A Study of Replicators and Hypercycles by Hofstadter’s Typogenetics

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ABSTRACT

A Typogenetics is a formal system designed to study origins of life from a “primordial soup” of DNA molecules, enzymes and other building materials. It was introduced by Hofstadter (1979) in his seminal book Dialogues with Gödel, Escher, Bach: An Eternal Golden Braid. Autoreplicating molecules and systems of mutually replicating and catalyzing molecules (autoreplicators and hypercycles) are modeled in the present paper in a form composed of two strands of symbols. These strands are vehicle of two fold information: The first one corresponds to information that is transferred by strands. The second type of information specifies a process of strand replication. The used replicating molecules - strands are created by an approach closely related to evolutionary algorithms. While a small hypercycle of two molecules mutually supporting their reproduction can be created without extreme difficulties, it is nearly impossible to create a hypercycle involving more than 4 autoreplicators at once. This paper demonstrates that larger hypercycles can be created by an optimization and inclusion of new molecules into a smaller hypercycle. Such a sequential construction of hypercycles can substantially reduce the combinatorial complexity in comparison with a simultaneous optimization of single components of a large hypercycle.

Keywords: Autoreplicators, Evolutionary Algorithms, Hofstadter, Hypercycles, Typogenetics

INTRODUCTION

Computer studies of origins of life belong to crucial topics of artificial intelligence, in general, and artificial life, in particular. Unfortunately, a more realistic study using quantum chemistry (computational chemistry) methods is not feasible, since the number of molecules required for such a task is too huge. It is therefore necessary to use simplified models of molecules and reactions. One of the most famous models in this field is the Typogenetics, a formal system initially devised by Douglas Hofstadter in his famous book Dialogues with Gödel, Escher, Bach: An Eternal Golden Braid (Hofstadter, 1979) (cf. refs. (Morris, 1989; Varetto, 1998; Varetto, 1998).
Typogenetics replaces DNA molecules by strings (called strands by Hofstadter) that are composed of four kinds of symbols - letters, which represent the so called bases (chemical molecule forming building block of DNA). The really significant simplification consists in definition of parts of DNA sequences which code elementary operations acting in turn on the DNA sequence itself. In reality a part of the DNA substrand codes the instructions prescribing a production of enzymes. Each enzyme codes a different type of operation acting on DNA. These enzymes then use the DNA which coded them as a plan to create a copy of this DNA or a copy of another molecule (another strand in the Typogenetics formalism). While in the real life these substrands used for definition of enzymes are very large, in Typogenetics these codes of “enzymes” or “elementary operations” are smaller by orders of magnitude. Typogenetics is using the sequence of elementary operations coded by a strand to transform this strand (parent) onto another strand (offspring).

Typogenetics as presented by Hofstadter (Hofstadter, 1979) was not formulated in a very precise and exact way, many concepts and notions were presented only in a “fuzzy” verbal form and the reader was left to an improvisation and an ad-hoc additional specification of many notions of Typogenetics. Morris (1989) was the first one who seriously attempted to formulate the Typogenetics in a precise manner and presented many illustrative examples and explanations that substantially facilitated an understanding of Typogenetics. At the same time Varetto (1993) has published an article where he demonstrated that Typogenetics is a proper formal environment for a systematic constructive enumeration of strands that are capable of an autoreplication. Latterly, Varetto (1998) published another paper, where Typogenetics was applied to a generation of the so-called tanglecycles that are simplified versions of hypercycles of Eigen and Schuster (1979; Eigen, 1971). At the beginning of the current century, authors of this paper published two papers (Kvasnička, Pospíchal, & Kaláb 2001; Kvasnička & Pospíchal, 2001), where an idea of evolutionary algorithms was used to create Eigen’s and Schuster’s autoreplicators and hypercycles. In particular, we have studied in great details an evolutionary construction of autoreplicators. There was demonstrated that neutral evolutionary stages (where a fitness is kept fixed for many evolutionary epochs) are necessary for overcoming of deep fitness valley between two fitness peaks. Finally, in 2009 we published two extensive papers on Typogenetics (Bobrik, Kvasnička, & Pospíchal, 2008a; 2008b), where the formalism of Typogenetics is extended also to single/strand biomacromolecules of the RNA type.

The purpose of this renewed communication is to introduce a simplified version of Typogenetics that will be still capable to form a proper environment for Artificial Life studies of autoreplicators and hypercycles, both entities that belong to basic concepts of modern efforts (Adami, 1998; Banatre & Le Metayer, 1990; Banzhaf, 1993,1994; Berry, & Boudol, 1992; Biebricher & Gardiner, 1997; Dittrich & Banzhaf, 1998; Eigen & Schuster, 1979; Eigen, 1971; Farmer & all, 1982; Fontana & Schuster, 1998; Hosokawa & all, 1994; Ikegami & Hashimoto 1995; Kauffman, 1986; Pargellis, 1996; Rasmussen & all, 1990; Stadler & all, 1993; Suzuki & Tanaka, 1997) to simulate life in-silico. It is demonstrated that a construction of autoreplicators and hypercycles belongs to very complicated combinatorial problems and therefore an effort to generate them by a systematic constructive enumeration is hopeless. This is the main reason why we turned our attention to evolutionary methods of spontaneous emergence of autoreplicators and hypercycles. One of objectives of the present paper is to demonstrate an effectiveness of a simple version of evolutionary algorithm to create autoreplicators and hypercycles in a way closely related to Darwinian evolution.

Finally, we would like to emphasize that a theoretical study of autoreplicators and hyper-
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