CYBERNETICS AND BIOLOGY

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In 1948 two epoch-making books were published: Norbert Wiener's *Cybernetics* and Claude E. Shannon's *Mathematical Theory of Communication*. The first dealt with feedback and control mechanisms, the second with the definition and measurement of information and with the quantitative capacity of channels in telecommunication. Neither treated biology directly, but together they have greatly increased our insight into genetics, development and behavior by bypassing the old mechanist-vitalist controversy.

Cybernetic devices are composed of one or more control loops, each consisting of two components and an automatic valve as, for example, a thermostatic system made up of a heater, a thermometer and an automatic switch. By building up systems of interrelated loops employing very rapid and sensitive electronic valves, extremely complex devices can be constructed - tracking devices, automatic industrial plants, computers. There are no theoretical limits to the complexity of such machines; there are not even any theoretical reasons why they should not be self-reproducing. Sensitive relays produce non-proportionate responses to environmental stimuli and even a few interrelated feedbacks produce indeterminate behavior, two characteristics of living organisms which the vitalists were long able to maintain that the mechanists could not explain.

In any cybernetic device there is a cycle or series of cycles of behavior determined by the design and construction. Any activity inconsistent with this program of cycles is error. Thus every such device is teleonomic
in that its designer prescribed its program, but it is not teleological because it has no ultimate purpose. The cycles function through the communication of output from one component to another which receives it as input and then acts according to the program. For consistent performance accurate communication is indispensible.

Information is a description of the form, composition and state of some segment of the universe either concrete or abstract. The amount of information is the degree of departure from complete randomness so that zero information corresponds to maximum entropy. Information is commonly measured as the number of equally probable either-or choices necessary to make the description, one such choice being a unit of information or bit. The number of bits in a message is the logarithm to the base 2 of the number of equal choices necessary to determine it. It would take five bits to single out one of thirty-two equally probable choices. Any information, however coded - on a printed page, a punched card, magnetic tape or in a series of electrical impulses - can be measured and can be translated from code to code.

In any given message there may be more information that is necessary for its meaning. The excess is termed redundancy. It can be illustrated by the fact that in written English one misprinted letter in ten is not likely to destroy the sense. In a telephone number, however, redundancy is very low; one erroneous digit destroys its effectiveness. In any communication channel
there are random events of the same nature as the signals. These are termed noise and reduce the amount of information transmitted. If redundancy is high, an effective message is likely to get through in spite of the noise. When redundancy is low, noise is likely to destroy the accuracy of the message.

No cybernetic system can function without the accurate transfer of information from one component to another. The output-input relation is a transfer of information. Inaccurate communication between components will result in erroneous performance. Redundancy increases the probability of accurate communication and reduces the likelihood of bad performance.

An organism is a cybernetic device built up of components related to each other by output-input and feedback. The control of temperature, respiration and circulation in warm-blooded animals are obvious examples. The feedback control of muscular activity in walking is another. The organism is an integrated whole built with a certain pattern and programmed to follow a series of cycles resulting in perpetuation from generation to generation. Genetics is the study of the transfer of the information which defines the program from generation to generation. This is coded in the DNA where every nucleotide pair can code two bits of information.

The nervous system of higher organisms exists to provide intercellular transfer of information. We are now learning much about intracellular communication. DNA is transcribed to m-RNA; m-RNA, s-RNA, enzymes and ribosomes intercommunicate information to effect peptide synthesis. Enzymes and metabolites synthesize new molecules by output-input relationships. Abnormal
metabolites give false signals and prevent normal functioning, for example, sulfa drugs in bacteria. The allosteric inhibition of the first enzyme of a synthetic pathway by the final product is a perfect illustration of feedback. Similarly, repression of enzyme synthesis by the increased concentration of the end product is another.

The adult organism contains more information than the fertilized egg. This added information comes from the environment. The organism seeks out and incorporates negative entropy which it uses to elaborate itself according to the plan coded in its genetic endowment. If the environment is deficient in the nutrients needed or contains poisons containing signals that interrupt the programmed cycle, development stops and death results.
DR. JAMES C. KING - "CYBERNETICS AND BIOLOGY"

JACK BENNETT: Would you compare the numbers of "bits" in the DNA of the chicken or a man with a number of "bits" in a TV picture?

KING: Actually in the human zygote, that is in a diploid genome of a human being, there are about as many bits as it takes for 1 or 2 minutes of color TV. Now, of course, this is a ridiculous comparison because bits can only produce a man in the proper environment and again, there is a tremendous amount of information we acquire from the environment.

R. BAMMI: How much of the total information contained in the total DNA of an organism is transcribed at any one time?

KING: That is a question I don't know any way to answer because you see this is tied up very closely with the problem of differentiation and we don't know how much. Obviously huge quantities of the DNA are never transcribed in most cells.

G. E. DICKERSON: How long might it be before we can get the DNA code to produce a man - let's say?

KING: I don't know just how long this will be but this is not an impossibility. Let's take, for example the tryptophane synthetase locus in E. coli. It is known now what the sequences of amino acids in the two polypeptides are and from that you can deduce exactly what the sequences of nucleotides are in the RNA and DNA. Now we could do the same thing with
hemoglobin right now. We could say precisely how many nucleotides are tied
up for the production of hemoglobin and what they are. It is only a matter
of time.

S. R. YOUNG: Might you then define "heterosis" as "redundancy" (without
being repetitious)?

KING: I do. I will go into that a little bit tomorrow.