

INFORMATION PROCESSING: FROM A MECHANISTIC TO A
NATURAL SYSTEMS APPROACH.
WHY CONNECTIONISM IS COMPATIBLE WITH THE IDEA OF AN
ACTIVE INFORMATION PROCESSOR.

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Abstract

During the last decade connectionism attracted the enthusiasm of many AI-researchers. Yet there is doubt concerning the advantages of implementing the cognitive connectionist findings into cognitive psychology. The main problem is that the PDP-models use a mechanistic systems view to information processing, which doesn't coincide with the natural systems approach of cognitive psychology.

In this paper we want to argue that connectionism is indeed compatible with the idea of an active information processor. Moreover we put forward the hypothesis that a mechanistic systems approach is a necessary preliminary phase in the evolution of all information processing models.

We defend this hypothesis by applying the Overton-Reese analysis to the evolution of the different information processing models during the twentieth century. In this evolution we see a periodically reoccurring pendular movement between a mechanistic and a natural systems approach, giving way to a higher level theory applicable to human cognitive functioning.

1. A survey of the evolution of information processing models in the 20th century

1.1. What came first: from "eidola" to deformations.

Looking from a historical perspective the systematic research on perception was mainly the concern of philosophy, more specific of the branch named epistemology. Epistemology puts the question whether our experiences are an exact reflection of the

physical world. This interest in perception goes back to classical Greece.

Among the Greek philosophers it was thought that perception of the world was caused by the entrance in the mind - by means of the senses - of miniature copies (eidola) of external objects. This naive realism can immediately be discarded because of the existence of visual illusions and ambiguous figures. Here the perceptual system has to add something to the way things are perceived, because the stimuli don't determine the perceptual experience by themselves.

Nevertheless knowledge of the occurrence of visual illusions dates from the classical period, as can be seen for example in the building style of the Parthenon. The writings of Vitruvius clearly demonstrate that intentional corrections were made to prevent the deformation of its harmonic appearance by visual illusions. There exist two different points of view on explanations of these phenomena:

- a) Sensory input is variable and inaccurate. One of the main functions of the brain is to correct these inexactitudes to give an accurate representation of the external world. As such, Plato (\pm 400 B.C.) argues that one has to speak about seeing objects with the mind but through the sense organs, because the sense organs themselves only provide an imperfect copy of the world.
- b) The sense organs are inherently accurate and therefore responsible for a true image of the environment. Only the mind and its judgmental capacities are limited.

From the first point of view perceptual mistakes occur when one puts more trust on the sense organs than on the mind. From the second point of view these mistakes are caused by inferences of the mind with the operations of sensorial perception. Both points of view were very popular in ancient Greece and dominated the thoughts on perception and cognition for more than 2000 years. In this discord Aristotle took a compromise position wherein elements from both points of view were incorporated. This general line of thinking survived at least until the Middle Ages. Even the position of Descartes was not very different from Aristotle's. He distinguishes for example both a phase of registration and of interpretation, and notes that perceptual mistakes can take place during both phases on their way to the brain (Coren & Girgus, 1978).

This much approved view assumes a constructive-rationalistic epistemology according to which the knowing subject constructs its knowledge in an active way. Despite the impressive track record of this position, the early experimental psychology again supported the traditional eidola theorists. Because of the diverse

influences from topical physics and neurology, this empiristic approach survived until the first half of this century.

Before Müller, during the period of 1830, perception was being considered as a process where the receptors take the equivalent of a picture of the stimuli and carry this to the "sensorium" for analysis. In Müller's conception the physiological processes translate the image into a pattern of neural activity, as to permit interpretation and selection. During this processing phase the possibility arises that perceptual deformation will take place. During the same period Weber struggled with a series of systematic discrepancies between physical reality and conscious perception. Contrary to Müller however, he did not try to explain why these illusions took place. Using the methodology of physics he limited himself to giving a quantitative description of the deformations.

These findings and approaches were integrated by Fechner in the system of classical psychophysics. We note that the psychophysical approach essentially denies the existence of visual illusions, by stating that every illusion can be reduced to a quantitatively predictable deviation between conscious perception and the physical stimulus.

1.2. *The New Look*

At the time psychophysics flourished due to the enthusiasm of the upcoming computer technology, the information pickup approach emerged; i.e. the new uprising of "eidola" theory for which the Gibsons stand as a clear example until now. As suggested by its name, this approach considers an unprocessed input of material into a passively responsive organism.

As a reaction in the beginning of the fifties, a series of publications in experimental psychology suggested that the perception of external stimuli is being influenced by internal states. Attitudes, values, expectations, needs and psychodynamic defences were all considered as acting upon perception. This point of view became known as the New Look.

In 1958 Broadbent's "Perception and Communication" brought a radical transformation to perception research. Information processing as a basic framework for the conceptualization of cognitive activities became predominant. This approach was created by Shannon 10 years before. It described the flow of information by statistic concepts while not taking into account the contents of the message.

With a model of humans that took the topical developing computer as a root metaphor, the New Look was to expect an

inevitable death: a new pendular backsliding from constructivism-rationalism to realism-empiricism.

1.3 *The information processing approach: basic assumptions*

Based on experimental research and a series of hypothetical flowcharts the information processing movement makes three assumptions, which we will sum up briefly.

A first main premiss states that perception is not a direct consequence of stimulation, but results from the input being sequentially subjected to different types of transformations and storages (Erdelyi, 1974). Every perception is therefore the result of a sequence of processes that are allotted a fixed amount of time each, during which they carry out their characteristic operations. This allotment of time is only theoretical, since it disregards the interactions between operations that take place. These operations that transform the information in different ways (transfer of information between different storages, coding processes, ...) are assumed to be limited in the amount of information they can handle during a given period of time. This is a limitation depending on the circumstances which supposes selectivity, as does each capacity limitation (Haber & Hershenson, 1980; Schadé, 1984). In other words the postulation of a selection forms the second main premiss.

A third assumption concerns the continuity of sensations, perception, memory and thinking. Perception cannot be isolated from memory as recoding and storage take place on each level of the processing sequence (Reed, 1973). Within this framework information processing research studied the interactions between the subsystems of the perceptual apparatus as well as the interactions between perception and other cognitive processes (Dember & Warm, 1979).

1.4 *Broadbent's filter model or the 'homunculus problem'*

What used to be no more than a criticism to the New Look, soon became part of the reaction to the selection assumption of the information processing approach. Who or what is selecting the perceptual input? The critics had formulated the 'homunculus' or 'little-man-in-the-head' problem.

Broadbent suggested that the listener acquires selectivity because of a filter inside of the brain blocking the input after it had reached the sensory storage, i.e. the level of sensations at the primary sensory receptors. The information was, in comparison to the computer metaphor, supposed to be chosen on the

basis of the physical characteristics by which the filter had been programmed.

This filter model received its experimental support from research settings that were based on the 'cocktail party' situation, which for example included shadowing experiments. Here the subject receives a different message to each ear, and one of these has to be 'shadowed'. In this situation where the subjects are forced to direct their attention to only one of the two channels, one observes that the content of the neglected channel becomes irreversibly lost to conscious perception. This is indeed the case as the execution of the selection occurs a priori.

Nevertheless, electrophysiological registration showed that in certain cases the content of the neglected channel did find its way through to the perceptual analysis. Therefore, for instance, the listeners detected their own name in the neglected channel. This is not exceptional as we notice in the real life 'cocktail party' situation how one can concentrate on the conversation in which one participates, but anyway will experience a shift of attention the moment his name is mentioned in another conversation.

This means that besides physical characteristics, stimuli are also analysed on behalf of their meaning. Therefore a modification of Broadbent's filter model was proposed. The first modification was done by Treisman, who placed the filter in a later phase of the processing sequence to make the model compatible with the data that indicated a total semantic analysis.

Yet, as pointed out by Norman, the experimental findings rather suggest that the semantic analysis takes place at a relatively early processing phase. The combination of both views and the acceptance of a semantic analysis by Broadbent led to a modified filter model, sometimes referred to as the Broadbent-Treisman model.

1.5 *The evolution to an 'active organism' model*

What only seemed to be an elaboration, implicates however a fundamental change in methodology, since it concerns an adjustment from a 'responsive organism' to an 'active organism' model of humans (cf. Overton, 1984). Indeed a total semantic analysis implies an active search of the sensory storage and that way results in a subjective implication.

Shiffrin and his colleagues have extended this filter notion to vision where it also stood the test. This leads to the acceptance in perception research of the assumption that the symbolic input becomes administered to a complex symbolic analysis before

the selective filtering takes place.

The information processing approach considers long term memory to be this filter which decides what passes and what is blocked from the field of consciousness (Erdelyi, 1974). Even though these processes imply an active organism processor, the way of processing still is consistent with the computer metaphor, where the only transformation of the current input is the one in function of formerly stocked input. Thus in essence it is not the metaphor that determines to which world view a theory belongs. Fundamental is the absence or the incorporation of some top-down processes from the memory store onto the current perceptual input.

1.6 *The PDP-approach*

Early models, like the Broadbent-Treisman model, presuppose that the perceptual input is scanned serially in view of the semantic analysis. The idea is that the analysis of perceptual data proceeds by one unit per time interval, in this way protecting the system from overload. An overwhelming amount of empirical findings concerning neurophysiological and behavioral observations (e.g. Dember & Warm, 1979) is found to support this idea.

Recent models on the other hand emphasize the compatibility of parallel processing with the idea of limited processing capacity. Therefore it is also possible to explain the neurophysiological and behavioral findings by a parallel processing model. Moreover there is experimental evidence to support the existence of a parallel processor (Reed, 1973), which is not the case for the assumption of a serial course. That way parallel processing seems to be the most valid assumption.

One of the prominent advocates of this new way of thinking was Marr (1982). He tackles the question of "vision" in a purely bottom-up way, mostly concentrating on computer vision. As such he gives a clear example of "mechanistic systems" research as will be explained later on. Another example in the same line of research is the work of Biederman (1985) on generalized cones.

The methods of these recent models are incorporated in what is called the PDP approach, which stands for "Parallel Distributed Processing", also known as connectionism. Here one starts from the axiom that intelligence is the result of the interaction of a large amount of single processing units (Rumelhart & McClelland, 1986).

This way of tackling the underlying mechanisms of cognition gave way to a considerable progress in the field of Artificial

Intelligence, but also led the critics to fear once again a shift towards a realism-empiricism epistemology.

However, as mentioned before, success with the computer metaphor doesn't condemn a theory to a "mechanistic organism" model of humans. Moreover, history shows that an epistemology should not be considered as inherent to the respective research model. More important are the contents given to it by researchers and adherents. Although connectionism is for the moment perhaps the most prominent example of a mechanistic systems world view, we will try to argue next that it doesn't in any case exclude an "active organism" model of humans.

2. *The Overton-Reese analysis*

2.1 *World views and families of theories*

The evolution within the information processing approach can globally be seen as a pendular movement between two kinds of theories which can be differentiated on the basis of the epistemology that they support.

A taxonomy that employs this difference in epistemology is the Overton-Reese analysis, which classifies theories according to the world view on which they are based. This world view represents the essential characteristics of the scientific activity of these groups of theories, named families of theories.

According to Overton (1984) the difference between both families of theories is, from an historical perspective, founded in the categorical question of "Being" or "Becoming", and in the question of accidental or necessary organization. The first question has to do with the fundamental nature of objects and events as fixed and stable (Being) or as active and changing (Becoming).

The "Being"-position requires that activity and change are explained by the accidental organization. The theme of necessary or accidental organization was for the first time developed by Plato and Aristotle, and later became elaborated by the rationalist philosophers (e.g. Kant). Accidental activity and change have an external cause, while necessary activity and change are independent from causal events because they are inherent to the system.

Both world views are based on a root metaphor, which defines the family of theories and the accessory models of humans. We give a summary of Overton's description in table 1. Overton (1984) indicates these families by respectively "or-

"Mechanistic systems" theories	"Natural systems" theories
Lockean-Humean philosophy of "Being"	Ontological commitment Kantian-Hegelian philosophy of "Becoming"
Stability, fixation and uniformity are considered as fundamental	Status of change Activity, change and organization are considered as natural and necessary features of cosmos
Organization and change are the result of accidental factors	Status of accidental factors Accidental factors can influence activity, organization and change, but cannot explain them
Realism-empiricism: the subject reflects a copy of reality	Epistemology Constructive-rationalism: the subject constructs its knowledge actively
"Responsive organism" model	Model of humans "Active organism" model
Machine	Root Metaphor Living organism

Status of organization

Human beings have no inherent organization. The appearance of organization and functions is only seemingly, and has to be considered as the result of external factors

Human beings exhibit a necessary inherent organization, which consists of physical functions as representation, perception and attention

Status of activity

Activity is the result of external factors, because man is inherently in a status of rest

The human being, and not the environment, is the source of activity

Family of theories

Behavioristic and neobehavioristic theories (Skinner), observational learning (Bandura) and information processing theories (Gibson)

Gestalt theories and the contemporary structuralists (Piaget, Chomsky, Kelly, ...)

Table 1: Characteristics of "natural systems" and "mechanistic systems" theories, based on Overton (1984)

“Mechanistic systems” approach	“Natural systems” approach
Naive realism	Constructivism
Information pick-up approach (Gibson)	
'48: Shannon: information processing approach	'50: New Look
'58: Broadbent: “Perception and Communication”	
Treisman: Modification of the Broadbent model	
Norman: semantic analysis	Translation of the New Look into information processing terminology
Broadbent-Treisman model	

Table 2: Evolution of the information processing approach

ganismic” and “mechanistic” theories. Wieland and Ullrich (1976) on the contrary prefer to speak of “natural systems” and “mechanistic systems” theories. We will use this last terminology because, according to our opinion, it catches the entity under consideration more accurately: indeed families of theories are not “mechanistic” or “organismic” in itself, but they do look at systems as being either “organismic” or “mechanistic”.

2.2 Situation of the information processing theories within the Overton Reese analysis

Overton (1984) classifies the information processing theories as an entity under the “mechanistic systems” family of theories, naming Gibson as an example. According to Coren and Girgus (1978) however, the Gibsons are adherents to the information pick-up approach. This can be understood as follows.

The information processing approach is based on a naive-realistic world view. As mentioned before, since 1948 perception research became modified as a result of Shannon's establishment of the information processing approach. However the modification we refer to was effectuated within the same world view as its predecessor the information pick-up approach. That way it is to be seen more or less as a prolongation of the latter.

Information processing was further pronounced by Broadbent, starting with the publication of his book "Perception and Communication". In the meantime the constructivist world view gave birth to the New Look which was later also translated in information processing terminology (Erdelyi, 1974).

This means that the current information processing approach consists of two drifts: a constructivist and a realistic. It therefore implies a localization under both the "natural systems" as well as the "mechanistic systems" family of theories. And here we find Gibson as an example of the latter.

It has to be pointed out that the Gibsons are one of the only current adherents of the "mechanistic systems" information processing approach. Other scientists have evolved to the "natural systems" view; among which Broadbent as mentioned.

Consequently, another problem is the question of Broadbent's position, or what is the Broadbent filter model? Is it the original one from which Broadbent started off in a "mechanical systems" view, or is it the Broadbent-Treisman model which includes a semantic analysis?

Stated as such the question is arbitrarily, one needs only to specify which of both models is meant. Practice shows however that such specifications are hardly ever made (cf. McGuire, 1983). And this is especially here the case, because - working in his own field outlined by either a "mechanistic systems" or a "natural systems" world view - each researcher only "sees" one of both models.

Many explanations can be given to this phenomenon: in terms of theory ladenness, of selective perceptual or cognitive attention, of cognitive dissonance... One thing however stays clear: we should start looking at things at a "metalevel", independent of either one world view. One method to keep in mind when facing such black-and-white controversies is considering the assumption that the question might be put wrong. This may probably lead to an acceptable solution.

2.3 *The realism/constructivism pendulum*

This evolution in information processing may seem strange if one

refers to Kuhn's (1970) axiom that scientists do not convert themselves to a new research tradition, yet extinct. This means that the transition from one research tradition to another depends on a new generation of investigators, while the former generation holds on to the original program.

Here this is obviously not the case, but one can ask oneself the question whether we are indeed faced with a change of research tradition. According to its definition this is not the case since both the research object and the methods of approach remain the same.

Either way one has to consider the fundamental nature of the revolution that took place, especially as it is a revolution that repeats itself in the course of epistemological history. Therefore we are inclined to suppose that a "mechanistic systems" theory forms a necessary preliminary phase to the development of an equivalent "organismic systems" theory, just as is the case with the qualitative/quantitative distinction.

Here a qualitative approach forms a preliminary phase to every quantitative one, with the consequence that the applied language (verbal or mathematical) reflects the progress within the research tradition. According to De Groot (1969), a verbal theory consists mainly of a descriptive definitional system and frame of reference. It is only in a limited way a theory - in the true sense of the world - from which one can extract hypotheses about the outcome of a series of operations.

On the other hand this might be exactly what is necessary for a systematic exploitation of the subject. In this sense McAnally (1974, p. 10-11) warns against the dangers that rise when applying a quantitative conceptualization in a too early phase. One first has to strive at gaining the comprehension of the research object in qualitative terms before administering a mathematical form to it.

The evolution from qualitative to quantitative represents an augmentation in formalization so that the area of applicability of the postulated axioms enlarges: from ideographical to global applicability. We assume an identical interaction at the basis of the pendular movement realism/constructivism in cognitive psychology.

Here one starts from a machine-metaphor and likewise arrives at a model applicable to a machine, i.e. a "responsive organism" model, in which only the bottom-up processes are taken into account: the input of the raw data.

In a following phase the transition takes place to the constructivist drift, where one expands the model with the top-down processes and as such generalizes it as to make it applicable to

the reality of an "active organism" model.

2.4 *The PDP-approach*

From this point of view we proclaim that the PDP-approach will evolve into a "natural systems" model in the near future. As in former information processing models there is room for a model of humans that sees the subject as an active information processor. This is even so when one considers this active component as a function or a result of the programming-characteristics of the system.

The translators of the New Look into information processing terminology have recognized the same: processing has to proceed as a function of the programming of the system in order to avoid the necessity of postulating a homunculus. The degree to which the model leaves room for the conceivment of top-down processes determines if a model is or is not an "active" one.

A model is active when it selects its input to one or another degree on the basis of formerly stored material. This subjective component is therefore not present from the beginning, but has to result from the experience of the subject (cf. Atlan, 1987).

This implies that each system that is capable of acquiring experience is an active system, for experience isn't experience when it doesn't have any impact on the present. This is likewise the case with PDP-models.

Rumelhart and McClelland (1986, p. 9) have incorporated this notion of the presence of top-down processes in their classic work on connectionism: "Parallel Distributed Processing: Explorations in the Microstructure of Cognition". Here they stress the interaction of knowledge structures that are build on experience, as to explain the generative capacity of human cognition in new situations.

That it concerns a study of the microstructure has little impact on the possibility of transition to a "natural systems" approach. It's important to realize that the real functional system of human cognition also depends on a microstructure, and nonetheless leads to a subjective implication in that same cognition.

2.5 *The semantic component: a gaze at the future*

According to Atlan (1987) the subjective implication is a by-product of the semantic structure, because it is this structure that consists of experience. This point of view is interesting because of its reoccurring character. The transition from a

"mechanistic" to a "natural systems" drift within the information processing approach did also occur with the implementation of the memory component.

We recall that the modified filter model by Broadbent and Treisman also postulated a total semantic analysis by way of long term memory store (Erdelyi, 1974). This refers to the same "semantic" component, though in our point of view, has to be understood in the "broad" sense of the word.

Elsewhere we put forward the thesis that the term "semantic" refers to the structure of the total net of concept knots. In consequence the opposition between an episodic versus a semantic memory store seems to be based on a different interpretation of the word "semantic". Here the term "semantic" doesn't stand for an indication of a separate memory pigeon-hole, but on the contrary as an indication of the nature of memory in its totality.

Many authors have subscribed to this ambiguity (e.g. Wilks, 1983) trying to make it clear by choosing a different term or by construing a neologism. One of those proposals is the term "conceptual" which was brought forward by the school of Schank. According to Wilks this term doesn't cover the contents, but anyway offers the advantage of not being subject to multiple contents.

In this view the semantic component is an entity of empty concepts that can be defined by a label and where the meaning is generated by the associative connections to other concepts (Cohen, 1977). A suchlike component is totally acceptable within the frame of connectionist methodology, for its description clearly resembles the description of a neural connectionist network as given by Caudill (1987). As far as this semantic component isn't incorporated in some PDP-models already, its incorporation surely is predictable within near future.

We like to conclude by stating that enough arguments are present to ensure a transition of connectionism from a "mechanistic systems" to a "natural systems" family of theories as a natural evolution of the research tradition itself.

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