Dynamical Hierarchies

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In 2002, M. Bedau et al. [2] postulated a set of fourteen open problems in Artificial Life. The content of this special issue specifically addresses one of those suggested problems: *How can we create a formal framework for synthesizing dynamical hierarchies at all scales?* The concept of dynamical hierarchy refers to systems that consist of multiple levels of organization having dynamics within and between the entities described at each of the different levels within the complete system. An important aspect of this concept is the fact that entities at different levels can have different functionalities that emerge from the interactions of the lower level units. In other words, dynamical hierarchies define a system that is structured by part-whole relationships between objects where each whole can exhibit properties and can interact in ways different from its parts. As a consequence, the complete system needs to be modeled as structures relating different description levels of dynamical systems and their interconnectedness. A typical example in this context is the functional differences between proteins and their building blocks i.e. amino acids. The functionality of proteins are not directly the result of the properties of the amino acids. The overall protein structure plays a crucial role here. As a consequence, properties that amino acids do not exhibit in their solitary state, can be exhibited collectively. The same observations can be made when moving from solitary proteins to the level of protein-protein interactions. New functionalities emerge a result of the different complexes produced by these interactions. It is the combination of all these dynamical levels from amino acids to multicellular organisms that make it a dynamical hierarchy and not only some simple emergent phenomenon.

Though dynamical hierarchies are ubiquitous in living systems and fundamental to concepts of self-organisation, recreating dynamical hierarchies spontaneously in Artificial Life systems has proved difficult. Although it is often arguable that some form of emergent structure may arise in various Artificial Life simulations, showing more than one hierarchical level of emergent structure, and formal synthetic frameworks, are rare [1, 8, 5, 7, 3, 4]. A complete synthetic framework for dynamical hierarchies will provide not only an understanding of the organization and origin of complexity of biological systems, but also impact on all fields which have adopted biological theories or appeal to some form of emergence to create complexity out of simplicity.

This special issue (and the previously organised workshop at Alife VIII in Sydney [6]) attempts to provide background information and initial steps toward addressing this fundamental topic in Artificial Life research. In this special issue, you will find a collection of articles which cover different issues on the road toward a formal framework for dynamical hierarchies. The articles deal with the identification of second and third level structures in a new example, the role of structured populations in the evolution of far-sighted adaptations, the notion of modularity and its importance in evolvability, the definition of transitions between descriptive levels of a dynamical system, the formation of wholes from the interaction of the parts and the description of an alternative theory for the discussion of dynamical hierarchies based on information theory. We hope that given the importance of the subject, these articles will stimulate more people to work in this area.

In continuation of previous work by Rasmussen and colleagues [8], Mikhail Prokopenko et al. describe in their article a new example of dynamical hierarchies in the context of multi-cellular sensing and communicating networks embedded in an ageless aerospace vehicle. They discuss in this particular context the emergence of second level structures, i.e. chains of simple cells, and third level structures i.e. the combination of cell chains and the elementary cells they enclose. They argue that these higher-level structures posses novel properties and analyze their results using graph-theoretic and information theoretic techniques.

Not only is it important to identify new levels, these levels should also have a functional purpose. In the second article, Lee Altenberg discusses, from an evolutionary perspective, the difference between simple dynamics in panmictic populations and hierarchical dynamics in structured populations. Important in this discussion is the effect these hierarchical dynamics have on the evolvability of a biological system. Altenberg investigates how hierarchical population dynamics can protect a population from the invasion of pathologies i.e. traits which promote the extinction of the population. This example illustrates that the effect higher-level components may have on the persistent properties of lower-level entities.

In the previous paragraph it was discussed how modular populations influence lower-level (individual) dynamics. Yet as explained in the beginning of this editorial, the dynamics don't end there. In the third article Richard Watson and Jordan Pollack discuss the effect of the interconnectedness of such modules on the dynamics of the overall system. Their discussion is based on Herbert Simon's work on the evolution of complexity in modular systems and the concept of nearly-decomposability [9, 10]. They argue that modular systems which are decomposable but not separable (systems with modular interdependency) can form hierarchical systems where all levels of organization are significant. They further show that such systems can cause problems for evolution and provide an alternative which can improve on this.

The three remaining articles provide models from the perspective of dynamical systems theory. Simon McGregor and Chrisantha Fernando discuss an alternative to the hyper-structure model that was developed by N. Baas [1]. Their work was triggered by certain problems that may exist in that model and it's adaptations. As a solution they propose to define dynamical hierarchies through information theory as was originally indicated by Dorin and McCormack [3]. Concretely, they define the concept of hyperdescriptions i.e dynamical systems descriptions of other dynamical systems.

A similar approach is taken in the contribution by John Rowe *et al.*. These authors argue that higher-level units should be structured in a way that is compatible with the dynamics of the underlying system. They further claim that under only this condition can the new units be said to emerge in the system. This argument is clarified using a formal model and some Artificial Life examples.

The final article is provided by Martin Nilsson. He focuses particularly on the relations that need to exist between the degrees of freedom used at different levels and the dynamics observable at each level. To identify new levels, Nilsson requires the emergence of novelty in the dynamics at the higher level. Thus novelty, as argued in other definitions, plays again a crucial role for identification of new levels. Interesting is the relation that he draws with interaction networks (a.k.a complex networks) as an intermediate step toward the construction of a dynamical hierarchy.

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