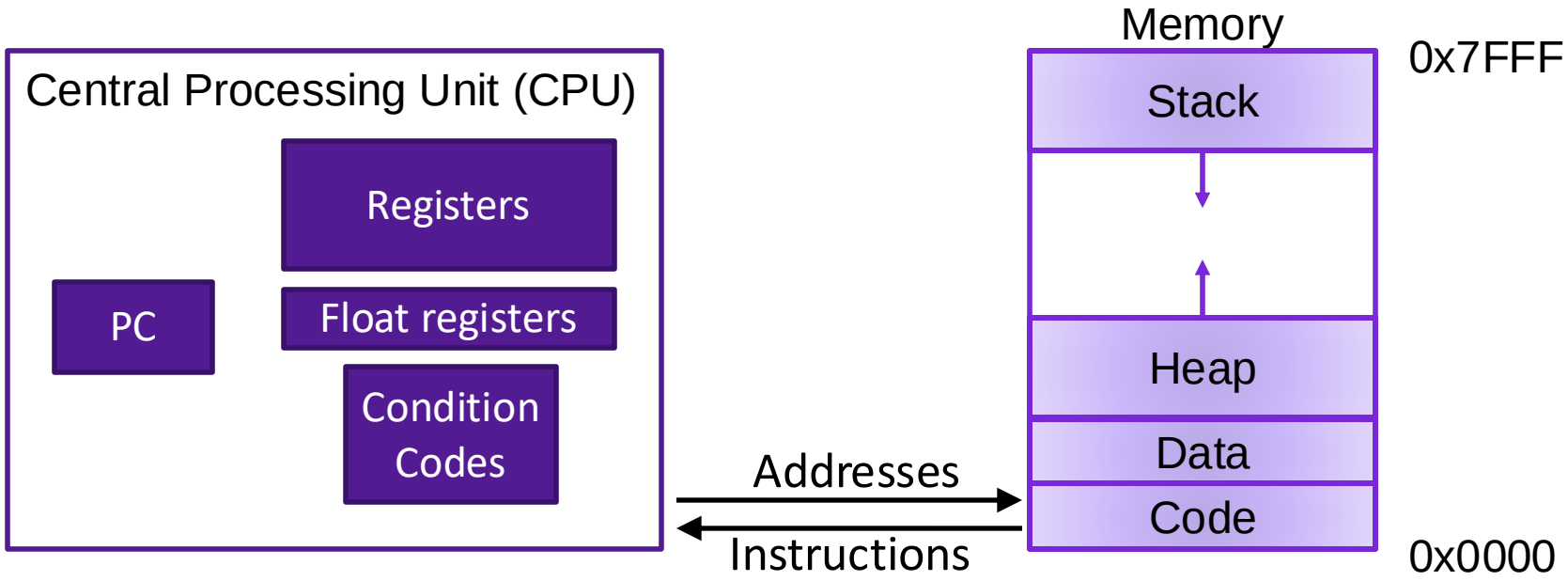
Lecture 5: Operations and Jumps in Assembly

CS 105

Fall 2024

Review: Assembly/Machine Code View



Programmer-Visible State

- PC: Program counter (%rip)
- Register file: 16 Registers
- Float registers
- Condition codes

Memory

- Byte addressable array
- Code and user data
- Stack to support procedures

Review: X86-64 Integer Registers

`%rax` (function result)	`%r8` (fifth argument)
`%rbx`	`%r9` (sixth argument)
`%rcx` (fourth argument)	`%r10`
`%rdx` (third argument)	`%r11`
`%rsi` (second argument)	`%r12`
`%rdi` (first argument)	`%r13`
`%rsp` (stack pointer)	`%r14`
`%rbp`	`%r15`

Review: Assembly Operations

- Transfer data between memory and register
  - Load data from memory into register
  - Store register data into memory
- Perform arithmetic function on register or memory data
- Transfer control
  - Conditional branches
  - Unconditional jumps to/from procedures

Review: Operand Forms

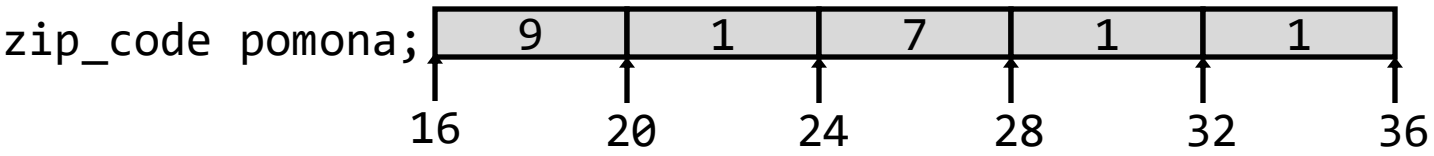
- Immediate:
  - Syntax: $c Ex: $47 Val: c C Equiv: 47
- Register:
  - Syntax: r Ex: %rbp Val: Reg[r] C Equiv: x
- Memory (Absolute):
  - Syntax: addr Ex: 0x4050 Val: Mem[addr] C Equiv: *0x60201a
- Memory (Indirect):
  - Syntax: (r) Ex: (%rsp) Val: Mem[Reg[r]] C Equiv: *x
- Memory (Base+displacement):
  - Syntax: c(r) Ex: 12(%rsp) Val: Mem[Reg[r]+c] C Equiv: *(x+12)

Review: Data Movement Instructions

- MOV source, dest — Move data source->dest
  - `movb` — Move 1 byte
  - `movw` — Move 2 bytes
  - `movl` — Move 4 bytes
  - `movq` — Move 8 bytes

Review: Array Accessing

Register	Use(s)
%rdi	z
%rsi	digit
%rax	return val




```
int get_digit(int* zipcode, int digit){
  return z[digit];
}
```

???

Operand Forms

- Immediate:
  - Syntax: $c Ex: $47 Val: c C Equiv: 47
- Register:
  - Syntax: r Ex: %rbp Val: Reg[r] C Equiv: x
- Memory (Absolute):
  - Syntax: addr Ex: 0x4050 Val: Mem[addr] C Equiv: *0x60201a
- Memory (Indirect):
  - Syntax: (r) Ex: (%rsp) Val: Mem[Reg[r]] C Equiv: *x
- Memory (Base+displacement):
  - Syntax: c(r) Ex: 12(%rsp) Val: Mem[Reg[r]+c] C Equiv: *(x+12)
- Memory (Scaled indexed):
  - Syntax: (r1,r2,s) Ex: (%rdx,%rsi,4) Val: Mem[Reg[r1]+Reg[r2]*s] C: r1[r2]
- Memory (Scaled indexed w/ displacement):
  - Syntax: c(r1,r2,s) Ex: 8(%rdx,%rsi,4) Val: Mem[Reg[r1]+Reg[r2]*s+c] C: (r1+8)[r2]

Exercise 1: Operands

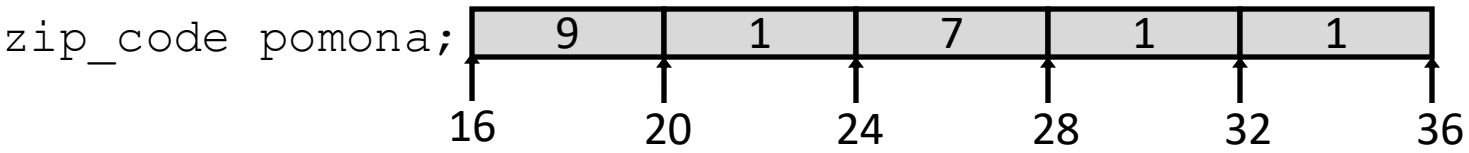
Register	Value
%rax	0x100
%rcx	0x01
%rdx	0x03

Memory Address	Value
0x108	0xFF
0x109	0x47
0x10a	0x13
0x10b	0xE1
0x10c	0xAB
0x10d	0x2F
0x10e	0x07

- What are the values of the following operands (assuming register and memory state shown above)?
  1. `(%rax,%rcx,4)`
  2. `(%rax,%rdx,2)`
  3. `1(%rax,%rcx,4)`

Array Accessing Example

Register	Use(s)
%rdi	z
%rsi	digit
%rax	return val



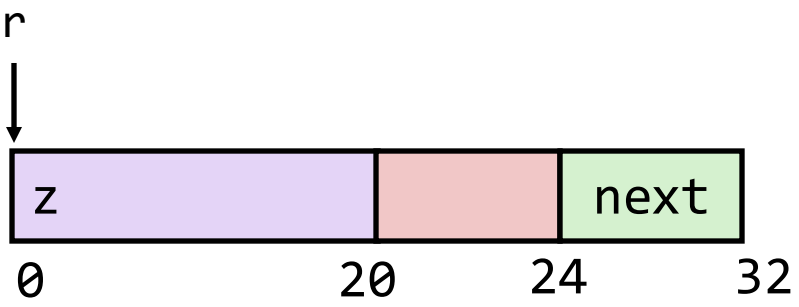

```
int get_digit(int* zipcode, int digit){
  return z[digit];
}
```

```
movl (%rdi,%rsi,4), %eax  # ret = z[digit]
```

- Register `%rdi` contains starting address of array `zipcode`
- Register `%rsi` contains array index `digit`
- Desired digit at `%rdi + 4*%rsi`
- Use memory reference `(%rdi,%rsi,4)`

Structure Representation

```
typedef struct node {
  int z[5];
  struct node* next;
} node_t;
```

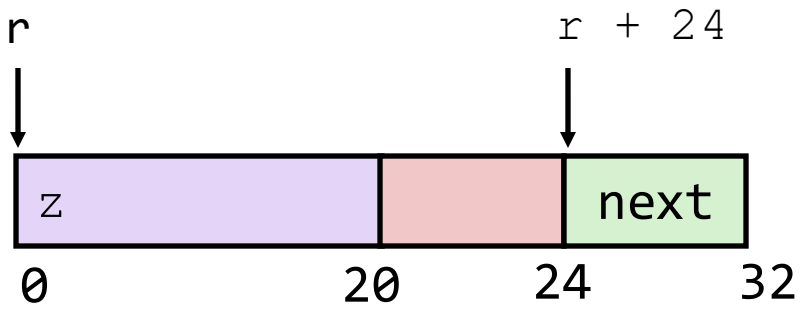


- Structure represented as block of memory
  - **Big enough to hold all of the fields**
- Fields ordered according to declaration
  - **Even if another ordering could yield a more compact representation**
- Compiler determines overall size + positions of fields
  - **Machine-level program has no understanding of the structures in the source code**

Register	Use(s)
%rdi	n
%rax	return val

Accessing Fields

```
typedef struct node {
  int z[5];
  struct node* next;
} node_t;
```



- Accessing a field in a struct
  - Offset of each structure member determined at compile time

```
node_t* get_next(node_t* n){
  return n->next;
}
```

```
  # n in %rdi
  movq   24(%rdi), %rax
  ret
```

ARITHMETIC IN ASSEMBLY

Some Arithmetic Operations

- Two Operand Instructions:

Format		*Computation*	
andq	*Src,Dest*	Dest = Dest & Src	
orq	*Src,Dest*	Dest = Dest | Src	
xorq	*Src,Dest*	Dest = Dest ^ Src	
shlq	*Src,Dest*	Dest = Dest << Src	***Also called salq***
shrq	*Src,Dest*	Dest = Dest >> Src	***Logical***
sarq	*Src,Dest*	Dest = Dest >> Src	***Arithmetic***
addq	*Src,Dest*	Dest = Dest + Src	
subq	*Src,Dest*	Dest = Dest – Src	
imulq	*Src,Dest*	Dest = Dest * Src	

Suffixes

char	**b**	**1**
short	**w**	**2**
int	**l**	**4**
long	**q**	**8**
pointer	**q**	**8**

Some Arithmetic Operations

- One Operand Instructions

notq	*Dest*	*Dest = ~Dest*
incq	*Dest*	*Dest = Dest + 1*
decq	*Dest*	*Dest = Dest – 1*
negq	*Dest*	*Dest = – Dest*

Suffixes

char	**b**	**1**
short	**w**	**2**
int	**l**	**4**
long	**q**	**8**
pointer	**q**	**8**

Exercise 2: Assembly Operations

Register	Value
%rax	0x100
%rbx	0x110
%rdi	0x02

Address	Value
0x100	0x012
0x108	0x99a
0x110	0x809

Value	Location

1. `addq $0x47, %rax`
2. `subq %rax, %rbx`
3. `addq (%rbx), %rax`
4. `shlq %rdi, (%rax)`
5. `addq (%rax,%rdi,8), %rax`

Example: Translating Assembly

```
arith:
  orq     %rsi, %rdi
  sarq    $3, %rdi
  notq    %rdi
  movq    %rdx, %rax
  subq    %rdi, %rax
  ret
```

```
long arith(long x, long y, long z){
  x = x | y;
  x = x >> 3;
  x = ~x;

  long ret = z - x;
  return ret;
}
```

Interesting Instructions

- **`sarq`**: arithmetic right shift

Register	Use(s)
`%rdi`	Argument **`x`**
`%rsi`	Argument **`y`**
`%rdx`	Argument **`z`**
`%rax`	return value

lea Instruction

Scaled Memory Operands

`movq (%rdi,%rsi,8), %rax`

```
void ex1(long* xp, long yp){

  long* p = xp + 8*yp;
  long ret = *p;

}
```

`leaq` *Source*, *Dest*

`leaq (%rdi,%rsi,8), %rax`

```
void ex3(long xp, long yp){
  long ret = xp + 8*yp;
}
```

- pointer arithmetic
  - E.g., p = x + i;
- arithmetic
  - expressions x + k*y (k=1, 2, 4, 8)

Used by compiler to optimize:

```
long m12(long x){

  return x*12;

}
```

```
leaq (%rdi,%rdi,2), %rax # ret <- x+x*2
salq $2, %rax            # return ret<<2
```

CONDITIONAL JUMPS

Jumps

- A jump instruction can cause the execution to switch to a completely new position in the program (updates the program counter)
  - jmp Label
  - jmp *Operand

```
.L0:
  movq   $0, %rax
  jmp    .L1
  movq   (%rax), %rdx
.L1:
  movq   %rcx, %rax
```

```
jmp *%rdi
```

Conditional Jumps

- jX instructions
  - Jump to different part of code if condition is true

jX	Description
jmp	Unconditional
je	Equal to Zero
jne	Not Equal to Zero
js	Negative
jns	Nonnegative
jl	Less (Signed)
jle	Less or Equal (Signed)
jg	Greater (Signed)
jge	Greater or Equal (Signed)

What condition are we evaluating?

Conditional Jumps

- Whether or not we jump depends on how the output of the last arithmetic operation compares to zero

```
movq $47, %rax
subq $13, %rax
jg .L2
```

jump

```
movq $47, %rax
subq $13, %rax
je .L2
```

no jump

- Not set by **`lea`** instruction

- Unless there's an explicit conditional evaluation more recently

Condition Evaluations

- **`cmp a,b`** like computing **`b-a`** without setting destination
- **`test a,b`** like computing **`a&b`** without setting destination

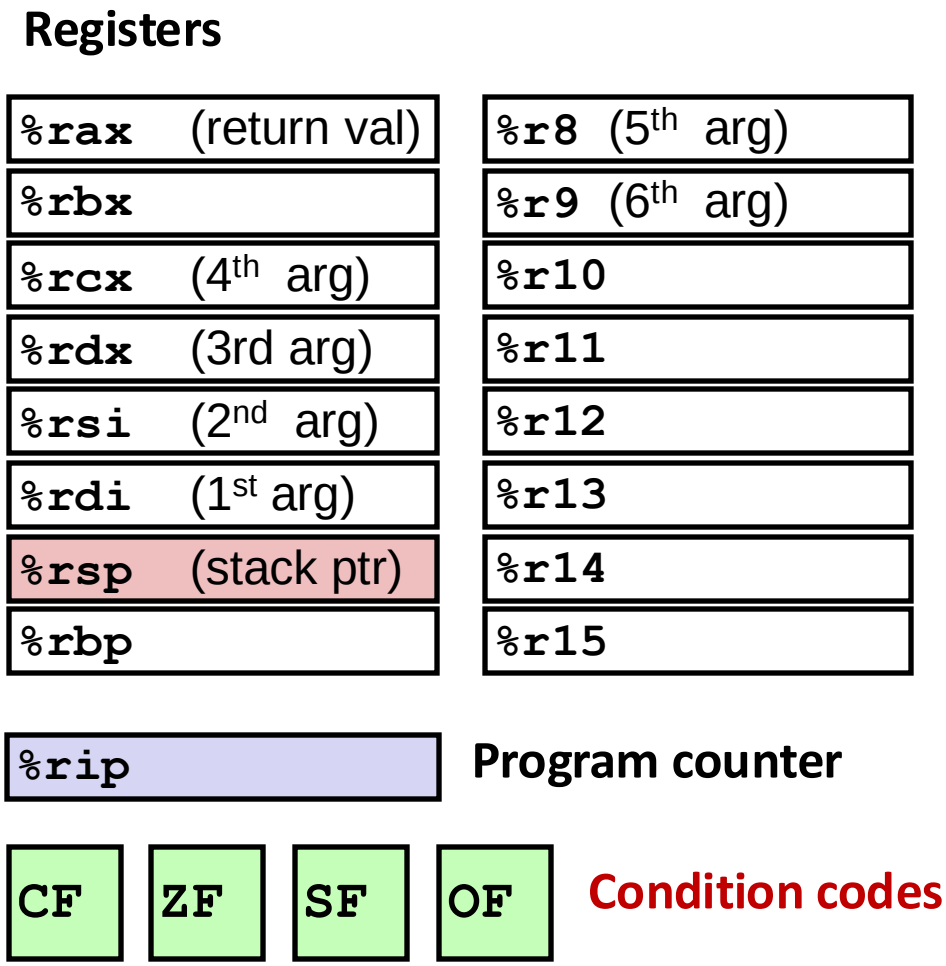
Exercise 3: Conditional Jumps

- Consider each of the following segments of assembly code, and indicate whether or not the jump will occur. In all cases, assume that `%rdi` contains the value `47` and `%rsi` contains the value `13`

1.
```
addq %rdi, %rsi
je .L0
```
2.
```
subq %rdi, %rsi
jge .L0
```
3.
```
cmpq %rdi, %rsi
jl .L0
```
4.
```
testq %rdi, %rdi
jne .L0
```

Branches and Jumps

- Processor state (partial)
  - Temporary data (**%rax**, …)
  - Location of runtime stack (**%rsp**)
  - Location of next instruction to execute (**%rip**)
  - Status of recent tests (**CF, ZF, SF, OF**)



Condition Codes

- Single bit registers
  - **ZF** Zero Flag
  - **PF** Parity Flag
  - **SF** Sign Flag (for signed)
  - **OF** Overflow Flag (for signed)
  - CF Carry Flag (for unsigned)
- Implicitly set (as a side effect) by arithmetic operations
- Explicitly set by **`cmp`** and **`test`**
- Not set by **`leaq`** instruction

Example Condition Codes: `compare`

- Instruction **`cmp`** explicitly sets condition codes

- **`cmpq a,b`** like computing **`b-a`** without setting destination
  - **ZF set** if **`(b-a) == 0`**
  - **PF set** if **`(b-a) % 2 == 1`**
  - **SF set** if **`(b-a) < 0`** (as signed)
  - **OF set** if two's-complement (signed) overflow
  - **CF set** if carry out from most significant bit (used for unsigned comparisons)

Jumping

- jX instructions
  - Jump to different part of code if condition is true

jX	Condition	Description
jmp	1	Unconditional
je	ZF	Equal / Zero
jne	~ZF	Not Equal / Not Zero
js	SF	Negative
jns	~SF	Nonnegative
jl	(SF^OF)	Less (Signed)
jle	(SF^OF) | ZF	Less or Equal (Signed)
jg	~(SF^OF) & ~ZF	Greater (Signed)
jge	~(SF^OF)	Greater or Equal (Signed)
jb	CF	Below (unsigned)
jbe	CF | ZF	Below or Equal (Signed)
ja	~ZF & ~CF	Above (unsigned)
jae	~CF	Above or Equal (Signed)