Cellular Automata and Agent-based modelling

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Topics to cover
- Basic concepts and principles of Cellular Automata (CA) and agent-based modelling (or Multiagent simulation, MAS in short);
- To introduce a suite of software of CA and MAS and some interesting projects,
- To further stimulate discussions on research towards integrating CA and MAS into GIS.

Outline of the talk
- Geographic systems are dynamic in essence
- What is CA and MAS?
- Simple vs complex systems
- Decentralization and self-organization
- Software perspectives on CA and MAS
- Some typical CA and MAS systems
- Beyond CA and MAS

Geographic systems are dynamic
- Vehicle, and pedestrian flow, urban growth, landuse changes, and environment changes etc..
- However,
- Current GIS are difficult to handle dynamic phenomena
  - GI is layer-based (snapshot)
  - No time component involved
- Time GIS is in a research agenda + dynamic modelling approaches such as CA and agent based simulations

Cell-based GIS
- Basic notions:
  - Cell/location
  - Neighbourhood
  - Zone
  - Layer

Local neighbourhoods
- Von Neumann
- Moore

Local neighbourhoods
A definition of cellular automata

- A cellular automaton is a discrete dynamical system. Space, time, and the states of the system are discrete. Each point in a regular spatial lattice, called a cell, can have any one of a finite number of states. The states of the cells in the lattice are updated according to a local rule. That is, the state of a cell at a given time depends only on its own state one time step previously, and the states of its nearby neighbors at the previous time step. All cells on the lattice are updated synchronously. Thus the state of the entire lattice advances in discrete time steps. - Lyman Hurd * -From Alife Online

The game of life? (John Conway)

- The Game of Life (or simply Life) is not a game in the conventional sense, no players, no winning or losing.
- Once the "pieces" are placed in the starting position, the rules determine everything that happens later.
- Nevertheless, Life is full of surprises!
- In most cases, it is impossible to look at a starting position (or pattern) and see what will happen in the future. The only way to find out is to follow the rules of the game.

Demo of Life (NetLogo)

Facts of the game of life

- Life is played on a grid of square cells--like a chess board but extending infinitely in every direction - 2D squared and wrapped space.
- A cell can be live or dead - two states.
- A live cell is shown by putting a marker on its square. A dead cell is shown by leaving the square empty.
- Each cell in the grid has a neighborhood consisting of the eight cells in every direction including diagonals – Moore neighbourhood.

Rules of the game of life

- Birth rule: a dead cell with exactly three live neighbors becomes a live cell.
- Survival rule: a live cell with two or three live neighbors stays alive.
- Die of overcrowding or loneliness rule: in all other cases, a cell dies or remains dead.

Why is Life so interesting?

- Life is one of the simplest examples of what is sometimes called "emergent complexity" or "self-organizing systems."
- This subject area has captured the attention of scientists and mathematicians in diverse fields. It is the study of how elaborate patterns and behaviors can emerge from very simple rules.
- It helps us understand, for example, how the petals on a rose or the stripes on a zebra can arise from a tissue of living cells growing together. It can even help us understand the diversity of life that has evolved on earth.
Simple, complicated systems
(the double pendulum, the Boeing 747-400, $3 \times 10^6$ parts)

Complex animal behaviours

Complex human systems

Defining a complex system

- A complex system is a system with a large number of elements, building blocks or agents, capable of interacting with each other and with their environment.
- The interaction between elements may occur only with immediate neighbors or with distant ones; the agents can be all identical or different; they may move in space or occupy fixed positions, and can be in one of two states or of multiple states.
- The common characteristic of all complex systems is that they display organization without any external organizing principle being applied. The whole is much more than the sum of its parts. (Amaral and Ottino 2004)

Tools for the study of complex systems
(Amaral and Ottino 2004)

- Nonlinear dynamics and chaos
- Statistical physics: universality and scaling
  - Scaling
  - Universality
- Discrete models (e.g. agent-based modeling), in contrast to equation-based approaches
- Network theory

Institutions in complexity
An agent is an intelligent agent

- A system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda, and
- so as to effect what it senses in the future (Franklin and Graesser 1997, pp. 25).
- e.g. humans, animals, autonomous mobile robots, artificial life creatures, and software agents.

An agent IS NOT Intelligence agent

Properties of agents (after Franklin and Graesser 1997)

<table>
<thead>
<tr>
<th>Property</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emceor</td>
<td>Responds as if a highly evolved organism</td>
</tr>
<tr>
<td>Autonomy</td>
<td>Exerts control over its own actions</td>
</tr>
<tr>
<td>Goal-orienterd</td>
<td>Act in response to the environment</td>
</tr>
<tr>
<td>Purposeful</td>
<td>Autonomous and goal-orienterd</td>
</tr>
<tr>
<td>Temporality</td>
<td>Continuous or recurring process</td>
</tr>
<tr>
<td>Coordinating</td>
<td>Communicates with other agents, perhaps including people</td>
</tr>
<tr>
<td>Imaging-adaptive</td>
<td>Change in behavior based on past experience</td>
</tr>
<tr>
<td>Mobile</td>
<td>Able to transport itself from one machine to another</td>
</tr>
<tr>
<td>Flexible</td>
<td>Needs not be adapted</td>
</tr>
<tr>
<td>Obedient</td>
<td>Behaves like a “personality”</td>
</tr>
</tbody>
</table>

Elements of multiagent simulations

Cell-based GIS, CA and MAS

Self-organization

- Self-organization is basically a process of evolution where the effect of the environment is minimal, i.e.
- where the development of new, complex structures takes place primarily in and through the system itself.
- “Organized without an organizer, coordinated without a coordinator”
- e.g. Language is a typical self-organizing system, as well as flocks
Real vs simulated flocks
A flock is NOT bird, a bird is not flock

Real flocks

Copyright: Craig W. Reynolds

Self-organized systems

- Ant colonies
- Highway traffic
- Linux
- Market economies
- Immune systems
- etc...

Surface complexity out of simplicity

- Order out of chaos
  by Ilya Prigogine and Isabelle Stengers
  Prigogine is a Belgian-American scientist, working mainly in physical chemistry and statistical mechanics.

Three rules of bird flocking - BOIDS

- Separation: steer to avoid crowding local flockmates;
- Alignment: steer towards the average heading of local flockmates; and
- Cohesion: steer to move toward the average position of local flockmates

Linux as a decentralized system

- In 1991, Finnish hacker Linus Tovalds created LINUX
- "If your efforts are freely distributable, I’d like to hear from you, so that I add them to the system"

Congestion pricing

- by Nobel Prize-winning William Vickrey
- In February 2003, London started charging people to drive into the centre, i.e. £5 [7am-6:30pm], otherwise £80. In theory, it raises £180M and cuts congestion 20%.
It is important to realize ...
- Traffic = flock in the sense of self-organization or decentralized nature.
- **BUT**
- Cars ≠ traffic
- Birds ≠ flock

Modeling advantages of CA and MAS
- A paradigm shift from Newton’s physics metaphor (cause-effect) to biology metaphor
- From centralised models to decentralised models
- It is a bottom up approach,
- combined with modeling and visual simulation, and
- used to set up a virtual lab – “would-be worlds”

www.Google.com
- PageRank algorithm
- PageRank relies on the uniquely democratic nature of the web by using its vast link structure ...

- Swarm is a software package for multi-agent simulation of complex systems, originally developed at the Santa Fe Institute. Swarm is intended to be a useful tool for researchers in the study of agent based models.
- Some core libraries: defobj, collections, random, tkobjc, activity, swarmobject, and simtools.
- Modelling languages in objective-C or Java computer languages

Logo and turtle geometry
- "Logo is the name for a philosophy of education and a continually evolving family of programming languages that aid in its realization." - Harold Abelson, Apple Logo, 1982

StarLogo
- StarLogo is a programmable modeling environment for exploring the workings of decentralized systems - systems that are organized without an organizer, coordinated without a coordinator.
  [http://education.mit.edu/starlogo/](http://education.mit.edu/starlogo/)
StarLogoT and NetLogo

- NetLogo is a cross-platform multi-agent programmable modeling environment from (the people who brought you StarLogoT). NetLogo also powers the HubNet participatory simulation system.
  
  [Image of NetLogo]

NetLogo

- Welcome to NetLogo

StarLogoT

- 2002

RePast [http://repast.sourceforge.net/]

- The Recursive Porous Agent Simulation Toolkit (Repast) borrows many concepts from the Swarm. Repast is differentiated from Swarm since Repast has multiple pure implementations in several languages and built-in adaptive features such as genetic algorithms and regression.

RePast: A Software Toolkit for Agent-Based Social Science Modeling

UrbanSim [http://www.urbansim.org/index.shtml]

- UrbanSim is a software-based simulation model for integrated planning and analysis of urban development, incorporating the interactions between land use, transportation, and public policy.
- It is intended for use by Metropolitan Planning Organizations and others needing to interface existing travel models with new land use forecasting and analysis capabilities.

TRANSIMS [http://transims.tsara.lanl.gov/]

- TRANSIMS is an agent-based simulation system capable of simulating the second-by-second movements of every person and every vehicle through the transportation network of a large metropolitan area.

SimPed

- SimPed simulates pedestrian flows in a virtual urban virtual environment, to assess whether or not street structure has impacts on people's movement.
  
  [Image of SimPed]

UrbanSim


SimPed


Sugarscape (Epstein and Axtell 1996)

- Sugarscape models an artificial society in which agents move over a 50 by 50 cell grid.
- Each cell has a gradually renewable quantity of 'sugar' which the agent located at that cell can eat.
- Agents have to consume sugar in order to survive.
- If they harvest more sugar than they need immediately, they can save it and eat it later or, in more complex variants of the model, can trade it with other agents.
**Pareto’s law - 80/20 rule**
- The 80/20 Rule, also called the Pareto’s law after its founder, the Italian economist Vilfredo Pareto, who first wrote about it in 1895.
- Pareto noticed that people in his/her society seemed to divide naturally into what he called the “vital few,” the top 20% in terms of money and influence, and the “trivial many,” the bottom 80%.
- E.g. 80% of profits are produced by only 20% of the employees;
- 80% wealth is owned by only 20% people.

**WildFire**
- IF a cell is surrounded by more than one tree
- THEN [fire diffuse]
- ELSE [fire is distinguished]

**Computation of isovists**

**Enhanced traffic model**
Further research

- Graph based CA by David O’Sullivan
- Voronio-based by Wenzhong Shi and Matthew Yick Cheung Pang
- Object-based geosimulation by Itzhak Benenson and Paul M. Torrens

Further readings


Readings on complexity and agent