Complex Systems Approaches to the Ontogenetic Development of Behavior

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Abstract

Complex systems theory is the study of the emergent properties of homogeneous and heterogeneous collections of components into complex patterns of organized relationships (Bar-Yam, 1997). There are deep similarities in the organizational mechanisms of such collective dynamics along many time scales, from the evolutionary time scales of species in ecosystems, to the developmental time scales of neuronal populations in biological brains (Kelso, 1995; Thelen & Smith, 1994; Oyama, 1985; Solé & Goodwin, 2000). The action selection problem is the study of the mechanisms that allow an autonomous agent to handle multiple and sometimes conflicting goals in order to satisfy the needs and desires of the agent. The cognitive mechanisms of biological brains have provided many inspirations to the development of action selection mechanisms in autonomous agents. These range from hierarchical models from ethology (Blumberg, 1994; Tunstel, 2001; Huntsberger, 2001) to meshwork models that emphasize collective emergence such as the subsumption hierarchy (Brooks, 1990; Matarić & Brooks, 1999) and many others.

It is relatively had to find pure cases of hierarchies or meshworks in complex systems that we observe in nature. Almost always we observe a mix, a meshwork of hierarchies or a hierarchy of meshworks, or even more complicated interactions. For example, biological species can be thought of as an example of homogeneous collection of elements. Environmental ecosystems are classic examples of meshworks of these homogeneous elements. Species interact with each other in many complicated ways. Ecosystems depend on the development of self-sustaining loops of interacting species with each species occupying an environmental niche in the ecosystem. This meshwork of hierarchies forms a complicated food web linking together a wide variety of animals and plants. Mechanisms that we can identify that are important in the development of the dynamics in ecosystems include competitive arms-races (predator-prey and host-parasite relations, for example), cooperative processes (symbiosis), and the collection of many of these types of relationships into self-sustained autocatalytic loops (Harter & Kozma, 2004b; Kauffman, 1993; De Landa, 1997).

The ontogenetic development of hierarchical/meshwork mechanisms in the biological limbic system is more appropriately viewed in terms of such an ecosystem of cooperating, competing and self-sustained loop relationships. And, as is often seen in such an ecosystem, the dynamics observed between the heterogeneous components are often not limited to simple point or limit cycle attractors. Chaotic attractors can play important parts in the development of ecosystems and in the development of meanings and structures in biological brains (Freeman, 1999). In this paper we present some of our work on developing such an ecosystem of neuronal components, based on the limbic system of biological brains, and emphasizing the importance of aperiodic dynamics in the development of such structures. We will discuss some of the necessary properties and mechanisms in emergent models of intentional behavior, and present some of our applications for developing cognitive mechanisms such as perception and memory based on aperiodic dynamics (Harter & Kozma, 2004c, 2004a).

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