Evolution of Biological Clocks and Differentiation with artificial Genetic Regulatory Networks

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Introduction

Genes guide the behaviour of all the different kinds of cells in our bodies as they grow and develop. As part of Genetic Regulatory Networks (GRNs), they encode nano-scale “machines” (called “proteins”) that do the work of the cell and even regulate each other’s rates of production. GRNs are very flexible and powerful: during the course of evolution on earth a huge variety of species have come into existence. In multi-cellular organisms such as people, cows and sweetcorn, cells are differentiated into many types, resulting in efficient division of labour, even though all cells have the same genome. We use GRNs and evolution inside computers to study how to make their behaviour more highly evolvable. Understanding the evolution of artificial GRNs could help biologists to gain insights into their natural counterparts. Furthermore, harnessing the evolvability of GRNs could lead to huge improvements in the automatic engineering of control systems.

Project detail

In particular we are interested in GRNs’ responsiveness to their environment and their potential to create efficient division of labour (differentiation).

Biological clocks provide one of the simplest yet most characteristic examples of the responsiveness of life on earth: every organism’s regulatory dynamics respond with daily activity in close coupling with periodic cycles of environmental stimuli such as the rhythm of light and dark or the effects of lunar gravitation in the ebb and flow of tides. Biological clocks are believed to have originated already in the earliest cells. The atmosphere on early earth allowed much higher ultraviolet radiation to penetrate during day-time, and timing cell division to occur at night provided protection for replicating DNA. This behaviour can, for example, today still be found in the single-celled red tide organism Gonyaulax polyedra.

We generate relatively simple networks that are evolved to respond like biological clocks to periodic environmental stimuli. To capture differentiation, our artificial organisms have two types of cells. One cell produces the inverse of the other cell’s behaviour, a simple form of differentiation. This difference is signalled only by an inducing signal that acts like a switch.

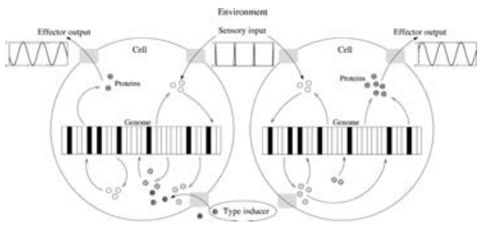
Starting from random gene networks our evolutionary algorithm picks the best performing individuals to be “parents” for the next generation of GRNs. These GRNs control the cells in the evolved artificial organisms.

Our GRNs can continue oscillating during blackout periods of no stimuli, are robust to perturbations of various kinds, and are capable of differentiated behaviour when presented with slightly different stimuli, very much like GRNs found in nature.

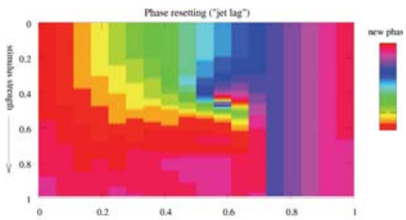
Analysis revealed phase resetting behaviour (which was not selected for) similar to patterns observed in natural organisms, allowing them to reset their biological clocks when needed. Slight changes in the genome often lead to slight changes in the development of the organism, a mechanism called “heterochrony” that biologists think is very important for evolvability.

Using artificial evolution, we have shown that GRNs can begin to let us realize important principles shaping life on earth within computers.

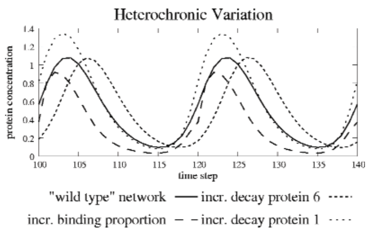
Image of the single celled red tide organism which uses a biological clock to time its activities



Schema of our differentiation model, both cells have the same genome but have to produce inverse dynamics



Phase resetting plot, patterns are very similar to those found in real organisms



Mutations of the genome keep the general dynamic behaviour

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