Introduction to ABMs and IBMs

No Coding Today: For tomorrow read: "Thinking like a Wolf, a Sheep or a Firefly: Learning Biology through Constructing and Testing Computational Theories – an Embodied Modeling Approach."

Today:

1. Simulation and Modeling
2. Systems-Level vs. Agent-Based Modeling/Simulation
3. ABMs and IBMs
4. Designing a Worthwhile Model, Part 1

What is Computer "Modeling"?

A model is a *"simplified representation of a real system."* … "Modeling attempts to capture the essence of a system well enough to address specific questions about the system." (G. & R.)

Computer Modeling is representing some real-world phenomena (system) on a computer (or computers) through the use of (mathematical) models.

What is "Simulation"?

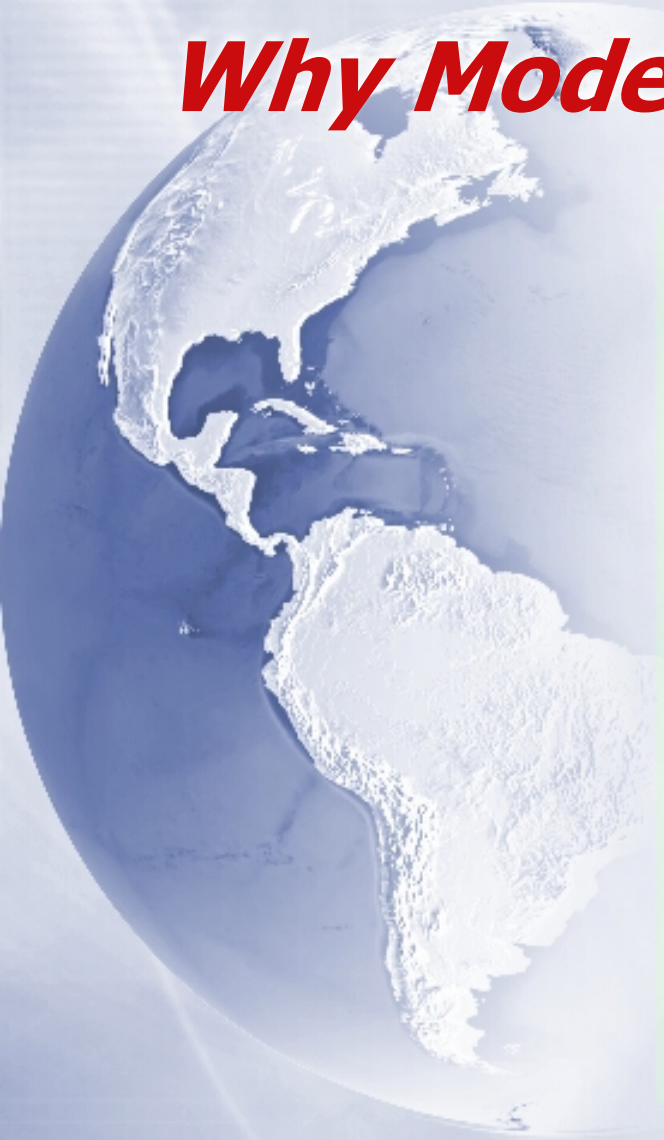
- **Simulation is:**
  - "…*experimenting* with a *model*." (Klugl)
  - "…the *imitation* of the operation of a real-world process or system *over time*." (Banks, et al.)
  - MD: Does it have to be "real world"? What does "real world" mean?
- **Examples:** *Weather prediction, traffic flow (auto and airplane), finances, engineering/architecture, aero- and hydro-dynamics, etc.*

What is "Simulation"?

- **Simulation** "involves the generation of an artificial history of a system, and the observation of that artificial history to draw inferences concerning the operation characteristics of the real system." (Banks, et al.)

NOTE: All simulations involve *simplification* and *abstraction.* The research question determines the simplifications.

Why Modeling and Simulation?



(From Klugl)

1. inaccessibility
2. ethics or prohibitions
3. time scale problems
4. real system not (or in the important case of prediction, not *yet*) existing

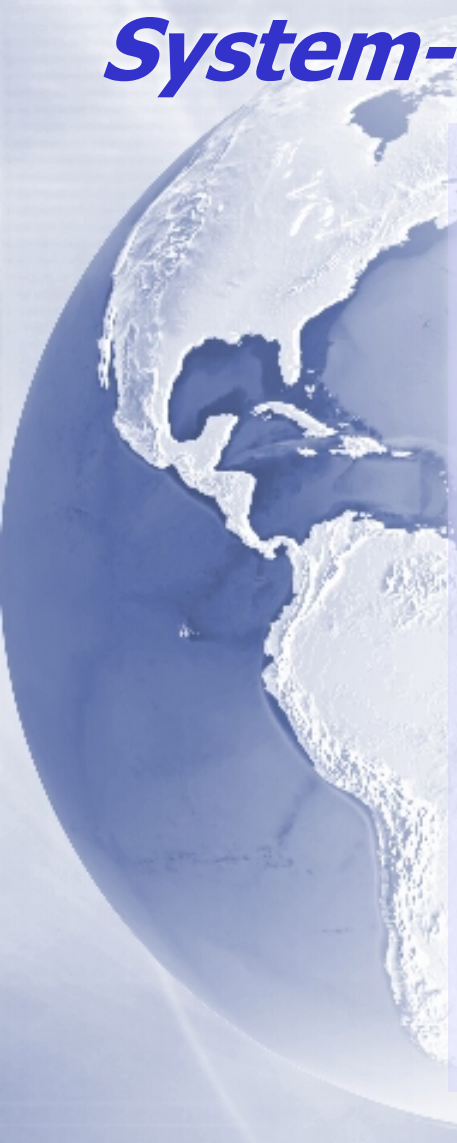
Multi-Agent (Agent-Based) vs. System-Level Simulation?

- **definition**: ”system level” simulation attempts to model (understand) a phenomenon using equations (or systems of equations, perhaps very complex) that describe the entire system (i.e. with global knowledge).

- Traditional “system level” models are *often* very useful (and worth continued study and use)… but there are many real world phenomena for which comprehensive mathematical models are too complex. Often the system as a whole emerges from the behavior of a collection of individuals rather than from rules for the entire system.

  For example, many or most biological systems.

Multi-Agent (Agent-Based) vs. System-Level Simulation?



- Agent-based models instead define the behavior of agents within the system…
  - …without complex system-wide equations
  - …i.e. without global knowledge
  - …localized decision making and limited knowledge
  - …system-wide behavior is not explicitly described but ***emerges*** from the behaviors of (multiple) individual agents.
  - **emergent behavior:** a global (system-wide) phenomenon (result, pattern) that comes from many local individual behaviors.

What is an agent?

- **Definition** (From Honovar): "An **agent** is any entity that can be viewed as *perceiving* its *environment* through *sensors* and *acting* upon its environment through *effectors*"
- **Explanation**: "Intelligent agents *continuously* perform three functions: *perception* of *dynamic conditions* in the *environment*; *action to effect conditions in the environment; and reasoning* to *interpret* perceptions, *solve problems*, *draw inferences*, and *determine actions*." (Hayes-Roth)

U.Wilensky: *"Modeling Nature's Emergent Patterns with Multi-agent Languages"* (2001)

"Large scale patterns in the world are usually the result of the interaction of large numbers of small pieces that somehow combine in surprising ways to create the large-scale pattern."

"... These patterns are emergent [;] there is no leader... which other[s] follow, no conductor... leading the band -- these patterns emerge out of the behavior of individuals and the adjustment of that behavior in interaction with other individuals."

Individual-based Modeling and Ecology

Grimm & Railsback (Princeton U. Press)

"Individuals are the building blocks of ecological systems. The properties and behavior of individuals determine the properties of the systems they compose."

also true of physics, but…

"… most physics questions can be addressed without referring explicitly to atoms."

Atoms are agents, but not individuals. They don't behave differently based on past experience. They don't get born, die, or reproduce.

Grimm & Railsback (cont' d)

Getting Beyond ***Agents*** to ***Individuals***

- "In ecology, individuals are not atoms but living organisms. Individual organisms have properties an atom does not have. Individuals grow and develop, changing in many ways over their life cycle. Individuals reproduce and die, typically persisting for much less time than the systems to which they belong."
- "Because individuals need resources, they modify their environment."
- "Individuals differ from each other, even within the same species and age, so each interacts with its environment in unique ways."

Grimm & Railsback (cont' d)

Getting Beyond ***Agents*** to ***Individuals***

Ecologists "are interested in such population-level properties as persistence, resilience, and patterns of abundance over space and time. None of these properties is just the sum of the properties of individuals. Instead, population-level properties **emerge** from the interactions of adaptive individuals with each other and with their environment."

Grimm & Railsback

Principles of "Individual-Based Modeling/Ecology"

1. Systems are understood as **collections of individuals**. Dynamics come from interactions of individuals with each other and the environment.
2. **Modeling/simulation** is the "primary tool"; emergent properties are key.
3. **Theories** provide models of individual behavior. They are developed from both field research and past knowledge, and evaluated experimentally.
4. **Observed patterns** are important observations used to test theories.
5. Behavior not defined by global equations. Instead, we study **emergence**, adaptation, fitness.
6. Models are implemented with **computer simulation**.
7. **Field studies** are crucial for IBEs.

ABMs and IBMs

Designing a Worthwhile Model

The ODD protocol

(Beyond just writing NetLogo code)

ODD: *Overview, Design Concepts, and Detail*

Overview:

Purpose; Agents, Variables, and Spatial-Temporal Scale; Process overview and scheduling

Design Concepts

Principles, emergence, objectives, learning, prediction, sensing, interaction, stochasticity

Details

Initialization, input, structure and submodels