# Collective Behaviour Summer School

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Uppsala, 2012

# Welcome!

# Structure

- Morning lectures by David Sumpter.

- Afternoon practical sessions.

1. Differential equation models (Stam Nicolis)
2. Self-propelled particles (Daniel Strömbom)
3. Data analysis (Andrea Perna)
4. Model fitting (Richard Mann)

- Wednesday guest talks in the morning (Mario Romero, Jens Krause, Peter Hedström) then free afternoon.

# Course Outline

1, Modelling animal behaviour **(1)**.
2, Functional explanations **(2, 10)**.
3, Information transfer and synergy **(3, 10)**.
4, Information transfer in humans.
5, Group decision-making **(4)**.
6, Collective motion **(5)**.
7, Quantifying individual interactions.
8, Collective structures **(7)**.
9, Negative feedback and regulation **(8)**.
10, Complicated individuals **(9)**.

Sumpter (2010), Collective Animal Behavior, Princeton University Press.

# Some points

- Please ask questions during the lectures (and afterwards).
- Balance between mathematics and biology.
- Ask me if you want me to cover something in particular later during the week.
- I will put up pdf’s of the talks in a Dropbox I will share with you.

# Collective Behaviour
# Lecture 1

Modelling Animal Behaviour

# What is mathematical modelling?

A way of travelling securely from **A** to **B**.

**A:** Assumptions about the world.

**B:** Consequences of those assumptions

Mathematics **is** rigorous thinking.

# Why mathematical modelling?

1, Explain data as simply as possible.

2, Link together levels of explanation.

3, To provide detailed descriptions.

4, To predict future outcomes.

# 1, Explaining data simply

Provide one or two simple rules from which everything else is explained.

This is qualitative modelling, but necessarily some comparison to data.

Explanation ratio: Explained/Assumptions

Dawkins: http://richarddawkins.net/articles/2236

# Example: logistic growth

$$\frac{dx}{dt} = px(1 - \frac{x}{n})$$

$x$ is the number of ‘infected’ individuals;

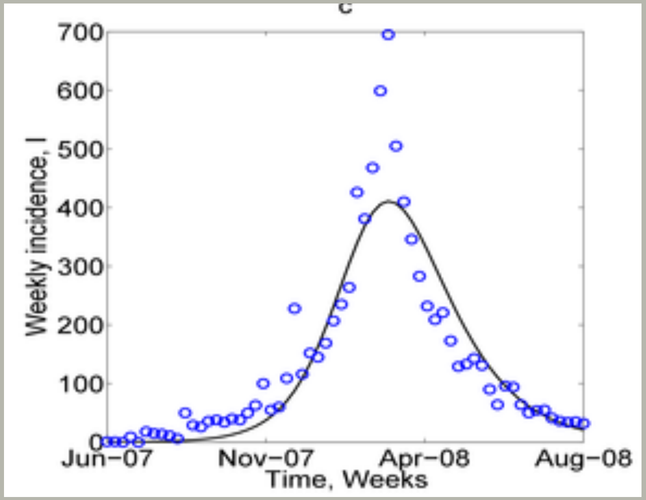
$px$ is the rate at which they contact others;

$(1 - \frac{x}{n})$ is the probability that a contact is with an uninfected individual.

# Example: logistic growth

Disease spread:

$$\frac{dx}{dt} = px\left(1 - \frac{x}{n}\right)$$



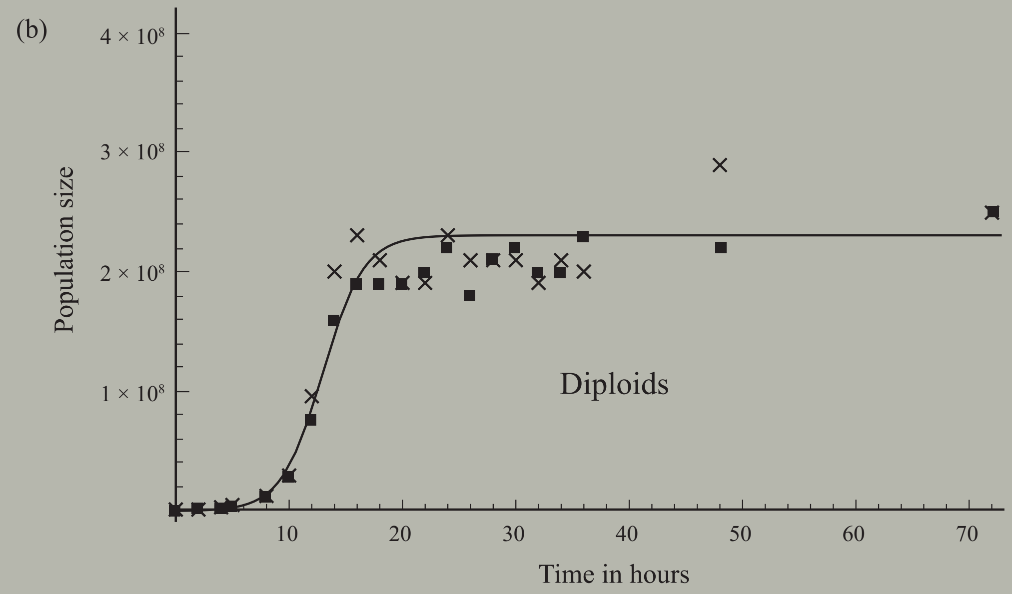

$x$ is the number infected;

$px$ is the rate of contacts;

$\left(1 - \frac{x}{n}\right)$ is the proportion of individuals that are susceptible.

Nannyonga et al. (2012) *PLoS One*

# Example: logistic growth




Yeast growth:

$$\frac{dx}{dt} = px\left(1 - \frac{x}{n}\right)$$

$x$ is the number of bacteria;

$px$ is the rate of dividing;

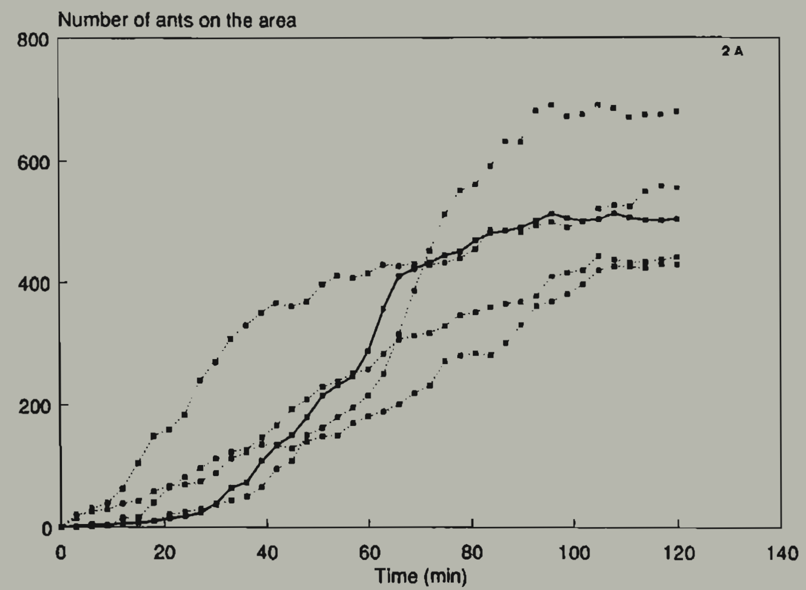
$\left(1 - \frac{x}{n}\right)$ is the proportion of environment which is unoccupied.

Otto & Day (2007) A biologists guide to mathematical modelling.

# Example: logistic growth

Information:

$$\frac{dx}{dt} = px(1 - \frac{x}{n})$$




$x$ are the ants foraging at a site;

$px$ is the rate of recruitment to a site;

$(1 - \frac{x}{n})$ is the proportion of colony who don't know about the site yet.

Detrain (2001) Self-organisation in biological systems

# Example: logistic growth

Innovation (Diffusion):

$$\frac{dx}{dt} = px(1 - \frac{x}{n})$$

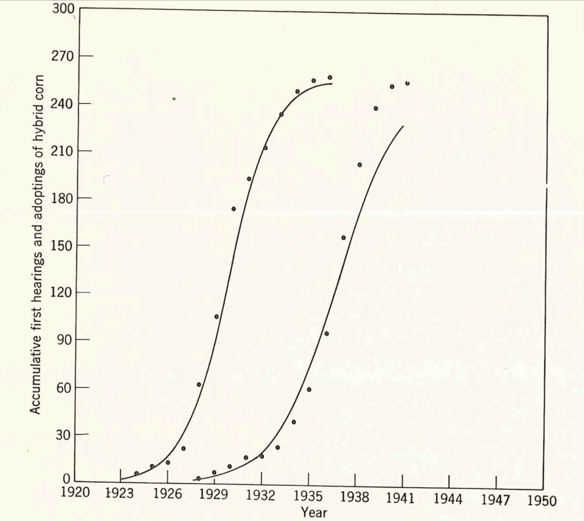



**Figure 3.3.** Accumulative first hearings and first adoptings of hybrid corn by farmers in two Iowa communities, plotted on arithmetic coordinates. The lines represent least-squares logistic equations. (Data from Ryan and Gross, 1943.)

$x$ is the number adopting a technology;

$px$ is the rate of informing about technology;

$(1 - \frac{x}{n})$ is the proportion of individuals not yet using the technology.

Hamblin et al. (1973) A mathematical theory of social change.

# 2, Linking levels of explanation

Large aggregates cannot be understood by simple extrapolation from the behaviour of a few particles.

Need mathematical models to integrate our understanding from one level to the next.

Explanation ratio may be lower, but more detailed.

# 2, Linking levels of explanation

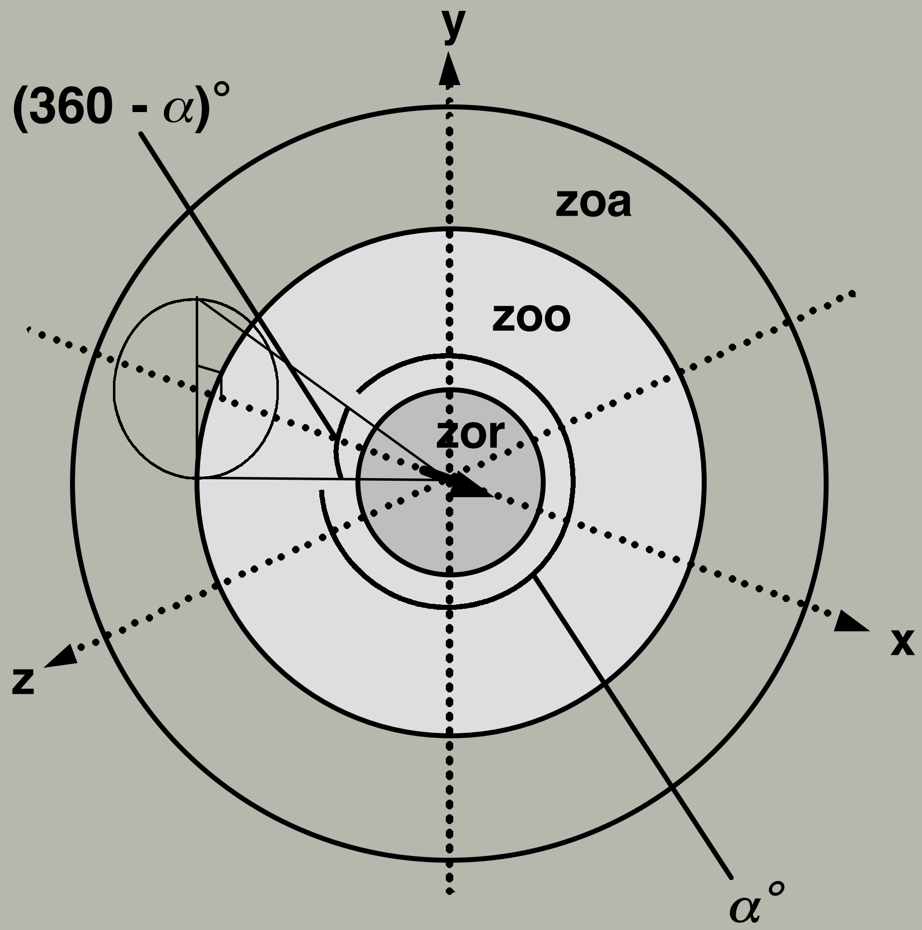
according to the idea: The elementary entities of science X obey the laws of science Y.

| X | Y |
|---|---|
| solid state or many-body physics | elementary particle physics |
| chemistry | many-body physics |
| molecular biology | chemistry |
| cell biology | molecular biology |
| • | • |
| • | • |
| • | • |
| psychology | physiology |
| social sciences | psychology |

But this hierarchy does not imply that science X is "just applied Y." At each stage entirely new laws, concepts, and generalizations are necessary, requiring inspiration and creativity to just as great a degree as in the previous one. Psychology is not applied biology, nor is biology applied chemistry.

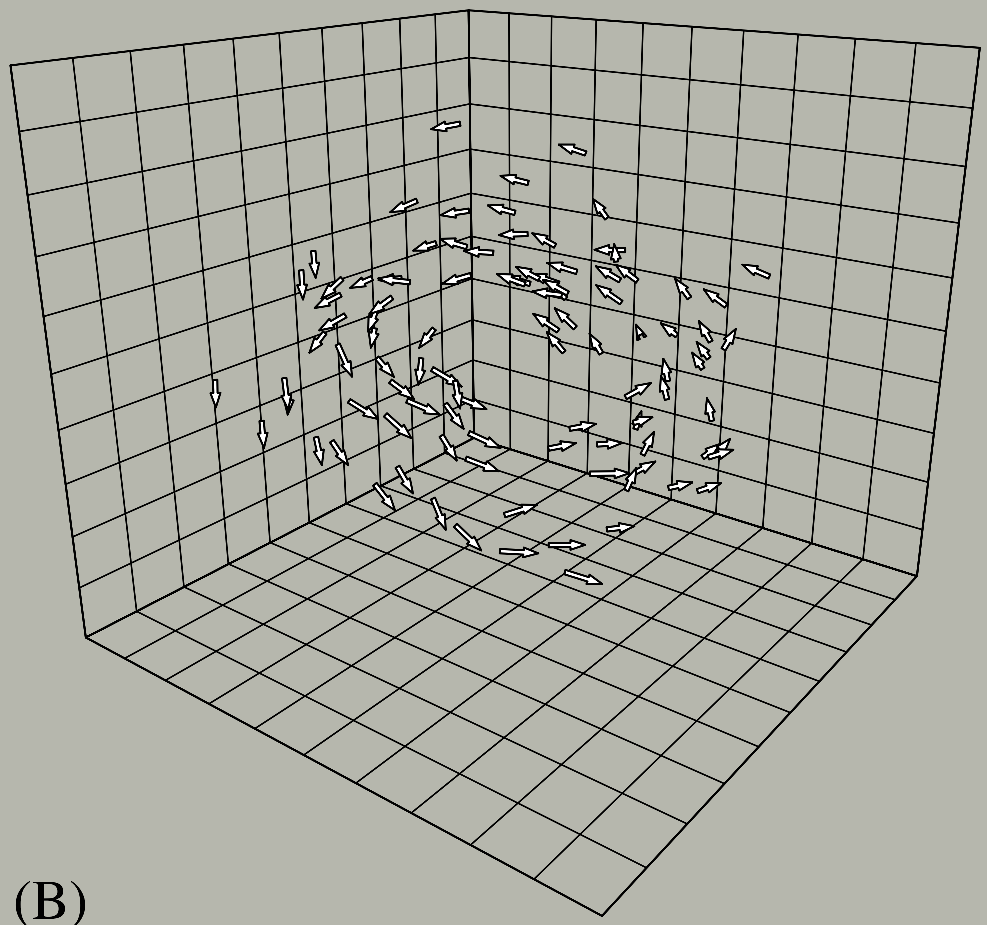
P. W. Anderson (1972) *Science*

# Example: self-propelled particles




Couzin et al. (2002) *Journal of theoretical biology*

# Example: self-propelled particles




Couzin et al. (2002) *Journal of theoretical biology*

# 3, Detailed descriptions

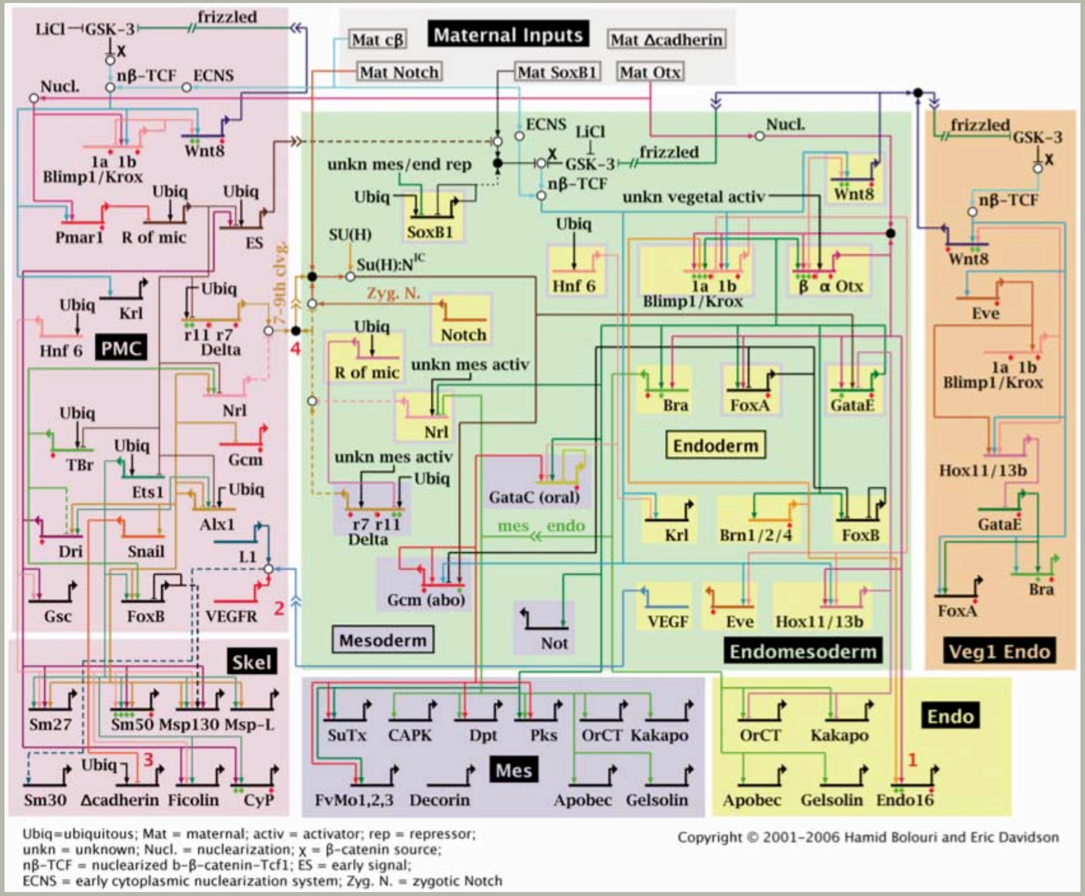
Put everything we know down in one place.

Quantitative modelling.

Test that this knowledge is self-consistent.

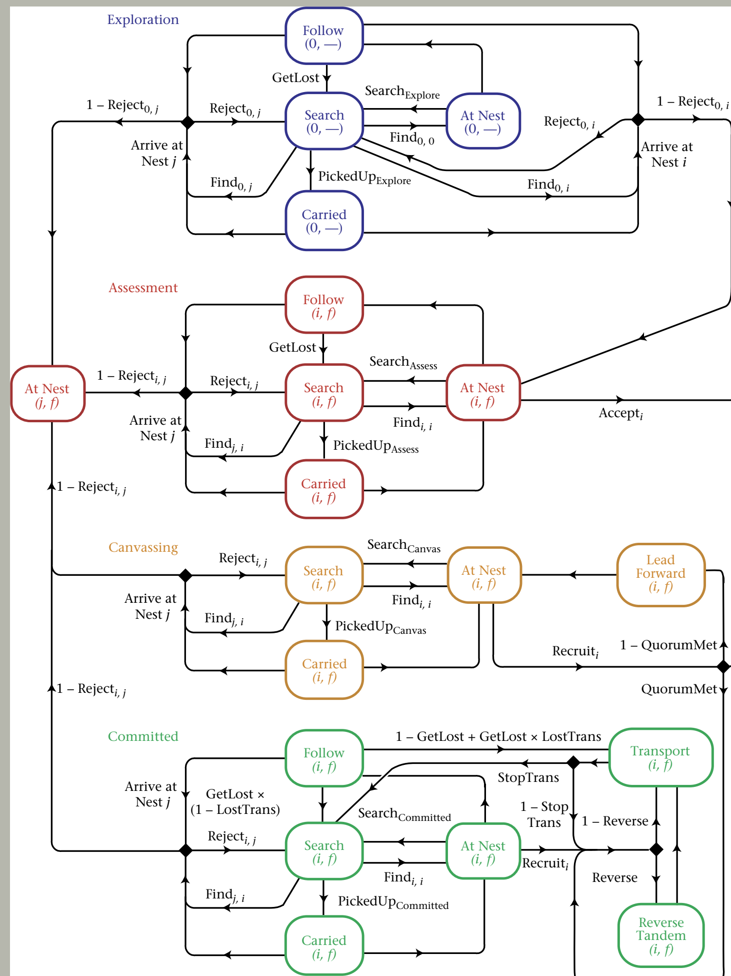
Find out if we really do understand how the system works.

# 3, Detailed descriptions



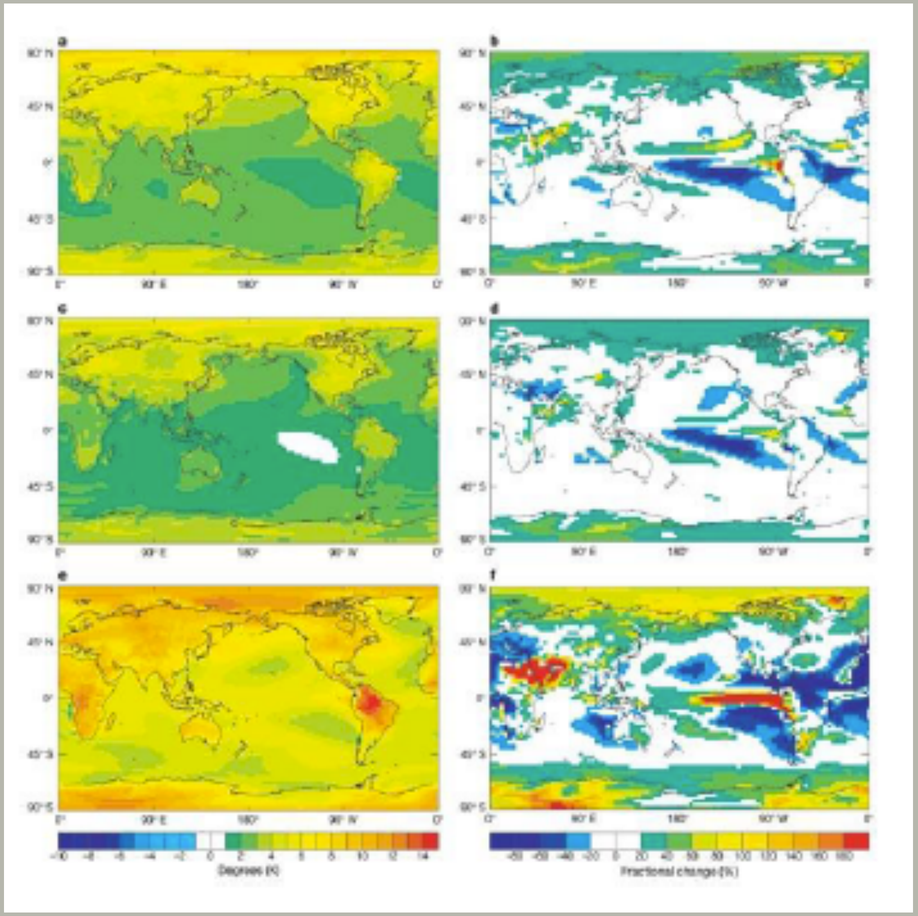

Longabaugh, Davidson & Bolouria (2005) Developmental biology

# 3, Detailed descriptions




Pratt et al. (2005) *Animal behaviour*

# 4, Predicting the future



Stainforth et al. (2005) *Nature*

# Why do we do mathematical modelling?

Decreasing level of abstraction

Increasing level of description

1, Explain data as simply as possible.

2, Link together levels of explanation.

3, To provide detailed descriptions.

4, To predict future outcomes.

# Why do we do mathematical modelling?

Qualitative comparison between systems

1, Explain data as simply as possible.

2, Link together levels of explanation.

Quantitative description of particular system

3, To provide detailed descriptions.

4, To predict future outcomes.

# Why do we do mathematical modelling?

Fun!

1, Explain data as simply as possible.

2, Link together levels of explanation.

Hard work

3, To provide detailed descriptions.

4, To predict future outcomes.