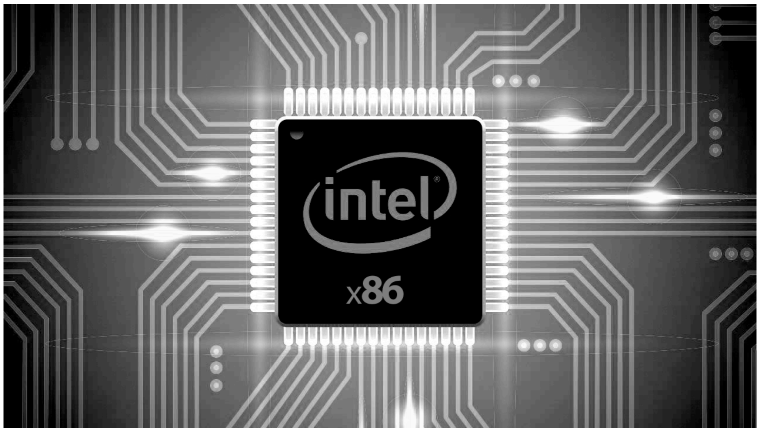
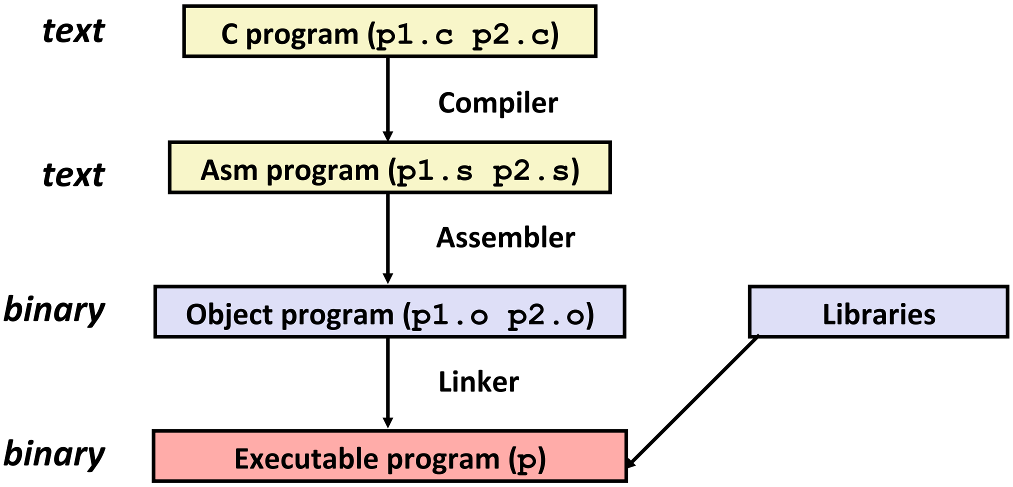
# Machine Code



# From C to Executable Code



text — C program (`p1.c p2.c`)

Compiler

text — Asm program (`p1.s p2.s`)

Assembler

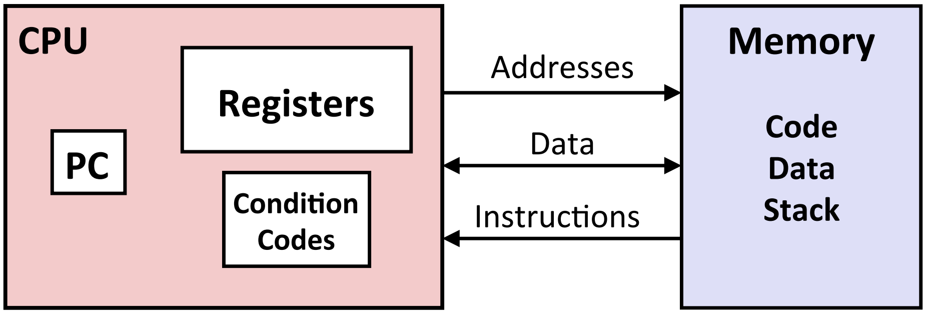
binary — Object program (`p1.o p2.o`)

Libraries

Linker

binary — Executable program (`p`)

# Assembly View of the Machine



CPU

PC

Registers

Condition Codes

Addresses

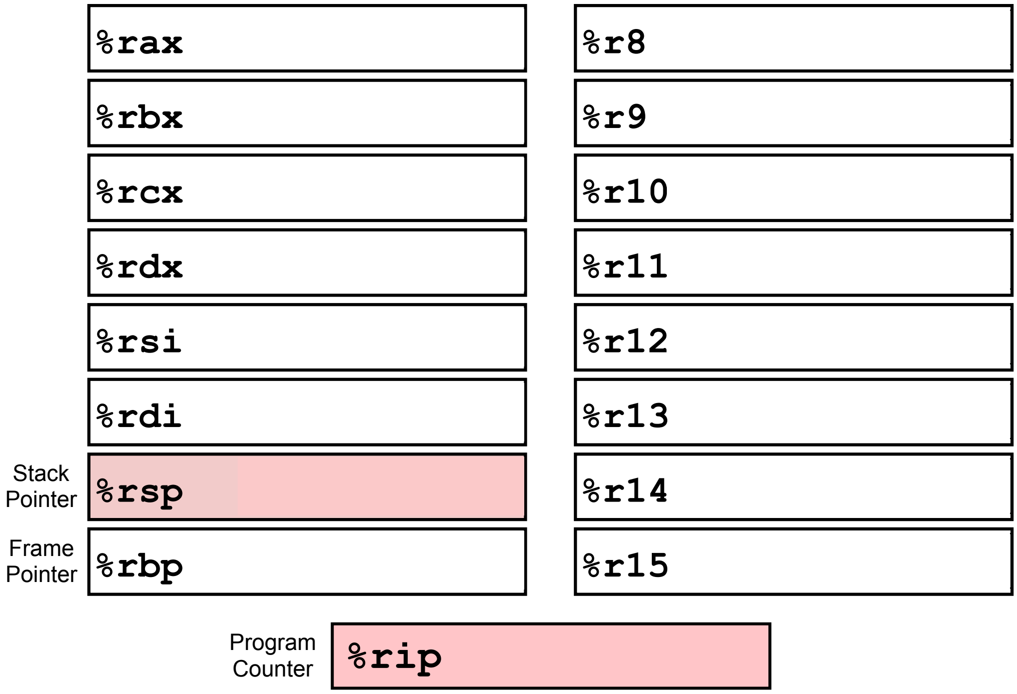
Data

Instructions

Memory

Code
Data
Stack

# x86-64 Integer Registers



%rax

%rbx

%rcx

%rdx

%rsi

%rdi

Stack Pointer %rsp

Frame Pointer %rbp

%r8

%r9

%r10

%r11

%r12

%r13

%r14

%r15

Program Counter %rip

# x86-64 Virtual Registers

| 64-Bit Register | Lowest 32 Bits | Lowest 16 Bits | Lowest 8 Bits |
|---|---|---|---|
| %rax | %eax | %ax | %al |
| %rbx | %ebx | %bx | %bl |
| %rcx | %ecx | %cx | %cl |
| %rdx | %edx | %dx | %dl |
| %rsi | %esi | %si | %sil |
| %rdi | %edi | %di | %dil |
| %rbp | %ebp | %bp | %bpl |
| %rsp | %esp | %sp | %spl |
| %r8 | %r8d | %r8w | %r8b |
| %r9 | %r9d | %r9w | %r9b |
| %r10 | %r10d | %r10w | %r10b |
| %r11 | %r11d | %r11w | %r11b |
| %r12 | %r12d | %r12w | %r12b |
| %r13 | %r13d | %r13w | %r13b |
| %r14 | %r14d | %r14w | %r14b |
| %r15 | %r15d | %r15w | %r15b |

# Data Size Suffixes

| Suffix | Size | Description |
|---|---|---|
| b | 8 bits | byte |
| w | 16 bits | word (historical) |
| l | 32 bits | long word |
| q | 64 bits | quad word |

# Operand Combinations

|  | Source | Dest | Src, Dest | C Analog |
|---|---|---|---|---|
| movq | *Imm* | *Reg* | `movq $0x4,%rax` | `temp = 0x4;` |
|  |  | *Mem* | `movq $-147,(%rax)` | `*p = -147;` |
|  | *Reg* | *Reg* | `movq %rax,%rdx` | `temp2 = temp1;` |
|  |  | *Mem* | `movq %rax,(%rdx)` | `*p = temp;` |
|  | *Mem* | *Reg* | `movq (%rax),%rdx` | `temp = *p;` |

# Exercise

**“Copy K bytes from [val N/addr N/reg N] to [addr M/reg M]”**

```
1. movq %rax, %rbx
2. movw %ax, %bx
3. movq $5, %rcx
4. movq $-12, (%rcx)
5. movl $0xFF, %eax
6. movb %al, (%rbx)
7. movl 5, %eax
8. movw %ax, 30
9. movl (%rax), %ebx
10.movb $1, (%rdx)
```

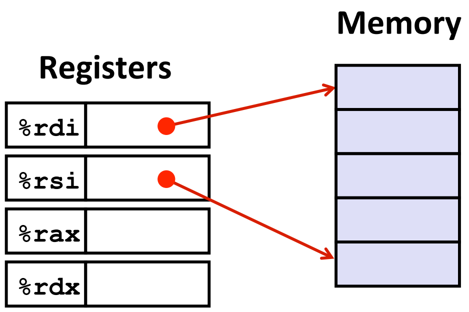
# Addressing Example

```
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
```

# Understanding Swap

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



| Register | Value |
|---|---|
| %rdi | xp |
| %rsi | yp |
| %rax | t0 |
| %rdx | t1 |

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

# General Memory Addressing

- General Form:

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

  - **D** Constant “displacement”
  - **Rb** Base register
  - **Ri** Index register
  - **S** Scale constant: 1, 2, 4, or 8

- Special Cases:

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

# Arithmetic Operations

| | | | |
|---|---|---|---|
| `addq` | *Src,Dest* | Dest = Dest + Src | |
| `subq` | *Src,Dest* | Dest = Dest - Src | |
| `imulq` | *Src,Dest* | Dest = Dest * Src | |
| `sarq` | *Src,Dest* | Dest = Dest >> Src | ***Arithmetic RShift*** |
| `shrq` | *Src,Dest* | Dest = Dest >> Src | ***Logical RShift*** |
| `salq` | *Src,Dest* | Dest = Dest << Src | ***Also called shlq*** |
| `xorq` | *Src,Dest* | Dest = Dest ^ Src | |
| `andq` | *Src,Dest* | Dest = Dest & Src | |
| `orq` | *Src,Dest* | Dest = Dest \| Src | |
| `incq` | *Dest* | *Dest = Dest + 1* | |
| `decq` | *Dest* | *Dest = Dest - 1* | |
| `negq` | *Dest* | *Dest = -Dest* | |
| `notq` | *Dest* | *Dest = ~Dest* | |
| `leaq` | *Src,Dest* | Dest = Src (as expr) | ***No memory access!*** |

# 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;
}
```

```
(x,y,z) -> (%rdi,%rsi,%rdx)
```

```
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
```

# Procedure Call Registers

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| Return | %rax | %eax | %r8 | %r8d | Arg 5 |
|  | %rbx | %ebx | %r9 | %r9d | Arg 6 |
| Arg 4 | %rcx | %ecx | %r10 | %r10d |  |
| Arg 3 | %rdx | %edx | %r11 | %r11d |  |
| Arg 2 | %rsi | %esi | %r12 | %r12d |  |
| Arg 1 | %rdi | %edi | %r13 | %r13d |  |
| Stack ptr | %rsp | %esp | %r14 | %r14d |  |
|  | %rbp | %ebp | %r15 | %r15d |  |