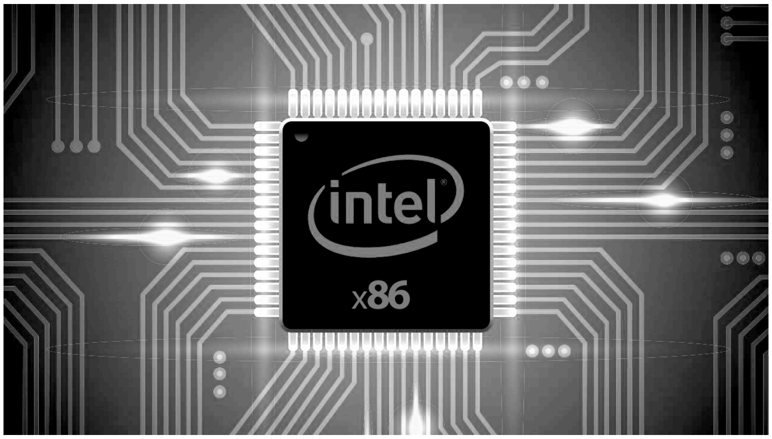
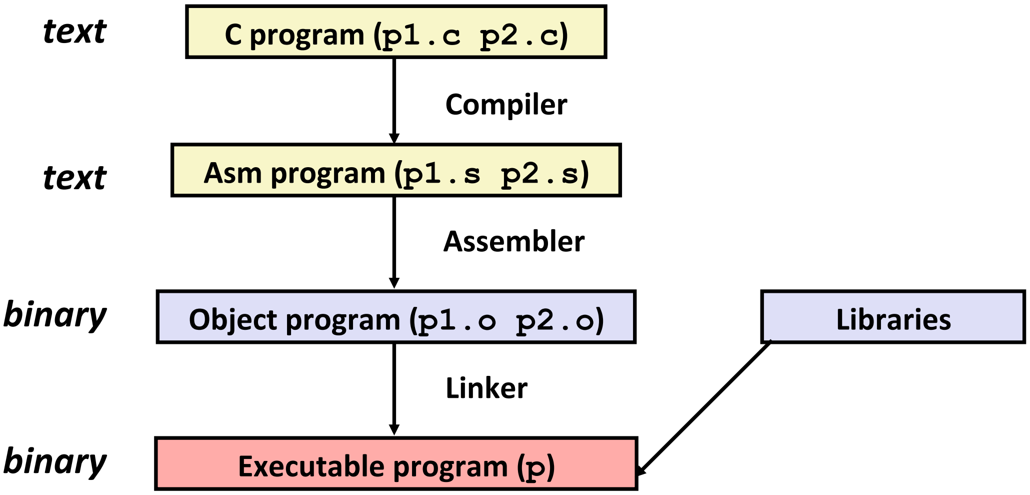
Machine Code



From C to Executable Code



text C program (`p1.c p2.c`)

Compiler

text Asm program (`p1.s p2.s`)

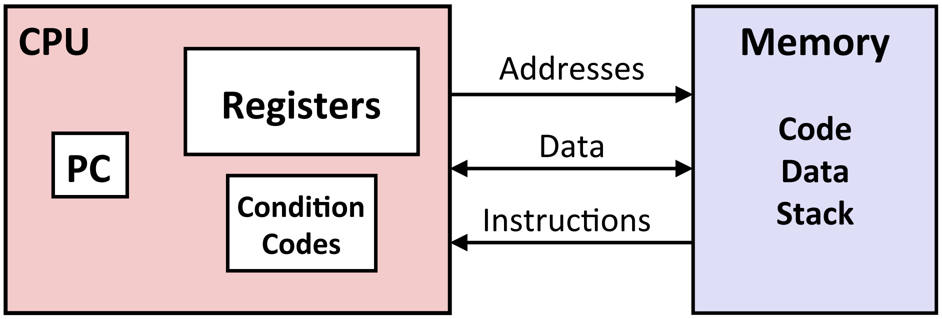
Assembler

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

Linker

binary Executable program (`p`)

Assembly View of the Machine



x86-64 Integer Registers

	`%rax`	`%r8`
	`%rbx`	`%r9`
	`%rcx`	`%r10`
	`%rdx`	`%r11`
	`%rsi`	`%r12`
	`%rdi`	`%r13`
Stack Pointer	`%rsp`	`%r14`
Frame/Base Pointer	`%rbp`	`%r15`

Program Counter (Instruction Pointer) `%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;`

Data Movement Examples

“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. movq (%rax), %rbx
10.movl (%rax), %ebx
```

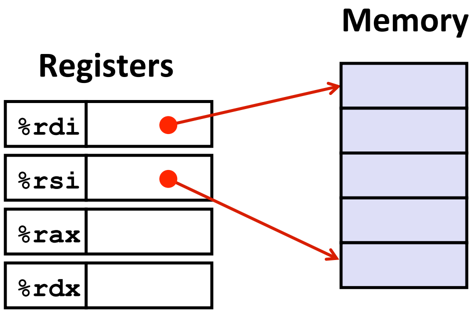
Assembly Translation Example

```
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

```
5(%rax,%rbx,8)   Mem[5 + %rax + 8 * %rbx]
```

Special Cases:

`(Rb)`	`(%rax)`	`Mem[Reg[Rb]`
`D(Rb)`	`5(%rax)`	`Mem[D + Reg[Rb]]`
`(Rb,Ri)`	`(%rax,%rbx)`	`Mem[Reg[Rb]+Reg[Ri]]`
`D(Rb,Ri)`	`5(%rax,%rbx)`	`Mem[D + Reg[Rb]+Reg[Ri]]`
`(Rb,Ri,S)`	`(%rax,%rbx,8)`	`Mem[Reg[Rb]+S*Reg[Ri]]`
`(,Ri,S)`	`(,%rbx,8)`	`Mem[S*Reg[Ri]]`
`D(,Ri,S)`	`5(,%rbx,8)`	`Mem[D + S*Reg[Ri]]`

Arithmetic Instructions

`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!***

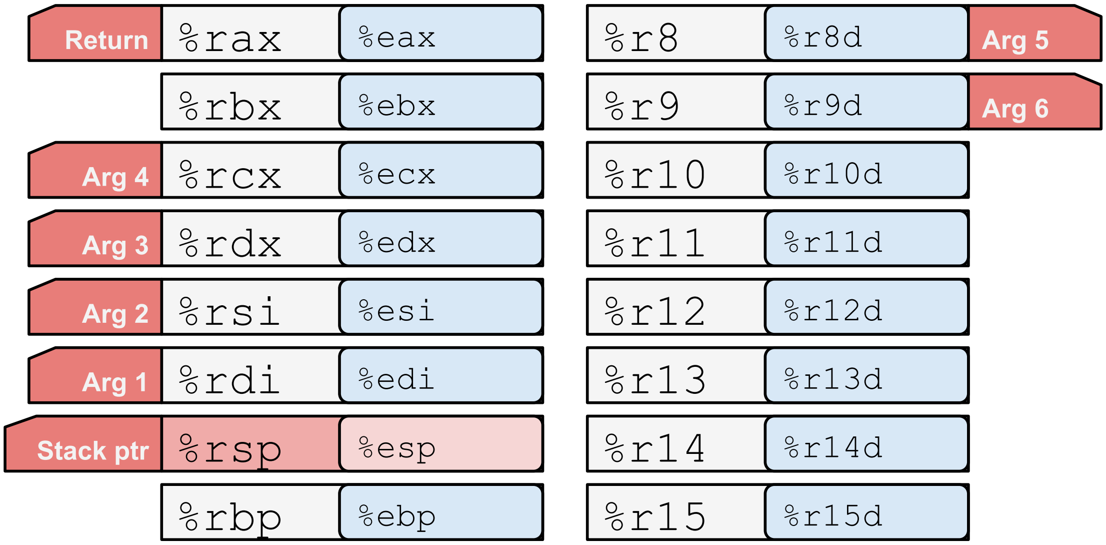
Arithmetic Example

```
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:
1. leaq    (%rdi,%rsi), %rax
2. addq    %rdx, %rax
3. leaq    (%rsi,%rsi,2), %rdx
4. salq    $4, %rdx
5. leaq    4(%rdi,%rdx), %rcx
6. 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	

Procedure Call Example

```
long x = add(3, 5);
doSomething(x);
```

```
long add(long x, long y) {
  return x + y;
}
```

```
movq $3, %rdi
movq $5, %rsi
callq add
movq %rax, %rdi
callq doSomething
```

```
add:
  movq %rdi, %rax
  addq %rsi, %rax
  ret
```