Theoretical Biology Working Group

Second Meeting

- Field observations (of what's in the box)
  - Mounds seem to either move very slowly or shift position by constantly reforming nearby
  - Some suggestion that mounds move more rapidly in vicinity of our outposts
  - Some suggestion that average density of mounds is increasing near our outposts

Is It Alive?

Lecture 2 I400/I590
Artificial Life as an approach to Artificial Intelligence

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What is Life?

- We need an answer, if our biological sciences are going to help us understand alien or artificial life.
- Conversely, an opportunity to study and understand artificial life will help us answer this question and broaden and generalize our biological sciences.
- Farmer & Belin - "If we ever make contact with life from other planets, will our science of biology help us understand it?"

Early Scientific Perspectives

- Schrödinger speaks of life being characterized by and feeding on "negative entropy" (*What Is Life?*, 1944)
- Von Neumann describes brain activity in terms of information flow (*The Computer and the Brain*, Silliman Lectures, 1958)

Early Scientific Perspectives

- Monod (*Chance and Necessity*, 1971)
  - Teleonomy — a structural and behavioral purpose having evolutionary value; form and function that are due to evolutionary fitness (as opposed to design)
  - Autonomous morphogenesis — form and function are derived from an internal self-description; phenotype derives from (and is different from) genotype
  - Reproductive invariance of information — form and function are carried from one generation to the next

Farmer & Belin's Criteria of Life

1. *Life is a pattern in spacetime*, rather than a material object. For example, most of our cells are replaced many times during our lifetime. It is the pattern and set of relationships that are important, rather than the specific identity of the atoms.
2. *Self-reproduction*, if not in the organism itself, at least in some related organism. (Mules are alive, but cannot reproduce. Viruses can only reproduce with the aid of a host.)

Farmer & Belin's Criteria of Life

3. *Information storage of a self-representation*. For example, contemporary natural organisms store a description of themselves in DNA molecules, which is interpreted in the context of the protein/RNA machinery.
4. *A metabolism* which converts matter and energy from the environment into the pattern and activities of the organism. Note that some organisms, such as viruses, do not have a metabolism of their own, but make use of the metabolisms of other organisms.

Farmer & Belin's Criteria of Life

5. *Functional interactions with the environment.* A living organism can respond to or anticipate changes in its environment. Organisms create and control their own local (internal) environments.
6. *Interdependence of parts.* The components of living systems depend on one another to preserve the identity of the organism. One manifestation of this is the ability to die. If we break a rock in two, we are left with two smaller rocks; if we break an organism in two, we often kill it.

Farmer & Belin's Criteria of Life

7. *Stability under perturbations* and insensitivity to small changes, allowing the organism to preserve its form and continue to function in a noisy environment, or after being subjected to minor damage.
8. *The ability to evolve.* This is not a property of an individual organism, but rather of its lineage. Indeed, the existence of a lineage is an important feature of living systems.

But what about…?

- Mule? — cannot self-reproduce; cannot evolve
- Virus? — cannot self-reproduce; does not have a metabolism
  - Tobacco mosaic virus can be decomposed into its proteins, the proteins separated and stored separately, but when combined they will self-organize into the fully functional, "living" virus
- Prion? — like a virus; no self-representation but itself (phenotype == genotype)
  - Blurs the distinction between living and non-living
  - Reveals the mechanistic nature of life
    - no nucleic acids, just an oddly shaped protein
    - corrupts production of a normal protein to reproduce

But what about?

- Intelligent robot? — may not be able to reproduce; may not have a complete self-representation; may not be able to evolve, yet…
  - Say it shared your tastes in science fiction, but preferred jazz to your musical preference for rock…
  - Say it agreed with you that the first Matrix film was great, but definitely preferred the second one…
  - Say it understood the concepts of *noblesse oblige*, of the *gentleman farmer*, of *belaboring the obvious*…
- Could you consider it as anything but alive?

Farmer & Belin Acknowledgement

- "This list is far from adequate—an illustration of the poverty of our understanding. We hope that as the field of artificial life develops, one of its accomplishments will be to give a sharper definition of what it means to be alive."

Farmer & Belin Insight

- "It is not clear that life should be an either/or property."
- "It seems more appropriate to consider life as a continuum property of organizational patterns, with some more or less alive than others."

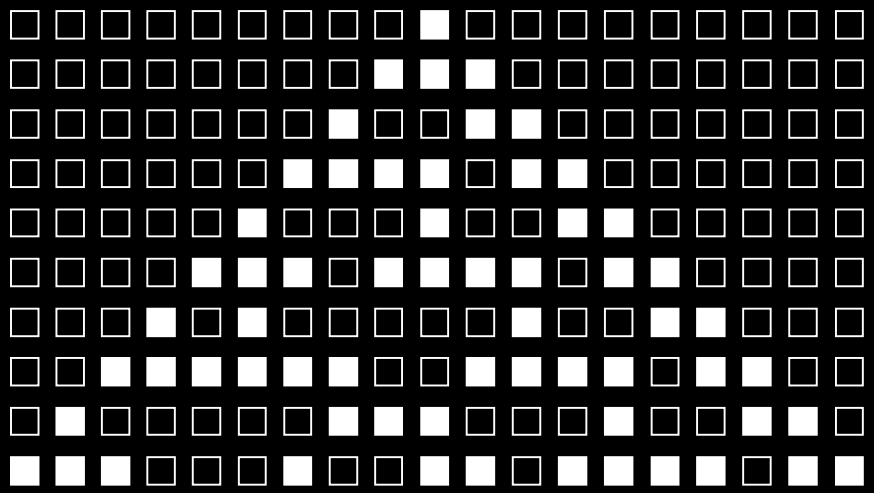
Why Artificial Life? (Again)

- "The act of construction is instructive about the nature of function."
  - Indeed, it is a fundamental educational tenet that construction of a thing is one of the best ways to learn about it.
- It provides a "broader palette", making it possible to "separate the universal from the parochial aspects of life".
- Constructed life forms, particularly those in the computer, are much easier to dissect and study.

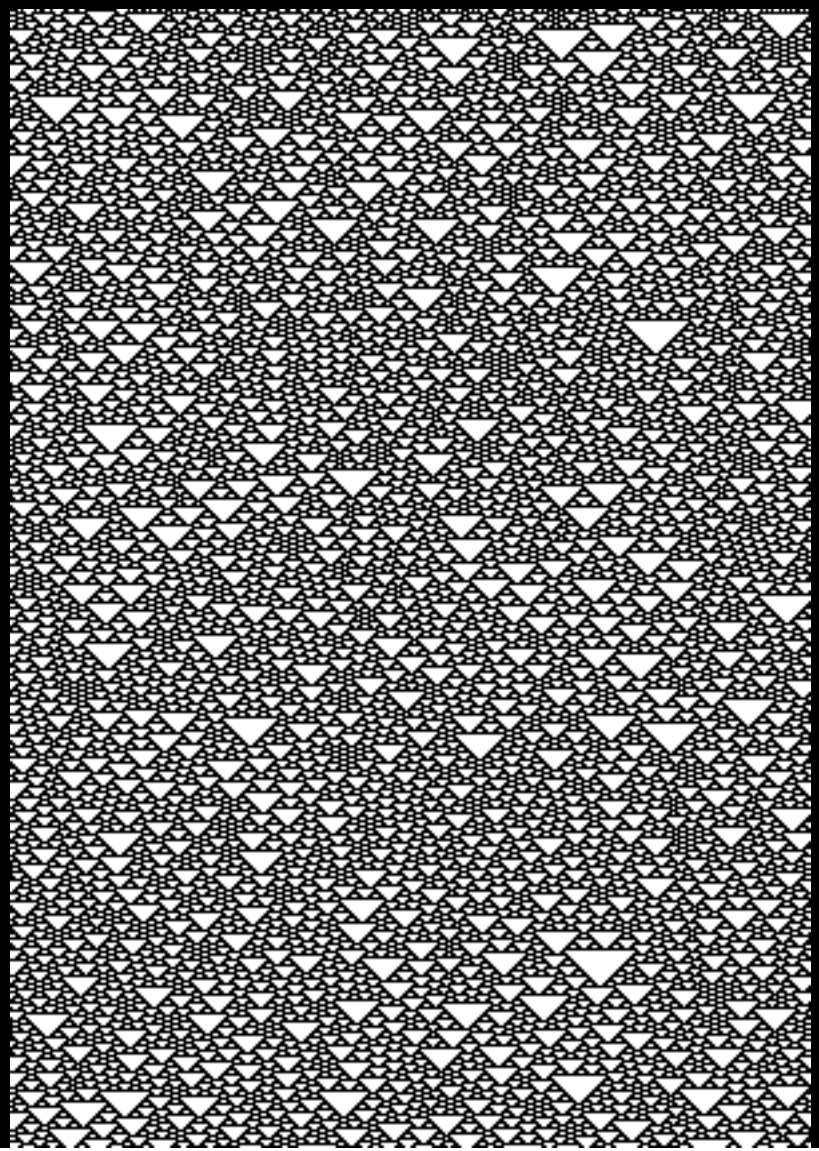
Primitive Artificial Life

- Cellular Automata

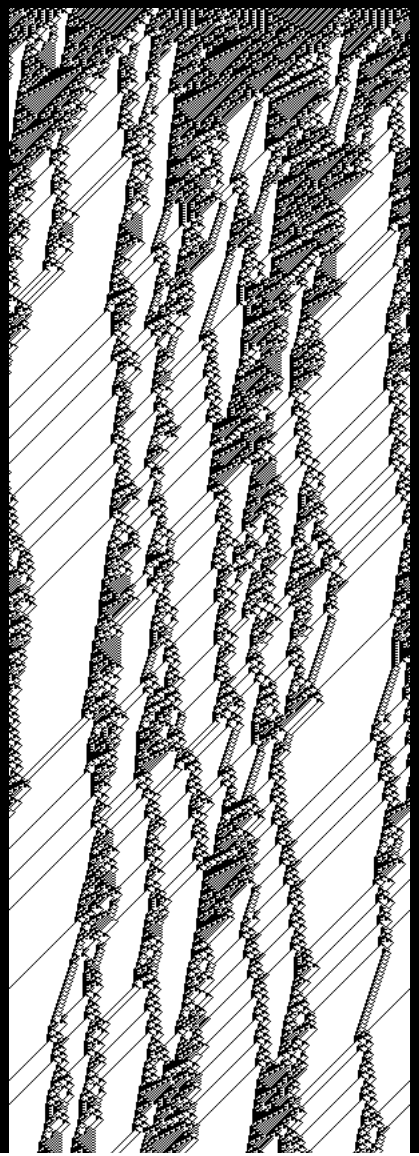
■ White = On
□ Black = Off

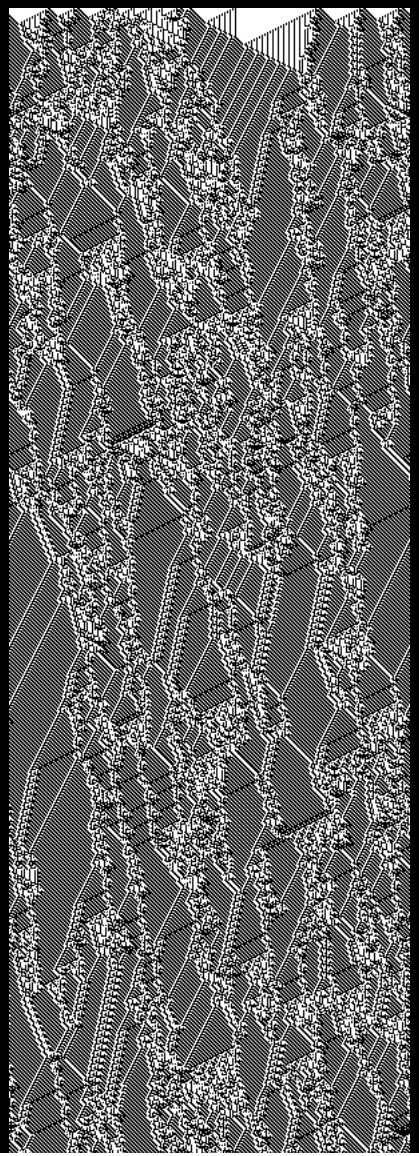


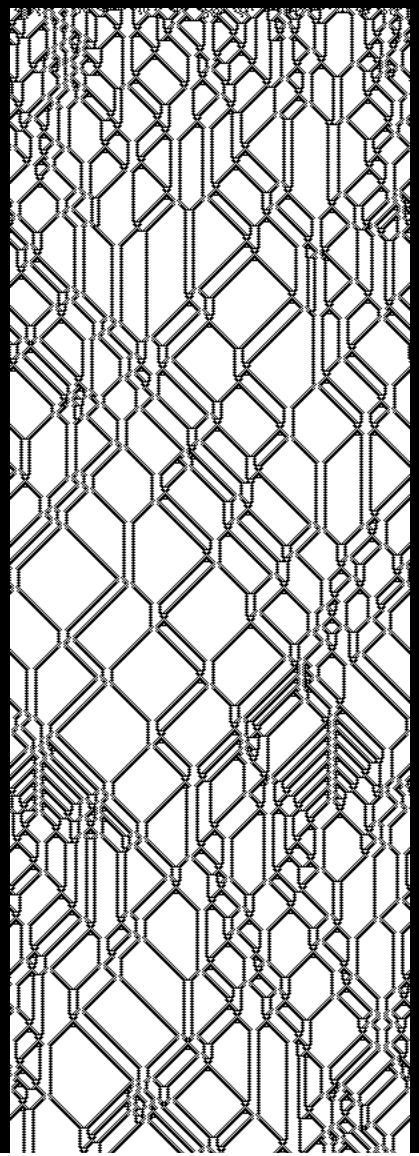
Complexity from Simplicity



More Complex CA

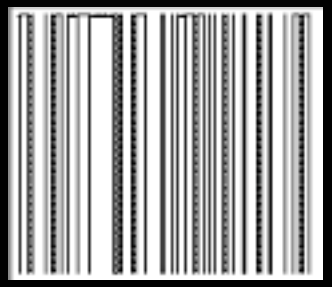




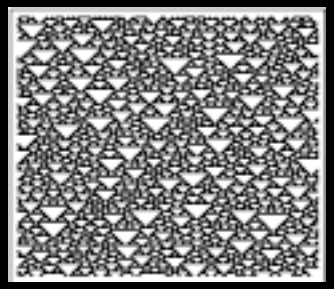


Classifying Complexity in CA (Wolfram)

Class I — Iterates to a fixed, constant state; each cell adopts a value that ceases to change



Class II — Forms a periodic structure; cells cycle through a fixed sequence of states

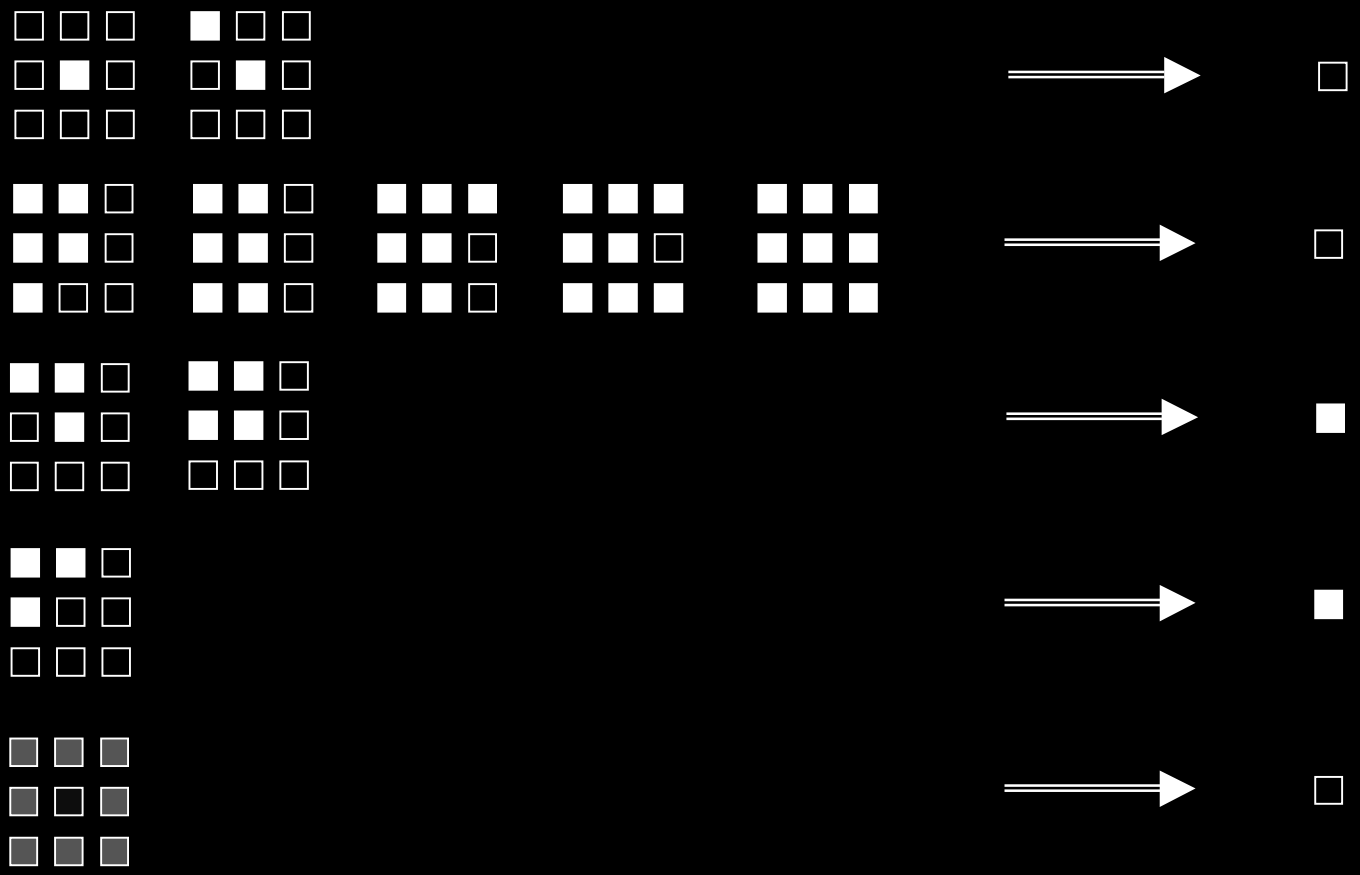


Class III — Forms a chaotic (random-like) pattern; cells chaotically flip states

Class IV — Forms complex, persistent patterns, with localized structures that "migrate"; cell states seem to alternate amongst other classes

Conway's Game of Life

- 2-D Cellular Automata



Arbitrary Complexity

- "Glider guns" and "gliders" can transmit information like electrical wires
- CA, in general, and Conway's Game of Life, in particular, have been proven to be capable of "universal computation"
- CA has been constructed capable of computing all prime numbers

Self-reproducing CA

- John von Neumann worked on self-reproducing CA until his death, and, as completed by Arthur Burks in 1949, achieved this with a CA that had 29 states in a large CA lattice
- Chris Langton, in 1984, devised a self-reproducing "Loops" CA with just 7 states on a 15x10 lattice (which has since been simplified further) LangtonLoops Applet
- So far, however, all such self-reproducing CA tend to be crystalline in their uniformity and brittle with respect to any variation that might support natural selection

"Wet" Artificial Life

- Plant breeding, animal husbandry, and pet domestication have already created a plethora of artificial (man-made) organisms
- Genetic engineering is already used to create more radical variations on existing life forms, and is likely to be applied to humankind some day
- Urey & Miller, Miller & Orgel, and Fox "primordial soup" experiments have yielded amino acids and "protenoid" spheres
- "Test tube evolution" is used to amplify desired behaviors of enzymes, drugs, RNA (Gerald Joyce)
- Early ALife pioneers—Norm Packard, Steen Rasmussen, Mark Bedau—have formed ProtoLife organization, to re-evolve organic matter from inorganic matter
- Craig Venter (Celera, sequencer of human genome) claims to have created (and is attempting to patent) a "minimal bacterial genome" that he deems artificial life
- MIT, Harvard, and UCSF have formed a non-profit BioBricks Foundation to foster development and application of BioBrick fundamental building blocks of "synthetic biology"

Evolution and Self-Organization

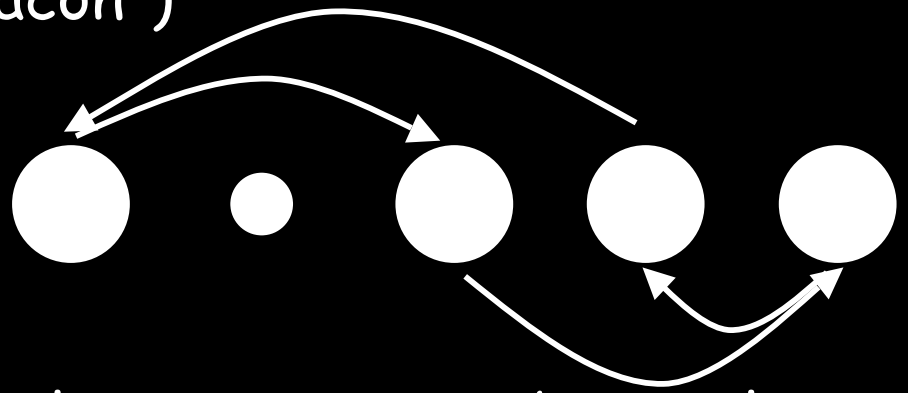
- Herbert Spencer in *First Principles* (1862) put forward the idea that biological evolution is a special case of the universe's tendency to self-organize
- According to Spencer, this kind of evolution:
  - Gives rise to increasing differentiation of parts
  - Increasing integration of these parts
  - Underlies the spontaneous formation of all structure, including matter, stars, geological formations, biological species, and social groups
  - Is the antagonist of dissolution (entropy)
- Note that this is 100% consistent with the tautological form of evolution, and with the idea that life is profoundly negentropic (positive information)

Lamarckian vs. Darwinian Evolution

- In Darwinian evolution, the only information passed between generations is genetic information
- Lamarck proposed a theory of evolution in which information learned during an organism's lifetime was also passed from one generation to the next
- Biological evolution has proven to be strictly Darwinian
- However, ALife simulations by David Ackley and Michael Littman have demonstrated that Lamarckian evolution "blows the doors off of" Darwinian evolution
- Communication and cultural institutions permit a Lamarckian transfer of learning between generations

Accelerating Evolution

- Autocatalytic sets probably preceded self-reproduction
  - Think "six degrees of separation" (or "six degrees of Kevin Bacon")



  - Autocatalysis appears to be an almost unavoidable consequence of the connectivity properties of random directed graphs (Stuart Kauffman, 1986)
  - Probability of closure becomes a "percolation problem" on such reaction graphs

Accelerating *Evolution*

- With self-reproduction, it became possible to more directly transmit past information to the future
  - This is what produced the explosion of life we see around us
- With communication, particularly language and its ability to transmit cultural information, greater quantities and more immediate information could be passed on, ala Lamarck
  - This is what fueled the rapid expansion of societies and technologies that we live in today
  - Without further genetic evolution, however, brain capacities place a limit on this benefit

Accelerating ……Evolution

- Genetic engineering allows Lamarckian evolution to act directly on biological organisms
- Artificial Life will allow Lamarckian evolution to act directly on artificial organisms
- Farmer & Belin speculate that these innovations will produce as great an acceleration of evolution as did culture and self-reproduction

- So, hold onto your hats…!

Credits

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