Chapter 1
Outline

INTRODUCTION

Ever more frequently, contemporary science finds itself in situations in which the only way it can address the complexity of nature is to develop new methods. One of the most common models is the Cellular Automaton - a system in which large numbers of particles, distributed on a lattice, developing according to deterministic local rules, generate unpredictable large scale behavior. Cellular Automata (from now on CAs) provide important insights into a vast range of physical, biological, social, economic and psychological phenomena.

The theme of this book is the use of CAs to model biological systems. More specifically, we will describe how we have used 2-D CAs to create populations of “life-like agents” with their own genomes, whose development and morphology (the pattern generated by the CAs) are determined by the collective behavior of smaller units, comparable to the molecules and cells of biological organisms. Often, when we seek to explain complex processes in life forms, our tools are too weak or too difficult to use. Mathematical modeling with CAs allows us to go beyond traditional approaches. The ultimate goal is to eliminate some of the intrinsic complexity of biological systems, and find what this complexity hides: general laws of self-organization common to a wide range of natural phenomena. So how can we

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analyze the behaviors of these systems that resemble biological organisms? And what sort of biological problems can we address in this way? In this chapter, we describe the relationship between CAs and biological systems and identify the fundamental questions we will address in the rest of the book. To help readers in finding their way, we conclude with a short outline of what is to follow.

BACKGROUND

This book brings together two programs of research which, though distinct, have many tools and methods in common. The first is one more attempt by humans to compete with the Great Architect and build life-like properties into human artifacts. This is the program initiated by von Neumann and carried forward by Langton and followers. The second program, originating in the early 1980s, is an attempt to create “new kind of science”, (Wolfram, 2002) rooted in concepts such as complexity, emergence and the collective behavior of automata. As we will see, this second program of research brings together empirical data (Wolfram’s computer experiments), with solid mathematics: the description of the discrete behaviors of 1-D CAs, using systems of non-linear equations (Chua, 2006; 2007).

The Problem of Self-Replication

As early as the 1940s, researchers saw the study of artificial self-replicating systems as a way of understanding the properties of biological organisms. Today, we think of self-replication in far broader terms, as a fundamental property of many natural and artificial systems (Maynard Smith and Szathmáry, 1995; Langton, 1995).

To self-replicate a system needs to generate a structure with functionality similar to its own. In many systems, self-replication involves a cycle of growth followed by separation (the separation of the membrane during the replication of biological cells, a baby’s separation from its mother after it is born, social separation leading to the creation of new social units, etc.). Other systems spread by producing systems similar to themselves, at distant points in time and space. This too is self-replication. In both cases, we observe complex, self-organizing development processes, allowing systems to grow and spread in time and space. If we view life as a machine for processing information, it follows that these processes will require the transport of information. This vision is shared by neurobiology, logic, automata theory, cognitive psychology and even molecular biology. It is closely connected to McCulloch and Pitt’s use of mathematical logic to define the first neural networks (in the early 1940s) (McCulloch & Pitt, 1943; 1947) and to von Neumann’s concept of a self-
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