An Alternative Approach to the Synthesis of Life

Tim Taylor

tim.taylor@ed.ac.uk

http://www.dai.ed.ac.uk/homes/timt/

Keywords: Open-Ended Evolution; Evolvability; Origin of Life; Sensor Evolution; Autopoiesis

The Question

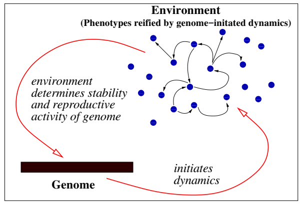
- How to create an evolutionary system capable of producing agents that can control and exploit their environment in unlimited and increasingly complex ways? In other words, how to achieve high evolvability?

Problems with Previous Approaches

- Strong representational distinction between organisms & environment.
  - Implies a limited, predefined set of ways of interacting with environment. E.g., Tierran programs could never evolve a method to read the system time even though this information is available in the host PC, because there are no instructions in the instruction set to do this.
- An over-emphasis on computational capacities.
  - For example, the Tierran language is computationally universal, but this still does not mean that it can interact with the environment in unlimited ways. Input and output processes are just as important as "computation."
  - "Life as computation" (maybe "life as interaction" more appropriate?)
- An over-emphasis on the process of self-replication rather than on properties of the environment.
  - Self-replication is insufficient to explain origin of complexity in nature *or* in simulation (c.f. attempts to evolve RNA sequences in vitro).
  - Abiotic environments often modelled as a rather inert medium.

An Alternative Approach

- View the environment as a dynamical system.
  - It has its own dynamics and self-organisational properties.
  - The idea is that genotypes can "sculpt" the dynamics of the environment by supplying constraints.
- No representational distinction between organism and environment.
- The important distinction is now between genotypes (relatively inert structures) and [phenotypes+environment] (dynamic).
  - Genotypes supply initial conditions for dynamics of the environment.
  - The evolutionary success of a genotype is governed by the local environment (i.e. specification of longevity, fecundity and copy-fidelity).
- Self-replication of genotypes is taken for granted (under the appropriate environmental conditions); it is not regarded as a major issue.
- The origin and evolution of life is now a question of how genotypes evolve to progressively control and exploit dynamics of environment in more complex ways to promote their own evolutionary success.



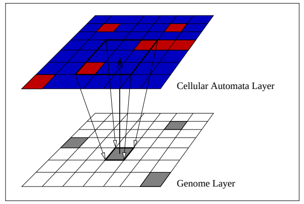
Closing the loop between genotype, phenotype and environment

Advantages

- Any process supported by the environment, in any modality, can now, in principle, become incorporated by an organism's phenotype (with only weak assumptions about the dynamics).
  - This only depends on the level at which genotypes specify initial conditions for the dynamics.
  - Sensor evolution is therefore unproblematic.
- All phenotypes are fully embedded in the environment.
  - They are therefore part of the environment experienced by other organisms (rich co-evolutionary potential).
  - There is no pre-defined notion of what structure a phenotype must have; this can therefore evolve over time.

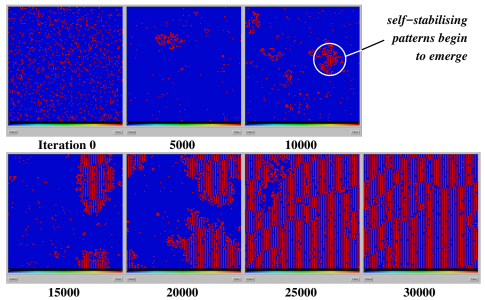
EvoCA: A Simple Model

- Environment modelled as a Cellular Automata (CA) array.
  - A simple, discrete-time and -space dynamical system.
- Consists of two layers:
  - Layer 1 is the environment. Any CA update rules can be used here (e.g. Game of Life).
  - Layer 2 contains genotypes. Each genotype is associated with a particular cell in Layer 1. This layer has no dynamics as such (i.e. genotypes are relatively inert structures).
- Each gene has a precondition and an action. Precondition specifies a particular state of the local environment (i.e. a particular configuration of a subarray of the CA). Action sets the state of the associated cell in the CA to a particular value.
- Genotype longevity, fecundity & fidelity governed by local environment.
- Genotypes which initiate dynamics that promote their own survival will tend to flourish (natural selection).
  - This involves gaining control of the local environment in the face of perturbations from abiotic and other biotic sources.
  - Selection pressure for self-generating and self-maintaining phenotypes (i.e. autopoiesis) is therefore an inherent feature of the model.



EvoCA

Some Initial Results



Research Directions

- Under what range of conditions do genome-regulated self-stabilising dynamics arise?
- How does the behaviour change under different CA dynamics?
  - Incrementally add more physically realistic dynamics (e.g. entropy increase, conservation of matter, energy economy, membranes).