


# A Quick Start Guide to CS/COE 0447

Informal discussion about basic concepts

We'll refine and more formally define many of this material over the next few weeks!!!

## Digital Computer

- Stores information and operates on discrete numbers, proceeding in discrete steps from one "instruction" to the next
- Basic representation is "**binary number**"
  - Each numeric *binary digit* (a *bit*) is a "0" or "1". **Base-2 number**.
  - Put several digits together for a larger number (e.g., 0101b is 5d)
- Binary numbers used for many items
  - Characters (letters, like 'A', 'B', 'C', …)
  - Positive & negative integer numbers (no decimal point)
  - Fractional numbers (with a decimal point)
  - Pixels (dots) on a graphics display
- Binary number as a sequence of 0s and 1s
  - 0100 0001 is a 8-bit binary number (byte)
  - Represents the character 'A' in the ASCII encoding (later)
  - Represents the decimal number 65

## Binary Numbers

- Computer operates on a **"native" fixed-size binary quantity**
  - 4-bit computer: Native size is a binary number with **4 bits** (nibble)
  - 8-bit computer: Native size is a binary number with **8 bits** (byte)
  - 16-bit computer: Native size is a binary number with **16 bits** (halfword)
  - 32-bit computer: Native size is a binary number with **32 digits** (word)
  - 64-bit computer: Native size is a binary number with **64 digits**
  - 36-bit computer: Native size is a binary number with **36 digits**

## Binary Numbers

Really just a ***different representation*** for a quantity

How many ways can we represent these animals?

"Ten happy cows"

"Dix vaches heureux "

"10 cows"

10 (decimal quantity)

**1010b (base-2 quantity for 10 decimal)**

**110001b 110000b (base-2 quantity for characters '1', '0')**

Ah (base-16 quantity for 10 decimal)

12o (base-8 quantity for 10 decimal)

## Other Representations

- Base-10 numbers (decimal)
  - Each digit represents one of ten values
  - 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
- Base-16 numbers (hexadecimal)
  - Each digit represents one of sixteen values
  - 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F
- Base-8 numbers (octal)
  - Each digit represents one of eight values
  - 0, 1, 2, 3, 4, 5, 6, 7
- Do you get the idea??? ? ☺

## A bag o' pennies!

Consider a bag of 100 pennies.

How can we represent it?

$1, 0.63 GBP, 0.76 Euro, 1 Susan B Anthony coin

OK, let's try our bases…

Base-10: 100
Base-2: 1100100b
Base-16: 64h
Base-8: 144o

## Why all this fuss?

- Binary numbers
  - Digital computers use "***on/off***" switches (***transistors***)
  - ***On*** is the binary digit 1
  - ***Off*** is the binary digit 0

- Have you written down a 32 digit binary number?

  11000010111101010001100010010011b

- What a pain! Is there a better way?

- **Base-16 (hexadecimal) is convenient notation**
  - Compact form
  - Easy and fast conversion binary <-> hexadecimal
  - Fixed sizes tend to be "chunkable" into 4s (consider slide 3)

## Hexadecimal numbers

**Compare**: 11000010111101010001100010010011b
**To**: C2F51893h

What about a 64-bit number? Which would you rather write????

**How can we convert from binary to/from hex?**

Simple, quick approach: A table approach (*we'll be more formal later*)
Construct a table that maps binary numbers to hex numbers

Hex digit is one of 16 numbers
Binary digit is one of 2 numbers

We need one hex digit for every four binary digits (4 digits, 2 per digit = $2^4$ = 16)

## How to count in binary?

Suppose, we add two 1-bit binary numbers:

0 + 0 = 0 0 + 1 = 1 1 + 0 = 1

But what about 1 + 1?

It's just like decimal numbers. We must carry the one:

```
   1       10       11      100
 + 1      + 1      + 1     +  1
 ---      ---      ---     ----
  10       11      100      101
```

We have to **carry the one** since a single bit is only 0 or 1

## Binary - Hex Table

Count from 0 to 15 in binary, then write hex digit

| binary | hex | binary | hex |
|---|---|---|---|
| 0000 | 0 | 1000 | 8 |
| 0001 | 1 | 1001 | 9 |
| 0010 | 2 | 1010 | A |
| 0011 | 3 | 1011 | B |
| 0100 | 4 | 1100 | C |
| 0101 | 5 | 1101 | D |
| 0110 | 6 | 1110 | E |
| 0111 | 7 | 1111 | F |

remember how to add in binary, e.g.,:

```
   0001      0101      1011
+  0001   +  0001   +  0001
   ------    ------    ------
   0010      0110      1100
```

## Use table to convert

For **every four binary digits, look up the hex symbol**
Write the **hex symbol in corresponding position** for four binary digits
e.g., 00001110001111010000100011000100b

Grouped into "chunks" with four binary digits per chunk:

| 0000 | 1110 | 0011 | 1101 | 0000 | 1000 | 1100 | 0100 |
|---|---|---|---|---|---|---|---|
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| 0 | E | 3 | D | 0 | 8 | C | 4 |

To go from hex to binary, simply do this process in reverse.

## Converting Decimal to/from Binary

- How can we convert between decimal and binary?

- Binary numbers represent "sums of powers of 2"
- We can exploit this property to easily convert

- From decimal to binary
  - You are given the binary number size (e.g., 8 bits, 16 bits, 32 bits)
  - Write decimal number as a ***sum of powers of 2***
  - Each exponent value determines a ***"position"*** in the binary number
  - Positions numbered ***0 to number size – 1***
  - Positions ordered right to left (0 is rightmost, number size – 1 is left)
    - 8-bit number: $bit^7$ $bit^6$ $bit^5$ $bit^4$ $bit^3$ $bit^2$ $bit^1$ $bit^0$
  - Write "1" in exponent position for each power of 2 in sum
  - Write "0" in all other positions

## Example: Decimal to Binary

- Suppose 8 bit number
- Consider 63 decimal

- What are the powers of 2 for 63?
- How many "positions" are in the binary number?
- Which positions have 1s and which ones have 0s?
- Write down the 1s and 0s for the number?

- Answers:
  - $63 = 32 + 16 + 8 + 4 + 2 + 1 = 2^5 + 2^4 + 2^3 + 2^2 + 2^1 + 2^0$
  - 8 positions b/c it's an 8-bit binary number
  - 1s in positions 0, 1, 2, 3, 4, 5 and 0s in positions 6, 7
  - 00111111

## From Binary to Decimal

- There's a "1" in any position with a power of 2 value
- Thus, we can sum the powers of 2s that correspond to the "1s positions" to get the decimal number!

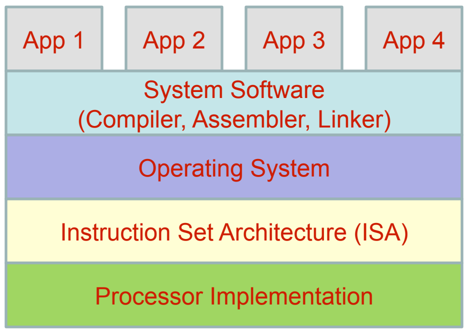
- Consider the 8-bit number: 00101101b

- What positions (powers of 2) have 1s?
- What is the sum of the powers of 2?

- Answer:
  - Positions 0, 2, 3, 5
  - Sum is: $2^0 + 2^2 + 2^3 + 2^5 = 45$ decimal

## System layers

- Computer system consists of several "layers"
- It's stack of components that work together

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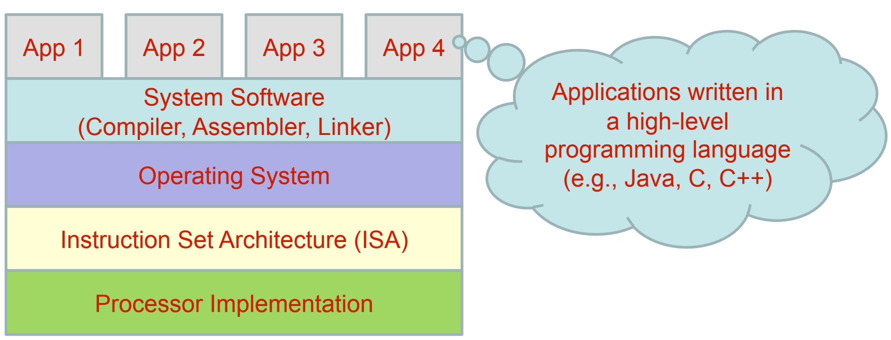

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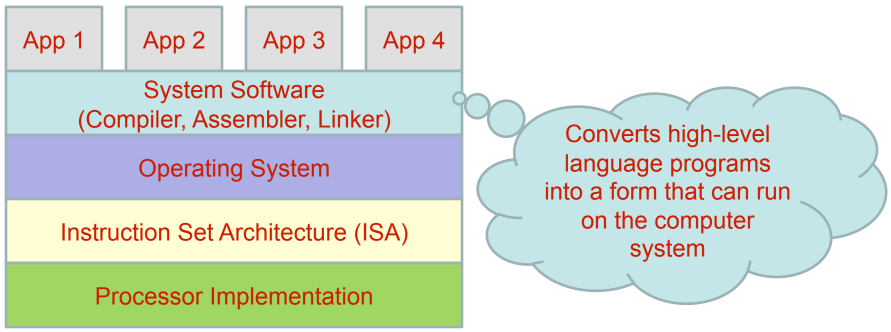



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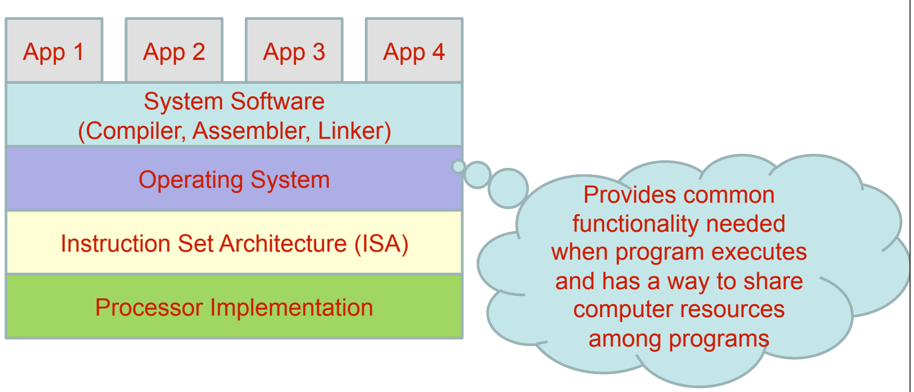

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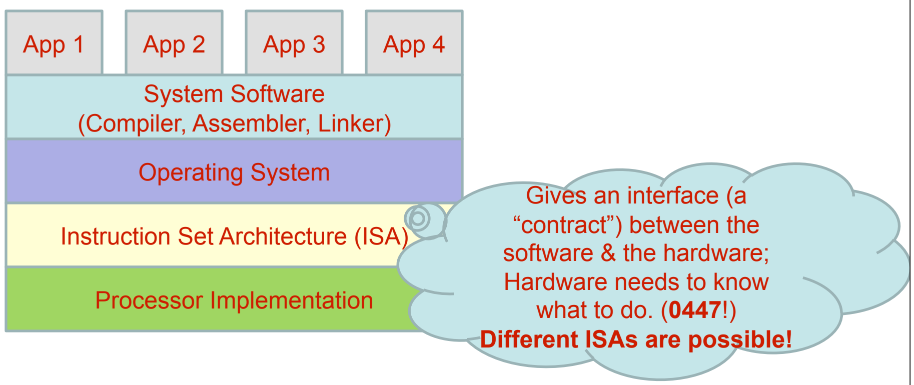


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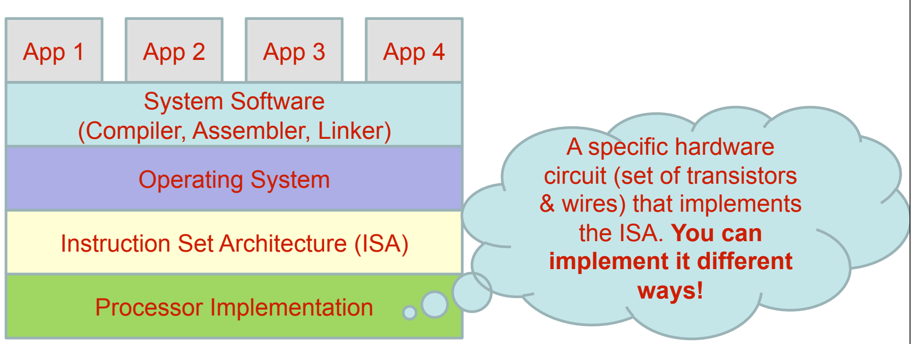


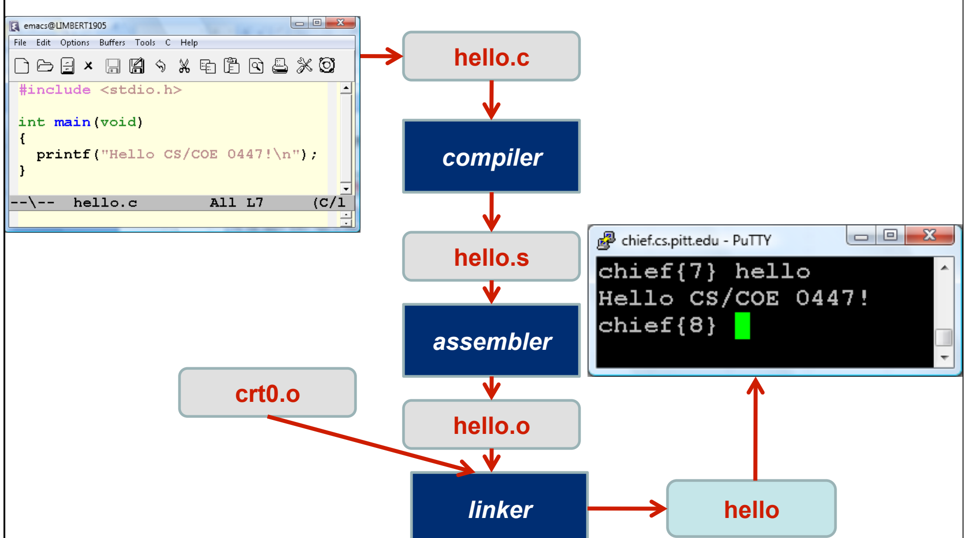
## From a C (C++ or Java) program to running it

- Software tools: Compiler, Assembler, Linker
  - Convert the HLL ***program into machine code***
  - Processor (computer system) ***fetches & executes machine code***
  - It doesn't "know" C, C++ or Java!

- Once program converted into machine code:
  - Program is stored in memory
  - **Processor fetches** one instruction at a time (the conveyor belt)
  - **Processor executes** the instruction until done (the control tower)
  - Continues executing instructions until program is done

- This is the "**fetch-execute cycle**". Fetch an instruction, execute it.

## From a C (C++ or Java) program to running it



## Assembly language and machine code

- Instruction set architecture
  - Describes the "***machine instructions***" that the processor can execute
  - Instructions say ***what computation to do*** (e.g., add two numbers)
  - Gives other details, such as temporary storage locations
  - ***Registers are "temporary storage"*** that can be used in computations
  - Many different instruction set architectures (Intel x86, Sun SPARC, etc)

- Assembly language
  - Simply a ***human readable form to write instructions***
  - It's a programming language, much like Java, C++ or C
  - Except it's at the ***lowest level of the software stack***
  - Many different assembly languages, usually one for each ISA

- Machine instructions (a.k.a., "machine code")
  - Simply a machine readable form of instructions
  - A machine instruction is simply a binary number!

## A little example

Let's add three numbers: 10, 20, 30

Here's a C program:

```
int main(void) {
    int sum;
    sum = 10 + 20 + 30; // sum is 10+20+30=60
}
```

Here's a MIPS program (assembly language):

```
addiu     $5,$0,10     ; $5 is register, $5=0+10=10
addiu     $5,$5,20     ; adds 20 to $5, $5=10+20=30
addiu     $5,$5,30     ; adds 30 to $5, $5=30+30=60
```

*The addition is done as three separate computations (0+10,10+20,30+30)*
*Register $5 is needed as temporary storage to hold sum between computations*

## A little example

Here's a MIPS program (assembly language):

```
addiu $5,$0,10    ; $5 is register, $5=0+10=10
addiu $5,$5,20    ; adds 20 to $5, $5=10+20=30
addiu $5,$5,30    ; adds 30 to $5, $5=30+30=60
```

How about the machine code?

Assembler converts the above form into binary numbers

```
0x2405000a        binary for addiu $5,$0,10
0x24a50014        binary for addiu $5,$5,20
0x24a5001e        binary for addiu $5,$5,30
```

note: 0x notation means the number that follows is hexadecimal

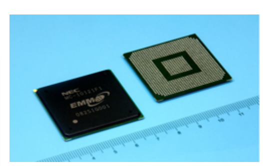
## A Loop on Two Architectures

How much does the assembly language differ between ISAs?

```
int main(void)
{
   int i, sum;
   sum = 0;
   for (i = 0; i < 10; i++)       // sum numbers 0 to 9
   sum = sum + i;
}
```

The assembly language and machine instructions for this program were created for two different instruction sets:

Sun SPARC processor
MIPS processor

## A Loop on Two Architectures

C program

```
int main(void) {
   int i, sum;

   sum = 0;
   for (i=0;i<10; i++)
        sum=sum+i;
}
```

Let's see this loop on the SPARC and MIPS processors.

Careful look at the assembly and the machine code!

## A Loop on Two Architectures

C program

```
int main(void) {
   int i, sum;

   sum = 0;
   for (i=0;i<10; i++)
        sum=sum+i;
}
```

Compiler

SPARC Assembly

```
     mov     0,%o1
     mov     0,%g1

L2:  add     %o1,%g1,%o1
     add     %g1,1,%g1
     cmp     %g1,10
     blt     L2
     ...
```

Compiler translates the C program into a sequence of assembly language instructions for the Sun SPARC processor.

## A Loop on Two Architectures

**C program**

```
int main(void) {
   int i, sum;

   sum = 0;
   for (i=0;i<10; i++)
        sum=sum+i;
}
```

Compiler

**SPARC Assembly**

```
     mov      0,%o1
     mov      0,%g1

L2:  add      %o1,%g1,%o1
     add      %g1,1,%g1
     cmp      %g1,10
     blt      L2
     ...
```

**MIPS Assembly**

```
     move     $5,$0
     move     $3,$0

L2:add      $5,$5,$3
   addi     $3,$3,1
   slti     $2,$3,10
   bne      $2,$0,L2
   ...
```

The same C program can be translated by a compiler for the MIPS processor as well.

Do you see differences?

## A Loop on Two Architectures

**C program**

```
int main(void) {
   int i, sum;

   sum = 0;
   for (i=0;i<10; i++)
        sum=sum+i;
}
```

Compiler

**SPARC Assembly**

```
     mov      0,%o1
     mov      0,%g1

 L2: add      %o1,%g1,%o1
     add      %g1,1,%g1
     cmp      %g1,10
     blt      L2
     ...
```

**MIPS Assembly**

```
     move     $5,$0
     move     $3,$0

L2:add      $5,$5,$3
   addi     $3,$3,1
   slti     $2,$3,10
   bne      $2,$0,L2
   ...
```

Assembler

**SPARC Machine Code**

```
0x9de3bf90
0x92102000
0x82102000
0x92024001
0x82006001
0x80x06009
...
```

The assembler for the SPARC converts the human readable assembly into actual machine code that the processor is able to execute (binary 32-bit numbers).

## A Loop on Two Architectures

**C program**

```
int main(void) {
   int i, sum;

   sum = 0;
   for (i=0;i<10; i++)
        sum=sum+i;
}
```

Compiler

**SPARC Assembly**

```
    mov     0,%o1
    mov     0,%g1

L2: add     %o1,%g1,%o1
    add     %g1,1,%g1
    cmp     %g1,10
    blt     L2
    ...
```

**MIPS Assembly**

```
    move    $5,$0
    move    $3,$0

L2:add      $5,$5,$3
    addi    $3,$3,1
    slti    $2,$3,10
    bne     $2,$0,L2
     ...
```

Assembler

**SPARC Machine Code**

```
0x9de3bf90
0x92102000
0x82102000
0x92024001
0x82006001
0x80x06009
...
```

**MIPS Machine Code**

```
0x00002821
0x00001821
0x00a32821
0x24630001
0x2c62000a
0x1440fffc
...
```

Similarly, the assembler for MIPS turns the assembly into machine code.

MIPS also has 32-bit instr.

Do you see differences?

## A Loop on Two Architectures

**What is the correct value for `sum`?**

- **45 in decimal**
- **101101 in binary**
- **2D in hexadecimal**
- 55 in octal (base-8 ☺ )

## Try Running the Assembly Program with MARS

The assembly file is on the CS 0447 web site:

- http://www.cs.pitt.edu/~childers/CS0447/examples/loop-mars.asm

Steps to run the program

1. Save this file to a local directory on your computer (say "foo")
2. Download the MARS simulator (see CS0447 web site).
3. Double click on the simulator icon (the jar file)
4. Select "File" -> "Open", then navigate to directory "foo", select the file "loop-mars.asm".
5. Select "Run" -> "Assemble". This assembles your program.
   - You are now in the Execute window, which shows the machine code.
6. Select "Run" -> "Go". This runs your program. It stops with:
   -- program is finished running –
7. Look in the Registers window. The value of $a1 should be 45. This is the total sum of the numbers 0 to 10.