Agent-based Modeling

Computational Social Systems I (VU) (706.616)

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Agent-based Modeling (ABM)

- What is ABM?
- Phenomena that can be modeled using ABM
- Examples in NetLogo

What is Agent-based Modeling (ABM)?

- Approach to model systems
- Model consists of autonomous, interacting agents
- Agent interaction simulated repeatedly over time

Agents (1/2)

- Autonomous, model intelligent behavior with simple set of rules
- Situated in space (e.g. a grid or a network)
- Interact with each other locally (i.e., they are social)
- Have only a partial local information
- Different types of agents can follow different set of rules
- Rules may be deterministic or probabilistic

Agents (2/2)

- Self-contained: identifiable, discrete, set of attributes, behaviours and decision-making capability
- Can have memory - then, they can learn and adapt their behaviour
- Examples for agents: people, groups, organizations, insects, swarms, robots, biological entities,..

Agent-based models

- Used to simulate actions and interactions of agents and to study their effects on system as a whole
- Understanding relations between individual decisions and system behavior
- Micromotives vs. Macrobehavior (Schelling's book[1])
- ABMs are computational, i.e., simulations

[1] https://www.goodreads.com/book/show/317333.Micromotives_and_Macrobehavior

Advantages of Agent-based models

- ABMs are extensible
- ABM are interpretable
- Can answer multiple questions (“many question models”)

Tools to build ABM

- Agent-based modeling and simulation toolkits: Repast (Java), Swarm (Objective C, Java), NetLogo, StarLogo, MASON, AnyLogix

- Generall tools: e.g. MATLAB, spreadsheets, ABM with programming languages (Python, Java,...)

Selected models

1. Life
2. Schelling Model
3. Viruses on networks
4. Ising model
5. Forest fire

Life (1/3)

- Developed by mathematician John Conway
- Based on cellular automata (CA): 2-dimensional grid partitioned into cells
- Each cell assumes one of a finite nr of states at any point in time - On or Off
- Value of each cell is determined by set of rules, based on cell's previous state and value of its immediate 8 neighbours
- Each cell updated at each time step according to the rules

Life (2/3)

Life has 3 rules that determine next state of each cell:

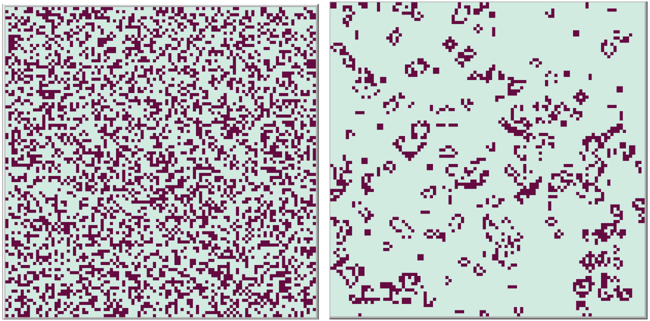
- Rule 1: cell will be On in the next generation if exactly 3 of its 8 neighboring cells are currently On
- Rule 2: cell will retain its current state if exactly two of its neighbors are On
- Rule 3: cell will be Off otherwise

Life (3/3)

Life as ABM:

- Each cell is an agent
- States of cell (On and Off) are the possible states of an agent
- Cell update rules represent an agent's behaviour
- The states of all the agents taken together at a specific time in the simulation is the state of the model (system)
- Grid is the environment of Life - determine agent's neighborhood

Example of Life



(a) Initial stage (b) After 40 times

Figure: Life simulation: (a) initial random layout of cells in the On state, (b) after all cells updated 40 times

Netlogo Example of the Life Model

- http://ccl.northwestern.edu/netlogo/
- Go to File/Model Library/Computer Science/Cellular Automata/Life

Observations from Life Model

- Rules are simple and use only local information as each cell's state is based on its current state and the state of its immediate neighbors
- Resulting patterns of Life depend on initial conditions - each simulation gives different patterns of On and Off cells
- Patterns can *emerge* in systems that are completely described by simple, deterministic rules based on only local information
- Based on simple rules of behavior and nature of agent interactions, systems can show collective intelligence, even without existence of a central authority

The Schelling Model

- A small preference for a specific kind of neighbors lead to total segregation
- Shows how global patterns (spatial segregation) can arise from local preferences (homophily)
- A simple robust mechanism leads to segregation
- Segregation achieved even if no one explicitly aims for it

How does the Schelling Model work? (1/2)

- Assume a population of agents of type X or O
- Types represent immutable characteristics (e.g., ethnicity)
- Two populations initially placed into random locations of grid
- So, each cell is either occupied by an agent or empty

How does the Schelling Model work? (2/2)

- Determine if each agent is satisfied with its current location
- Agent is satisfied if surrounded by at least t of its own type of neighboring agents
- Threshold t applies to all agents in the model
- The higher t, the higher the likelihood that agents will not be satisfied with their current location
- If agent dissatisfied, changes its location in the grid
- Any algorithm can be used to choose new location (e.g., random selection, nearest available location, 1 row at a time)

Example

X1*	X2*				
X3	O1*		O2		
X4	X5	O3	O4	O5*	
X6*	O6			X7	X8
	O7	O8	X9*	X10	X11
		O9	O10	O11*	

(a) Initial stage

X3	X6	O1	O2		
X4	X5	O3	O4		
	O6	X2	X1	X7	X8
O11	O7	O8	X9	X10	X11
	O5	O9	O10*		

(b) After one round

Figure: Left image: all dissatisfied agents have an asterisk next to them. Right image: shows new configuration after all dissatisfied agents have been moved to unoccupied cells (1 row at a time) where they are satisfied. May cause other agents to become unsatisfied, then new round of movement begins

What is t?

Netlogo Example of the Schelling Model

- http://ccl.northwestern.edu/netlogo/
- Go to File/Model Library/Social Science/Segregation

Observations from Schelling's Model

- Spatial segregation even if no individual agent actively seeks it
- Segregation doesn't happen due to built-in model agents that are willing to be in the minority
- Ideally, all agents are carefully arranged in an integrated pattern
- However, from random start hard for agents to find such integrated patterns
- Schelling model is an example of how fixed characteristics (e.g., ethnicity) can become highly correlated with mutable characteristics
- E.g. decision where to live, which over time conforms to similarities in agents immutable types, producing segregation

How does the Forest Fire work?

- Forest is a grid of cells
- Cell either occupied by tree or empty
- Fire starts on the left edge of the forest
- Spreads to neighboring trees in all four directions: north, south, east, west
- Fire cannot skip an empty cell
- No wind

Netlogo Example of the Forest Fire model

- http://ccl.northwestern.edu/netlogo/
- Go to File/Model Library/Earth Science/Fire

Questions

- With density around 50% how much of the forest burns
- With different initial settings do the same tree burn?
- Each cell is first on and then off if burnt
- The fire is made of burning trees that do not move
- But the fire itself moves!
- Local vs. global level
- Emergence of properties at a global level that do not exist on the local level

Questions

- Often very small margin for parameters where system goes quickly from one state into another - **phase transition**
- Phase transition around 59%
- Reaching the other edge of the grid
- Scenarios where you could apply the forest fire on the Web?
- Viral marketing

How does the Ising model work?

- Originally from physics
- Models magnetization of a material
- Each cell in the grid has a spin s_i: $+1$ or -1
- Cells can flip their spin
- Energy of a cell calculated from its 4 neighbors (north, south, east, west) as $E_i = \sum_j s_i s_j$
- Total energy is $E = \sum_i E_i$
- System always tries to reach state of minimal energy with some randomness, which increases with temperature

Netlogo Example of the Ising model

- http://ccl.northwestern.edu/netlogo/
- Go to File/Model Library/Chemistry & Physics/Ising

Questions

- What happens when temperature is low?
  - Cells align their spins
- What happens when the temperature is high?
  - Alignment is not likely anymore
- There is a specific temperature, which separates those two modes: $\frac{2}{ln(1+\sqrt{2})}$ on an infinite grid
- Phase transition
- For what phenomenon could you use the Ising model on the Web?
  - Opinion dynamics, consensus reaching, etc.

Summary

Agent-based modeling

- Why? To model complex systems and to study emergent phenomena, e.g. from animal behavior, social sciences, ecology, ...
- Complex system: individual behavior and properties better understood than behavior and properties of whole system
- Examples for ABM: Life, Schelling, Ising, Forest Fire

Take away

We can model and understand real-world phenomena by constructing models that exhibit complex emergent behavior resulting from local, simplified agent interaction.

How would you build an ABM?

- Pro tip: Take an established model and see whether you can build upon it
- Requires model literacy!

Thanks for your attention!