Cognitive systems and the special order of their environment:

Uri Hershberg[1] & Anat Ninio[2].
1 Interdisciplinary Center for Neuronal Computation, at the Hebrew University, Jerusalem, Israel.
2 Department of Psychology, Hebrew University, Jerusalem, Israel.

Abstract
We wish to propose a general theory of cognitive systems. This theory emphasizes the common aspects of cognitive systems, which unify such diverse systems as language and immunity. We propose a basic criterion for all cognitive systems, namely that in order to reach their final capabilities, the system must interact with its environment. Despite the obvious diversity in the specific reactions and sensitivities which make up the behavior of a given system in its environment, the overall dynamics of these interactions are the same in the different cognitive systems and are essential in creating the eventual forms of the systems. An easily observed feature of this common structure can be seen in the ordered nature of the environment with which a given cognitive system interacts. The environment is ordered in a specific way which is especially pertinent to a naive unformed system. In these environments a small number of examples are highly expressed, while the rest are far less frequent. Furthermore, the highly expressed examples are also extremely central to the system's relationship with the environment. This is not a chance occurrence; it is a reflection of the fact that cognitive systems are fitted to certain niches. We suggest that in natural cognitive systems the inside, the outside, and the process of internalization are tightly interconnected. We propose, therefore, that the study of cognitive systems should encompass the fundamental mutual resonance of the learner, the to be learned, and of the learning process.

Keywords:
Conceptual systemic models, Cognitive systems, Complexity, Interaction.

1. Introduction – Cognitive systems resonate with their environments

We wish to present a definitive view of cognitive systems which differentiates between cognitive and non cognitive systems at an organizational level. Cognitive systems are commonly seen as perceptual interactive systems that deal with complex, complicated patterns reaching specific conclusions. This view has lead to a widening of the scope of systems described as cognitive, including systems such as the immune system [Varela 1994, Cohen 2000] and to some extent connecting between them and the very concept of living systems [Stewart 1996].

Describing the difference between living systems and other systems as being an organizational one is not new. At its center is the view that living systems are autopoetic. This type of organization has two important factors: 1) a delineation of the system and its environment, 2) that the system's own processes, as influenced by the environment, are those that create the system [Maturana and Varela 1980]. We wish to take this view of cognition and autopoetic systems one step further by defining a unique factor of the organization of cognitive systems. This factor is the resonating nature of the relationship of cognitive systems and their environments. We will further show how the shape of the environments and their relationship to the cognitive systems effects the development and final capabilities of the systems. Important ideas about the resonance of developing cognitive systems with features of the environment have been put forward as early as Gibson [Gibson JJ 1966 see also Gibson EJ 1967]. However, we now propose a novel particularization of these ideas connecting them to the autopoetic description of living systems. Cognitive systems are unique in having capabilities which have 'fluid' definitions. To some extent they appear to fit themselves to the task at hand. In any systemic description of a cognitive system the eventual capabilities of the system and its function in the environment are not fully determined in any internal plan of the system. Rather they are a result of interaction of the system with its environment [Hershberg and Efroni 2001]. To describe a cognitive system we must include the statistical shape of the natural environments in which they develop and operate, as this appears to be one of the essential features of their development. We propose that certain elements of the environment play a crucial threefold part in the development of cognitive systems.

First, we claim that environments to be learned by cognitive systems contain core, central or generic exemplars which embody the essential features of the environment. The reason why the environments of natural cognitive systems possess such crucially important exemplars varies from system to system, but, we claim, all to-be-learned cognitively relevant environments possess them in one form or another. It is obvious that learning the central exemplars would give a learning entity a much higher dividend in terms of added knowledge than learning other, more peripheral, exemplars of the environment. In addition and not unrelatedly, these core exemplars are not only important as the organizers and representatives of the central tendencies of the environment but they are also ubiquitous and highly frequent.

Second, the learning process whereby cognitive systems come to internalize the environment is biased to start with the core exemplars, whether because of a basic frequency effect on the learning process, because such exemplars are inherently easier to learn, or because of predisposition of the system to learn such types of items. Namely, the core environmental exemplars not only order the environment but they also order the learning process. In addition, a learning process geared to utilize early-learned core exemplars will be an exemplar-based learning process, with an inherent ability to transfer information from earlier-learned to later-learned exemplars and from earlier to later learning situations.

Third, the core exemplars, having been learned earliest, also order the cognitive system itself in that they are the constitutive members of its knowledge structure. Though them, the developing cognitive systems comes to emulate or recreate the structure of the environment it is learning about.

We have explored the development of a resonating cognitive system in two very different domains: the acquisition of syntax in young children [Ninio 1999a, Ninio1999b], and the formation of the immune system's sensitivities [Hershberg and Efroni 20001]. As a result, we have developed a model of cognitive development which is a form of learning we call Optimal Exemplar Learning.

2. Optimal exemplar learning

Cognitive systems learn to be cognitive systems by interactions with the environment. These interactions are what we call optimal exemplar learning. According to the hypothesis, this is the process by which cognitive systems reach the rules or general properties of their environment. In optimal exemplar learning, the specific interaction of the cognitive system with any example is identical. However, not all examples of the environment are equally encountered in natural interactions with the environment. There is a class of examples that are ubiquitously encountered and generic of the general properties of the environment. This ensures that they will be the first noticed and learned by the system. The frequency of examples is a marker of their importance.

Optimal exemplar-based learning is a form of exemplar-based leaning. In such learning the limiting stage is not the formation of rules or hypothesis-testing; it is the acquiring of examples.

Optimal exemplar-based learning has five essential principles:

1. All interactions with the environment are of the same type.
2. The system's learning is a result of unsupervised interactions with concrete examples of the environment.

These two steps alone are enough to bring about learning because:

3. The environment is ordered. Examples of the general properties of this order are ubiquitous and generic to the environment. In other words certain examples are of higher frequency in the environment. We call these optimal exemplars of the environment "useful examples" because they are useful to learning the environment and its relevant general properties.
4. As a result of genetic inheritance or previous stages of cognitive development cognitive systems have perceptual tendencies. These tendencies define the framework of the environment and set the stage for the cognitive system to notice it.
5. Learning of examples of the general properties of the system does not change the types of interactions with new examples; however, due to the nature of these examples in the environment it causes a transfer of knowledge, which facilitates the acquiring of and correct reaction to new examples.

3. Language

Let us see how language acquisition follows these principles, focusing on the acquisition of simple syntactic phrases. It a fact of long standing that, in general, the statistical shape of language is such that a relatively small subset of words are highly frequent while the rest are used at lower frequency [Zipf 1935]. This however leaves out the need for the high frequency examples to be important to the relationship between system and environment. In studies concerning the use of intransitive and transitive verbs in syntactic combinations, in parents' conversations with their children, it was seen that parents use a very small subset of verbs at a very high frequency when talking to their children. Words like 'want', 'come', 'go' and 'make' account for a high proportion of the verbs used in parental conversation. All these high frequency verbs are very general, have uses that are almost empty semantically and can be said to be generic of the verb sub-categories to which they belong. In return, all the first verbs used by children are drawn from this group of verbs (though individually each child's first verb need not be the most commonly said word of his parent). Once the first verbs are learned in a certain syntactic construction, the speed of learning other verbs in the same syntactic construction, but not necessarily in other constructions, is greatly enhanced. This could be indicative of a scenario where the child learns with relatively great effort the first 2-3 examples, after which the others are greatly facilitated. In effect, due to the statistical distribution of words in language, in the course of normal conversation children are exposed to the optimal exemplars of the different types of syntactic combinations and the correct use of language [Ninio 1999a, Ninio 1999b].

As the example above shows, the central exemplars play a threefold role in Optimal exemplar-based learning. The ubiquitous examples which are first learned, are at the same time examples of general properties of the environment. By studying these exemplars, we gain information not only about the environment but also about the cognitive system and the mechanisms of learning and interaction between them.

4. Immunity

It is important to stress that the common characteristics and relationships between cognitive systems and their environments that we are describing here are not of the specific system but of the overall relationship. The reason why certain examples of language are high frequency, namely - their generality of use, will not be the reason certain examples are high frequency in other modalities. To make this point clearer we will now describe the immune system.

The immune system starts with a large random collection of receptors from which only a subset survives. The receptors of the immune system are selected according to a certain level of affinity to antigen examples from the body. Through a process of negative and positive selection in which all receptors of too high or too low an affinity to these antigen examples are killed (along with the cells that produce them). These examples reflect the expression of proteins in the various cells of our bodies. As in other perceptual systems the selection of receptors is competitive. If a receptor spends a longtime inactive it will be pushed aside by more active receptors [Goldrath and Bevan 1999]. The immune system is left with a repertoire of cells that all share this level of affinity to the antigen examples of the body. . As in language the environment is ordered, the antigens, which select the cells, have a distribution which is similar in shape to that of words in language. In an antigen presenting cell 50% of all antigens presented will belong to 200 of a possible 10^14. Antigens [Barton and Rudensky 1999]. It is not possible to identify exactly which proteins in the body are responsible for the high frequency antigens however we do have some pointers as to which proteins these could be. We a re looking for a family of highly expressed proteins found in all cells of the body. Such a ubiquitous group of proteins are those known as "housekeeping proteins", which have essential functions in DNA manipulation and energy production in cells. Receptors derived with an affinity for antigens of these proeitns would make good sensors of as these proteins are 1. Expressed in times of stress 2.Necessary in all cells and so are expressed in all the cells of our body. 3.They have changed very little over the evolution of life on earth and so are extremely similar in us and in the bacterial pathogens that invade us [Gupta 1998]. Therefore receptors for such examples would have to change little to become efficient identifiers of foreign proteins and their derivatives. Most importantly such proteins and the immune receptors that are sensitive to them have been found to be important for good immune reactions [Cohen and Young 1991].

Once more we see a relationship with the environment fitting in with our description. However the reason for the importance of the high frequency examples is not the same as in language; rather, it stems from the common heritage of all living systems which highlights those parts of cellular life which are essential for survival, never more so than during times of stress.

5. Conclusions for the study and emulation of cognitive systems

The proposed learning mechanism allocates great importance to the statistical structure of the natural environment and in particular, to the identity of its most frequent exemplars. In attempts to create artificial cognitive systems, in general, and communicative systems in particular, we must retain the statistical shape of the natural environments in which they develop, as this appears to be one of the essential features in their development. Even before we consider other aspects of cognitive learning implied by the principles of optimal exemplar learning, for example the embodiment of examples in their natural environment, the importance of the behavioral and perceptual tendencies of the system and so forth, we must consider the statistical distribution of the environments we present to our artificial learning systems. This distribution by itself may direct us to the essential pieces of information that the system uses to learn its capabilities.

To capture the essence of the principles of optimal exemplar learning requires an environment of the type described in principle 3. In such an environment we can still capture much of the process of learning in cognitive systems even if the system we create is merely following a plan of exemplar-based learning with some minimal form of transfer of information between examples, such as similarity matching.

An essential stage in creating artificial systems which behave like natural cognitive, communicative or perceptual systems, is to recreate their environments or at the very least capture the statistical distribution of the exemplars of the environment. It is therefore unfortunate that in many artificial systems, hardly any thought is given to what exactly is the form of this distribution. It is common failing of attempts to emulate learning patterns of cognitive systems that little effort is put into accurately replicating the statistical shape of the environment that is being learned. As we have tried to argue, the environments with which natural cognitive systems interact are ordered in a specific way relevant to the cognitive system's ability to learn. Respecting this principle could be crucial for achieving a successful emulation of natural learning processes.

Beyond these general dividends in cognitive study, such a formulation solves an essential problem in the learning of complex domains as put forth by Elman (5). Elman suggested that complex domains cannot be learned by a system possessing its full capabilities. Instead, it is necessary to artificially grade the system's interaction with the environment. This is done by limiting either the amount of environment it interacts with (a move Elman found ineffective) or, preferably, by limiting the system's working memory capacity. Only gradually, with further learning, can the system be allowed a greater capacity. Our proposal, even at its most simplistic formulation of merely respecting the natural statistical form of the environment, answers this problem by showing that there is no need for internal changes in capacity as the environment by its very shape is presenting itself to the system in a gradual fashion.

It is our firm belief that following the principles of optimal exemplar learning should solve many more problems in the modeling and simulation of complex learning systems in general and cognitive systems in particular.

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