Non Symbolic AI - Lecture 13

Symbolic AI is often associated with the idea that "*Intelligence is Computation*" and "*The Brain is a Computer*"

Non Symbolic AI is often associated with the idea that *"Intelligence is Adaptive Behaviour"* and *"it arises from the dynamical interactions of networks of simple components"*

Eg **ANNs** (Artificial Neural Networks)

Cellular Automata (and Random Boolean Networks)

These are another class of systems that fit this last description.

In the wide spectrum of approaches to synthesising 'lifelike' behaviour, **CA**s and **RBN**s are amongst the most abstract and mathematical.

A lot of the interest in this comes from people with a Physics background. Cf. Los Alamos, Santa Fe, the 'chaos cabal' .

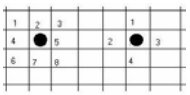
(pop book on the chaos cabal: "The Newtonian Casino" T. Bass 1990 Longmans, (US= "The Eudaemonic Pie" 1985)

The Game of Life

Best known CA is John Horton Conway's "Game of Life". Invented 1970 in Cambridge.

Objective: To make a 'game' as unpredictable as possible with the simplest possible rules.

2-dimensional grid of squares on a (possibly infinite) plane. Each square can be blank (white) or occupied (black).



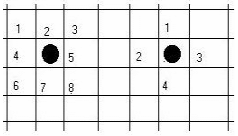
More Game of Life

At any time there are a number of squares with black dots. At the 'regular tick of a clock' all squares are updated simultaneously, according to a few simple rules, depending on the **local situation**.

For the 'Game of Life' **local situation** means, for any one cell, the current values of itself and 8 immediate neighbours ('Moore neighbourhood')

Neighbourhoods

8 immediate neighbours = 'Moore neighbourhood', on L
For different CAs, different neighbourhoods might be chosen; e.g. the 'von Neumann neighbourhood', on R.



Readable pop sci on CAs: William Poundstone "The Recursive Universe" OUP 1985

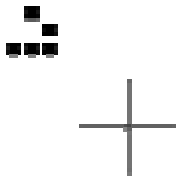
Game of Life: rules

Update rule for each cell:

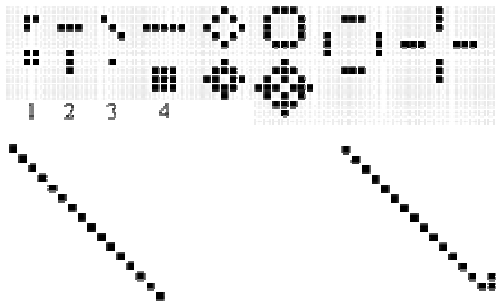
- ✓**If** you have exactly 2 'on' nbrs (ie 2 blacks) stay the same
- ✓**If** you have exactly 3 'on' nbrs you will be 'on' (black) next timestep (ie change to on if you are blank, and remain on if you already are)
- ✓**If** you have less than 2, or more than 3 on nbrs you will be off (blank) next timestep

Thats all !

Glider



Sequences

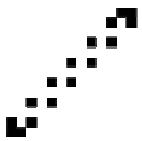


More

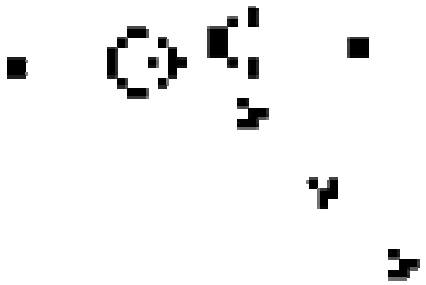
Sequence leading to Blinkers

Clock

Barber's pole



A Glider Gun



More formal definition of CA

- ✓A regular lattice — eg. grid
- ✓of finite automata — eg. cells
- ✓each of which can be in one of a finite number of states — eg. black/white tho could be 10 or 100

- ✓transitions between states are governed by a state-transition table — eg. GoL rules

- ✓input to rule-table = state of cell and specified local neighbourhood (In GoL 2 ^9 = 512 inputs)
- ✓output of rule-table = next state of that cell

CAs

All automata in the lattice (all cells on the grid) obey the same transition table, and are updated simultaneously.

From any starting setup on the lattice, at each timestep everything changes **deterministically** according to the rule-table.

Game of Life: rules (again!)

Update rule for each cell:

- ✓**If** you have exactly 2 'on' nbrs (ie 2 blacks) stay the same
- ✓**If** you have exactly 3 'on' nbrs you will be 'on' (black) next timestep (ie change to on if you are blank, and remain on if you already are)
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Thats all !

Alternative version of rules

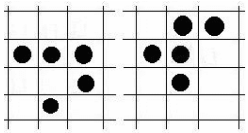
Every cell is updated simultaneously, according to these rules, at each timestep.

Alternative (equivalent) formulation of Game of Life rules:

0,1 nbrs = starve, die 2 nbrs = stay alive
3 nbrs = new birth 4+ nbrs = stifle, die

Gliders and pentominoes

On the left: a **'Glider'**
On a clear background, this shape will 'move' to the NorthEast one cell diagonally after 4 timesteps.



Each cell does not 'move', but the 'pattern of cells' can be seen by an observer as a glider travelling across the background.

Emergence

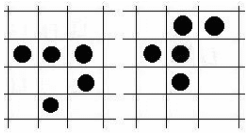
This behaviour can be observed as 'the movement of a glider', even though no glider was mentioned in the rules.

'Emergent' behaviour at a higher level of description, emerging from simple low-level rules.

Emergence = emergence-in-the-eye-of-the-beholder (dangerous word, controversial)

Pentominoes

On the right: a 'pentomino'.
Simple starting state on a blank background => immense complexity, over 1000 steps before it settles.



(Pop Sci) William Poundstone "The Recursive Universe" OUP 1985

(Primordial Soup kitchen) http://psoup.math.wisc.edu/kitchen.html
http://www.math.com/students/wonders/life/life.html
http://www.bitstorm.org/gameoflife/

Game of Life - implications

Typical Artificial Life, or Non-Symbolic AI, computational paradigm:
- ✓bottom-up
- ✓parallel
- ✓locally-determined

Complex behaviour from (... emergent from ...) simple rules.

Gliders, blocks, traffic lights, blinkers, glider-guns, eaters, puffer-trains ...

Game of Life as a Computer ?

Higher-level units in GoL can in principle be assembled into complex 'machines' -- even into a full computer, or Universal Turing Machine.

(Berlekamp, Conway and Guy, "Winning Ways" vol 2, Academic Press New York 1982)

'Computer memory' held as 'bits' denoted by 'blocks' laid out in a row stretching out as a potentially infinite 'tape'. Bits can be turned on/off by well-aimed gliders.

Self-reproducing CAs

von Neumann saw CAs as a good framework for studying the necessary and sufficient conditions for **self-replication of structures.**

von N's approach: self-rep of abstract structures, in the sense that gliders are abstract structures.

His CA had 29 possible states for each cell (compare with Game of Life 2, black and white) and his minimum self-rep structure had some 200,000 cells.

Self-rep and DNA

This was early 1950s, pre-discovery of DNA, but von N's machine had clear analogue of DNA which is **both:**

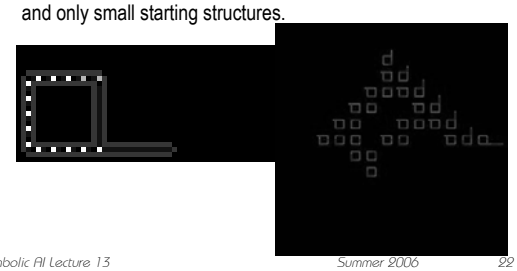
- ✓used to determine pattern of 'body' **interpreted**
- ✓and itself copied directly **copied** without interpretation as a symbol string

Simplest general logical form of reproduction (?)

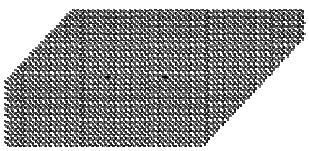
How simple can you get?

Langton's Loops

Chris Langton formulated a much simpler form of self-rep structure - Langton's loops - with only a few different states, and only small starting structures.



Snowflakes



One dimensional CAs

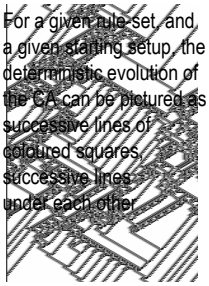
Game of Life is 2-D. Many simpler 1-D CAs have been studied, indeed whole classes of CAs have been.

Eg. a 1-D CA with 5 states (a b c d and - = blank) can have current state of lattice such as

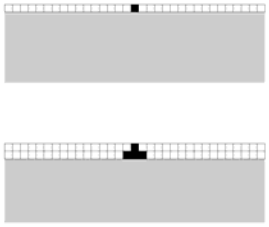
- - - a - b c d c a - - -

or pictorially with coloured squares instead of a b c d Then neighbours of each cell are (typically) one on each side, or 2 on each side, or ... ...

Spacetime picture



For a given rule-set, and a given starting setup, the deterministic evolution of the CA can be pictured as successive lines of coloured squares, successive lines under each other.



DDLab

That coloured spacetime picture was taken from Andy Wuensche's page
www.ddlab.com

DDLab is

Discrete Dynamics Lab

Wuensche's work allows one to run CAs backwards, to see what previous state(s) of the world could (according to the rules) have preceded the present state.

Wolfram's CA classes 1,2

From observation, initially of 1-D CA spacetime patterns, Wolfram noticed 4 different classes of rule-sets. Any particular rule-set falls into one of these:-:

CLASS 1: From any starting setup, pattern converges to all blank -- **fixed attractor**

CLASS 2: From any start, goes to a limit cycle, repeats same sequence of patterns for ever. **-- cyclic attractors**

Wolfram's CA classes 3,4

CLASS 3: From any start, patterns emerge and continue continue without repetition for a very long time (could only be 'forever' in infinite grid)

CLASS 4: Turbulent mess, no patterns to be seen.

Classes 1 and 2 are boring, Class 4 is messy, Class 3 is **'At the Edge of Chaos'** - at the transition between order and chaos -- where Game of Life is!.

Applications of CAs

Modelling physical phenomena, eg diffusion.

Image processing, eg blurring, aliasing, deblurring.

Danny Hillis's Connection Machine based on CAs.

Modelling competition of plants or organisms within some space or environment.

To Finish up -- Hot Research topics

Hot research topics in NSAI and Alife – eg looking ahead to 3rd year u/g project topics

With personal bias and prejudice

- Evolutionary Robotics
- Hardware Evolution
- Molecular Drug Design
- Incremental Artificial Evolution (SAGA)
- Neutral Networks (Neutral with a T)

That last topic …

Quick few slides on Neutral Networks

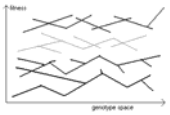
Neutral Networks

Neutral Networks have been much discussed in the context of RNA (including in Alife circles) but they are overdue for appreciation as crucially relevant to all of evolutionary computation

-- and particularly much Alife artificial evolution, just because that is macro-evolution

How do Neutral Nets work ?

If local optima are not points to get stuck on, but ridges of the same fitness percolating through genotype space, then you can escape.



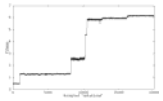
Conditions you need are:

- Very high dimensional search space
- Very many->one genotype->phenotype mapping
- Some statistical correlation structure to the search space

What happens ?

Punctuated equilibria

Most of evolution is running around the current neutral network 'looking for' a portal to a higher one.



Much of macro-evolution, the sort that is relevant to Alife as well as RNA worlds, just is this kind of evolution – the LONG HAUL or SAGA, rather than the BIG BANG.

Recent Work

… relevant outside the RNA world includes theoretical work by Erik van Nimwegen and colleagues at SFI.

Lionel Barnett at Sussex - "Ruggedness and Neutrality: the NKp family of Fitness Landscapes" – Alife VI

Rob Shipman and colleagues from BT at this Alife VII

But do the conditions for NNs to exist actually apply in real practical problems? -- recent work suggests probably YES!

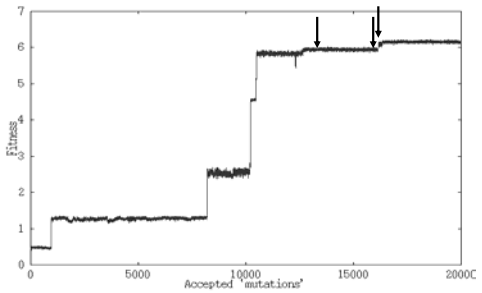
Evolvable Hardware

Adrian Thompson (Sussex) configured one of his experiments directly evolving electronic circuits on a FPGA silicon chip to test the hypothesis that Neutral Networks existed and were used.

Population size 1+1, and only genetic operator (something like|) single mutations.

Search space size 2^{1900}, and an expected number of solutions say roughly 2^{1200}.

Punk Eek



Analysis

Looking at 3 individuals

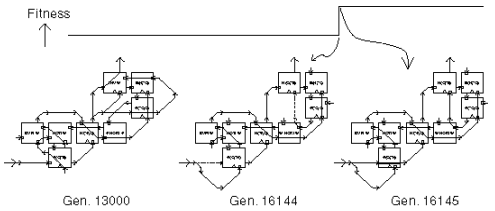
A at beginning of a plateau

B at the end of a plateau

C after the single step up to next plateau

One could check out what happened.

History of a Walk



Was the Walk Necessary ?

Yes.

On checking, none of the possible mutations from A led to higher fitness.

The B->C mutation, if applied to A, actually decreased its fitness.

So the Neutral Network was essential, and was indeed used.