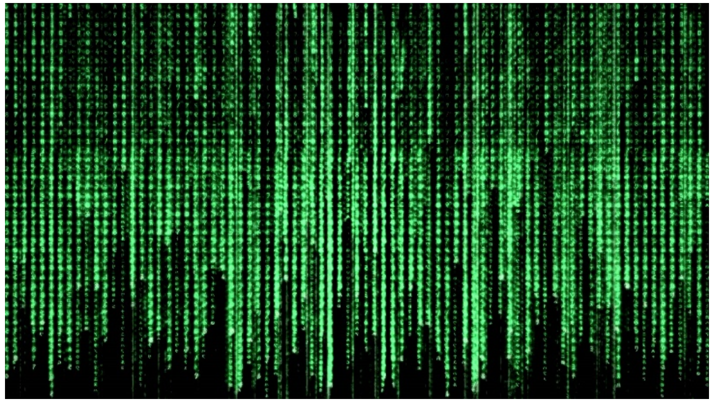
DATA REPRESENTATION

Problem Solving with Computers-I

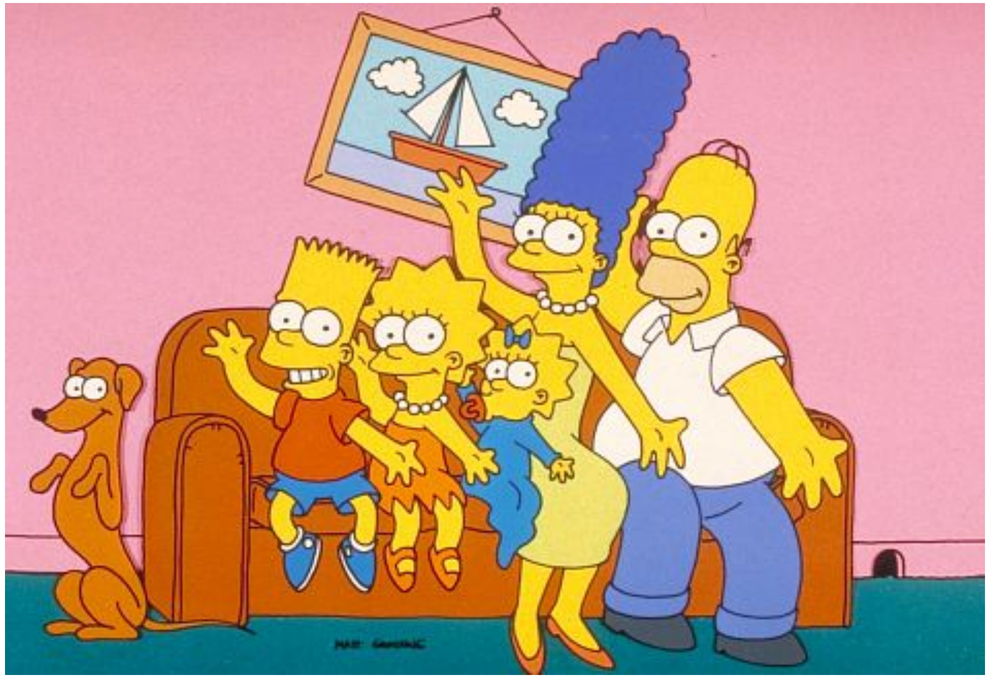
What does 'data' on a computer look like?

- Imagine diving deep into a computer
- Expect to see all your data as high and low voltages
- In CS we use the abstraction:
  - High voltage: 1 (true)
  - Low voltage: 0 (false)



Decimal (base ten)

- Why do we count in base ten?
- Which base would the Simpson's use?



External vs. Internal Representation

- External representation:
  - Convenient for programmer

- Internal representation:
  - Actual representation of data in the computer's memory and registers: Always binary (1's and 0's)

Positional encoding for non-negative numbers

- Each position represents some power of the base

Why is each base important??

101_5 = ? In decimal

A. 26

B. 51

C. 126

D. 130

Binary representation (base 2)

- On a computer all data is stored in binary
- Only two symbols: 0 and 1
- Each position is called a *bit*
- *Bits take up space*
- 8 bits make a *byte*
- *Example of a 4-bit number*

Converting between binary and decimal

Binary to decimal: $1\ 0\ 1\ 1\ 0_2 = ?_{10}$

Decimal to binary: $34_{10}=?_2$

Hex to binary

- Each hex digit corresponds directly to four binary digits
- Programmers love hex, why?

$25B_{16}$ = ? In binary

00	0	0000
01	1	0001
02	2	0010
03	3	0011
04	4	0100
05	5	0101
06	6	0110
07	7	0111
08	8	1000
09	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

Hexadecimal to decimal

$25B_{16}$ = ? Decimal

Hexadecimal to decimal

- Use polynomial expansion

- $25B_{16}$ = 2*256 + 5*16 + 11*1 = 512 + 80 + 11
  = 603

- Decimal to hex: $36_{10}=?_{16}$

Binary to hex: 1000111100

A. 8F0

B. 23C

C. None of the above

BIG IDEA: Bits can represent anything!!

Numbers	Binary Code
0	
1	
2	
3	

How many (minimum) bits are required to represent the numbers 0 to 3?

BIG IDEA: Bits can represent anything!!

Colors	Binary code
Red	
Green	
Blue	

How many (minimum) bits are required to represent the three colors?

BIG IDEA: Bits can represent anything!!

Characters

‘a’

‘b’

‘c’

‘d’

‘e’

N bits can represent at most 2^N things

What is the minimum number of bits required to represent all the letters in the English alphabet?

A. 3
B. 4
C. 5
D. 6
E. 26

BIG IDEA: Bits can represent anything!!

- Logical values?
  - 0 ⇒ False, 1 ⇒ True
- colors ?
- Characters?
  - 26 letters ⇒ 5 bits ($2^5 = 32$)
  - upper/lower case + punctuation
    ⇒ 7 bits (in 8) ("ASCII")
  - standard code to cover all the world's languages ⇒ 8,16,32 bits ("Unicode")
    www.unicode.com
- locations / addresses? commands?

Red

Green

Blue

- MEMORIZE: N bits ⇔ at most 2^N things

What is the maximum positive value that can be stored in a byte?

A. 127

B. 128

C. 255

D. 256

BIG IDEA: Bits can represent anything!!

Signed numbers	Binary Code
-3	
-2	
-1	
0	
1	
2	

How many (minimum) bits are required to represent the numbers -3 to 2?

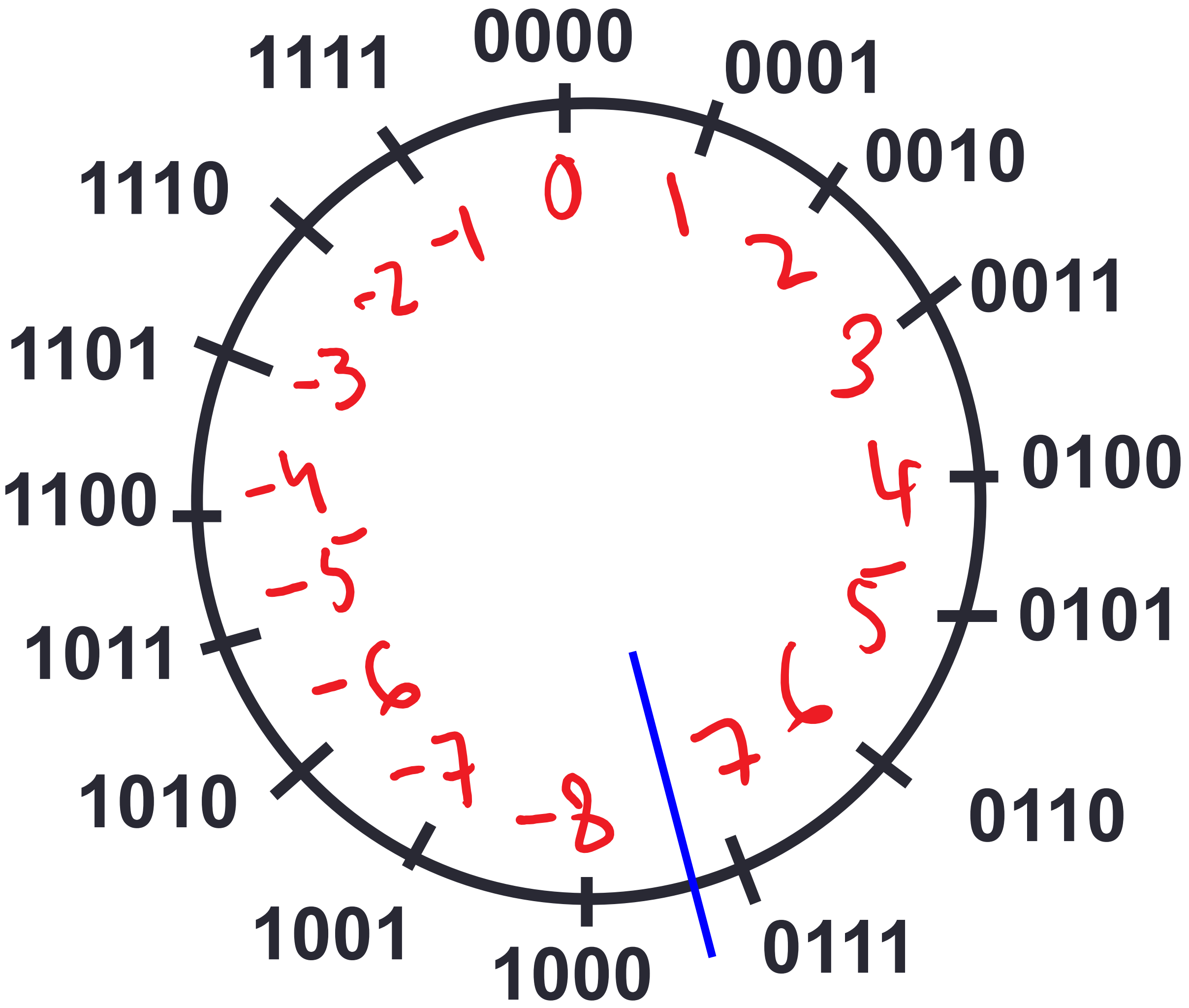
Two’s Compliment

- Most significant bit represents a large negative weight:

- To find the 2’s complement representation
  - Write unsigned representation of the number saving one bit for sign
  - Flip all the bits
  - Add 1

Two's Complement

- Flip all the bits of unsigned representation and add 1



2 - 3 = ?

Two's Complement: $1101_2 = ?_{10}$

A. -2

B. -3

C. -4

D. -5

Addition and Subtraction

- Positive and negative numbers are handled in the same way.
- The carry out from the most significant bit is ignored.
- To perform the subtraction A - B, compute A + (two's complement of B)

Data types

Binary numbers in memory are stored using a finite, fixed number of bits typically:

8 bits (byte)

16 bits (half word)

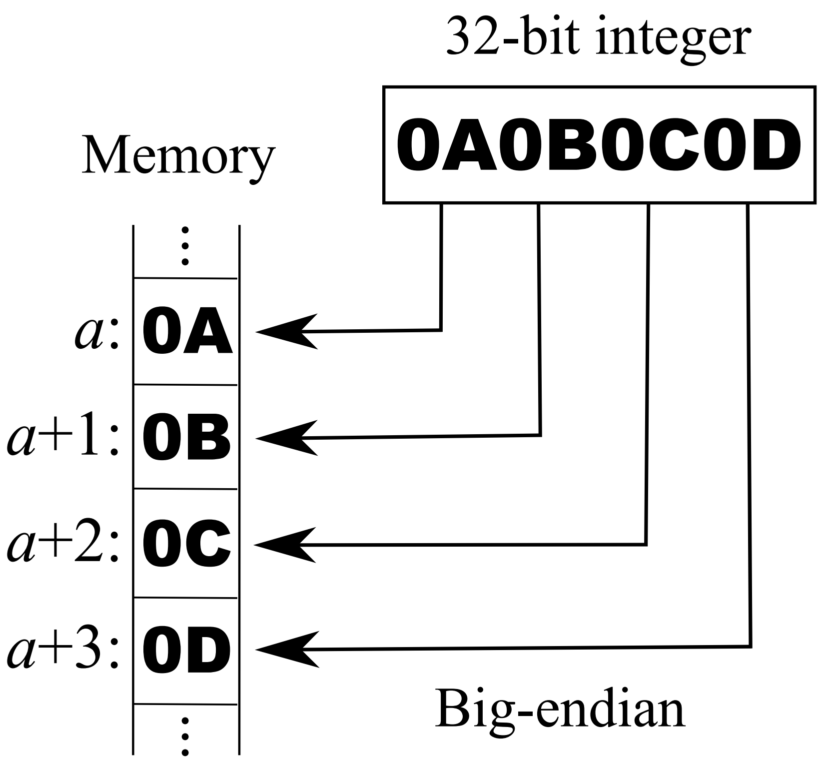
32 bits (word)

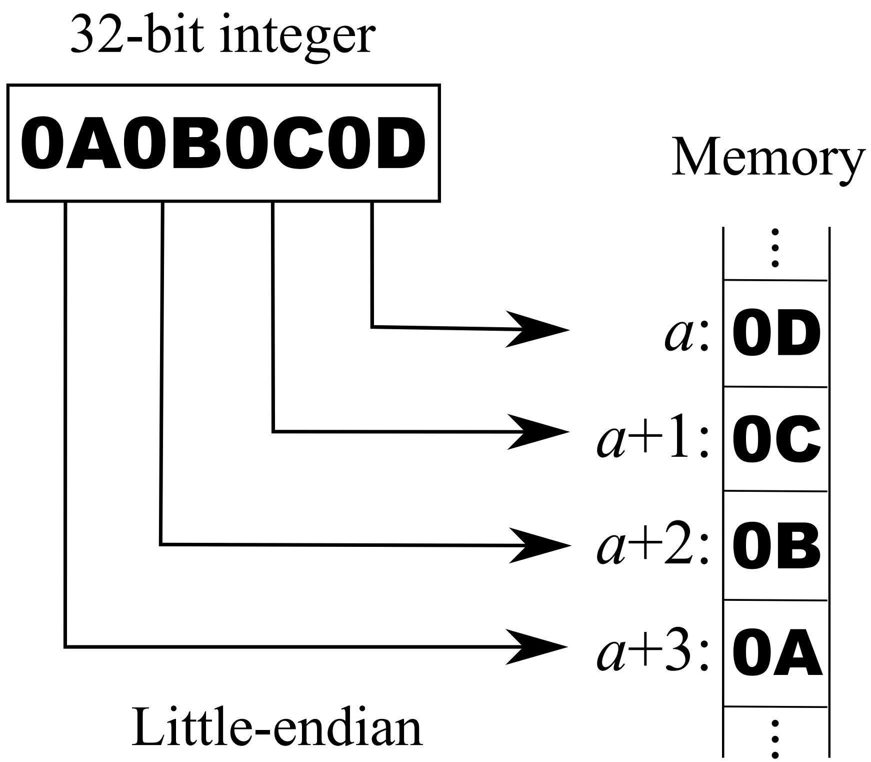
64 bits (double word or quad)

Data type of a variable determines the:

- exact representation of variable in memory
- number of bits used (fixed and finite)
  - range of values that can be correctly represented

Big/Little Endian





Bitwise operators

- || ➔ |
- && ➔ &
- ! ➔ ~
- ^ doesn't have a Boolean equivalent

- How could you use bitwise operators to figure out if a number is odd/even?