Control Logic

Part 5

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Intel x86 Jump Instructions

Fly over code

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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

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Operations: Program Flow Control

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

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Types of Jumps: Unconditional

- Unconditional jumps simple 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)

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Instruction: Jump

```
JMP address
```

Usually a label – a constant that holds an address

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Infinite Loop

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

.text
.global _start

_start:
    lea  rcx, message
Loop:
    call  PrintStringZ
    jmp   Loop
```


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Infinite Loop

```
_start:
    lea  rcx, message
Loop:
    call PrintStringZ
    jmp  Loop
```


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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

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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

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Instruction: Compare

Register, Memory

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

Immediate, Register, Memory

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Conditional Jumps

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

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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

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Conditional Jump Example

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

Equal:
    ...
```

rcx = 13?

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Conditional Jump Example

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

Bigger:
    add  rcx, 5
```

rcx >= 13?

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If Statements on the x86

How to we conditionally execute code?

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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

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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…

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If Statement jumps over code

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

False

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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)`

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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

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Converting an If Statement

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

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

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Jump over true part

```
        cmp   rcx, 21
        jl    End

        #true block

    End:
```

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

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Jump over true part

```
        cmp   rcx, 21
        jl    End

        #true block

    End:
```

Jumps over true part

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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!*

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Else Clause

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


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Jump over true part

```
        cmp  rcx, 21
        jl   Else

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

Jump to false block

False block flows down to End

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Jump over true part

```
        cmp  rcx, 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

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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

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If Statement – No Else

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

Jumps to true block

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If Statement – No Else

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

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

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If Statement with Else

```
        cmp   rcx, 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

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While Loops

Doing the same thing again and again
… and again

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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

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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 :(

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Converting an While Statement

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

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

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Converting an While Statement

```
While:
    cmp  rcx, 21
    jge  End

    #true block
    jmp  While
End:
```

Loop after block executes

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Converting an While Statement

```
While:
    cmp  rcx, 21
    jge  End

    #true block
    jmp  While
End:
```

Escape infinite loop

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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

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Alternative Approach

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


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Alternative Approach

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

Jumps to Do Block

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Alternative Approach

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

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

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Alternative Approach

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

Repeat the loop

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Do Loops

Post-Test While Loops

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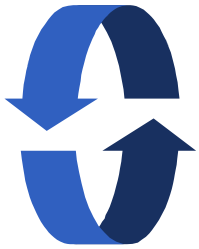
Do Loops

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



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Converting Do Loops

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

We jump UP when TRUE

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Converting Do Loops

```
Do:
    #true block

    cmp  rcx, 21
    jl   Do
```

Positive logic

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Alternative Approach

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

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Alternative Approach

```
Do:
    #true block

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

Negative logic

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Alternative Approach

```
Do:
    #true block

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

Infinite loop

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Switch Statements on the x86

Reason for the C, Java, and C# design

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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

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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

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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

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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

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C/Java Code

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


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Assembly Code

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

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


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Assembly Code

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

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

Jump header

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Assembly Code: Jump Header

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

case 10:

case 11:

default:

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Assembly Code

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

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

Case Body

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Assembly Code: The Case Body

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

Each "falls through". They are just labels!

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Fall-Through Labels

```
10
Halloween
Thanksgiving
Christmas
```


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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

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Java Code

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

Let's jump to the end

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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

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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

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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

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Primes: Jump Header

```
mov  rcx, number

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

jmp  default
```

These are our primes

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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.

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