Chapter 5
Modeling a Simple Self-Organizing System

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ABSTRACT

This chapter presents a System Dynamics (SD) simulation model that not only replicates self-organizing system uncertainty results but also looks at self-organization causally. The SD simulation and model analysis results show exactly how distributed control leads positive feedback to explosive growth, which ends when all dynamics have been absorbed into an attractor, leaving the system in a stable, negative feedback state. The chapter’s SD model analysis helps explain why phenomena of interest emerge in agent-based models, a topic crucial in understanding and designing Complex Adaptive Self-Organizing Systems (CASOS).

INTRODUCTION

A multitude of systems, including biological ecosystems (Kauffman 1995) and markets (Arthur et al 1997, Ormerod 1999) are complex, adaptive, self-organizing systems (CASOS). In these systems, as in ant colonies and swarms of bees, beautiful patterns of behavior emerge without central control. Instead, global coherent patterns emerge out of local agent interactions and distributed control among system components. Some of these components are feedback loops.

CASOS ideas also provide an emerging framework for business and economics (Beinhocker 2006). Internet users self-organize to create social networks (e.g. Facebook or LinkedIn), to produce knowledge (e.g., Wikipedia), to trade goods (e.g., eBay), to fund projects (crowdfunding) and to develop software (e.g., open source software communities). Taking advantage of global Internet connectivity, these communities have attracted business interest because they demonstrate the capacity of self-organizing systems to innovate and to create economic value.

Most importantly CASOS concepts inspired by nature can provide the framework for solving a wide variety of distributed computing and engineering problems (Bonabeau et al 1999, Dorigo
and Stutzle 2004). Mamei and Zambonelli (2007) propose a system exploiting digital pheromones to coordinate autonomous agents in pervasive environments making use of RFID tags. We propose that CASOS concepts inspired by nature and biology can motivate biologically-inspired IS research.

Understanding, designing or even influencing systems that combine individual autonomy with global order is not a trivial task, as systems tend to run down from order to disorder. Kugler and Turvey (1987) argue, for example, that to contain disorder in a multi-agent system, one must couple that system to another, in which disorder increases. Accordingly, Parunak and Brueckner (2001) simulate an ant pheromone-driven CASOS and measure Shannon’s statistical entropy or uncertainty at the ant agent and pheromone molecule levels, showing an entropy-based view of self-organization.

The focal contribution of our chapter is looking at self-organization causally, i.e., looking at the causes that make self-organization emerge. The culmination of Parunak and Brueckner’s (2001) ant pheromone-driven self-organizing system into a system dynamics (SD) model, allows unearthing exactly how circular feedback-loop relations determine emergent phenomena in self-organizing systems. Cast as a methodological contribution to understanding CASOS, this chapter explains why phenomena of interest emerge in agent-based models. Our chapter demonstrates the value of system dynamics modeling in analyzing the behavior of natural and social CASOS. This may help the community design better “artificial swarm-intelligence” systems and motivate the future use of SD modeling in the analysis of distributed-computing CASOS.

The chapter uses the loop polarity and dominance ideas from the system dynamics literature (e.g., Rahmandad and Sterman 2008, Richardson 1995) to explain complex agent dynamics. The ant-pheromone SD model analysis results show that three feedback loops become prominent in generating the ant pheromone-driven dynamics, two balancing or negative loops at the pheromones level and one reinforcing or positive loop at the ant agent level.

As shifting loop polarity (slp) determines system behavior (Richardson 1995), distributed, as opposed to central, control leads positive feedback relations to explosive growth, which ends when all dynamics gets absorbed into an attractor, leaving the system in stable, negative feedback. What is unique and interesting here is that, following prior work on CASOS, this chapter goes a step further in explicitly analyzing a CASOS in terms of the causal feedback-loop relations responsible for its dynamics.

Below is a brief overview of SD model analysis. Then the chapter moves on to model description, through the listing of the SD model equations, to experimental simulation and model analysis results, and to a brief discussion.

**SYSTEM DYNAMICS (SD) MODEL ANALYSIS**

Influenced by engineering control theory, SD calls for simulation modeling that provides a rigorous understanding of system behavior through time. The SD modeling process helps articulate exactly how the structure of feedback loop relations among variables in a system determines its performance through time (Sterman 2000).

Two types of diagrams help formalize system structure: causal loop diagrams (CLDs) and stock and flow diagrams. CLDs depict relations among variables (see Figure 4a for example). Complementary to CLDs, stock and flow diagrams are graphical representations of differential equations. They show how flow variables accumulate into stocks. There is a one-to-one correspondence between SD model diagrams and equations in the iThink® software, thus this chapter only lists the equations on Tables 2 and 3, since they completely describe the underlying causal system structure.
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