Agent-Based Modeling and Simulation

The ODD Protocol

Dr. Alejandro Guerra-Hernández

Universidad Veracruzana
Centro de Investigación en Inteligencia Artificial
Sebastián Camacho No. 5, Xalapa, Ver., México 91000

mailto:aguerra@uv.mx
http://www.uv.mx/personal/aguerra

August 2019 - January 2020

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Credits

- These slides are completely based on the book of Railsback and Grimm [2], chapter 3.
- Any difference with this source is my responsibility.

Formulating an AMB

- It means progressing from the heuristic part of modeling, in which we first think about the problem, data, ideas, and hypotheses, to the first formal and rigorous representation of the model.
- We try to write it down in words, diagrams, equations, etc., which requires us to make a series of decisions about the model's structure.
- It is important to realize that a model simply does not exist before it has been formulated explicitly so people can understand it.

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Purposes

- To make ourselves, the model's authors, think explicitly about all parts of the model.
- To communicate the model to our colleagues or supervisors, which usually leads to further discussions and modifications of the formulation.
- As the basis for the model's implementation –the computer program that executes it.
- To publish results based on a complete and accurate description of the model.

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Why so early?

- We use the protocol throughout the rest of this course.
- To learn from the very start to think about ABMs in a systematic and organized way.

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Learning Objectives

- To develop a firm understanding of the Overview and Details elements of ODD.
- To develop an introductory understanding of the Design concepts element.
- To understand, from its ODD description, the model we will program and use in the next two sessions.

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Replicability

- It can be difficult to keep all of the ABM's characteristics in mind.
- In fact, many ABMs in the literature are incomplete, which makes it impossible to reimplement the models and replicate their results.
- Replication, however, is key to science: models that cannot be reproduced are unscientific.
- Moreover, ABM descriptions are often a wordy mixture of factual description and lengthy justifications, explanations, and discussions of all kinds.
- How can we describe ABMs in a way that is easy to understand yet complete? Standarization ODD

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ODD components

Overview	1. Purpose
	2. Entities, state variables, and scales
	3. Process overview and scheduling
Design concepts	4. Design concepts - Basic Principles - Emergence - Adaptation - Objectives - Learning - Prediction - Sensing - Interaction - Stochasticity - Collectives - Observation
Details	5. Initialization
	6. Input data
	7. Submodels

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Purpose

- A clear and concise statement of the question or problem addressed by the model: what system we are modeling, and what we are trying to learn about it.
- It is impossible to make any decisions about the model without purpose.
- Knowing a model's purpose is like having a roadmap to the rest of the model description.

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Entities, State Variables, and Scales I

- What are its entities –kinds of things represented in the mode?
- What variable are used to characterize them?
- Types of entities:
  - One or more types of agents;
  - The environment where the agents live and interact. It's often broken into local units or patches; and the global environment that affects all agents.
- Entities are characterized by their state variables which specifies the state of the model at any time.
- Agent's state:
  - Properties or attributes (size, age, savings, memory, etc.).
  - Behavioral strategy (searching behavior, bidding strategy, learning algorithm, etc.).

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Entities, State Variables, and Scales II

- Some variables are static and do not change. Still, they are different among agents. Otherwise, there is no need for the variable, e.g., if only females are represented in the model.
- State variables do not include quantities that can be deduced or calculated from the states of the agent and the environment, e.g., the distance to the closest bank.
- Many ABMs are spatially explicit and the space is often heterogeneous. The space can be continous or discrete (patches).
- Patches are also characterizes by state variables, e.g., position.
- The global environment refers to variables that vary in time, but not necessarily in space, e.g., temperature, tax rates, etc.
- These global variables are provided by data or sub-models external to the ABMs.

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Entities, State Variables, and Scales III

- Temporal scales refer to how time is represented:
  - How long a time is simulated?
  - How the passage of time is simulated? e.g, day, week, year, etc.
- The use of time steps means that all the processes and changes happening at times shorter than a time step are only summarized and represented by how they make state variables jump from one time step to the next.
- The temporal extent is usually determined by system-level phenomena produced by the model, whereas temporal resolution is usually determined by the agent-level phenomena driving the model internally.

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Process Overview and Scheduling I

- This element deals with the dynamics of the model: The processes that change the state variables of model entities.
- Every process, with one important exception, describes the behavior or dynamics of the model's entities.
- What are the entities doing?
- What behaviors do the agents execute as simulated time proceeds?
- What updates and changes happen in their environment?
- Succinct descriptions of these issues. Processes usually are treated as sub-models in the final part of the protocol.
- The exception is the observer processes: Observe and record what the model entities do, and why and when they do it.

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Process Overview and Scheduling II

- The ODD protocol includes a description of observer processes because the way we observe a model –the kind of data we collect from it and how we look at those data– can strongly affect how we interpret the model and what we learn from it.
- The schedule defines the order in which the processes are executed by the computer.
- An ABM's schedule, when described well, provides a concise yet complete outline of the whole model.
- A model's schedule can be thought of as a sequence of actions; an action specifies (a) which model entities execute (b) which processes, in (c) what order.

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ask turtles [move]
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Process Overview and Scheduling III

- The ask statement causes the turtles to execute move one at a time, and in randomized order: each time the ask statement is executed, the order in which turtles do move is randomly shuffled.
- Some schedules are simple enough to be described by simply listing the model processes in plain words. Others, more complicated, would require the use of pseudo-code.

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Justification

- This section describes how the model implements a set of basic concepts that are important for designing ABMs.
- Such concepts provide a standardized way to think about very important characteristics of ABMs that cannot be described well using other conceptual frameworks, e.g., differential equations.
- Examples. Emergent outcomes, adaptive decisions, collectives, etc.
- For each one of the eleven design concepts in the ODD protocol, a set of questions is proposed to make design decisions about them conscious.
- Not all of these concepts are relevant for all ABMs.

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Basic principles

1. What general concepts, theories, hypotheses, or modeling approaches underlie the model's design? How is the model related to previous thinking about the problem it addresses?
2. How were these principles incorporated in the model's design? Does the model implement the principles in its design; or address them as a study topic, e.g., by evaluating and proposing alternatives to them?

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Emergence

3. What are the model's important results and outputs? Which of them emerge from mechanistic representation of the adaptive behavior of individuals, and which are imposed by rules that force the model to produce certain results?

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Adaptation

4. What adaptive behaviors do agents have? In what ways can they respond to changes in their environment and themselves? What decisions do they make?
5. How are these behaviors modeled? Do adaptive traits (models of adaptive behavior) assume agents choose among alternatives by explicitly considering which is the most likely to increase some specific objective (direct objective-seeking), or do traits simply force agents to reproduce behavior patterns observed in real systems (indirect objective-seeking)?

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Objectives

6. For direct objective-seeking, what measure of agent objectives, e.g., fitness, utility, etc., is used to rate decision alternatives? This measure is the agent's internal model of how it would benefit from each choice it might make? What elements of future success are in the objectives measure, e.g., survival, profit, etc.? How does the objetive measure represent processes that link adaptive behaviors to important variables of the agents and their environment?
7. How were the variables and mechanisms in the objective measure, e.g., mortality, bankruptcy, etc., chosen considering the model's purpose and the real system it represents? How is the agent's current internal state considered in the modeling decisions? Does the objective measure change as the agents change?

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Learning

8. Do individuals change their adaptive traits over time as a consequence of their experience? If so, how? Reinforcement learning.

Prediction

9. How do agents predict future conditions (environmental and internal) in their adaptive traits? What assumptions about, or mechanisms of, the real individuals being modeled were the basis for how prediction is modeled?
10. How does simulated prediction make use of mechanisms such as memory, learning, or environmental cues? Or is prediction “tacit”: only implied in simple adaptive traits?

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Sensing

11. What variables of their environment and themselves are agents assumed to sense and therefore be able to consider in their behavior?
12. What sensing mechanisms are modeled explicitly, and which sensed variables are agents instead assumed simply to "know"?
13. With what accuracy or uncertainty are agents assumed to "know" or sense which variables? Over what distances in geographic, network, grid, or other space?

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Interaction

14. How do model's agents interact? Do they interact directly with each other, e.g., does one agent directly change the state of others? Or is interaction mediated, such as via competition for a resource?
15. With which other agents does an agent interact?
16. What real interaction mechanisms were the model's representation of interaction based on? At what spatial and temporal scales do they occur?

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Stochasticity

17. How are stochastic processes (based on pseudorandom numbers) used in the model and why?
18. Are stochastic processes used:
    - To initialize the model?
    - Because it is believed important to represent the causes of variability?
    - To reproduce observed behaviors using empirically determined probabilities?

Collectives

18. Are collectives –agregations of agents that affect the state or behavior of member agents and are affected by their members– represented in the model?
19. If so, how are collectives represented? Do they emerge from the traits of agents, or are agents given traits that impose the formation of collectives? Or are the collectives modeled as another type of agent with its own traits and state variables?

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Observation

20. What outputs of the model are needed to observe its internal dynamics as well as its system-level behavior? What tools, e.g., graphics, file output, data on individuals, etc., are needed to obtain these outputs?
21. What outputs are needed to test the model and to solve the problem the model was designed for?

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Initialization

- We must describe how we set up the model World at the beginning of the simulation, because results of the model often depend on these initial conditions.
- Examples. Number of agents created and the initial values given to their state variables, e.g., location, size, etc.; and how the initial values of the environment variables are set.
- Sometimes we want a model's result to depend on its initial conditions, e.g., to undersand how the system responds to a new situation; In other cases, we want to make model results independent of the initial conditions.
- To make results reproducible, we have to specify the initial state of all the state variables of all entities in the model.

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Input Data

- Models often include environmental variables, e.g, temperature or market price that change over time and are read into, instead of simulated within, the model.
- These inputs are usually read in from data files as the model executes. Input here does not refer to parameter values or initialization data, which are also sometimes read in from files at the start of a simulation.

Submodels

- Up to this point, the ODD protocol has specified the skeleton of the model: its entities, state variables, and the names all of the processes and how they are scheduled.
- Here, we put flesh on the bones: all the major processes in the model are considered submodels.
- You can think of a submodel as a model of one process in the ABM; submodels are often almost completely independent of each other and can be designed and tested independently.
- We must describe all equations, logical rules, and algorithms that constitute the submodels. We also need to document why we formulated the submodels as we did, e.g., literature, assumptions, parameter values, test, and calibration.

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Corridors

- Many animals disperse –leave their home location and move long distances for purposes such as mating—at some point in their life.
- Dispersing animals respond to the landscape, avoiding some features and being attracted to others.
- These behavioral responses to the landscape can channel their movement into pathways referred to as corridors –Linear elements in the landscape that facilitate dispersal; e.g., include hedgerows, fences, and vegetation along roads.
- However, our perception of corridors certainly is limited because we can't see the landscape through the animals' eyes. Could it be that some places where we see high numbers of dispersing animals are virtual corridors? Subtle emergence?

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A Model for Corridors

- Pe'Er, Saltz, and Frank [1] chose an extremely simple system in which it is easy to observe real individuals in corridors: mate-finding by butterflies.
- Many butterfly species adopt a hilltopping strategy to mate: They simply move uphill until they are concentrated on hilltops where they can meet and mate.
- The proposed model is an example of how simple a model can be and still capture the essence of a system with regard to a certain question.

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Visually [1]

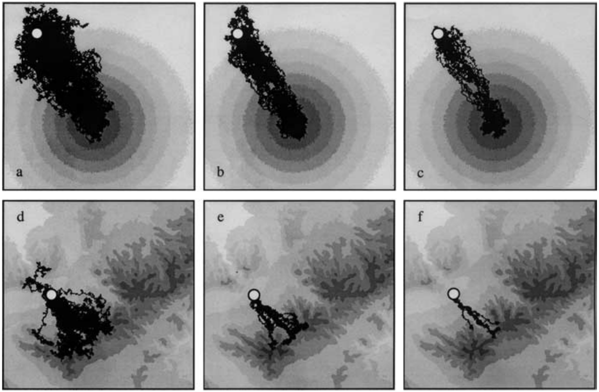

Figure 1. The trajectories of 100 individual butterflies (black marks) moving 1000 time steps from a single source patch (white circle) toward the mountain summit/s on (a–c) a virtual landscape with one summit and on (d–f) a realistic landscape of 7500 × 7500 m (cell size = 25 m). We used different probabilities of the butterflies moving upward (q): (a,d) q = 0.2; (b,e) q = 0.5; and (c,f) q = 0.8. Gray shading reflects elevation (darker is higher).

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Purpose

- The model was designed to explore questions about virtual corridors.
- Under what conditions do the interactions of butterfly hilltopping behavior and landscape topography lead to the emergence of virtual corridors, that is, relatively narrow paths along which many butterflies move?
- How does variability in the butterflies' tendency to move uphill affect the emergence of virtual corridors?

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Entitites, Variables, and Scales

- Entities: butterflies and square patches of land.
- The patches make up a square grid landscape of 150 $\times$ 150 patches, and each patch has one state variable: its elevation.
- Butterflies are characterized only by their location –the x- and y-coordinates of the center of their patch.
- Patch size and the length of one time step in the simulation are not specified because the model is generic.
- But, when real landscapes are used, a patch corresponds to 25 $\times$ 25 m2. Simulations last for 1000 time steps; the length of one time step is not specified but should be about the time it takes a butterfly to move 25–35 m.

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Process Overview and Scheduling

- There is only one process in the model: movement of the butterflies.
- On each time step, each butterfly moves once. The order in which the butterflies execute this action is unimportant because there are no interactions among the butterflies.

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Design principles I

- The basic principle addressed by this model is the concept of virtual corridors –pathways used by many individuals when there is nothing particularly beneficial about the habitat in them.
- This concept is addressed by seeing when corridors emerge from two parts of the model: the adaptive movement behavior of butterflies and the landscape they move through.
- This adaptive behavior is modeled via a simple empirical rule that reproduces the behavior observed in real butterflies: moving uphill.
- This behavior is based on the understanding (not included in the model) that moving uphill leads to mating, which conveys fitness (success at passing on genes, the presumed ultimate objective of organisms).

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Design principles II

- Because the hilltopping behavior is assumed *a priori* to be the objective of the butterflies, the concepts of Objectives and Prediction are not explicitly considered.
- There is no learning in the model.
- Sensing is important in this model: butterflies are assumed able to identify which of the surrounding patches has the highest elevation, but to use no information about elevation at further distances.
- Although real butterflies stop to visit each other on the way uphill, it was decided it is not important to include such interactions in the model.

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Design principles III

- Stochasticity is used to represent two sources of variability in movement that are too complex to represent mechanistically. Real butterflies do not always move directly uphill, likely because of
  1. Limits in the ability of the butterflies to sense the highest area in their neighborhood, and
  2. Factors other than topography (e.g., flowers that need investigation along the way) that influence movement direction.
- This variability is represented by assuming butterflies do not move uphill every time step; sometimes they move randomly instead.
- Whether a butterfly moves directly uphill or randomly at any time step is modeled stochastically, using a parameter q that is the probability of an individual moving directly uphill instead of randomly.

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Design principles IV

- To allow observation of virtual corridors, we will define a specific corridor width measure that characterizes the width of a butterfly's path from its starting patch to a hilltop.

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Initialization

- The topography of the landscape (elevation of each patch) is initialized when the model starts.
- Two kinds of landscapes are used in different versions of the model:
  1. A simple artificial topography, and
  2. The topography of a real study site, imported from a file containing elevation values for each patch.
- The butterflies are initialized by creating five hundred of them and setting their initial location to a single patch or small region.

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Input Data

- The environment is assumed to be constant, so the model has no input data.

Submodels I

- The movement submodel defines exactly how butterflies decide whether to move uphill or randomly.
- First, to move uphill is defined specifically as moving to the neighbor patch that has the highest elevation; if two patches have the same elevation, one is chosen randomly.
- Move randomly is defined as moving to one of the neighboring patches, with equal probability of choosing any patch.
- Neighbor patches are the eight patches surrounding the butterfly's current patch.

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Submodels II

- The decision of whether to move uphill or randomly is controlled by the parameter q, which ranges from 0.0 to 1.0 (a global variable: all butterflies use the same value).
- On each time step, each butterfly draws a random number from a uniform distribution between 0.0 and 1.0. If this random number is less than q, the butterfly moves uphill; otherwise, the butterfly moves randomly.

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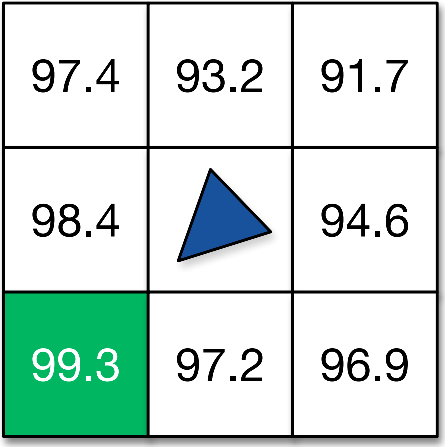
Visually



Benefits

- Describing a model on paper is perhaps the most important part of modeling: very few benefits of modeling can be achieved without it.
- For ABMs, it is especially important to use standard concepts and formats to describe and design models: these models are complex, so we need a clear, standard way to think and write about them.
- The standard languages of differential equations and statistical modeling cannot describe ABMs, so instead we use the ODD protocol and its design concepts.
- Without such a standard, ABMs are often too incompletely described to be replicated, which makes them unscientific.

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Generic and Hierarchical

- ODD is generic and hierarchical.
- Generic means that is can be used to describe any ABM in any field of application or discipline.
- Hierarchical means that it starts with an overview of a model's structure, scales, processes, and scheduling, so we can understand the model's basics, before presenting the details needed to understand how processes are actually represented.
- In between, important concepts underlying the model's design are explained, for example: what key behaviors in the model are emergent instead of being imposed? To what extent and why is stochasticity included? How do we observe model behavior to better understand how model output emerges?

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A Framework

- The ODD protocol provides a very useful framework to think about and formulating ABMs.
- Once a model is written down in ODD format, it is very clear how to translate it into a NetLogo program.

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Referencias I

G Pe'Er, D Saltz, and K Frank. "Virtual corridors for conservation management". In: *Conservation Biology* 19.6 (2005), pp. 1997–2003.

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