x86-64 Programming II

CSE 351 Spring 2022

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http://xkcd.com/99/

Relevant Course Information

- hw7 due TONIGHT (4/15) @ 11:59 pm
- Lab 1b, due Monday 4/18
  - Submit `aisle_manager.c`, `store_client.c`, and `lab1Bsynthesis.txt`
- Lab 2 (x86-64) coming soon!
  - Learn to read x86-64 assembly and use GDB
- Midterm:
  - Released Mon 5/2 11:59pm, due Wed 5/4 11:59pm
  - Take home, Individual but some discussion permitted
  - More details later

Extra Credit

- All labs starting with Lab 2 have extra credit portions
  - These are meant to be fun extensions to the labs

- Extra credit points *don't* affect your lab grades
  - From the course policies: "they will be accumulated over the course and will be used to bump up borderline grades at the end of the quarter."
  - Make sure you finish the rest of the lab before attempting any extra credit

Example of Basic Addressing Modes

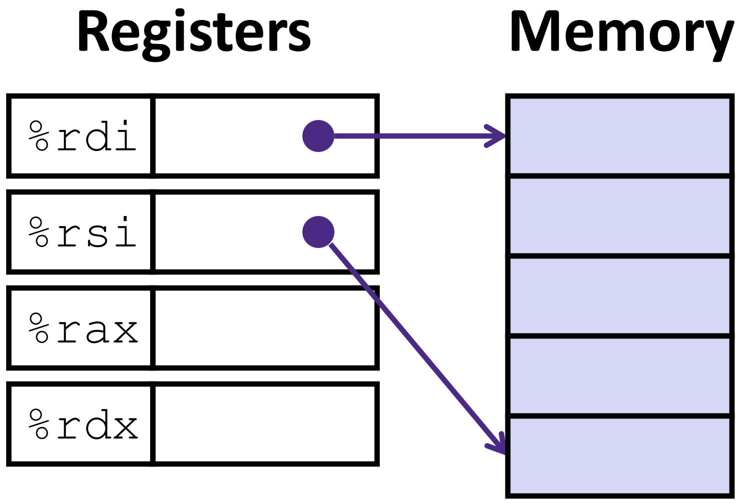
```c
void swap(long* xp, long* yp)
{
  long t0 = *xp;
  long t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

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

Compiler Explorer:
https://godbolt.org/z/zc4Pcq

Understanding swap()

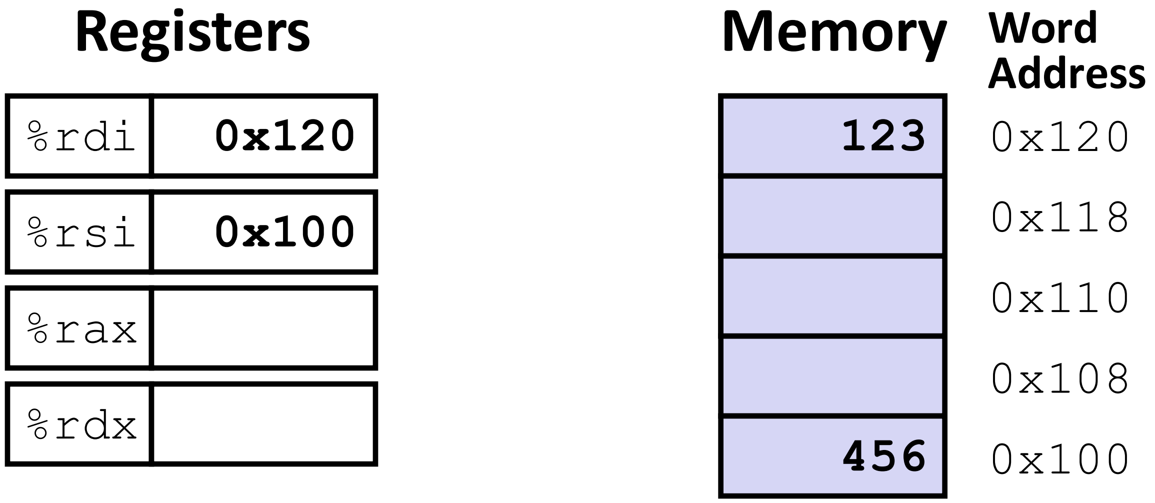
```
void swap(long *xp, long *yp)
{
   long t0 = *xp;
   long t1 = *yp;
   *xp = t1;
   *yp = t0;
}
```



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

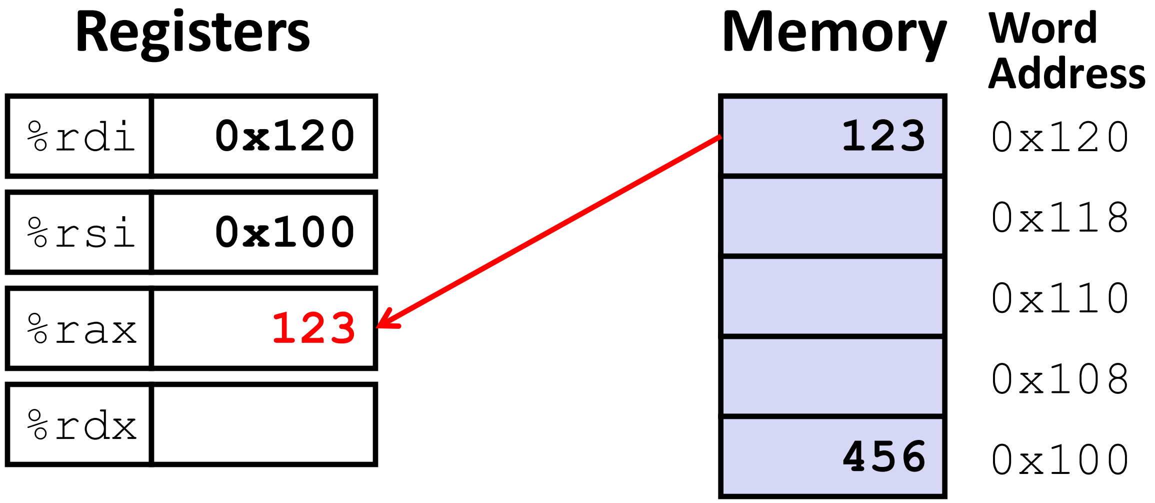
Register		Variable
%rdi	⇔	xp
%rsi	⇔	yp
%rax	⇔	t0
%rdx	⇔	t1

Understanding `swap()`



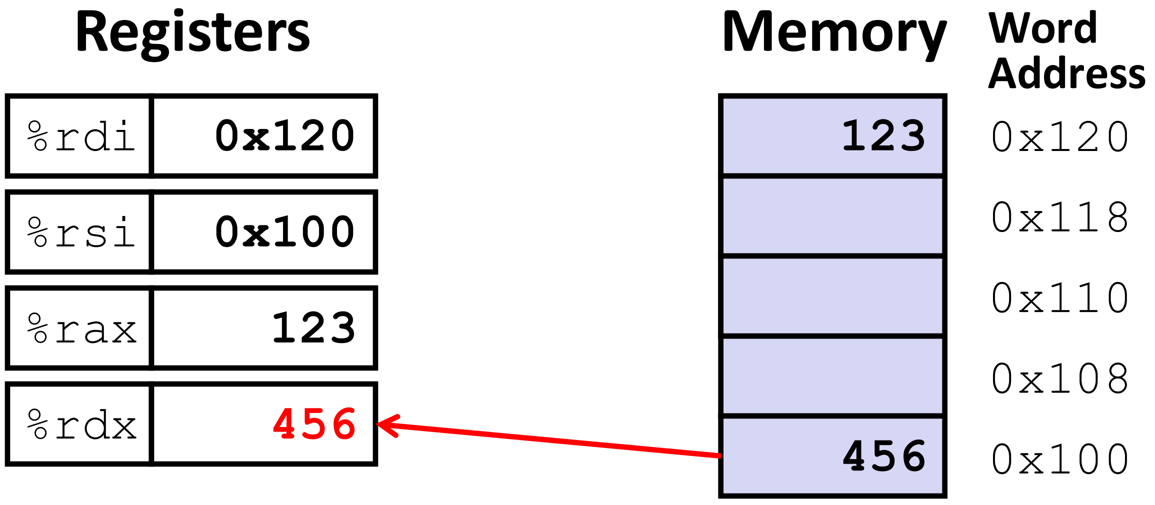
```
swap:
    movq   (%rdi), %rax   #  t0 = *xp
    movq   (%rsi), %rdx   #  t1 = *yp
    movq   %rdx, (%rdi)   # *xp =  t1
    movq   %rax, (%rsi)   # *yp =  t0
    ret
```

Understanding swap()



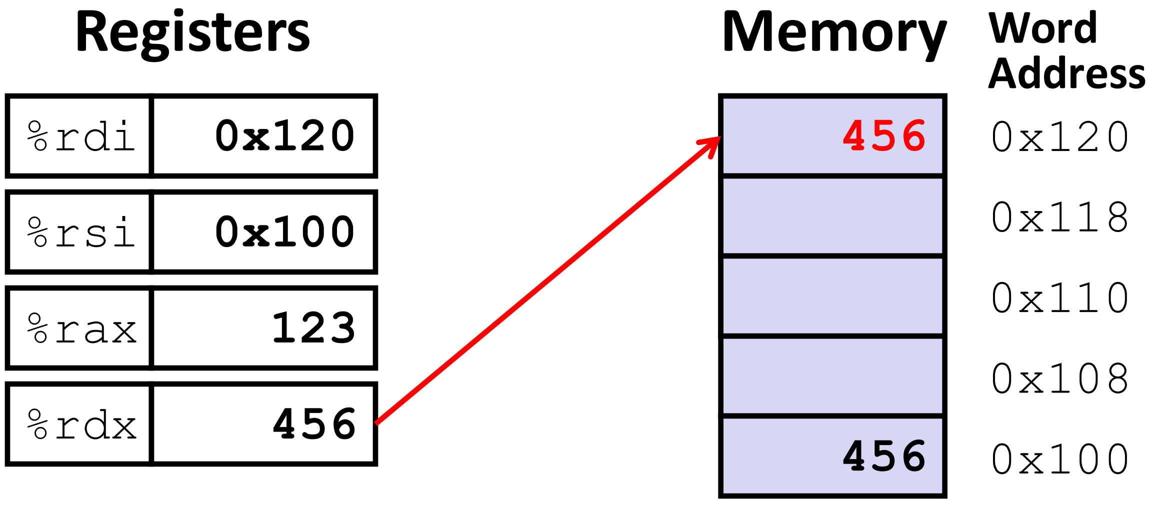
```
swap:
    movq   (%rdi), %rax   #  t0 = *xp
    movq   (%rsi), %rdx   #  t1 = *yp
    movq   %rdx, (%rdi)   # *xp =  t1
    movq   %rax, (%rsi)   # *yp =  t0
    ret
```

Understanding `swap()`



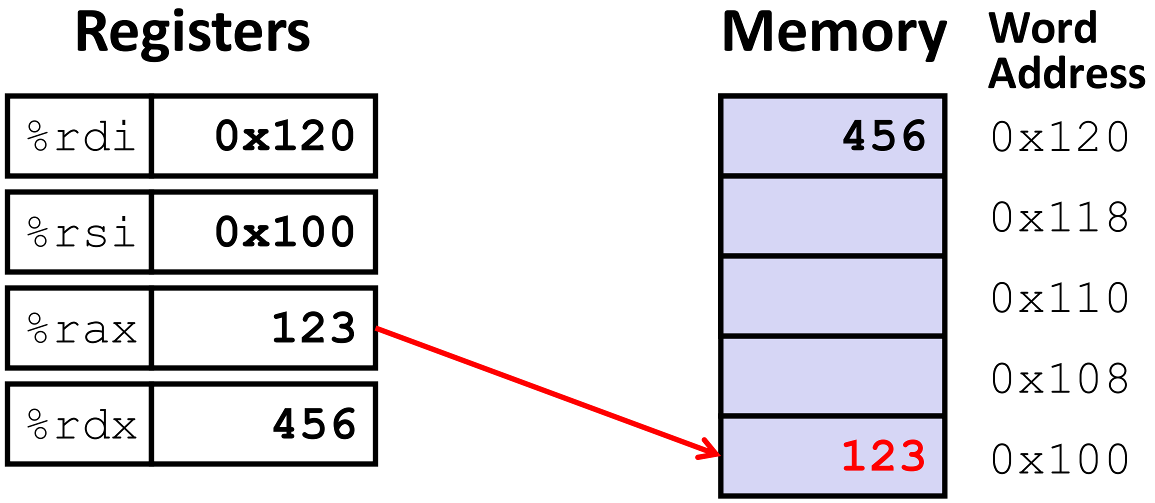
```
swap:
    movq   (%rdi), %rax   #  t0 = *xp
    movq   (%rsi), %rdx   #  t1 = *yp
    movq   %rdx, (%rdi)   # *xp =  t1
    movq   %rax, (%rsi)   # *yp =  t0
    ret
```

Understanding swap()



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

Memory Addressing Modes: Basic

- **Indirect:** `(R)` Mem[Reg[`R`]]
  - Data in register `R` specifies the memory address
  - Like pointer dereference in C
  - Example: `movq (%rcx), %rax`

- **Displacement:** `D(R)` Mem[Reg[`R`]+`D`]
  - Data in register `R` specifies the *start* of some memory region
  - Constant displacement `D` specifies the offset from that address
  - Example: `movq 8(%rbp), %rdx`

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)

`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`]

ignore the memory access for now

Expression	Address Computation	Address (8 bytes wide)
`0x8(%rdx)`		
`(%rdx,%rcx)`		
`(%rdx,%rcx,4)`		
`0x80(,%rdx,2)`		

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

- 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`

- If `%rsi` is 0x B0BACAFE 1EE7 F0 0D, 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	
%rbx	
%rcx	0x4
%rdx	0x100
%rdi	
%rsi	

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

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

`lea` – "It just does math"

Arithmetic Example

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

```
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
```

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

Arithmetic Example

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
```

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

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

Conditional jump

Unconditional jump

```
max:
  if x <= y then jump to else
  movq   %rdi, %rax
  jump to done
else:
  movq   %rsi, %rax
done:
  ret
```

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`** {…}

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