

Floating Point

Ref: 2.4

Decimal Floating Point

3.141593

“decimal point”

6.02×10^{23}

Scientific Notation

33.33333...

Normalized Numbers

1.0×10^{-9}

Binary Floating Point

100.0100

Binary Point

1.111111...

*Positional Representation
(negative powers of 2)*

$.001 \times 2^5$

Normalized Numbers

1.001×2^{17}

Binary Normalization

Normalized: one *digit*
to the left of the binary point.
It must be a 1!

$$101.0111 \times 2^{13}$$

↓ **normalize**

$$1.010111 \times 2^{15}$$

We still use the term *digit*,
although we mean "0" or "1".

$$1.010111 \times 2^{00001111}$$

↑ **exponents are binary !**

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Representation

- For each binary floating point number we need:
 - sign
 - significand (mantissa).
 - exponent
 - need a signed exponent!

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Choices

- Suppose we want to store floating point numbers in 32 bits.
 - we need to decide how many bits should be used for the significand and how many for the exponent.
 - There is a tradeoff between *range* and *accuracy*.

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Desirable properties of a floating point format.

- Large Range – large and small exponents
- High Accuracy – make the most out of the significand.
- We want it to be *easy* to compare two numbers.

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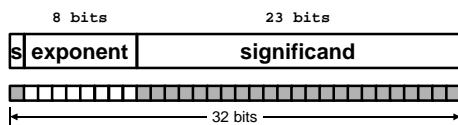
IEEE 754 floating point standard

- Folks realized that it was silly to have different floating point formats on different computers:
 - sharing of data was a hassle.
 - an algorithm written to work with one format might need to be adjusted to work with other formats.
- Today, just about all computers support IEEE 754 format.

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32 bit IEEE 754 format



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Sign and Magnitude

- Sign Bit:
– 0 means positive, 1 means negative

Value of a number is:

$$(-1)^s \times F \times 2^E$$

← **exponent**

↑ **significand**

*as we will see,
IEEE 754 is more
complex than this!*

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Normalized Numbers and the significand

- Normalized binary numbers *always* start with a 1 (the leftmost bit of the significand value is a 1).
- Why store the 1 (it's always there)?
- IEEE 754 uses this, so the significand is really 24 bits (but only 23 need to be stored).
- All numbers must be normalized!

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A Tradeoff

- If $-x$ is the smallest exponent (most negative), then the smallest number that can be represented as a normalized number:

$$1.000000000000000000000000 \times 2^{-x}$$

- If we don't require normalization we could represent

$$0.000000000000000000000001 \times 2^{-x-23}$$

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Denorms

- IEEE 754 actually supports *denormalized* numbers, but not all vendors support this part of the standard.
 - it adds a lot of complexity to the implementation of floating point arithmetic.
 - complexity means loss of speed (usually).

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Exponent Representation

- We need negative and positive exponents.
- Could use 2s complement notation
 - this would make comparison of floating point numbers a bit tricky.
 - exponent value 11111111 is smaller than 00000000.
- Instead they chose a *biased* representation.
 - exponent values are offset by a fixed bias.

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32 bit IEEE 754 exponent

- The exponent uses 8 bits.
- The *bias* is 127.
 - treat the 8 bit exponent as an unsigned integer and subtract 127 from it.

00000001 is the representation for -126

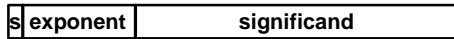
10000000 is the representation for +1

11111110 is the representation for +127

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Comparing Numbers

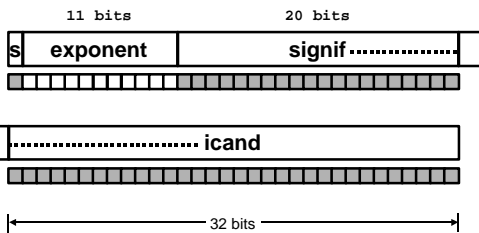


- Comparison of *normalized* floating point numbers:
 - check sign bits
 - check exponents.
 - unsigned integer comparison works. Larger exponents are represented by larger unsigned ints.
 - check significand.

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Double Precision



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64 bit IEEE 754

- exponent is 11 bits
 - bias is 1023
 - range is a *little* larger than the 32 bit format.
- Significand is 55 bits
 - plus the leading 1.
 - accuracy is much better than 32 bit format.

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Example Representations

$0.75_{10} \rightsquigarrow \frac{1}{2} + \frac{1}{4} \rightsquigarrow 0.11 \times 2^0 \rightsquigarrow 1.1 \times 2^{-1}$

0 01111110 100000000000000000000000

s exponent

significand

↑
As unsigned int is 126.
 $126 - 127 = -1$

↑
Leading 1 is not stored!

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What number is this?

0 10000001 110000000000000000000000

s exponent

significand

You get 7 guesses.
If you get it wrong we will do 7 more of these.

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Exercises

- What is the double precision (64 bit format) representation for the number 128?
- What is the single precision format for the number -8.125 ?

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Floating Point Addition

What is the sum of $1,234,823.333 + .0011$?

- Need to line up the decimal points first!
 - This is the same as shifting the significand while changing the exponents.

$$1,234,823.333 = 1.234823333 \times 10^6$$

$$.0011 = 1.1 \times 10^{-3} = 0.0000000011 \times 10^6$$

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Binary Floating Point Addition

Just like decimal:

- Line up the binary points
 - Shift one of the numbers
- Add significands (using integer addition)
- Normalize the result
- Might need to round the result or truncate.

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Floating Point Multiplication

- 1.3×10^3 times $3.0 \times 10^{-2} = 3.9 \times 10^1$

Add exponents

Multiply significands

Normalize result.

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Rounding

- Intermediate results (in the middle of multiplication or addition operations) might not fit.
- The internal representation of intermediate values uses 2 extra bits: *round* and *guard*.

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Decimal Rounding Example

- Add 2.56 to 2.34×10^2
- Assume we have only 3 significant decimal digits.

$$\begin{array}{r} 2.3400 \\ + 0.0256 \\ \hline 2.3656 \end{array} \rightarrow 2.37$$

guard round

$$\begin{array}{r} 2.34 \\ + 0.02 \\ \hline 2.36 \end{array}$$

without round and
guard digits

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