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—*Leonid Broukhis and Mike Yaroslavtsev*

Binary System

Today's numerical systems are based in the positional notation: The location of each digit in a string determines its *weight*. In decimal notation, the number 385, for example, is just an abbreviation for the number 300 + 80 + 5. The weights of the digits 5, 8, and 3 are the successive potencies of 10–1, 10, and 100. Binary notation uses the same positional representation, but the weights of the numbers are potencies of 2, which is called the *base* of the system. In base 2, only the digits 0 and 1 are used at each position.

The German philosopher **Gottfried Leibniz** (1646–1716) was the first mathematician who thoroughly studied the properties of the binary system. In several papers and letters between 1679 and 1697, Leibniz developed a notation for binary numbers and showed how to perform the basic arithmetic operations. The binary system was important for the metaphysicist Leibniz because "the void and obscurity correspond to zero and nothing, but God's radiant spirit corresponds to the one."

The binary system was also known to the Chinese; the hexagrams of the *I Ching*, the "book of changes," contain some binary pictorial representations. The Buddhist doctrine of Ying and Yang operated with these two "binary" principles from which the world could be constructed. Leibniz got acquainted with the *I Ching* hexagrams through a letter exchange with a missionary who was living in Peking around 1700.

Numbers can be transformed from decimal to binary notation by a process of successive division. To transform the number 123 from decimal to binary, the number is divided by 2 iteratively, and the remainder of the division is stored. The remainders, from the last to first, written from left to right, provide the binary representation of the number. In the example below, we write the quotient of the division under the number being divided, and the remainder to the left, separated by a line:

123	
61	1
30	1
15	0
7	1
3	1
1	1
0	1

The iterative process ends when the quotient is 0. The binary representation of 123 is therefore 1111011. Transforming numbers from binary to decimal is simpler: Just multiply each binary digit by its weight, performing the operations in decimal. The binary number 111, for example, corresponds to the number 4 + 2 + 1 = 7.

Computers use the binary system because it is simpler to build **logic gates** that deal with only two states instead of 10. The hardware that performs additions of binary numbers, for example, has to deal only with four cases: 0 + 0, 0 + 1, 1 + 0, and 1 + 1. A decimal addition unit has to process many more combinations of digits. Multiplication is also very simple in the binary system: Only the multiplication table for the digits 0 and 1 has to be "learned." The multiplication table for the decimal system is much harder to remember, as the reader probably knows from experience.

Although computers compute internally using binary numbers, programmers usually abbreviate the numbers using octal or hexadecimal notation—that is, base 8 or 16. A number can be transformed from binary to octal notation just by grouping successive sets of three binary digits: the binary number 111101, for example, corresponds to the octal number 75. The reader can readily check that 111 is the binary representation of 7, that 101 is the binary representation of 5, and that 75 in base 8 is the same decimal number as 111101 in base 2. Octal numbers are written using the eight digits from 0 to 7. Hexadecimal notation requires more digits, 16 to be exact. The digits 0 to 9, followed by the letters A, B, C, D, E , and F, are used for this purpose. The hexadecimal number A7 corresponds to the decimal number $10 \times 16 + 7 = 167$. Transforming binary numbers to hexadecimal notation is done as in the case of octal, but groups of four binary digits are used. The binary number 00110111, for example, corresponds to the hexadecimal number 37H. The trailing H is used to mark the number as a hexadecimal number. In the case of octal numbers, a trailing O is used.

Further Reading

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—*Raúl Rojas*

Biochips

Biochips are devices that combine electronics with biological reactions. An electronic nose, for example, is a chip that contains many molecular receptors attached to a **silicon** plate; the molecules of some odors bind to the different receptors and the resulting pattern can be analyzed with a computer in order to classify the odor. A notable example of biochips is *microarrays* of DNA strands on an electronic chip, which can be used to detect parts of the DNA code present in a gene. It is then possible to classify genes much faster than with traditional laboratory methods.

Biotechnology is, together with microelectronics, one of the most rapidly growing industrial branches. Both fields deal with extremely small objects, in one case biological molecules, in the other electronic components. Not surprisingly, many researchers have started thinking about ways of building devices that combine microelectronics with biotechnology.

The great book of life is written in the language of DNA. Genes are long DNA chains containing a sequence of only four component nucleotides: adenine (A), thymine (T), cytosine (C), and guanine (G). All genes are written using only these four "letters." Groups of three letters code specific amino acids, which are the building blocks of proteins. Knowing how to read the genetic code, it is also possible to determine what proteins are coded by specific genes. Some medical conditions are caused by defective genes, and therefore, much has been invested in genetic research.

A DNA chain is simply a chain of the four letters, such as ATTAGGCC. The DNA nucleotides have the property of binding to their complementary base (i.e., adenine to thymine, and cytosine to guanine). The complementary chain of the chain above is TAATCCGG. Normally, DNA strands form a *double helix*: One side of the strand has a certain code, and the complementary side has the complementary code. In this way, the double helix is resilient to change and encodes information in a reliable way.

DNA double helices can be broken into their component chains, called *single-strand DNA*. We can synthesize in the lab the chain of three nucleotides with, for example, the code AAA. Now we test if any DNA from a probe gets attached to this small string. We go "fishing" with AAA as the decoy and observe if any DNA from the test tube gets attached to our probe. If this happens, we know that the original chain contains the complementary combination TTT somewhere along the chain.

Now assume that all possible four-letter combinations of the letters A, G, T, and C are tested. There are 256 of them and we would have to repeat the experiment above, 256 times. However, assume that we manage to arrange the 256 four-letter combinations on a small plate (on a 16 by 16 grid). We can now immerse the plate in the probe and by reading out which elements on the grid did bind some DNA from the probe, we then know which of the 256 four-letter combinations are present in the DNA we are testing. This information could already be sufficient to identify a known gene or a genetic defect. The readout of the plate can be done by optical or electronic methods. If we attach some electronic components to each point in the 16 by 16 grid, small configuration changes can be read by electrical means, making the entire decoding of the plate much easier.

Building such plates of *microarrays*, as they are called, is a very time consuming process, better left to a