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Chapter VIII

Emergent Specialization in Biologically Inspired Collective Behavior Systems

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Abstract

Specialization is observable in many complex adaptive systems and is thought by many to be a fundamental mechanism for achieving optimal efficiency within organizations operating within complex adaptive systems. This chapter presents a survey and critique of collective behavior systems designed using biologically inspired principles. Specifically, we are interested in collective behavior systems where specialization emerges as a result of system dynamics and where emergent specialization is used as a problem solver or means to increase task performance. The chapter presents an argument for developing

design methodologies and principles that facilitate emergent specialization in collective behavior systems. Open problems of current research as well as future research directions are highlighted for the purpose of encouraging the development of such emergent specialization design methodologies.

Introduction

Specialization is observable in many complex adaptive systems[1] and is thought by many to be a fundamental mechanism for achieving optimal efficiency within certain complex adaptive systems. In complex ecological communities, specializations have evolved over time as a means of diversifying the community in order to adapt to the environment (Seligmann, 1999). Over the course of evolutionary time, specialization in biological communities has assumed both morphological (Wenseleers, Ratnieks, & Billen, 2003) and behavioral forms (Bonabeau, Theraulaz, & Deneubourg, 1996). For example, morphologically specialized castes have emerged in certain termite colonies (Noirot & Pasteels, 1987), and honeybees dynamically adapt their foraging behavior for pollen, nectar, and water as a function of individual preference and colony demand (Calderone & Page, 1988). The consequence of such specializations is that labor is efficiently divided between specialized castes[2] and individuals for the benefit of accomplishing group tasks. In such a sense, specialization can be viewed as an adaptive mechanism in a complex adaptive system.

Many artificial complex adaptive systems that exhibit collective behavior have used design principles, which draw their inspiration from examples of specialization in nature. Such examples include complex ecological communities such as social insect colonies (Bonabeau et al., 1996; Bonabeau, Sobkowski, Theraulaz, & Deneubourg, 1997; Calderone et al., 1988; Noirot et al., 1987; Seligmann, 1999; Wenseleers et al., 2003) biological neural networks (Baev, 1997), multi-cellular organisms (Hawthorne, 2001), economies of a nation, companies, corporations, and other business organizations (Abdel-Rahman, 2001; Ng & Yang, 1997; Resnick, 1997). Such biologically inspired design principles are especially prevalent in multi-robot (Potter, Meeden, & Schultz, 2001) swarm intelligence (Bonabeau, Dorigo, & Theraulaz, 1998) and artificial life systems (Nishimura & Takashi, 1997) where it is highly desirable to replicate the success of biological collective behavior systems.