CSC 211: Object Oriented Programming

Number Systems, Further look into DataTypes

Michael Conti

Department of Computer Science and Statistics
University of Rhode Island

Fall 2020

THINK BIG WE DO℠

Original design and development by Dr. Marco Alvarez

Number systems

- A way to represent numbers
  - numbers are expressed in a certain **base**
- Why study number systems in CS?
  - to understand data representation
- Examples of number systems
  - binary
  - decimal
  - octal
  - hexadecimal

Positional number systems

assuming base **b**:

$$\ldots d_2 b^2 + d_1 b^1 + d_0 b^0 + d_{-1} b^{-1} + d_{-2} b^{-2} \ldots$$

$$43.23 = 4 \cdot 10^1 + 3 \cdot 10^0 + 2 \cdot 10^{-1} + 3 \cdot 10^{-2}$$

Decimal number system

- Base 10
- Symbols

0 1 2 3 4 5 6 7 8 9

$$456 = 4 \cdot 10^2 + 5 \cdot 10^1 + 6 \cdot 10^0$$

Binary number system

- Base 2
- Symbols

0 1

Most Significant Bit

Least Significant Bit

$$1010 = (1 \cdot 2^3) + (0 \cdot 2^2) + (1 \cdot 2^1) + (0 \cdot 2^0)$$

Binary to Decimal?

1 0 0 1 0 1 0 0 0

1 1 0 . 1 0 1

Try these ..

1 0 0 1 1 1 0 1

1 1 0 1 0 0 1 1

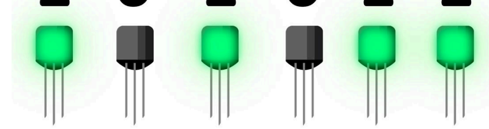
1 1 1 1 1 1 1 1

What is a **bit**? What is a **byte**?

Bits and computers

- A bit can only have two values (states)
  - easy to embed into physical devices
- **Transistor**
  - processors have billions of transistors
  - transistors can be switched **on** and **off**

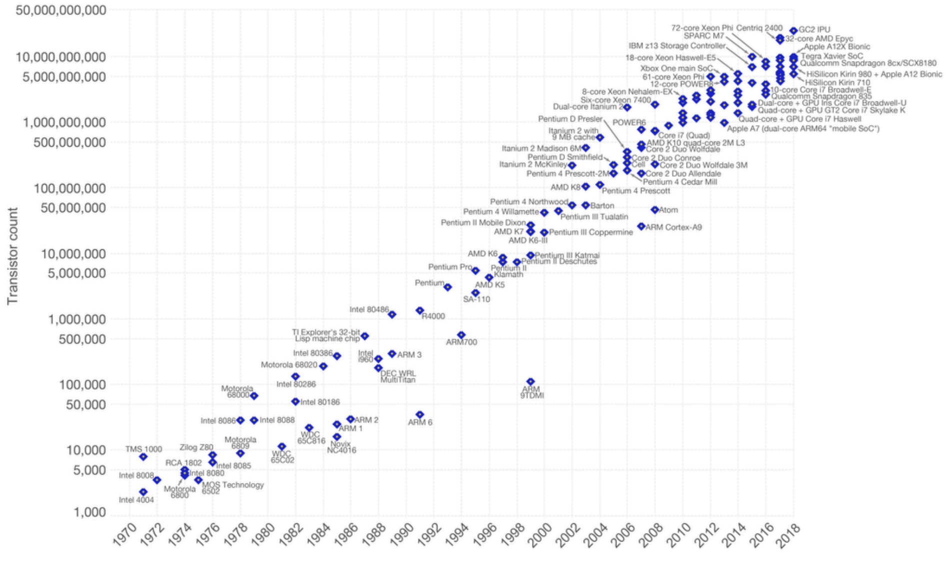
1 0 1 0 1 1



Moore's Law – The number of transistors on integrated circuit chips (1971-2018)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.

Our World in Data



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

Decimal to other bases

- Repeatedly divide by **base**
  - collect remainders
  - output in reverse order

57_{10}

- $57 \ / \ 2 = 28 \text{ R } 1$
- $28 \ / \ 2 = 14 \text{ R } 0$
- $14 \ / \ 2 = 7 \text{ R } 0$
- $7 \ / \ 2 = 3 \text{ R } 1$
- $3 \ / \ 2 = 1 \text{ R } 1$
- $1 \ / \ 2 = 0 \text{ R } 1$

111001_2

Hexadecimal number system

- Base 16
- Symbols

0 1 2 3 4 5 6 7 8 9 A B C D E F

$$4A1C = (4 \cdot 16^3) + (10 \cdot 16^2) + (1 \cdot 16^1) + (12 \cdot 16^0)$$

Hexadecimal to decimal

1 0 5 0 B

A 0 1 0 F

Binary to hexadecimal

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

1 0 0 1 1 1 0 1

1 1 0 1 0 0 1 1

1 1 1 1 1 1 1 1

Humans think in **base 10.** Computers think in **base 2.**
Humans use **base 16** to easily manipulate data in **base 2.**

Color codes

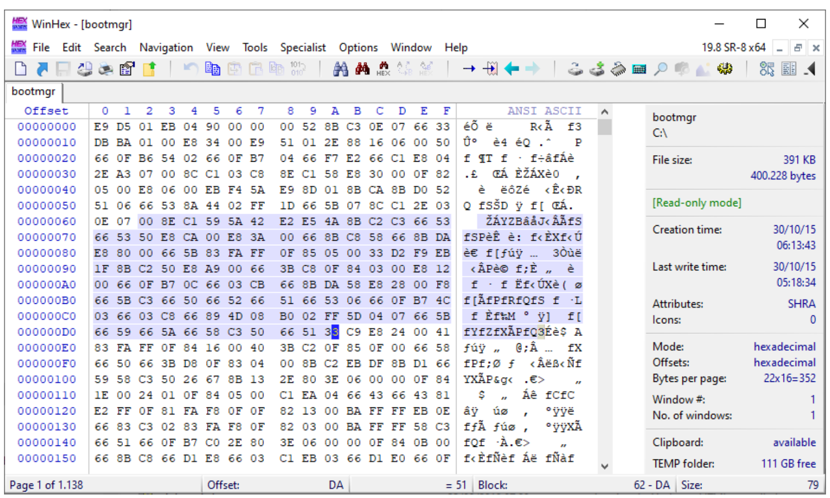
Shades of yellow color chart

Color	HTML / CSS Color Name	Hex Code #RRGGBB	Decimal Code (R,G,B)
	lightyellow	#FFFFE0	rgb(255,255,224)
	lemonchiffon	#FFFACD	rgb(255,250,205)
	lightgoldenrodyellow	#FAFAD2	rgb(250,250,210)
	papayawhip	#FFEFD5	rgb(255,239,213)
	moccasin	#FFE4B5	rgb(255,228,181)
	peachpuff	#FFDAB9	rgb(255,218,185)
	palegoldenrod	#EEE8AA	rgb(238,232,170)
	khaki	#F0E68C	rgb(240,230,140)
	darkkhaki	#BDB76B	rgb(189,183,107)
	yellow	#FFFF00	rgb(255,255,0)
	olive	#808000	rgb(128,128,0)
	greenyellow	#ADFF2F	rgb(173,255,47)
	yellowgreen	#9ACD32	rgb(154,205,50)

What is the color code of 'greenyellow' in **binary**?

https://www.rapidtables.com/web/color/Yellow_Color.html

Forensic Analysis



31 oct = 25 dec?

Going back to C++ …

Integer literals in C++

```cpp
int d = 42;
int o = 052;
int x = 0x2a;
int X = 0X2A;
int b = 0b101010; // C++14
```

- **decimal-literal** is a non-zero decimal digit (1, 2, 3, 4, 5, 6, 7, 8, 9), followed by zero or more decimal digits (0, 1, 2, 3, 4, 5, 6, 7, 8, 9)
- **octal-literal** is the digit zero (0) followed by zero or more octal digits (0, 1, 2, 3, 4, 5, 6, 7)
- **hex-literal** is the character sequence `0x` or the character sequence `0X` followed by one or more hexadecimal digits (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, a, A, b, B, c, C, d, D, e, E, f, F)
- **binary-literal** is the character sequence `0b` or the character sequence `0B` followed by one or more binary digits (0, 1)

https://en.cppreference.com/w/cpp/language/integer_literal

DISPLAY 2.2 Some Number Types

Type Name	Memory Used	Size Range	Precision
short (also called *short int*)	2 bytes	−32,768 to 32,767	(not applicable)
int	4 bytes	−2,147,483,648 to 2,147,483,647	(not applicable)
long (also called *long int*)	4 bytes	−2,147,483,648 to 2,147,483,647	(not applicable)
float	4 bytes	approximately 10^{-38} to 10^{38}	7 digits
double	8 bytes	approximately 10^{-308} to 10^{308}	15 digits
long double	10 bytes	approximately 10^{-4932} to 10^{4932}	19 digits

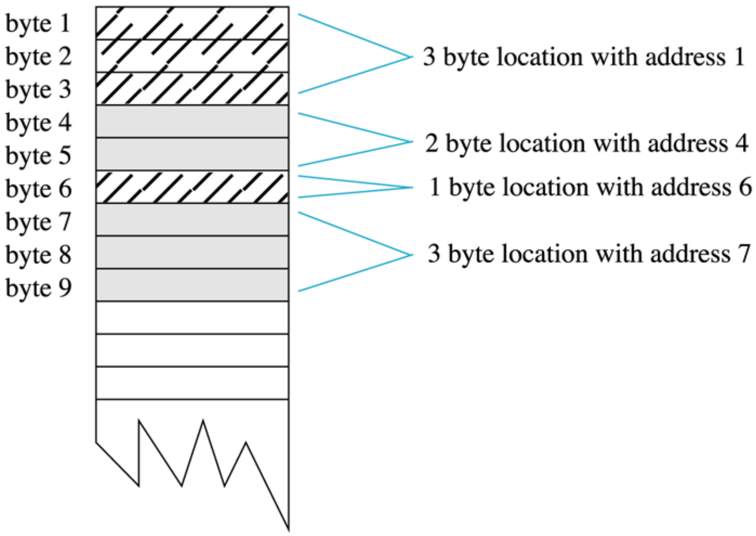
These are only sample values to give you a general idea of how the types differ. The values for any of these entries may be different on your system. **Precision** *refers to the number of meaningful digits, including digits in front of the decimal point. The ranges for the types* **float**, **double**, *and* **long double** *are the ranges for positive numbers. Negative numbers have a similar range, but with a negative sign in front of each number.*

from: Problem Solving with C++, 10th Edition, Walter Savitch

Type	Size in bits	Format	Value range	
			Approximate	Exact
character	8	signed		-128 to 127
		unsigned		0 to 255
	16	unsigned		0 to 65535
	32	unsigned		0 to 1114111 (0x10ffff)
integer	16	signed	$\pm 3.27 \cdot 10^{4}$	-32768 to 32767
		unsigned	0 to $6.55 \cdot 10^{4}$	0 to 65535
	32	signed	$\pm 2.14 \cdot 10^{9}$	-2,147,483,648 to 2,147,483,647
		unsigned	0 to $4.29 \cdot 10^{9}$	0 to 4,294,967,295
	64	signed	$\pm 9.22 \cdot 10^{18}$	-9,223,372,036,854,775,808 to 9,223,372,036,854,775,807
		unsigned	0 to $1.84 \cdot 10^{19}$	0 to 18,446,744,073,709,551,615
floating point	32	IEEE-754	• min subnormal: $\pm 1.401,298,4 \cdot 10^{-45}$ • min normal: $\pm 1.175,494,3 \cdot 10^{-38}$ • max: $\pm 3.402,823,4 \cdot 10^{38}$	• min subnormal: ±0x1p-149 • min normal: ±0x1p-126 • max: ±0x1.fffffep+127
	64	IEEE-754	• min subnormal: $\pm 4.940,656,458,412 \cdot 10^{-324}$ • min normal: $\pm 2.225,073,858,507,201,4 \cdot 10^{-308}$ • max: $\pm 1.797,693,134,862,315,7 \cdot 10^{308}$	• min subnormal: ±0x1p-1074 • min normal: ±0x1p-1022 • max: ±0x1.fffffffffffffp+1023

https://en.cppreference.com/w/cpp/language/types

Memory Locations and Bytes



from: Problem Solving with C++, 10th Edition, Walter Savitch