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Chapter II

Evolutionary Turing Machines: The Quest for Busy Beavers

Penousal Machado, ISEC, Portugal

Francisco B. Pereira, ISEC, Portugal

Jorge Tavares, CISUC, Portugal

Ernesto Costa, CISUC, Portugal

Amílcar Cardoso, CISUC, Portugal

ABSTRACT

In this chapter we study the feasibility of using Turing Machines as a model for the evolution of computer programs. To assess this idea we select, as test problem, the Busy Beaver — a well-known theoretical problem of undisputed interest and difficulty proposed by Tibor Rado in 1962. We focus our research on representational issues and on the development of specific genetic operators, proposing alternative ways of encoding and manipulating Turing Machines. The results attained on a comprehensive set of experiments show that the proposed techniques bring significant performance improvements. Moreover, the use of a graph based crossover operator, in conjunction with new representation techniques, allowed us to establish new best candidates for the 6, 7, and 8 states instances of the 4-tuple Busy Beaver problem.

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INTRODUCTION

In 1937 Alan Turing, while trying to solve one of the problems posed by Hilbert, developed a theoretical computational model that became known as Turing Machines (Turing, 1937). According to the Church-Turing thesis, these finite state machines, although simple, are able to solve any problem that is solvable by an algorithm. Nowadays this thesis is well accepted, and, as such, the class computable and Turing-computable problems are recognized as equivalent.

The main goal of our research is to test the viability of using Turing Machines (TMs) as a model for the evolution of computer programs. More specifically, we propose a framework for the evolution of TMs, and test its performance in a well-known problem, the Busy Beaver (BB). This problem was proposed by Tibor Rado in 1962 (Rado, 1962) and became one of the most famous in the area of Theory of Computation.

In a colloquial way, this problem can be formulated as follows:

"What is the maximum number of **1***s that an N-state halting TM can write when started on a blank tape?"*

The N-state machine that writes the maximum number of **1**s is named Busy Beaver.

The rationale for choosing the BB problem lies in some of its properties that make it extremely appealing to study the competence of an Evolutionary Computation (EC) algorithm. Some of these properties are:

- It is an undecidable problem. Most approaches that deal with it try to perform an exhaustive search over the space of possible solutions. We expect that an EC algorithm can discover good quality candidates just by investigating a small part of the search space.
- The search space is very large. For an instance with N states, there are $(4\times(N+1))^{2N}$ possible solutions. Given that the size of the search space depends on the number of states, we can test the scalability of the used algorithms.
- As far as we know, there are no specific heuristics that can help knowledge-based methods to find TMs with high productivity.
- The fitness landscape defined by the BB problem is highly irregular (Pereira, 2002).
- For non-trivial instances, the optimum is not known. This way, development of new methods can lead to the discovery of new best candidates, which adds an additional motivation to the research that is performed.

The formal description of the BB problem and its variants can be found in the following section, which also includes a synthesis of related research.

In the third section, we present an initial evolutionary approach to the BB problem. We start by analyzing previous approaches in which EC techniques are used in the search for Busy Beavers. Subsequently, we describe our initial approach giving emphasis to representation, genetic operators, and fitness assignment issues. The results achieved with this approach are promising, outperforming previous EC approaches.

Encouraged by the success of the initial approach, we made modifications in two key components of the EC algorithm — representation and genetic operators — aiming to improve its performance.

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