Cellular Automata
A not very accurate history...

- **1940's: Stanislas Ulam**
  - interested in evolution of graphic construction based on really simple rules
  - e.g. grid of cells, either on or off, if cell in contact with two on cells it switches on otherwise it's off

- **1940s-50s von Neumann**
  - thinking of model for self reproduction in biology
  - After suggestion from Ulam arrived at 2D automata
  - early model emulating components in electronic computer had 29 colours per cell
  - outlined construction of 200,000 cell configuration which could produce itself

- **1970's: CA became famous – Conway's *Game of Life***
  - 2 states / cell and only three rules ...

http://www.wolframscience.com/reference/notes/876b
Some applications

- Simulation of a gas
- Ferromagnetism (Ising model)
- Percolation! (everything we covered before)
- Massive parallel computers
- Urban development
- Graphic generators

Much more interesting →

http://www.rennard.org/alife/english/acintrogb02.html#acapplic
A universe in a grid...

- Can study how complexity arises from very simple rules “emergent complexity”
- c.f. *our universe* – laws of physics are relatively simple for the complexity we see … but we don't know all the rules.
- For CA we know **all** parameters
- Gives insight to stripes of a zebra or petals of a rose (big structures arising from small components interacting locally) …
- Maybe some complex behaviours (e.g. ants) have just a few simple rules we haven't found.

Termites piling wood chips

Start from a random distribution of 'termites' (red) and 'wood chips' (yellow)

If termites
(1) don't "know" where they are,
(2) don't know what direction they're headed,
(3) only know a wood chip by bumping into it.
(4) can pick up a wood chip when they bump into one
(5) can only carrying one wood chip at a time.

Can a piling behaviour “emerge”?

Yes!, with only two rules!

Is complex behaviour really that complex?

http://www.umcs.maine.edu/~larry/microworlds/termites.html
A cellular automaton

- Consists of a grid of cells (any dimension)
- Each cell can have a number of states
- Time occurs in steps (*generations*):
  - Calculate a new value for a cell by applying a few *local* rules
    - $2^9 = 512$
    - e.g. for 2 states and surrounding cells there are already 512 patterns to base rules on
  - rules applied globally
  - each generation is based on the previous generation (not the one being calculated)
- Keep iterating and see what emerges...

http://viswiki.com/en/Cellular_automaton
Rule 110

- 1D cellular automaton
- Rules:

<table>
<thead>
<tr>
<th>Old:</th>
<th>000</th>
<th>001</th>
<th>010</th>
<th>011</th>
<th>100</th>
<th>101</th>
<th>110</th>
<th>111</th>
</tr>
</thead>
<tbody>
<tr>
<td>New (middle):</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
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250 generations later ...

http://mathworld.wolfram.com/Rule110.html
Game of Life

- Best known cellular automaton
- John Conway 1970 ...

2011-January-16

Is Life omniperiodic?

A cellular automaton is said to be omniperiodic if, for every natural number \( n \), there exists an oscillator of period \( n \) ...

To prove Life omniperiodic, we also require oscillators of all periods less than 62...

Oscillators of periods 19, 23, 34, 38, 41, 43, and 53 are yet to be found.


37 period oscillator

Lots of software to explore life .. eg “golly” http://golly.sourceforge.net/
Rules of Life...

(1) dead cell surrounded by three live cells turns on. It's “born”

(2) A live cell surrounded by 2 or 3 live ones remains alive

(3) All other case, cell remains dead or dies through loneliness or overcrowding

% life.m - Conway's Game of Life

% A grid of dead and living cells is made.
% Cells are born to three adjacent parents,
% and die of overcrowding or loneliness.
%      Iain Haslam, December 2005

len=50; GRID=int8(rand(len,len));
up=[2:len 1]; down=[len 1:len-1]; %the world is round
colormap(gray(2));
for i=1:100
    neighbours=GRID(up,:)+GRID(down,:)+GRID(:,up)+GRID(:,down)+...
                GRID(up,up)+GRID(up,down)+GRID(down,up)+GRID(down,down);
    GRID = neighbours==3 | GRID & neighbours==2;
    image(GRID*2); pause(0.2);
end
Emergent objects

Oscillators

e.g. period-2

binker
toad

Glider

+Breeders,
rakes, guns,
puffers ...

Still life

block
beehive
boat
ship
loaf

Honey farm

More life...
Life and computation

- The gliders and spaceships act as wires carrying information
- Collisions can be arranged to simulate logic operations
- Could run any program a modern computer could run (would be very large)

E.g. Four prime-number calculators

--- 1st quadrant (upper right):
Original sieve by Dean Hickerson, 1 November 1991
--- 2nd quadrant (upper left): new sieve #1
Uses every glider relay, p60 instead of p40 LWSS rake.
--- 3rd quadrant (lower left): new sieve #2
Vertical guns replaced with an equivalent reflector.
--- 4th quadrant (lower right): new sieve #3
Contains no glider guns, only pentadecathlon reflectors.

Turing machines

- in a paper in 1936 Turing developed an abstract notion of a programmable computer (a *Turing machine*)

- Turing showed that there is a *universal Turing machine* that can simulate any other Turing machine

- every plausible design for a computing device so far advanced can be emulated by a universal Turing machine

- Systems that can simulate a universal Turing machine are called *Turing complete*

- all modern computers are Turing complete (in a slightly looser way from original formulation, e.g. if they had unlimited storage)
Church-Turing thesis

- Turing claimed that a Universal Turing Machine completely captures what it means to perform an algorithmic task.
- This means if an algorithm can be performed on any piece of hardware then there is an equivalent algorithm for the universal Turing machine.
- NB this doesn't say they are equivalent in speed or efficiency!

[http://en.wikipedia.org/wiki/Turing_complete]
[Nielsen & Chuang, Quantum computation and Quantum Information]
Strong Church-Turing thesis

- The strong Church-Turing thesis states that *any algorithmic process can be simulated efficiently using a Turing machine*.

- This has been challenged by algorithms using randomness as an essential part of the algorithm.

- Could modify it to: *any algorithmic process can be simulated efficiently using a probabilistic Turing machine* …

- Can physics be used?

- **Church–Turing–Deutsch principle:** *a universal computing device can simulate every physical process*.

- Open problem!

http://michaelnielsen.org/blog/?p=71
A Turing machine in life:


http://rendell-attic.org/gol/tm.htm
Rule 110 reloaded

- *Turing complete!"
CA and music...

e.g.

- Automatous Monk
  - http://www.automatous-monk.com/
  - explanation:
- http://jmge.net/camusica.htm
- ...