Computing Hardware

Required Reading

Table of contents

1 Bits and Bytes

At the smallest scale in the computer, information is stored as bits and bytes. In this section, we'll learn how bits and bytes encode information.

1.1 Bit

- a "bit" is atomic: the smallest unit of storage
- A bit stores just a 0 or 1
- "In the computer it's all 0's and 1's" ... bits
- Anything with two separate states can store 1 bit
- In a chip: electric charge = 0/1
- In a hard drive: spots of North/South magnetism = 0/1
- A bit is too small to be much use
- Group 8 bits together to make 1 byte
- Everything in a computer is 0's and 1's. The bit stores just a 0 or 1: it's the smallest building block of storage.

1.2 Byte

- One byte = collection of 8 bits
- e.g. 0 1 0 1 1 0 1 0
- One byte can store one character, e.g. 'A' or 'x' or '$'

1.2.1 How Many Patterns With N Bits? (demo)

How many different patterns can be made with 1, 2, or 3 bits? 2^n

Number of bits	Different Patterns
1	0 1 *2*
2	00 01 10 11 *4*
3	000 001 010 011 100 101 110 111 *8*

1.2.1.1 3 bits vs. 2 bits

- Consider just the leftmost bit
- It can only be 0 or 1
- Leftmost bit is 0, then append 2-bit patterns
- Leftmost bit is 1, then append 2-bit patterns again
- 3-bits has twice as many patterns as 2-bits

Number of bits	Different Patterns
1	0 1
2	00 01 10 11

Number of bits	Different Patterns
3	000 001 010 011 100 101 110 111

- In general: add 1 bit, double the number of patterns
- 1 bit - 2 patterns
- 2 bits - 4
- 3 bits - 8
- 4 bits - 16
- 5 bits - 32
- 6 bits - 64
- 7 bits - 128
- 8 bits - 256 - one byte
- Mathematically: n bits yields $2\char`^n$ patterns (2 to the nth power)

1.2.2 One Byte - 256 Patterns (demo)

- 1 byte is group of 8 bits
- 8 bits can make 256 different patterns
- How to use the 256 patterns?
- How to store a number in a byte?
- Start with 0, go up, one pattern per number, until run out of patterns
- 0, 1, 2, 3, 4, 5, ... 254, 255
- One byte can hold a number between 0 and 255
- i.e. with 256 different patterns, we can store a number in the range 0..255
- Really good for storing characters/letters.

1.3 Bytes

- "Byte" - unit of information storage
- A document, an image, a movie .. how many bytes?
- 1 byte is enough to hold about 1 typed character, e.g. 'b' or 'X' or '$'
- All storage is measured in bytes, despite being very different hardware
- Kilobyte, KB, about 1 thousand bytes
- Megabyte, MB, about 1 million bytes
- Gigabyte, GB, about 1 billion bytes
- Terabyte, TB, about 1 trillion bytes (rare)

1.4 Bytes and Characters - ASCII Code

ASCII is an encoding representing each typed character by a number. Each number is stored in one byte (so the number is in 0..255).

Character	ASCII Code
A	65
B	66
a	96
space	32
...	...

"Unicode" is an encoding for mandarin, greek, arabic, etc. languages, typically 2-bytes per "character".

1.5 Typing, Bytes, and You

- Each letter is stored in a byte, as below
- 100 typed letters takes up 100 bytes
- When you send, say, a text message, the numbers are sent
- Text is quite compact, using few bytes, compared to images etc.

1.6 Numbers in Computers

- One byte works well for individual characters, but computers are also good at manipulating numbers.
- Integers are typically stored with either 4 or 8 bytes
- 4 bytes can store numbers between -2147483648 and 2147483647
- 8 bytes can store numbers between -9223372036854775808 and 9223372036854775807
- Adding in binary is just like normal addition with carrying
- But when you run out of bits you can't carry anymore
- Leftmost bit indicates sign, so carrying to the leftmost bit changes a number from positive to negative.
- So adding 1 to 2147483647 goes to -2147483648!
- Called Integer Overflow
- **Gangnam Style Example**: The YouTube view counter for the "Gangnam Style" music video once exceeded the maximum value that could be held in a 32-bit integer, causing an integer overflow error. This led YouTube to upgrade their system to handle larger numbers.

2 Kilobytes, Megabytes, Gigabytes, Terabytes

2.1 Introduction

The size of information in the computer is measured in kilobytes, megabytes, gigabytes, and terabytes. In this section, we'll look at common sizes you would see in real life and learn how to reason about various numbers of bytes.

2.2 Kilobyte (KB)

- **Kilobyte (KB)**: about 1 thousand bytes
- **1 byte**: one typed character
- **Examples**:
    - An email without images: 2 KB
    - A five-page paper: 100 KB
    - 23,000 bytes: 23 KB

- **Note**: Text is compact, requiring few bytes compared to images or sound or video. In non-roman alphabets, such as Mandarin, the storage takes up 2 or 4 bytes per "letter."

2.3 Megabyte (MB)

- **Megabyte (MB)**: about 1 million bytes (1000 KB)
- **Examples**:
    - MP3 audio: 1 megabyte per minute
    - High-quality digital picture: 2-5 megabytes
    - 45,400 KB: 45.4 MB

- **Fun Fact**: A data CD disk stores about 700 MB. The whole spiral on a CD is over 5km long.

2.3.1 Math - You Try It

MB = 1 million bytes

- 2,000,000 bytes: how many MB? 2 MB
- 23,000 KB: how many MB? 23 MB
- 500 KB: how many MB? 0,5 MB

2.4 Gigabyte (GB)

- **Gigabyte (GB)**: about a billion bytes (1000 MB)
- **Examples**:
    - 4000 MB: 4 GB
    - Ordinary computer: 4 GB or RAM, 256 GB of persistent storage
    - DVD disk capacity: 4.7GB (single layer)
    - Flash drive: 32 GB
    - Hard drive: 750 GB

2.4.1 Math - You Try It

- 4,000,000,000 bytes: 4 GB   **4 billion bytes**
- 5 MB JPEG images on a 16 GB flash drive: 3,200 images

2.5 Terabyte (TB)

16 billion / 5 million = 3200

- **One terabyte (TB)**: about 1000 gigabytes, or roughly 1 trillion bytes
- **Note**: You can buy 4 TB hard drives today, so we are beginning the time when this term comes in to common use.

2.6 Gigahertz - Speed, not Bytes

- **One gigahertz**: 1 billion cycles per second
- **Note**: Gigahertz is a measure of speed, not bytes. Almost all cell phones currently use ARM CPUs.

2.7 Word Problems

2600 MB = 2.6 GB

- **Alice's Data**: 600 MB + 2000 MB on Alice's 4 GB thumb drive? Yes, it fits.
- **Image Storage**: 100 small images at 500 KB each: 50 MB.
- **Ghost Hunting Audio**: 20 hours of MP3 audio: 1.2 GB.

↳ 1 megabyte per minute

2.8 Alternate Terminology: Kibibyte, Mebibyte, Gibibyte, Tebibyte

- **Problem**: Confusion between 1024-based units and 1000-based units.
- **Solution**: Terms like "kibibyte" "mebibyte" "gibibyte" "tebibyte" have been introduced to specifically mean the 1024 based units.
- **Note**: "About a million" will be our close-enough interpretation for "megabyte."