Cellular Automata in Biology

One-dimensional CA, rule 110
Lambda Parameter
Two-dimensional and mobile CA
Natural CA-like Phenomena
Alife Mutants

1D Cellular Automata

- Cellular Automata (CA) – a type of computing machine
- The formalism for CA was invented by Jon von Neumann in the 1940s.
- Linear grid extends to the left and right. The grid consists of the cells that may be in only one of a finite number of states. At each time step, the next state of a cell is computed as a function of its neighbors local in space.
  - A graphical representation of the rule 254 for one-dimensional CA
  - Evolution a cellular automaton
    - (10 steps)

The World of 256 Simple Programs

- Each array was started with a single "on" cell in the middle
- The top line in each block is a random initial array of 1's (white) and 0's (black)

Wolfram’s CA Classification (1980)

- The behavior of all CA falls into one of only four classes:
  1. Evolution leads to a homogeneous state
  2. Evolution leads to a set of separated simple stable or periodic structures
  3. Evolution leads to a chaotic pattern
  4. Evolution leads to complex localized structures, sometimes long-lived (i.e. gliders)
Rule 110 has recently gained attention as a result of a book written by Stephen Wolfram, known as the author of the software program Mathematica. The book, called *A New Kind of Science*, suggests that both space and time can be modeled by cellular automata such that a relatively simple set of rules governing the content of a cell might lead to the actual complexity that we experience in the physical world. A cell in this case would be a discrete unit of space, itself spread in various states along a time axis, with rules governing its transition from one state to another based on the properties of neighboring cells.

*Like Wolfram, Langton ran thousands of CA simulations and cataloged the rules that yielded the types of dynamics.*

\[ \lambda = \frac{N(n_1)}{N}, \]

- \( \lambda \) – fraction of rules that map to the quiescent state
- \( N \) – total number of entries in the rule table
- \( n_1 \) – number of rules that map to the quiescent state

\( \lambda \approx (0.0, 0.3, 0.228, 0.439, 0.816, 0.502) \) are average values of \( \lambda \) for different classes.

\( \lambda \approx 0.502 \) – only here can information be stable enough to support a message and loose enough to transmit messages. Life lives there!
2D Cellular Automata

John Conway’s Game of Life. In 1960, Conway was motivated to extend von Neumann’s work:
- If a live cell has less than two neighbors, then it dies (loneliness)
- If a live cell has more than three neighbors, then it dies (overcrowding)
- If an empty cell has three live neighbors, then it comes to life (reproduction)
- Otherwise (exactly two live neighbors), a cell stays as is (stasis)

Chris Langton’s Self-Reproducing Loop (1979)

Mobile Cellular Automata

Vants – virtual ants (Langton) – the simplest and most persuasive examples of emergence of high-level structures from low-level dynamics:
- Vants live on a 2D Euclidean lattice and come in two flavors, red and blue
- Each vant can move in any of four directions. Each lattice site is either empty or contains one of two types of food, green or yellow
- How a vant moves through the lattice depends on its color...

Agent based StarLogo programming – decentralization, parallel execution

Natural CA-like Phenomena

- Evolution of CA obtained by successive random mutations
- L-systems (Lindenmeyer, 1968)
- Biomorphs (Richard Dawkins)
- Biological Pigmentation Patterns
- The Algorithmic Beauty of
  - Plants
  - Seaweeds, Sponges and Corals
  - Sea Shells

Principia Evolvica

- Genetic algorithms (GA) are computational models of adaptation based on natural selection (John Holland, 1960)
- Genetic operations: reproduction, crossover, mutation
- CA + GA = evolution
- Christian Jacob – Principia Evolvica, 1997
Artificial Life (AL) is an attempt to understand life as a larger context
- Carlo Comis – DarwinBots http://digilander.libero.it/darwinbots

CA Rule Extraction
Konrad Zuse’s (1967) idea that the simple rules generate both the common structures and the complexity.
Ed Fredkin’s point of view that a mouse, for example, is “a big, complicated informational process”
- Richards, Meyer, Packard (1989) have suggested a way to extract 2D CA rules directly from experimental data
  - They idea is to use a genetic algorithm to search through a space of a certain class of cellular automata rules for a local rule that best reproduces the observed behavior of the data
  - It was applied to pattern of dendrites formed by NH$_3$Br

rule 110, AMHSO, 06-13 march 2004, Bielefeld (Germany)
- Annual meeting to discover the rules that govern life, the universe and everything by computer simulation
- Cellular automaton that is able to perform universal computation
- Mutants of all species, recombine!

Key Topics
- artificial societies
- evolution and development
- growth and form
- dynamic systems
- networks and small worlds
- origins of life
- swarm intelligence
- selfassembly
- selforganisation and selfreplication
Alife Mutants