ON LOCAL PRINCIPLES OF ANIMAL BEHAVIOR

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Abstract

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ON LOCAL PRINCIPLES OF ANIMAL BEHAVIOR

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In ([1]) an integral formulation was proposed for the basic principle of animal behavior—the principle of homeostasis. According to this formulation, every organism strives to minimize the functional

$$I = \int_0^T W\,dt = \int_0^T \sum_i \frac{a_i y_i^2}{2}\,dt, \tag{1}$$

where y_i is the deviation of some vitally important variable from the norm (a need); a_i is the subjective weight or importance of this need; t is time; the product $M_i = a_i y_i$ is the subjective sensation of the need, or motivation (desire, drive).

The rates of change of the variables $\dot{y}_i$ are, as a rule, subject to a nonintegrable constraint (the law of exclusivity ([2])):

$$\dot{y}_i \dot{y}_k = 0, \quad i \neq k. \tag{2}$$

A consequence of the law of exclusivity is the emergence of an alternative situation, when the animal is forced to choose between reaction i and reaction k. The purpose of the present work is to find an algorithm for this choice.

Formally, the problem may be posed as follows: if, from two decisions u_i and u_k (for example, eating and drinking), the animal chooses decision u_i, this means that decision u_i is in some respect better than u_k, i.e., some quantity (choice criterion) E is greater in this case:

$$E_i > E_k. \tag{3}$$

Let $u_i = +1$, $u_k = -1$; $u = \pm 1$; then the choice algorithms can be written as follows:

$$u = \operatorname{sign}(E_i - E_k). \tag{4}$$

The problem is to determine the structure of E, i.e., to find the functional dependence of E on a, y, t, and possibly on some other variables.

Suppose that the animal has chosen decision u_i. Let us divide time into intervals and imagine the subsequent behavior in the following form. At each interval the animal receives a triggering signal with probability s_i and reacts to it with probability r_i. As a result of the reaction the animal receives reinforcement (a partial reduction of the need), whose expected magnitude is equal to $\overline{\Delta y_i}$. Then the mean rate of satisfaction of the need is

$$\dot{y}_i = -s_i r_i \frac{\overline{\Delta y_i}}{\Delta t} \frac{1+u}{2}. \tag{5}$$

Analogously, for decision u_k:

$$\dot{y}_k = -s_k r_k \frac{\overline{\Delta y_k}}{\Delta t} \frac{1-u}{2}. \tag{6}$$

Here Δt is the duration of the interval: $\Delta t = \Delta t_0 + \Delta t_c$; Δt_0 is the waiting time for reinforcement; Δt_c is the proper time of satisfying the need.

The dependence of $\dot{y}$ on u is chosen so as to satisfy the law of exclusivity

$$\dot{y}_i \dot{y}_k = s_i s_k r_i r_k \frac{\overline{\Delta y_i}\,\overline{\Delta y_k}}{\Delta t^2} \frac{1-u^2}{4} = 0. \tag{7}$$

Let us find a choice algorithm that ensures a minimum of I under the additional conditions (5)–(6). Since $\dot{y}$ does not enter the integrand explicitly, a sufficient condition for a minimum of I is $\min W$ at each instant of time t. In turn, in order to achieve $\min W(t)$, it is sufficient to choose u in such a way that the increment dW on each time interval dt is minimal:

$$dW = (W_{y_i} \dot{y}_i + W_{y_k} \dot{y}_k)\, dt =$$

$$= \left(-M_i s_i r_i \frac{\Delta y_i}{\Delta t} \frac{1+u}{2} - M_k s_k r_k \frac{\Delta y_k}{\Delta t} \frac{1-u}{2} \right) = \min_u dW. \tag{8}$$

Hence it follows immediately that

$$u = \operatorname{sign} \left(M_i s_i r_i \frac{\overline{\Delta y_i}}{\Delta t} - M_k s_k r_k \frac{\overline{\Delta y_k}}{\Delta t} \right). \tag{9}$$

Comparing this expression with (4), we find

$$E = Msr\frac{\overline{\Delta y}}{\Delta t} = Msr\frac{\overline{\Delta y}}{\Delta t_0 + \Delta t_c}. \quad (10)$$

Attempts are known to solve this problem in a purely empirical way. For comparison we cite the results of K. Hull ([3]). Hull introduces an intermediate variable ${}_{sE}R$ (reaction potential), which determines all the basic characteristics of the reaction. In particular, in an alternative situation of two reactions, the one is chosen for which ${}_{sE}R$ is larger. In this sense ${}_{sE}R$ is identical to E. According to Hull, the structure of ${}_{sE}R$ is

$${}_{sE}R = D \times V \times {}_{sH}R \times K \times J, \quad (11)$$

where D is motivation ($= M$); V is the intensity of the triggering stimulus (analog of s); ${}_{sH}R$ is habit (analog of r); $K(\Delta y)$ is an increasing function of the magnitude of reinforcement; $J(\Delta t_0)$ is a decreasing function of the waiting time for reinforcement.

For small values of Δy, the quantities K and Δy coincide up to a constant factor. The same may be said with respect to J and Δt_0. The probability s of perceiving a signal, taking into account the threshold of receptor sensitivity and the presence of internal and external noise, will be greater the greater the signal intensity V. Thus, s is an increasing function of V. The variables ${}_{sH}R$ and r differ in that r reflects both the formation and the extinction of a reaction; in Hull, ${}_{sH}R$ describes only the acquisition of a habit; to describe extinction of the reaction Hull introduces an additional variable—the inhibitory potential, which is subtracted from ${}_{sE}R$.

Thus, there is an undoubted similarity between formulas (10) and (11). This fact may be regarded as empirical confirmation of the theory, since Hull' s formula is based on extensive experimental material. At the same time, the advantage of our approach should be noted: Hull' s formula was selected empirically and is therefore inevitably arbitrary in many respects. Formula (11), however, is obtained as a direct consequence of the single general and sufficiently firmly established principle—the principle of homeostasis.

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CITED LITERATURE

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2. P. K. Anokhin, *Internal Inhibition as a Problem of Physiology*, Moscow, 1957.

3. C. L. Hull, *Essentials of Behavior*, New Haven, 1951.

Note: Figure translations are in progress. See original paper for figures.