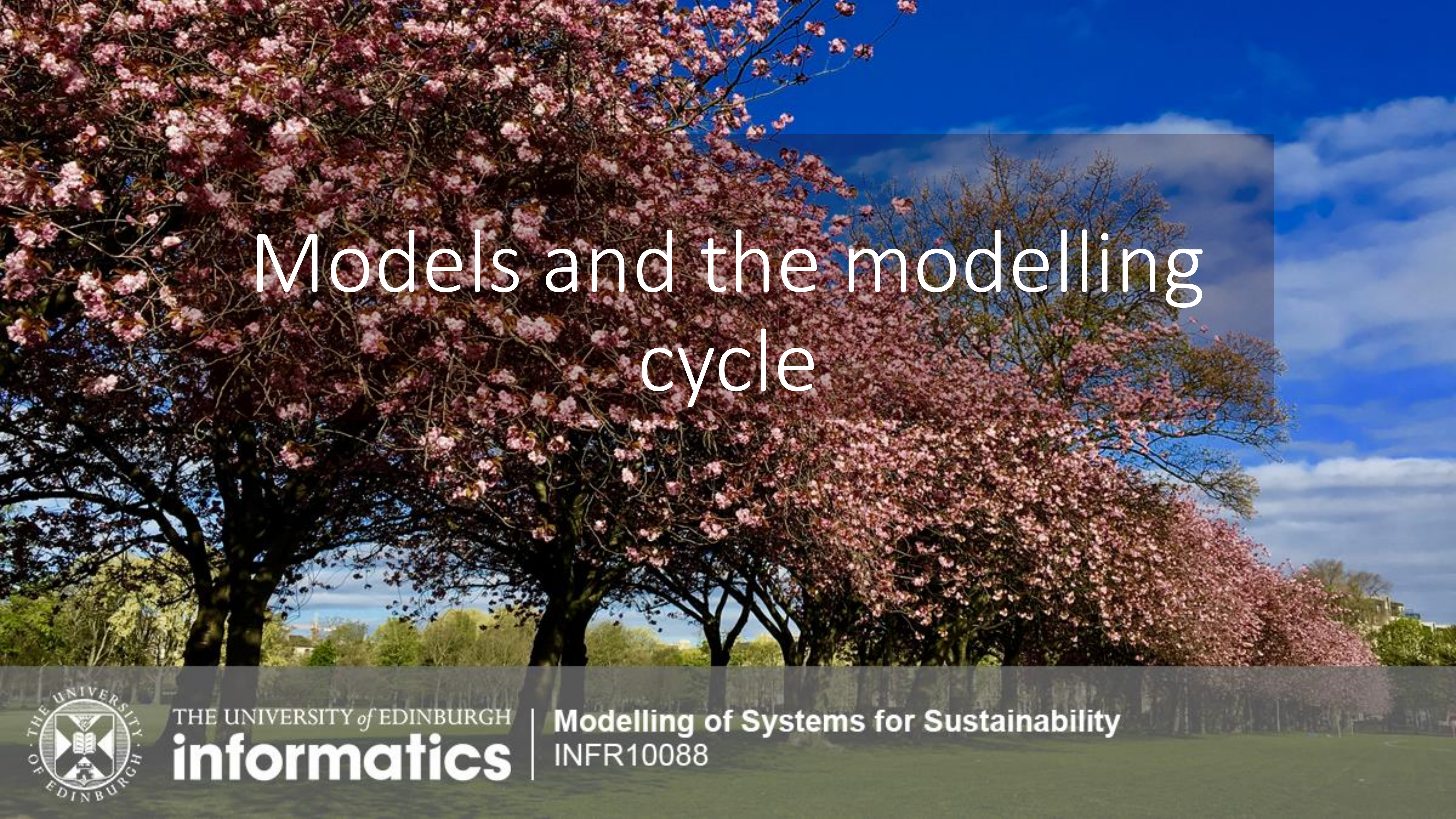


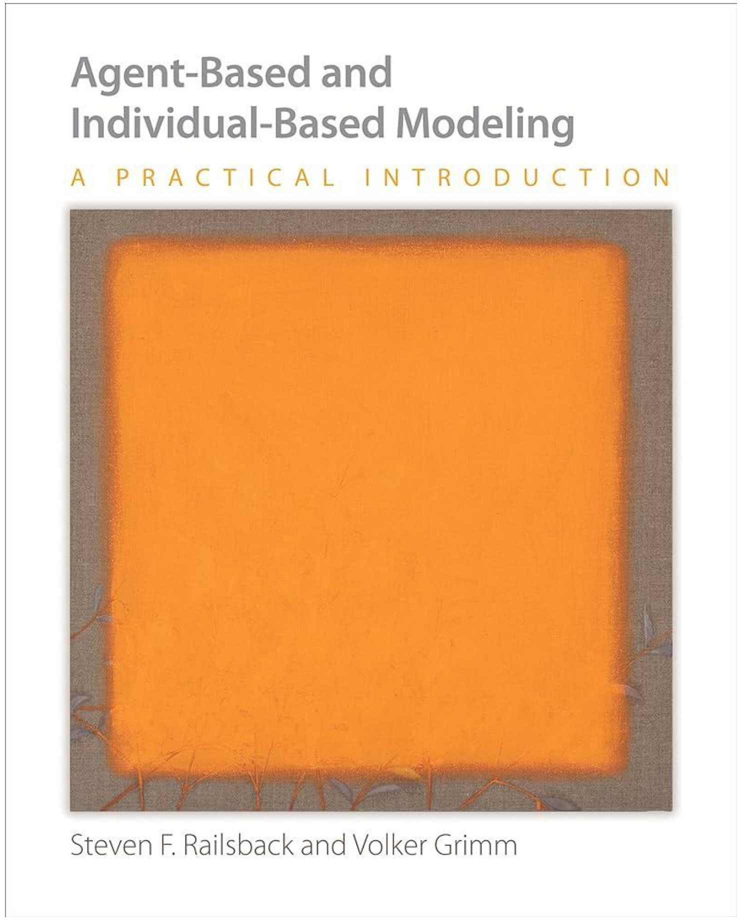
Models and the modelling cycle

Overview - aims

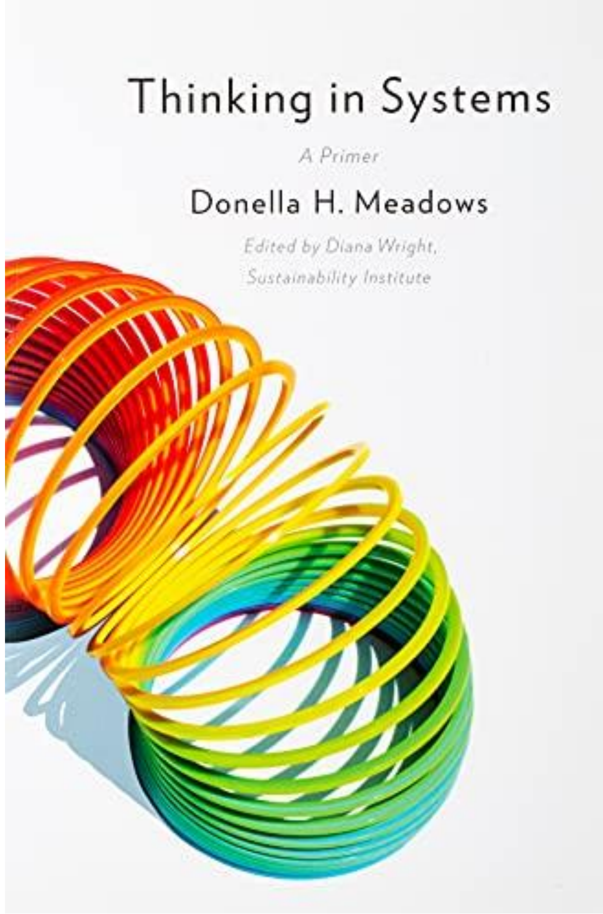
- Overall aim (Course Learning Outcome 1):
  "explain how computational modelling frameworks can be used to understand the behaviours of complex interacting systems involved in sustainability such as social, economic and ecological systems"
- This lecture:
  - What are models? And why do we build models?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

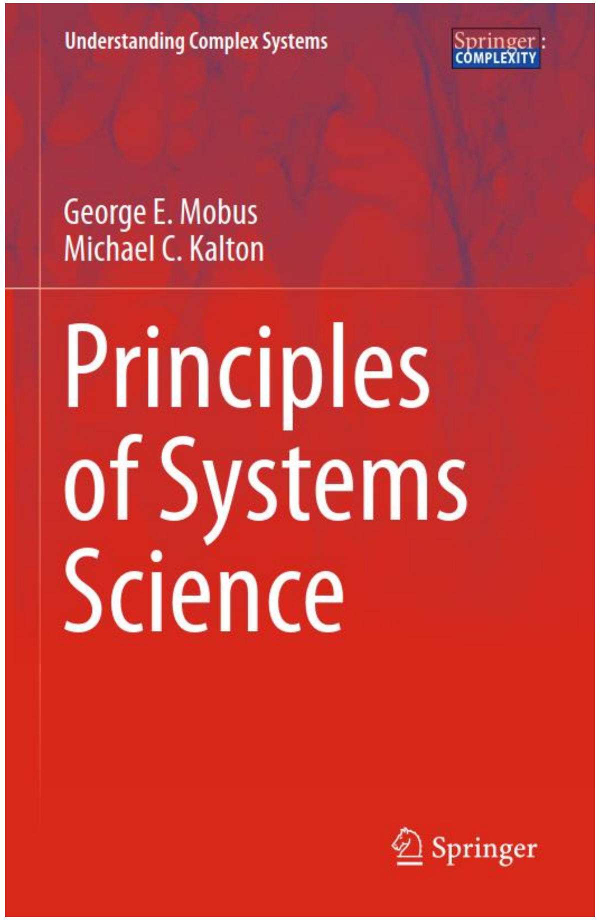
See "Resource List" on course website for links to online versions – chapters to read indicated in Schedule



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



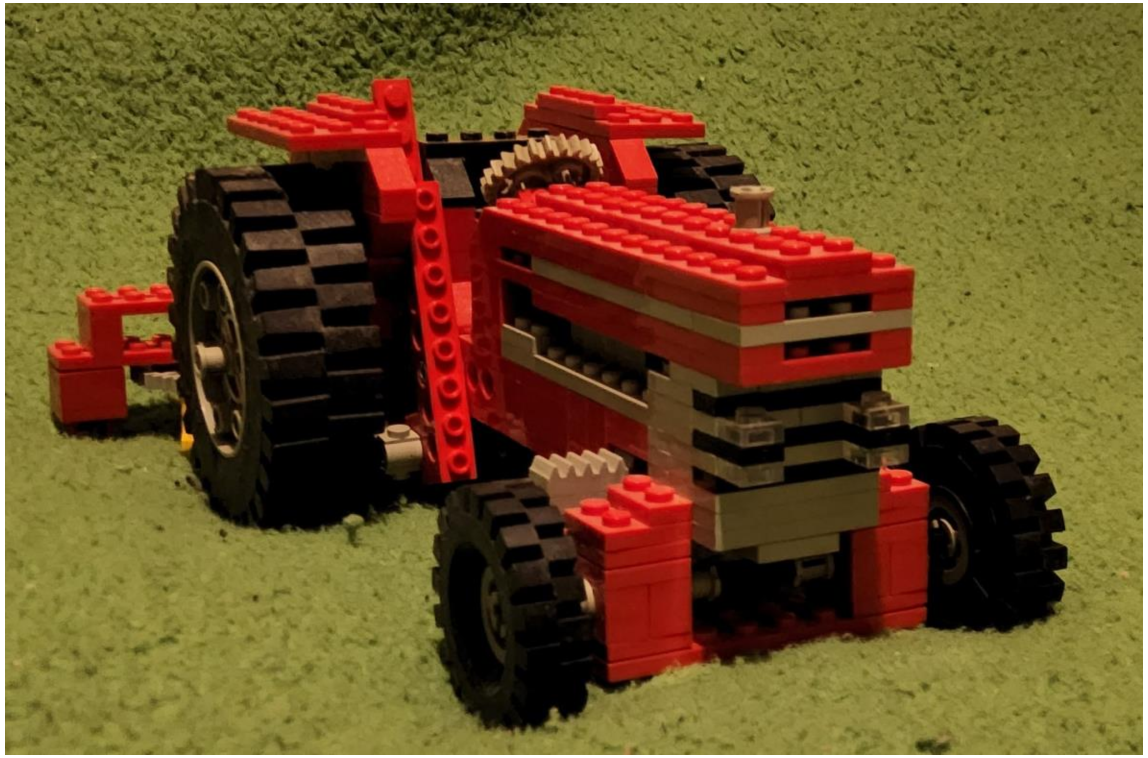
Mobus and Kalton
For principles of systems thinking

What are models?
Why do we build them?

What is a model?

What makes this...

... a model of this?



Lego Expert Builder set 952. David Sterratt

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

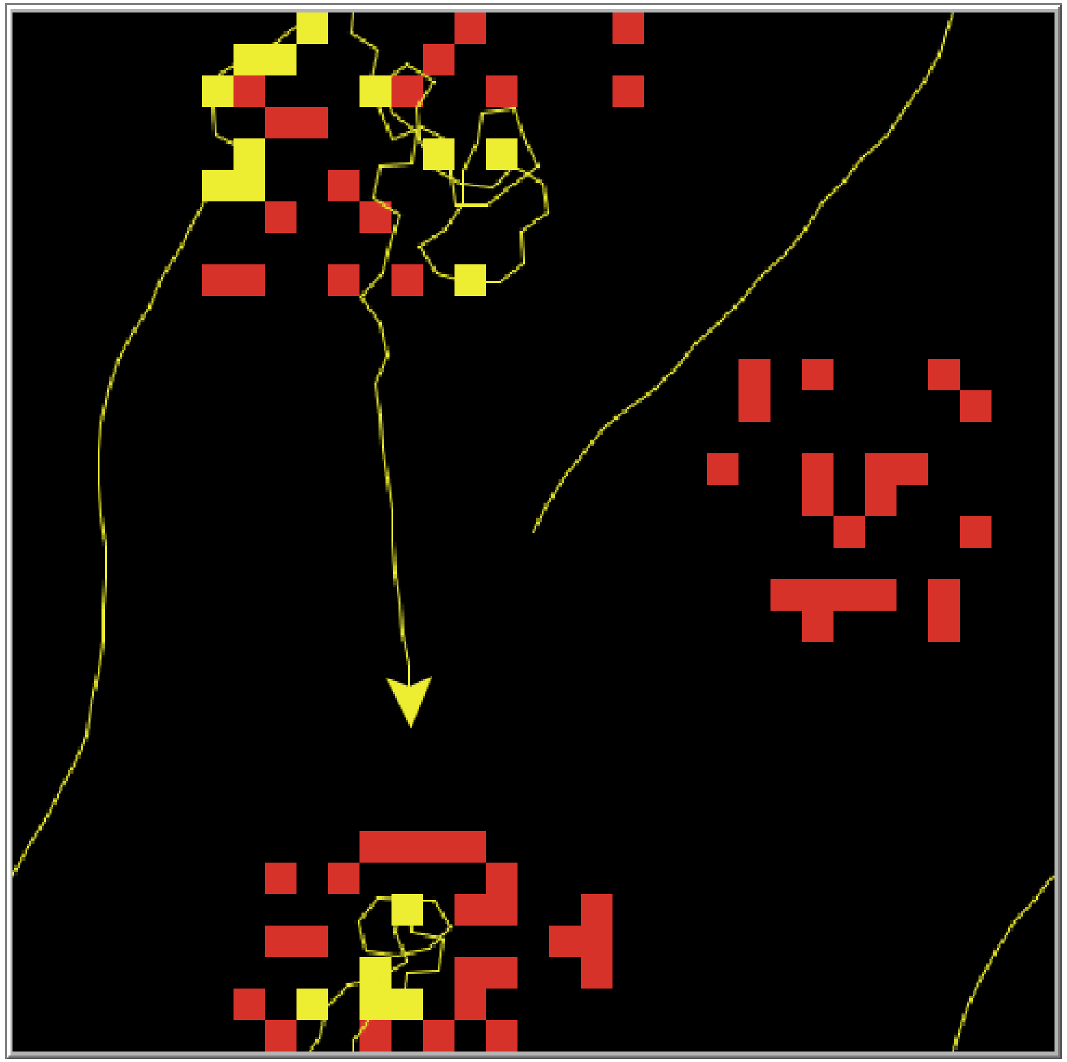
- The representation of objects is by digital objects
  - Program
  - Simulation package
- Once built, the representation can be used to generate a **simulation** of the behaviour of the system
- Very simple models can sometimes be formulated mathematically, which can give insights into more complex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

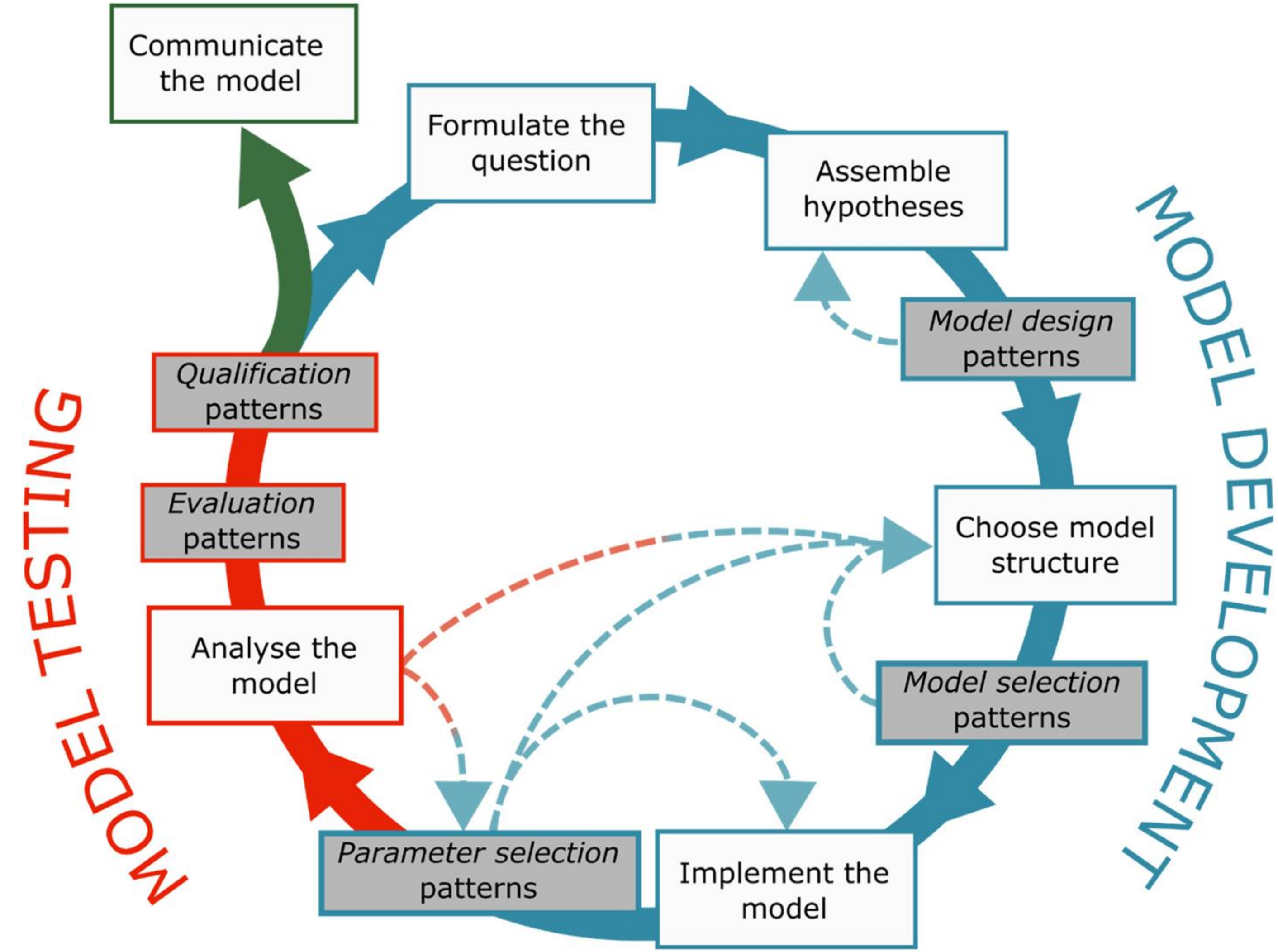
- Ignore:
  - Types of trees
  - Types of mushroom
  - Topography of the landscape
- Include:
  - Mushrooms as points in a 2D grid
  - Mushroom hunter as a moving point in the environment that can sense nearby mushrooms and has a search strategy



The modelling cycle

The modelling cycle

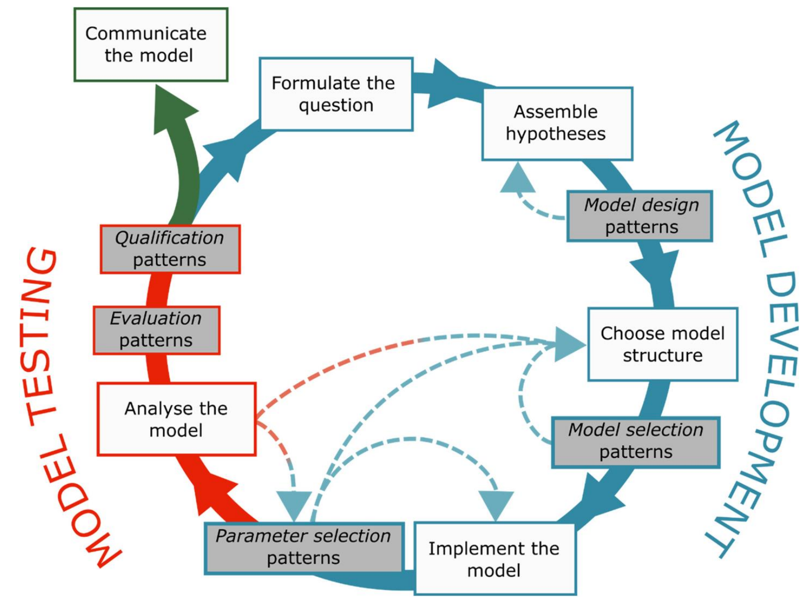
- An **iterative** process



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

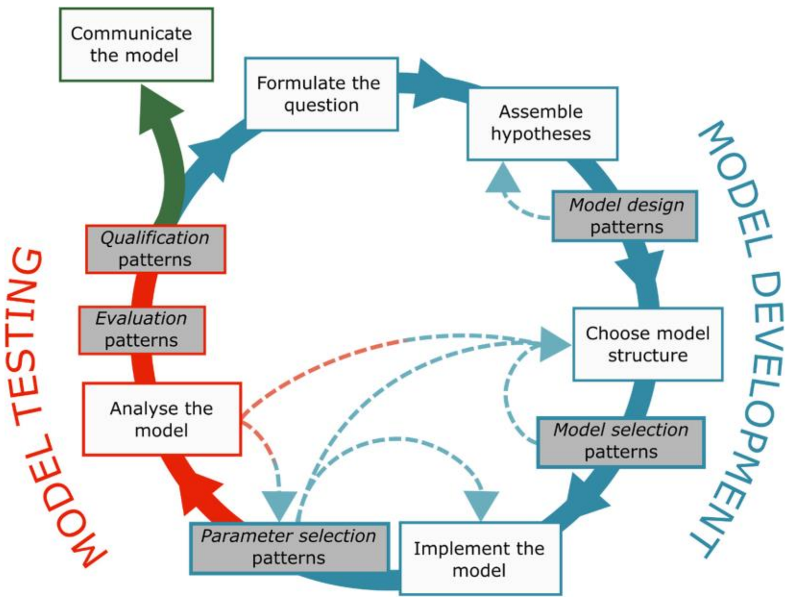
1. Formulate the question

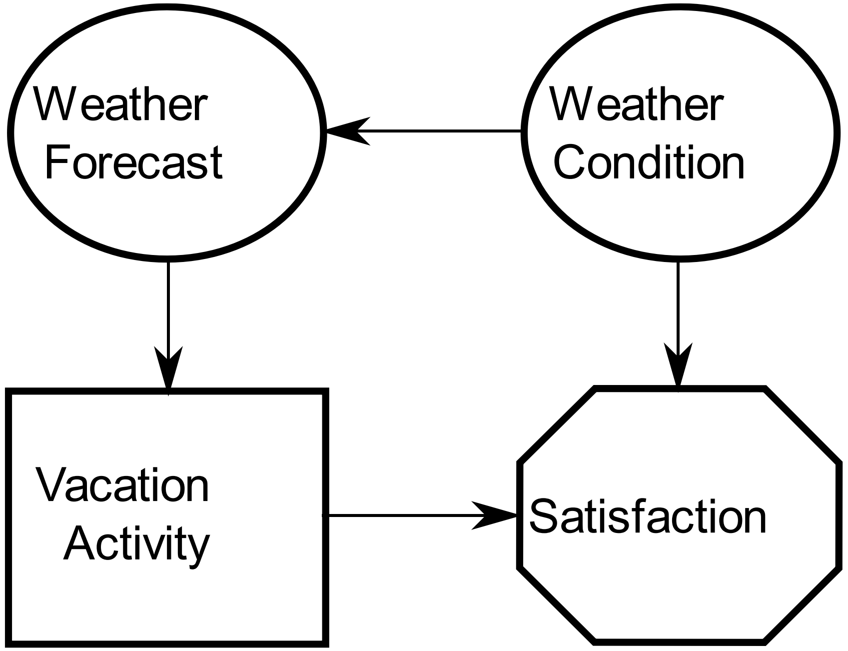
- Question serves as primary guide in constructing the model
- Formulating a clear question can be a major task
  - Especially difficult for large, complex systems
- May need to reformulate the question after further work
- Question for mushroom hunter example: "What search strategy maximises the rate 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-orientatated** modelling help
- Mushroom hunter e.g.: Essential process is switching between large scale "scanning" and small scale "searching"



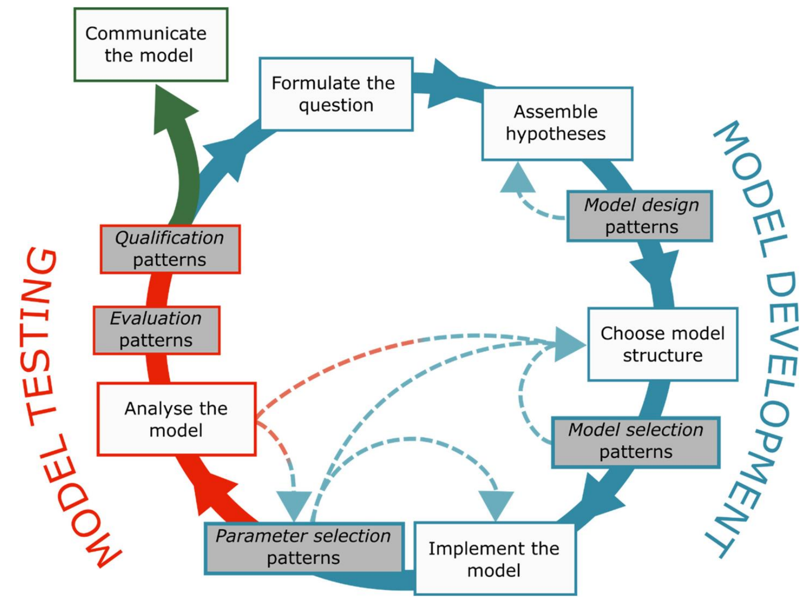


Wikipedia article on Influence Diagrams

Aside: patterns

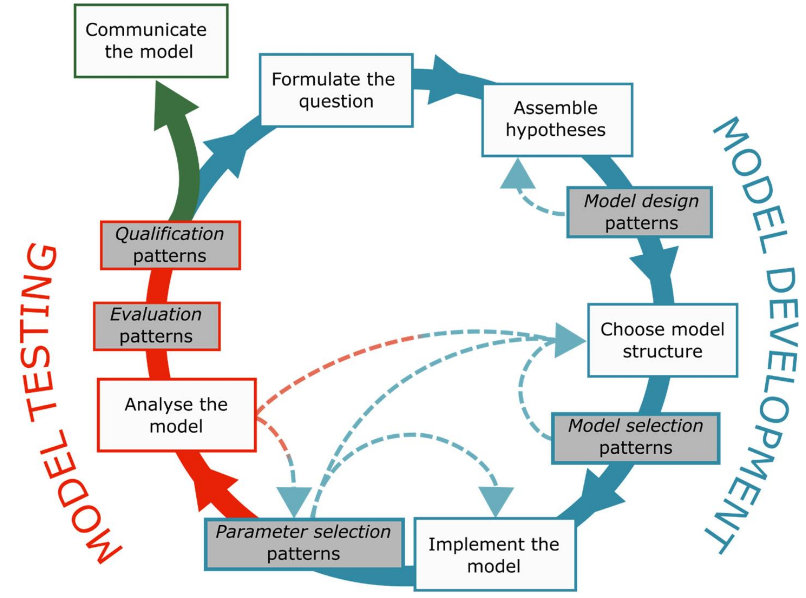
- A **pattern**, sometimes referred to in economics as a **stylised fact** can be defined as:
  "Stylised facts are broad but not necessarily universal generalisations of empirical observations and describe essential characteristics of a phenomenon that call for an explanation" (Heine et al. 2007, after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

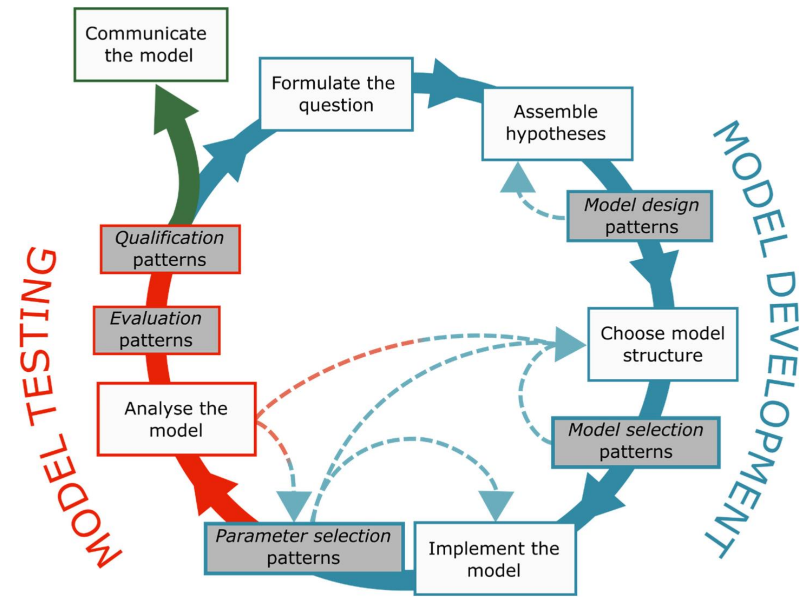
4. Implement the model



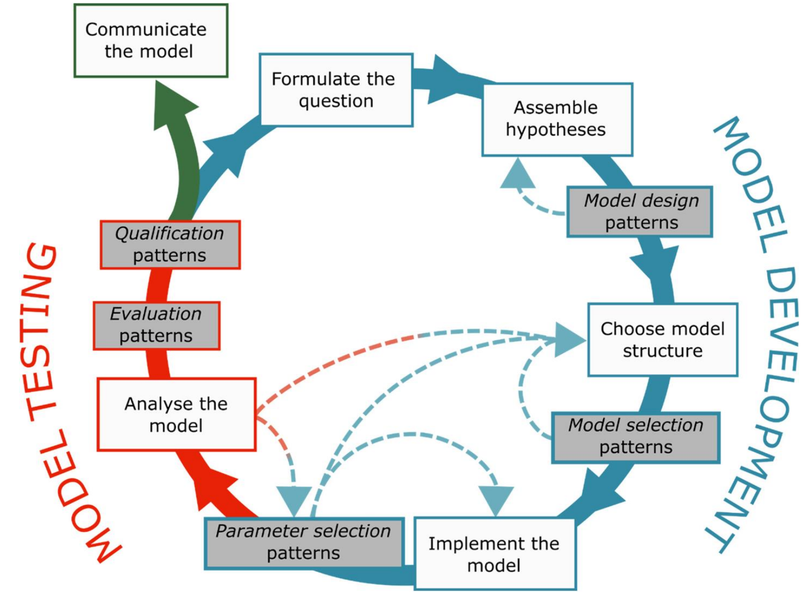
- Translate the verbal model description into a computational model, perhaps using a modelling package
  - An implementation
  - A precise formulation of a **theory**
- Run the model implementation
  - Generate **predictions** from the **theory** precisely
  - We call a run of a model a **simulation**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

Agent based models

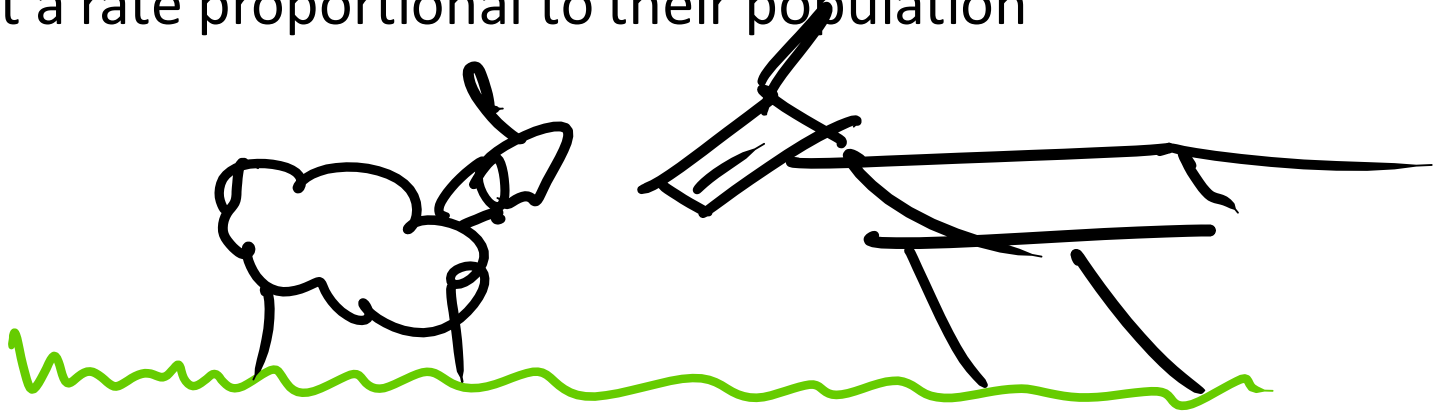
- Defined as "models where individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally" (Railsback and Grimm)
- Represent system components and behaviours as individual agents with behaviours:
  - E.g. the mushroom hunter, 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

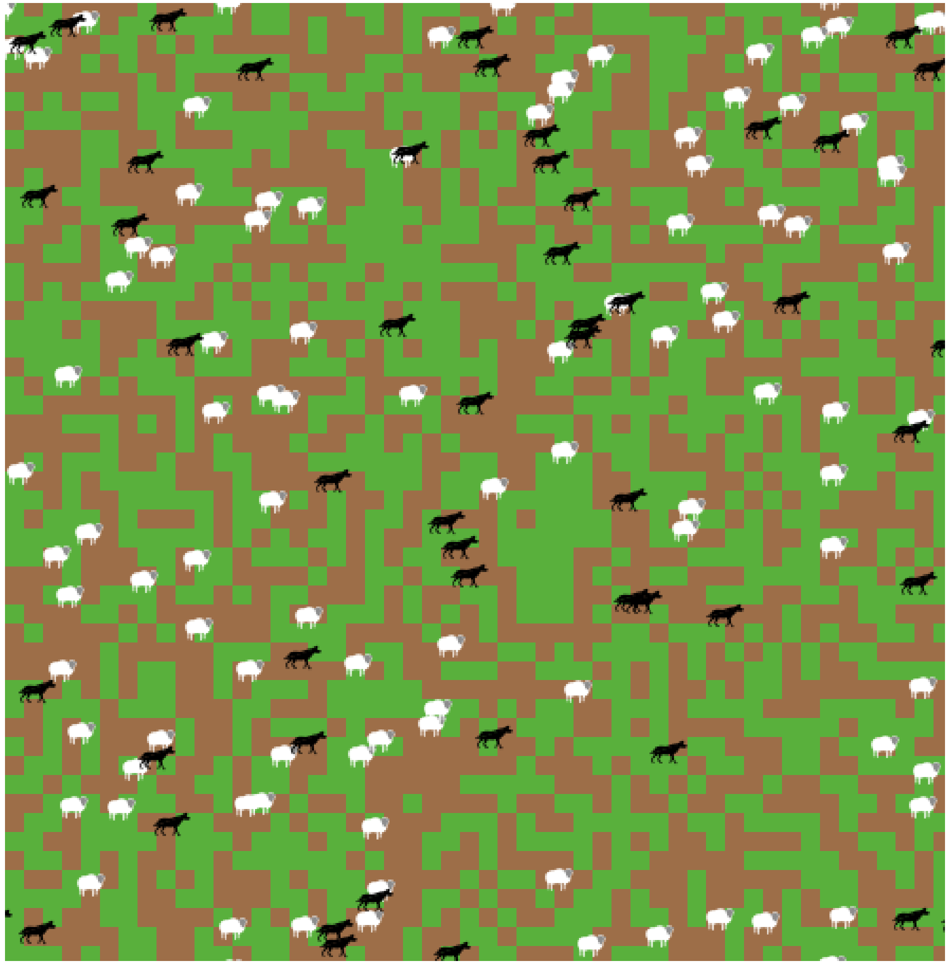
Example – predator prey

- 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



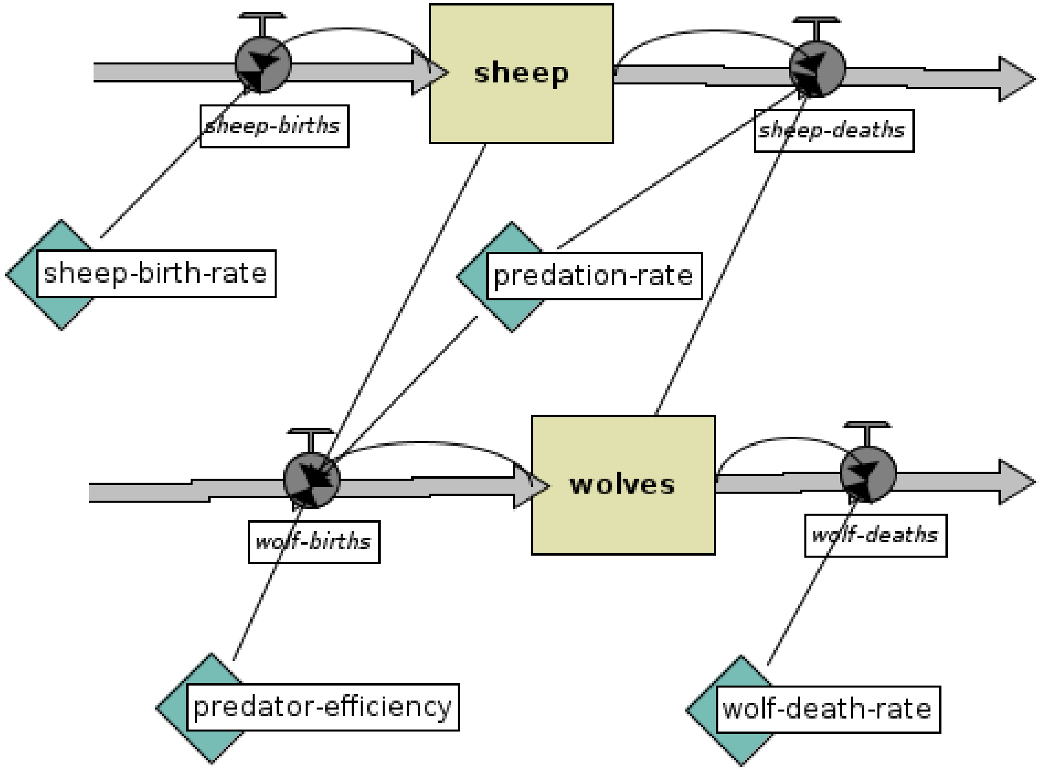
Agent-based approach

- 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