DPhil Proposal

Dynamics of Neutral Evolution in the Development of Neural Controllers

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Evolutionary robotics has successfully exploited the principle of natural selection. This approach places great importance in understanding the dynamics of the evolutionary process. Increasing amount of research points towards selective neutrality as an important and beneficial factor in evolution. Among other things, it eliminates the picture of populations becoming trapped on local hilltops. This research asks, what are the benefits of neutrality in the evolution of simple model nervous systems for autonomous agents? And what mechanisms can be incorporated in the development of neural controllers which make use of neutral networks during evolution? Potential mechanisms have been suggested to arise in more biological plausible genotype-phenotype mappings, such as the use of a genetic regulatory network or a morphogenetic process. Progress in this area would be of major significance in the evolutionary approach to robotics. Furthermore, it would help understand the role of neutral networks in evolution and the (far from understood) relationship between embryological development and evolution.

1 Introduction

Evolutionary robotics has successfully exploited the principal of natural selection to find fit solutions to specific task environments. In the last decade significant progress has been made in adapting artificial agents and in using these experiments to further scientific understanding of natural evolution and of how real nervous systems may work. A dynamical systems perspective has been crucial towards the achieved successes, namely the idea that an agent's behaviour arises not simply from within the agent itself, but rather through its interaction with its environment [1, 4].

Important work on an evolutionary approach to agent control has been done, among others, by researchers in the Dynamics of Adaptive Behavior Research Group at Case Western University [5] and the Evolutionary and Adaptive Systems group at Sussex [8], evolving dynamical neural networks. In many of this models importance has been given to the use of continuous dynamics, on the basis that the dynamics of nervous systems and the physical world are continuous in nature, likewise on the use of networks with recurrent connections, motivated by the substantiation of internal states. Additionally, genetic algorithms have been the most common form of algorithm used for the sort of adaptive improvement needed in this approach.

The use of such evolutionary techniques for the development of increasingly complex robot control systems has placed great importance in understanding the dynamics of evolving populations. Classically, fitness landscapes have been treated as rugged, hilly terrains on which populations perform hill-climbing. In this sense, selective pressure drags a population towards peaks of relative high fitness while mutation and recombination searches the surrounding landscape. This poses the problem of populations becoming trapped on local hilltops.

More recent developments in evolutionary theory and molecular biology have pointed to selective neutrality as an important factor in the dynamics of evolution. This has lead to a picture of populations engaged not in hill-climbing but rather drifting along connected networks of genotypes of equal fitness, with sporadic jumps between networks [2, 3].

2 Motivation

Within the last few years there has been an increasing amount of research into the possible benefits and application of Neutral Networks in the field of Evolutionary Computation (summary in [24]). Nearly all of this work has been primarily concerned with binary search landscapes. Conversely, work in evolving dynamical neural networks, such as the ones used in evolutionary robotics, has been based mostly on real-value search spaces. There are currently little or no proposed methods by which neutrality can be introduced or measured in real-value search spaces, and conversions from real to binary representations all seem inappropriate at the moment.

In natural and artificial evolution, neutrality may be present or introduced at various different levels [18]. S*tructural neutrality,* where two different genotypes develop the same phenotype; *functional neutrality*, where two different phenotypes produce the same behaviour; and *behavioural neutrality*, where two different behaviours output equal fitness.

In real-world environments, as is the case when evolving neural controllers for autonomous agents, behavioural neutrality is usually present because of the inherently noisy environment in which the evaluation is being performed. Similarly, several cases of functional neutrality have been argued to arise naturally from the possibilities of symmetrical architectures in the use of neural networks as phenotypes for neural controllers. However, even though the increasing amount of work in molecular biology points towards the importance of neutrality at the genotype-phenotype mapping level [9], the introduction of neutrality in the encoding scheme for evolving neural controllers has been very little studied and what's more, classically regarded as inefficient.

In addition to this, development in artificial evolution, in the sense of the embryological process from genotype to phenotype, has been greatly uncared for until recently, with a few notable exceptions (amongst them [6, 7, 11, 13]). In nature, the genotype-phenotype mapping process is the result of the evolutionary process. In artificial evolution, instead, the rules that determine the relations between genotype and phenotype are decided quite arbitrarily.

All of these considerations suggest that progress in this area would significantly improve the adaptive power of artificial evolution. Also, considering that the relation between development and evolution is far from being well understood in biology, investigations in artificial evolution may help understand the role of development in natural evolution [14] and its role in neutral evolution.

3 Proposed Area of Research

The aim of my research is on generating a solid framework for the developmental process in the evolution of neural controllers for autonomous agents in the light of neutral evolution. The main focus of this line of work would be directed towards allowing these, generally real-valued, genotypes of dynamical neural networks (i.e. CTRNNs) to drift through percolating neutral networks, by modifying not only the encoding scheme but the genotype-phenotype mapping process as well.

The task of allowing populations to benefit from the constant-innovative property brought by neutrality hinges towards selectivity not on the parameter space of the agent's dynamics directly, but rather the parameter space of a developmental process. As a consequence, work on two derivative themes is considered important and despite falling short of their ambitious goals, they outline long-term aims for achieving appropriate neutral artificial evolution:

Genetic Regulatory Networks: according to Kauffman [12] (and similar views by others) large scale order arises spontaneously in complex systems comprised of many interacting parts, without the necessity for selection to produce such order by acting on the phenotypic expressions of genotypic variations. In this sense, work towards developing phenotypic mappings which are based on complex interactions of networks of genes turning each other on and off, could potentially lead to orderly systems engaging in useful genetic drifting.

Coupled Dynamics: according to Oyama's notion of ontogenesis of information [15] (and similar views by others), a picture is emerging of phenotypes as resulting from the interactions between genetic and environmental information. In a fashion similar to that put forward by Beer to approach the *(phenotype + environment) -> behaviour* mapping, wherein the behaviour of an agent is explained as the coupled dynamics of agent and its environment, so should the developmental systems be explained in terms of the coupled dynamics of the genomic regulatory system and the environmental factors in which it develops.

There are other motivations for this work apart from pure academic interest. In general, work in any of the facets mentioned above would be of major significance in the current evolutionary and dynamical approach to the design of nervous systems for autonomous agents. More specifically, recent studies have argued that neutrality is a beneficial and, in some cases, necessary factor in producing evolvability [17, 19, 20], adaptation [9, 21, 22], increasingly complex behaviour [10], and in the evolution of gene regulation [16]. Additionally, work in this area could help understand the complex genetic regulations found in biological systems and as a consequence bring light to the relation between self-organization and evolution. Furthermore, the analysis of the dynamics between genetic and environmental subsystems could aid the understanding of the relationship between ontogeny and evolution [23].

4 Immediate Plans

At present, work in measuring the neutrality (or lack of) in populations of evolving continuous time recurrent neural networks with the commonly used real-value direct encoding, where the effectiveness of the evolved artefact depends on the long-term behaviour of the dynamical system; and on developing alternative encodings and mappings which increase the presence of neutrality and allow for certain stage-setting mutations to take place, will serve as an initial step into the ambitious goals proposed herein. Also, current investigations are pointed towards understanding the importance of nearly-neutral mutations in real-valued fitness landscapes given the highly improbability of two different individuals having the exact same fitness.

An intermediate plan is to investigate on an artificial morphogenesis method in which the neural network is developed from the interaction of networks of regulatory genes, in the form of Kauffman's interconnected genes as boolean switches (something along these lines), and again to analyse, test and measure such mapping for neutrality.

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