CSCU9YM: Modelling for Complex Systems

Lecture 3: Designing Agent-Based Models

Designing agent-based models

- As with all software, ABM should be designed before they can be implemented.
- The Overview, Design concepts, Details (ODD) protocol is a framework for describing the design of an ABM.
- ODD provides a systematic method for documenting and communicating the main elements of an ABM model.

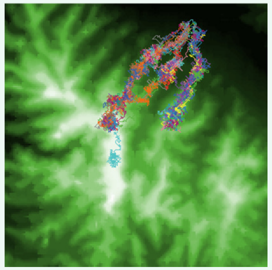
Elements of the ODD Protocol
Overview...
Design concepts...
Details...

- We will look at each of these in depth. But first, let's meet an example which we will use to illustrate the ODD protocol: butterfly corridors

Example: butterfly corridors

- Many animals travel long distances for their own purposes. They choose routes in response to landscape features and their own preferences.
- This can lead to the emergence of "corridors": pathways chosen by large numbers of dispersing animals.
- A 2005 paper (Pe'er et al) studied the movements of butterflies and how corridors emerge in response to the landscape.

- Butterflies prefer to mate at the tops of hills (!)
- They therefore tend to travel uphill.
- However they also may move randomly.
- How does this behaviour create corridors?



ODD Protocol: Overview

Elements of the ODD Protocol
Overview. Purpose Entities, state variables, scales Process overview and scheduling
Design concepts...
Details...

ODD Protocol: Overview: Purpose

- Question (to be asked for all models):

  (1) What is the purpose of the model?

- Answer (Butterfly corridor model):

  – The model is 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?

ODD: Overview: Entities, variables, scales

(2) What entities are represented in the model?

– Two kinds of entities: butterflies and square patches of land in a 150x150 grid.

(3) What are the state variables belonging to each entity?

– A land patch has an **elevation** (height above sea level).

– Butterflies are characterized by their location (the patch they occupy) and have no other state variables.

(4) What are the spatial and time scales represented by the model?

– A patch corresponds to a land area of about 25x25 m^2.

– A time step corresponds to the time it takes a butterfly to move from one patch to a neighbouring patch (a distance of 25 to 35m).

ODD: Overview: Processes and scheduling

(5) What processes are represented in the model?

– The only process that takes place is the movement of the butterflies from patch to patch.

(6) When do the processes take place? Are there any ordering or scheduling constraints?

– On each time step each butterfly moves once. The order in which the butterflies carry out this action does not matter because there are no interactions among the butterflies.

ODD Protocol: Design concepts

Elements of the ODD Protocol
Overview...
Design concepts Basic principles Emergence Adaptation Objectives Learning Prediction Sensing Interaction Stochasticity Collectives Observation
Details...

ODD: Design concepts: basic principles

(7) What general concepts, theories, hypotheses, or modelling approaches underlie the model's design? How is the model related to previous thinking about the problem it approaches?

– The basic principle addressed is the concept of virtual corridors: pathways used by many individuals when there is nothing particularly beneficial about the habitat in them.

(8) 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.

– The concept is addressed by seeing when virtual corridors emerge as a result of the interaction between the butterflies' behaviour and the landscape they move through.

ODD: Design concepts: Emergence

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

– The model's result is the appearance of virtual corridors. These emerge from two parts of the model: the adaptive behaviour of butterflies and the landscape that they move through.

ODD: Design concepts: Adaptation

(10) What adaptive behaviour do agents have? In what ways can they respond to changes in their environment and themselves? What decisions do they make?

– Butterflies follow a simple empirical rule that reproduces the behaviour observed in real butterflies: moving uphill. This behaviour 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).

ODD: Design concepts: Objectives

(11) For adaptive traits modeled as direct objective seeking, what measure of agent objectives (for example, "fitness" in ecology, "utility" in economics) is used to rate decision making alternatives? This objective measure is the agent's internal model of how it would benefit from each choice it might make.

– There is no explicit objective seeking in the butterfly corridor model because it is assumed a priori that butterflies tend to move uphill.

(12) How were the variables and mechanisms in the objective measure chosen considering the model's purpose and the real system it represents? How is the agent's current internal state considered in modeling decisions? Does the objective measure change as the agent changes?

– Not applicable to butterfly corridor model.

ODD: Design concepts: Learning

(13) Do individuals change their adaptive traits over time as a consequence of their experience? If so, how?

– There is no learning in the butterfly corridor model.

ODD: Design concepts: Prediction

(14) How do agents predict future conditions (environmental and internal) in their adaptive traits? What assumptions about, or mechanisms of, the real individuals being modelled were the basis for how prediction is modelled?

– There is no explicit prediction in the butterfly corridor model.

(15) 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?

– Prediction may be viewed as tacit, in that butterflies implicitly predict that hilltopping behaviour leads to mating success. However, mating success is not included in the model.

ODD: Design concepts: Sensing

(16) What variables of their environment and themselves are agents assumed to sense and therefore be able to consider in their behaviour?

– Butterflies can identify which of their surrounding patches has the highest elevation.

(17) What sensing mechanisms are modelled explicitly, and which sensed variables are agents assumed simply to know?

– Butterflies explicitly sense the elevation of neighbouring patches.

(18) With what accuracy or uncertainty are agents assumed to "know" or sense which variables? Over what distances?

– Butterflies can sense the elevation of immediate neighbour patches but have no information about elevation further away. Butterflies may occasionally make errors in sensing (represented by random moves).

ODD: Design concepts: Interaction

(19) How do the 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?

(20) With which other agents does an agent interact?

(21) What real interaction mechanisms were the model's representation of interaction based on? At what spatial and temporal scales do they occur?

– The model does not include interaction among butterflies. Real butterflies apparently do interact (they stop to visit each other on the way uphill) but this is not considered to be important in a model of virtual corridors.

ODD: Design concepts: Stochasticity

(22) How are stochastic processes used in the model and why? Are stochastic processes used: To initialize the model? Or because it is believed important for some processes to be variable but unimportant to represent the causes of variability? Or to reproduce observed behaviours using empirically determined probabilities?

– Stochasticity is used to represent two sources of variability in movement that are two complex to represent mechanistically. Real butterflies do not always move directly uphill, likely because of (a) limits in the ability of butterflies to sense the highest area in the neighbourhood and (b) factors other than topography, such as inviting flowers. This variability is represented by assuming butterflies do not move uphill each time step; sometimes they move randomly instead.

ODD: Design concepts: Collectives

(23) Are collectives (aggregations of agents that affect the state or behaviour of member agents and are affected by their members) represented in the model?

(24) 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 modelled as another type of agent with its own trait and state variables?

– There are no collectives represented in the butterfly corridor model.

ODD: Design concepts: Observation

(25) What outputs from the model are needed to observe its internal dynamics as well as its system-level behaviour? What tools (graphics, file-output, data on individuals, etc) are needed to obtain these outputs?

(26) What outputs are needed to test the model and to solve the problem the model was designed for?

– 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. Plots and file output will be used to obtain this output.

ODD Protocol: Details

Elements of the ODD Protocol
Overview...
Design concepts
Details Initialization Input data Submodels

ODD: Details: Initialization

(27) How is the model initialized, that is, what are the initial condtions at the beginning of a simulation run?

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

ODD: Details: Input Data

(28) What input data does the model need (other than initialization data or parameter data)?

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

ODD: Details: Submodels

(29) Which component parts or processes in the system are represented as independent submodels? What are the details of the representation of these submodels and the assumptions or justifications that underly these?

– The **movement** submodel defines exactly how butterflies decide whether to move uphill or randomly. First to **"move uphill"** is defined as moving to the neighbour patch with the highest elevation. If two patches have the same elevation, one is chosen randomly. **"Move randomly"** is defined as moving to one of the neighbouring patches, with equal probability of choosing any patch. "Neighbour patches" are the 8 patches surrounding the butterfly's current patch. The decision how to move (uphill or randomly) is controlled by a parameter *q*, which lies in the range 0.0 to 1.0. On each time step, each butterfly picks a random number from 0.0 to 1.0; if this is less than *q* the butterfly moves uphill; otherwise it moves randomly.

Network structures

- The ODD protocol does not include any questions that explicitly address use of network structures. I believe this is an oversight, because network structures are an important aspect of many models and should be described explicitly.

- Network structures are generally used for one/both of two purposes:

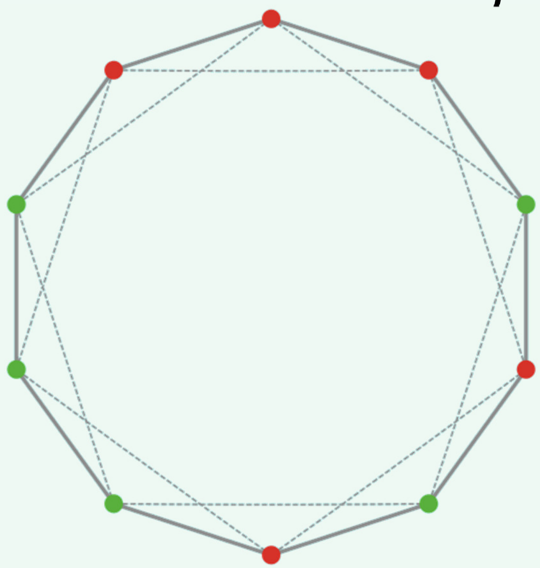
  – Modelling how space is structured. In this case, the network should be described as part of the general description of how space is modelled (question 4 in the "Overview" section).

  – Modelling which agents interact. In this case, the network structure should be described under "interaction" (questions 19-21 in the "Design" section).

Network structure: example

- In this example, networks are used to model both spatial structure and interaction:
  - Model of farmers' responses to a conservation incentive scheme.
  - The scheme aims to incentivize neighbouring farms to manage their land in the same way, to create larger areas of contiguous habitat.
  - Space is modelled using farms arranged on a ring (e.g. farms along a riverbank, simplified so all farms have 2 neighbours).
  - Interaction (representing sharing of information about choices whether to participate in the scheme and payments received) is modelled using various different network structures, e.g.
    - » *Information spill-over*, where information is shared with both direct and indirect neighbours (modelled using a *ring lattice* network, shown on next slide).

Network structure: example (continued)



- Green circles: farms adopting conservation scheme
- Red circles: farms not adopting conservation scheme
- Solid lines: spatial network
- Broken lines: information sharing network

End of lecture