Essay 5

Perception, Adaptation and Learning

Alvaro Moreno[*]
Juan Julian Merelo[†]
Arantza Etxeberria[*]

[*]Dpt. de Logica y Filosofia de la Ciencia,
UPV/EHU, Spain.

[†]Dpt. de Electronica y Technologia de Computadores,
Fac. de Ciencias,
Universidad de Granada, Spain.

Abstract

We attempt to distinguish, in a biological frame, ontogenetical adaptation from learning. Ontogenetical adaptation arises as a second order (sensorimotor) loop on the ground of the operational closure that provides autonomy and reproductive identity to the living system. Adaptation ensures, through perception, the functional correlation between metabolic-motor states and the states of the environment. Learning brings about a qualitative change in regard to adaptation, the most generic and simple form of optimization at an individual scale. It implies the idea of new knowledge, in the sense that the organism links what formerly appeared as an undistinguished whole. In other words, it means the capability to change its own codes of meaning. Finally, we outline some basic ideas for modelling an adaptive sensor embedded in a (partially) autonomous system, which implies the former distinction between adaptation and learning.

5.1 Introduction

Everyone has an everyday experience of "perceiving" and "knowing". Nevertheless, one of the most difficult problems for Biology and Cognitive Science is to distinguish among biological functions the properly cognitive ones. For the organism, the environment is a set of processes and components that have to be recognized and manipulated in order to be capable to survive and reproduce. Processes of selection and manipulation of materials are necessary to construct new copies of the organism (reproduction), to continuously renew its own components (metabolism), to discriminate harmful materials or organisms (defense), etc. In other words these relations are defined by the very nature of biological organization; therefore it is important to know what this organization is.

As the autopoietical theory states, biological organization is mainly formed of a recursive network of component production (Varela 1979). But the existence of (informational[1]) components that contain an abbreviated description of the very network is essential to ensure its reproductive self-maintenance. Therefore the minimal living system is a network of component production where the genome allows the construction of regulative components. This network is enclosed by a semipermeable membrane through which there is a selective exchange of raw materials and forms of energy (for example, light). The origin of cognitive functions is related to the complexization and selective specificity of this exchange.

Darwinian evolution—selection of the fittest genomes—acts as a mechanism of phylogenetic adaptation. The most primitive organisms could adapt only through this mechanism, that is to say, they died when the environmental conditions were adverse for the maintenance of their living operations (However, with the exception of viruses—which cannot be considered proper organisms—no living form exists today without some form of ontogenetic adaptation. The more primitive the organisms, the more phylogenetic is adaptation).

Surely very early evolution generated ontogenetically adaptive organisms. Ontogenetic adaptation implies that the organism metabolism possesses a capacity of (self) modulation depending on the characteristics of the environment which are relevant for it. Organisms have developed capacities to interact with their environments in a specific and effective way. Specificity and effectiveness depend on the gradual evolutive complexization of functional interactions with the environment towards epistemic interactions.

5.2 The origin of perception

In its simplest forms, ontogenetic adaptation is achieved through the selective activation of the pertinent genes given the detection of certain environmental conditions. This kind of adaptation can be understood as ways of connecting detection mechanisms with the ones that regulate the genetic repertoire, enhancing the production of the components the adequate action and without any reproductive consequences. These detection mechanisms constitute the most elemental version of perception.

Several authors (Pattee 1982; Conrad 1988) have proposed the classifying capacity of the substrate-recognition by the enzyme as the most elemental form of perception. This hypothesis is supported by the fact that all the increase of complexity of epistemic processes brought about by biological evolution, including the nervous system, are grounded on mechanisms of enzymatic recognition (Koshland *et al.* 1982). But the process of perception entails more than the classifying capacity of the enzymes. In the cell, the configurational change of some membrane proteins (or by a specific set of

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[1] By information we mean the capacity of certain physical entities of presenting alternative configurations and consequently of exerting different actions in regard to other components or the whole system. Information is a macroscopic characteristic of a physical entity and its origin is energetic, it depends on the microscopic-macroscopic relationship.

such molecules—Kremen 1992), when they receive specific physical patterns, triggers metabolic-motor reactions.

So, a perceptive process starts with certain changes occurring in the environment that are detected in the boundary of the organism. Perception is basically a pattern-recognition process coupled with some functional consequences for the system which performs such pattern-recognition. Insofar as any pattern-recognition is a many-to-one mapping, this raises the question of how to determine whether the classification is adequate or not. The only possible answer seems to be that adequation must coincide with the biological functionality of the system: an adequate sensorimotor correlation will be established if it is viable for the system in a specific ecological context. We understand by viability the fact that the mechanism that supports the epistemic interaction with the environment is embedded in the global process that ensures the reproduction and, furthermore, the survival of the organism. To fix the sensorimotor loop, living systems (either phylogenetically and/or ontogenetically) should selectively discard a great amount of components and metabolic paths. In this way, epistemic adequation is achieved through recursive interaction with the environment (producing its modification), a mutual and progressive organism/environment adjustment until some stability points are reached. The organism/environment relation can be seen as a closed correlation between perceptions of the relevant properties of the environment (its "affordances") and motor actions on it. Both processes are complementary in the sense that perception must be active (the organism moves towards its goal object, acts to perceive it) and action must be guided by perception. Perception is a requisite for optimum action, but both are entangled in a closed loop.

5.3 Adaptation and Cognition

Once epistemologically outlined the adaptive mechanism at individual scale, we are prepared to pose the following question: can perceptive-functional organisms whose adaptive processes are based on an enzymatic control be considered really cognitive? Although phenomena such as taxia, as they are primitive forms of perception-action, can be considered generically cognitive, the usual sense we give to the term is related to the development of learning, memory and anticipatory behavior.[2] To realize these functions it is simultaneously required a big increase in the capacities of detection, a complex process of transformations and reorder of the results of detection, and a correlated sophistication of the effector organs. The idea we are defending here is that the functions that are usually considered cognitive are the result of a specialised subsystem of the organism continuously reconstructing patterns that are functional or referentially correlated with certain changes occurring in the environment. This set of patterns (built up during the existence of each cognitive organism) makes up what we usually call information. Thus, in contrast to the previous types of adaptive response, exclusively based on the control exerted on metabolic processes, cognitive functions are based on the control on information.

While in purely adaptive organisms perception is, as we said before, the direct cause of certain metabolic-motor actions, in cognitive organisms the physical patterns impinging on sensors are transformed in trains of discrete sequences that modify the dynamics of a network of information processing. Very clearly the biological function of these informational patterns is to ensure the maintenance of an adequate relationship between the activity of the organism and changes in the environment.

There is a main reason why only those organisms whose interaction with the environment is performed through a specialized system of processing the information coming from perception can exhibit a fully cognitive evolution. Because the construction of informational patterns is detached from the other global metabolic functions, cognition makes possible a minimization of the energetic costs of the mechanism of selection of such informational patterns by trial and error. As a consequence of it, cognitive organisms can construct and control a potentially unlimited variety of internal representations of their environment.

All the functioning of the cognitive system is based on a strong selective process of the high number of the available informational patterns. But, at the same time, the bigger is the number of informational patterns or configurations of which the system gets rid, the bigger will be also the knowledge it acquires. This selection can be achieved either by:

1. A modification of the processes that control the relations between discrete informational states,

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[2] An intuitive idea of anticipatory behaviour is that it is an operation performed by a biological system through which it re-constructs on its inside its own environment in such a way that it becomes capable of succesfully anticipating some external events. Of course, cognition implies many other behaviours, but anticipation is a good example, for it shows the modelling relation between some pattern of the cognitive (sub)system of the organism and some other of the external world.

and/or:

2. A modification of sensor organs (and/or of motor ones).

Nevertheless, this does not mean that the whole cognitive system has homogeneous plasticity levels. Organisms are the result of a long evolutive process that structures in the course of phylogenetic changes several cognitive levels, some deeper and more stable, others more plastic.

All this shows that the key concept to explain the differences between the respective epistemic capacities of the purely adaptive systems and of the properly cognitive ones is the capacity of the latter to change, *in somatic time,* the very structure of the system that correlates sensors and motors.

5.4 Cognition as function

From the viewpoint of its origins, cognition has the biological "metafuction" of allowing the adequate realization of the rest of the biological functions. Although cognition does not define the set of biological needs (biological functions), it is directed to the optimization of their realization. Therefore, even if cognition cannot be studied apart from biological functions, it has a different specificity: the optimization of those through mechanisms that imply informational processes.

Cognition implies a systemic coordination of components specialized in information detection and trigger changes in the system. Epistemologically it can be considered as a material process of creation of representations of the relevant reality of the organism and adequation of functional behavior to them (Moreno & Etxeberria 1992). It requires the existence of sensors (which provide signals or records indicative of the relevant properties of the environment) and effectors (that adequate their activity to this information). Between sensors and effectors there mediates a system of internal processing of the sensors' results which allow in certain cases the realization of typically cognitive behaviors: learning, associative memory, anticipation, etc.

In cognitive organisms the nervous system accomplishes this intermediate role. The function of the neuron as a component of an informational system emerges from properties of intraneural specialized elements (enzymatic diffusion, cytoskeleton). Different correlations or codes in neural networks (Cariani 1991) are the next level of structural emergence.

The very organization of networks was formed through processes of variation and selection that act in somatic time. Learning appears as the capacity to re-structure this internal network of informational processes depending on the characteristics of the environment and past experience. It does not depend directly on regulation on the genetic repertoire.

This intermediate system has generally been considered as the totality of the cognitive system (for example in classical computationalism). Connectionist networks provide appropriate metaphors to characterize the processes of this subsystem; instead of taking them to be formal and fixed, the connectionist viewpoint poses the problem of learning and information manipulation and selection in a biologically more realist context, closer to the real operation of organisms.

5.5 Basic ideas on the modelization of a cognitive system

If we want to place the problem of modelling a cognitive system in its biological ground, we should move from the domain of AI to the one of Artificial Life. There are, however two different (though not incompatible with each other) approaches and research programs in AL. The most popular one is based on computational simulations; the other one is to attempt to construct artificial living beings in the real world. The attempt to creation of artificial living beings inside the real world (as opposed to pure simulations) belongs to the research program of realizations in AL.

With current technology, it is clearly not possible to create artificial organisms that thrive in real world, getting their perceptions from outside, and moving, feeding and reproducing inside it. The main difficulty to this would be the implementation of evolution, connected with reproduction. It is not possible to create a building procedure robust enough to admit variations, and simple enough to be implemented on a small machine.

Thus, our endeavour must be focused on the creation of simulated artificial worlds (aworlds) with artificial life (alife) beings living inside them. All simulations can be placed now at this level. It is then pointless to discuss if simulations of alife beings are actually alive. The creators of alife beings just try to implement as many traits of life as possible into their beings.

One of this traits, with which we are dealing here, is cognition. But now all epistemic processes, like perception, learning or anticipatory behaviour, must take place inside the artificial world, and thus they would be simulated perception, learning, etc., in the same sense that it is a simulated life.

How should we simulate an artificial world for artificial cognitive beings? In this world there should be some "laws" (in fact, rules) imbued by its creator, that we call the *Physics* of the world. These rules are as low-level as possible, so that they must not constrain high levels of behaviour, but lowest level (movement, feeding...).

The physics of an aworld (artificial world) must at least include the following rules:

Space dimensionality and dimension: is it 3-d, 2-d, discrete or continuous? Is it a 2-d square grid, a torus, a cube?

Object characteristics: are the world objects solid, flat, visible, can they be heard?

For instance, an alife being living in cyberspace (the space formed by all the nodes and links of the world net) must face some constraints: it can only move (or parts of it can only move) as fast as the slowest modem allows and it cannot run instructions faster than the processor in which it dwells allows. In the same way, real creatures face some constraints, imposed by their "creator": men cannot fly (unless they use a plane), flies cannot fly faster than 9 km/h, and fishes cannot breath outside water.

The important thing about these rules is that they must be self-consistent, and as low-level as possible (this is rather ambiguous, but rules as "if 3 alife beings are within a radius of 4 squares, then another one is born" should not be allowed).

For an alife being to be cognitive, it must learn, of course, inside the aworld; it must create new meanings for old inputs, that is, it must possess an adaptive sensor. A sensor is adaptive in two senses:

- In an ontogenetic scale, it can develop and read new inputs to the alife being.
- In a phylogenetic scale, it can give new meanings to old inputs, for instance, when a system attractor is reached.

Thus, in a phylogenetic scale, there must be a development of new sensorial structures, able to perceive farther, closer, or just another way. In an ontogenetic timescale, a sensor cannot pick-up new types of inputs, but the input/output mapping should vary.

To implement this, the tools we have got at hand are neural networks and genetic algorithms. The most powerful to implement a learning system nowadays is a neural network, whose structure, in order to evolve, must be genetically coded. Besides, genetic operators, as powerful recombination and structure evolution operators, can be applied in an ontogenetic timescale, to perform adaptation in lifetime. In this case, genetic operators play the role of metarules of learning, they code different training rules for the neural network, so that these rules can vary in somatic time (Ackley & Litman 1991; Merelo *et al.* 1992).

The model proposed for an adaptive sensor has got the following parts:

Input: Composed of functions and rules that map the world to the input of the following processing part:

$$\begin{aligned} f_i : W &\rightarrow \Re^n \\ f_i(\{w_{ij}\}) &= v_j \end{aligned}$$

These functions are genetically coded, and vary ontogenetically as well as phylogenetically; however, n, the dimensionality of the output, can only vary phylogenetically, in accordance with the variation of the rest of the sensor. The number of rules (the number of senses) can only vary phylogenetically. These rules must follow the physics of the world: if there is a solid object in the line of sight, what is farther cannot be seen, for instance.

Neural network: That receives input from previous processing step, and gives an output to the motor organs. This neural network can vary structurally in a phylogenetic time, as well as during the lifetime of the alife being, according to inputs received.

This way, our model could overcome some epistemological limitations of current connectionist approaches to cognition. In such approaches, the cognitive systems are not able to autonomously find solutions for certain tasks, nor determine their goals by themselves or change the ones specified from the outside (van de Vijver 1991). As a consequence the (relative) self-organization in the solution of cognitive problems is basically external to the process of constructive self-organization of the very cognitive system. In our opinion, the root of this unsatisfactory situation lies in the fact that the cognitive process is not considered as related in its origin to the self-reproductive one (Moreno & Etxeberria 1992).

5.6 Conclusions

Cognition transfers progressively the functions of phylogenetic adaptation to the spatial and temporal scale of the lifetime of an organism (plasticity and structural change as learning in the cognitive subsystem). It establishes a new relation in the activity of the organism in its environment. This process appears internally as a functional hierarchization, where the cognitive system operates as a meta-function for the general regulation of the rest of them.

Both aspects—the relation of the organism with its environment and the organization of its functions—are coupled in the development of a rich and versatile universe of internal configurations (related to the external world through sensors and effectors).

From this approach the function of cognition appears as:

1. An increase of the complexity of the regulation (as a metafunction) of the rest of the metabolic-motor functions. This is not possible without the development of an internal universe coupled to the environment of the organism (sensors and effectors) as rich and modulable as possible.

2. A transfer of the function of phylogenetic adaptation to the somatic time scale. This is not possible without the development of an internal universe coupled to the environment of the organism (sensors and effectors) as rich and modulable as possible.

3. The generation of a viable mechanism (in terms of energetic costs and other physical factors) for the canalization of the material supports induced by sensors (which avoids the diffusion of those material supports). Without this system of canalization no metabolic meta-function is possible. Thus, instead of a metabolic self-control, cognition brings about an informational meta-control on metabolic-motor functions.

4. The possibility of anticipatory behaviors. Anticipatory behavior shows the modelling relation between some pattern of the cognitive (sub)system of the organism and some other of the external world. This is not possible without the development of an internal universe, articulated on a canalization system as rich and modulable as possible of the material supports induced by the sensors.

5. The possibility of learning, as the acquisition of new knowledge, in the sense that the organism links what formerly appeared unconnected before it and/or discriminates what appeared as an undistinguished *whole*.

The development of the mentioned functions (meta-regulation and the capacity of a restructuration on an ontogenetic scale) implies the development of an internal universe of configurations coupled with sensors and effectors; with the physical canalization of material supports (that is, information) able to vehicle that coupling; with fast, versatile and reliable internal mechanisms of modification of internal configurations through recursive modifications of the system of canalization (that is, of the signal connection network). And all these operations are selected depending on a fitness principle which is ultimately phylogenetically relevant.