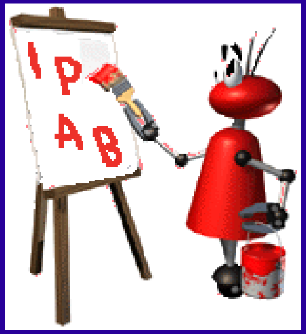
Evolvability and the Origin of Meaning in Artificial Systems

Tim Taylor

Institute of Perception, Action and Behaviour
School of Informatics
University of Edinburgh

tim.taylor@ed.ac.uk
http://homepages.inf.ed.ac.uk/timt/



Talk outline

- Synthetic evolution
  - Scientific and technological issues
- Some previous work and its limitations
- An alternative perspective
  - Addressing the nature of the relationship between organisms and environment
- The EvoCA model: description and demos
- Results and implications
  - The origin of meaning in dynamical systems
- Future research topics

Creative evolution on computers and other media

Evolve controller for a given body shape to perform a particular task

NaturalMotion Ltd, 2002

Some big questions

- How to explain the origin of living organisms from a non-living environment?
- How to build highly evolvable systems?
  - Where agents can control and exploit their environment in unlimited and increasingly complex ways
  - Involves the evolution of new sensors and effectors

Evolution of RNA in a test tube

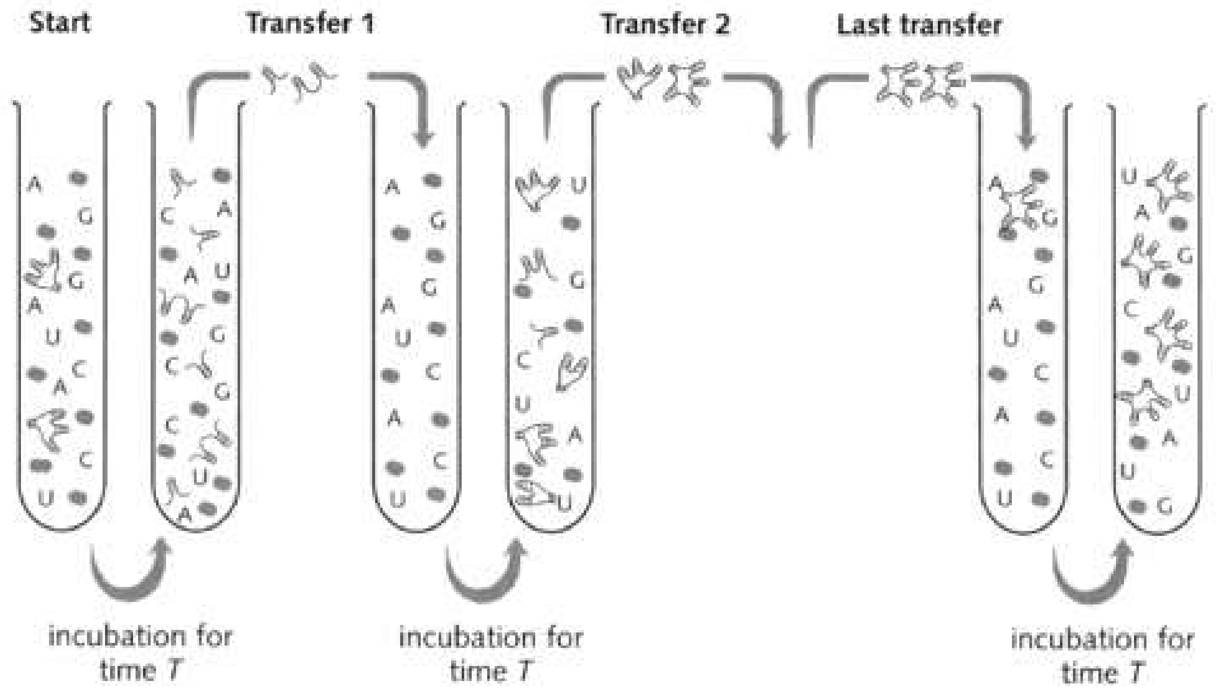


Figure 3.1 Evolution in a test-tube. The initial tube contains the four nucleotides from which RNA is synthesized, a replicase enzyme that copies RNA, and a 'primer' RNA molecule. This primer molecule is copied many times, with some errors. After incubation for time *T*, a drop of solution is transferred to a new tube containing nucleotides and enzyme (but not, of course, any primer). The process of incubation and transfer can be repeated indefinitely, and evolutionary changes in the population of RNA molecules observed.

Experiments by Spiegelman, Orgel, and others

Evolution of RNA in a test tube

"More or less independently of the starting point ... the end point is a rather small molecule, some 200 bases long, with a particular sequence and structure that enable it to be replicated particularly rapidly.

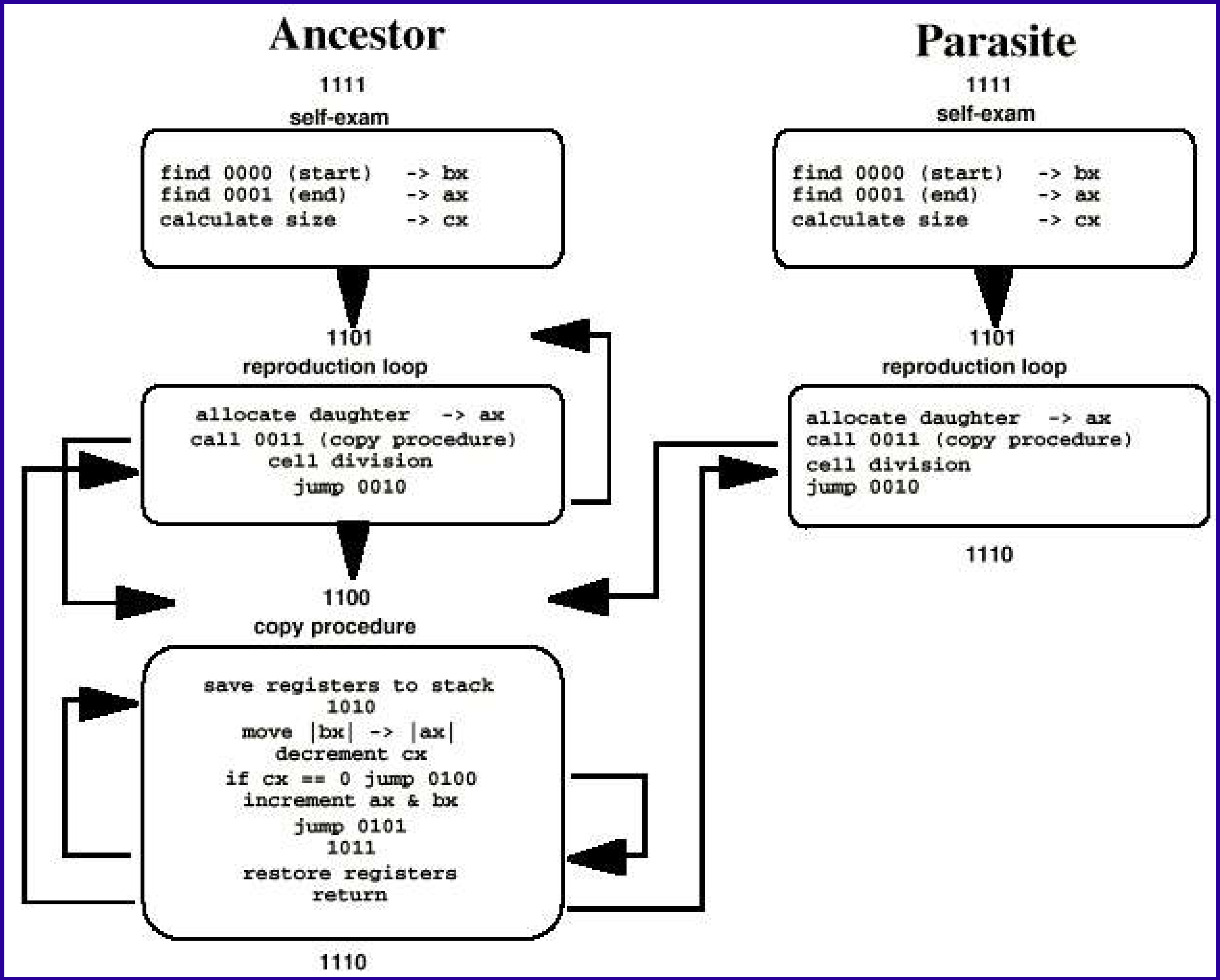
In this simple and well-defined system, natural selection does not lead to continuing change, still less to anything that could be recognized as an increase in complexity: it leads to a stable and rather simple end point.

This raises the following simple, and I think unanswered question: What features must be present in a system if it is to lead to indefinitely continuing evolutionary change?"

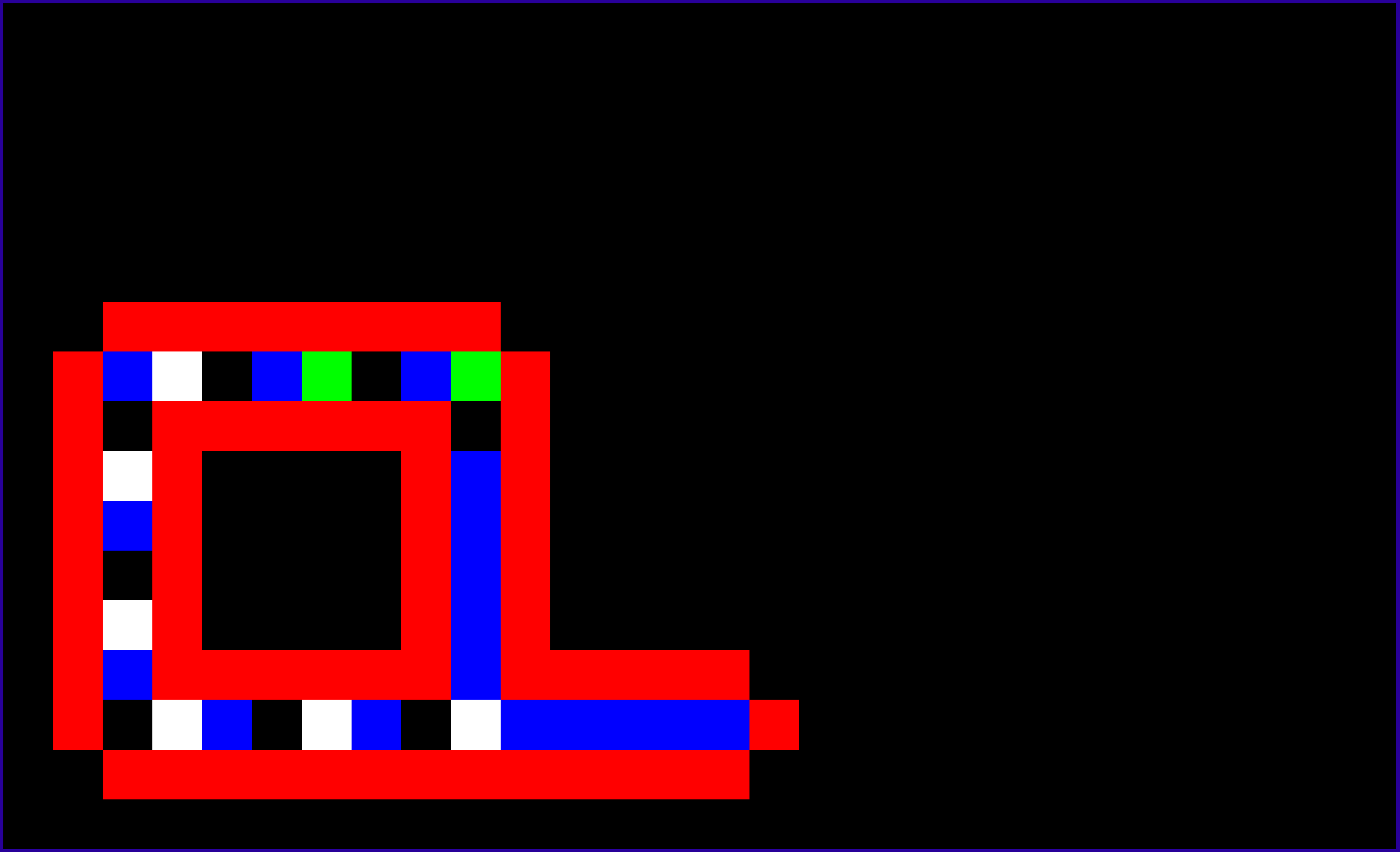
[Maynard Smith 88]

Self-replicating computer programs (Tierra by Tom Ray)

- Self-reproducing computer programs
- Evolution of parasites and related phenomena
- Programs also evolved to reproduce faster
- But not much else happened...

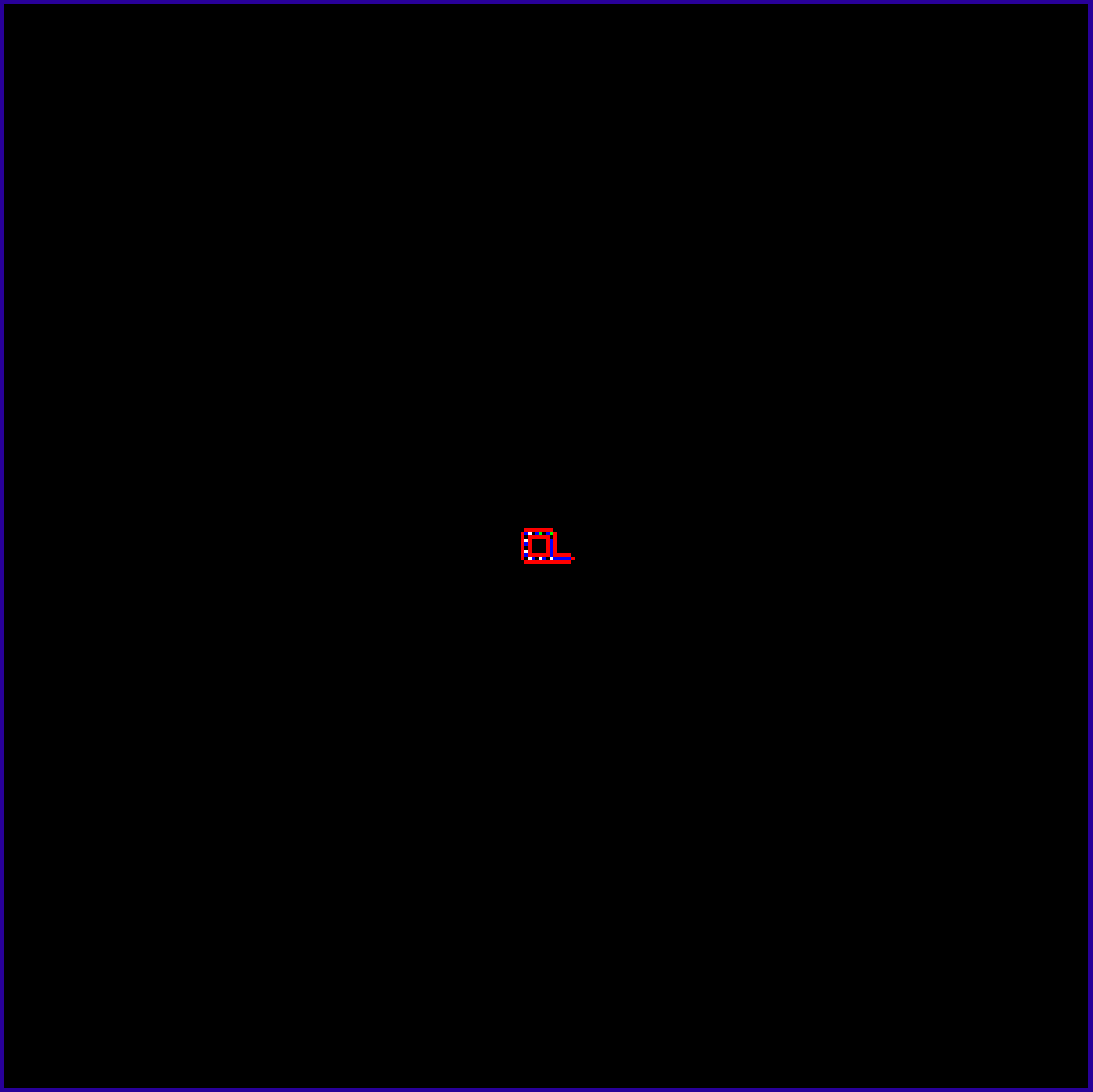


Self-replication in Cellular Automata



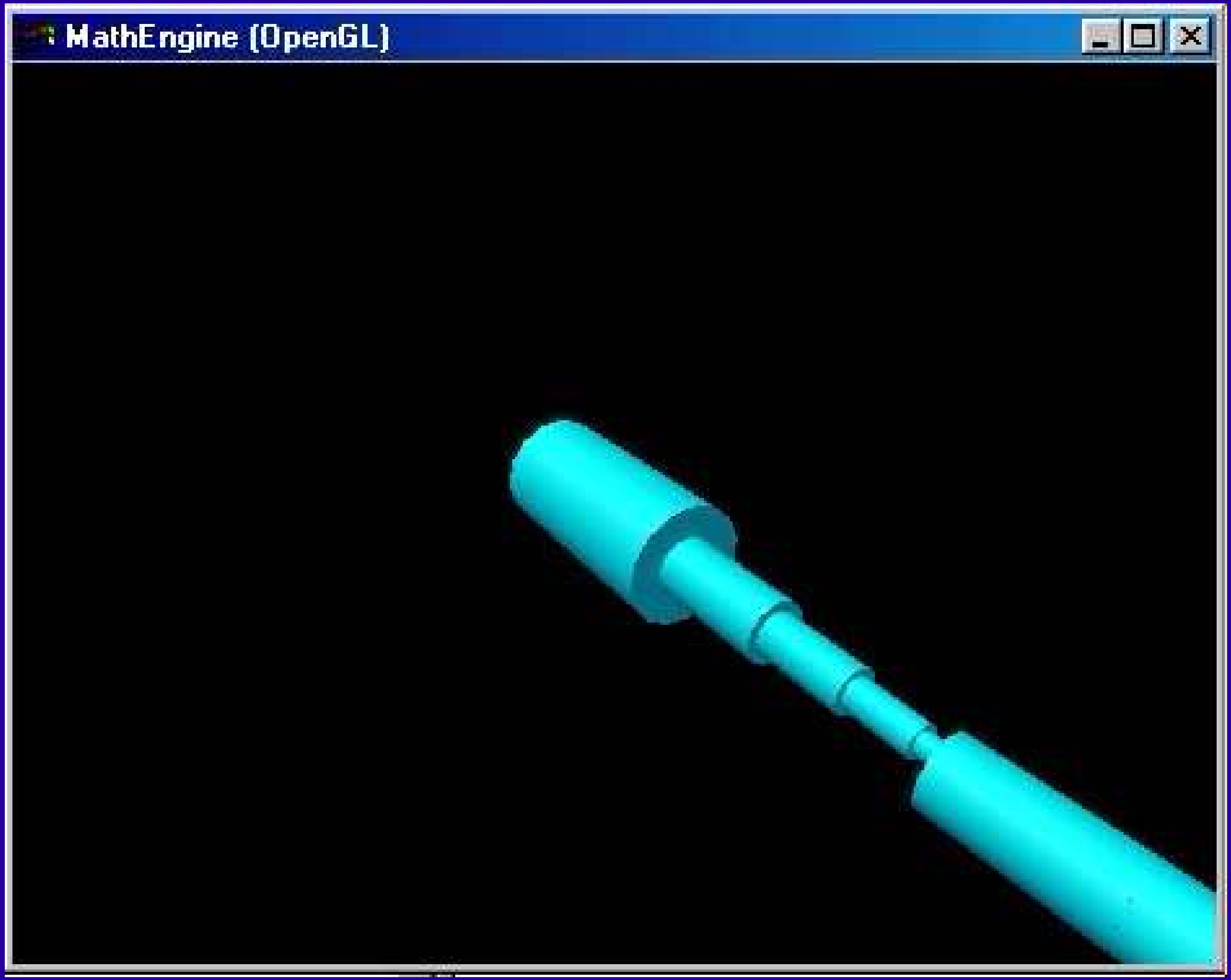
Langton’s Loop (movie by Hiroki Sayama)

Self-replication in Cellular Automata



Virtual creatures for computer games and animation

Evolution of controller + body shape



Taylor & Massey, 1999

Virtual creatures for computer games and animation

- In these cases, 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

Previous approaches

- Most previous Alife work employs a strong representational distinction between organism and environment
  - e.g. Tierra, PolyWorld, Sims, etc. etc.
- Other work involves carefully crafted dynamics to achieve a particular result
  - e.g. von Neumann, Langton, et al.
- Neither approach can provide much insight of how life first originated from a non-living environment
  - and associated problems for sensor/effector evolution

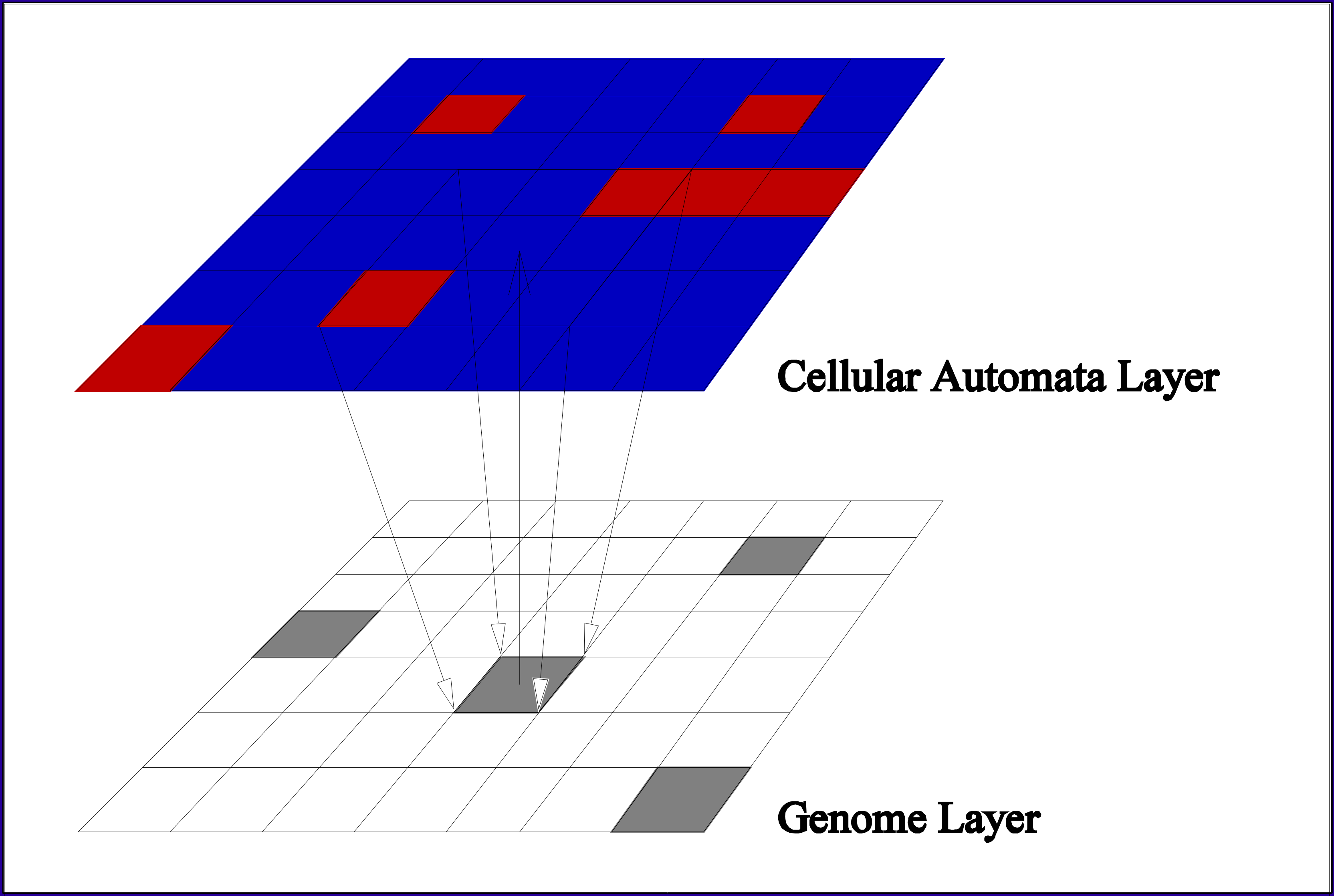
An alternative approach

- Can organisms and environment be represented as a single system?
  - Treat them as a single dynamical system
    - But not with carefully crafted laws of physics
  - Genes supply initial conditions/constraints for the dynamics of the environment (cf. Howard Pattee)
  - Evolution of constraints for a dynamical system
- Sensor and effector evolution
  - How do organisms evolve to exploit dynamics of environment?

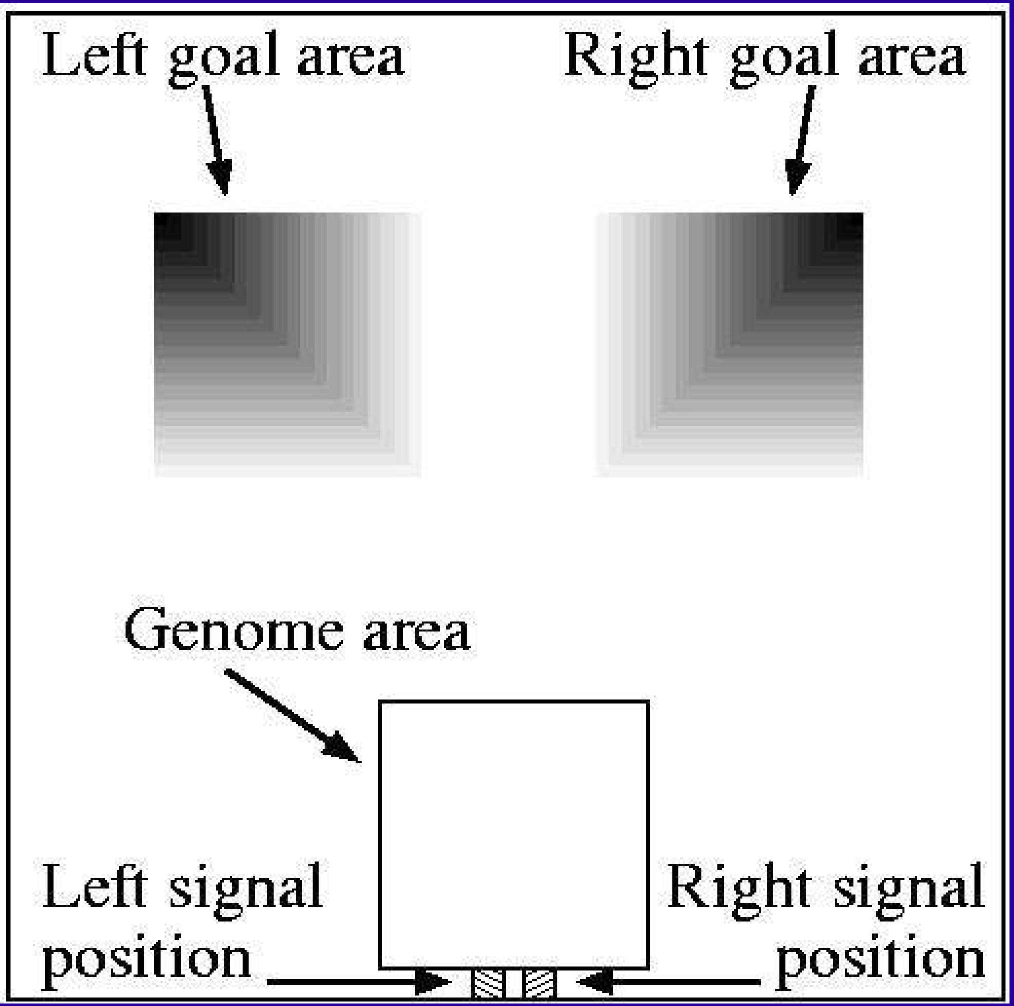
An experimental platform: EvoCA

- 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)
    - Organism phenotypes are expressed in this layer
  - 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



Example 1: artificial selection

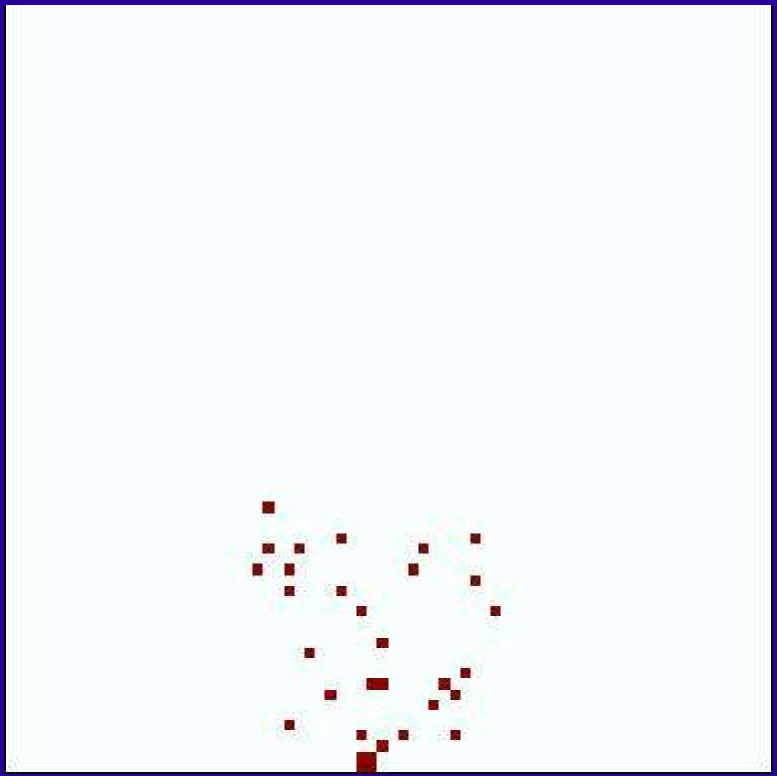


Features of example 1

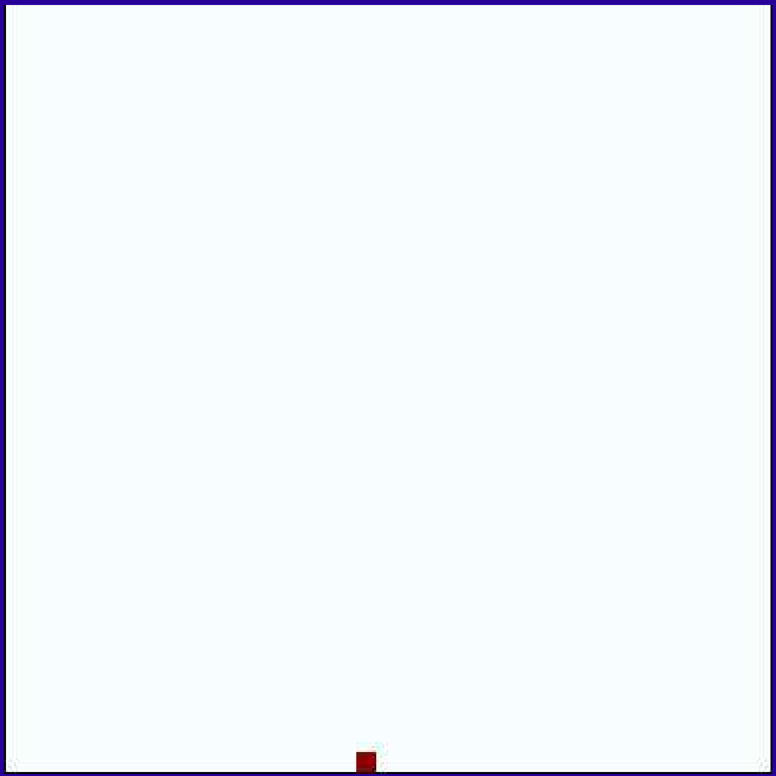
- Organisms tested one at a time, and evolved using a standard genetic algorithm
- “Game of Life” rules used in Layer 1
- Genome can only act on a sub-area of environment
- Success requires
  - Sensitivity to signal presence and location
  - Exploitation of environmental dynamics
    - For long-range communication

Results from example 1

Glider



Spreading Activation



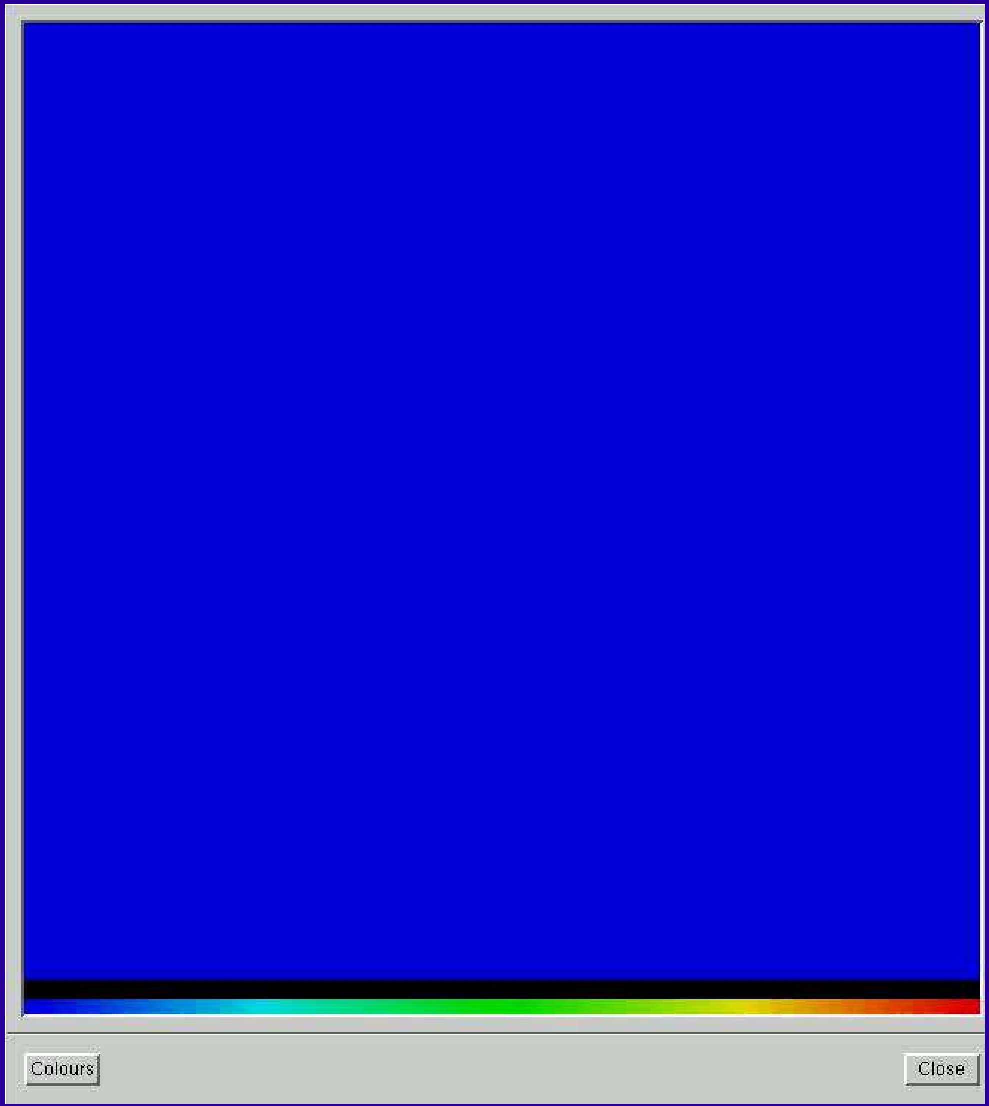
Comments on example 1

- The action of selection during evolution introduces the potential for a new level of description of the system, e.g.
  - Responding to signals
  - Producing gliders
- By exploiting dynamics of environment, the phenotype space is much larger than the set of states that the genome can directly manipulate
  - Evolution of new sensors and effectors

Example 2: natural selection

- Some local environments promote a genome’s existence and reproduction, others are harmful
- This time, allow many organisms to co-exist in environment
  - Initialise with 100 random genomes
- Game of Life rules
- New genomes introduced at a low rate
  - 0.1% probability per cell per iteration
- What happens?

Results from example 2



Comments on example 2

- Genomes which initiate dynamics that promote their own survival will tend to flourish (natural selection)
  - Richly co-evolutionary (all organisms part of same dynamical system!)
  - Selection pressure for self-generating, self-maintaining phenotypes

General comments about EvoCA

- The important representational distinction is between genotypes and [phenotypes+environment]
  - Genotypes are relatively stable structures that supply constraints to the dynamics of the environment
- No pre-defined specification of phenotype, so this is free to evolve
- More complex organisms from more complex environments?

Future research questions

- Shift of focus from self-replication to properties of the environment
  - What features must the environment possess to enable open-ended evolution
  - What features must the environment possess to enable the evolution of “living” organisms?
    - Conservation of matter? Energy flow? Entropy increase? Semi-permeable membrane? Communication channels?
- Transfer of information from environment to genome
- Lowering of entropy

Summary

- Despite some successes in previous work, we still have a long way to go to understand how to build a system that exhibits open-ended evolution
- Lots of work up to now has focused on the role of individual self-replicators
- In future, there is also a need to consider the nature of the relationship between organism and environment:
  - Dynamics of the environment
  - Interactions between organism and environment
- EvoCA is designed to explore these issues
  - A different perspective on modelling the origin and evolution of life

Some references

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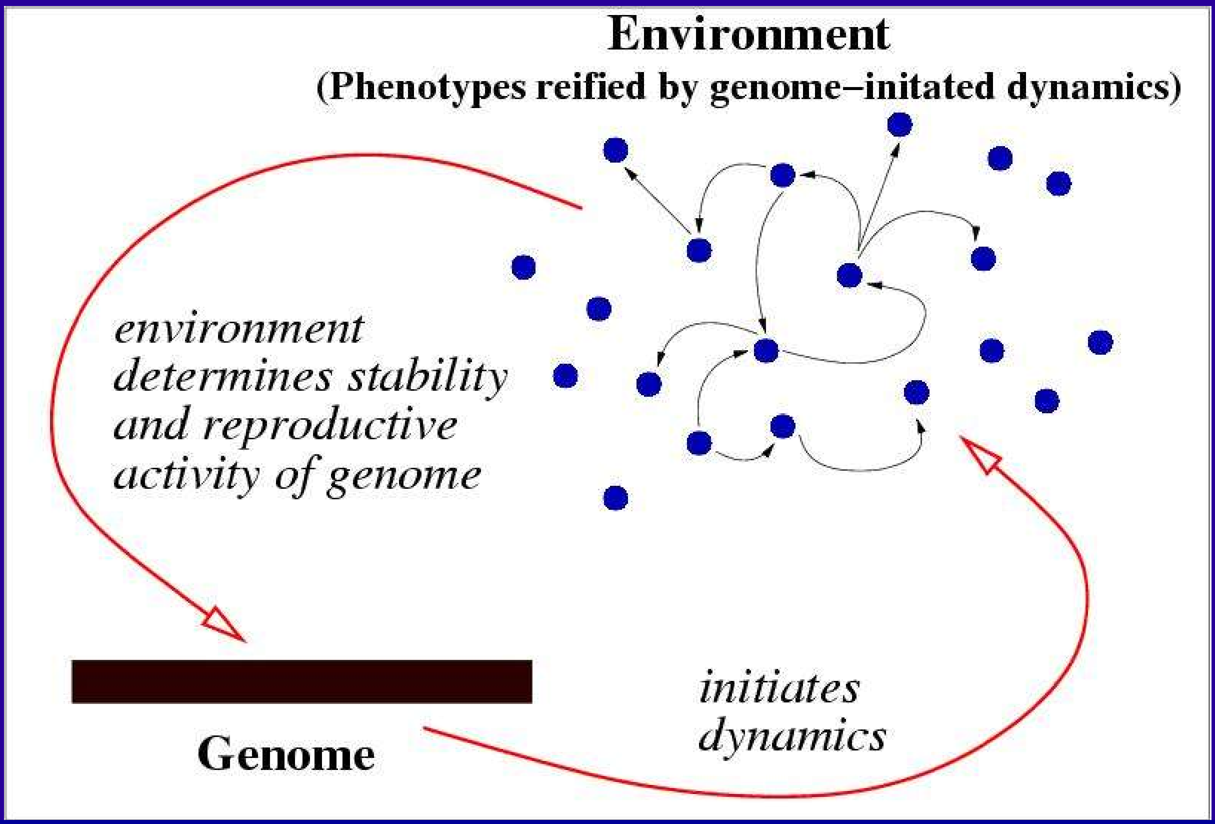
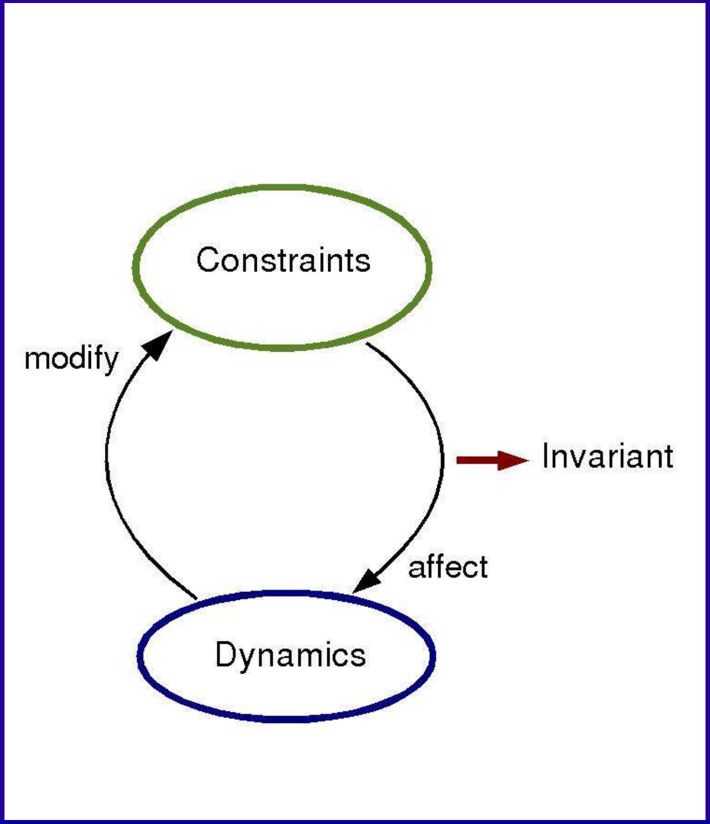
Pattee's definition of symbols

"Writing symbols is a time-dependent dynamic activity that leaves time-independent structure or record…Symbols are read when these structures re-enter the dynamics of laws as constraints. Any highly evolved formal symbol system may be viewed as a particularly versatile collection of initial conditions or constraints, often stored in a memory, producing significant or functional behavior that is usefully described by locally selected rules rather than physical laws…[A]ll symbol systems must have material embodiments that obey physical laws. But for the reasons just stated, the lawful description of symbols, even though correct in all details, can reveal no significance."

[H. H. Pattee, "Evolving Self-Reference: Matter, symbols and semantic closure" *Communications and Cognition – Artificial Intelligence*, 12(1-2):9-28, 1995]

Semantic closure & historical systems





A cybernetic view: Ashby

"We can thus trace, from a perfectly natural origin, the gene-patterns that today inhabit the earth; we are not surprised that the earth has developed forms that show, in conjunction with their environments, the most remarkable power of being resistant to the change-inducing actions of the world around them. They are resistant, not in the static and uninteresting way that a piece of granite, or a run-down clock, is resistant, but in the dynamic and much more interesting way of forming intricate dynamic systems around themselves (their so-called 'bodies', with extensions such as nests and tools) so that the whole is homeostatic and self-preserving by active *defences"*

[W. Ross Ashby, *Design for a Brain,1952*]