Chapter 7
Searching for Self-Replicating Systems

INTRODUCTION

In Complexity Science (Bak, 1996; Morin, 2001; Gell-Mann, 1994; Prigogine & Stengers, 1984) and Artificial Life (Langton, 1995; Adami, 1998), almost all attempts to simulate or synthesize living systems in new media are somehow related to the influential work of John von Neumann (1966). These studies can be grouped into four basic categories (Sipper et al., 1998):

1. Attempts to build universal constructors based on von Neumann’s self-replicating automaton. This work mainly dates to the 1950s and 1960s. (von Neumann 1966; Codd 1968; Vitányi, 1973);
2. Attempts to create a minimal system capable of non-trivial self replication. This line of study began with Langton (1984) with later contributions from (Bty 1989; Reggia et al.1993; Morita and Imai 1996).
3. The enhancement of self-replicators with additional computational capabilities. This was a key topic of research in the 1990s (Tempesti 1995; Perrier, Sipper and Zahnd 1996; Chou and Reggia 1998);

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The basic idea underlying all this work is that an artificial self-replicating system can be described by a logical sequence of steps or an algorithm. Until a few years ago, we were aware of only a relatively small number of such systems. Today, however, many researchers have developed highly effective methods for generating these systems. One of these methods is to use Genetic Algorithms (Mitchell et al., 1994; Mitchell, 1996). Particularly important is Wuensche’s method (1999), which measures order and chaos in CA rules by measuring Shannon Entropy in the frequency of use of specific elementary rules.

The values for this distribution vary over time, following the evolutionary process. Wuensche identified characteristic features in the dynamics of his indicator and used them as the basis for an empirical classification of CA behavior. Ordered systems converge rapidly to equilibrium, after which they generate no further structural change apart from short period oscillations. As a rule, they use relatively few rules, some frequently and others very rarely. In chaotic systems, the frequency distribution is uniform. These systems have no preference for specific rules or for rules with a special ability to process information. Finally, complex systems use just a few rules, characterized by a high variance in Input Entropy. Frequencies of use of other rules are uniform.

Starting our own work from the method devised by Wuensche, we began with 2-D cellular automata, as described in Chapter 2, and used evolutionary techniques to generate a wide range of self-replicating systems. Later we came to see self-replicators as living organisms that adapt to the environments they inhabit (Bilotta et al., 2003). These changes involve changes in their genomes. In our work, we discovered that some of these changes change the morphological structure of patterns and their behavior. Speaking in biological terms, we can say that some change is adaptive, while some has less adaptive value and some leads to the death of the organisms concerned. The environment selects specific traits in organisms. So individual agents, with their own specific traits, all adapt in their own specific ways, following their own evolutionary trajectories. *A priori*, these trajectories are unpredictable. So, we used Genetic Algorithms to simulate long term evolutionary processes and to analyze the relationship between organisms in the initial population and those evolved by the algorithm. To this end, we conducted a phylogenetic analysis that generated explicit, verifiable data. Our initial idea was that a group of agents with a common behavior is likely to have a common evolutionary history and that organisms belonging to the group would thus be more closely related to each other than to other organisms. In our work, we were guided by three basic assumptions. First, any group of artificial organisms must necessarily share a common ancestor. Second, evolution involves specific sequence of bifurcations. Third, changes in traits take place over time. So, once we had found a self-replicator we began to modify its genetic networks, trying to identify universals and fundamental schemas and looking at possible mutations.
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