Sensor Evolution in Artificial Systems

Towards a more appropriate model of the relationship between organism & environment

Tim Taylor

IPAB, School of Informatics, University of Edinburgh

Talk outline

- What's the problem?
  - Open-ended evolution and sensor evolution in computational evolutionary systems
  - Limitations of previous approaches
  - Where are we going wrong?
- An alternative approach
  - Softening the representational distinction between organism and environment
- A simple model & some (preliminary) demonstrations
- Discussion
  - Future research directions
  - Relevance to other work

What's the problem?

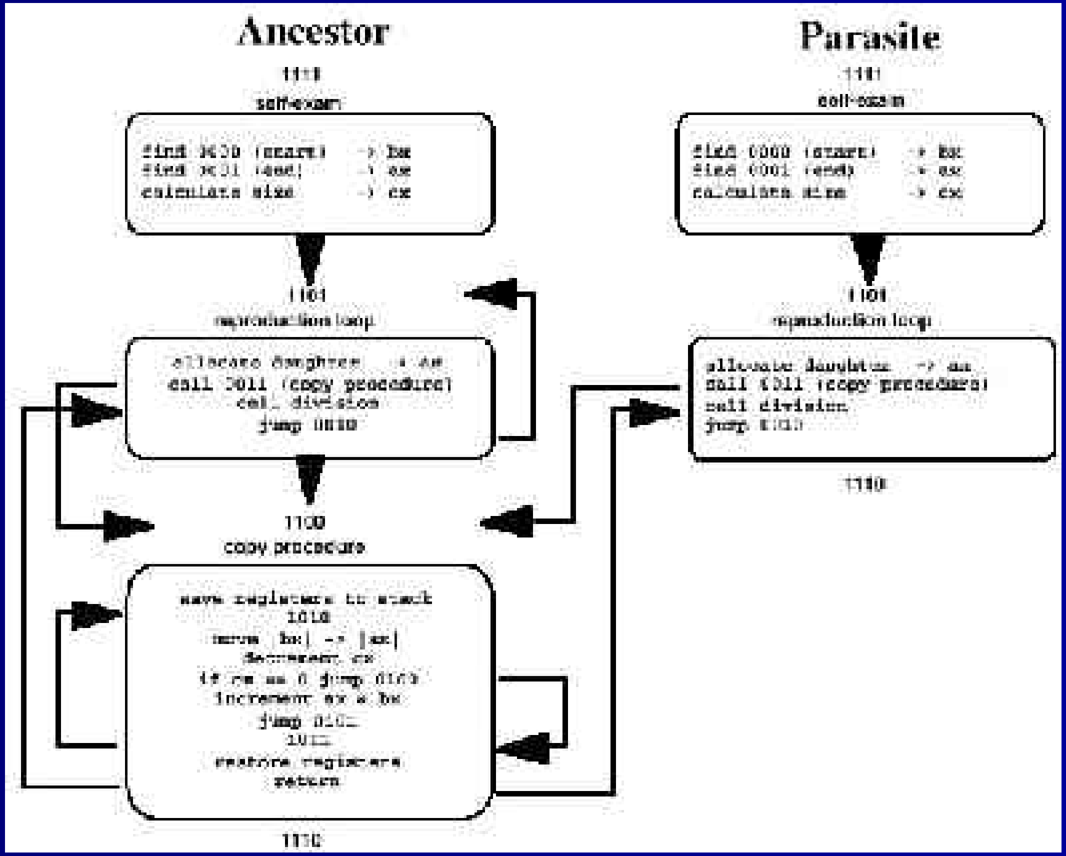
- The context: evolution by natural selection on a computer
- An observation: Biological systems, starting from zero, have evolved an awe-inspiring variety of ways of sensing (and interacting with) their environment
- The problem: How can computational organisms possibly evolve (say) new sensory channels beyond those provided by the system's designer?

Some previous work

- Evolution of self-reproducing computer programs
  - Tom Ray
- Evolved 3D creatures in dynamic virtual environments
  - Karl Sims

Ray's Tierra: Results

- Self-reproducing computer programs
- Mutations can produce heritable variations (and therefore evolution)
- Results include:
  - Parasites
  - Immunity to parasites
  - Hyper-parasites
  - More efficient replication

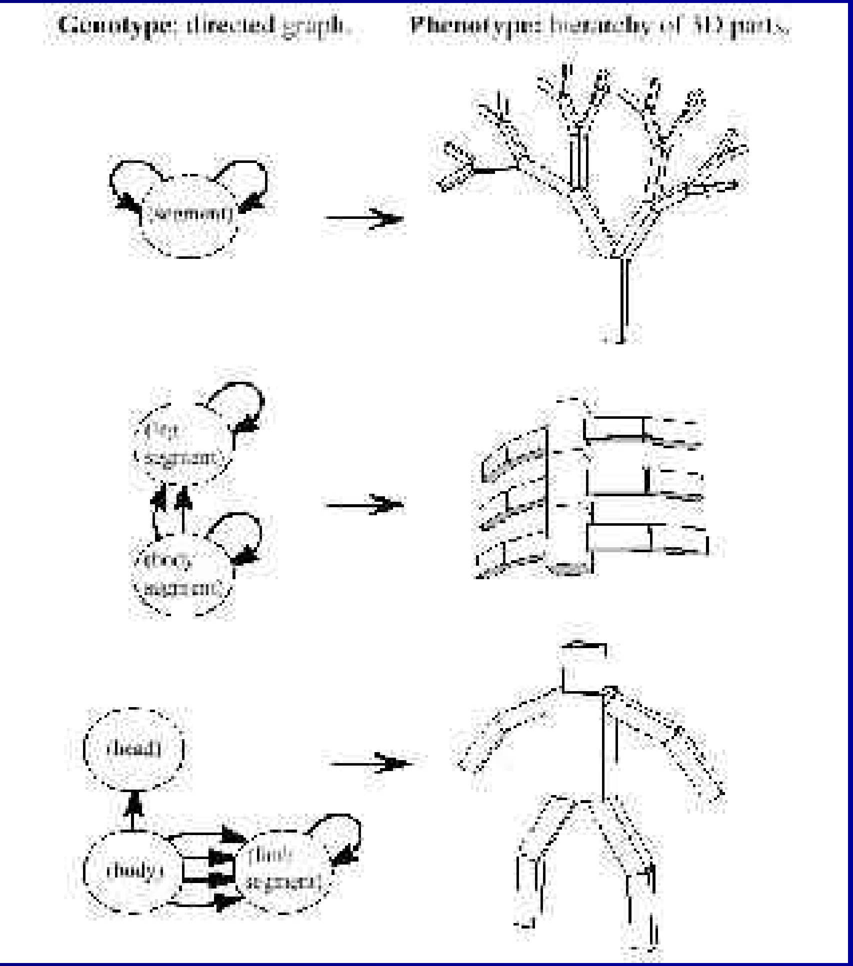


Ray's Tierra: Limitations

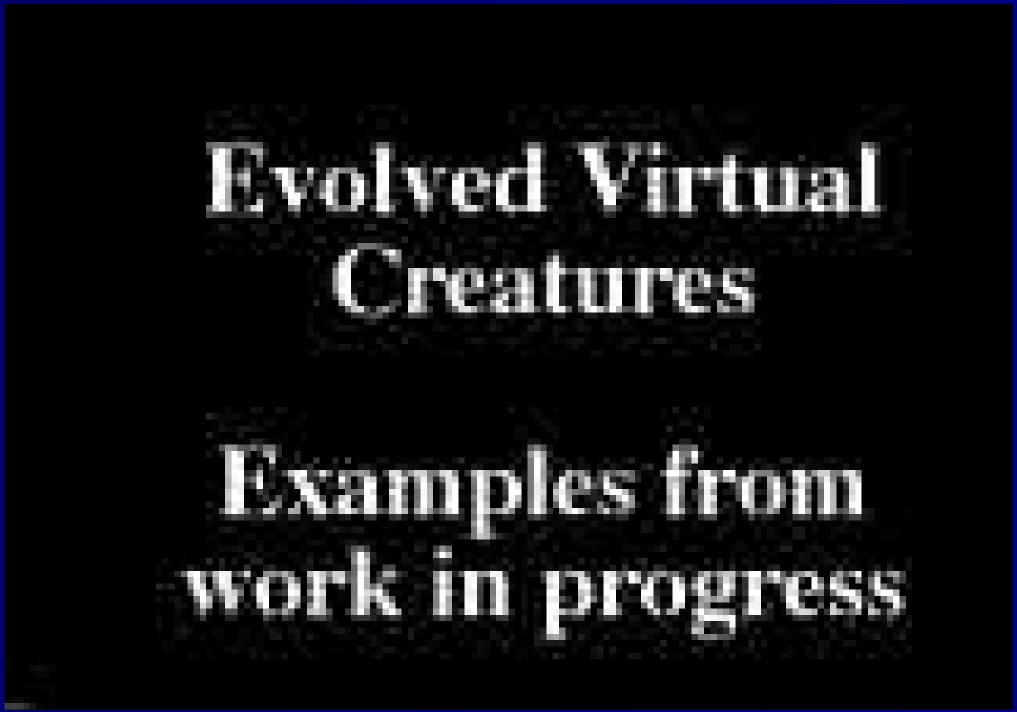
- After initial successes, Tierra failed to evolve any remarkably new innovations in a further decade of research
- Limited, pre-defined set of instructions for interacting with environment
  - E.g. how to evolve a sensor of the current system time?

Sims' Evolved Virtual Creatures: Design

- 3D virtual environment with simulation of real-world dynamics.
- Creatures represented as articulated bodies with controllers connected to muscles and sensors.
- Evolved simple behaviours (swimming, walking, jumping, following), and co-evolved opponents in simple games.



Sims' Evolved Virtual Creatures: Results



Sims' Evolved Virtual Creatures: Comments

- In this case, the environment has its own dynamics
- Behaviour of creatures is due to the interaction of their limb movements with the dynamics of the environment
- Still has a limited, pre-defined set of sensors and actuators for interacting with the environment

Where are we now?

- None of these systems exhibits open-ended evolution
  - Although each produced interesting results, no evidence that they could continue to produce innovative adaptations, if left to evolve for longer
- Why not?

Where are we going wrong?

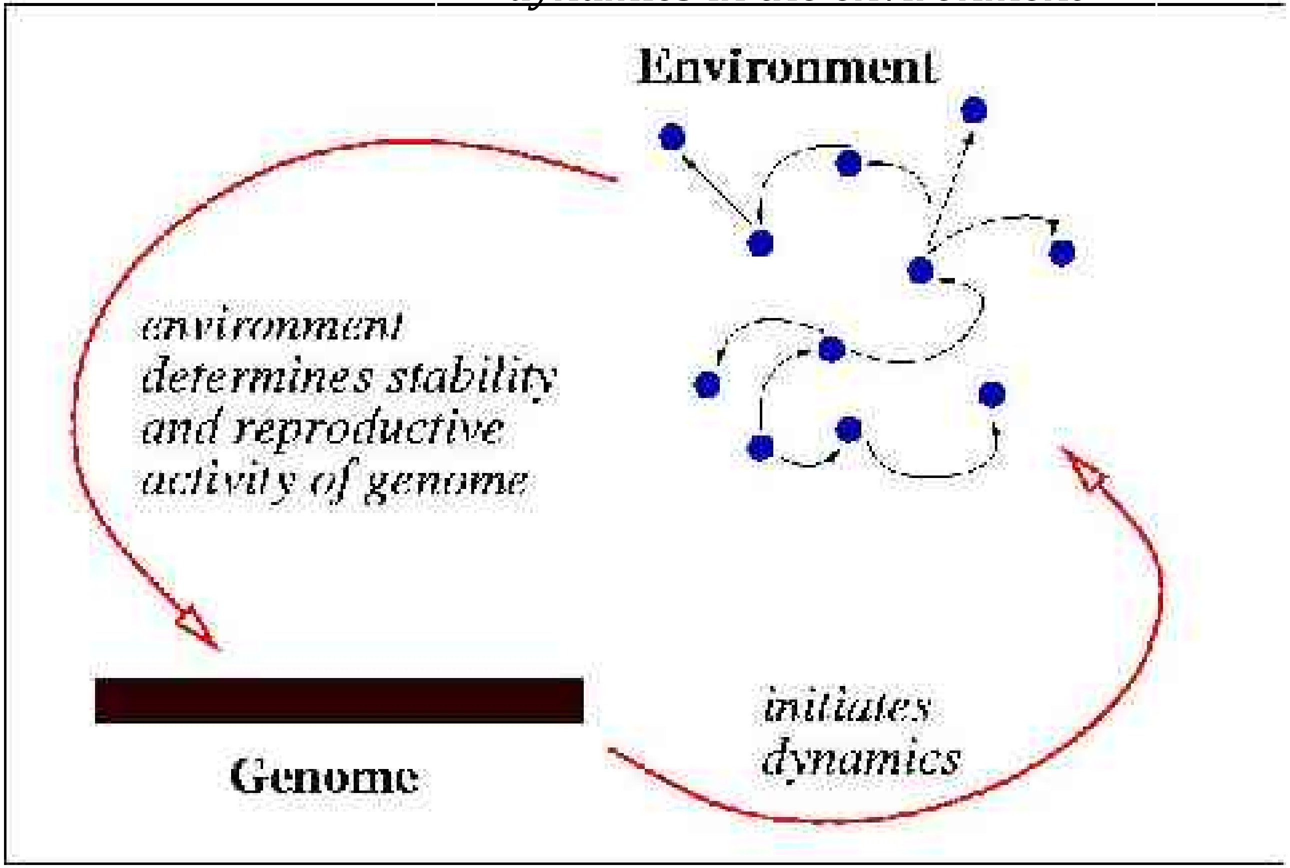
- Strong representational distinction between organism and environment
  - Implies a limited, predefined set of ways of interacting with the environment
  - Over-emphasis on the individual, especially the process of self-reproduction
- Little attention to the dynamic properties of the environment
- Little attention to the nature of the relationship between organism and environment

An alternative approach

- Pay more attention to the dynamic properties of the environment
  - Work with them, not against them!
- Concentrate on how organisms interact with environment (not just computation)
- Soften the representational distinction between organism and environment
  - The important representational distinction is between genotype (semantic) and phenotype+environment (dynamic)
  - Genotypes supply initial conditions for the dynamics of the environment

The general idea…

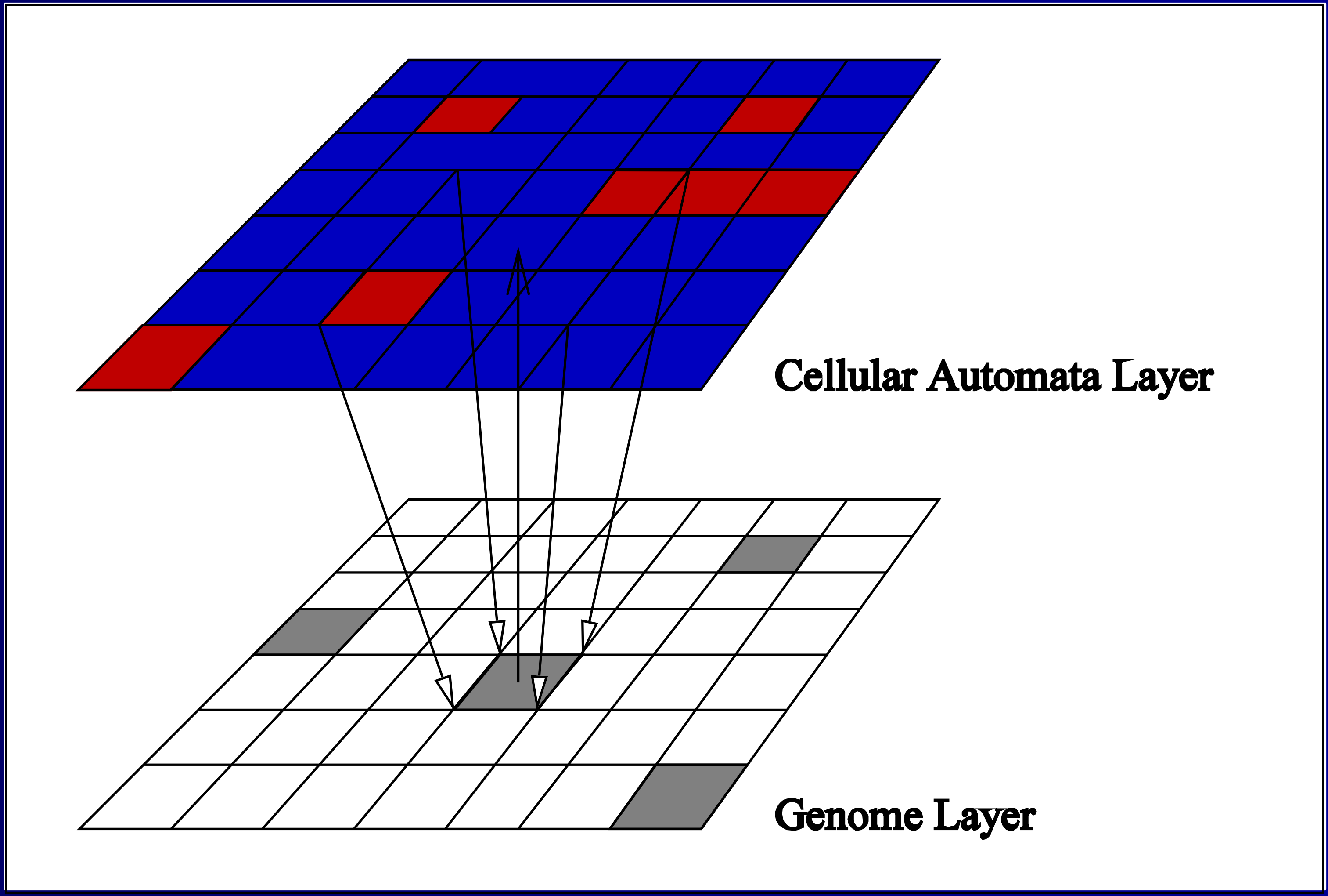
Phenotypes are genome-initiated dynamics in the environment



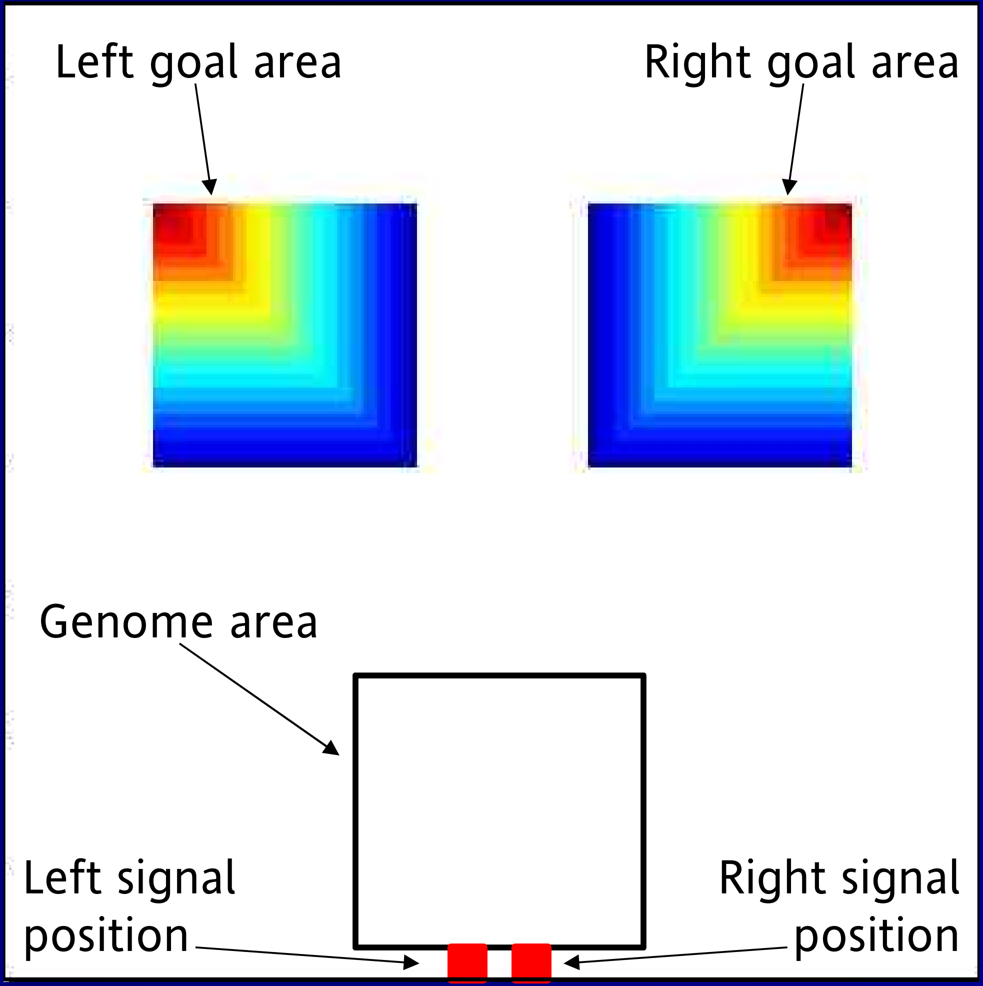
Introduction to the EvoCA model

- EvoCA is a simple model to explore these ideas
- It is based upon Cellular Automata
- It 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 genomes. This layer has no dynamics as such, but genomes interact with Layer 1 by setting states of cells.
    - Timed genes
    - Conditional genes

EvoCA: overview



A simple example

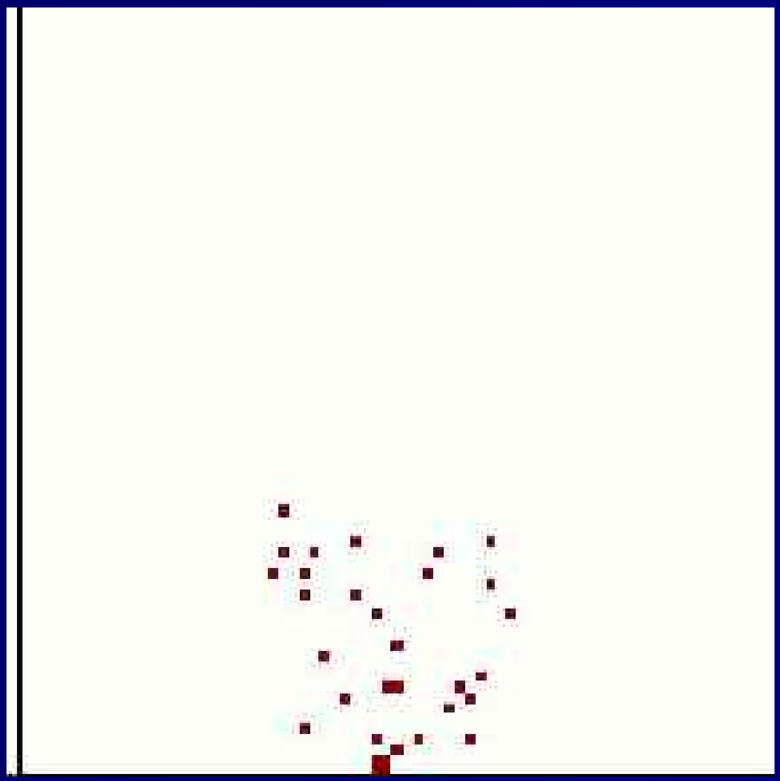


Features of example

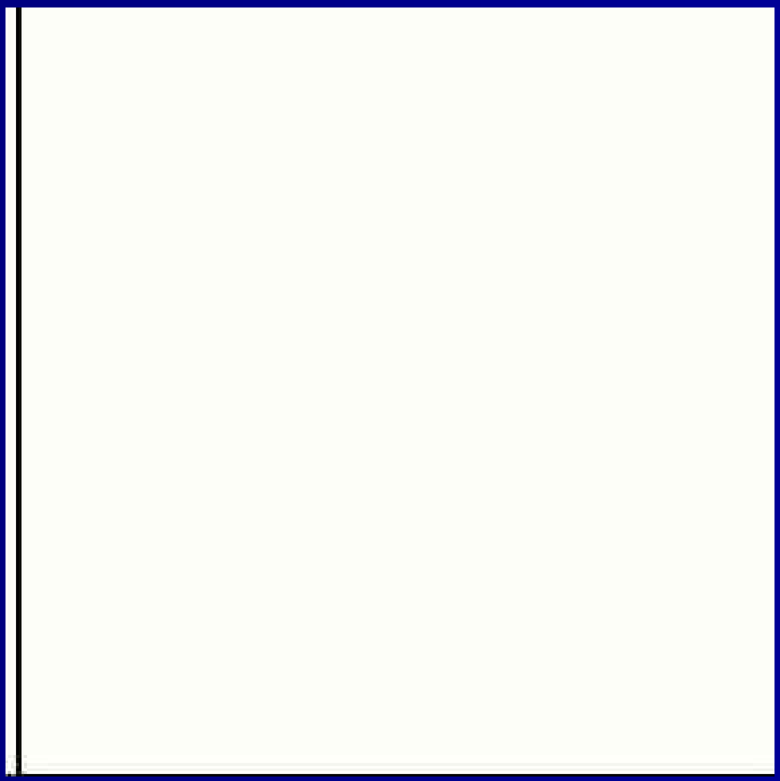
- Genome can only act on a sub-area of the environment
- Genes can only set a cell to state 0 or 1
- Success requires
  - Sensitivity to signal presence and location
  - Sensitivity to signal state
  - Exploitation of environmental dynamics
    - For long-range communication
    - For activation of states other than 0 and 1

Results I: 2 states

Environmental State

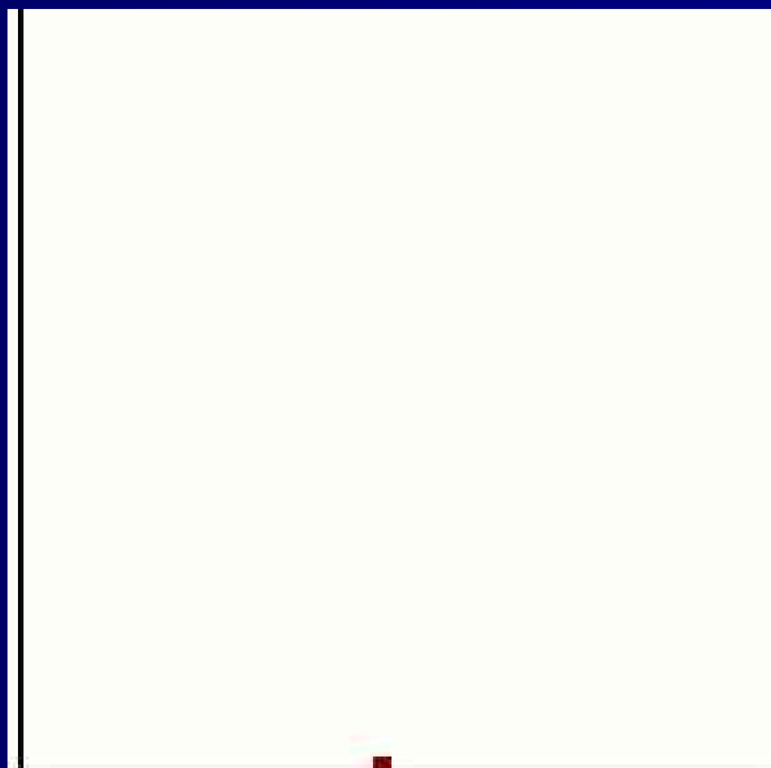


Fitness Contribution

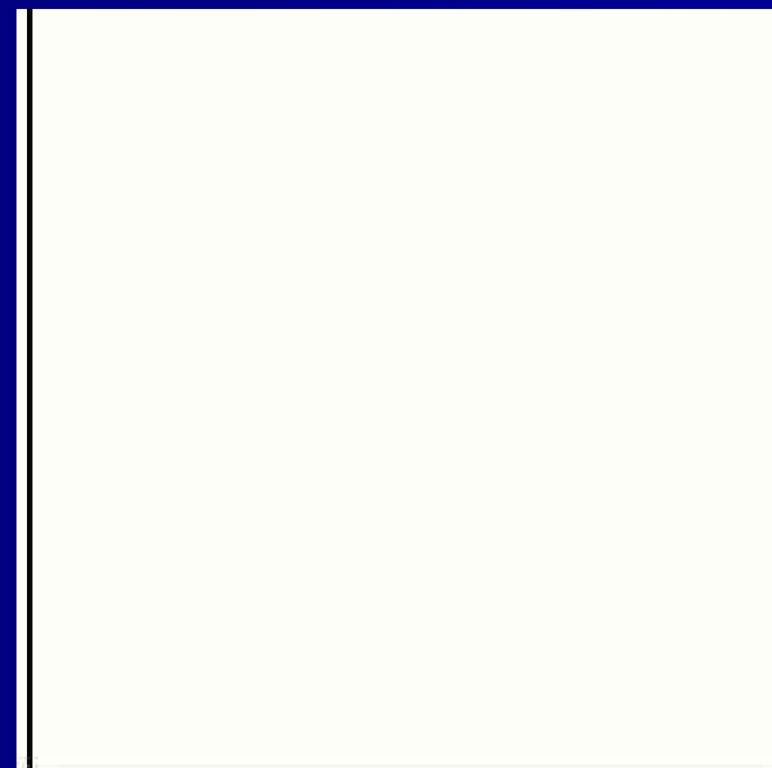


Results II: 2 states

Environmental State

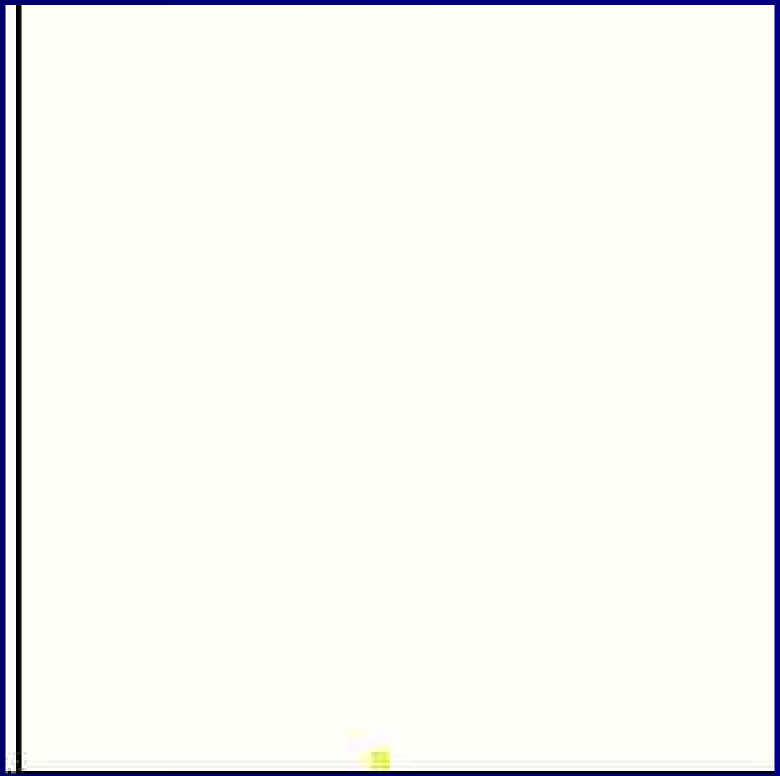


Fitness Contribution



Results III: 5 states

Environmental State



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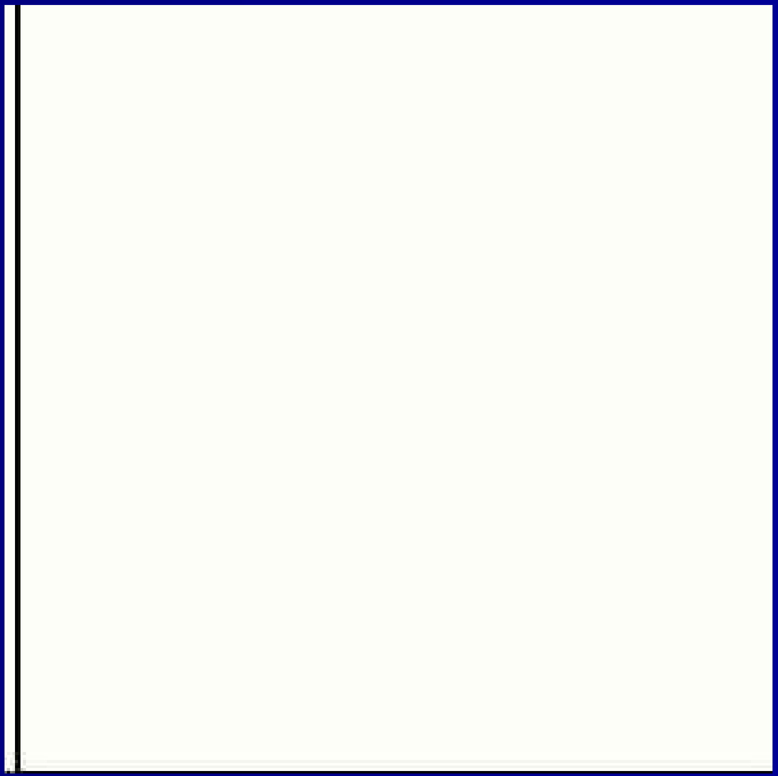
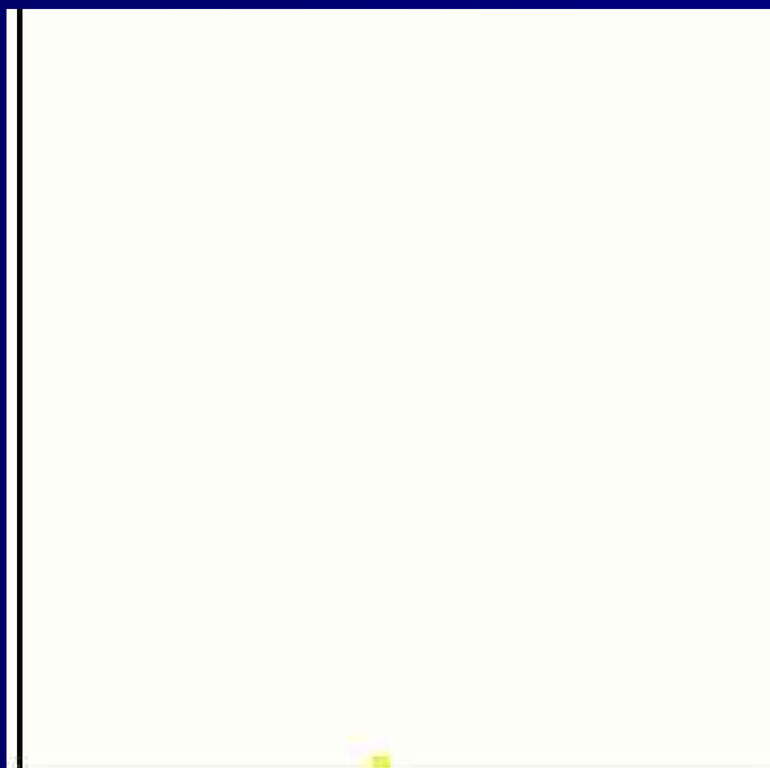
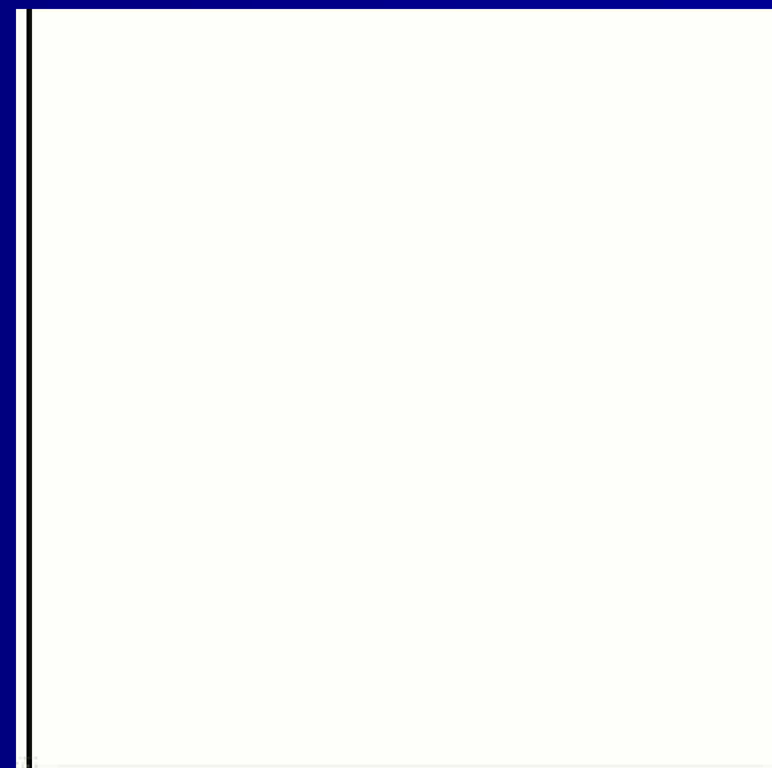


Results IV: 5 states

Environmental State

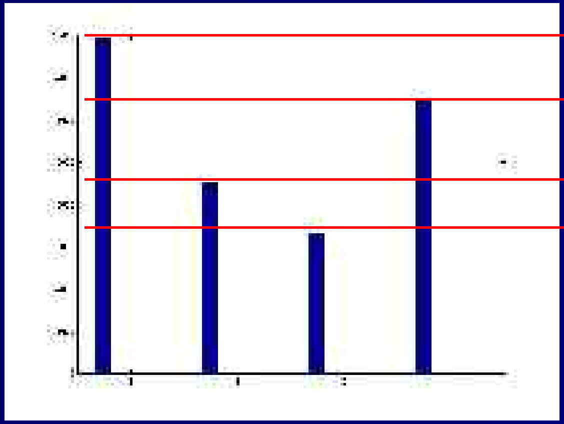


Fitness Contribution

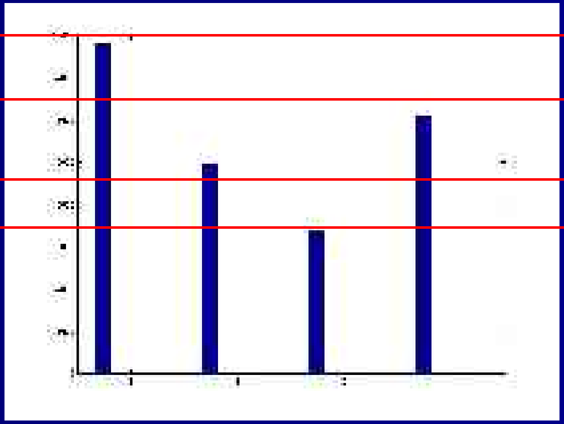


Sensitivity to state?

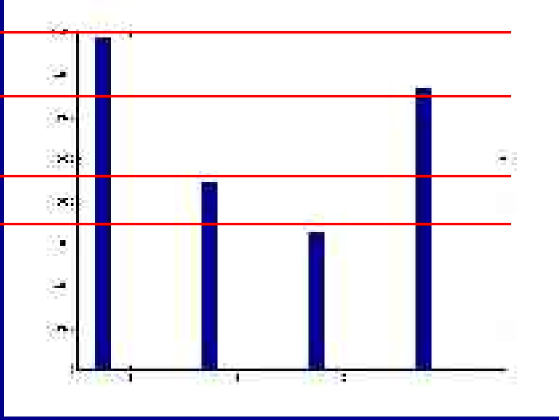
Histograms of cell state counts in goal areas



Signal state 1



Signal state 2



Signal state 4

General comments about the approach

- Assumes genomes to be relatively unreactive, only participating in environmental dynamics by supplying constraints
- The important representational distinction is thus between genotypes and [phenotypes+environment]
- General approach is to have a simple set of mechanisms for evolution, and to achieve evolution of complex organisms by increasing the complexity of the environment
  - E.g. adding conservation of matter, entropy increase, energy flow, membranes, computational universality, etc.

General comments #2

- No pre-defined specification of phenotype, so this is free to evolve
- By exploiting dynamics of environment, the phenotype space is much larger than the set of states that the genome can directly manipulate
- If more than one organism exists in the environment, they will experience rich co-evolutionary pressures (they are all part of the same dynamical system!)

Future research directions

- Modify system for natural selection rather than artificial selection
  - Some local environments will promote genome survival and reproduction, others will be hostile
- Basic programme involves investgating effect on evolutionary dynamics as more physical and computational properties are incrementally added to the environment

Relevance to other work

- A more appropriate model of the relationship between organism and environment in biological systems?
- Compared to other computational systems, softens the distinction between organism and environment
- Work in evolutionary electronics (`in materio'), where rich physical effects are exploited, is closely related