?
  - Vote at http://pollev.com/rea

A. `leaq (,%rdi,9), %rax` — S ∈ {1,2,4,8}
B. `movq (,%rdi,9), %rax`
C. `leaq (%rdi,%rdi,8), %rax` → %rax = 9 * %rdi
D. `movq (%rdi,%rdi,8), %rax` → %rax = *(9 * %rdi)
E. We're lost…

Control Flow

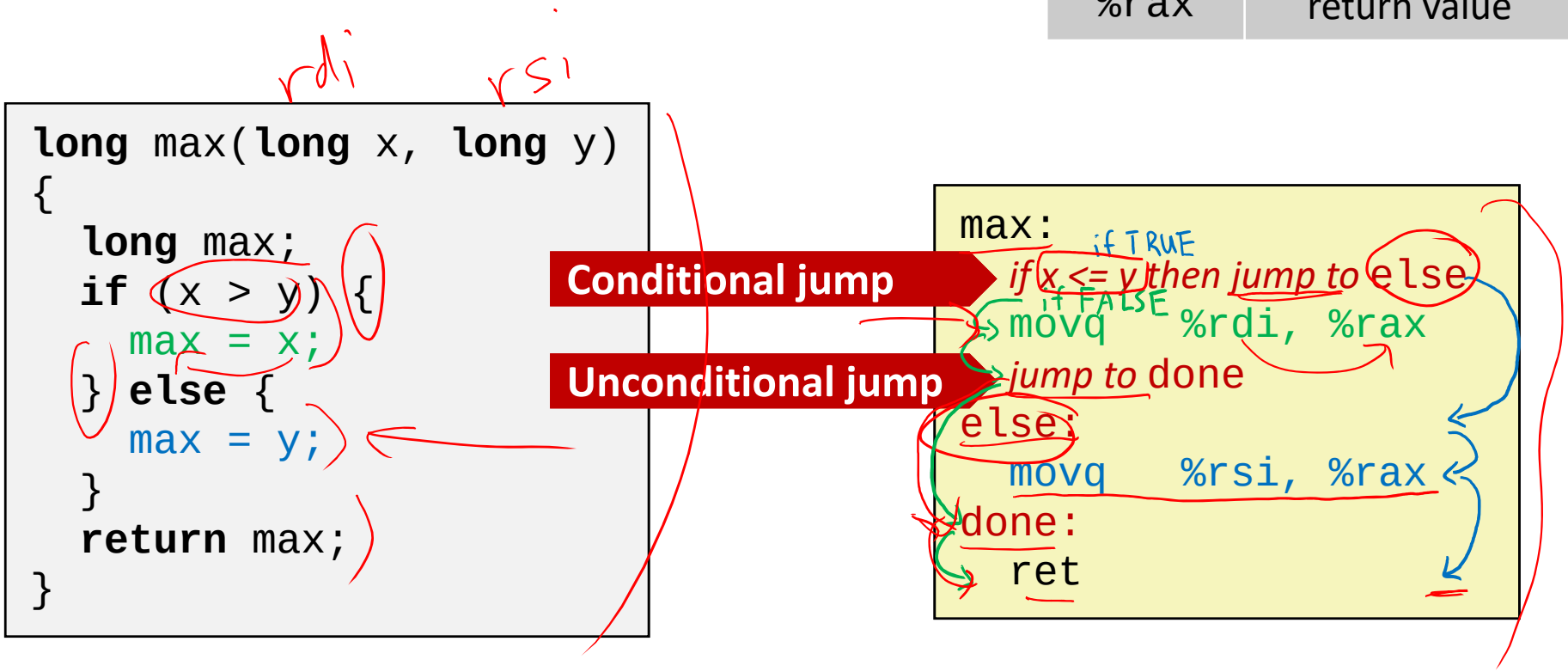
Register	Use(s)
%rdi	1st argument (x)
%rsi	2nd argument (y)
%rax	return value

```
long max(long x, long y)
{
  long max;
  if (x > y) {
    max = x;
  } else {
    max = y;
  }
  return max;
}
```

```
max:
  ???
  movq   %rdi, %rax
  ???
  ???
  movq   %rsi, %rax
  ???
  ret
```

Control Flow

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



Conditionals and Control Flow

- Conditional branch/*jump*
  - Jump to somewhere else if some *condition* is true, otherwise execute next instruction
- Unconditional branch/*jump*
  - *Always* jump when you get to this instruction

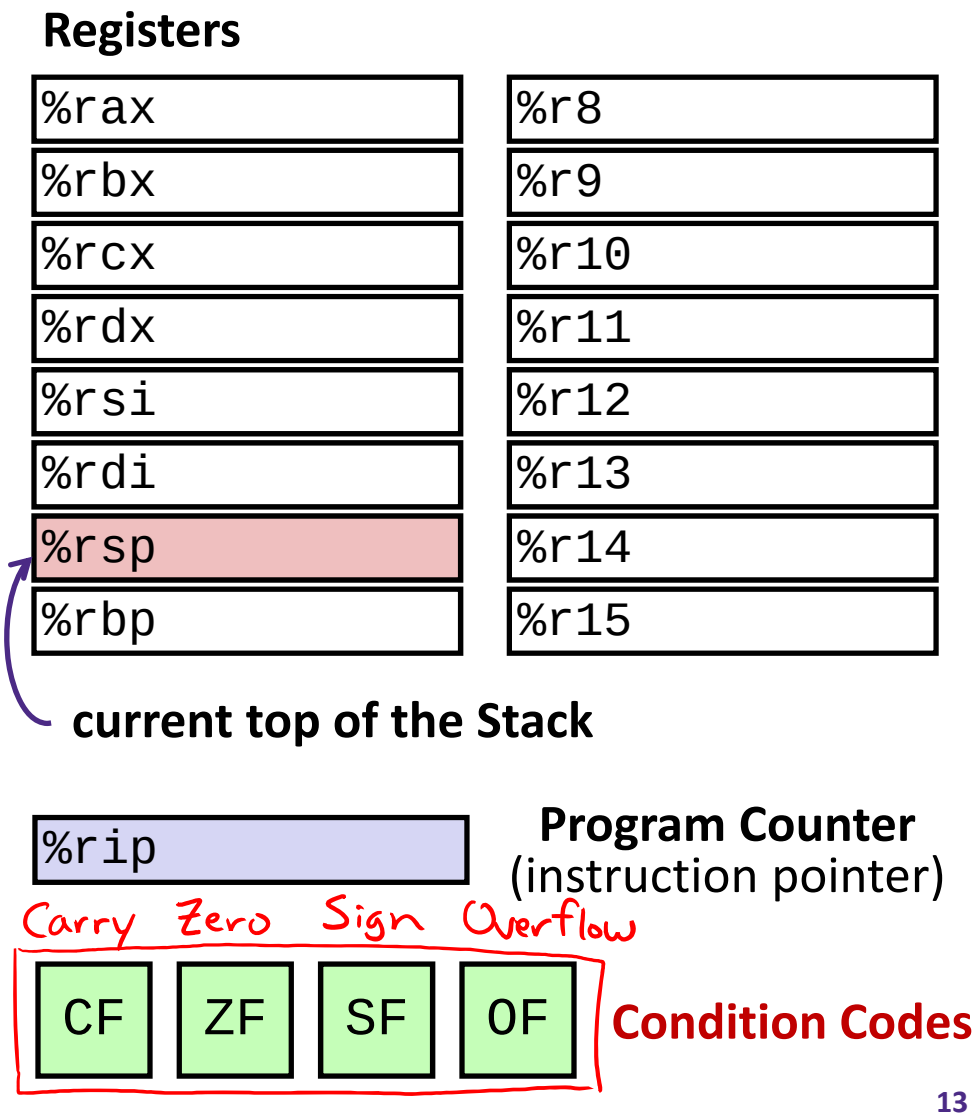
- Together, they can implement most control flow constructs in high-level languages:
  - **`if`** (*condition*) **`then`** {…} **`else`** {…}
  - **`while`** (*condition*) {…}
  - **`do`** {…} **`while`** (*condition*)
  - **`for`** (*initialization*; *condition*; *iterative*) {…}
  - **`switch`** {…}

x86 Control Flow

- **Condition codes**
- **Conditional and unconditional branches**
- Loops
- Switches

Processor State (x86-64, partial)

- Information about currently executing program
  - Temporary data (`%rax`, …)
  - Location of runtime stack (`%rsp`)
  - Location of current code control point (`%rip`, …)
  - Status of recent tests (**CF**, **ZF**, **SF**, **OF**) "flags"
    - Single bit registers:



Condition Codes (Implicit Setting)

- *Implicitly* set by **arithmetic** operations
  - (think of it as side effects)
  - Example: **addq** `src, dst` ↔ `r = d+s`

- **CF=1** if carry out from MSB (*unsigned* overflow)
- **ZF=1** if `r==0`
- **SF=1** if `r<0` (if MSB is 1)
- **OF=1** if *signed* overflow

```
(s>0 && d>0 && r<0)||(s<0 && d<0 && r>=0)
```

- *Not* set by `lea` instruction (beware!)

CF	*Carry Flag*	ZF	*Zero Flag*	SF	*Sign Flag*	OF	*Overflow Flag*

Condition Codes (Explicit Setting: Compare)

- *Explicitly* set by **Compare** instruction
  - **cmpq** `src1, src2` like subq a, b → b - a
  - **cmpq** `a, b` sets flags based on `b-a`, but doesn't store the result

  - **CF=1** if carry out from MSB (good for *unsigned* comparison)
  - **ZF=1** if `a==b` (b-a==0)
  - **SF=1** if `(b-a)<0` (if MSB is 1)
  - **OF=1** if *signed* overflow

```
(a>0 && b<0 && (b-a)>0) ||
(a<0 && b>0 && (b-a)<0)
```

Condition Codes (Explicit Setting: Test)

- *Explicitly* set by **Test** instruction
  - **`testq`** `src2, src1` like andq a, b
  - **`testq`** `a, b` sets flags based on a&b, but doesn't store the result
    - Useful to have one of the operands be a ***mask***
  - Can't have carry out (**CF**) or overflow (**OF**) = 0 = 0
  - **ZF=1** if `a&b==0`
  - **SF=1** if `a&b<0` (signed)

CF	*Carry Flag*	ZF	*Zero Flag*	SF	*Sign Flag*	OF	*Overflow Flag*

Using Condition Codes: Jumping

- `j*` Instructions
  - Jumps to ***target*** (an address) based on condition codes

don't worry about the details

Instruction	Condition	Description (always compared to 0)
`jmp` *target*	1	Unconditional
`je` *target*	ZF	Equal / Zero
`jne` *target*	~ZF	Not Equal / Not Zero
`js` *target*	SF	Negative
`jns` *target*	~SF	Nonnegative
`jg` *target*	~(SF^OF)&~ZF	Greater (Signed)
`jge` *target*	~(SF^OF)	Greater or Equal (Signed)
`jl` *target*	(SF^OF)	Less (Signed)
`jle` *target*	(SF^OF)|ZF	Less or Equal (Signed)
`ja` *target*	~CF&~ZF	Above (unsigned “>”)
`jb` *target*	CF	Below (unsigned “<“)

Using Condition Codes: Setting

- `set*` Instructions
  - Set low-order byte of `dst` to 0 or 1 based on condition codes
  - Does not alter remaining 7 bytes

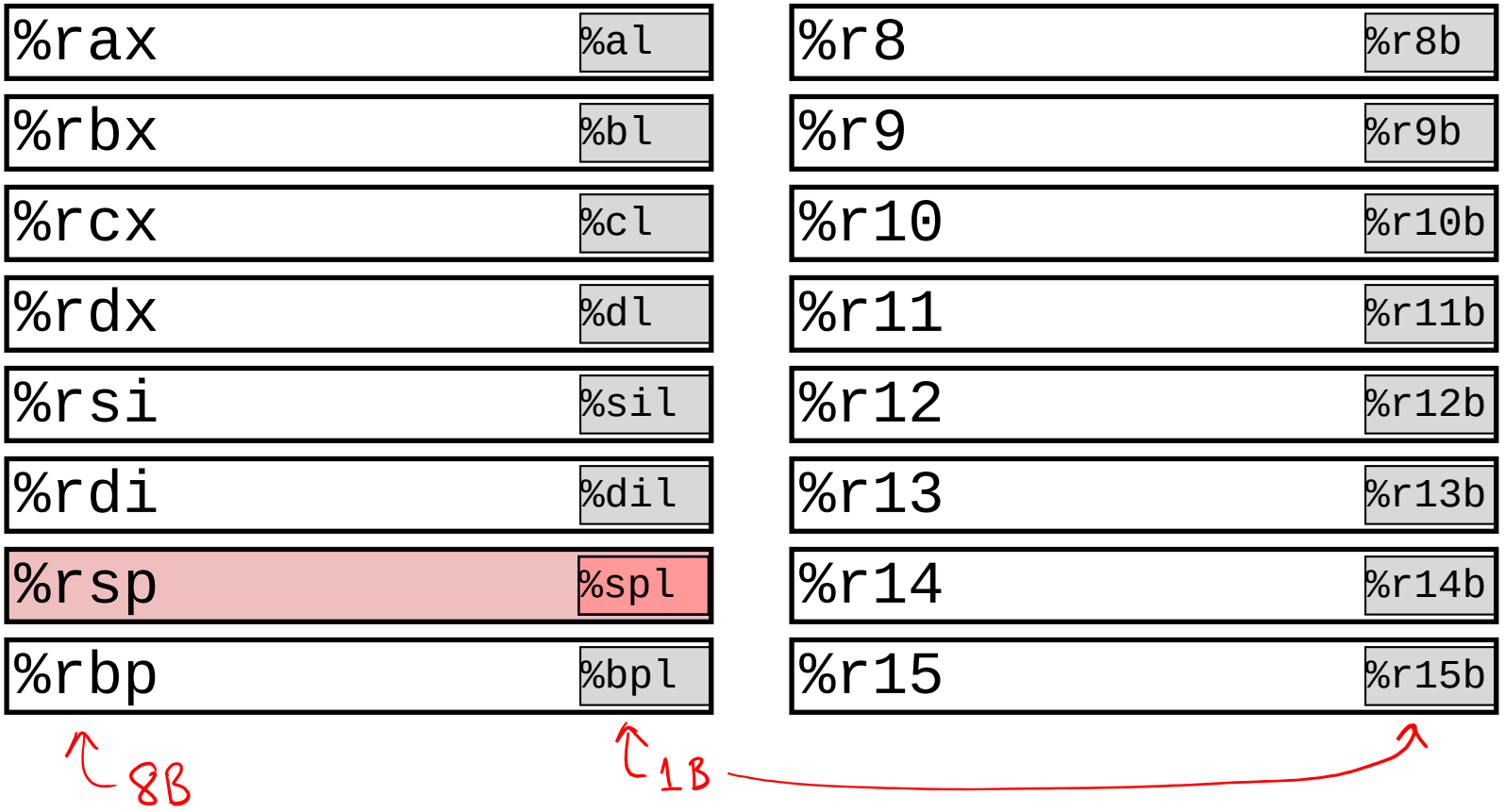
False → 0b 0000 0000 = 0x 00
True → 0b 0000 0001 = 0x 01

same instruction suffixes as j* instructions!

Instruction	Condition	Description
sete *dst*	ZF	Equal / Zero
setne *dst*	~ZF	Not Equal / Not Zero
sets *dst*	SF	Negative
setns *dst*	~SF	Nonnegative
setg *dst*	~(SF^OF)&~ZF	Greater (Signed)
setge *dst*	~(SF^OF)	Greater or Equal (Signed)
setl *dst*	(SF^OF)	Less (Signed)
setle *dst*	(SF^OF)|ZF	Less or Equal (Signed)
seta *dst*	~CF&~ZF	Above (unsigned “>”)
setb *dst*	CF	Below (unsigned “<”)

Reminder: x86-64 Integer Registers

- Accessing the low-order byte:



Reading Condition Codes

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

- `set*` Instructions (e, ne, g, l, ...)
  - Set a low-order byte to 0 or 1 based on condition codes
  - Operand is byte register (e.g. `al`, `dl`) or a byte in memory
  - Do not alter remaining bytes in register
    - Typically use `movzbl` (zero-extended `mov`) to finish job

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

// x - y > 0

```
cmpq    %rsi, %rdi    # set flags based on x-y
setg    %al           # %al = (x>y)
movzbl  %al, %eax     # %rax = (x>y)
ret
```

a(y), b(x)

zero-extend

← lowest byte

← whole register

Reading Condition Codes

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

- `set*` Instructions
  - Set a low-order byte to 0 or 1 based on condition codes
  - Operand is byte register (e.g. `al`, `dl`) or a byte in memory
  - Do not alter remaining bytes in register
    - Typically use `movzbl` (zero-extended `mov`) to finish job

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

```
cmpq    %rsi, %rdi    # Compare x:y
setg    %al           # Set when >
movzbl  %al, %eax     # Zero rest of %rax
ret
```

Set cmA codes based on: x - y x - y > 0 x > y

Aside: movz and movs

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

2 width specifiers: b, w, l, q (1 2 4 8 bytes)

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

movz*SD* / movs*SD*:

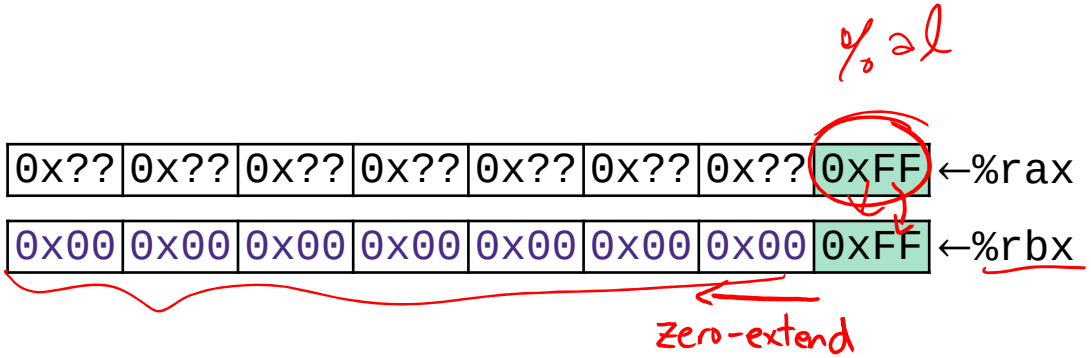
S – size of source (**b** = 1 byte, **w** = 2)

D – size of dest (**w** = 2 bytes, **l** = 4, **q** = 8)

Example:

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

zero-extend; 1 byte; 8 bytes



Aside: 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; 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)

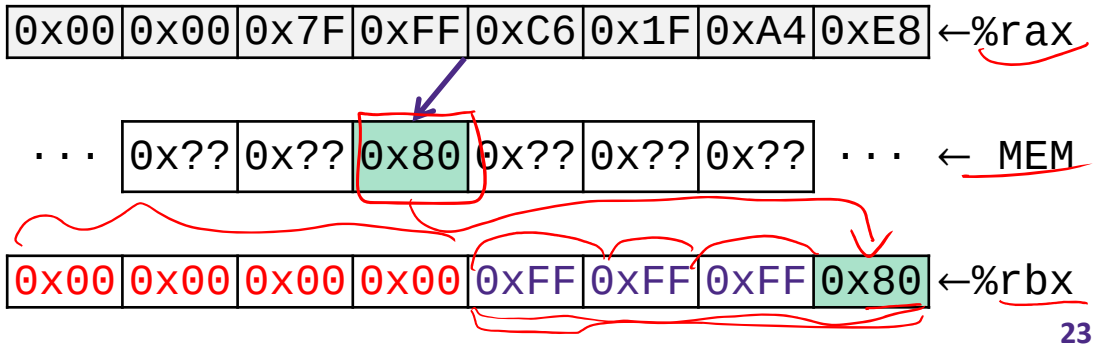
D – size of dest (**`w`** = 2 bytes, **`l`** = 4, **`q`** = 8)

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. Good example on p. 184 in the textbook.

Example:

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

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



Summary

- Control flow in x86 determined by status of Condition Codes
  - Showed **C**arry, **Z**ero, **S**ign, and **O**verflow, though others exist
  - Set flags with arithmetic instructions (implicit) or Compare and Test (explicit)
  - Set instructions read out flag values
  - Jump instructions use flag values to determine next instruction to execute