Agent-Based Modeling, Part 2

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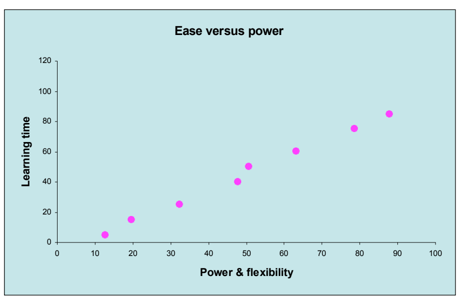
In Pinyin: 'Zhan'

Today's topics:

- Choosing a platform
- Some classic examples of ABMs

Platform trade-off:



Types of platforms

- Closed systems
  Agents & methods already provided
  Quick start, but limited flexibility
  - Starlogo
  - NetLogo
- General purpose OOP language
  Great flexibility
  Requires more skill & time
- ABM libraries
  Great flexibility, saves some time
  - Swarm
  - Repast
  - Ascape

Some classic examples of agent-based models:

1) Non-spatial models
   - Prisoner's dilemma – evolution of cooperation
   - Minority game – market dynamics, dynamics of frustrated systems

2) Fixed positions: Cellular automata
   - Pattern formation
   - Emergent computation

1) Mobile agents on 2D spatial grids
   - self-organized animal movement

An example of an (originally) non-spatial ABM

- Question: how can cooperative behavior evolve by natural selection, or persist in human behavior, if it carries an individual cost?

An ABM model of cooperation:

The 'Prisoner's Dilemma' game:

- Individuals have paired interactions
  - Each can express one of two discrete 'strategies': 'cooperate' or 'defect'
  - Both fare better with mutual cooperation than with mutual defection.
  - But each can gain an individual advantage by defecting.

The 'Prisoner's Dilemma':

row column

The Prisoner's Dilemma payoff matrix:

	c	d
c	R,R	S,T
d	T,S	P,P

The ‘Prisoner’s Dilemma’:

The Prisoner’s Dilemma payoff matrix:

column row

	c	d
c	2,2	0,3
d	3,0	1,1

Results: Cooperation can evolve in PD games if…

- Interactions are repeated, and current strategy is conditional on partner’s previous behavior (e.g., ‘tit-for-tat’ strategy).
- The game is spatial, with neighbors interacting, and offspring born near parents

Agents with fixed positions: Cellular automata

- Not an all-purpose modeling tool, but one prominent example of a modeling paradigm that is not based on equations, or necessarily on any mathematics.

Cellular automata are…

- Explicitly spatial models.
- Usually used to model spatial processes and the spatial patterns they generate.
- Often used as an abstract model of ‘complex systems’, in which multiple simple subunits interact to produce emergent patterns or behaviors with properties that are not easily inferred from those of the subunits.

Definitions

automaton: a self-operating machine or mechanism (plural *automata*)

A finite-state automaton has:

- a finite number of possible states
- a current state
- a set of inputs (e.g., states of neighbors)
- a 'transition rule' for choosing its next state based on its inputs

A cellular automaton is:

An array of 'cells', each of which contains one finite state automaton (typically all identical in their set of possible states, and transition rule, but not current state).

All the finite state automata are typically synchronized by a global clock (but this can be relaxed).

Well –studied cellular automata include:

- 1-dimensional, or 'linear' CAs (a single row of cells)
  - A second dimension is often added to represent time.
  - Often used to study spatial-temporal patterns
  - Used in computer science, and in studies of complex systems and self-organization
  - Sometimes used in biology (e.g., pattern formation in mollusc shells)

Well –studied cellular automata include:

- 2-dimensional CAs (2D array of cells)
  - Typically a rectangular grid
  - have a history as a game or amusement (John Conway's 'game of Life')

- are often used in biology, e.g.:
  - excitable media
  - reaction-diffusion systems
    - forest fire dynamics
    - spatial epidemiology
    - spatial ecology (e.g., vegetation succession)

How do patterns arise in biology?

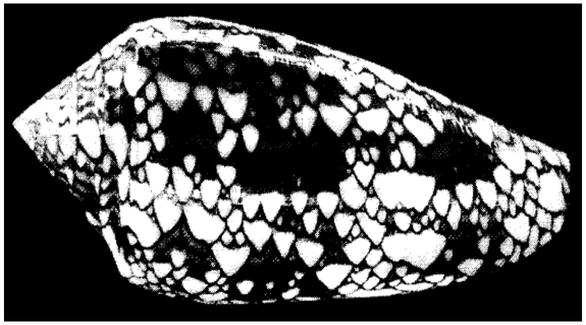
•A "blueprint" or "template" of some sort?

•Centralized control?

•Environmental input?

•Emergent self-organization?

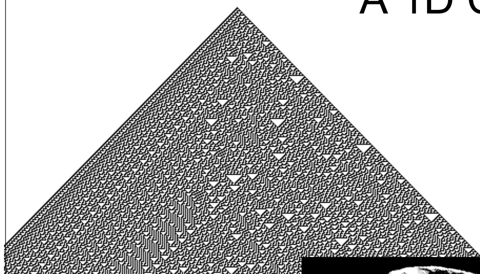
Pattern on a 'cone shell' (a sea mollusc)

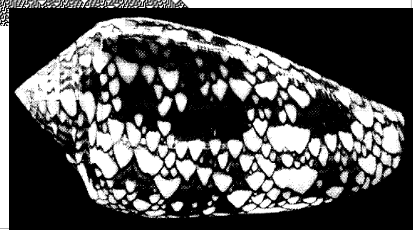


Mollusc shell growth:

- The 2D surface of the shell grows along one edge, as a linear array of shell-building cells lays down shell matrix either with or without pigmentation.

A 1D CA





Caveats…

- Beware of “gee whiz modeling”!
- A subjective impression of similarity to a natural pattern is not a scientific result….
- But it may well inspire a hypothesis that comes with testable predictions.
- That’s exactly what theory is supposed to do for us!

A 1D CA can also serve as a minimal model of a concept:

See work of J. Crutchfield *et al.* on:

- Information theory
- Emergent computation

Mobile agents on a 2D grid :

- A very common ABM environment
- Many simple ‘closed’ modeling platforms use this environment
  - Including *NetLogo*
- One classic application is models of animal group movement (flocks & schools).

Mobile agents in 2D space

- Flocking models:
- How does a flock of birds or a school of fish coordinate its movements?
  - Leadership or central control?
  - Coordination via signaling?
  - Emergent self-organization?

3 agent rules for flocking:

Separation: steer to avoid crowding local flockmates

Alignment: steer towards the average heading of local flockmates

Cohesion: steer to move toward the average position of local flockmates

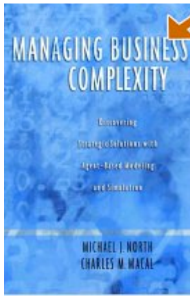
Switch to netlogo program

To see flocking program running

More resources…

North & Macal 2007

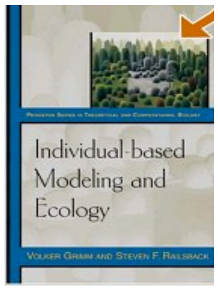
- Mostly oriented toward business applications
- But lots of good basic information on ABM



More resources…

Grimm & Railsback 2007

- Oriented toward basic science
- Applicable beyond ecology



More resources…

- Free platform downloads:
  - NetLogo: http://ccl.northwestern.edu/netlogo/
  - Swarm: http://www.swarm.org/
  - Repast: http://repast.sourceforge.net/