Agent-based Modeling

Web Science (VU) (706.716)

Elisabeth Lex

ISDS, TU Graz

May 28, 2018

Repetition

- Information Cascades, Herding
- Modeling with Bayes' Rule
- Linear Threshold Model
- Probabilistic Models: SIR, SIS

Today

Agent-based Modeling (ABM)

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

What is Agent-based Modeling (ABM)?

- New approach to modeling systems that consist of autonomous, interacting agents
- Dynamic processes of agent interaction are simulated repeatedly over time
- Thus, an ABM is a model in which agents interact repeatedly
- Ideas for an example from nature?

What is Agent-based Modeling (ABM)?

- New approach to modeling systems that consist of autonomous, interacting agents
- Dynamic processes of agent interaction are simulated repeatedly over time
- Thus, an ABM is a model in which agents interact repeatedly
- Ideas for an example from nature?
- Ant colonies: organizes itself to carry out complex tasks of gathering food and building a nest while being extremely resilient if colony is disrupted ("swarm intelligence")

The need for Agent-based Modeling

We live in an increasingly complex world

- Our systems are increasingly complex and interdependent: e.g electrical infrastructures, telecommunication networks, transportation networks, social systems, social networks
- Some systems have always been too complex to model realistically: e.g models for economic markets
- New tools and modeling approaches available that help us analyze complex systems
- Lots of empirical data available and computational power
- Example use cases for ABM: modeling agent behaviour in the stock market, supply chains, consumer markets, spreading of epidemics, understanding social systems,..
- All those are *Complex Systems*: individual behavior and properties better understood than behavior and properties of whole system

Agent-based models

- Agents are autonomous and model intelligent behavior with a simple set of rules
- The agents are situated in space (e.g. a grid or a network)
- The agents interact with each other locally (i.e., they are social)
- The agents have only a partial local information
- There are often different types of agents following different set of rules
- The rules may be deterministic or probabilistic
- There are often random elements in the world

Agents

- Agents are self-contained: identifiable, discrete, has set of characteristics / attributes, behaviours and decision-making capability
- Agents can have memory - then, they can learn and adapt their behaviour (dynamic agent attribute)
- Examples for agents: people, groups, organizations, insects, swarms, robots, biological entities,..

Agent-based models

- Argent-based models are used to simulate actions and interactions of autonomous agents and to assess their effects on system as a whole
- Understanding relations between individual decisions and system behavior
- Micromotives vs. Macrobehavior (Schelling's book)
- They are always computational, i.e., simulations
- They are intuitive for implementation, experiments, interpretation

Advantages of Agent-based models

- ABMs are extensible
- ABM are interpretable: one can use them to transparently plan real-world concepts
- Holistic modeling approach: can be used to answer multiple questions ("many question models")
- Typically, individual-level behavior better understood than aggregate (population) level. One can start with sth that is better understood to understand macro behavior
- ABMs help tackle complexity and well suited to model behavior

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:

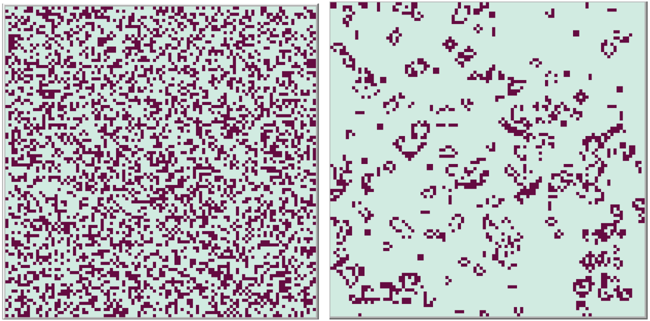
- Rule 1: The cell will be On in the next generation if exactly three of its eight neighboring cells are currently On.
- Rule 2: The cell will retain its current state if exactly two of its neighbors are On.
- Rule 3: The cell will be Off otherwise.

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 - minimal function as reference point to 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

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

Netlogo Example of the Life Model

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

The Schelling Model

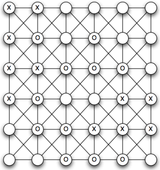
- A small preference for a specific kind of neighbors lead to total segregation
- Shows how global patterns (spatial segregation) can arise from local preferences (homophily)
- A simple robust mechanism leads to segregation
- Segregation achieved even if no one explicitly aims for it

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

- Assume a population of individuals (aka agents) of type X or O
- Types represent immutable characteristics (e.g., age)
- Two populations are initially placed into random locations of a neighborhood grid
- After placing all agents, each cell is either occupied by an agent or empty
- The neighbor relationships among the cells can be represented very simply as a graph: cells are the nodes, edges are inserted between two cells that are neighbors on the grid

x	x				
x	o		o		
x	x	o	o	o	
x	o			x	x
	o	o	x	x	x
		o	o	o	

(a) *Agents occupying cells on a grid.*



(b) *Neighbor relations as a graph.*

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

- Now, determine if each agent is satisfied with its current location
- Agent is satisfied if is surrounded by at least t of its own type of neighboring agents
- Threshold t applies to all agents in the model (in reality everyone might have a different threshold they are satisfied with)
- The higher t, the higher the likelihood that agents will not be satisfied with their current location
- Example:
  - For example, if $t = 3$, agent X is satisfied if at least 3 of its neighbors are also X
  - If fewer than 3 are X, then the agent is not satisfied, and it will want to change 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

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 takes place even though 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
- At more general level, 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

Rep: How does the epidemics work?

- The models originally come from biology
- How viruses and diseases spread in social networks
- We have different types of nodes
- Infected (I): people who got the virus
- Susceptible (S): people who do not have virus but can check it
- Recovered (R): people who had the virus but got recovered and can not catch it again (in some models people can become immune)
- Various model: SI, SIR, SIS, SIRS

Netlogo Example of the Epidemics

- http://ccl.northwestern.edu/netlogo/
- Go to File/Model Library/Networks/Virus on a Network

Questions

- What happens in SI model after long time?

Questions

- What happens in SI model after long time?
- Everyone is infected
- Which model do we have if we set gain-resistance-chance to 0?

Questions

- What happens in SI model after long time?
- Everyone is infected
- Which model do we have if we set gain-resistance-chance to 0?
- SIS
- When we will have an outbreak in SIS?

Questions

- What happens in SI model after long time?
- Everyone is infected
- Which model do we have if we set gain-resistance-chance to 0?
- SIS
- When we will have an outbreak in SIS?
- E.g. if recovery chance is low and transmission rate is high

Phase transition

- Outbreak depends on the relation between dynamical parameters and the network structure
- With fixed dynamical parameters in what kind of the network an outbreak is more likely?
- With higher or lower average degree?

Phase transition

- Outbreak depends on the relation between dynamical parameters and the network structure
- With fixed dynamical parameters in what kind of the network an outbreak is more likely?
- With higher or lower average degree?
- Higher degree

Phase transition

- Outbreak depends on the relation between dynamical parameters and the network structure
- With fixed dynamical parameters in what kind of the network an outbreak is more likely?
- With higher or lower average degree?
- Higher degree
- Often there is a very small margin for parameters and the network structure where the system goes quickly from one state into another
- Phase transition

How does the Forest Fire work?

- The forest is a grid of cells
- A cell is either occupied by a tree or empty
- The fire starts on the left edge of the forest
- It spreads to the neighboring trees in all four directions
- North, south, east, west
- Fire can not skip an empty cell
- There is 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 point that represents a tree burning is born and then dies
- It never moves whatsoever
- 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

- Again phase transition around 59%
- Reaching the other edge of the grid
- For which scenarios could we apply the forest fire on the Web?

Questions

- Again phase transition around 59%
- Reaching the other edge of the grid
- For which scenarios could we apply the forest fire on the Web?
- Viral marketing

How does the Ising model work?

- The model originally comes from physics
- It models the magnetization of a material
- The cells are organized in a grid
- Each cell has a spin s_i: it is represented by $+1$ or -1
- The cells can flip their spin
- The energy of a cell is calculated from its four neighbors (north, south, east, west) as $E_i = \sum_j s_i s_j$
- The total energy is $E = \sum_i E_i$
- The system always tries to reach the state of the 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 the temperature is low?

Questions

- What happens when the temperature is low?
- The cells will align their spins
- What happens when the temperature is high?

Questions

- What happens when the temperature is low?
- The cells will align their spins
- What happens when the temperature is high?
- The 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 ca we use Ising model on the Web?

Questions

- What happens when the temperature is low?
- The cells will align their spins
- What happens when the temperature is high?
- The 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 ca we use Ising model on the Web?
- Opinion dynamics, consensus reaching, etc.

How does the wealth distribution work?

- We have population living on a grid of cells
- Each cell has an amount of grain and an grain capacity
- People collect grain from the cells and eat (some of) the grain to survive
- How much grain each person accumulates is her wealth
- Initially, a roughly equal distribution
- Each person attempts to move to a cell with more grain (if free)
- People have a life expectancy and can die and can also die if they have no grain
- If a person dies an offspring is born with a random amount of grain (no inheritance)

Netlogo Example of the Wealth Distribution model

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

Questions

- What kind of wealth distribution do we expect to see?

Questions

- What kind of wealth distribution do we expect to see?
- A power-law distribution! Why?

Questions

- What kind of wealth distribution do we expect to see?
- A power-law distribution! Why?
- Because agents are heterogeneous
- They have different visions, metabolism, life expectancy, and so on
- Those agents who gain an initial advantage will keep that advantage
- Preferential attachment

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, Epidemics, Ising, Forest Fire, Wealth distribution

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?

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 - Questions?