The math behind bits and bytes

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Computers have their very own language, made of just two symbols: 0 and 1. Photo from Pexels

Mathematics is integral to computers. Most computer processes and functions rely on mathematical principles. The word "computers" is derived from computing, meaning the process of solving a problem mathematically. Large complex calculations (or computing) in engineering and scientific research often require basic calculators and computers.

Computers have evolved greatly over the years. These days, computers are used for practically anything under the sun, education, communication, business, shopping, or entertainment. Mathematics forms the basis of all these applications.

Applications of mathematical concepts are seen in the way computers process data (or information) in the form of bits, bytes and codes, store large quantities of data by compression, and send data from one computer to another by transmission. With the advent of the Internet, communication has become extremely easy. Every computer is assigned a unique identity, using mathematical principles, making communication possible. In addition, mathematics has also found other applications in computers, such as security and encryption.

Binary System

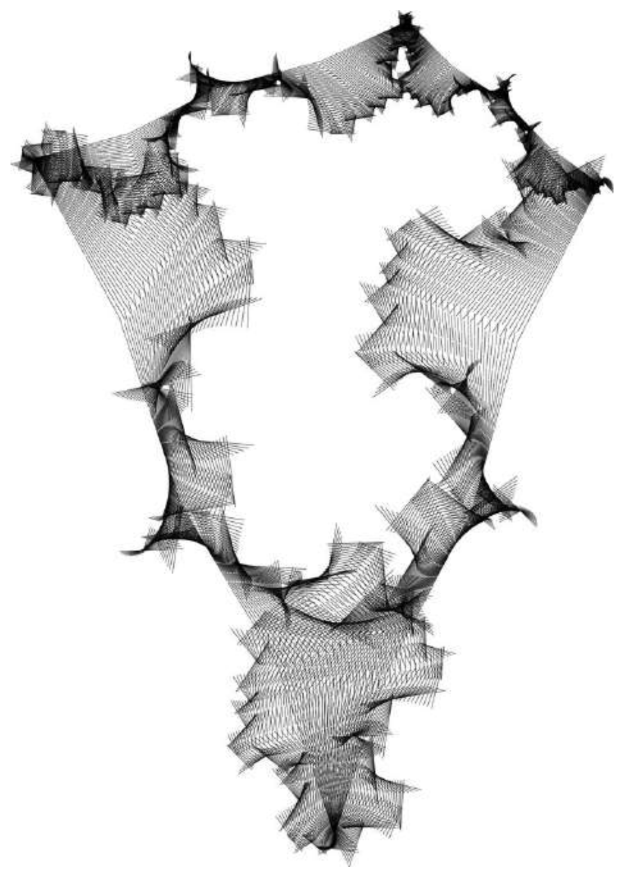
All computers or computing devices think and process in binary code, a binary number system. In a binary number system, everything is described using two values — on or off, true or false, yes or no, one or zero, and so on. The simplest example of a binary system is a light switch, which is always either on or off. A computer contains millions of similar switches. The status of each switch in the computer represents a bit or binary digit. In other words, each switch is either on or off. The computer describes one as "on" and zero as "off."

Any number can be represented in the binary system as a combination of zeros and ones. In the binary number system, each number holds the value of increasing powers of two, e.g., 20, 21, and so on. This makes counting in binary easy. The binary representation for the numbers 1 to 10 can be shown as follows:

Decimal		Binary
0	=	0
1	=	1
2	=	10
3	=	11
4	=	100
5	=	101
6	=	110
7	=	111
8	=	1000
9	=	1001
10	=	1010

Algorithms

The key principle in all computing devices is a systematic process for completing a task. In mathematics, this systematic process is called an algorithm. Algorithms are common in daily life as well. For example, when building a house, the first step involves building the floor base (or foundation), followed by the walls, and then the ceiling or roof. This systematic procedure to solve the problem of building a house is an example of an algorithm.

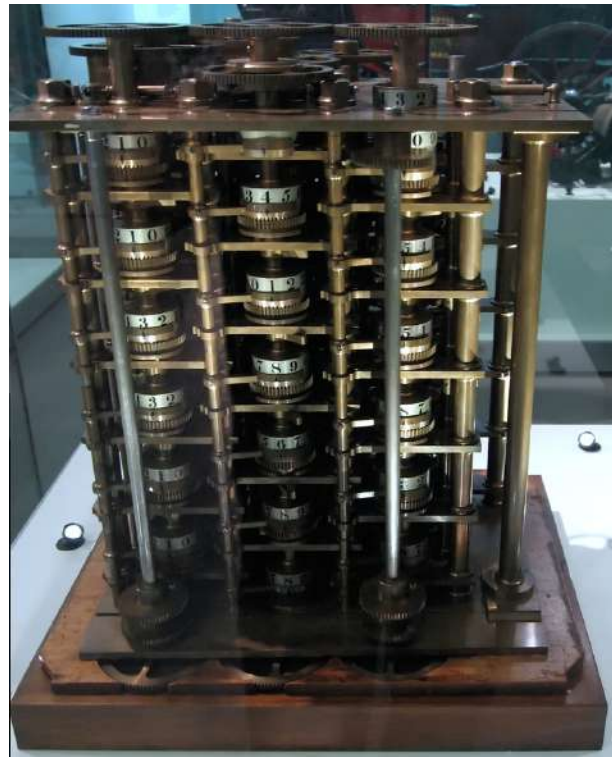


In a nutshell, algorithms are a list of step-by-step instructions. In mathematical terms, these are also sometimes known as theorems. A computer program, or application, is made up of a number of such algorithms. Besides, every process in a computer also depends on a specific algorithm. For example, when switching on the computer, the computer does what is known as "booting." Booting helps in properly loading the operating system (Windows, Mac, Dos, UNIX, and so on). During booting, the computer follows a set of instructions (defined by an algorithm). Similarly, while opening any program (say, MS Word), the computer is again instructed to follow a set of tasks so that the program opens properly.

Like complex mathematical problems, even the most complex software programs are based on numerous algorithms.

A Brief History Of Discovery And Development

Although the modern computer was built only in the 20th century, many primitive forms of the computer were used in ancient times. The early calculators can also be considered as extremely basic computers based on similar mathematical concepts. The word calculator, is derived from the Latin word calculus (or a small stone). Early human civilizations used small stones for counting. Counting boards made up of stones were used for basic arithmetic tasks such as addition, subtraction and multiplication. This led to development of devices that enabled calculation of more complex numbers, and in quick time. With the progress of civilization, man saw the development of the abacus, the adding machine, the Babbage, and the prototype mainframe computers.



Modern computers, however, were invented in the 20th century. In 1948, the mathematician Claude Shannon (1916–2001), working at Bell Laboratories in the United States, developed computing concepts that would form the basis of modern information theory. Shannon is often known as the father of information science. Computers were earlier only used by government institutions. Home or personal computers (known as PCs) came much later in the late 1970s and 1980s.

Today, personal computers and servers with a microprocessor chip (a small piece of computer hardware) are embedded in almost all lifestyle electronic products, from the washing machine and television to calculators and automobiles. Many of these chips are capable of computing in the same capacity as some basic computers. The advancement of mathematical concepts and theories has made it possible to develop sophisticated computers in smaller and smaller sizes, such as those found in handheld computers like the PDA (personal data assistant) and PMP (personal media player).

Ciphers, codes, and secret writing based on mathematical concepts have been around since ancient times. In ancient Rome, they were used to communicate secrets over long distances. Such codes are now used extensively in the field of computer science.

Bits

The bit is the smallest unit of information in a computer. As discussed earlier, a bit is a basic unit in a binary number system. A bit or binary digit stands for true or false, one or zero, on or off. The computer is made up of numerous switches. Each switch has two states (on and off). The value of each state represents a bit.

Bits are the basic unit of storage in computers. In other words, all data is stored in the form of bits. The reason for using a binary number system rather than decimal system for storage (and other purposes) is that with prevailing technology, it is much easier to implement the binary system in computers. Implementing the binary system is significantly cheaper, as well.

Bytes

In computers, bits are bundled together into manageable collections called bytes. A byte consists of eight bits. Bits and bytes are always clubbed together like atoms and molecules. Computers are designed to store data and process instructions in bytes. To handle large quantities of information (or bits), other units such as kilobytes, megabytes, and gigabytes are used. One kilobyte (KB) = 1,024 bytes = 210 bytes (and not 1,000 bytes as commonly thought). Similarly, 1 megabyte (MB) = 1,048,576 bytes 220 bytes, and 1 gigabyte (GB) = 1,073,741,824 bytes = 230 bytes.

The first computers were 1-byte machines. In other words, they used octets or 8-bit bytes to store information, and they represented 256 values (28 values, integers zero to 255).

The latest computing machines are 64-bit (or 8 bytes). This type of representation makes computing easier in terms of both storage and speed. Bits and bytes form the basis of many other computer processes and functions. These include CD storage, screen resolution, text coding, data comparison, data transmission, and much more.

Text Code

All information in the computer is stored in the form of binary numbers. This includes text, as well. In other words, text is not stored as text, but as binary numbers. The rule that governs this representation is known as ASCII (American Standard Code for Information Interchange). The ASCII system assigns a code to every letter of the alphabet (and other characters). This code is stored as a seven digit binary number in computers. Moreover, the ASCII code for a capital letter is different than the code for the small letter. For example, the ASCII code for "A" is 10, whereas that for "a" is 97. Consequently, the value of "A" is stored as 0001010 (its binary representation), whereas "a" is 1100001.

Every character is stored as 8 bits (a leading bit in addition to the 7 bits for the ASCII code), or 1 byte. Thus, the word "happy" would require 5 bytes. An entire page with 20 lines and 60 characters per line would require 1,200 bytes.

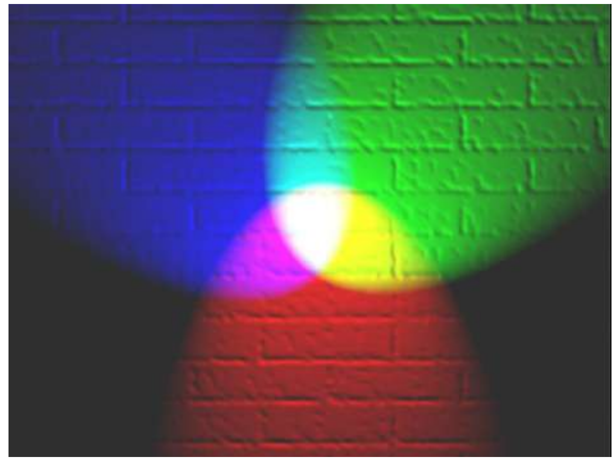
The main benefit of storing text code as binary numbers is that it makes it easier for the computer to store and process the data. Besides, mathematical operations can be performed on binary representations of text.

Pixels, Screen Size And Resolution

A pixel is derived from the words picture and element. The smallest and the most basic unit of images in computers is the pixel. A pixel is a tiny square block. Images are made up of numerous pixels. The total number of pixels in a computer image is known as the resolution of the image. For example, a standard computer monitor displays images with the resolution 800 × 600. This simply means that the image (or the entire computer screen) is 800 pixels wide and 600 pixels high.

Each pixel is also stored as 8 bits (or 1 byte). Again, its representation is in the form of binary numbers. Storing the value of the color of a pixel is far easier in binary format, as compared with other formats. The maximum number of combinations of zeros and ones in an 8-bit number is 256 (28). Each combination represents a color. Simply put, every pixel can have one of 256 different colors.

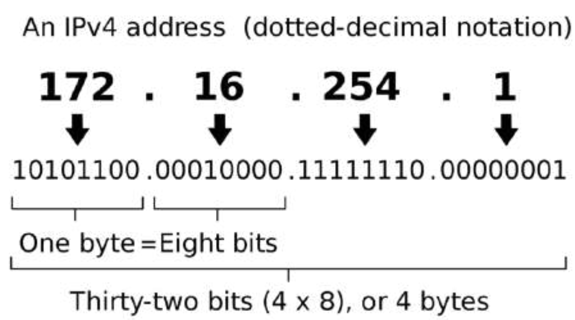
This kind of computer display is called an "8-bit" or "256-color" display, and was very common in computers built in the 1990s. In contrast, newer computer monitors built after the year 2000 have a significantly higher number of colors (in millions). These are the 16-bit and 24-bit monitors. The color of every pixel in a computer image is a combination of three different colors — red, green, and blue (RGB). RGB is common terminology used in computer graphics and images, and simply means that every color is a combination of some portion of red, green and blue colors. The value of each of these colors is stored in one byte. For example, the color of a pixel could be 100 of red, 155 of green, and 200 of blue. Each of these values is stored in binary format in a byte. Note that the color values can range from zero to 255. Thus, every color pixel has three bytes. Subsequently, a computer monitor with the resolution 800 × 600 would need 3 × 800 × 600, or 1,440,000 bytes.



IP Address

Every computer on a network has a specific address. A number, known as the Internet protocol address, or IP address, indicates this. The reason for having an IP address is simple. To send a packet or a letter through regular mail, the address of the recipient is required. Similarly, for communicating with a computer (from another computer), the address of that computer is required. Every computer has a unique IP address that clearly distinguishes it from other computers. The concept of the IP address is based on mathematical principles, and there are rules that govern the value of the IP address. For example, an IP address is always a set of four numbers separated by dots (e.g., 204.65.130.40).

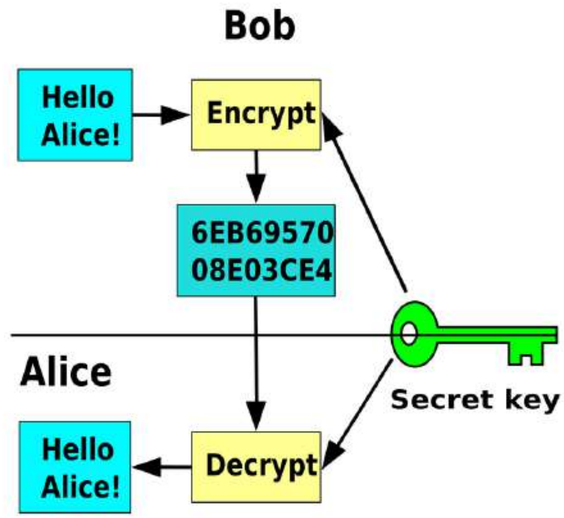
Remember, the computer only understands binary numbers. Consequently, the IP address is also represented as a binary number. The binary representation is octet (equivalent to the representation of a byte). Technically, every IP address is a 32-bit number divided into 4 bytes, or octets (8 bites). Each octet represents a specific number. For example, in the above case, 204 would be stored in one octet, 65 in another octet, and so on. The binary representation (as stored in the computer) for the above-mentioned IP address would be: 11001100.01000001.10000010.0101000.



Encryption

Considerable confidential data is stored and transmitted from computers. Security of such data is essential. This can be achieved through specialized techniques known as encryption. Encryption converts the original message into coded form that cannot be interpreted unless it is decoded back to the original (decryption). Encryption, a concept of cryptography, is the most effective way to achieve data security. It is based on complex mathematical algorithms.

Consider the message abcdef1234ghij56789. There are several ways of coding (or encrypting) this information. One of the simplest ways is to replace each alphabet by a corresponding number, and vice versa. For example, "a" would become "1," "b" would be "2," and so on. The above original message can, thus be encrypted as 123456abcd78910 efghi. The message is decrypted using the same process and converted back in the original form.



Complex mathematical algorithms are designed to create far more complex encryption methods. The information regarding the encryption method is known as the key.

Cryptography provides three types of security for data:

• Confidentiality through encryption — This is the process mentioned above. All confidential data is encrypted using certain mathematical algorithms. A key is required to decrypt the data back into its original form. Only the right people have access to the key.

• Authentication — A user trying to access coded or protected data must authenticate himself/herself. This is done through his/her personal information. Password protection is a type of authentication that is widely used in computers and on the Internet.

• Integrity — This type of security does not limit access to confidential information, as in the above cases. However, it detects when such confidential is modified. Cryptographic techniques, in this case, do not show how the information has been modified, just that it has been modified.

Encryption is used frequently in computers. Most data is protected using one of the above-mentioned encryption techniques. The Internet also widely applies encryption. Most websites protect their content using these methods. In addition, payment processing on websites also follows complex encryption algorithms (or standards) to protect transactions.

Quiz

1 Read the following sentence from the introduction of the article [paragraphs 1-3].

Most computer processes and functions rely on mathematical principles.

What does the verb "rely" convey in the sentence?

(A) It conveys how computers have evolved over time as technology has improved.

(B) It conveys the simplicity of early computers in comparison with their modern equivalents.

(C) It conveys the importance of mathematics to the operation of all computers.

(D) It conveys how the use of computers has become commonplace in every industry.

2 The authors creates an informative tone in the article.

How do the authors develop this tone over the course of the article?

(A) by providing the reader with facts about computing and specific examples of the role played by mathematics in the development of computers

(B) by arguing that the history of mathematics is emphasizing the incorrect historical figures and offering an alternative explanation

(C) by suggesting that modern computers are inferior to their older counterparts and citing specific statistics that confirm that view

(D) by offering their opinions on the best types of computers and encryption programs

3 Who would find the images MOST helpful and why?

(A) computer designers; they could use the images to create faster computers

(B) teachers; they could use the images as examples of how mathematics are the key to computing

(C) mathematicians; they could use the images to help discover new mathematical processes

(D) security experts; they could use the images to improve the encryption on their computer systems

4 Which image included with the article BEST depicts the idea that all messages inside of a computer use the binary system?

(A) the top image

(B) the image that accompanies the section "Algorithms"

(C) the image that accompanies the section "A Brief History of Discovery And Development"

(D) the image that accompanies the section "IP Address"