COMPUTER ORGANIZATION

DATA REPRESENTATION

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CONTENT

- WHAT & WHY
- HOW
- INTEGERS
- REAL NUMBERS
- THE JAVA/C CONNECTION
- EXERCISES

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WHAT & WHY

- What
  Convert any data type to bits
- WHY
  Computer memory consists of bits
- MEMORY MODEL
  b/B, LSb/MSb, Kb/KB, MB, GB, TB
  Block, LSB/MSB, Endianness
  ```
  0=0000, 1=0001 … 9=1001
  A=1010, B=1011 … F=1111
  ```
- The 2^n Rule

0	
.	
.	
.	
24	1111 0000 *x*
25	1010 1010 *y*
26	1111 1111 *z*
27	0000 0000
28	0000 0000 *t*
29	0000 0000
30	1111 1111
31	1111 1111
.	
.	

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HOW

Strategy: *Convert any data type to numbers!*

- STRINGS
  Codes (ASCII, Unicode, ...)

- PICTURES
  Raster graphics plus RGB

- Media
  Video clips, audio, ...

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UNSIGNED INTEGERS

- THE BINARY SYSTEM
  Positional notation and powers of 2

- CONVERTING TO/FROM DECIMAL
  Repeated division

- Left/Right Shifts

- Arithmetic Shifts and Rotation

- Arithmetic in Binary
  Add, sub, mult, and div in binary

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SIGNED INTEGERS

- THE 2'S COMPLEMENT SYSTEM
  A sign bit w/o a sign bit!

- CONVERTING TO/FROM DECIMAL
  Not simple

- A Neat Observation
  What is x + ~x

- Arithmetic Right Shifts

- Sign-Extension vs. Zero-Extension
  Enlarging the block size

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THE MAGIC OF 2'S COMP

Compute 0x4E + 0xA3

```
0x4E =
0xA3 =
```

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THE MAGIC OF 2'S COMP

Compute 0x4E + 0xA3

```
0x4E = 0 1 0 0 1 1 1 0    78     +78
0xA3 = 1 0 1 0 0 0 1 1   163     -93
0xF1 = 1 1 1 1 0 0 0 1   241     -15
```

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REAL NUMBERS

- **THE CHALLENGE**
  Enormous range and high accuracy!

- **KEY IDEA**
  Exact magnitude + Diminishing accuracy

- **IEEE-754**
  Single-Precision (float) 32-bit
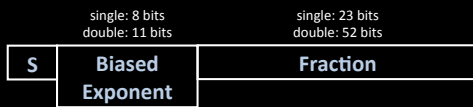 *Double-Precision (double) 64-bit*

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IEEE-754

	single: 8 bits double: 11 bits	single: 23 bits double: 52 bits
S	**Biased Exponent**	**Fraction**

$$x = (-1)^S \times (1 + \text{Fraction}) \times 2^{\text{Exponent}}$$

1. Normalize to 1.fraction times exponent
2. Bias the exponent by adding 127/1023 → make it unsigned

- Biased Exponents 00...00 and 11...11 are reserved
- Biased Expo 0 (denormalized) and Fraction 0 is 0
- Biased Expo 11...11 and Fraction 0: Infinity
- Biased Expo 11...11 and Fraction != 0: NaN

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EXAMPLES

- 13.75
  Single: 0x415C 0000
  Double: 0x402B 8000 0000 0000

- -15.2
  Single: 0xC173 3333
  Double: 0xC02E 6666 6666 6666

- 0.001
  Single: 0x3A83 126F
  Double: 0x3F50 624D D2F1 A9FC

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THE JAVA/C CONNECTION

Types	Values
byte x;	use 0x for hex
short z;	
char c;	
float f;	
double d;	

Operators	Unsigned
& | ^ ~	Java: char only
<< >> >>>	C: unsigned prefix

Methods
Integer.toBinaryString(int)
Double.doubleToLongBits(double)
BigInteger: constructor and doubleValue

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Bare Metal Java

- Linux and Mac
  Terminal Window then ssh red.eecs.yorku.ca
- Windows
  Download putty and connect to red
- Editor
  pico, nano, vim, …
- Compile
  java file.java → file.class
- Run
  java file

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Exercises

- *Consider the bit pattern 0xAFC7 and imagine shifting all its bits left by one position. Show that it becomes 0x5F8E*

- *Represent the unsigned integer 75*

- *Determine the decimal value of the unsigned integer 0x4A.*

- *Given an unsigned integer k, how many bits are needed to represent it?*

- *Compute largest unsigned integer that can fit in one, two, four, and eight bytes. Are your answers consistent with the 2^n rule?*

- *How many bytes are needed to store a 640 x 320 coloured picture using 16 colour shade for each of Red, Green, and Blue?*

- *Size of a 10 min 1920 x 1080 @ 25 fps video clip with 16b RGB*

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Exercises

- *Represent the signed integer -75*

- *Determine the decimal value of the signed integer 0x4A.*

- *Why does sign extension work?*

- *Compute smallest and largest signed integer that can fit in one, two, four, and eight bytes. Are your answers consistent with 2^n ?*

- *Represent 17.4 as a float*

- *What is the decimal value of the float: 11000000101000…00*

- *What is the largest possible IEEE float? How about double?*

- *How many floats are there between 64,005 and 64,006*

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