Control Logic

Part 4

1

Intel x86 Jump Instructions

Fly over code

2

Operations: Program Flow Control

- Unlike high-level languages, processors don't have fancy expressions or blocks
- Programs are controlled by jumping over blocks of code

3

Operations: Program Flow Control

- The processor moves the instruction pointer *(where your program is running in memory)* to a new address and execution continues

4

Types of Jumps: Unconditional

- *Unconditional jumps* simply transfers the running program to a new address
- Basically, it just "gotos" to a new line
- These are used extensively to recreate the blocks we use in 3GLs (like Java)

5

Instruction: Jump

```
JMP address
```

Usually a label – a constant that holds an address

6

Infinite Loop

```
.intel_syntax noprefix
.data
message:
   .ascii "I'm getting dizzy!\n\0"

.text
.global _start

_start:
    lea  rax, message
Loop:
    call  PrintString
    jmp   Loop
```


7

Infinite Loop

```
_start:
    lea   rdx, message
Loop:
    call PrintString
    jmp  Loop
```


8

Conditional Jumps

- *Conditional jumps* (aka *branching*) will only jump if a certain condition is met
- What happens
  - processor jumps if and only if a specific status is set
  - otherwise, it simply continues with the next instruction

9

Instruction: Compare

- Performs a comparison operation between two arguments
- The result of the comparison is used for conditional jumps
- We will get into how this works a tad later

10

Instruction: Compare

Register, Memory

CMP ***arg1*** **,** ***arg2***

Immediate, Register, Memory

11

Conditional Jumps

- x86 contains a large number of conditional jump instructions
- x86 assembly has several names for the same instruction – which adds readability

12

Conditional Jumps

Jump	Description
JE	Jump Equal
JNE	Jump Not equal
JG	Jump Greater than
JGE	Jump Greater than or Equal
JL	Jump Less than
JLE	Jump Less than or Equal

13

Conditional Jump Example

```
_start:
    cmp  rax, 13
    je   Equal
    ...

Equal:
    ...
```

rax = 13?

14

Conditional Jump Example

```
_start:
    mov  rax, 42
    cmp  rax, 13
    jge  Bigger
    ...

Bigger:
    add  rax, 5
```

rax >= 13?

15

If Statements on the x86

How to we conditionally execute code?

16

If Statements in Assembly

- High-level programming language have easy to use If-Statements
- However, processors handle all branching logic using jumps
- You basically jump over true and else blocks

17

If Statements in Assembly

- Converting from an If Statement to assembly is easy
- Let's look at If Statements…
  - block is only executed if the expression is true
  - so, if the expression is false your program will skip over the block
  - this is a jump…

18

If Statement jumps over code

```
rax = 18;
if (rax >= 21)
{
    //true part
}
rbx = 12;
```

False

19

Converting an If Statement

- Compare the two values
- If the result is *false* …
  - then jump over the true block
  - you will need label to jump to
- To jump on false, reverse your logic
  - `a < b` → `not (a >= b)`
  - `a >= b` → `not (a < b)`

20

Please Note…

- Following examples use *very* generic label names
- In your program, each label you create must be unique
- So, please don't think that each label (as it is typed) is "the" label you need to use

21

Converting an If Statement

```
if (rax >= 21)
{
    //true block
}
//end
```

Greater-Than or Equal
So, jump on Less-Than

22

Jump over true part

```
        cmp   rax, 21
        jl    End

        #true block

    End:
```

Branch when false. JL (Jump Less Than) is the opposite of JGE

23

Jump over true part

```
        cmp   rax, 21
        jl    End

        #true block

    End:
```

Jumps over true part

24

Else Clause

- The Else Clause is a tad more complex
- You need to have a true block and a false block
- Like before…
  - you must jump over instructions
  - just remember… *the program will continue with the next instruction unless you jump!*

25

Else Clause

```
if (rax >= 21)
{
   //true block
}
else
{
   //false block
}
//end
```


26

Jump over true part

```
        cmp  rax, 21
        jl   Else

        #true block
        jmp  End
    Else:
        #false block
    End:
```

Jump to false block

False block flows down to End

27

Jump over true part

```
        cmp  rax, 21
        jl   Else

        #true block
        jmp  End
    Else:
        #false block
    End:
```

If we run the true block, we have to jump over the false block

28

Alternative Approach

- In these examples, I put the False Block first and used inverted logic for the jump
- You can construct If Statements without inverting the conditional jump, but the format is layout is different

29

If Statement – No Else

```
        cmp  rax, 21
        jge  Then
        jmp  End
    Then:
        #true block
    End:
```

Jumps to true block

30

If Statement – No Else

```
        cmp   rax, 21
        jge   Then
        jmp   End
    Then:
        #true block
    End:
```

Jump to end if false (it didn't jump with JGE)

31

If Statement with Else

```
        cmp   rax, 21
        jge   Then

        #false block
        jmp   End
    Then:
        #true block
    End:
```

Notice that this is identical to the last slide – the false block is just empty

32

3 Rules of Engineering

1. If it works… *it works!*
2. If it ain't broke… *don't fix it!*
3. Reread rules 1 and 2 you moron!

33

While Loops

Doing the same thing again and again
… and again

34

While Statement

- Processors do not have While Statements – just like If Statements
- Looping is performed much like an implementing an If Statement
- A While Statement is, in fact, the same thing as an If Statement

35

Converting a While Statement

- To create a While Statement
  - start with an If Statement and…
  - add an unconditional jump at the end of the block that jumps to the beginning
- You will "branch out" of an infinite loop
- Structurally, this is almost identical to what you did before
- However, you do need another label :(

36

Converting an While Statement

```
while (rax < 21)
{
    //true block
}
//end
```

Less-Than.
So, jump on
Greater-Than or Equal

37

Converting an While Statement

```
While:
    cmp  rax, 21
    jge  End

    #true block
    jmp  While
End:
```

Loop after
block executes

38

Converting an While Statement

```
While:
    cmp  rax, 21
    jge  End

    #true block
    jmp  While
End:
```

Escape infinite
loop

39

Alternative Approach

- Before, we created an If Statement by inverting the branch logic (jump on false)
- You can, also implement a While Statement without inverting the logic
- Either approach is valid – use what you think is best

40

Alternative Approach

```
while (rax < 21)
{
    //true block
}
//end
```


41

Alternative Approach

```
While:
    cmp  rax, 21
    jl   Do
    jmp  End
Do:
    #true block
    jmp  While
End:
```

Jumps to Do
Block

42

Alternative Approach

```
While:
    cmp  rax, 21
    jl   Do
    jmp  End
Do:
    #true block
    jmp  While
End:
```

jl didn't jump, so jump out of the loop

43

Alternative Approach

```
While:
    cmp  rax, 21
    jl   Do
    jmp  End
Do:
    #true block
    jmp  While
End:
```

Repeat the loop

44

Do Loops

Post-Test While Loops

45

Do Loops

- Programming languages also support post-test loop statements
- Many programming languages use the keyword "repeat" or "do"
- Easier than While Statements

46

Converting Do Loops

```
do
{
    //true block
}
while (rax < 21);
//end
```

We jump UP when TRUE

47

Converting Do Loops

```
Do:
    #true block

    cmp  rax, 21
    jl   Do
```

Positive logic

48

Alternative Approach

- You can also implement Do Loops using negative logic
- But it requires a few an extra label and jump statement

49

Alternative Approach

```
Do:
    #true block

    cmp  rax, 21
    jge  End
    jmp  Do
End:
```

Negative logic

50

Alternative Approach

```
Do:
    #true block

    cmp  rax, 21
    jge  End
    jmp  Do
End:
```

Infinite loop

51

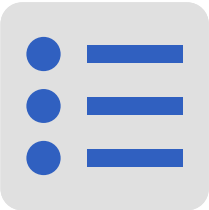
Switch Statements on the x86

Reason for the C, Java, and C# design

52

Switch Statements on the x86

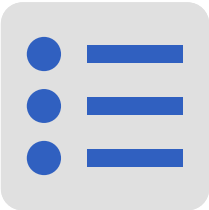
- You might have noticed the strange behavior of Switch statements in C, Java, and C#
- Java and C# inherited their behavior from C



53

Switch Statements on the x86

- C, in turn, was designed for embedded systems
- Language creates very efficient assembly code
- The Switch Statement converts easily to efficient code



54

Switch Statement

- It is very efficient because…
  - it is restricted to integer constants
  - once a case is matched, no others are checked
  - they can fall through to match multiple values
- So, how?
  - start of the statement sets up just 1 register
  - compared to each "case" constant
  - jumps to a label created for each

55

Switch Statement Syntax

```
switch (integer)
{
  case value:
    Statements

  default:
    Statements
}
```

integer expression

You can have as many of these as needed

Executed if nothing matched

56

C/Java Code

```
switch (month)
{
   case 10:
      Halloween();
   case 11:
      Thanksgiving();
   default:
      Christmas();
}
```


57

Assembly Code

```
    mov  rax, month
    cmp  rax, 10
    je   case_10
    cmp  rax, 11
    je   case_11
    jmp  default

case_10:
    call Halloween
case_11:
    call Thanksgiving
default:
    call Christmas
```


58

Assembly Code

```
    mov  rax, month
    cmp  rax, 10
    je   case_10
    cmp  rax, 11
    je   case_11
    jmp  default

case_10:
    call Halloween
case_11:
    call Thanksgiving
default:
    call Christmas
```

Jump header

59

Assembly Code: Jump Header

```
mov  rax, month
cmp  rax, 10
je   case_10
cmp  rax, 11
je   case_11
jmp  default
```

case 10:

case 11:

default:

60

Assembly Code

```
    mov  rax, month
    cmp  rax, 10
    je   case_10
    cmp  rax, 11
    je   case_11
    jmp  default

case_10:
    call Halloween
case_11:
    call Thanksgiving
default:
    call Christmas
```

Case Body

61

Assembly Code: The Case Body

```
case_10:
    call Halloween
case_11:
    call Thanksgiving
default:
    call Christmas
```

Each "falls through". They are just labels!

62

Fall-Through Labels

```
10
Halloween
Thanksgiving
Christmas
```


63

Break Statement

- Even in the last example, we still fall-through to the default
- The "Break" Statement is used exit a case
- Semantics
  - simply jumps to a label after the last case
  - so, break converts directly to a single jump

64

Java Code

```
switch (month)
{
  case 10:
     Halloween();
     break;
  case 11:
     Thanksgiving();
     break;
  default:
     Christmas();
}
```

Let's jump to the end

65

Assembly Code: The Cases

```
case_10:
    call Halloween
    jmp  End
case_11:
    call Thanksgiving
    jmp  End
default:
    call Christmas
End:
```

Break jumps to the end

66

When Fallthrough Works

- The fallthrough behavior of C was designed for a reason
- It makes it easy to combine "cases" – make a Switch Statement match multiple values
- … and keeps the same efficient assembly code

67

Java Code: Primes from 1 to 10

```
switch (number)
{
  case 2:
  case 3:
  case 5:
  case 7:
     result = True;
     break;
  default:
     result = False;
}
```

Match Multiple

68

Primes: Jump Header

```
mov  rax, number

cmp  rax, 2
je   case_2
cmp  rax, 3
je   case_3
cmp  rax, 5
je   case_5
cmp  rax, 7
je   case_7

jmp  default
```

These are our primes

69

Assembly Code: The Cases

```
case_2:
case_3:
case_7:
case_9:
    movq  result, 1
    jmp   End
default:
    movq  result, 0
```

All these labels will be at the same address. You, of course, would write prettier code.

70