More design concepts, uncertainty and parameters

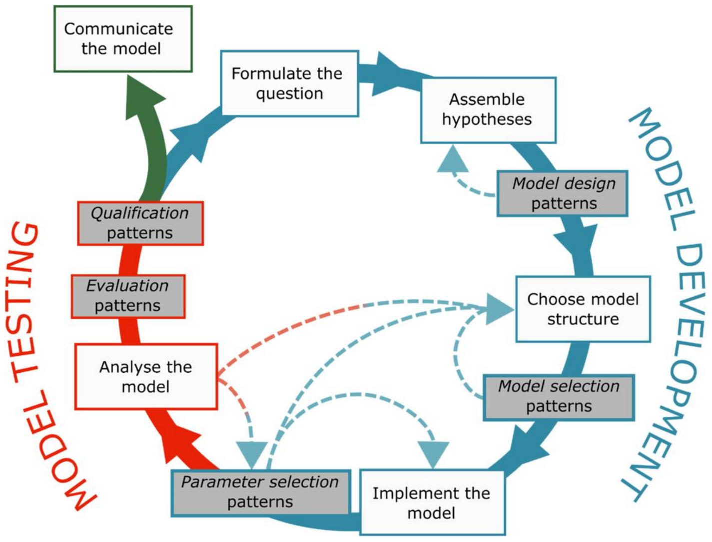
THE UNIVERSITY of EDINBURGH
informatics

Modelling of Systems for Sustainability
INFR10088

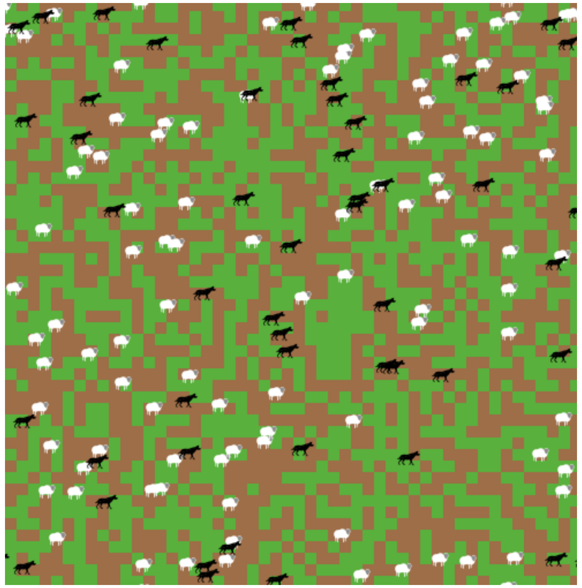
Group formation and project selection

- We are aiming to form groups that are interdisciplinarity (I.e. mix of Informatics and non-Informatics students) and which are reasonably well-matched to your interests. The plan to achieve these aims is:
- Week 4, Monday-Thursday: If you have a clear idea of a questions or system to work on, use the proposal form to put forward a specific project, which other students may register an interest in at the next stage of the process. This stage is optional. Nigel and David will check the proposals to make sure they are feasible
- Week 5, Monday-Thursday: Indicate your interest in one or more categories of question/model (e.g. social, ecological, economic) and/or specific projects (which were collected at Stage 1).
- Week 5, Friday: Nigel and David will form groups that are interdisciplinary and bring together (as much as possible) students with similar interests.
- Week 6, Monday: Groups announced.

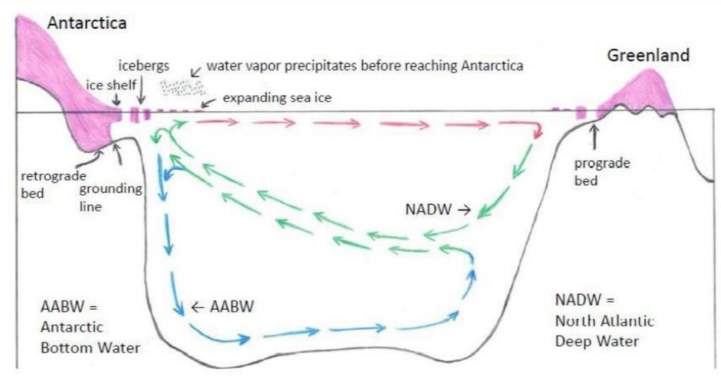
So far...



The modelling cycle



Agent-based modelling...

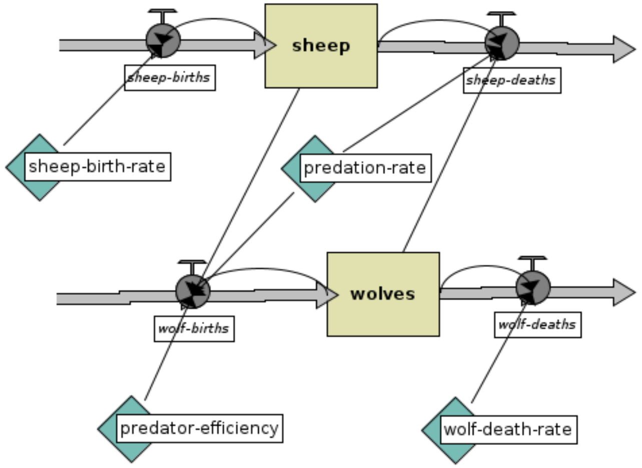


Real systems, e.g. Atlantic Meridional Overturning Circulation

Overview

Design concepts

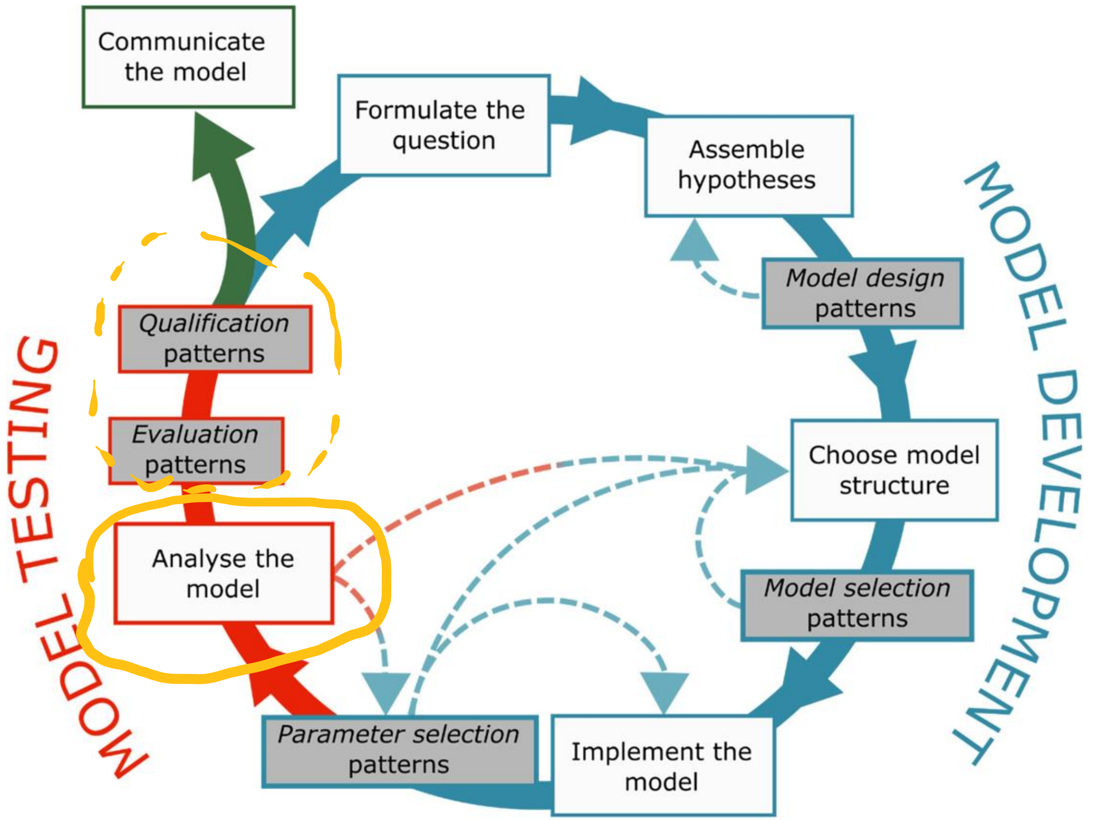
Details



...and system dynamics

Today...

- **D**esign concepts
- Uncertainty
- Model analysis:
  - Parameterisation and Calibration
  - Sensitivity analysis



Overview - aims

- Overall aim (Course Learning Outcome 2):
  investigate a sustainability system question, identify system elements and their interactions, and codify a system model using an appropriate model description framework
- This lecture:
  - Design concepts in the context of an example
    - Collectives
    - Sensing
    - Stochasticity
  - Parameterisation and calibration
  - Sensitivity analysis

Example model: African Wild Dogs

Railsback and Grimm, Chapter 10

African wild dogs in Hluhluwe-iMfolozi Park, South Africa

- Sub-Saharan Africa's most endangered carnivore, <6000 in wild
- Can small populations exist in small dispersed habitats?
- What is the optimal reintroduction strategy?
- Gusset et (2009, *Biological Conservation*) investigated these questions with agent based model

Dogs on the catwalk: Modelling re-introduction and translocation of endangered wild dogs in South Africa

Markus Gusset[a,b,c], Oliver Jakoby[c], Michael S. Müller[c], Michael J. Somers[b,d], Rob Slotow[a], Volker Grimm[c]

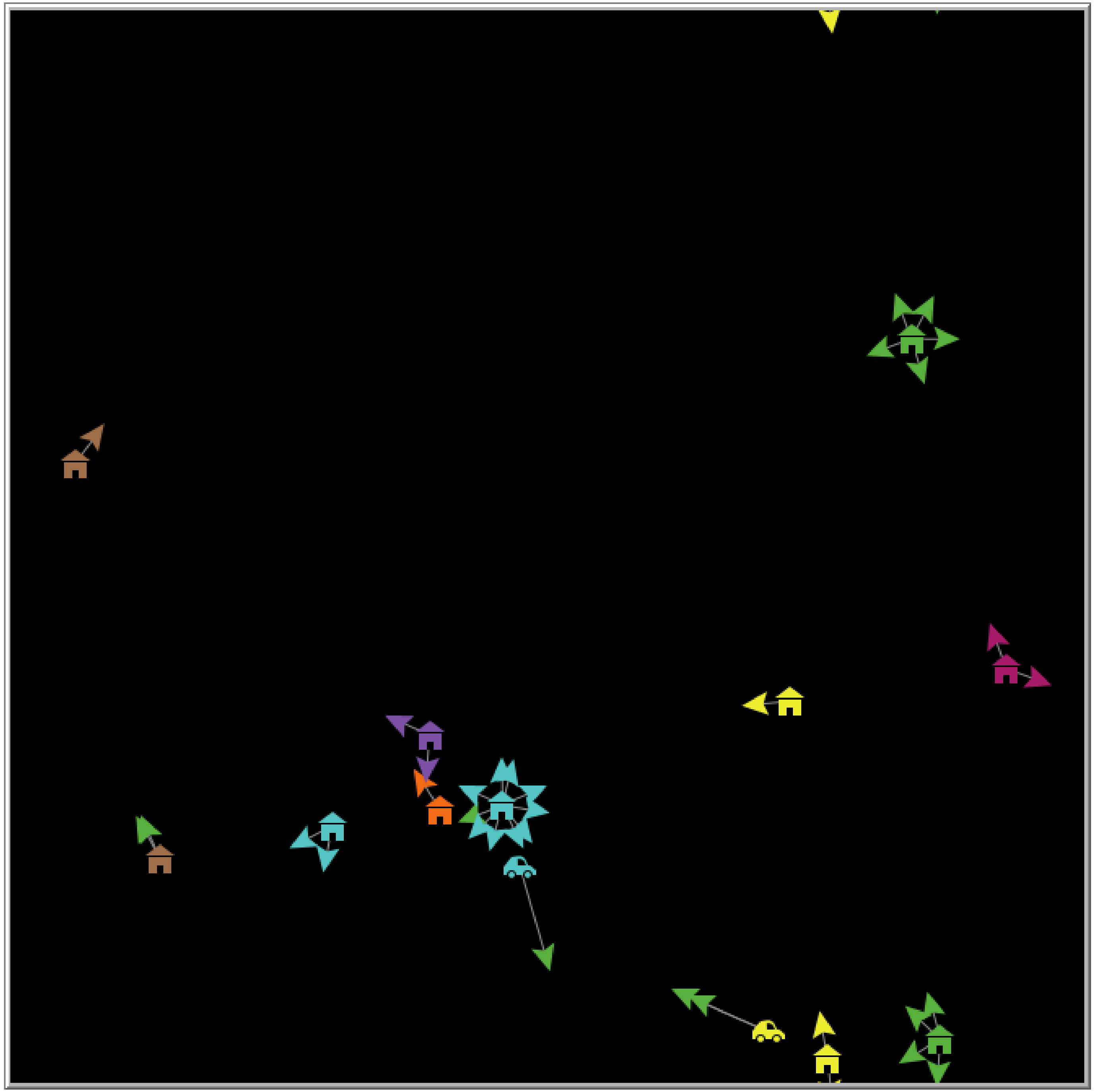
Hluhlwe-iMfolozi Park, Bjørn Christian Tørrissen, CC BY-SA-4.0. *Lycaon pictus* Charles J Sharp CC BY-SA 4.0, Wikipedia

African wild dog behaviour

- Live in packs with one alpha female and one alpha male, the only individuals that reproduce
- Non-alpha siblings of the same sex sometimes form disperser groups, in search of other disperser groups
- If disperser groups meet, they may form a new pack
- Dogs in disperser groups are more likely to die than if in a pack
- Landscape has limited carrying capacity, so reproduction rate goes down as population increases

Overview of model

- Space doesn't matter (just for visualisation)
- Dogs (status: pups, yearlings, subordinates or alphas)
- Packs
- Dispersing groups



Design concept: collectives

- Collectives are collections co-operating individuals or entities
- May arise out of simple rules – e.g. flocking behaviour
- May be explicity coded as collective agent with:
  - Own state variables, incluing list of individuals belonging to the collective
  - Submodels
- NetLOGO implementation: breeds (think wolves & sheep)
- Own state variables
- Confusingly `dogs` are also `turtles`

Collectives in African Wild dog example

```
breed [dogs dog] ; agent
breed [packs pack] ; collective
breed [disperser-groups disperser-group] ; collective
dogs-own
[
  age
  sex
  status
]
hatch-dogs 1 [ … ]
```

Design concept: sensing

- Sensing is about what information agents have, including what they can know about other agents
  - For example, how does a dog in a pack know who the alpha is
- Sensing can also relate to how reliable the information is
  - For example, in a business situation, how reliable is a salesperson's estimate of the profit from a particular investment
- NetLOGO concept of `links:` exist between pairs of agents at any locations in the environment, and allow information sharing
- Links can be directional (from/to) or bidirectional

Sensing: connection between dogs and pack

```
create-packs initial-num-packs
  [ ; now in pack context
    let num-dogs random-poisson initial-mean-pack-size
    hatch-dogs num-dogs
    [ ; now in dog context
      ...
      ; create a link between the dog and its pack
      create-link-with myself ; "myself" is the pack
      ...
    ] ; end of hatch dogs
```

Design concept: stochasticity

- **Stochastic** describes processes that depend at least party on random numbers and events; cf **deterministic**
- Choices to make and consequences of stochastic models
  - What statistical distribution?
  - What parameters for the distribution, or how do they depend on other simulation quantities?
  - Need to run replications to understand how much of variability is due to stochastic processes
- Random number generation is only *pseudo-random*
- Set **seed** to replicate behaviour of particular model, set seed
  - But **do not** to get replicates and **be careful** in BehaviourSpace!

Stochasticity: African dog distributions

```
let num-dogs random-poisson mean-birth-rate
```

- Why Poisson?
- Other distributions are built in, e.g.
  ```
  random ; uniform distribution, already seen
  random-normal
  random-gamma
  random-exponential
  ```

Design concept: Interaction

- **Interaction**: how agents communicate with or affect each other, such as by exchanging information or competing for resources
- Indirect interaction
  - for example, competition for a limited resource
- Direct interaction
  - For example, dispersing packs meeting one another
- Interactions can be **global** or **local**
  - The space need not be geographic – for example connections between relatives in different countries

Interaction in African Dogs example (highlights)

```
to do-pack-formation ; disperser-group context
  let other-groups other disperser-groups ; agentset
  let source-group self
  hatch-packs 1 [
    if (([sex] of other-group) != sex and
      ([natal-pack-ID] of other-group != natal-pack-ID)) [
        let all-dogs (turtle-set [link-neighbors] of source-group
                                 [link-neighbors] of other-group)
        ask all-dogs [ create-link-with myself ]
    ask other-group [die] ; get rid of disperser groups
    die ; get rid of disperser groups
  ]
end
```

Insights from building the model

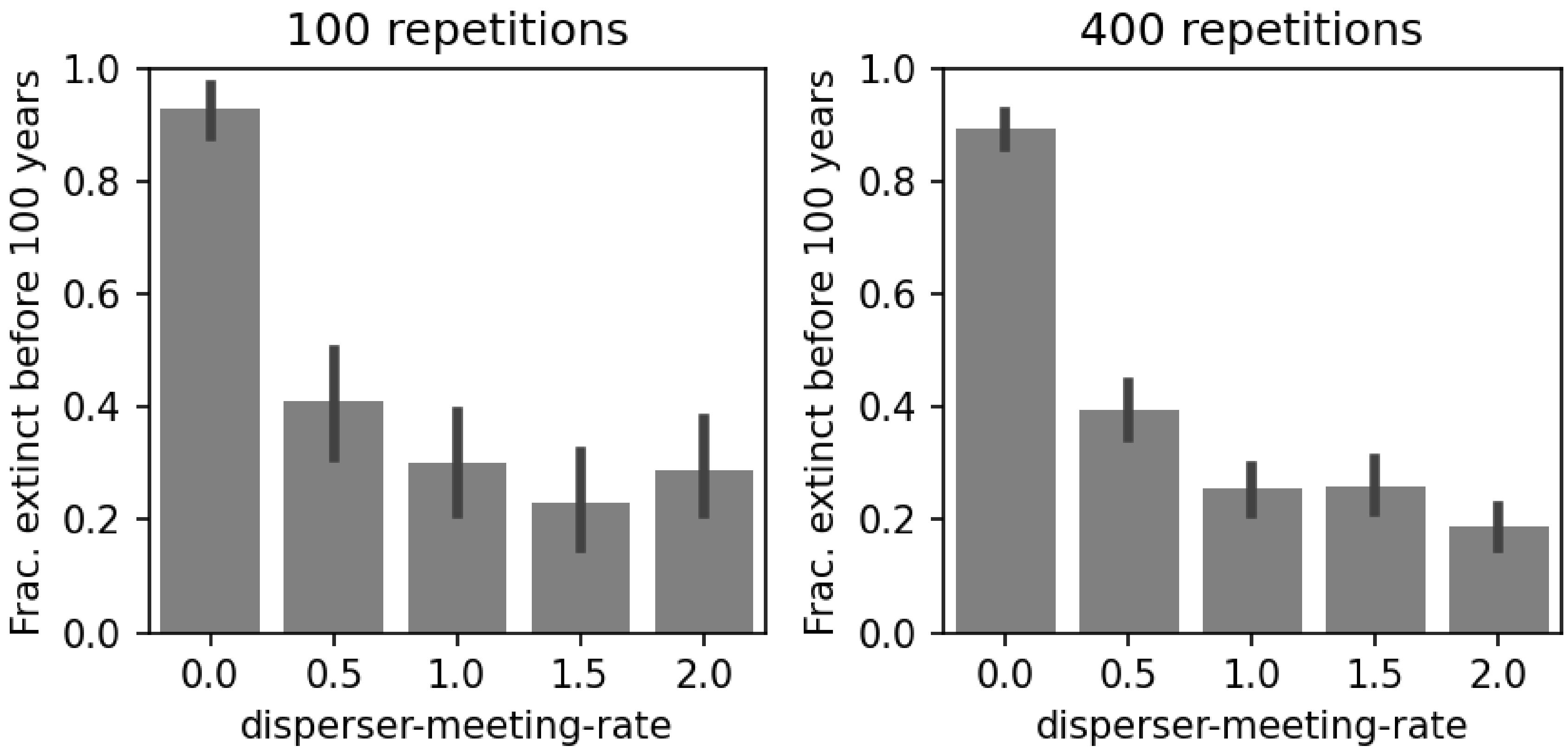
- Test subroutines: code up one-by-one
- Print helpful output
- Click forward step-by step with "Go"
- Create plots to assess behaviour

Expressing uncertainty in results

- **Observe** a **statistic** of the simulation
- Statistic – are the dogs extinct by 100 years? (True/false)
- Because simulation is **stochastic,** results will be uncertain
- Uncertainty around mean is inversely proportional to the square root of the number of replications
- Best practice: indicate this uncertainty graphically and in tables

Effect of Disperser Meeting Rate

- Could control rate, .e.g using fencing
- Error bars are 95% confidence intervals
  - Always state what measure of uncertainty you are using!
- Intepretation:
  - no meetings definitely bad
  - Things improve quickly up to a rate of 1.0



95% C.I. = sqrt(p*(1-p)/n)*1.96

Parameterisation and Calibration

Parameters

- **Parameters**: the constants used in equations (system dynamics & ABMs) and algorithms (ABMs only)
  - E.g. randomness q in the Butterfly hilltopping model
  - The efficiency in the Fisheries model
- **Parameterisation:** the general process of setting parameters:
  - Some parameters may be well known, measureable or estimateable: e.g. average number of pups in a litter
  - Some parameters may be harder to estimate, e.g. carrying capacity of environment
- **Calibration (**aka **parameter fitting**) is the process of adjusting parameters to match observed **patterns**

Pattern-oriented modelling

- Idea: find as many possible observed **patterns** that the model should produce
- => Greater likelihood of falsification, hence "Strong inference" (Platt, 1964) if patterns are produced
- Quantitative patterns are OK: "Many – perhaps most – of the great issues of science are qualitative, not quantitative, even in physics and chemistry" (Platt, 1964)
  - E.g. Discovery of DNA

Calibration/Parameter-fitting

- **Categorical calibration**: produce results within a category or range we deem acceptable
  - E.g., do we have collapses and regrowth in a fisheries model?
  - Is the period roughly that observed historically?
- **Best fit calibration:** Find the set of parameters that minimises an objective function
  - E.g., how closely can we fit the observed mean and standard deviation of the population of wild dogs?
  - Eaiser with deterministic models
- Increases in difficulty with the number of parameters

Calibration strategies

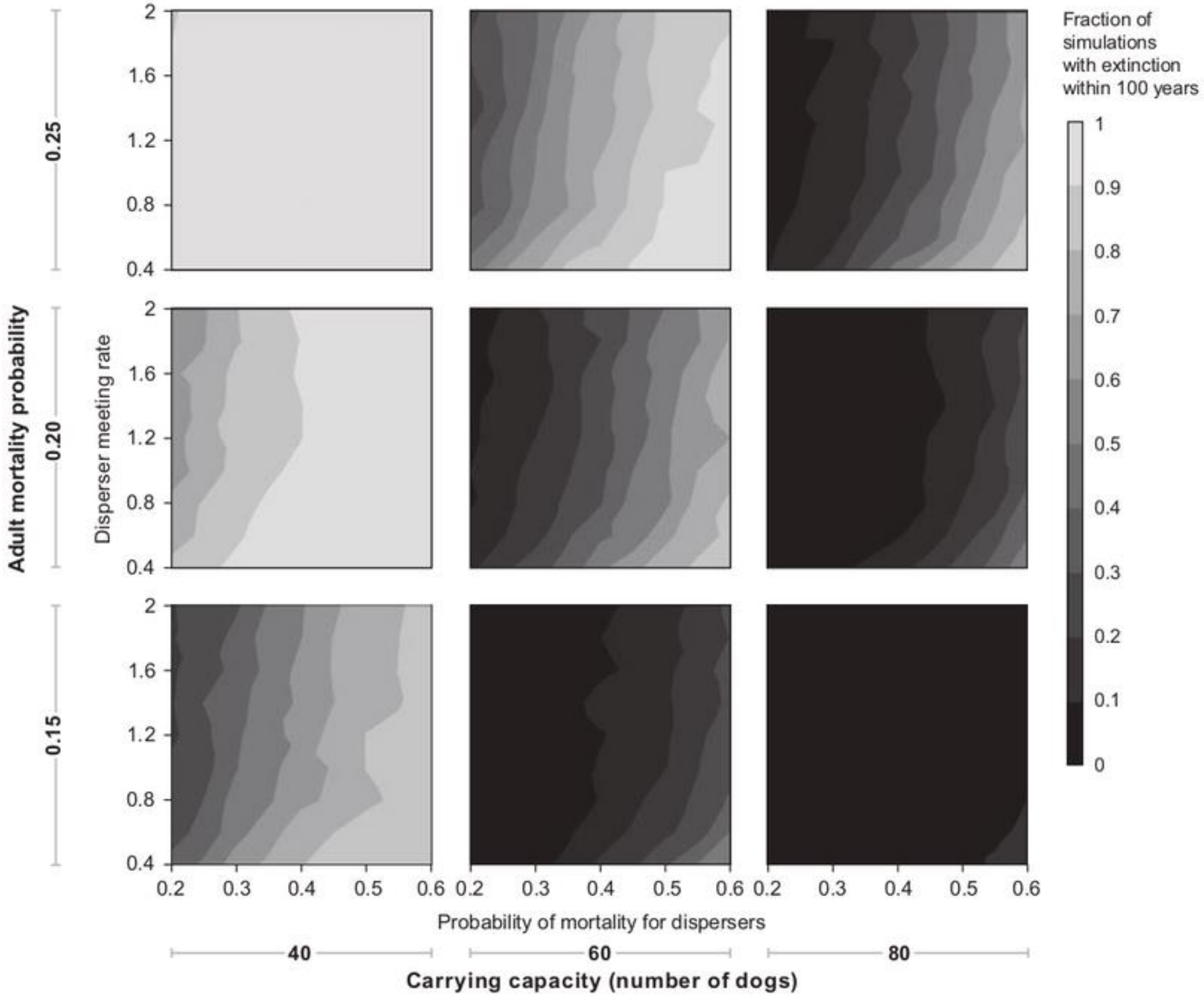
- Testing parameters takes time
- Focus on parameters that are **uncertain** and **important**
- **Sensitivity analysis** can help to determine which parameters are important
- Try to make parameters identifiable, i.e. parameters should have disitnct effects
  - E.g., in wild dog model, suppose we had rate of dispersers meeting in the day-time and the rate of meeting at night-time
  - Essentially the same effect, but larger parameter space

Multiple parameters

- Suppose we want 400 replications for each of 10 values of one parameter
  - => 400*10 = 4000 runs needed
- Suppose we want 400 replications for all combinations of 10 values of two parameters
  - => 400*10*10 = 40000 runs needed
- Repeat for 3, 4 parameters...
- Exploring large paramter spaces is a challenge!

Strategies for large parameter spaces

- Avoid large parameter spaces
- 2 parameters: contour plots or heatmaps
- 3 parameters: multiple contour plots or heatmaps
- Beyond 3 parameters:
  - Deterministic models: optimisation methods, e.g. gradient descent
  - Stochastic models: Monte-Carlo methods, e.g. Approximate Bayesian Computation



Railsback & Grimm (2019)

Model analysis: sensitivity analysis

Local variation around default set of parameters

- 0.5 to 1.5 in steps of 0.05
- Linear regression fit
- Slope is sensitivity

```
                            OLS Regression Results
==============================================================================
Dep. Variable:     Frac. extinct before 100 years   R-squared:                       0.013
Model:                                        OLS   Adj. R-squared:                  0.013
Method:                             Least Squares   F-statistic:                     28.06
Date:                            Mon, 09 Oct 2023   Prob (F-statistic):           1.30e-07
Time:                                    13:51:31   Log-Likelihood:                -1294.0
No. Observations:                            2100   AIC:                             2592.
Df Residuals:                                2098   BIC:                             2603.
Df Model:                                       1
Covariance Type:                        nonrobust
==============================================================================
                            coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const                     0.4555      0.034     13.491      0.000       0.389       0.522
disperser-meeting-rate   -0.1712      0.032     -5.298      0.000      -0.235      -0.108
==============================================================================
Omnibus:                      861.038   Durbin-Watson:                   2.116
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              405.314
Skew:                           0.938   Prob(JB):                     9.71e-89
Kurtosis:                       1.944   Cond. No.                         6.76
==============================================================================
```

Summary

- Design concepts in the context of the African Wild dogs model