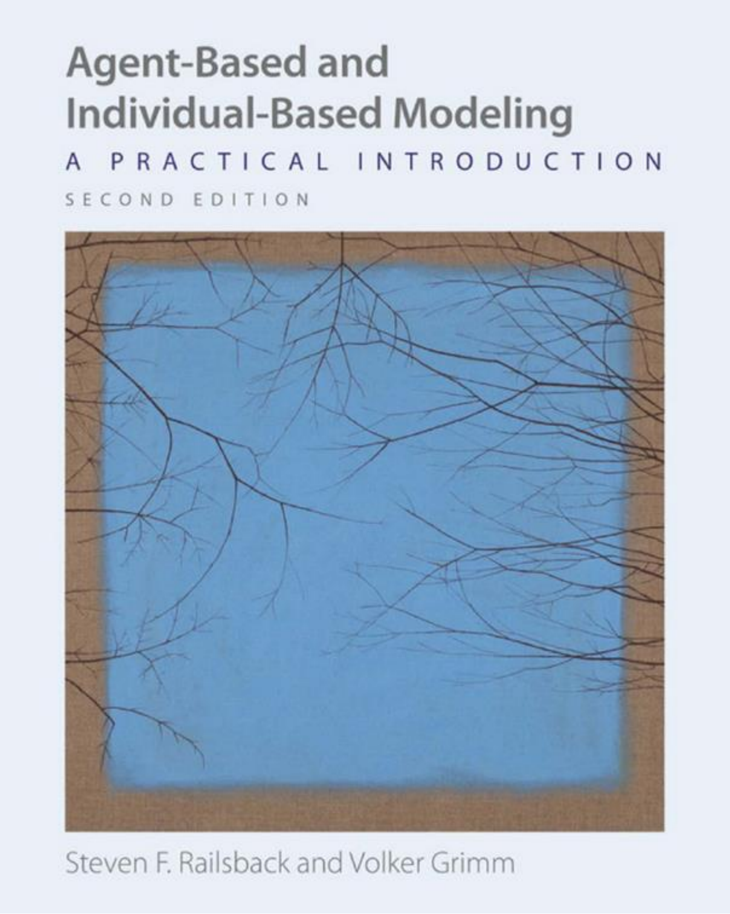
Models and the modelling cycle

Overview - aims

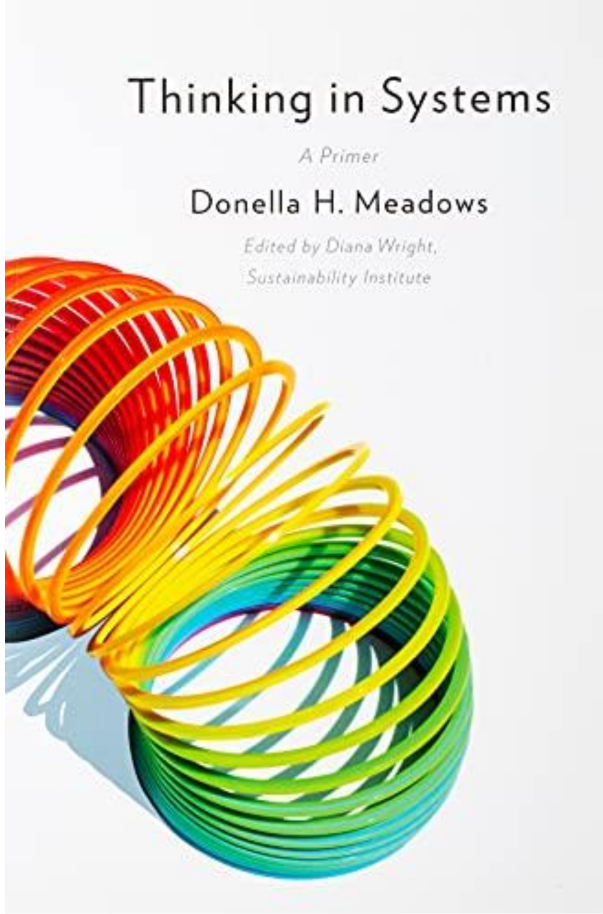
- Overall aim (Course Learning Outcome 1):
  "explain how computational modelling frameworks can be used to understand the behaviours of complex interacting systems involved in sustainability such as social, economic and ecological systems"
- This lecture:
  - What are models? And why do we build models?
  - 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

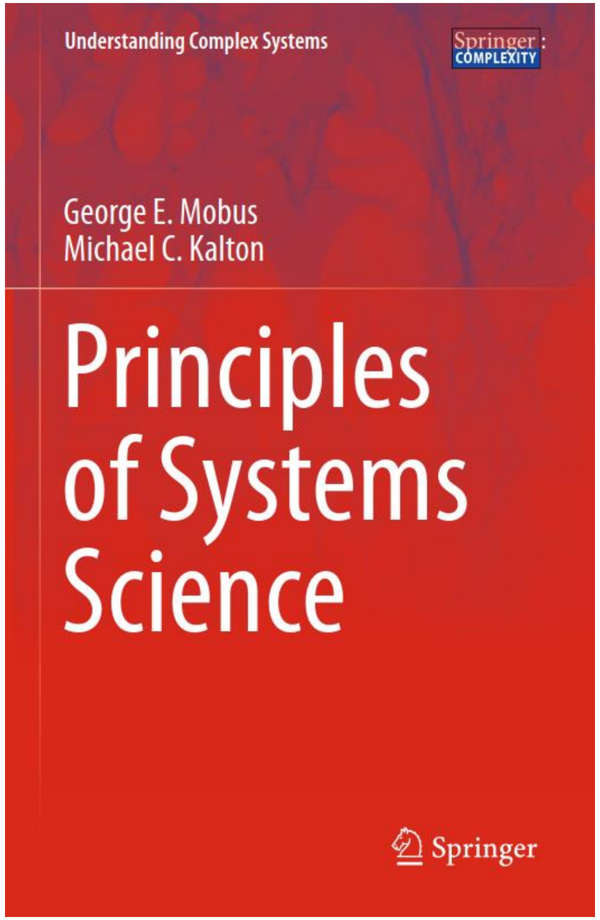
See "Resource List" on course website for links to online versions – chapters to read indicated in Schedule



Railsback and Grimm, Edition 2
For agent-based modelling and ODD



Meadows
For philosophy of systems thinking and system dynamics approach

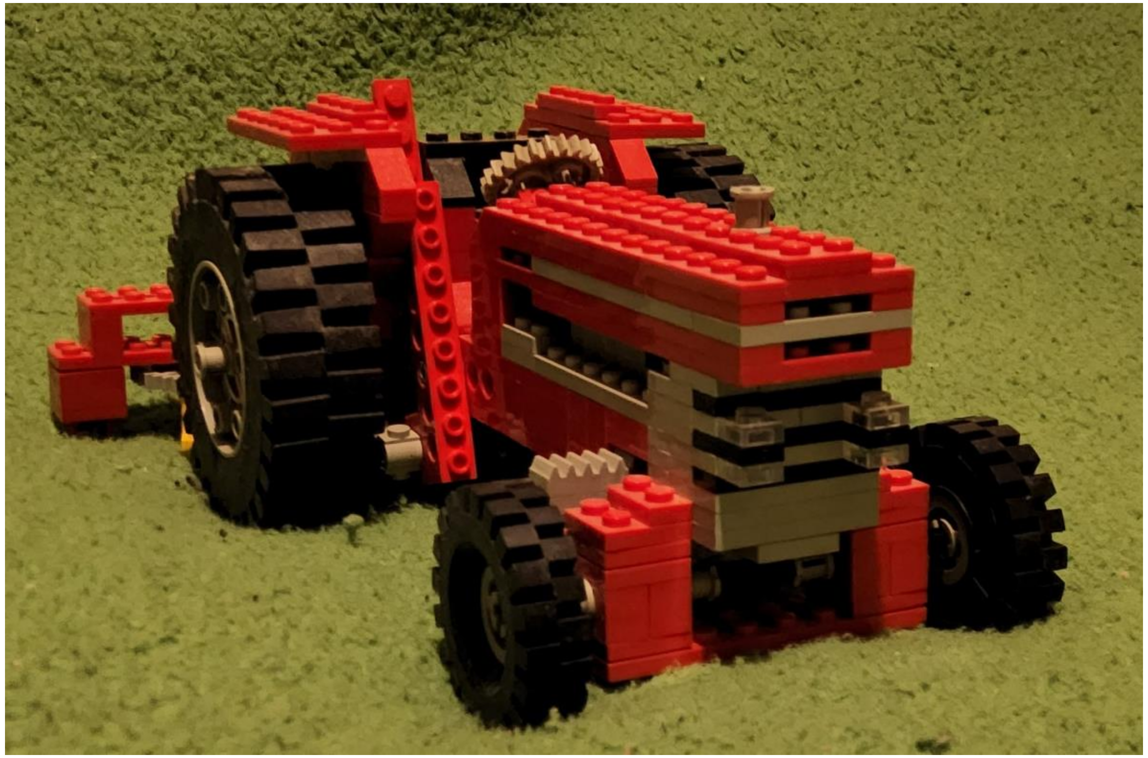


Mobus and Kalton
For principles of systems thinking

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

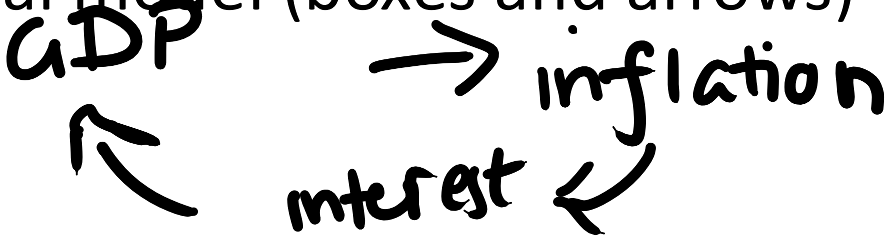
- A model is a **purposeful representation** of some **real system.**
  - *Starfield et al. (1990), quoted in Railsback & Grimm*
- **Purpose** - the "why"
  - Understand a system
  - Answer a question
  - Solve a problem
  - *Make predictions or explore scenarios*
- **Representation –** the "how"
  - Will be simplified
  - Level of detail depends on purpose
  - Does not need to be detailed to be useful

Types of model

Mental (language-based) model

"The economy does well, so inflation goes up, so then interest rates rise, when then reduces spending... etc."

Visual model (boxes and arrows)

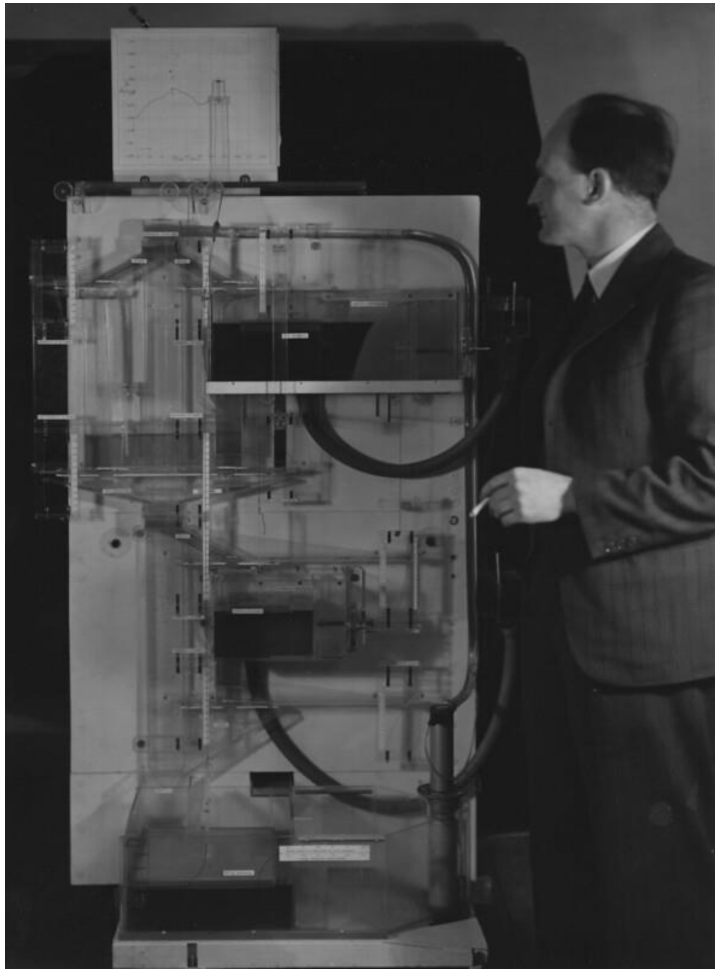


Mathematical model

$$\frac{dI}{dt} = \gamma G(t - \tau)$$

$$\frac{dR}{dt} = \delta I(t - \tau)$$

Physical model (or analouge)



LSE Library, public domain

Animal model (Biology)

Rama, Wikipedia CC BY-SA 3.0

Statistical model

Each type has advantages and disadvantages

Computational modelling

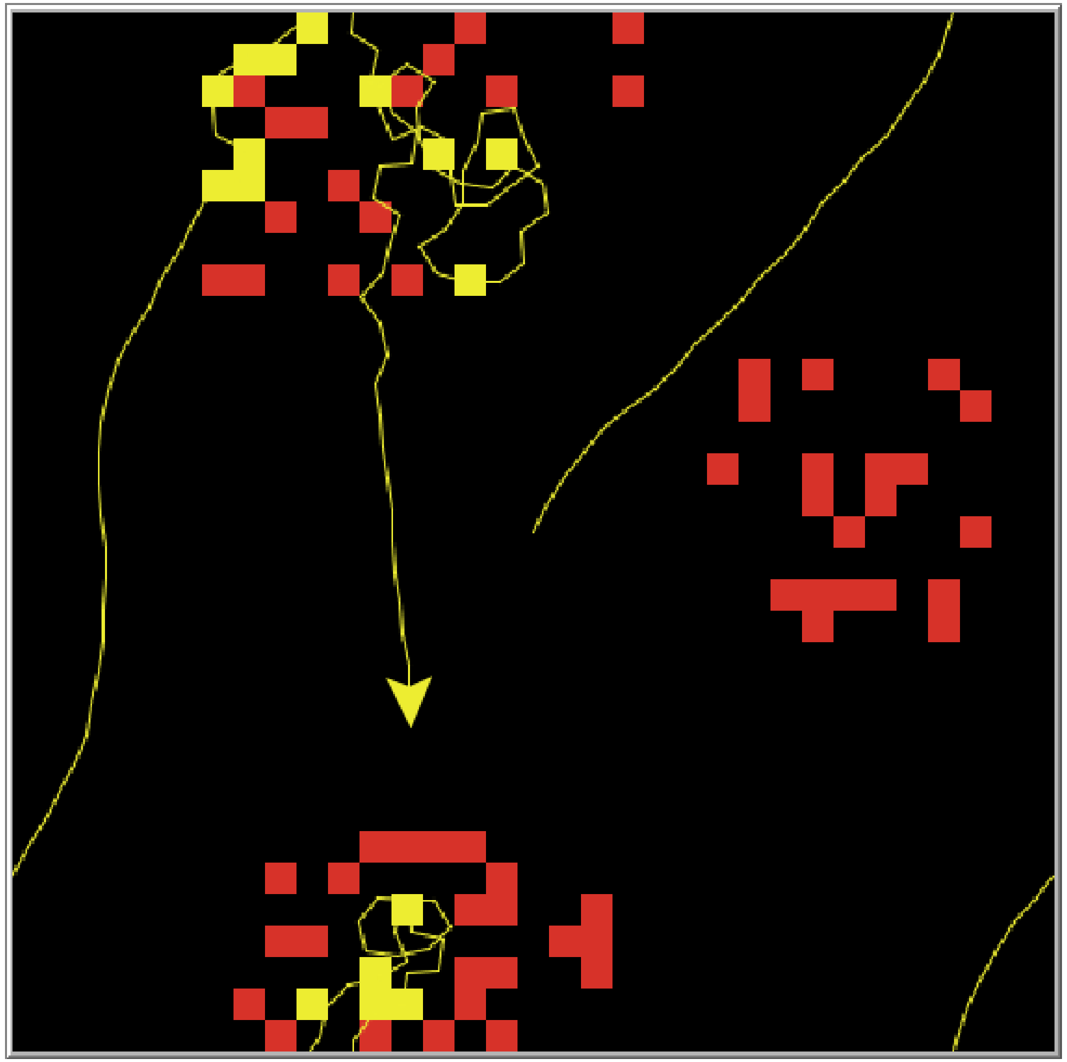
- The representation of objects is by digital objects
  - Program
  - Simulation package
- Once built, the representation can be used to generate a **simulation** of the behaviour of the system
- Very simple models can sometimes be formulated mathematically, which can give insights into more complex 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

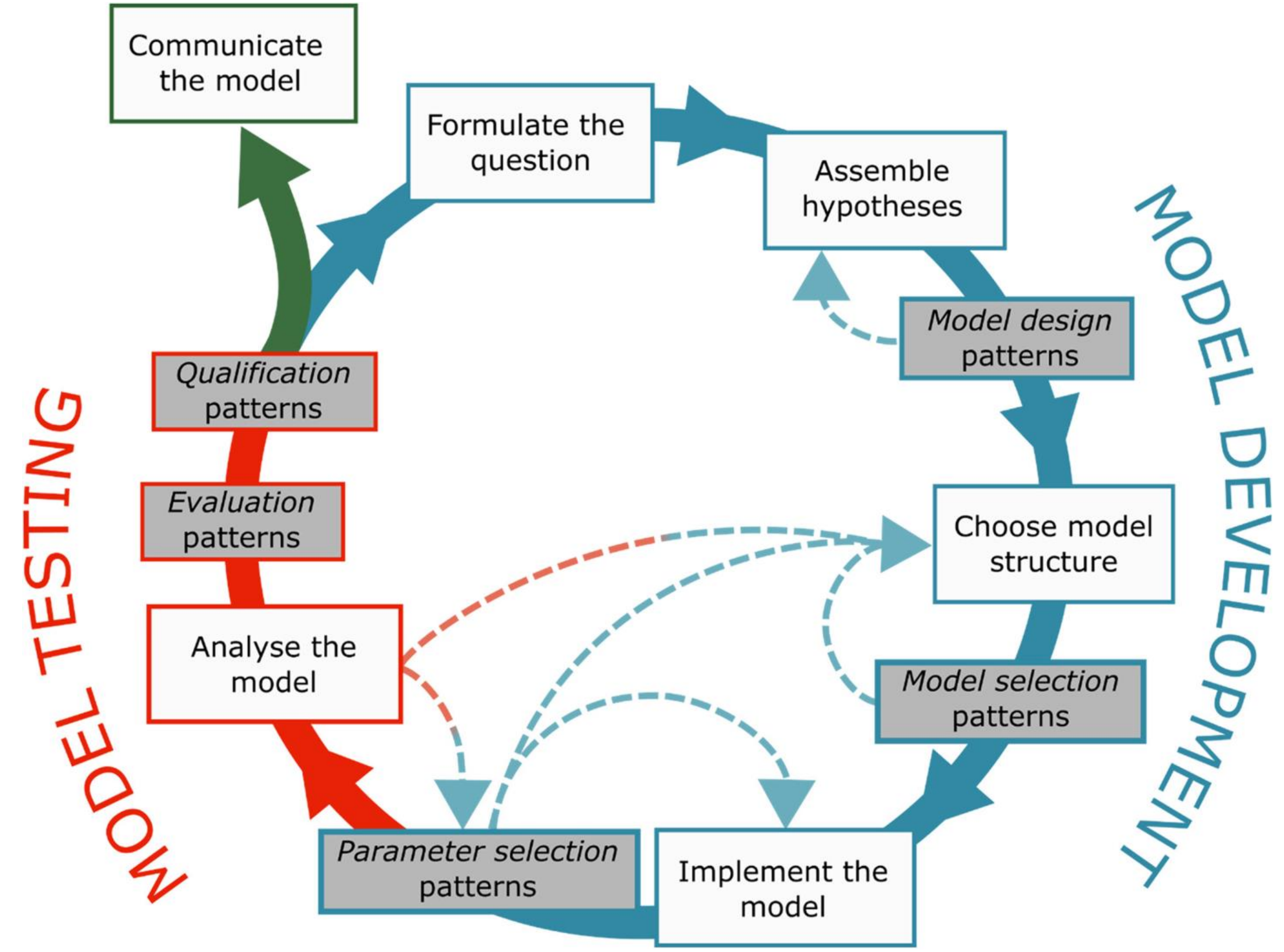
- Ignore:
  - Types of trees
  - Types of mushroom
  - Topography of the landscape
- Include:
  - Mushrooms as points in a 2D grid
  - Mushroom hunter as a moving point in the environment that can sense nearby mushrooms and has a search strategy



The modelling cycle

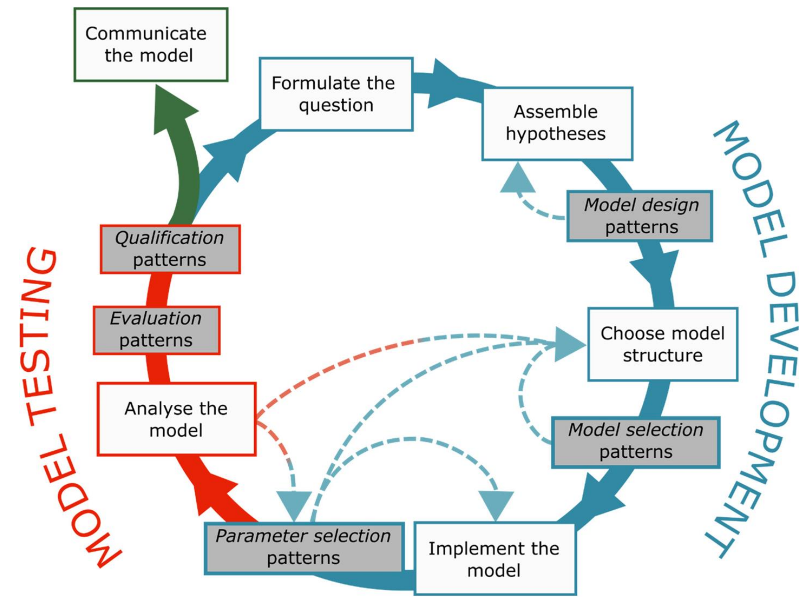
The modelling cycle

- An **iterative** process



Gallagher et al. Biological Reviews, Volume: 96, Issue: 5, Pages: 1868-1888, First published: 12 May 2021, DOI: (10.1111/brv.12729) . CC-BY-4.0

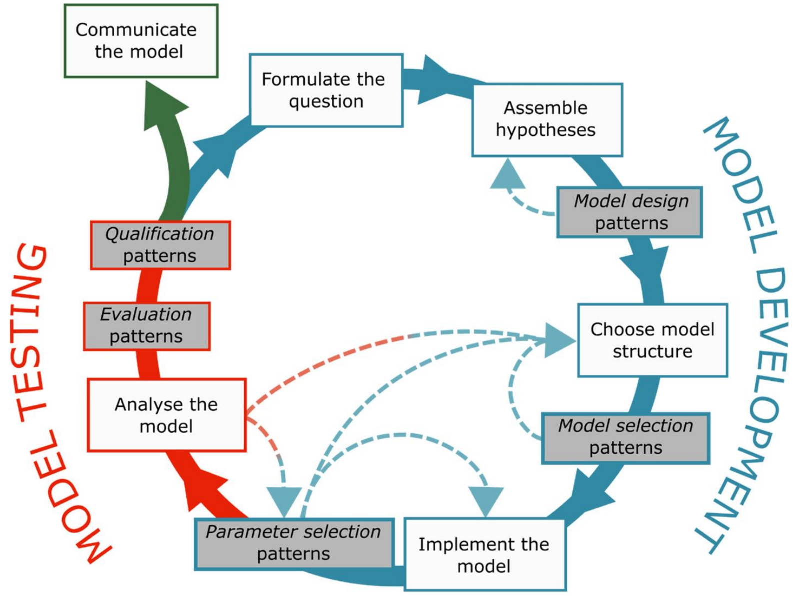
1. Formulate the question

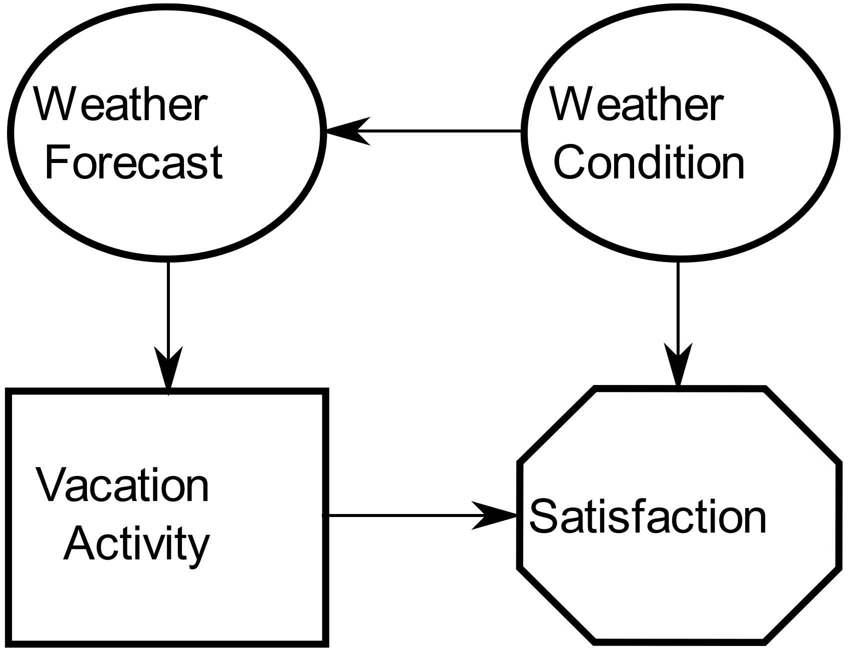


- Question serves as primary guide in constructing the model
- Formulating a clear question can be a major task
  - Especially difficult for large, complex systems
- May need to reformulate the question after further work
- Question for mushroom hunter example: "What search strategy maximises the rate 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"



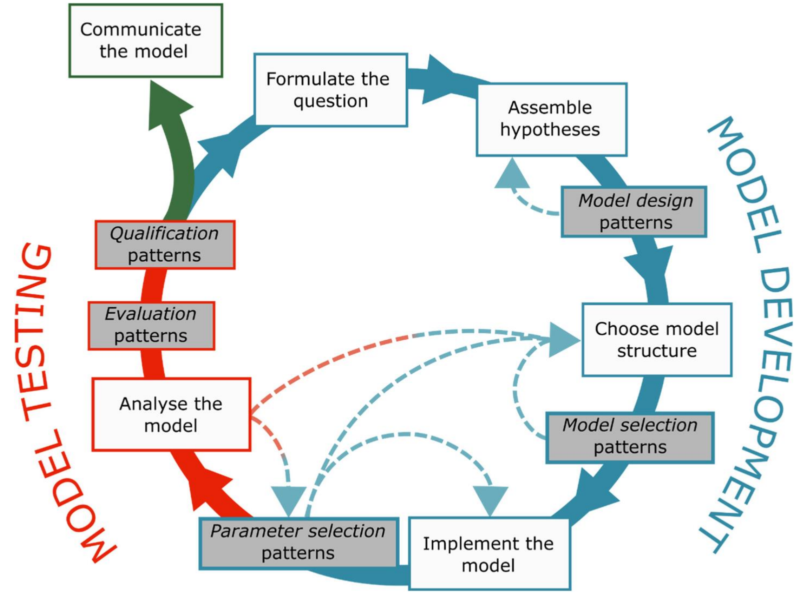


Wikipedia article on Influence Diagrams

Aside: patterns

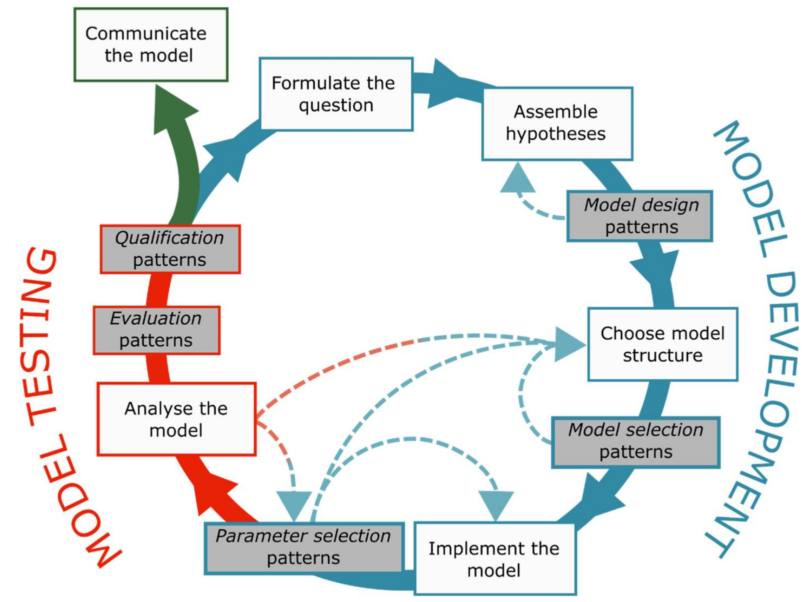
- A **pattern**, sometimes referred to in economics as a **stylised fact** can be defined as:
  "Stylised facts are broad but not necessarily universal generalisations of empirical observations and describe essential characteristics of a phenomenon that call for an explanation" (Heine et al. 2007, after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

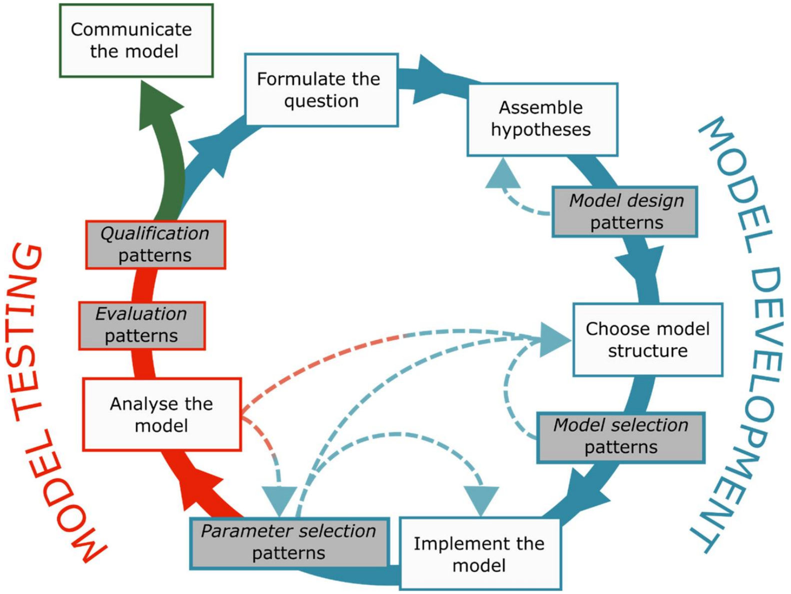
4. Implement the model



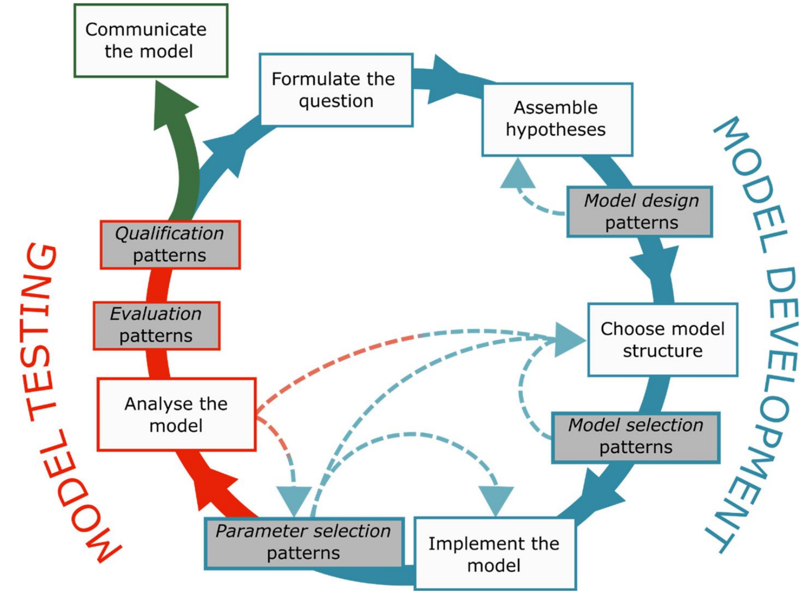
- Translate the verbal model description into a computational model, perhaps using a modelling package
  - An implementation
  - A precise formulation of a **theory**
- Run the model implementation
  - Generate **predictions** from the **theory** precisely
  - We call a run of a model a **simulation**
  - 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

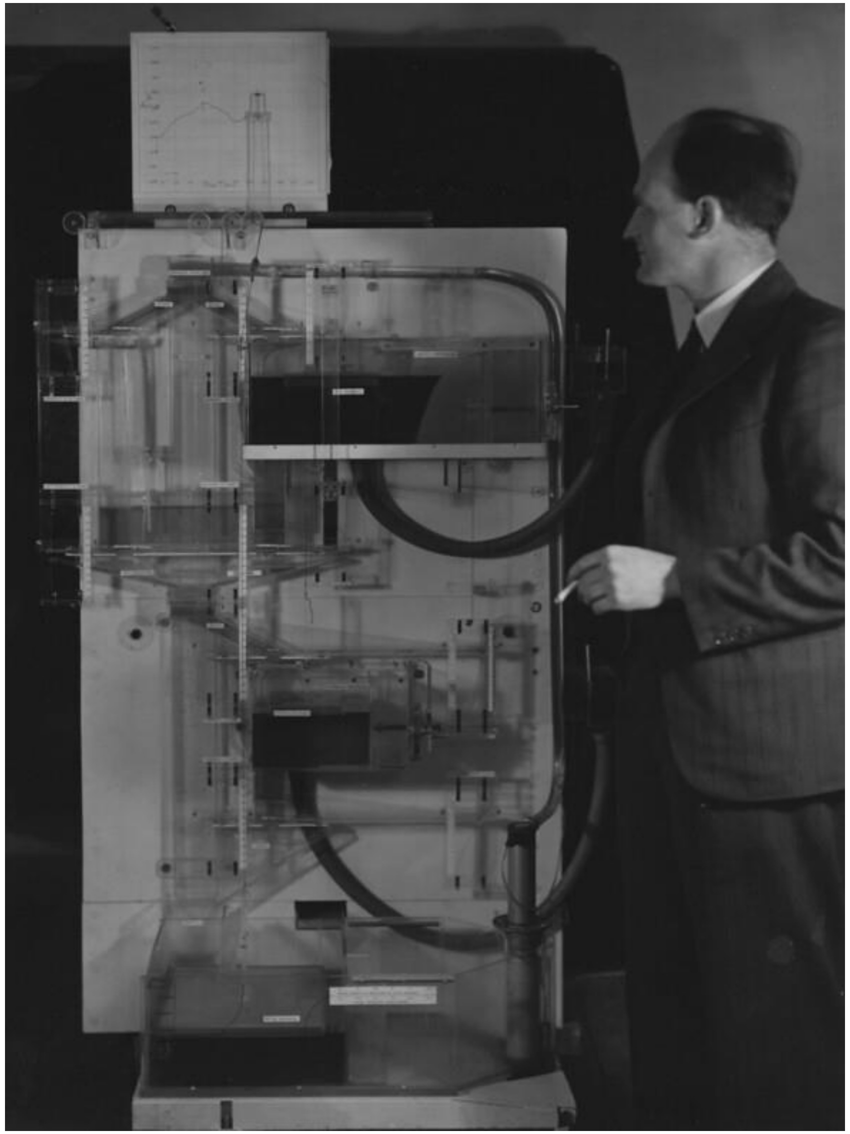
Introduction to agent-based models and system dynamics models

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

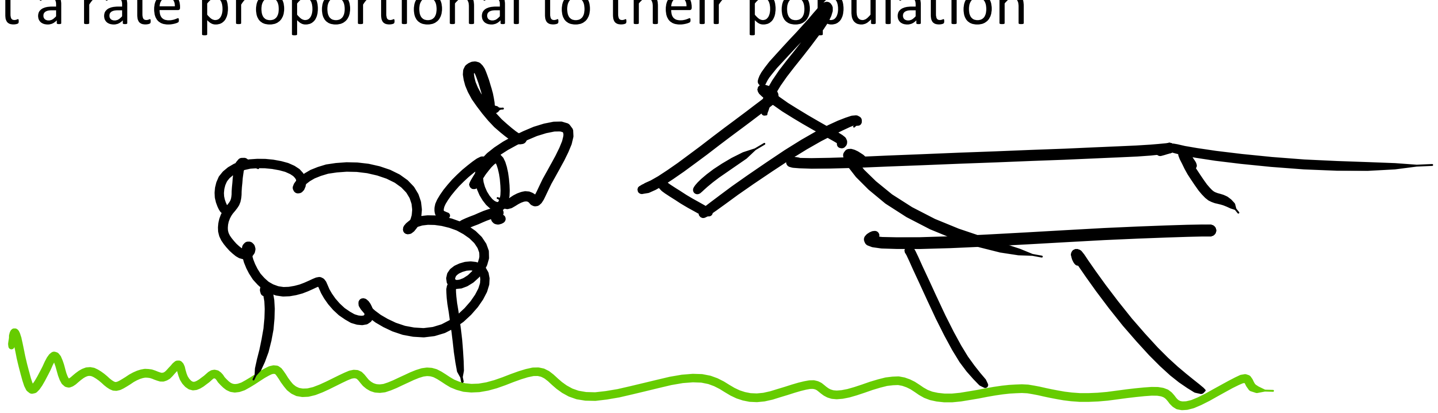
System dynamics models

- Stocks and flows
- Turn into differential equations



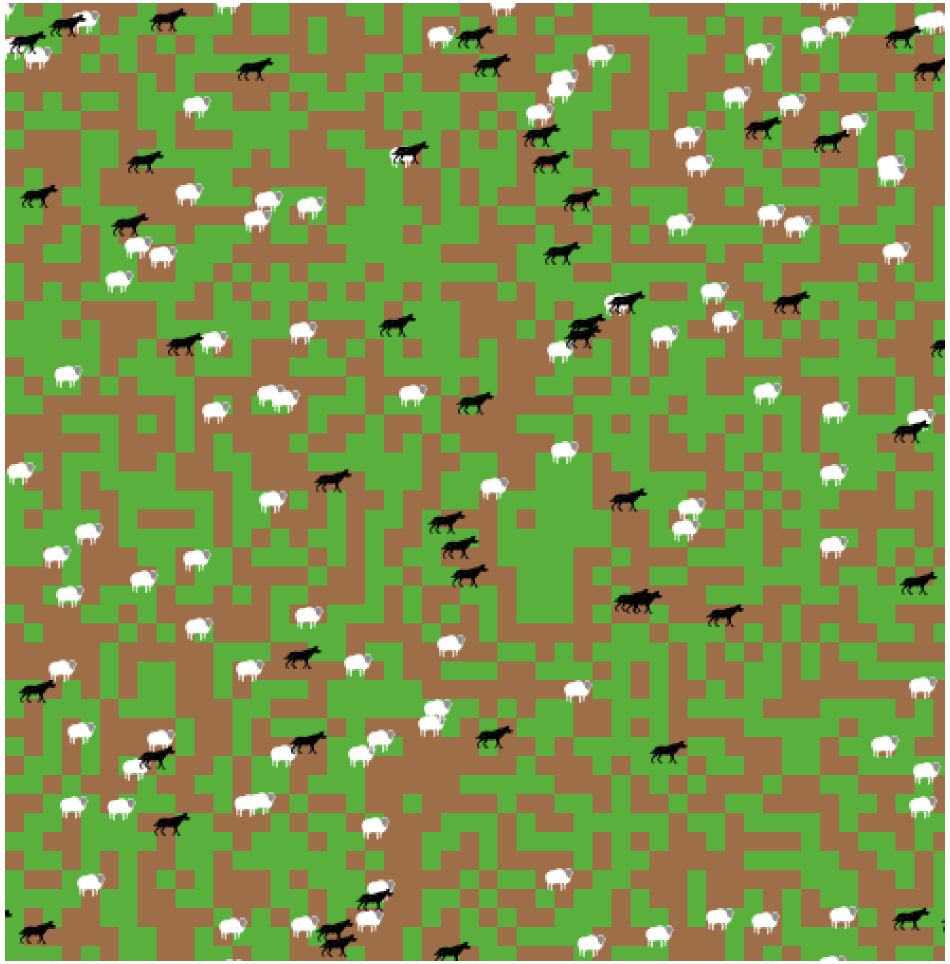
Example – predator prey

- 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 the sheep 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



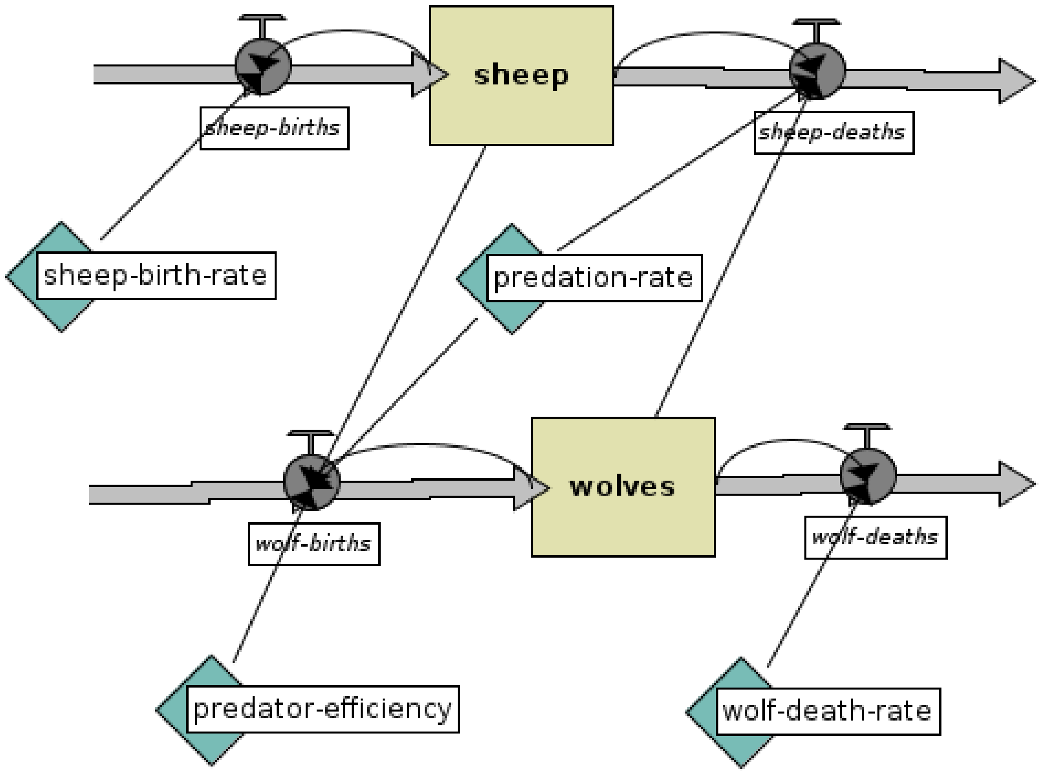
Agent-based approach

- 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)
- Lotka & Volterra model (1925, 1926)



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