SOME BIO-SOCIOLOGICAL ASPECTS OF THE MATHEMATICAL THEORY OF COMMUNICATION

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In the first part of the paper a general discussion of the transmission of information through neural chains is given in terms of the Shannon-Weaver theory. It is pointed out that with the all-or-none law a single chain of neurons connected in series transmits one bit of information per signal. A set of $N$ independent parallel chains transmits $N$ bits per signal. If, however, the chains are interconnected, the amount of information is reduced. At the same time, however, the degree of coordination of the final neuromuscular reaction is increased. A relation between the maximum possible speed of a reaction and its degree of coordination is derived, and possible applications to spoken language are suggested. A general quantitative discussion of the relation between amount of information and amount of knowledge which an individual may obtain when confronted with the external world is made and a possible connection with new trends in logical thinking is pointed out.

In the second part transmission of information through “social chains” is discussed under certain special assumptions. An expression for the “social channel noise” in terms of the length of the channel is derived. Finally an expression is given for the amount of information transmitted from one individual to another in a social group of uniform density as a function of the physical distance between the two individuals.

The possible importance of the mathematical theory of communication for biology and sociology has been discussed in recent publications (Wiener, 1948; Shannon and Weaver, 1949). The purpose of this paper is to discuss some possible applications more specifically than has been done hitherto. In our discussion we shall follow the presentation and notations of C. Shannon and W. Weaver (1949). We shall first mention in a most general way some applications to the biology of the individual, then we shall study more specifically a problem of communication in social groups.

I. The Individual.

The overt, observable behavior of an individual is manifested in the vast majority of cases by a set of more or less complex motor reactions, which may be, and are frequently, used as channels of
communication. Perhaps the most important of those motor reactions is speech. The relatively more rare non-motor reactions are glandular secretions, such as sweating, salivating, and weeping. Of those only the latter is used as a channel of communication, and a rather important one at that. Confining ourselves to motor reactions does not entail any loss of generality.

Individual elementary motor reactions may be considered as signals or symbols, in the same sense as used by C. Shannon. They are caused either by external stimuli, or by internal stimuli or drives, which originate endogenically in the brain. In either case there is a transmission from the site of the stimulus to the motor ending. Different regions of the brain thus act as communication channels.

Assuming the general validity of the all-or-none law, we see that a neuron can either only fire or not fire. Thus it is capable of transmitting exactly one bit of information per signal (Shannon and Weaver, 1949). A simple chain of neurons in which all thresholds are sufficiently low, so that the firing of a preceding neuron always results in a firing of the subsequent one, also transmits exactly one bit per signal. If \( \nu \) is the frequency of firing of each neuron in the chain, the rate of transmission \( C \) of information by such a simple chain is \( \nu \) bits per second. The frequency \( \nu \) is limited by the duration of the refractory phase of the neuron, and its highest possible value is of the order of magnitude of \( 10^2 \) sec\(^{-1} \). Hence the maximum channel capacity \( C \) of a simple chain of neurons is about \( 10^2 \) bits sec\(^{-1} \). If we have \( N \) independent parallel chains, then the channel capacity of such a system is of the order \( 10^N \) bits sec\(^{-1} \).

If the individual parallel chains are, however, interconnected by either excitatory or inhibitory links, the capacity of the channel is decreased. We shall illustrate this on the following examples.

Consider first two parallel chains. The amount of information transmitted per signal is, as we have seen, exactly two bits. Let the two chains, however, crossinhibit each other, so as to form the well-known circuit, studied by H. D. Landahl (1937) (cf. also Rashevsky, 1948). Let us first consider the case in which the random fluctuations of excitation and/or thresholds are absent. Then, with a proper choice of the parameters involved, the circuit can produce either one of the two reactions \( R_1 \) or \( R_2 \), or none, depending on the intensities \( S_1 \) and \( S_2 \) of the stimuli. We shall denote the latter case symbolically by \( \bar{R}_1 \cdot \bar{R}_2 \). This circuit cannot produce both reactions. Now we have three possible signals: \( R_1 \), when \( S_1 - S_2 > h \); \( R_2 \), when \( S_2 - S_1 > h \); and \( \bar{R}_1 \cdot \bar{R}_2 \), when \( |S_1 - S_2| < h \). Hence the in-