

Data Representation

- Refs: O'H&Bryant sect 2.1,2.4, Null&Lobur sect 2.5–2.7, Tanembaum appendix B, related web links
- bit, byte and word
- characters and strings, ASCII
- big-endian, little-endian
- representing real numbers

Bit, Byte and Word

- basic unit of memory is the bit (Binary digit)
- one bit is too small to be generally useful, so bits are grouped together:
 - byte: 8 bits (e.g. 1010 1010 or 1000 0001)
 - word: 1, 2, 4 or 8 bytes (usually 2 or 4)
 - word length depends on processor, operating system, etc. (e.g. 8 bytes for Intel's I-64 or Compaq Alpha architectures)
- data and machine instructions are stored and accessed in words (in memory)
- 1 Kilobyte (KB) = 1024 bytes = 2^{10} bytes
- 1 Megabyte (MB) = 1024 KB = 1,048,576 bytes
- 1 Gigabyte (GB) = 1024 MB
- typical modern computers have millions of bytes of memory (e.g. PC with 512 Megabytes, servers 4-16 Gigabytes)
- CD-ROMs store around 650 Megabytes (MB)
- DVDs store around 4.7 Gigabytes (GB), up to 17 GB

Characters and Strings

- text can be stored in memory by using a number to represent every character
 - ASCII (American Standard Code for Information Interchange): 7 bits, 128 characters
 - EBCDIC: Extended Binary-Coded Decimal Interchange Code (8 bits)
 - UCS/UNICODE: attempts to extend ASCII to other languages (65,536 characters)
- a string is a sequence of characters, usually terminated with a byte value of 0
- example: 43 4F 4D 50 32 33 30 30 0₁₆

Big-endian versus Little-endian Integers

- small (how small?) integers are sometimes stored in one byte
- most integers are stored in (longer) words; how are they arranged in memory?

Example: 126540713_{10} stored in 4 bytes: $00000111\ 10001010\ 11011011\ 10101001_2$

Address	big-endian	little-endian
FF_{16}	10101001	00000111
FE_{16}	11011011	10001010
FD_{16}	10001010	11011011
FC_{16}	00000111	10101001

- big-endian stores the most significant byte (MSB) at the lowest address in the word, little-endian in the highest (origin of term endian)
- similar to use of `me@cs.anu.edu.au` OR `me@au.edu.anu.cs` (e.g. JANET network in the UK)
- little endian: (Intel) more natural and consistent way to pick up 1, 2, 4, or longer byte integers (making multi-precision arithmetic easier)
- big endian: (SPARC, IBM) MSB first gives easy testing of +ve/-ve. Numbers stored in order they are printed, making binary to decimal conversion easier
- potential confusion in communication with differing endianness!

Representing Real Numbers: Fixed and Floating Point

- fixed-point numbers:

- a fixed number of bits for the integer component and a fixed number of bits for the fractional component
- needs a large number of bits to represent a useful range
- e.g. mass of electron is 9×10^{-28} grams, mass of the sun is 2×10^{33} , a range of 10^{60} !

need 200 bits to cover this range. \Rightarrow 200 bits of precision with solar masses (wasteful), but only a couple of bits with atomic masses (inaccurate)

- floating point numbers:

- similar to scientific notation: $x = f \times 10^e$ e.g. $3.141 = 0.3141 \times 10^1$
- general form $x = -1^s \times m \times 2^e$
 - ◆ 1 bit for sign (s : 0 - positive, 1 - negative)
 - ◆ precision is determined by the number of bits used for the mantissa (m)
 - ◆ range is determined by the number of bits used for the exponent (e)
- floating point numbers are usually normalised, e.g. $x = -1^s \times 1.m \times 2^e$

Floating Point Formats

- e.g. 32-bit IEEE 754 standard (float)

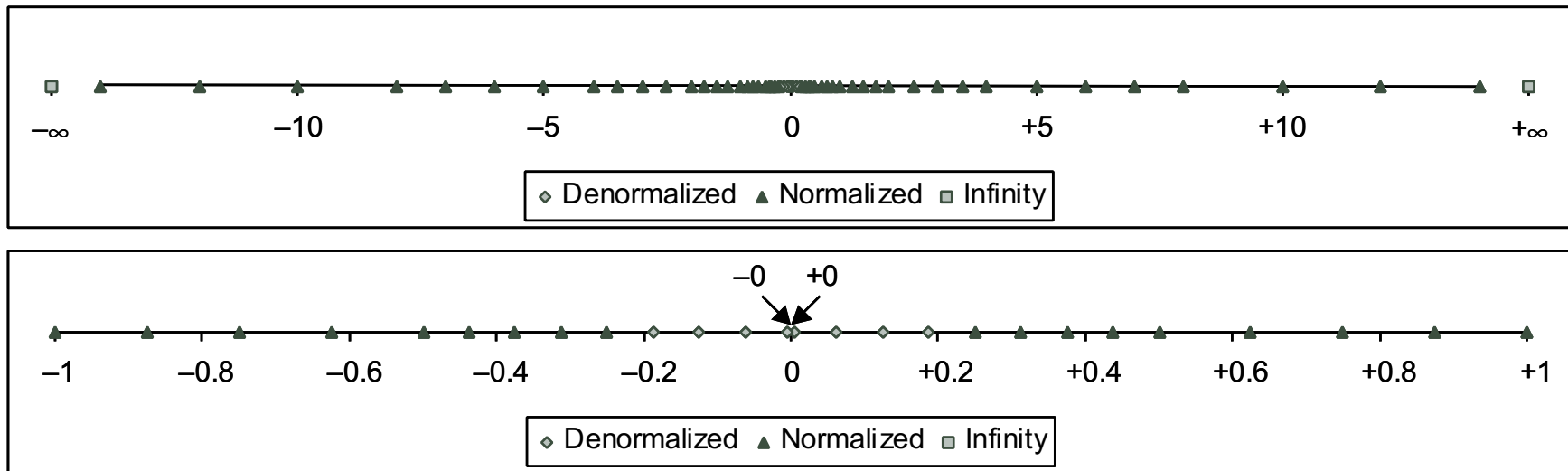
s	eeeeeeee	mmmmmm	mmmmmmmm	mmmmmmmm
1 bit	8 bits		23 bits	
sign	exponent		mantissa	

- e.g. 64-bit IEEE 754 (double): 1 bit sign, 11 bits exponent, 52 bits mantissa
- IEEE 754 standard also defines specific formats, behaviours and special values, like (+/-) infinity and not-a-number (NaN: e.g. error, not defined variable)
- some processors work with 80 bits internally, and store result back as 64 bits
- question: what is the final value of x in:

```
int i; float x = 0.0;
for (i=0; i < 1073741824 /* 2^30 */; i++)
    x = x + 1.0;
```

Floating Point Pitfalls: 'REALs aint Reals'

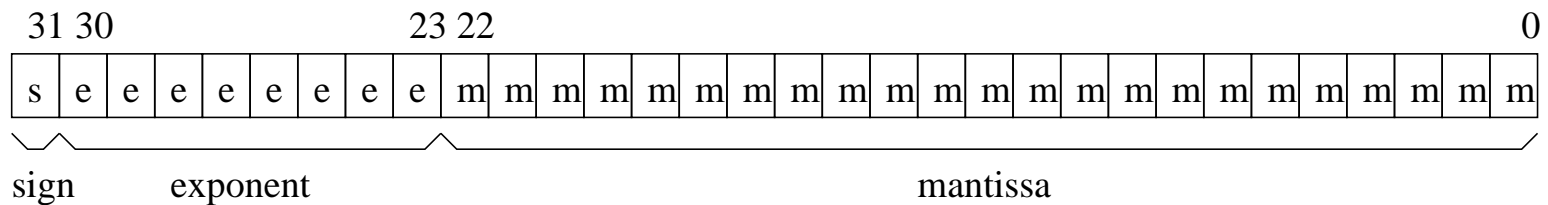
- from O'H&Bryant sect 2.4.3, fig 2.22: representable values in an 8-bit f.p. format



- not all numbers can be represented:
 - overflow: numbers bigger than $\text{maximum_mantissa} \times 2^{\text{maximum_exponent}}$
 - underflow: numbers smaller than $\text{minimum_mantissa} \times 2^{\text{minimum_exponent}}$
- rounding errors can & do accumulate to become significant
 - e.g. Patriot Missile System

IEEE 754 Single Precision - Details

- mantissa (m) is represented in 23 bits
 - since a normalized form is used, the leading '1.' is not represented explicitly
 - thus we have a precision of $2^{-24} \approx 10^{-7}$
- the exponent (e) is stored in 8 bits, with 127 added to the actual value
(thus e is an unsigned number, representing values from -127 to 128)
- thus, the number represented is $-1^s \times 1.m \times 2^{e-127}$



- what *tradeoffs* are involved here?
- zero is represented by a special bit pattern (of all 0's) – why is this important?
- e.g. $1.0 = -1^0 \times 1.00 \dots 0 \times 2^{127-127}$ has $s = 0_2$, $m = 000 \dots 0_2$, $e = 0111 1111_2$;
hex code $3F800000$
 $-2.5 = ?$