

Computer Science CSCI 261

Computer Architecture and Assembly Language

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Information Representation

- All information (instructions and data) in a binary digital system is encoded and transmitted as binary numbers

- Notation
 - bit: 1 digit binary number
 - byte: 8 digit binary number (8 bits)
 - word: 16 digit binary number (16 bits)
 - double word: 32 digit binary number (32 bits)

- Range
 - bit: 0 to $2^1 - 1 = 1$
 - byte: 0 to $2^8 - 1 = 255$
 - word: 0 to $2^{16} - 1 = 65,535$
 - n bits: 0 to $2^n - 1$

Numbering Systems

- Binary
 - base: 2
 - digits: 0 1
- Octal
 - base: 8
 - digits: 0 1 2 3 4 5 6 7
- Decimal
 - base: 10
 - digits: 0 1 2 3 4 5 6 7 8 9
- Hexadecimal (Hex)
 - base: 16
 - digits: 0 1 2 3 4 5 6 7 8 9 A B C D E F

Numbering Systems cont.

○ Byte Representations

- decimal: 65
- binary: 01000001 0b
- hex: 41 0x
- ascii character: 'A'

○ Bit Sequence

- 65, 41 0x, 'A', 01000001 0b are equivalent

○ Bit Sequence Interpretation

- is byte an instruction, numeric data or a character?
- depends on context

Positional Numbering Systems

○ Counting

| Decimal | Binary | Octal | Hex |
|---------|--------|-------|-----|
| 0 | 0000 | 0 | 0 |
| 1 | 0001 | 1 | 1 |
| 2 | 0010 | 2 | 2 |
| 3 | 0011 | 3 | 3 |
| 4 | 0100 | 4 | 4 |
| 5 | 0101 | 5 | 5 |
| 6 | 0110 | 6 | 6 |
| 7 | 0111 | 7 | 7 |
| 8 | 1000 | 10 | 8 |
| 9 | 1001 | 11 | 9 |
| 10 | 1010 | 12 | A |
| 11 | 1011 | 13 | B |
| 12 | 1100 | 14 | C |
| 13 | 1101 | 15 | D |
| 14 | 1110 | 16 | E |
| 15 | 1111 | 17 | F |
| 16 | 10000 | 20 | 10 |

Positional Numbering Systems

○ Addition

| | |
|--------|------|
| A24 0x | 743 |
| 195 0x | 373 |
| <hr/> | |
| BB9 0x | 1116 |

| | | | | | | | | |
|-------|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | |
| 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | |
| <hr/> | | | | | | | | |
| 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |

Converting to Decimal

○ Decimal To Decimal

- e.g. $354 = 4 * 10^0 + 5 * 10^1 + 3 * 10^2$

○ Binary To Decimal

- e.g. $1010b = 1 * 2^0 + 0 * 2^1 + 1 * 2^2$

○ Hex To Decimal

- e.g. $A0B0x = 11 * 16^0 + 0 * 16^1 + 10 * 16^2$

○ $x_{n-1}..x_2 x_1 x_0$ in base N To Decimal

- $\sum x_i * N^i (0 \leq i < n)$

Converting to Binary

○ Decimal To Decimal

- not useful, for demonstration purposes only

e.g. 341

$$\begin{array}{r} 10 \overline{) 341} \\ 10 \overline{) 34} \quad + 1 \\ 10 \overline{) 3} \quad + 4 \\ 0 \quad + 3 \end{array}$$



Converting to Binary cont.

○ Decimal To Binary

e.g. 4

$$2 \overline{) 4}$$

$$2 \overline{) 2} + 0$$

$$2 \overline{) 1} + 0$$

$$0 + 1$$



Most significant bit (msb)

All Other Conversions

○ Binary ↔ Octal ↔ Hex

e.g. 2A 0x

0 0 1 0

2

1 0 1 0

A

(Hex)

0 0 0

0

1 0 1

5

0 1 0

2

(Octal)

Computer Arithmetic

- Subtracting By Adding (Ns Complement)
 - consider a number x in base N with n digits
 - the Ns complement of x is $N_c = N^n - x$
 - assume two numbers a and b are in the same base with the same number of digits
 - a minus b is achieved by adding a to the Ns complement of b

Computer Arithmetic cont.

○ Decimal (10s Complement)

e.g. $n = 2$ $x = 12$ $N = 10$

10s Complement of $x = 100 - 12 = 88$

$$\begin{array}{r} - \quad 12 \\ \quad 12 \\ \hline \quad 00 \end{array} \quad \longrightarrow \quad \begin{array}{r} 12 \\ \quad 88 \\ \hline 1 \quad 00 \end{array} \quad +$$

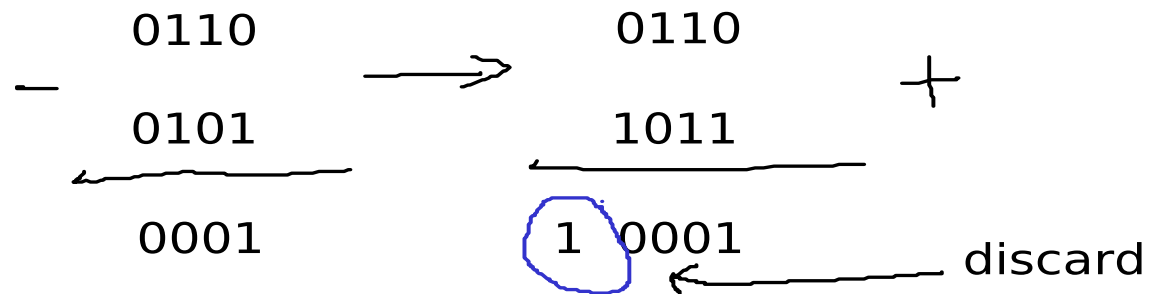
← discard

Computer Arithmetic cont.

○ Binary (2s Complement)

e.g. $n = 4$ $x = 5 = 0101$ $N = 2$

2s Complement of $x = 16 - 5 = 11 = 1011$



Computer Arithmetic cont.

○ Binary (2s Complement)

- easy way to get 2_c of x is to complement each digit in x and add 1 to the result

e.g. $n = 4$ $x = 5 = 0101$ $N = 2$

2s Complement of $x = 1010 + 1$

$$\begin{array}{r} 1010 \\ 1 \\ \hline 1011 \end{array} +$$

Different Representations (4 bits)

| Binary | Unsigned | Sign Magnitude | 2s Complement |
|--------|----------|----------------|---------------|
| 0000 | 0 | 0 | 0 |
| 0001 | 1 | 1 | 1 |
| 0010 | 2 | 2 | 2 |
| 0011 | 3 | 3 | 3 |
| 0100 | 4 | 4 | 4 |
| 0101 | 5 | 5 | 5 |
| 0110 | 6 | 6 | 6 |
| 0111 | 7 | 7 | 7 |
| 1000 | 8 | -0 | -8 |
| 1001 | 9 | -1 | -7 |
| 1010 | 10 | -2 | -6 |
| 1011 | 11 | -3 | -5 |
| 1100 | 12 | -4 | -4 |
| 1101 | 13 | -5 | -3 |
| 1110 | 14 | -6 | -2 |
| 1111 | 15 | -7 | -1 |