Agent Based Modelling Chp1

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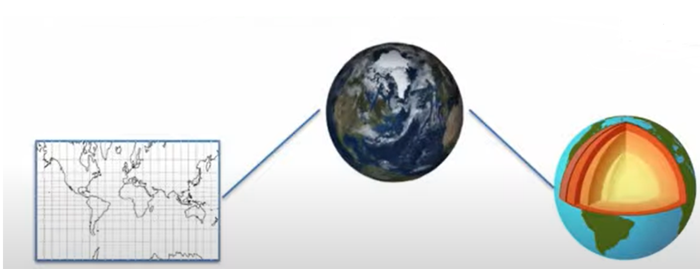
Introduction

Agent Based Modelling can help us find better solutions to many problems important to our environment, health, economy and so on. The common feature of these problems is that they occur in systems composed of "autonomous" *agents* that **interact** with **each other** and their **environment**, differ from each other and over space and time and have behaviours that are often very important to how the system works.

Models

"*A model is a purposeful representation of some real system.*"

Essentially a model is an **abstracted** description of a system that exaggerates certain aspects at the expense of others. The important point here is that it is **abstracted**, it is not a perfect representation, it does not perfectly match up with the real world, the important thing is that it exaggerates certain aspects at the expense of others. The perfect model is not the model that best represents the world around us but instead is a model that in some ways exaggerates the aspects of the world we are more interested in and can help us solve the problems we are looking at.



"*Essentially all models are wrong, but some are useful*"

Models are like political cartoons. They exaggerate and blow up certain aspects while backgrounding and hiding other aspects, so you can concentrate on the aspects they are trying to make a point about.

We build and use models to solve problems or answer questions about a system or class of systems.

Real systems are often too complex to model therefore we try to formulate a simplified representation of the system using equations or computer programs that we can then manipulate and experiment on.

There are often many ways of representing a real system in a simplified way, so how do we know which aspects to include? The answer this, the **model's purpose is decisive**. This means that the question we want to answer serves as a filter. All those aspects of the real system considered irrelevant for answering the question are filtered out.

Furthermore when creating a model how do we know whether a certain factor is important or not? The answer is we cant! That is exactly why we must **formulate, implement and analyze** a model because then we can use mathematics and computer logic to rigorously explore the consequences of our simplifying assumptions.

Our first formulation of a model must be based on our preliminary understanding of how the system works, what the important elements and processes are etc. These preliminary ideas might be based on empirical knowledge of the system's behaviour, on earlier models addressing similar questions , on there and so on. This means if we have no idea whatsoever of how the system works, we cannot formulate a model.
For example: even though scientist are happy to model almost everything, so far there seems to be no explicit model of human consciousness, simple because we have no clue what consciousness really is and how it emerges.

Because the assumptions in the first version of a model are experimental, we have to test whether they are appropriate and useful. For this, we need criteria for whether the model can be considered a good representation of the real system. These criteria are based on patterns or regularities that let us identify and characterize the real system in the first place.
For example: stock market models should produce the kinds of volatility and trends in prices we see in the real markets.

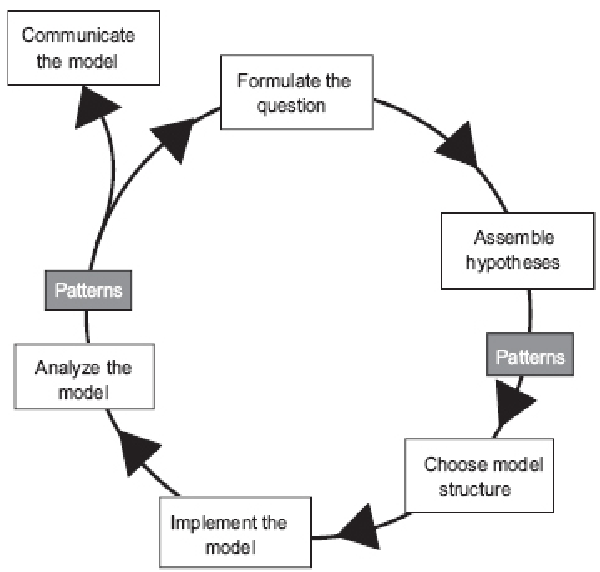
Often we find that first versions of models are too simple and lack important processes and structures. We thus go back and revise our simplifying assumptions.

The Model Cycle

Scientific Modeling means iterating to go through tasks in a systematic way and to use mathematics and computer algorithms to rigorously determine the consequences of simplifying assumptions that make up our models.

Being scientific always means iterating through the tasks of modeling several times, because our first model can always be improved in some way: they are too simple/complex or they made us realize that we were asking the wrong questions. We therefore view modeling as iterating through the **modeling cycle**.

Iterating does not mean we that we always go through the full cycle rather we often go through smaller loop i.e between problem formulation and verbal formulation of the model. The modeling cycle consists of the following tasks:



1. **Formulate the question** - We need to start with a very clear research question because this question then serves as the primary compass and filter for designing a model. Often, formulating a clear and productive question is by itself a major task because a clear question requires a clear focus. For complex systems, getting focused can be difficult. Very often, even our questions are only experimental and later we might need to reformulate the questions, perhaps because it turned out to be not clear enough, or too simple, or too complex.

2. **Assemble hypotheses for essential processes and structures** - Agent based modeling is "naive" in the sense that we are not trying to aggregate agents and what they are doing in some abstract variables like abundance, biomass, etc. Instead, we naively and directly represent agents and their behaviour. We create these agents, put them in a virtual environment, then let the virtual world run and see what we can learn from it. Usually we have to formulate many hypotheses for what processes and structures are essential to the question or problem we address. We can start top-down and ask ourselves questions such as:

- What factors have a strong influence on the phenomena of interest?
- Are these factors independent or interacting?
- Are they affected by other important factors?

We might draw so-called influence diagrams, flowchart or just caricatures of our system and question. But whatever technique we prefer this task has to combine existing knowledge and understanding, a "brainstorming" phase in which we wildly hypothesize and most importantly simplification phase.

We have to force ourselves to simplify as much as we can or even more. The modelling cycle must be started with the most simple model possible, because we want to develop understanding gradually, while iterating through the cycle. A common mistake in beginners is to throw too much in the first model version usually arguing that all these factor are well known and cant be ignored. Then the answer of the modeling expert is "yes, you might be right, but let us focus on the absolute minimum number of factor first. Put all other elements that you think might need to be in the model on your "wish list" and check their importance later."
The reason for this advice is this: just our preliminary understanding of a system is not sufficient for deciding whether things are more or less important in a model. It is the very purpose of the model to teach us what is important. So, it is a wise to have a model implemented as soon as possible, even if it is ridiculously simple. But the simpler the model is, the easier it is to implement and analyze, and the sooner we are productive. The real productive phase in a modelling project starts when we get the modeling cycle running: assumptions-implementations-analyses-interpretation-revised assumptions and so on.

It is difficult to formalize this task the modeling cycle. One important help is heuristics for modeling: rules of thumb or "assist in finding approximate solutions to complex problems" that are often, but not always, useful for designing models. We point out these heuristics throughout this book; use the index to find them.

3. **Choose scales, entities, state variables, processes and parameters** - Once we choose some simplifying assumptions and hypotheses to represent our system of interest, it is time to sit down and think through our model in detail. We thus produce a written formulation of the model. Producing and updating this formulation is essential for the entire modeling process, including delivery to our "clients". For example in the mushroom hunt example: specifying how the space that hunter moves through is represented, what kinds of objects are in the model, the state variables or characteristics of the hunter and exactly how the hunter searches.

4. **Implement the model** - This is the most technical part of the modeling cycle, where we use mathematics and computer programs to translate out verbal model description into an "animated" object. Why "animated" because in a way the implemented model has its own independent dynamics, driven by internal logic of the model. Our assumptions may be wrong or incomplete but the implementation itself is barring software always right: it allows us to explore, in a logical and rigorous way the consequences of our assumptions and see where our initial model looks useful.

5. **Analyze, test and revise the model** - Task analyzing a model and learning from it is the most time consuming and demanding is the most work. With tool like NetLogo you will learn to quickly implement your own ABMs. But doing science with ABMs requires much more. Much of this book will be devoted to this task: How can we learn from our models? We do not just want to see what happens when we create some agents and make up their behaviours we want to see what agent behaviours can explain and predict important characteristics of real systems.

Agent Based Modeling

An agent based model is a model composed of agents.
An agent is an "autonomous" individual element with properties and actions in a computer simulation.
An agent based modeling is the idea that the world can be modelled using agents, an environment and a description of agent-agent and agent-environment interactions.

ABMs represent a system's individual components and their behaviors. Instead of describing a system with only variables representing the state of the whole system, we model its individual agents.

ABMs are thus models where individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally.

Agents may be organisms, humans, businesses, institutions, and more. An agent can be any entity that pursues a goal.

Being **unique** implies agents usually are different from each other in characteristics such as size location, resources reserves and history.

Interacting **locally** means agents usually do not interact with <u>all</u> other agents but only with their neighbors-in geographic space (or in some other kind of "space" such as a network).

Being **autonomous** implies that agents act independently of each other and pursue their own objectives. I.e organisms strive to survive and traders in stock market try to make money.

Agents therefore use **adaptive behavior** in that they adjust their behavior to the current states of:

- themselves
- of other agents
- of their environment

Using ABMs let us address problems that concern **emergence**: system dynamics that arise from how the systems individual components interact with and respond to each other and their environment.

Hence with ABMs we can study questions of how a systems behavior arises from and is linked to, the characteristics and behaviors of its individual components. What kinds of questions are these:

- How can we manage tropical forests in a sustainable way, maintaining both economic uses and biodiversity levels critical fro forests" stability properties
- What causes complex and seemingly unpredictable dynamics of a stock market? Are market fluctuations caused by dynamic behavior of traders, variations in stock value, or simple the markets trading rules.

ABMs are useful for problems of emergence because they are **across level** models. ABMs are different to traditional modeling as they are concerned with two (sometimes more) levels and their interactions:

- we use them to both look at what happens to the **system** because of what its **individuals** do
- what happens to the **individuals** because of what the **system** does

So throughout this course there will be a focus on modelling behavior of agents and at the same time, observing and understanding the behaviour of the system made up by the agents.

ABMs are also different from traditional models in being "unsimplified" in other ways, such as representing how individuals and the environment variables that affect them, vary over space, time, or other dimensions. ABMs often include processes that we know to be important but are too complex to include in simpler models.

This course is designed to give you three very important skills for ABMs:

- A new language for thinking about and describing models. Because we cannot define ABMs concisely or accurately in the languages of differential equations or statistics, we need a standard set of concepts (e.g emergence, adaptive behavior, interaction, sensing) that describe the important elements of ABMs.
- The software skills to implement models on computers and to observe, test, control and analyze the models. Producing useful software is more complex for ABMs than fro most other kinds of models.
- Strategies for designing and analyzing models. There is almost no limit to how complex a computer simulation model can be, but if a model is too complex it quickly becomes too hard to parameterize, validate and analyze. We need a way to determine what entities, variables and processes should and should not be in a model and we need methods for analyzing a model, after it is built, to learn about the real system.

Full fledged ABMs assume that agents are different from each other; that they interact with only some, not all other agents; that they can have different "life cycles" or stages the progress through, possibly including birth and death; and that they make autonomous adaptive decisions to pursue their objectives. However as with any model assumption, assuming that these individual-level characteristics are important is experimental. It might turn our that for many questions we do not explicitly need all or even any of these characteristics. And in full fledged ABMs are quite rare.
For example: Many useful ABMs include only one individual-level characteristic, local interactions. Thus although ABMs are defined buy the assumption that agents are represented in some way, we still have to make many choices about what type of agents to represent and in what detail.

Because most model assumptions are experimental, we need to test our model: we must implement the model and analyze its assumptions. For complex systems we usually deal with in science, just thinking is not sufficient to rigorously deduce the consequences of our simplifying assumptions: we have to let computer show us what happens. We thus have to iterate through the modeling cycle.

Conclusion

In this chapter the goal was to provide some fundamental and important ideas about modeling and agent-based modeling.

Whenever you find yourself frustrated with either your own model or someone else's, in "big-picture" ways *(What exactly does this model do? Is it a good model or not? Should I add this or that process to my model? Is my model "done"?)*, it could be useful to review these fundamental ideas.

They are in summary

- A model is a purposeful simplification of a system fro solving a particular problem.
- We use ABMs when we think it is important for a model to include the systems individuals and what they do
- Modeling is a cycle of:
  - Formulating a precise questions
  - Assembling hypotheses for key process and structures
  - Formulating the model by choosing appropriate scales, entities, state variables. processes and parameters
  - Implementing the model in a computer program
  - Analyzing, testing and revisiting

Understanding the modeling cycle is so extremely important. In fact a recent review of modeling practises concluded that explicitly thinking about and documenting each step in the cycle is the primary way we can improve how are models are developed and used.

It is very important that you have a very basic understanding of these ideas from the start but for the rest of part 1 we will focus on obtaining a basic understanding of how to implement models on the computer.

In the rest of this course, however, we will come back to modeling ideas. As soon as you have some ability to program and analyze your own models and some understanding of how to use these modeling concepts you will rapidly become a real modeler.