HIERARCHIES OF CONTROL PROCESSES AND THE EVOLUTION OF CONSCIOUSNESS

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1. Introduction

The purpose of this paper is to sketch an application of some ideas in the mathematical theory of control processes to biological phenomena such as instinct, learning, curiosity, adaptation, and, finally, consciousness. We shall employ the language and methodology of the theory of dynamic programming. Detailed accounts of the mathematical ideas will be found in [1], [2], [3]. For a quite different approach to consciousness, see [6].

2. Control processes

We begin with the idea of a process. Consider a system described by a point p in a space S. Let $T(p)$ be a transformation with the property that $p_1 = T(p)$ belongs to S whenever p is in S. We call the pair $[p, T(p)]$ a process. More precisely, this is a particular description of a process.

When the transformation is repeated, yielding a sequence of states, $p_1, p_2, \cdots$, where $p_1 = T(p)$, $p_2 = T(p_1)$, $\cdots$, we call it a multistage process. This is an abstract version of a dynamic process.

Assume next that $T(p)$ is replaced by a transformation of the form $T(p, q)$ having the property that for any p in S and any q in a decision space D, the point $p_1 = T(p, q)$ is in S. A choice of vectors (decisions) $q_1, q_2, \cdots$, then yields a sequence of states $p_1 = T(p, q_1)$, $p_2 = T(p_1, q_2)$, $\cdots$. We call this a multistage decision process. It is also an abstract version of a control process. From the mathematical point of view, control and decision processes are equivalent; see [2], [3].

A determination of the q_i may be effected by maximizing a criterion function which depends on the history of the process $K = K(p, p_1, \cdots; q_1, q_2, \cdots)$. In many important cases this has a separable structure $K = k_1(p, q_1) + k_2(p_1, q_2) + \cdots$, in other words an accumulation of single stage effects. A criterion function is a measure of the effectiveness of a control process.

The maximizing q_i will be functions of the states $p_1, p_1, \cdots$. In the most important cases the q_i which maximizes depends only upon the present and past