Models of Ontogenetic Development: The Dynamics of Learning

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Biological organisms display an amazing ability during their ontogenetic development to adaptively develop solutions to the various problems of survival that their environments present to them. Dynamical and embodied models of cognition [2, 4, 6, 7, 8, 9, 11, 12, 13, 15, 16, 17] are beginning to offer new insights into how the numerous, heterogeneous elements of neural structures may self-organize during the development of the organism in order to effectively form adaptive categories and increasingly sophisticated skills, strategies and goals. The ontogenetic development of behavior in biological organisms represents a significant level of improvement over current learning methods for autonomous systems.

Biological organisms develop effective behaviors simply by perceiving and acting upon their environment in real time. Their learning is always guided by their basic needs. Through their experience with the environemnt, they begin to embody, anticipate and exploit the regularities that are present in the service of their intrinsic needs. Some models of learning for autonomous systems are beginning to display some of these same abilities [1, 3, 18, 19]. These abilities include the formation of embodied, organisim significant categories through experience. The development of active searching and anticipation of relevant stimuli. And the exploitation of environmental regularities in the service of intrinsic needs.

We consider biological organisms to be behaving intelligently when they act in ways that will enhance their current and future survival. The behavior exhibited by biological organisms is often very creative and flexible. Yet such behavior is always directed towards the satisfaction of the basic needs of the organism. Freeman [6, 7] describes such behavior as intentional behavior. Intentionality provides a key concept that links the neurodynamics of brains to goal-directed behavior.

One of the primary acts of intentional behavior is in directing sensory observation in expectation of information to guide future actions. Both the formation of expectations and the real-time dynamic interaction of the organism with the environment are important principles of intentional behavior. Freeman's view of the mechanisms of intentionality is one of nonlinear dynamic interaction of heterogeneous neural elements on many levels and time scales. The neurodynamic architecture of the brain forms many recurrent loops between brain and brain, brain and body, and organism and environment. But the basic architecture of intentional behavior can be found in the simplest and phylogenetically oldest parts of biological brains: the limbic system.

We propose to build on neurologically inspired, bottom-up, dynamic approaches to embodied category formation such as those done by Freeman [5, 7], Freeman and Kozma [8], Kozma and Freeman [13] and Almassy et al. [1]. We believe that building on such mechanisms from an embodied dynamical perspective will produce autonomous agents that display greatly increased flexibility in their behavior while also decreasing the amount of effort needed in order to program and train such agents to effectively perform the desired tasks. Such models will represent a better understanding of how the brain of biological organisms not only forms perceptual categories of its environment during development, but also form patterns of behavior based on such environmental categories.

We present an architecture for autonomous behaving systems that we are developing. Our agents are designed to develop skills in a real-time demanding task environment by a process of artificial ontogenetic development. In effect we are developing a simplified model of the biological limbic system for use as a control architecture in autonomous agents. Such a model is capable of supporting limited forms of intentional behavior and ontogenetic like development. The agent self-organizes embodied categories by observing and

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interacting with its environment. These embodied categories form the basis for action-oriented representations [2] that afford [10] opportunities for appropriate behaviors for the agent. From these basic categories, increasingly complex behaviors and skills are learned while interacting with the task domain. This work explores how well dynamical models of category formation can be thought of as mechanisms of embodied, situated category acquisition. It will also see if such mechanisms are suitable models of the phenomenon of affordances [10] in which such representations provide and inform opportunities for action for the organism given the current situation and its past experience. Such results will shed light on how biological organisms manage the complexity of their environmental niches through self-organizing chaotic dynamics.

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