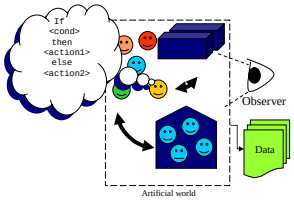
A brief introduction to Agent-Based Modeling



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Models are central to all of science

- We use them to formalize our assumptions and our hypotheses about how systems work
- They often help us move from a hunch to a clear hypothesis, or to an empirically testable prediction.

Two approaches to modeling

- Top-down
  - Usually mathematical.
  - 'Equation-based',
    - but may be solved numerically and computationally
- Bottom-up (or 'generative')
  - = agent-based

Modeling Complex Systems

- Complex systems tend to show patterns of organization that "emerge" out of the interactions of the variables or units they are composed of.
- This property is often central to studies of complex systems.
- "A complex system is a system formed out of many components whose behavior is emergent, that is, the behavior of the system cannot be simply inferred from the behavior of its components."
- What is the link between micro-rules ns macro-behaviors?

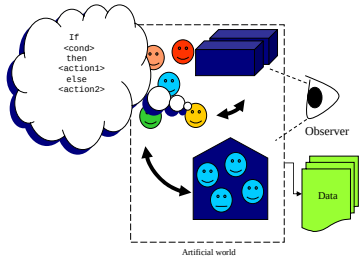
How to model emergence?

- Agent Based Modeling (ABM):
  - the basic unit of ABMs is **the agent**
  - Usually a model will contain many agents (occasionally many thousands)
  - Model outcomes are determined by agent interactions with environment and each other
  - Although the modeler only describes the agents and their behaviors, it is often the emergent group-level phenomenon that we are interested in studying with ABM, not the individual agents we spend so much time modeling.

What is an agent?

- Generally speaking, an agent is an identifiable unit of computer program code which is :
  - *autonomous*

A cartoon view of an agent-based model:



What is an agent?

- Generally speaking, an agent is an identifiable unit of computer program code which is :
  - ***autonomous:***
    capable of independent action based on explicit rules that may be very simple, or more complicated
  - ***a representation of the primary actor in the system***

What does an agent represent? (1)

- In many applications, an agent is an individual (person or organism)
  - In Population Biology and Ecology, ABM = IBM
  - 'individual-based modeling'
- But this is not always the case…

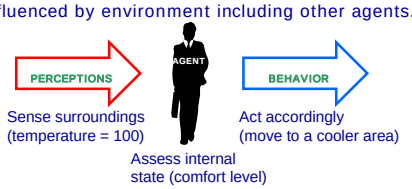
What does an agent represent? (2)

- In many situations in anthropology and social sciences, decisions are made and actions are taken by unified families or households.
  - Thus the *agents* in corresponding models represent households rather than individuals (examples coming soon…)

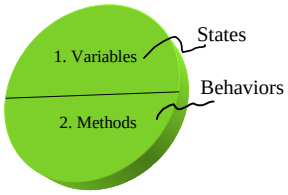
What does an agent represent? (3)

- To understand the origin and progression of cancer, we need to study the population dynamics and the evolution of cells within an individual
  - For this purpose, I use agent-based models where the agents are *cells*.

- An Agent is any component in an ABM that has:
  - Internal data representations (*states/variables*).
  - Means for sensing their states and their surroundings (*perceptions*).
  - Means for taking actions that may modify their internal state or external environment (*behaviors/methods*),. These actions are typically 'conditional' or 'contingent' – influenced by environment including other agents.

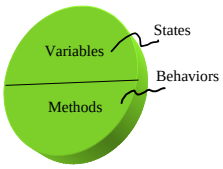


2 Components of an Agent



An abstract agent

2 Components of an Agent

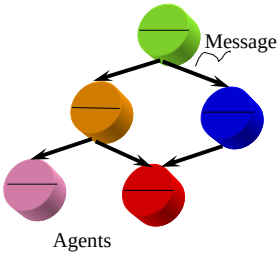


An agent

Variables
Age
Ability
Assets
Partnership
Debt

Methods
Work
Invest
Relocate
Pay expenses
Ask for business partner
Start another business
File Bankruptcy
Sell
Retire

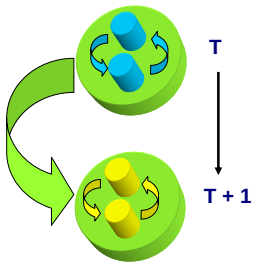
Interaction between agents takes place via messages



Messages from one agent may trigger methods in another, the results of which are often sent to other agents via additional messages.

Also, each agent modifies its own states via its own internal methods.

ABMs often use Discrete event simulation



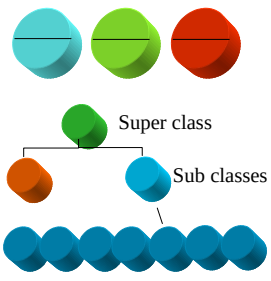
- Simulation proceeds in discrete time steps
- But interactions between agents or procedures during a time step may have their own event schedules or particular order

Some technical terms regarding implementation

- Class
  - The definition of an object type
- Superclass
  - The root or basal class from which others inherit behaviors and variables
- Subclass
  - A class that inherits behaviors and variables from a superclass, but adds others
- Instance
  - An individual agent that has been created and exists in memory
- Method
  - A function (action/ behavior) that can be "called" by sending an appropriate message to an object.

The three principles of Object-oriented programming

- **Encapsulation**
  - Allows objects to hide their functions (**methods**) and data (**variables**) from each other
- **Inheritance**
  - Each **subclass** inherits all variables of its **superclass**
- **Polymorphism**
  - Multiple instances of same class, sharing behavior but not state or memory; this results in a population of heterogeneous agents



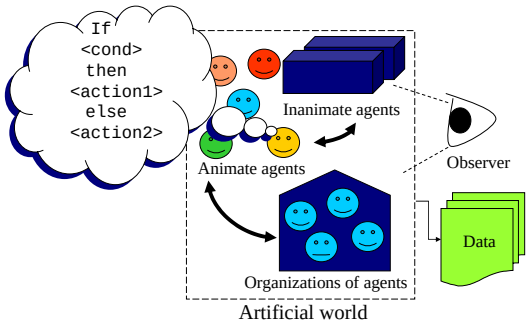
Agent Based Modeling

- Agent based models allow us to study
  - Spatial interaction
  - Adaptive, heterogeneous agents
  - Multilevel systems → economy, markets, firms, plants, employees
  - All of these aspects are often computationally impossible to address with Equation Based Models

Agent Based Modeling…

- Bottom-up approach
- Generative vs. deterministic
- Can avoid some assumptions built into equation-based (ODE) models.
  - continuous quantities
  - Collection of homogenous entities
  - linear responses

Bottom up modeling



Three kinds of models with different purposes:

1) Minimal models for ideas

   Intended to explore a concept without reference to a particular species, place, etc.

2) Minimal models for systems

   A simplified view of a particular kind of system.

2) Synthetic models of systems

   A synthesis of detailed descriptions of all parts and processes in some system – more common in management than basic research.

2 types of ABMs approaches

1. Simulation (emulate, imitate): try to reproduce an empirical observation with a highly detailed model.

- Suffers from equifinality.
- In the end, this type of approach informs one of his/her programming prowess but does not allow one to systematically explore past possibilities.

2 types of ABMs (cont'd)

2. Exploration and experimentation: analyze the effects of varying parameters in a simple model to better understand the entire range of possibilities.

- Interest is in the interaction of model components rather than in achieving a predetermined outcome.

Criteria for a good model:

- Simplicity
- Clarity
- Objectivity (freedom from bias)
- Tractability

Less is more…

- A simple model provides more clarity, tractability, more complete analysis, and easier communication.
- In most cases the real art of modeling lies in *leaving things out*!