Bits, bytes and digital information

Lecture 2 – COMPSCI111/111G SS 2018

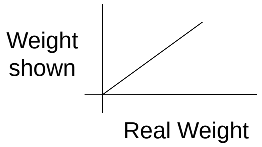
THE HISTORY OF MEMORY
IN 1940 I INVENTED A BIT OF MEMORY
1953: I INVENTED A BYTE OF MEMORY
1966: 1 K
1978: 32 K
ONLY $999
2011: LOOK, 100 TERABYTES
2038:
WHAT MEMORY?
TOM SLOAN ©2011

Today's lecture

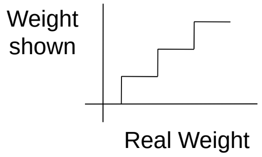
- Understand the difference between analogue and digital information
- Convert between decimal numbers and binary numbers

Analogue vs digital information

- Information in the real world is continuous
  - Continuous signal

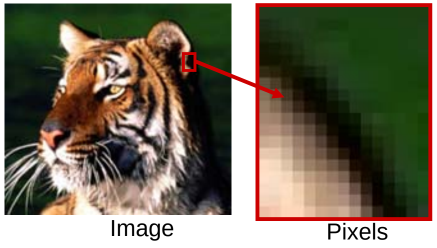


- Information stored by a computer is digital
  - Represented by discrete numbers



Encoding information

- Real world information is stored by a computer using numbers
- Visual information

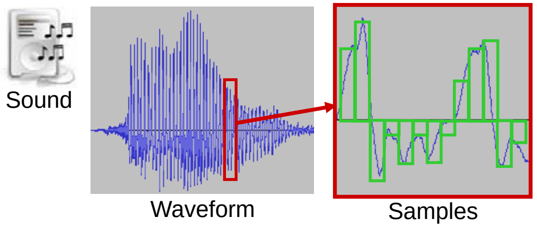


```
1111111111111111111111
0111111111111111111111
0000111111111111111111
0000001111111111111111
0000000001111111111111
4444400000111111111111
7544400000001111111111
5555440100000011111111
3336754400000001111111
2228355444400000011111
9992835754400000001111
9999923365750400000111
9999998366655440000011
9999992833867440000001
```

1. Give each pixel colour a number.
2. Let the computer draw the numbers as coloured pixels (eg. black = 0).

Encoding information

- Sound information



1. Give each sample a number (height of green box).
2. Let the computer move the loudspeaker membrane according to the samples.

Numbers and Computing

- Numbers are used to represent all information manipulated by a computer.
- Computers use the binary number system:
  - Binary values are either 0 or 1.
- We use the decimal number system:
  - 0 to 9 are decimal values.

Number Systems

- Base:
  - Specifies the number of digits used by the system.
  - Binary is base 2.
  - Decimal is base 10.
- Positional notation:
  - Describes how numbers are written.

$$d_n d_{n-1} \cdots d_1$$

Most significant digit

Least significant digit

Positional Notation

- Any number can be expressed as:

$$d_n * b^{n-1} + d_{n-1} * b^{n-2} + \cdots + d_1 * b^0$$

where d_i is the digit at position i, and b is the base.

Decimal Examples

- 657

$$6 * 10^2 + 5 * 10^1 + 7 * 10^0$$

$$\downarrow$$

$$600 + 50 + 7 = 657$$

- 9308

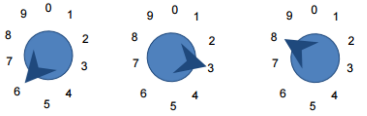
$$9 * 10^3 + 3 * 10^2 + 0 * 10^1 + 8 * 10^0$$

$$\downarrow$$

$$9000 + 300 + 0 + 8 = 9308$$

Storing Decimal Numbers in a Computer

- Series of dials:
  - Each dial goes from 0 to 9.
- Information is stored digitally:
  - Finite number of states – 10 per dial.
  - No in-between states.
- Decimal number system:
  - 1st dial from right: 10^0
  - 2nd dial from right: 10^1
  - 3rd dial from right: 10^2
  - etc.



$$6 * 10^2 + 3 * 10^1 + 8 * 10^0 = 638$$

Exercises

The following two questions relate to dials that have 10 different states, as discussed in the previous slide.

- Given a machine that uses 4 dials, how many different numbers can we represent?
- If we want to represent 256 different values, how many dials do we need?

Switches

- A dial is complicated.
  - Each dial has 10 different states (0 – 9).
  - Physically creating circuits that distinguish all states is complicated.
  - Would need to distinguish 10 different strengths of electricity (voltages).
- Switches are simple.
  - Each switch is off or on (0 or 1).
  - Physically creating the circuits is easy.
  - Switch off: electrical current cannot flow.
  - Switch on: electrical current can flow.

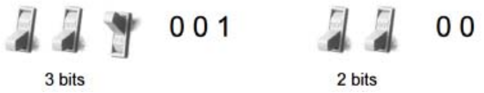
0

1

Bits and Bytes

- Each binary number is known as a **B**inary dig**IT**, or bit.
- A bit can be either a 0 or a 1

- Bits are used in groups.

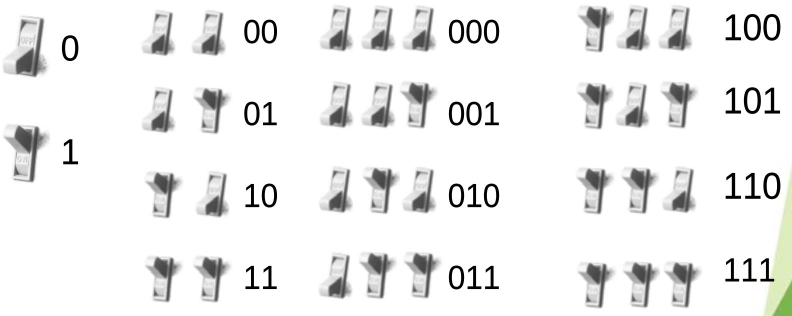


- A group of eight bits is referred to as a **byte**.

Using Binary Numbers

How many different values/states can we have with:

1 bit: 2 bits: 3 bits:



Exercises

- How many different values can we represent with a byte?
- If we want to represent 30 different values, how many bits would we need?

Converting binary to decimal

- 110

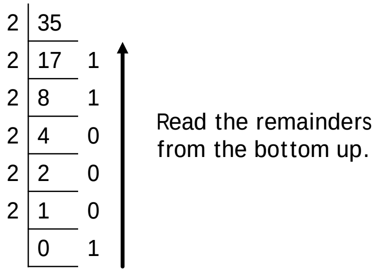
$$1 * 2^2 + 1 * 2^1 + 0 * 2^0$$
$$\downarrow$$
$$4 + 2 + 0 = 6$$

- 10110

$$1 * 2^4 + 0 * 2^3 + 1 * 2^2 + 1 * 2^1 + 0 * 2^0$$
$$\downarrow$$
$$16 + 0 + 4 + 2 + 0 = 22$$

Converting from decimal to binary

- 35

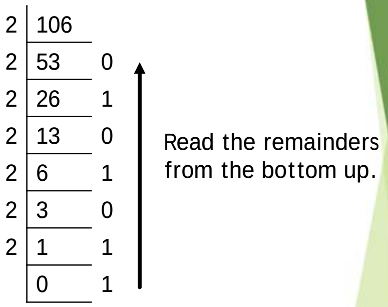


2	35	
2	17	1
2	8	1
2	4	0
2	2	0
2	1	0
	0	1

Read the remainders from the bottom up.

- 35 is 100011 in binary

- 106



2	106	
2	53	0
2	26	1
2	13	0
2	6	1
2	3	0
2	1	1
	0	1

Read the remainders from the bottom up.

- 106 is 1101010 in binary

Exercises

- What is the decimal equivalent of 101111?
- What is the binary equivalent of 123?

Prefixes

- A group of 8 bits is a **byte**
  - A group of 4 bits is a **nibble**
- Bytes are the common unit of measurement for memory capacity
- There are two sets of prefixes:
  - Decimal
  - Binary

Decimal prefixes

10^n	Prefix	Symbol	Decimal
1	none		1
10^3	kilo	K	1000
10^6	mega	M	1,000,000
10^9	giga	G	1,000,000,000
10^{12}	tera	T	1,000,000,000,000
10^{15}	peta	P	1,000,000,000,000,000
10^{18}	exa	E	1,000,000,000,000,000,000
10^{21}	zetta	Z	1,000,000,000,000,000,000,000

Binary prefixes

2^n	Prefix	Symbol	Decimal
2^0	none		1
2^{10}	kibi	Ki	1024
2^{20}	mebi	Mi	1,048,576
2^{30}	gibi	Gi	1,073,741,824
2^{40}	tebi	Ti	1,099,511,627,776
2^{50}	pebi	Pi	1,125,899,906,842,624
2^{60}	exbi	Ei	1,152,921,504,606,846,976
2^{70}	zebi	Zi	1,180,591,620,717,411,303,424

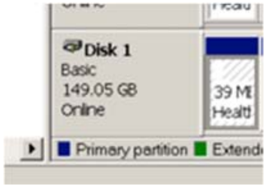
Prefixes in Computer Science

- Both decimal and binary prefixes are used in Computer Science
- Decimal prefixes are preferred because they are easier to calculate, however binary prefixes are more accurate

Binary prefix	Decimal prefix	Value (bytes)
8 bits	1 byte	same
1 KiB (1 x 2^{10} bytes)	1 KB (1 x 10^3 bytes)	1024 ≠ 1000
1 MiB (1 x 2^{20} bytes)	1 MB (1 x 10^6 bytes)	1,048,576 ≠ 1,000,000

Example – hard disk sizes

- A 160GB hard disk is equivalent to 149.01GiB
  - 160GB = 160 x 10^9
  - 149.01GiB = (160 x 10^9) ÷ 2^{30}


Disk 1
Basic
149.05 GB
Online

39 M
Healt

Primary partition
Extend

Exercises

- Which has more bytes, 1KB or 1KiB?
- How many bytes are in 128MB?

Summary

- Computers use the binary number system
  - We can convert numbers between decimal and binary
- Decimal prefixes and binary prefixes are used for counting large numbers of bytes