WORKING PAPER

ON THE MODELISATION OF A COGNITIVE PROCESS: A VIABILITY APPROACH

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

On the Modelisation of a Cognitive Process: a Viability Approach

Jean-Pierre Aubin
CEREMADE, Université de Paris-Dauphine
75775 PARIS cx(16), FRANCE
&
IIASA, Intenational Institute of Systems Analysis
2361 LAXENBURG, AUSTRIA

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FOREWORD

A dynamical description of an abstract cognitive system which should be closer to some cognitive considerations than pure automata or netwoks of automata is proposed. The system operates "sensory-motor" states, whose components are the state of the environment, its variation and the cerebral motor activity.

The main addition is the introduction of a "conceptual control" that is postulated in order to define a "learning process", which is a set-valued map associating conceptual controls with sensory-motor states.

A learning process must be consistent with a "recognition mechanism" which determines at each instant the set of possible metaphors, linking the perception of the environment and its variations with conceptual controls, as well as with "viability constraints"describing the consumption of the cognitive system, associating with each state of the environment the set of viable motor activities.

It also has to be consistent with an "action law", describing the evolution of the state of the environment in terms of the cerebral motor activity, and a "motor activity" law, describing the evolution of the motor acivity in terms of the perception of the environment and the conceptual controls. It suggests also that the evolution of a learning process obeys an "inertia principle" which allows to select specific choices of learning procedures.

This paper justifies this approach, which can used to prove mathematically the existence of a **largest learning process** and of specific "heavy evolutions" obeying an "inertia principle".

Alexander B. Kurzhanski
Chairman
System and Decision Sciences Program

Evolution Laws of a Cognitive System

We propose in this paper a dynamical description of an abstract cognitive system which should be closer to psychological and physiological motivations than pure automata or netwoks of automata. The main additional ingredient is the notion of a 'conceptual control" that we postulate in order to define learning processes. This requires a "regognition mechanism" which selects metaphors linking sensori-motor states to those conceptual controls.

We begin by isolating the variables of the cognitive system. We choose to describe them by the state of the cognitive system and a regulatory control (conceptual control). The state of the system (henceforth called the "**sensory-motor state**") is described by :

— *the state of the environment on which the cognitive system acts and its variation.*

— *the state of cerebral motor activity of the cognitive system, which guides his action on the environment.*

The regulatory control of the cognitive system is described by :

— *an endogenous cerebral activity which is not genetically programmed, but acquired by learning and recorded in the memory.* The purpose of this activity is to "interpret" (or "illuminate") the sensory perception of the environment, and we shall call it the "**conceptual control**".

We should emphasize that we shall study the evolution both of the state of the cognitive system and of its regulatory control. For this purpose, we must identify the laws that constrain and govern the evolution of the system. These are as follows :

— *A Recognition Mechanism*, with genetically programmed evolution, which matches the conceptual control to be chosen with the sensory perception of the environment and of variations in the environment.

— *A Viability Condition*, which expresses the fact that at each instant, the cognitive system transforms the environment by acting upon it and consuming scarce resources.

— *An Action Law* , which is a law for the evolution of the environment: the acceleration of this evolution depends upon both the environment and the cerebral motor activity.

— *A Motor Activity Law*, which is a law for the evolution of the cerebral motor activity : the velocity of this evolution depends upon both the sensory perception of the environment and its variation and the conceptual control (this law is used as a regulatory mechanism).

According to ideas of Piaget and others, we define

— *A Learning Process*, as a nondeterministic **feedback map associating a set of conceptual controls (possibly empty) with each sensory-motor state**, which is consistent with the viability constraints and the recognition mechanism.

Since a learning process is non deterministic and offer a priori many possibilities (contrary to stimuli-response laws), we have to propose a selection mechanism.

We shall postulate that the evolution of conceptual controls obeys a "inertia principle", which states that whenever a conceptual control "works" (i.e., allows to keep the evolution of the cognitive system viable), we keep it.

1 Justifications

There should be no difficulty in accepting the idea of an environment[1] on which the cognitive systems act, consuming scarce resources and transforming, creating or destroying this environment[2], since the ability to transform the environment has been recognized as one of the characteristics of living matter.

There should also be no problem in accepting the existence of cerebral activity which operates the internal organs of the body and the muscular activity by which interaction with the environment is possible.

The existence of conceptual controls and their use in a recognition mechanism are more questionable assumptions, which we shall attempt to justify at several levels.

— The ambiguous concept of **perception** includes both an "objective" and a "subjective" component. The objective component, which we call sensory perception, is provided by the neuronal circuit activated by the sensory receptors. But everyone knows that there is also a subjective component by which this sensory perception is interpreted : this interpretation may depend on many factors (previous experiences, emotional state, attention level, etc.), i.e., on a state of cerebral activity independent of the sensory inputs. This independent activity represents part of the regulatory control which we called conceptual control.

— If we accept the existence of an endogenous cerebral activity which "interprets" the sensory perception of the environment, we must postulate the existence of a recognition mechanism which tells us whether a conceptual control and the sensory perception of the environment and its variations are consistent.

It seems that brains have evolved systems which transform information on bodily needs and environmental events into cerebral activity producing either pleasure (comfort) or pain (discomfort). These systems are known by psychologists as **motivational systems**, and are naturally more sophisticated than strictly pleasure-seeking or pain-avoiding systems. They include the emotional system and the homeostatic drive systems, which basically keep the organism functioning (for example, the hunger drive).

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[1] both external, in terms of air, water, food, etc., and internal, in terms of the body and even the brain.

[2] Some four billion years ago the photosynthesis of the first organisms transformed the existing atmosphere of methane and ammonia to the oxygenated one we know today -this was probably the first example of pollution ! -

These systems reveal the relation between the perception of the environment and the conceptual controls : if these are not consistent the situation can be remedied by :

a)— acting on the environment (for example, by looking for and consuming food in the case of hunger);

b) — changing the conceptual control when action on the environment consistent with the existing conceptual control.

The latter strategy (change of conceptual controls) appears to be less frequent than the first and, for many subsystems (such as the homeostatic systems), is quite impossible. This is probably due to an **inertia principle** which we will postulate later, which states that whenever a conceptual control "works" (i.e., allows to keep the evolution of the cognitive system viable), we keep it.

— The idea of a recognition mechanism based on conceptual controls is consistent with the concept of **epigenesis**. The recognition mechanism outlined above is basically a selection mechanism with a definite Darwinian flavor, choosing conceptual controls as a function of the environment and changes in the environment. By representing the cerebral activity as the flux of neurotransmitters in individual synapses (see below), one could suppose that the synapses used most frequently would be stabilized, while those used less frequently would deteriorate. But the mere description of the synapses which are stabilized after a period of activity is capable of explaining epigenesis only to the extent that a road network can determine the routes taken by cars - in this case existing travel patterns require the maintenance of commonly used routes while the others can be neglected.

— We also postulated that the evolution of the recognition mechanism is programmed genetically. This recognition mechanism is probably rather simple : it may just open or close (activate or deactivate) a number of neuronal circuits during one or several specified periods of time, allowing both the neurotransmitters released by the perception of the environment and the conceptual controls to pass through.

It seems likely that some components of this mechanism (which should obey the laws of biochemistry) are **periodic** with overlapping periodicity, as specialists in chronobiology propose. These components are the many biological clocks involved in maintaining the homeostatic equilibrium of the organism[3].

[3]It may be postulated that the recognition of the periodicity of the sun and the moon by periodic components of the recognition mechanism in combination with suitable conceptual controls leads to the concept of time.

These periodic components of the recognition mechanism probably lie at the heart of the ability to recognize regularities and extrapolate them, as well as the desire to look for causal relations.

Other components of this mechanism are not periodic, but are active only during a certain period. This may be illustrated by the phenomenon of "imprinting" in ethology : in animal species where the young are able to walk almost immediately after birth,the new-born animals follow the first moving object that they perceive, whatever this may be. (In practice, it is usually a parent.) However, this susceptibility does not last indefinitely. For example, ducklings can be imprinted only during the first twenty-four hours of their life, with sensitivity at a maximum between the 14th and 17th hours. The crucial factor in imprinting is the mobility of the object to be imprinted, and this reveals the importance of the perception of variations in the environment.

— The assumption of a recognition mechanism using conceptual controls allows us to explain the **adaptability** and **redundancy** of cerebral activities. A cognitive system can recognize the same sensory perception using different conceptual controls at different times – this is redundancy. Then, thanks to the periodic nature of many components of cerebral activities, this sensory perception can be "interpreted" in several ways, provoking different actions (since we have assumed that the action taken depends upon the conceptual controls) – and this is adaptability.

The components of the recognition mechanism based on one or a small number of conceptual controls operate the automatic biological systems (the automatic nervous system, etc.), since in this case the subsystem inherits the genetic program of the component of the recognition mechanism.

— The concept of a recognition mechanism reflects the dichotomy between "**conceptually-driven** processes" and "**data-driven** processes" introduced by specialists in cognitive psychology and pattern recognition.

In this case the data-driven process is the cerebral activity provoked by the sensory perception of the environment while the conceptually-driven process takes the form of conceptual controls (this is the origin of our terminology). The idea of a recognition mechanism is also consistent with the concept of **metaphor**, regarded as a combination of a sensory perception of the environment and conceptual control **recognized** by the recognition mechanism. A feeling of understanding, which amounts to a feeling of pleasure, occurs when a metaphor is recognized by the recognition process. Perhaps thought processes also fit into this representation, since they involve setting up conceptual controls in the form of assumptions and then comparing them with the perception of the environment. This dynamical process of **making and matching** seems to be quite universal.

— The mathematical metaphor describes a **learning process** described as a feedback relation which associates a set of conceptual controls with each sensory-motor state. The larger the set of conceptual controls associated with a sensory-motor state, the less deterministic the learning process.

This fact has been observed and emphasizes by Piaget and others when they described the learning processes of children. Here, we characterize the viable learning processes and we deduce the existence of a largest learning process.

This in consistent with several observed facts. For instance, studies of the imprinting phenomenon have shown that the greater the effort made by the young animal to follow the moving object, the stronger is the imprint. When one of the components of the sensory-motor state is suppressed, the learning mechanism does not work normally. For instance, if kittens are raised in a visual environment composed of black and white vertical lines, they are unable to "see" horizontal stripes later in life. In another experiment, two kittens from the same litter spend several hours a day in a contraption which allows one kitten fairly complete freedom to explore and perceive its environment while the other is suspended passively in a "gondola" whose motion is controlled by the first kitten. Both animals receive the same visual stimulation, but the active kitten learns to interpret these signals to give it an accurate picture of its environment while the passive kitten learns nothing and is, in practical terms, "blind" to the real world.

One can translate mathematically these laws, as well as the regognition mechanism and the viability constraints and define the learning processes which are consistent with them (see [1]).

Then one can prove a characterization of the learning processes which are also consistent with the action law and the motor activity law in a sense that using the conceptual controls provided by the learning process, the cognitive system evolves and remains viable.

One also prove that given the recognition mechanism, the viability constaints, the action and motor activity laws, there exists a **largest learning process**.

The inertia principle can br implemented by selecting "heavy viable solutions", which minimize at each instant (the norm of) the velocity of the conceptual controls. Hence one derives from any viable learning process a deterministic laws which governs the evolution of the cognitive system.

The proofs of these theorems rely on Viability Theory and the differential calculus of set-valued maps. One cannot avoid the use of set-valued maps for defining the recognition mechanism, the viability constraints and the learning processes.

They also use differential inclusions[4] and even, differential inclusions with memory.

[4]The set-valued character of the differential inclusion takes into account the uncertainties of the events of the environment, the actions of the other cognitive systems, as well as lack of knowledge of the consequences of the motor activity up to time t.

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