x86-64 Programming II
CSE 351 Autumn 2022

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http://xkcd.com/99/
Relevant Course Information

❖ Lab submissions that fail the autograder get a ZERO
  ▪ No excuses – make full use of tools & Gradescope’s interface
  ▪ Leeway on Lab 1a won’t be given moving forward

❖ Lab 2 (x86-64) released today
  ▪ Learn to trace x86-64 assembly and use GDB

❖ Midterm is in two weeks (take home, 11/3–5)
  ▪ Open book; make notes and use midterm reference sheet
  ▪ Individual, but discussion allowed via “Gilligan’s Island Rule”
  ▪ Mix of “traditional” and design/reflection questions
    • Form study groups and look at past exams!
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
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

❖ Questions from the Reading?
Memory Addressing Modes (Review)

❖ **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 Instruction (Review)

- **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
Review Questions

❖ If %rdx = 0xf000 and %rcx = 0x100, what addresses are dereferenced by the following memory operands?

- (%rdx, %rcx)
- 0x80 (%rdx, 2)

❖ 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
Example: Basic Arithmetic

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

<table>
<thead>
<tr>
<th>Register</th>
<th>Use(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%rdi</td>
<td>1st argument (x)</td>
</tr>
<tr>
<td>%rsi</td>
<td>2nd argument (y)</td>
</tr>
<tr>
<td>%rax</td>
<td>return value</td>
</tr>
</tbody>
</table>

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

```
y += x;
y *= 3;
long r = y;
return r;
```
### Example: Using Memory

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

**Compiler Explorer:**

[https://godbolt.org/z/c9M9fMefa](https://godbolt.org/z/c9M9fMefa)

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**Register | Variable**

<table>
<thead>
<tr>
<th>%rdi</th>
<th>xp</th>
</tr>
</thead>
<tbody>
<tr>
<td>%rsi</td>
<td>yp</td>
</tr>
<tr>
<td>%rax</td>
<td>t0</td>
</tr>
<tr>
<td>%rdx</td>
<td>t1</td>
</tr>
</tbody>
</table>
Example: Using Memory

<table>
<thead>
<tr>
<th>Registers</th>
<th>Memory</th>
<th>Word Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>%rdi 0x120</td>
<td>123 0x120 0x118</td>
<td></td>
</tr>
<tr>
<td>%rsi 0x100</td>
<td></td>
<td>0x110</td>
</tr>
<tr>
<td>%rax</td>
<td></td>
<td>0x108</td>
</tr>
<tr>
<td>%rdx</td>
<td>456 0x100</td>
<td></td>
</tr>
</tbody>
</table>

swap:

```
  movq (%rdi), %rax  # t0 = *xp
  movq (%rsi), %rdx  # t1 = *yp
  movq %rdx, (%rdi)  # *xp = t1
  movq %rax, (%rsi)  # *yp = t0
  ret
```
## Example: `lea` vs. `mov`

### Registers

<table>
<thead>
<tr>
<th>Register</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>%rax</td>
<td></td>
</tr>
<tr>
<td>%rbx</td>
<td></td>
</tr>
<tr>
<td>%rcx</td>
<td>0x4</td>
</tr>
<tr>
<td>%rdx</td>
<td>0x100</td>
</tr>
<tr>
<td>%rdi</td>
<td></td>
</tr>
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### Memory

<table>
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<th>Word Address</th>
<th>Address</th>
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<tbody>
<tr>
<td>0x120</td>
<td>0x400</td>
</tr>
<tr>
<td>0x118</td>
<td>0xF</td>
</tr>
<tr>
<td>0x110</td>
<td>0x8</td>
</tr>
<tr>
<td>0x108</td>
<td>0x10</td>
</tr>
<tr>
<td>0x100</td>
<td>0x1</td>
</tr>
</tbody>
</table>

### Example Code

```assembly
leaq (%rdx,%rcx,4), %rax
movq (%rdx,%rcx,4), %rbx
leaq (%rdx), %rdi
movq (%rdx), %rsi
```
Example: lea Arithmetic

```c
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;
}
```

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<td>2nd argument (y)</td>
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<tr>
<td>%rdx</td>
<td>3rd argument (z)</td>
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**Interesting Instructions**
- leaq: “address” computation
- salq: shift
- imulq: multiplication
- Only used once!
Example: lea Arithmetic

```c
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;
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<td>%rsi</td>
<td>y</td>
</tr>
<tr>
<td>%rdx</td>
<td>z, t4</td>
</tr>
<tr>
<td>%rax</td>
<td>t1, t2, rval</td>
</tr>
<tr>
<td>%rcx</td>
<td>t5</td>
</tr>
</tbody>
</table>

arith:

```asm
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

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

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

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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

❖ **Load effective address (lea) instruction** used to compute addresses and perform basic arithmetic
  - *Doesn’t* dereference the source memory operand, unlike all other instructions!

❖ Control flow in x86 determined by Condition Codes