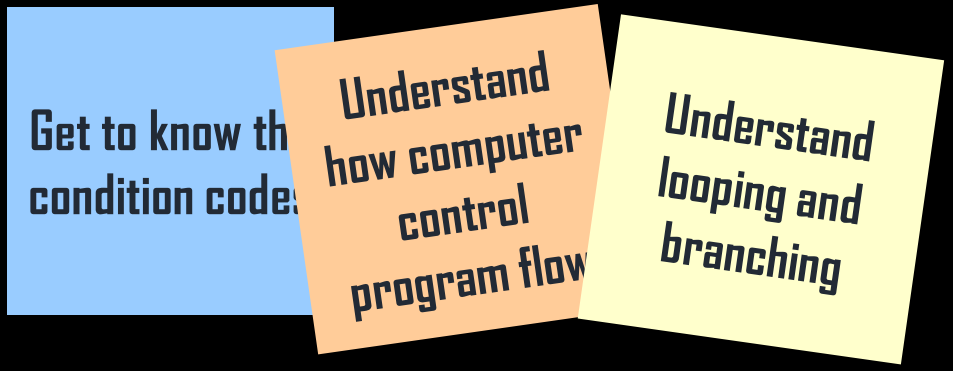


x86 Transfer Control

① Conditional Codes

② Jumping

Three Basic Kinds of Instructions

- Transfer data
  - MOV, LEA
- Arithmetic function
  - ADD, SUB, IMUL, SAL, SAR, SHR, XOR, AND, OR
  - INC, DEC, NEG, NOT
- Transfer control
  - JMP, JE, JNE, JS, JNS, JG, JGE, JL, JLE, JA, JB

Condition Codes

Implicitly set by arithmetic or logical operations (~~LEA~~)

CF	Carry Flag	Carry out of the MSB unsigned
ZF	Zero Flag	0
SF	Sign Flag	Negative value signed
OF	Overflow Flag	Two's complement overflow signed

Condition Codes Examples

CF `(unsigned) t < (unsigned) a`

ZF `t == 0`

t = a + b

SF `t < 0`

OF
```
(a>0 && b>0 && t<0) ||
(a<0 && b<0 && t>=0)
```

Set Condition Codes

CMP S1, S2

cmpb cmpw cmpl cmpq

Sets condition codes based on S2 – S1

```
cmpq %rax, %rbx
```

CF ZF SF OF

TEST S1, S2

testb testw testl testq

Sets condition codes based on S2 & S1

```
testq %rax, %rax
```

CF ZF SF OF

Accessing the Condition Codes

1. Set a byte to 0 or 1
2. Conditionally jump to other program part
3. Conditionally transfer data

The SET Instructions

1. Set a byte to 0 or 1

SET D

sete	setne	sets	setns
setg	setge	setl	setle
seta	setae	setb	setbe

```
comp:
   cmpq  %rsi, %rdi
   setl  %al
   movzbl %al, %eax
   ret
```

a < b

SET Instructions

Instruction	Synonym	Condition	Description
sete	setz	ZF	Equal / Zero
setne	setnz	~ZF	Not Equal / Not Zero
sets		SF	Negative
setns		~SF	Nonnegative
setg	setnle	~(SF^OF)&~ZF	Greater (signed)
setge	setnl	~(SF^OF)	Greater or Equal
setl	setnge	(SF^OF)	Less (signed)
setle	setng	(SF^OF)|ZF	Less or Equal
seta	setnbe	~CF&~ZF	Above (unsigned)
setae	setnb	~CF	Above or Equal
setb	setnae	CF	Below (unsigned)
setbe	setna	CF | ZF	Below or Equal

Accessing the Condition Codes

2. Conditionally jump to other program part

J Label

je	jne	js	jns
jg	jge	jl	jle
ja	jae	jb	jbe

jmp label

jmp *Operand

} Unconditional jumps

Conditional Jumps

Instruction	Synonym	Condition	Description
je	jz	ZF	Equal / Zero
jne	jnz	~ZF	Not Equal / Not Zero
js		SF	Negative
jns		~SF	Nonnegative
jg	jnle	~(SF^OF)&~ZF	Greater (signed)
jge	jnl	~(SF^OF)	Greater or Equal
jl	jnge	(SF^OF)	Less (signed)
jle	jng	(SF^OF)|ZF	Less or Equal
ja	jnbe	~CF&~ZF	Above (unsigned)
jae	jnb	~CF	Above or Equal
jb	jnae	CF	Below (unsigned)
jbe	jna	CF | ZF	Below or Equal

Jump Instruction Example

```
long absdiff
  (long x, long y)
{
  long result;
  if (x > y)
    result = x-y;
  else
    result = y-x;
  return result;
}
```

x in %rdi
y in %rsi

```
absdiff:
    cmpq    %rsi, %rdi
    jle     .L4
    movq    %rdi, %rax
    subq    %rsi, %rax
    ret
.L4:
    movq    %rsi, %rax
    subq    %rdi, %rax
    ret
```

Accessing the Condition Codes

3. Conditionally transfer data

   CMOV S, R

cmove	cmovne	cmovs	cmovns
cmovg	cmovge	cmovl	cmovle
cmova	cmovae	cmovb	cmovbe

not require control transfer

Conditional Move

Instruction	Synonym	Condition	Description
cmove	cmovz	ZF	Equal / Zero
cmovne	cmovnz	~ZF	Not Equal / Not Zero
cmovs		SF	Negative
cmovns		~SF	Nonnegative
cmovg	cmovnle	~(SF^OF)&~ZF	Greater (signed)
cmovge	cmovnl	~(SF^OF)	Greater or Equal
cmovl	cmovnge	(SF^OF)	Less (signed)
cmovle	cmovng	(SF^OF)|ZF	Less or Equal
cmova	cmovnbe	~CF&~ZF	Above (unsigned)
cmovae	cmovnb	~CF	Above or Equal
cmovb	cmovnae	CF	Below (unsigned)
cmovbe	cmovna	CF | ZF	Below or Equal

CMOV Instruction Example

```
long absdiff
  (long x, long y)
{
  long result;
  if (x > y)
    result = x-y;
  else
    result = y-x;
  return result;
}
```

x in %rdi
y in %rsi

```
absdiff:
    movq    %rdi, %rax
    subq    %rsi, %rax
    movq    %rsi, %rdx
    subq    %rdi, %rdx
    cmpq    %rsi, %rdi
    cmovle  %rdx, %rax
    ret
```

Do-While Loops

```
long pcount_do
  (unsigned long x)
{
  long result = 0;
  do {
    result += x & 0x1;
    x >>= 1;
  } while (x);
  return result;
}
```

x in %rdi

```
pcount_do:
    movl    $0, %eax
.L2:
   movq     %rdi, %rdx
   andl     $1, %edx
   addq     %rdx, %rax
   shrq     %rdi
   jne      .L2
   rep; ret
```

Do-While Loops

```
long pcount_goto
  (unsigned long x)
{
  long result = 0;
 loop:
  result += x & 0x1;
  x >>= 1;
  if(x) goto loop;
  return result;
}
```

x in %rdi

```
pcount_do:
    movl    $0, %eax
.L2:
   movq     %rdi, %rdx
   andl     $1, %edx
   addq     %rdx, %rax
   shrq     %rdi
   jne      .L2
   rep; ret
```

“Do-While” Translation

```
do
  Body
  while (Test);
```

```
Loop:
  Body
  if (Test)
    goto Loop
```

```
while (Test)
  Body;
```

```
 goto test;
loop:
  Body
test:
  if (Test)
    goto loop;
done:
```

While Loop Example 1

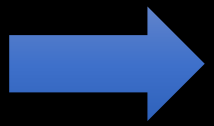
```
long pcount_while
  (unsigned long x) {
  long result = 0;
  while (x) {
    result += x & 0x1;
    x >>= 1;
  }
  return result;
}
```

```
long pcount_goto_jtm
  (unsigned long x)
{
  long result = 0;
  goto test;
 loop:
  result += x & 0x1;
  x >>= 1;
 test:
  if(x) goto loop;
  return result;
}
```

“While” Translation

```
while (Test)
  Body
```

```
  if (!Test)
    goto done;
  do
    Body
    while(Test);
done:
```



```
  if (!Test)
    goto done;
loop:
  Body
  if (Test)
    goto loop;
done:
```

While Loop Example 2

```
long pcount_while
  (unsigned long x) {
  long result = 0;
  while (x) {
    result += x & 0x1;
    x >>= 1;
  }
  return result;
}
```

```
long pcount_goto_dw
  (unsigned long x)
{
  long result = 0;
  if (!x) goto done;
 loop:
  result += x & 0x1;
  x >>= 1;
  if(x) goto loop;
 done:
  return result;
}
```

For Loops

```
#define WSIZE 8*sizeof(int)
long pcount_for (unsigned long x)
{
  size_t i;
  long result = 0;
  for (i = 0; i < WSIZE; i++)
  {
    unsigned bit = (x >> i) & 0x1;
    result += bit;
  }
  return result;
}
```

```
long pcount_for_goto_dw  (unsigned long x) {
  size_t i;
  long result = 0;
  i = 0;
  if (!(i < WSIZE))
    goto done;
 loop:
  {
    unsigned bit = (x >> i) & 0x1;
    result += bit;
  }
  i++;
  if (i < WSIZE)
    goto loop;
 done:
  return result;
}
```

```
void switch_eg
(long x, long n, long *dest)
{
    long val = x;
    switch(n) {
    case 100:
        val *= 13;
        break;
    case 102:
        val += 10;
        /* Fall through */
    case 103:
        val += 11;
        break;
    case 104:
    case 106:
        val *= val;
        break;
    default:
        val = 0;
    }
    *dest = val;
}
```

Block 0

Block 1

Block 2

Block 3

Block 4

```
switch_eg:
    subq    $100,%rsi
    cmpq    $6,%rsi
    ja      .L8
    jmp     *.L4(,%rsi,8)
.L3:
    leaq    (%rdi,%rdi,2),%rax
100 leaq    (%rdi,%rax,4),%rdi
    jmp     .L2
.L5:
102 addq    $10,%rdi
.L6:
    addq    $11,%rdi
103 jmp     .L2
.L7:
104 imulq   %rdi,%rdi
106 jmp     .L2
.L8:
    movl    $0,%edi
.L2:
    movq    %rdi,(%rdx)
    ret
```

Block 0

Block 1

Block 2

Block 3

Block 4

Jump table

Jump to .L4 + %rsi × 8

```
    .section .rodata
    .align 8
.L4:
    .quad   .L3
    .quad   .L8
    .quad   .L5
    .quad   .L6
    .quad   .L7
    .quad   .L8
    .quad   .L7
```

```
switch_eg:
    subq    $100,%rsi
    cmpq    $6,%rsi
    ja      .L8
    jmp     *.L4(,%rsi,8)
.L3:
    leaq    (%rdi,%rdi,2),%rax
100 leaq    (%rdi,%rax,4),%rdi
    jmp     .L2
.L5:
102 addq    $10,%rdi
.L6:
    addq    $11,%rdi
103 jmp     .L2
.L7:
104 imulq   %rdi,%rdi
106 jmp     .L2
.L8:
    movl    $0,%edi
.L2:
    movq    %rdi,(%rdx)
    ret
```

Block 0

Block 1

Block 2

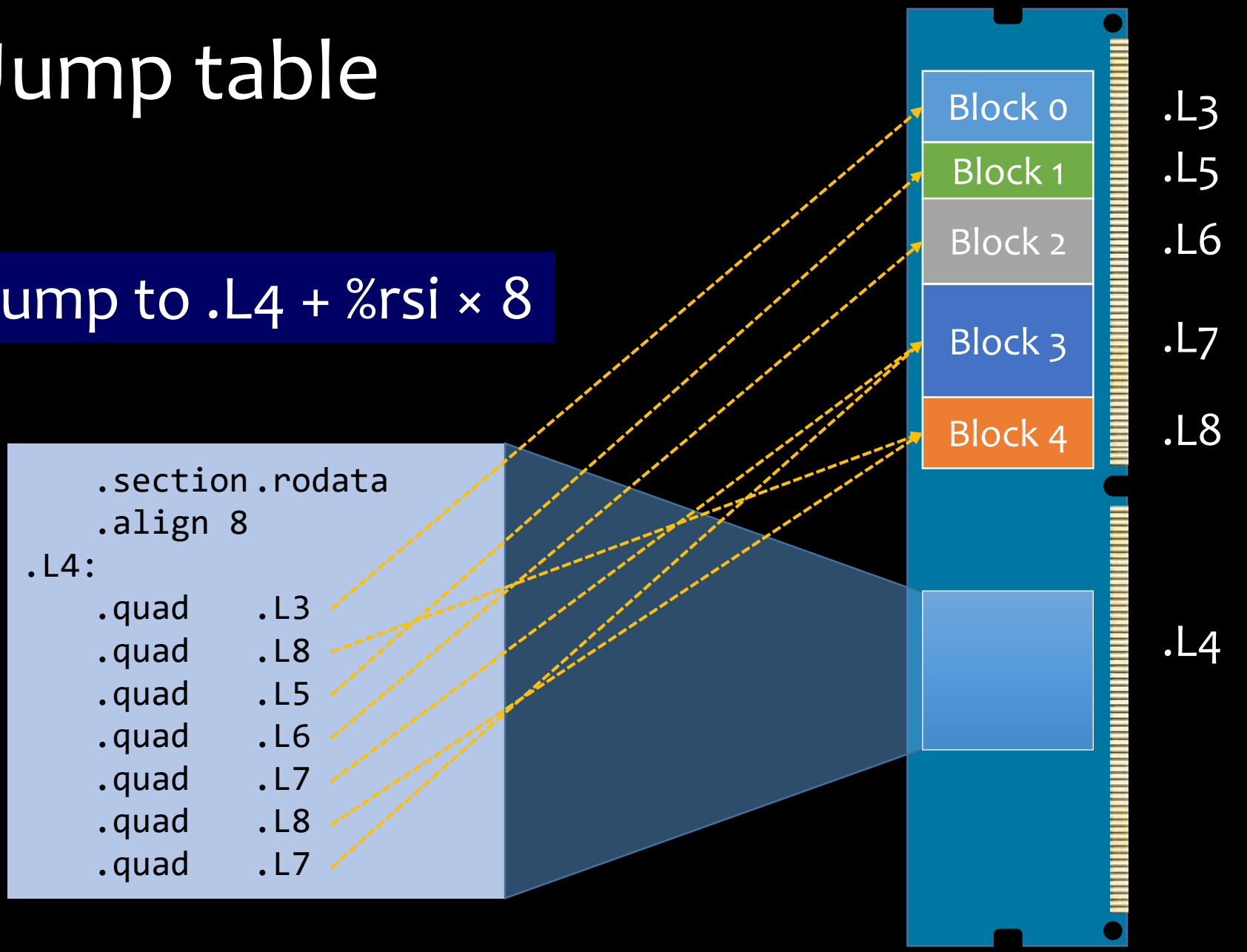
Block 3

Block 4

Jump table

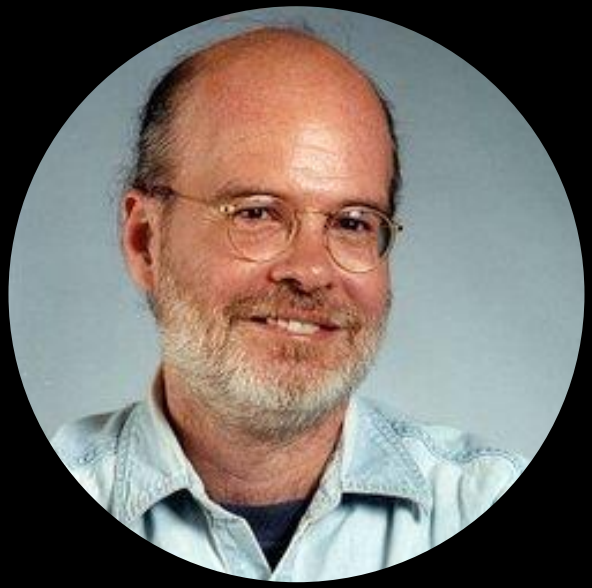
Jump to .L4 + %rsi × 8

```
    .section .rodata
    .align 8
.L4:
    .quad    .L3
    .quad    .L8
    .quad    .L5
    .quad    .L6
    .quad    .L7
    .quad    .L8
    .quad    .L7
```



Summary

- Transfer control
  - JMP
  - JE, JNE, JS, JNS, JG, JGE, JL, JLE, JA, JB
- Condition Codes
  - CF, ZF, SF, OF
  - CMP, TEST, SET
  - CMOV



Charles Petzold

American programmer, Microsoft MVP

> Programming in machine code is like eating with a toothpick.