Cellular Automata - So Far

elementary cellular automaton

- 1D array of cells
- 2 states
- update based on state of cell and immediate neighbors
- 8 possible updates
- 2^8 possible rules

behavioral classes of cellular automata

- class 1: quick evolution to homogeneous state, information is destroyed quickly
- class 2: reaches stable state quickly, information may be preserved, local changes remain local
- class 3: pseudo-random or chaotic evolution, information destroyed, local changes spread
- class 4: complex patterns evolve, structures may survive a long time

Rule 110

- elementary cellular automaton
- capable of universal computation

Conway's Game of Life

- totalistic rules (depends only on number of neighbors)
- capable of self-replication
- capable of universal computation
- rule: B3/S23 (birth: 3, survival: 2,3 neighbors)

Social Science Models

- gossip model - spreading of information, disease
- majority model - social conformance
- Schelling model - segregation

Physics / Chemistry Models

- Greenberg-Hastings model - reaction diffusion (more later)

More on Cellular Automata

Today

- Hashlife
- cellular automata and convolutions
- FFT Life
- LargerThanLife
- RealLife
- SmoothLife
- PDEs vs Cellular Automata

Today

- WireWorld
- Langton's Ant
- Langton's Loops, Evoloops
- Lattice Gases

Kinds of Cellular Automata

totalistic:

- next generation depends only on total number of neighbors

stochastic:

- finite state $\rightarrow$ Markov chains, locally interacting markov chains
- discrete state, stochastic state transitions

asynchronous:

- updates in regular cellular automata are all parallel, synchronous
- asynchronous updates tend to destroy structure
- http://en.wikipedia.org/wiki/Asynchronous_cellular_automaton
- synchronous behavior can be achieved by extending the cellular automaton

Implementations of Life

Hashlife

- efficient way of computing large scale, long-term evolution
- http://en.wikipedia.org/wiki/Hashlife
- http://www.drdobbs.com/jvm/an-algorithm-for-compressing-space-and-t/184406478
- decompose grid in a quad-tree like structure
- compute hash codes for nodes
- compute long term evolution for nodes and store it
- (demo)

Life Generalizations

- totalistic cellular automata and filtering
- large area totalistic automata, LargerThanLife, RealLife
- separable filters
- FFT and non-separable, smooth filters
- SmoothLife
- integro-differential equations

PDEs and Cellular Automata

- cellular automata can approximate differential equations
- effectively, simulate numerical solution to PDEs

Reverse:

- differential equations can simulate cellular automata
- Omohundro (1983): construction with C^∞ bump functions
- probably better, more natural constructions possible

Other Cellular Automata

WireWorld

- simple cellular automaton capable of universal computation
- rules divide the world into fixed “wires” and “insulators”
- wire is in one of three states: empty, electron head, electron tail
- rules are sufficient to build: clock generators, logic gates
- out of these, entire circuits and processors can be built
- no self-replication because no wires can be added (but can start out with infinite structure)
- can built Langton’s Ant, Turing-complete wireworld computer

Langton's Ant

- simple 2D turing machine
- state: head position, direction
- transition rules:
- at a white square, turn 90^o right, flip color, move forward
- at a black square, turn 90^o left, flip color, move forward
- complex behavior: simple patterns, then chaos, then "highway"
- Gajardo (2000): Langton's ant is computationally universal

Self-Reproducing Loops

- "self-reproduction" was one of the first motivations for cellular automata
- difficult in Conway's game of life (easier in some variants)
- other cellular automata variants make it easier

Langton's Loops

- 8 state cellular automaton
- states represent walls, background, information storage in the loop
- states inside the loop instruct the construction of loop extensions
- specific instructions result in self-replication

Self-Replicating Loops

- original: self-replication
- Byl's loop, Chou-Reggia loop: simpler loops w/o sheaths
- Perrier loop: self-replication plus Turing completeness
- Tempesti loop: self-replicaton plus internal structure
- SDSR loop: self-replication and death
- Evoloop: self-replication and mutation, demonstrates evolution