Evolving Interaction in Artificial Systems

An Historical Overview and Future Directions

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Talk Outline

- Previous attempts to engineer systems that exhibit open-ended evolution
  - A selective overview
  - Including work in software, hardware and wetware
  - The role of interaction
- What can we learn from these studies?
  - The interface between organism and environment
  - Evolving new forms of interaction

Open-Ended Evolution

Neo-Darwinism asserts that adaptations in organisms can be explained by the processes of:

- Reproduction
- Variation
- Natural Selection

There have been many attempts to create artificial systems which embody these processes

- The goal is to create an open-ended evolutionary process, where the complexity of organisms, interactions and ecologies increases over time

Nils Aall Barricelli

- The first person (to my knowledge) to run evolutionary experiments on computers
  - Barricelli was an Italian-Norwegian mathematician with a strong interest in evolution and symbiogenesis
  - Worked at Institute of Advanced Studies (IAS) in Princeton, New Jersey, over the period 1953-1956
- Created a very simple model to capture the properties of self-reproduction and mutation
  - Basically a one-dimensional cellular automata

Self-Reproduction & Mutation

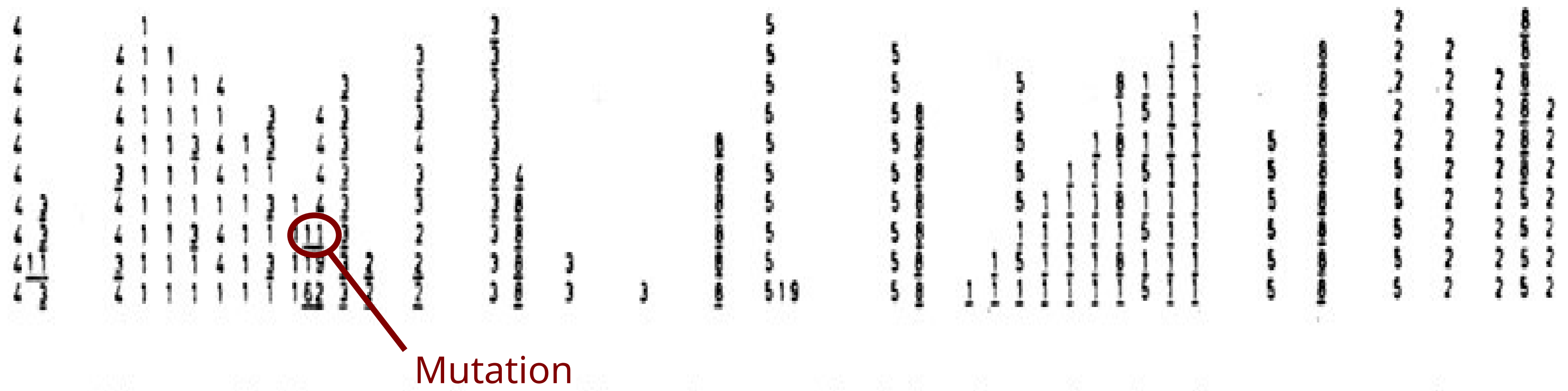


Fig. 1. Selfreproducing numbers (see text). Adaptive selection but no extensive evolution phenomena are possible.

“The numbers which have the greatest survival value in the environment created in Figure 1 by the rules stated above, will survive. The other numbers will be eliminated little by little. A process of adaptation to the environmental conditions, that is, a process of Darwinian evolution, will take place.”

An initial observation

"This example of Darwinian evolution clearly shows that something more is needed to understand the formation of organs and properties with a complexity comparable to those of living organisms. No matter how many mutations occur, the numbers in Figure 1 will never become anything more complex than plain numbers."

[Barricelli, 1962]

Adding Interactions

- Barricelli believed the model could be improved by adding interactions between elements
- Specifically, he added a rule for symbiosis
  - Numbers no longer reproduce automatically to the same position in the next line
  - Instead, reproduction only occurs if there is a number in the same position of the previous line
- The results were dramatic…

Reproduction requiring symbiosis

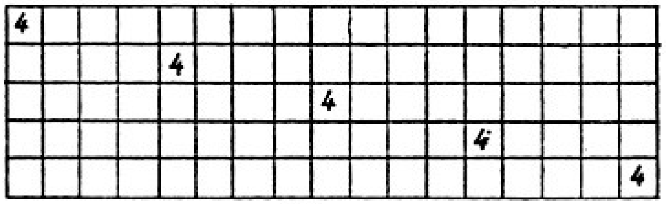


Fig. 2.

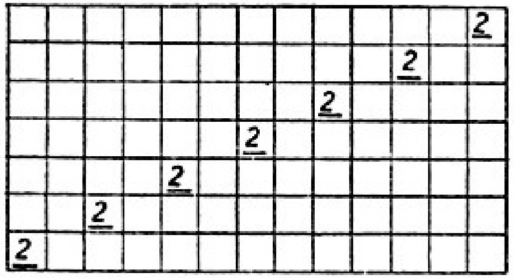


Fig. 3.

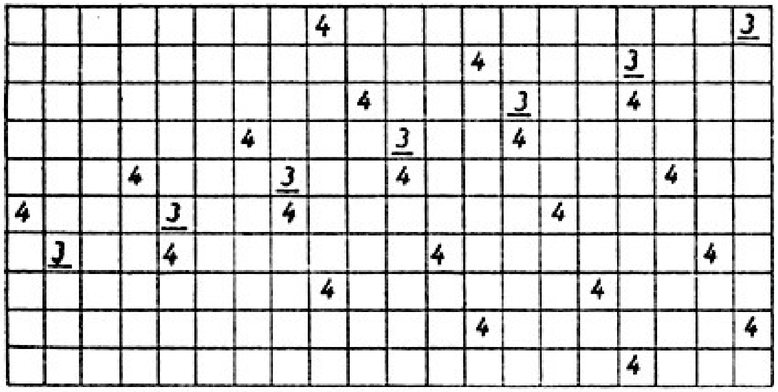


Fig. 4.

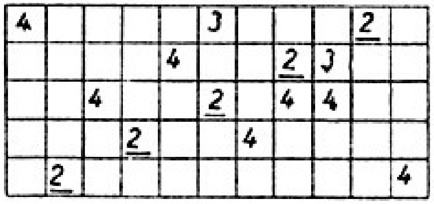
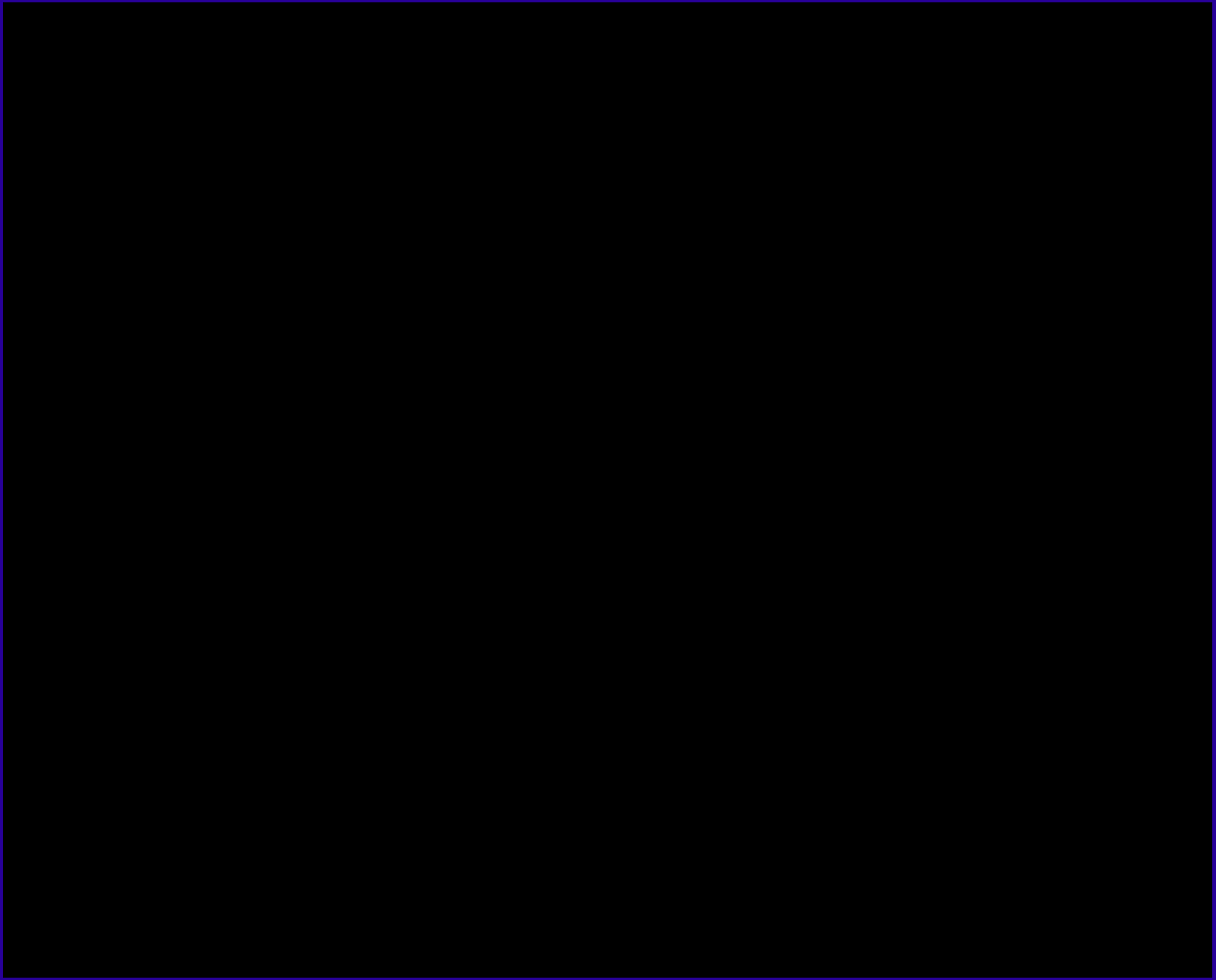


Fig. 5.

Fig. 2, 3, 4, 5. Reproduction rules requiring symbiosis (see text).

Formation of a symbioorganism



Spontaneous Formation & Evolution

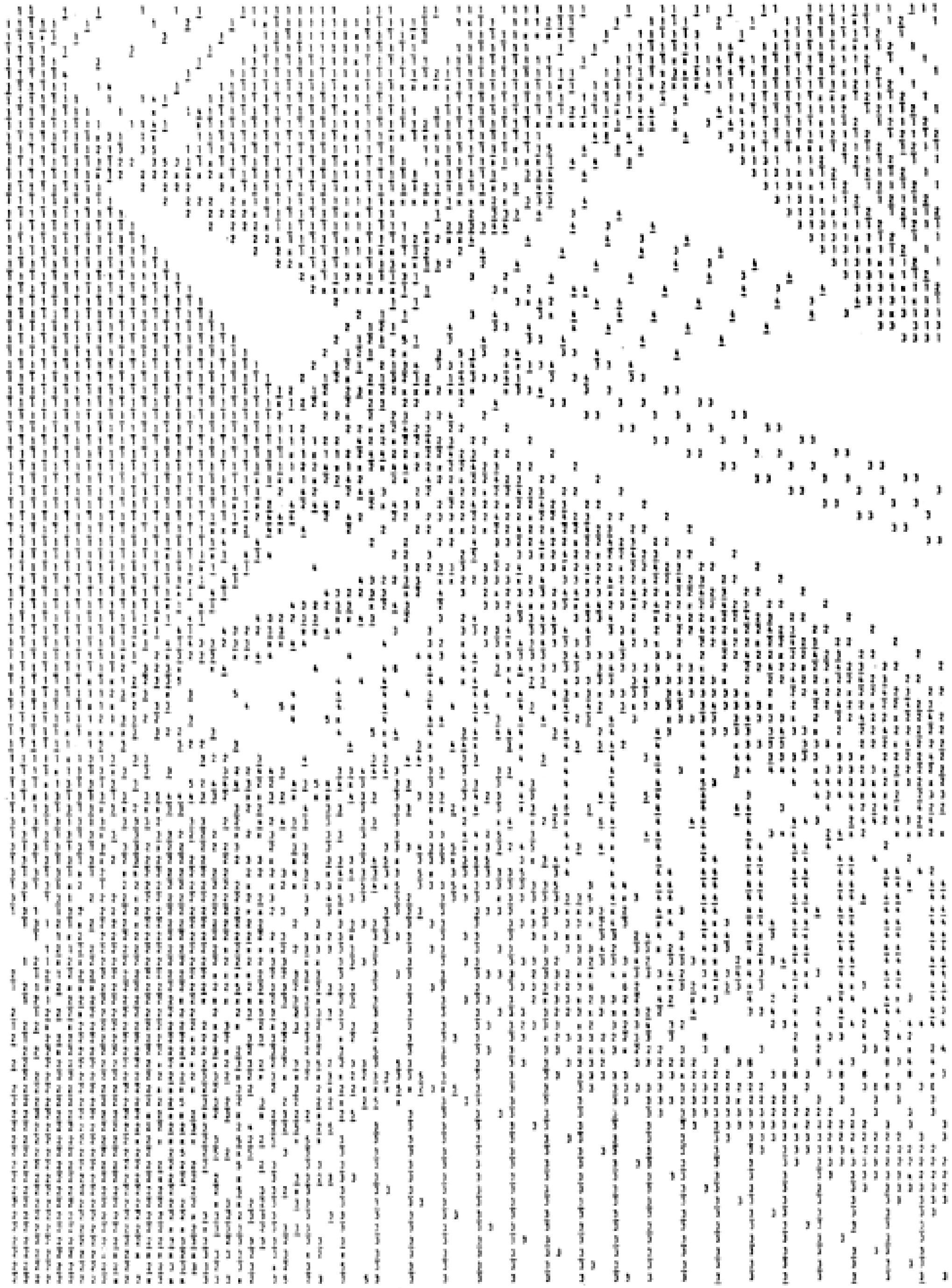


Fig. 15. Spontaneous formation of symbioorganisms in an experiment started with random numbers

Other results

Barricelli reported that the following properties were commonly found in the symbioorganisms:

- Self-reproduction
- Crossing
- Great variability
- Mutation
- Spontaneous formation
- Parasitism
- Repairing mechanism
- Evolution (if steps taken to avoid homogeneity)

Evolution of RNA in vitro

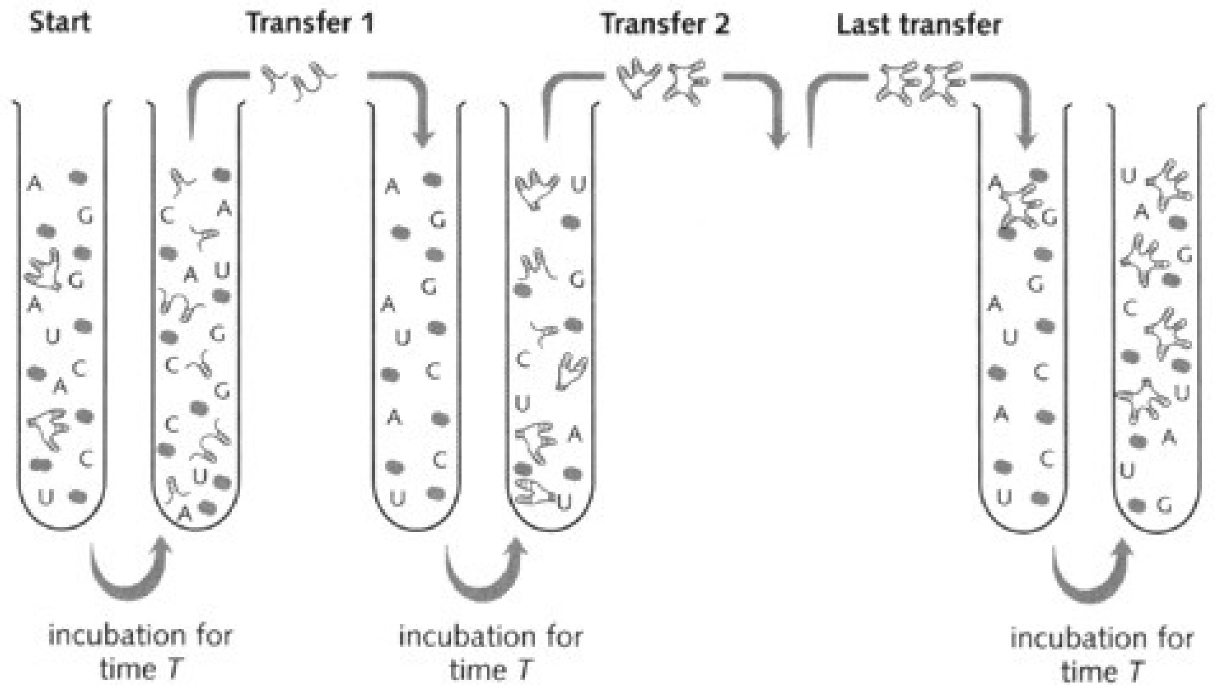


Figure 3.1 Evolution in a test-tube. The initial tube contains the four nucleotides from which RNA is synthesized, a replicase enzyme that copies RNA, and a 'primer' RNA molecule. This primer molecule is copied many times, with some errors. After incubation for time *T*, a drop of solution is transferred 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

(N.B. No translation)

Comment

“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.

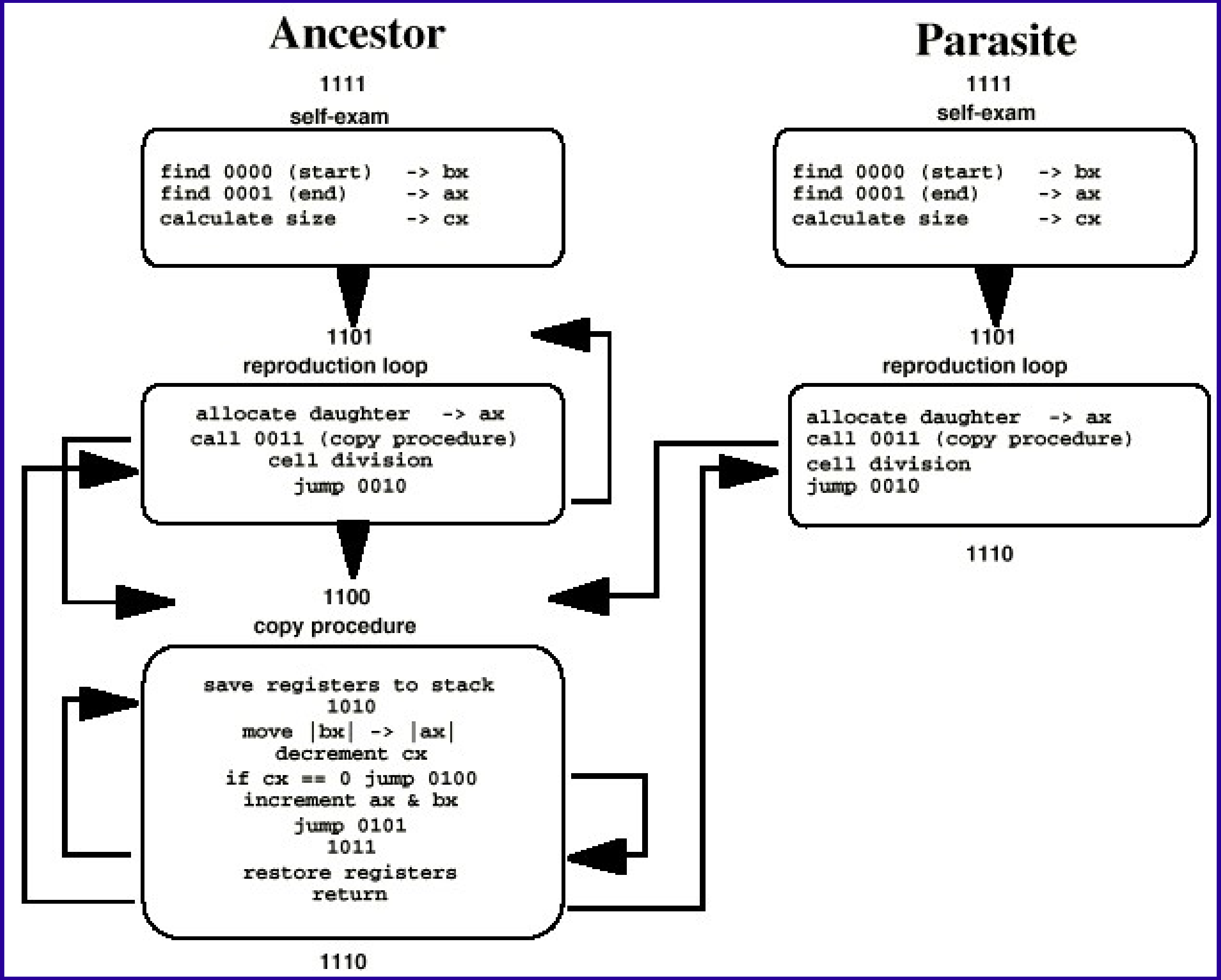
In this simple and well-defined system, natural selection does not lead to continuing change, still less to anything that could be recognized as an increase in complexity: it leads to a stable and rather simple end point.

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]

Tom Ray – Tierra

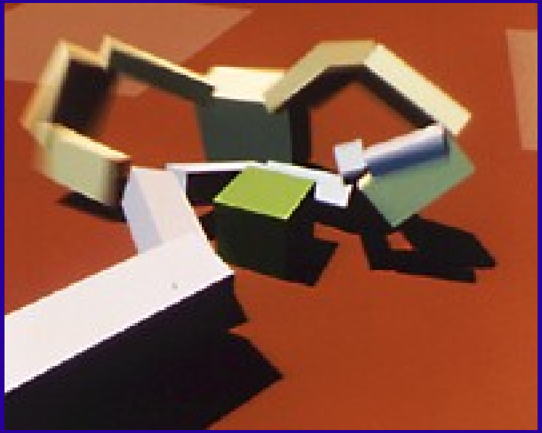
- Self-reproducing computer programs
- Parasites and related phenomena were observed to evolve
- Programs also evolved to reproduce faster
- But not much else happened…

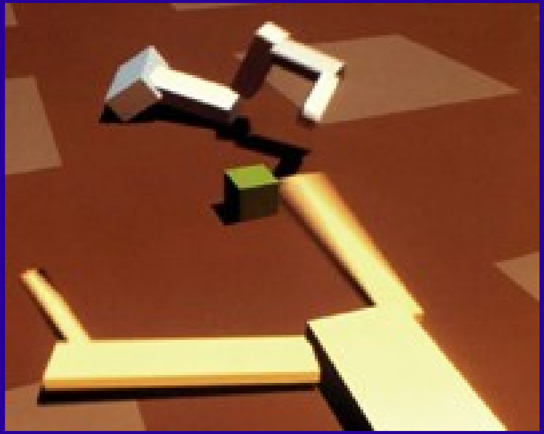


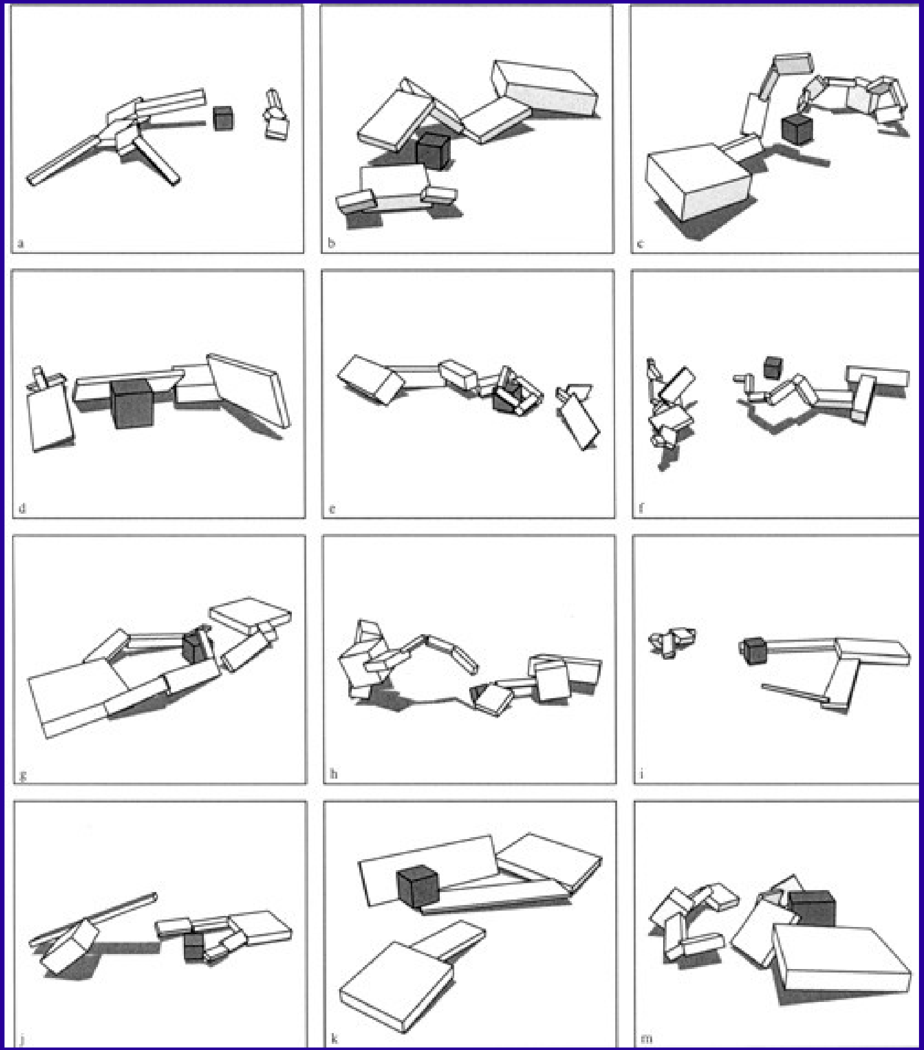
Karl Sims – 3D Creatures

Evolved morphology and behaviour of 3D virtual creatures in a physically realistic environment

Most impressive results involved co-evolution of creatures competing in games

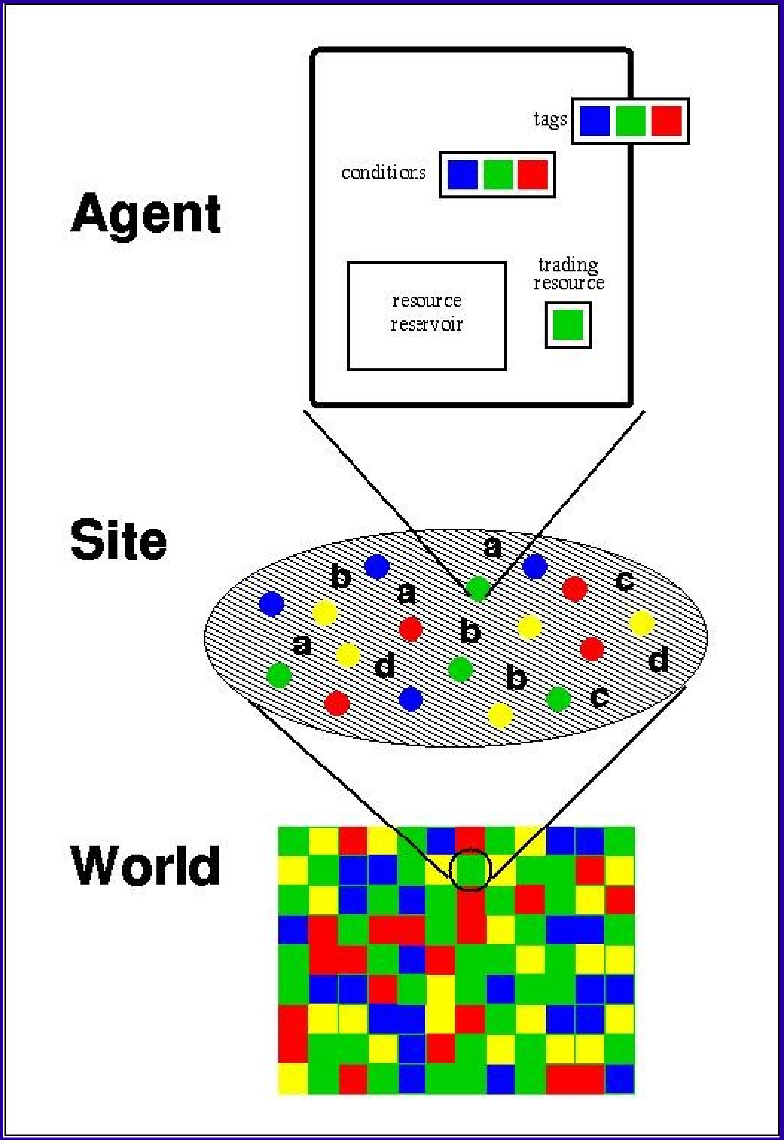






John Holland – Echo

- Specifically designed to model complex adaptive systems (CASs) involving combat, trade of resources and mating
- Has been used to model a variety of real-world systems
- But the set of possible interactions is not evolvable
- Smith & Bedau conclude that its dynamics as a CAS are limited, possibly because of this



Bird & Layzell – Evolved Radio

- Intrinsic evolution of electronic circuits in hardware
- Tried to evolve oscillator circuits of precise frequencies
- Succeeded, but circuits were hard to analyse
- It turned out that they often used electromagnetic information channels from external environment
  - Some evolved a radio antenna to amplify radio signals present in air (being emitted by nearby PCs)
  - Others used other signals such as the voltage supply to a nearby soldering iron

Evolution in Hardware

Gordon Pask had, in 1958, similarly evolved a physical (electrochemical) device that responded to external stimuli (e.g. Sound of a particular frequency)

Features shared by Pask's and Bird & Layzell's work:

- They are situated in the physical world
- Consist of primitives with no fixed functional roles
- Primitives are sensitive to a wide range of environmental stimuli

Lessons from previous work

- Evolutionary processes are very dull with no interaction between organisms
  - e.g. Barricelli's first expts, RNA evolution in vitro
- Addition of interactions greatly increases complexity of evolved dynamics
  - e.g. Barricelli's expts with symbiosis, Sims' creatures
- But still hard to evolve interactions based upon new information channels
  - The exceptions being the work of Pask and Bird & Layzell. These were both physically-situated

Open-Ended Evolution revisited

- How to design systems in which indefinitely many new types of interaction can evolve?
  - Organism-environment interactions
    - cf. Pask, Bird & Layzell
  - Organism-organism interactions
    - cf. Sims, co-evolution, Waddington's paradigm
- The distinction between these is artificial
  - Both involve the way in which an organism responds to environmental perturbations
- The fundamental issue is the nature of the interface between organism and environment

Organism-Environment Interface

In most software systems, interface is hard-coded and cannot evolve. The same is true for experiments of in vitro evolution of RNA molecules

Bird & Layzell argue that novel sensors and interactions can only evolve in systems situated in the physical world

I argue that it is possible to study these issues, to a degree, in software systems, but only if the nature of the relationship between organism and environment is reconsidered...

Future Directions for Open-Ended Evolution in Software

- Focus on modelling environment, not organisms
- No predefined phenotypes; genotypes represent constraints that initiate environmental dynamics
  - cf. Pattee
- In this way, organisms can evolve to utilise any dynamics available in the environment
- We can therefore study evolution of sensors, actions and communication, up to a limit defined by the complexity of the given environment
  - But this can be very large (e.g. Emergent dynamics in cellular automata)