Mathematical Modeling & Simulation

Humans are curious

- How does the world work?
- Why do we observe certain patterns?
- Can we predict a system's behavior?

Real systems are complex and might take a long time to observe experimentally.

Goal: Identify simple rules that can describe a system's complexity.

Models

A model is a purposeful simplification of a system for solving a particular problem (or category of problems).

- How do you simplify a complex system? Make assumptions.
- What questions do you hope to answer from each model?
- What do you include in a model and what do you ignore?
- How do you know whether certain factors are important to the questions being asked?

Computer simulation

- Enables experimentation
- Used to assess particular interventions
- Can investigate outcomes of different assumptions
- Need criteria to determine whether the model is a good representation of the real system
- Criteria based on what we know about the system: patterns and regularities that characterize the system

Modeling cycle

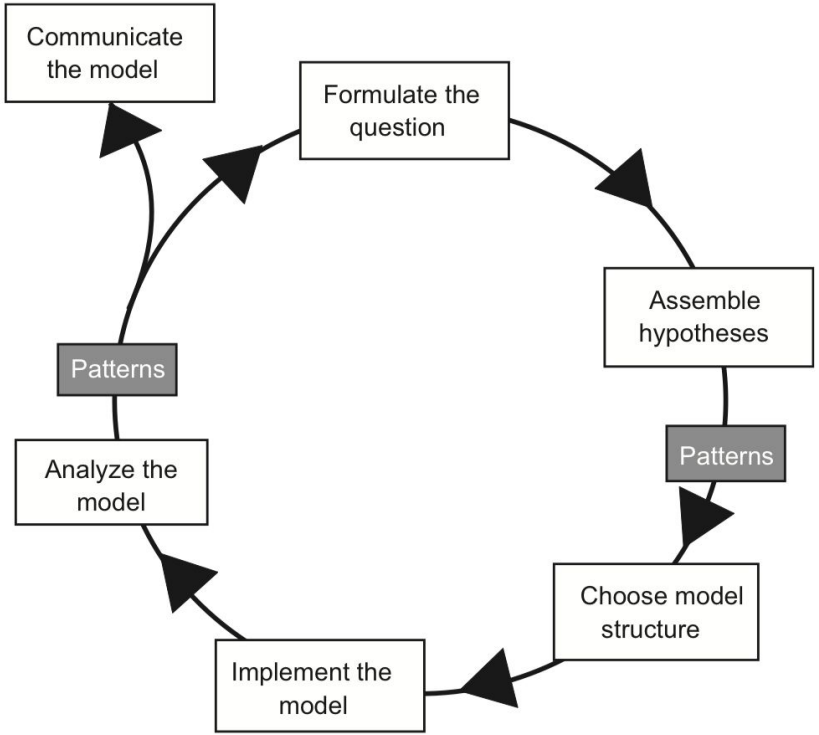
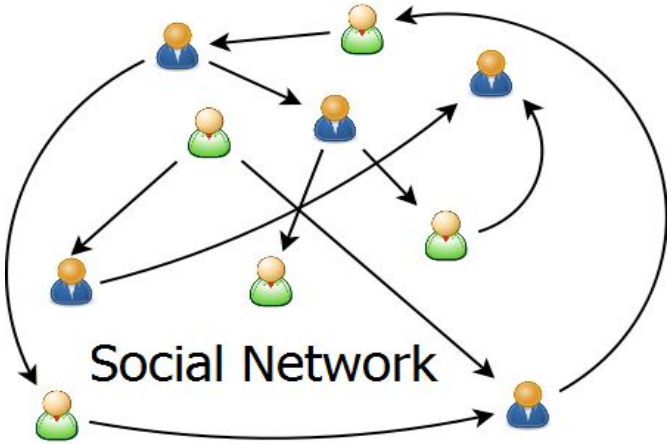
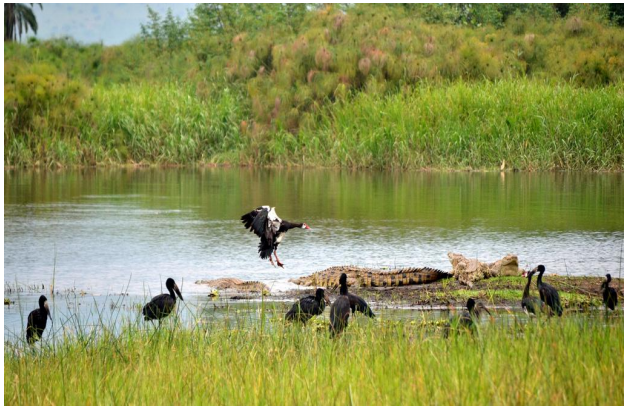


Figure 1.3
The modeling cycle (from Grimm and Railsback 2005).

Complex adaptive systems

Invasive species spread





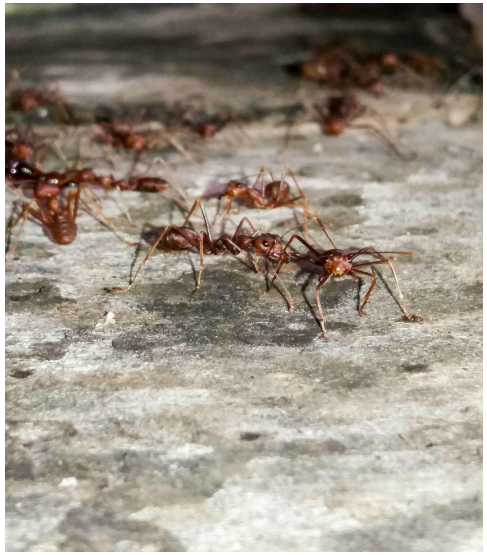
Ecosystem

Stock Market

Emergent behavior

Mexican Wave

Ant Colony



Flocking

Traffic jam

Emergence

Emergence: system dynamics that arise from how the system's individual components interact with and respond to each other and their environment

- Macro-level phenomenon arising from local-level interactions
- Macro-level can only be derived by studying consequences of micro-level agent behavior
- Micro-level agents don't always know implications of their decisions on a macro-level
- A bottom-up approach usually works best

Agent-based modeling

Individuals or agents are unique and autonomous entities that interact with each other and their environment locally.

Agents: organisms, humans, businesses, institutions

Unique: different size, location, resource reserves, history etc.

Interacting locally: agents usually interact with neighbors and not all agents in geographic space or network

Autonomous: agents act independently and have their own objectives

Adaptive: adjust behavior to current states of themselves or other agents or the environment

ABMs are usually composed of

- A number of agents
- A set of decision-making rules for each agent
- A set of learning rules for each agent
- A space in which the agents can move/operate and an environment in which they can interact

ABM simulation

1. Set up environment and agents
2. Run for each time step
    a. Interact
    b. Update
    c. Record
3. Report results

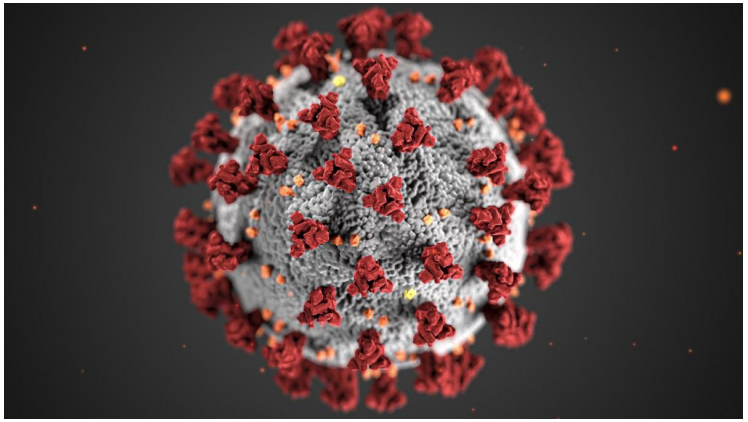
Good questions to keep in mind

- What exactly does this model do?
- Is it a good model or not?
- Should I add this or that process to my model?
- Does the model answer the questions I set out to answer?

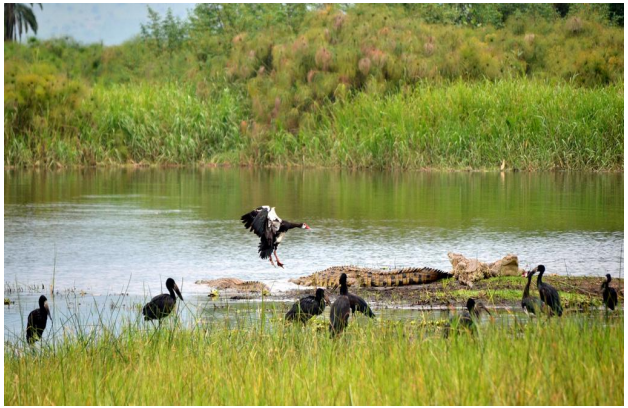
Complex adaptive systems

Invasive species spread

spotted lanternfly



Pandemic people



Ecosystem

organisms

↓

population dynamics.

buyers & sellers / traders Stock Market

Emergent behavior

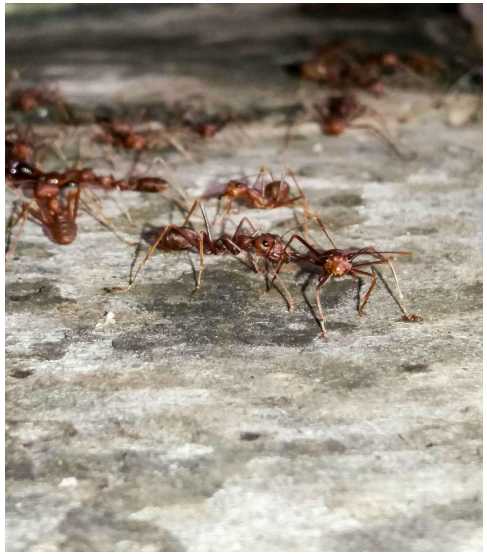
[Mexican Wave]

birds → migration / flocking

Flocking

Ant Colony

ants → ant colony



people in cars → Traffic jam