Evolution, development and learning - a nested hierarchy?

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Abstract

The Dynamical Hypothesis [22] is gathering force within cognitive science and within biology. Evolutionary, developmental and learning processes can all be characterised by the DH and any models should try to account for this property. The processes differ in terms of their operational time-scale and the resources each has to hand. Evolution sets the parameters for the dynamical interactions in development and learning. Could all three processes possibly be regarded as a nested hierarchy sharing the same dynamical properties? We ask this question and argue that a DH understanding of the potential evolution of cognitive systems could inform subsequent modelling.

1. Introduction

The aim of this paper is to provide a brief survey of the role of the "Dynamical Hypothesis" (DH) [22] within cognitive science at a number of different levels of explanation. We specifically want to make the following main points:

- The DH potentially unifies explanations of cognition at the evolutionary, developmental, and learning levels;
- Evolutionary constraints on cognition need to be seen as "running through" development and learning, but effects at the other levels can influence evolution;
- We need to model and simulate the above in order to support theory.

First, we shall make some general epistemological points to focus our argument.

Science is about discovering the order of the universe and explaining the causes and functions of that order. We observe order in our everyday dealings with the universe and such observations form the foundation of our folk theories. Scientific methods enable scientists to uncover fundamental natural kinds of the universe and understand how they interact in order to produce the higher level phenomena that interest us.

The behavioural and cognitive sciences are interested in explaining how it is that organisms regularly mediate between input and output. Hendriks-Jansen [10] has recently claimed that artificial intelligence (AI) has failed to truly determine natural kinds that provide illuminating explanations. Instead AI has embarked upon an exercise in mimicking input-output relations under the assumptions of a Universal Turing Machine that can implement input-output relations in any number of ways. Thus AI only provides us with formal task descriptions of what is to be explained. If we really want to understand Nature and the actual middle terms she employs we need a better approach than this. We believe this is true of much cognitive science.

Hendriks-Jansen further argued that we need to take an evolutionary perspective because such approaches will better inform our natural history of the original order of interest. In the next section we analyse recent attempts to apply evolutionary thinking to cognition. This will lead us to advocate a different approach to evolutionary theorising in the cognitive sciences, one that is firmly grounded within the DH.

2. Evolutionary Psychology (EP)

Recently some psychologists [2] have examined our complex psychological phenotype in terms of natural selection [6]. For a trait to be naturally selected it needs to provide a solution to a contingent adaptive problem, which needs to be fairly long term and stable. Cosmides and Tooby [5] suggest that the Pleistocene epoch was such an Environment of Evolutionary Adaptedness (EEA). During the EEA various discretely organised cognitive mechanisms were selected that solved these putative problems. For example, Cosmides [4] has demonstrated that people perform much better on the Wason Selection Task when the task is about seeking out violations of social contracts than in its original abstract form. Cosmides argues this is because finding cheats within a social system would have been a contingent ancestral problem and the species has evolved a specific module to deal with this. The fact that people find it hard to transfer their reasoning ability to the abstract task with the same underlying logic is indicative of a cognitive specialism. This approach led to a Massively Modular Hypothesis [20] about cognitive organisation whereby there are specific computations and stored representations for specific problems.

What EP is attempting to do is to show how evolutionary change has led to stable modern order in *Homo sapiens*. The central argument, that specific computational devices were selected for, focuses upon adult end-state and has little to say about ontogeny other than that ontogeny sees the coming on-line of these various mechanisms over time [21]. Thus there are hardwired computational systems whose successive staging is also hardwired. This makes EP a nativist approach that fits well with much contemporary developmentalism [3], but not with all.

3. Evolution and Development

It *may be* the case that evolution has selected for adult-end states that are modularly organised, and that it has also selected for specific successive staging. *But* this theoretical approach does not inform us about how such order emerges over ontogenetic and phylogenetic time, nor does it inform us about how such progression was selected for or why.

Recently a neo-constructivist view of development has emerged that takes a more parsimonious view [8, 19]. The hypothesis is that the infant has a number of low-level in-built systems. From interactions between such systems themselves, and with the environment, new behavioural capacities emerge in a principled manner. Where EP argued for a stable EEA, neo-constructivism says that it is the very stability of the environment, and low level cognitive architecture that allows the emergence of higher order phenomena regularly during development. Such neo-constructivist development is likely to be adaptive and therefore selected for.

Karmiloff-Smith [11] terms this approach as emergent modularisation, arguing that specific computational mechanisms for specific tasks will emerge as a part of this process, but that they are not in-built. The brain functionally organises itself as a response to the activity it is involved in during development. The brain is regarded as sufficiently plastic to afford a number of ontogenetic trajectories. Karmiloff-Smith suggests that "it is plausible that a fairly limited amount of innately specified, domain-specific predispositions (which are not strictly modular) would be sufficient to constrain the classes of inputs that the infant mind computes".

Karmiloff-Smith [12] has found support for this position in work on developmental disorders. Under the "traditional" view of development, disorders can be viewed in terms of the failure of certain modules to either come on line, or to operate properly once on line. There is no notion that this might affect the developmental trajectories of the other extant modules. Karmiloff-Smith has looked at Williams Syndrome (WS). People with WS have low IQ, deficits in spatio-constructive skills, numerical cognition, and in problem solving. The evidence that Karmiloff-Smith has presented suggests that deficits in certain cognitive domains will affect the outcome of the rest of development. For instance, WS people scored in the same range as normal controls for face processing tasks. However, the WS participants solved the problems in a very different manner (componentially rather than holistically). Karmiloff-Smith argues that this is indicative of different cognitive processes leading to the same behavioural outcomes. This might be the result of a process of modularisation affording the WS people a face processing module, but it emerges from an atypical developmental trajectory. New order emerges that satisfies certain functional demands in common with normal development but this order is reached differently.

Underlying neo-constructivism is the older notion that the brain is a dynamic system, consisting of certain variables that can interact in interestingly limited ways. From this interaction order can emerge. Theorists have begun to model just such development with some success [7]. For example, Mataric's robot exhibits wall following equipped only with some sensors and basic pre-set movements that are tripped by specific inputs [10]. It is the interaction of these simpler systems that leads to the emergence of wall following and such systems are arguably coherent natural kinds.

4. The Dynamical Hypothesis

What is the nature of the DH that underlies neoconstructivism? Van Gelder [22] has recently claimed that the DH "is the unifying essence of dynamical approaches to cognition. It is encapsulated in the simple slogan, *cognitive agents are dynamical* *systems*". He further splits this into the *knowledge hypothesis* and the *nature hypothesis*. The latter is the claim that we are dynamical systems at the cognitive level, consisting of a number of variables that interact with one another over time in such a way as to exhibit self-organisation. The knowledge hypothesis is the claim that we can understand cognitive agents in dynamical terms.

The key characteristic of DH that is of interest to us is the move away from input-output relations to a conception of ongoing and appropriate change. Appropriate change must be understood in relation to the adaptiveness of the system to its ecological niche. More generally, the idea that the system changes over time and is the result of limited interactions between all of its variables and the environment - that might consist of other systems - marks an important principle. ***The question for EP is now "how did such a dynamical system evolve in such a way as to ensure the specific emergence of order that we see in ontogeny?"***

5. What Changes During Evolution?

The preceding question does not assume that evolution has selected a "genetic program" that generates a dynamic cognitive phenotype. Traditional views of evolution have it that order is generated through natural selection weeding out adaptive variance. Kauffman [13] has noted that our notion of the genetic program contains the idea of a sequential processor gradually unfolding standard developmental trajectories by reading them off the genome. He has proposed that this is not the case and that much of the order we see in biological systems has emerged from the self-organising properties of "the genome". It is only when self-organised order has emerged that natural selection then has the opportunity to operate within larger gene space. Biological development can be seen in these dynamical terms too. Such a perspective makes for a better explanation of both the precision of development and the ability of organisms to withstand (some) minor alterations within the genome, as we see in the WS case which is caused by a chromosomal micro-deletion.

Kauffman envisages the genome as a space where each gene can potentially interact (epistasis) with other genes and in so doing affect the expression of the phenotype "controlled" by that gene and the overall "shape" of the organism. Genes are connected to other genes and become active (or inactive) when they receive specified inputs. The system shifts through various stages of activation. The number of genes in this space is N and the number of potential interactions is K. NK modelling allows for the emergence of stable patterns of activity, or state cycles, through the application of local rules within the network. Kauffman's early models were based on the observation that the human genome consists of around 100,000 genes but only 250 types of cell. Kauffman's intuition was that this observed pattern, and a similar one in his simplified models, was indicative of state cycles. It is the mathematical properties of the genome that have determined the number and kinds of cell types that there are - not natural selection. Of course, this poses interesting questions about the origin of these mathematical properties.

6. Where Are We?

Phenotypic stability can emerge from gene space and also from the dynamics of development. The phenotypic stability of evolutionary time scales is played out in a large gene space and produces distinct species that stabilise in a particular region of that space. Within a given species, when we look up close in ontogenetic time, we can see the emergence of phenotypic stability in terms of development of some specific low level systems, and the emergence of subsequent systems as a result of their interaction. We now face the challenge of finding a methodology to satisfactorily isolate and model the appropriate variables involved in such dynamics.

There is a further problem. Development might be regarded as nested within larger evolutionary processes but to some extent the opportunity for variance at the developmental level in terms of structural morphology and from learnt behaviour gives this system sufficient independence to potentially interact with and affect evolutionary processes. This form of interaction, in which two systems simultaneously alter each other's direction of change, is referred to as coupling [22].

Such coupling has arguably been demonstrated in discussion and simulations of the Baldwin Effect [1]. Thus far in the discussion we have been conflating gene space and phenotype space [16, 17, 18]. These are distinct spaces as natural selection operates over phenotypes and genotypes simply code for phenotypes. The Baldwin Effect is about the relationship between these two spaces - if individuals have sufficient phenotypic plasticity of the sort afforded by learning it is possible for them to acquire new adaptive traits. The individuals who are capable of doing this at low cost are likely to be selected for. Such learning can be characterised dynamically. The initial consequence of such selection is that individuals capable of this form of learning will dominate the population. It is also argued that the corresponding genotype for learners will be indirectly selected for. It is possible that this trait may eventually become genetically assimilated perhaps through the selection of faster and faster learners [16, 17]. It is also possible that individuals will be selected for that learn the trait so fast that it appears instinctive to external observers [9]. This will still affect the available genotype.

With the Baldwin Effect we see an effect of learning upon phenotype and then genotype. This is undeniably an effect from learning through to evolution. Potentially the alterations in genotype space will have generated other effects too as the NK parameters are altered, this in turn might lead to changes in the nature of relevant selection pressures that lead to selection of some ordered forms over others. This has been recently discussed in relation to niche construction [14]. The ability to build such things as dams, nests and burrows, for instance, are often learnt but might enter genotype space at some point. However, once the environment is substantially altered then the selection pressure changes too. Darwin's own example is of earthworms whose burrowing activities have radically altered the substructure of much land [14]. This has led to changes in the amount of mucus produced and the epidermal structure of earthworms. It is possible that the emergence of human culture might have wrought similar if not larger scale effects upon the evolution of our cognition [14].

Evolution, development and learning are to some extent hierarchically ordered if only in terms of time scales. What they are not is a nested hierarchy with a straightforward linear relationship. Instead it would appear that there is good argument for interactions between the systems. This evidence does not force us to abandon the role of natural selection, unfolding development or learning in our models of behavioural science but it does suggest a more complex picture than that which the input-output psychologists have painted.

7. Conclusion

The first two aims of this paper have been clearly met. The unification afforded by the DH is a result of taking seriously the self-organising aspects of the genome and cognitive systems. The potential for interaction between levels of explanation is a consequence of each level being regarded as a system in its own right and potentially open to coupling.

If we take the DH the job of cognitive science becomes one of finding out what low-level systems have been selected for. We have to try to understand how these "natural kinds" might interact with one another within a relatively stable environment to produce order over evolutionary time. We also have to understand how this order is able to develop over ontogenetic time and the levels and kinds of perturbation such systems can tolerate. Equally, we have to be aware of how learning can be dynamically understood and emerge from described developmental trajectories. Finally, we need to be aware of the potential role of Baldwin Effects in evolution as well as the possibility of feedback from niche construction and other activities.

Presently, these DH inspired ideas provide an interesting framework to reconceive data about development (and evolution) but the fine detail of such systems is unknown. It is at this point that modelling and simulation work must surely come into their own. Modellers must think about modelling the transition through evolutionary, developmental and learning time. In this way it might be possible to construct parsimonious models of cognition and behaviour constituted by the order of natural kind that Hendriks-Jansen finds so appealing.

We might recognise that cognitive developmental outcomes are dynamical and influenced by evolution but to actually model the order of cognition discussed is not easy. The problem of Leibniz's Law potentially raises its head. On the one hand, in reducing input-output explanations or descriptions to a dynamical model we have to be sure that we do not lose the point of initial reference, we have to be sure the dynamical language refers to the same initial phenomena as the traditional language did. On the other, it might be that the DH forces us to radically reconceive our list of natural cognitive kinds and to stop seeing them in the intentional and computational manner that we currently do. Thus computational accounts of input-output relations might have set the initial question and the answer might deny that antecedent. Indeed, the whole notion of input-output relations is questionable within the DH.

Despite the enormous difficulties of such modelling we feel that there is good reason to conceive of organisms dynamically. As the cognitive sciences are part of the biological sciences they have an epistemological duty of coherence to conform to biological theory. If this is at the expense of traditional or Classicist [15], folk-theory inspired conceptions of cognition, then so be it.

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