Models and the modelling cycle
Overview - aims

• Overall aim (Course Learning Outcome 1):
  "explain how computational modelling frameworks can be used to understand the behaviours of complex interacting systems involved in sustainability such as social, economic and ecological systems"

• This lecture:
  • What are models? And why do we build models?
  • The modelling cycle – the iterative process of designing, implementing and analysing models to understand systems.
  • Introduction to agent-based models and system dynamics models.
Books

See "Resource List" on course website for links to online versions – chapters to read indicated in Schedule

Railsback and Grimm, Edition 1
Edition 2 if fine if you are buying.
For agent-based modelling.

Meadows
For philosophy of systems thinking and system dynamics approach

Mobus and Kalton
For principles of systems thinking
What are models?
Why do we build them?
What is a model?

What makes this... Lego Expert Builder set 952. David Sterratt

... a model of this? Massey Fergusson 135. Credit: Lyle Buist

Is it a **good** model? Would you change anything about the model?
Definition of a model

• A model is a **purposeful representation** of some **real system**.  
  - *Starfield et al. (1990), quoted in Railsback & Grimm*

• **Purpose** - the "why"
  • Understand a system
  • Answer a question
  • Solve a problem
  • *Make predictions or explore scenarios*

• **Representation** – the "how"
  • Will be simplified
  • Level of detail depends on purpose
  • Does not need to be detailed to be useful
Types of model

• Physical model
• Mental (language-based) model
• Visual model - boxes and arrows
• Mathematical model
• Biological sciences: animal model
• Each has its own advantages and disadvantages
Computational modelling

• The representation of objects is by digital objects
  • Program
  • Simulation package
• Once built, the representation can be used to generate a simulation of the behaviour of the system
• Very simple models can sometimes be formulated mathematically, which can give insights into more complex models
• Crucially, the purpose should drive creating the representation, and there is almost always no "right" way to do this.
• Advantages: ability to do "what if" runs
• Disadvantages: numeric outputs can give false sense of certainty
Example: Mushroom hunting

• **Purpose:** discover what a good strategy is for finding mushrooms in a forest

• **What we know:**
  • We can only see mushrooms at close range
  • Mushrooms often appear in clumps

• **Representation:**
  • What do we need to include?
  • What should we ignore?
Mushroom hunt model

• Ignore:
  • Types of trees
  • Types of mushroom
  • Topography of the landscape

• Include:
  • Mushrooms as points in a 2D grid
  • Mushroom hunter as a moving point in the environment that can sense nearby mushrooms and has a search strategy
The modelling cycle
The modelling cycle

- An *iterative* process
1. Formulate the question

- Question serves as primary guide in constructing the model
- Formulating a clear question can be a major task
  - Especially difficult for large, complex systems
- May need to reformulate the question after further work
- Question for mushroom hunter example: "What search strategy maximises the rate of finding items if they are distributed in clusters?"
2. Assemble hypotheses for essential processes and structures

- Ask ourselves questions like:
  - What factors influence strongly the phenomena we're modelling?
  - Are the factors interacting or independent?
- Draw influence diagrams or flow charts
- Simplify!
  - Put details on a "wish list" for after you've got a simple model working
- Heuristics and **pattern-orientated** modelling help
- Mushroom hunter e.g.: Essential process is switching between large scale "scanning" and small scale "searching"
Aside: patterns

- A **pattern**, sometimes referred to in economics as a **stylised fact** can be defined as:
  "Stylised facts are broad but not necessarily universal generalisations of empirical observations and describe essential characteristics of a phenomenon that call for an explanation" (Heine et al. 2007, after Kaldor 1961, quoted in Railsback and Grimm)

- Mushroom hunter: a "pattern" is the pattern of long-range scanning and short range searching
3. Choose model structure

- Details of model
  - scales, entities, state variables, processes and parameters

- Written formulation of the model
  - Next lecture: the Overview, Design Concepts, Details (ODD) protocol
  - Important for both our own thinking and communication with "clients", e.g. journal reviewers, line manager, course lecturers

- Mushroom hunt example
  - **Scales**: Space represented by squares the size that the hunter can search in one time step
  - **Entities**: hunter and mushrooms
  - **State variables**: time hunted; number of mushrooms found; time since finding last mushroom
  - **Processes**: Long-range scanning; short-range searching
  - **Parameters**: Range of randomly-selected turning angles when in and out of a cluster
4. Implement the model

• Translate the verbal model description into a computational model, perhaps using a modelling package
  • An implementation
  • A precise formulation of a theory

• Run the model implementation
  • Generate predictions from the theory precisely
  • We call a run of a model a simulation
  • Uncertainty: A stochastic (random) model gives different results on each run

• A simulation is an "animated" object (Lotka 1925)
  • Own independent dynamics – its own "life"
  • Our theory/model may be wrong, but (apart from programming errors) the implementation is always right.
5. Analyse, revise and test the model

• The most time-consuming part of the process
• Implementation can be quick, but doing the science takes longer
• Mushroom hunter example: what search algorithms and parameter values give the highest rate of finding mushrooms
• Uncertainty in parameters leads to uncertainty in results
6. Communicate the model

- We need to communicate to other scientists, the public, media
  - In a variety of formats: journal article, press release, infographic
  - Communicate the range of predictions (uncertainty) and limitations
  - You understand the model, but can you convince me that it makes sense?

- You also need to communicate to the future you
  - You understand the model now, but will you be able to in a year's time?
  - Document, document, document!

- Communication is promotes modelling discipline and thinking
  - Document what you've done and learned to work out where you're going next
Introduction to agent-based models and systems dynamics models
Agent based models

• Defined as "models where individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally" (Railsback and Grimm)

• Represent system components and behaviours as individual agents with behaviours:
  • E.g. the mushroom hunter, the mushrooms, scanning and searching behaviour.
  • E.g. Stock traders, cars, bikes, businesses

• Agents have their own characteristics, history and goals

• More complex than "traditional" models, that represent total numbers of agents
system dynamics models

• Stocks and flows
• Turn into differential equations
Example – predator prey

• Question: if we have predators and prey in an ecosystem, how do their population sizes evolve over time?

• Hypotheses:
  • Grass grows at a constant rate
  • Sheep eat grass – the more grass there is the quicker they can breed
  • Wolves eat sheep – the more sheep there are, the faster wolves breed; the more wolves there are the faster sheep are eaten
  • Sheep and wolves both die at a rate proportional to their population
Agent-based approach

- Grass (in environment)
  - Regrows after time
- Sheep agent
  - Spends energy to move
  - Gains energy from eating grass
  - Dies when it runs out of energy
- Wolf agent
  - Spends energy to move
  - Gains energy from eating sheep
  - Dies when it runs out of energy
System dynamics approach (ignoring grass)

• Assume sheep are born at a fixed rate (no grass)
Summary

• Modelling
• The modelling cycle
• Introduction to agent-based and system dynamics models

Next:
  • Lecture: how to analyse a system and formulate a model
  • Lab next week: build the mushroom-hunter model