Day 1
Lecture 1: Introduction to infectious disease modelling

Short course on modelling infectious disease dynamics in R

Ankara, Türkiye, September 2025

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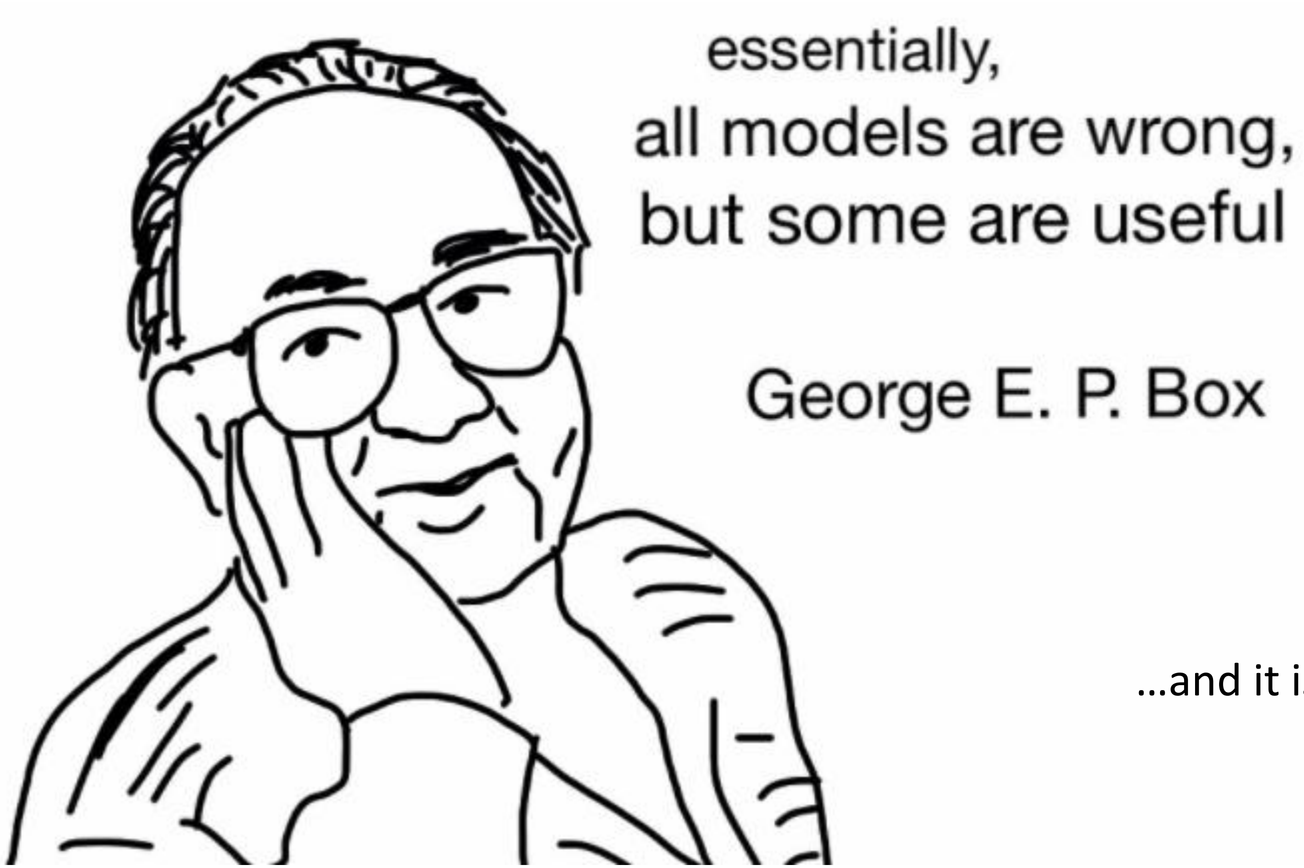
Aims of the session

- To Understand what do we mean by infectious disease models
- Introduced core concepts of infectious diseases dynamics
- Familiarize with existing types of ID models

[Widely repeated quote goes here]



…and it is true!

What are models

- Some models intend to infer conclusions as we accrue more data
  - Most statistical models -> the model emerges from the data !

- Some models intend to describe a mechanism behind a phenomenon
  - Mathematical models
  - Used for example in weather, physics, engineering, ecology, ***and infectious diseases***!

We need to understand the phenomenon

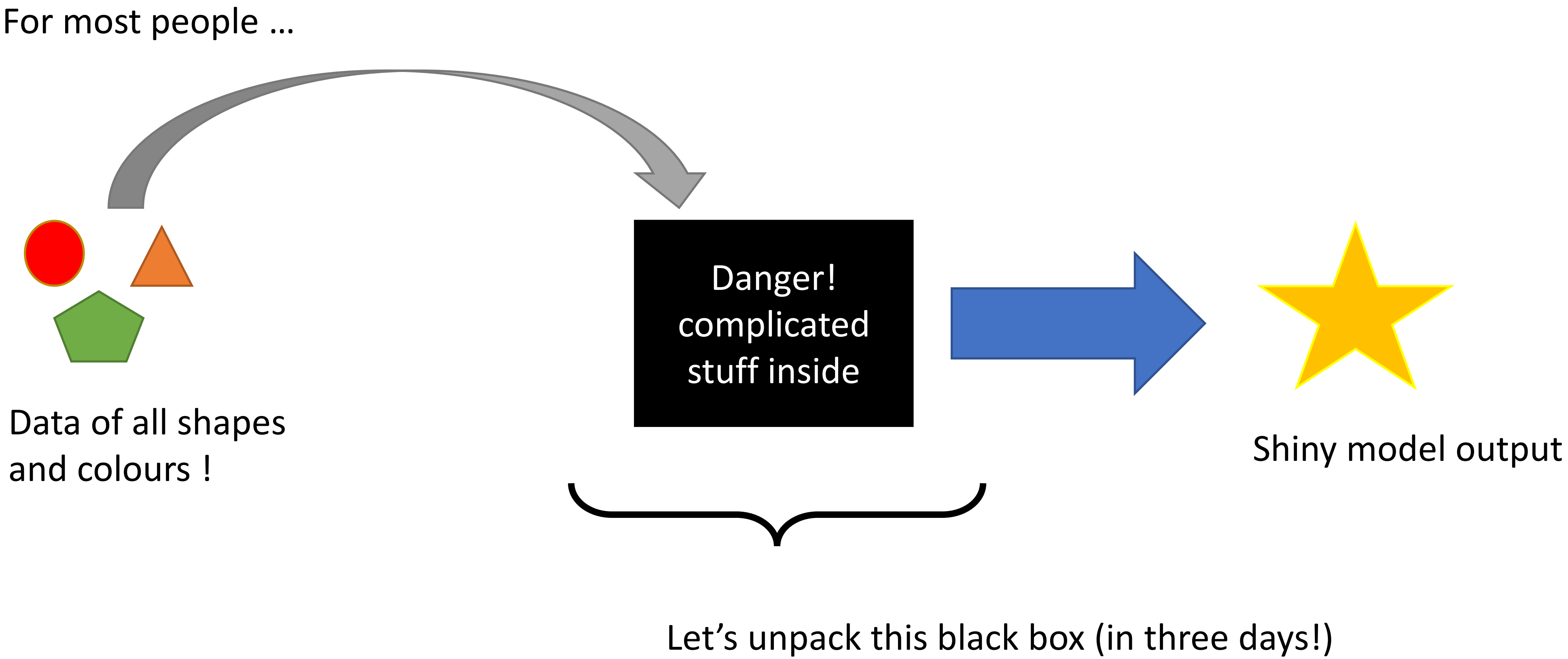
- Weather: very predictable -> laws of physics

- Infectious diseases -> very complex!

    - Biology of the pathogen
    - Clinical characteristics
    - Host behaviour
    - Population dynamics

By definition a multidisciplinary field (all are welcome!)

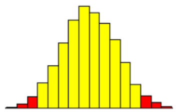
So how does an ID model looks like?



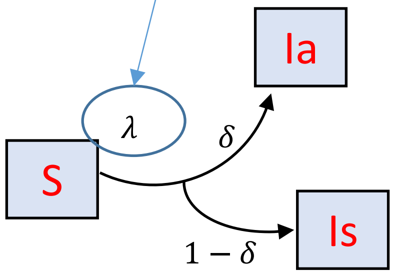
So how does an ID model looks like?

How it really looks…

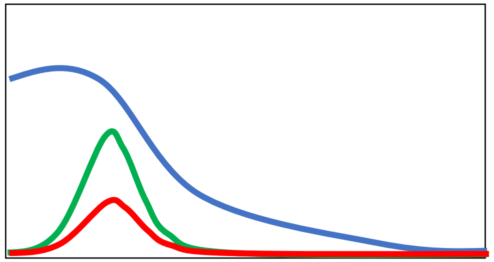
A dynamic component!



Carefully selected data to fuel our mechanism



A design of our phenomenon described with maths



A model projection

What type of data inputs?

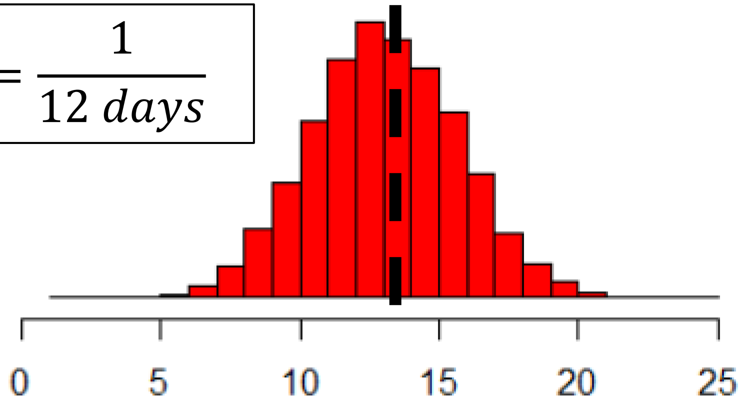
Given we understand the mechanism we want to describe:

- Model inputs are the pieces of information (facts) that bind together our model design.
- We need statistics to interpret these binding links.

Let's imagine a cohort where infected individuals become symptomatic

$$\theta = \frac{1}{mean\ incubation\ period}$$

$$\theta = \frac{1}{12\ days}$$



What do we need to design a mathematical model?

- Some maths
- For compartmental models we use ordinary differential equations (ODEs)
- Some statistics : for summarising model inputs and for processing model results

Ordinary differential equations (ODEs)

- Mathematics used to describe change of a system, e.g: speed (distance/time) :

Change in distance →

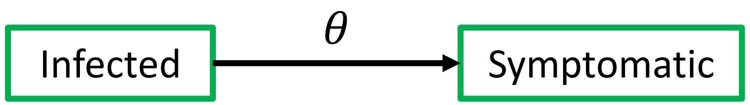
$$\frac{dx}{dt} = 70\ mph$$

Change in time →

- At a steady speed of 70mph how far can we get in 2 hours? Solve :
- $t(2) = 70\ x\ 2 = 140\ miles$
- We will review this further applied to infectious diseases!

What about compartments?

- The previous example requires one single function
- We are interested in ODE systems with more than one state



$$\begin{cases} \frac{dI}{dt} = -I(t)\theta \\ \frac{dS}{dt} = I(t)\theta \end{cases}$$

- It is clear that this system describes the average behaviour for such phenomenon

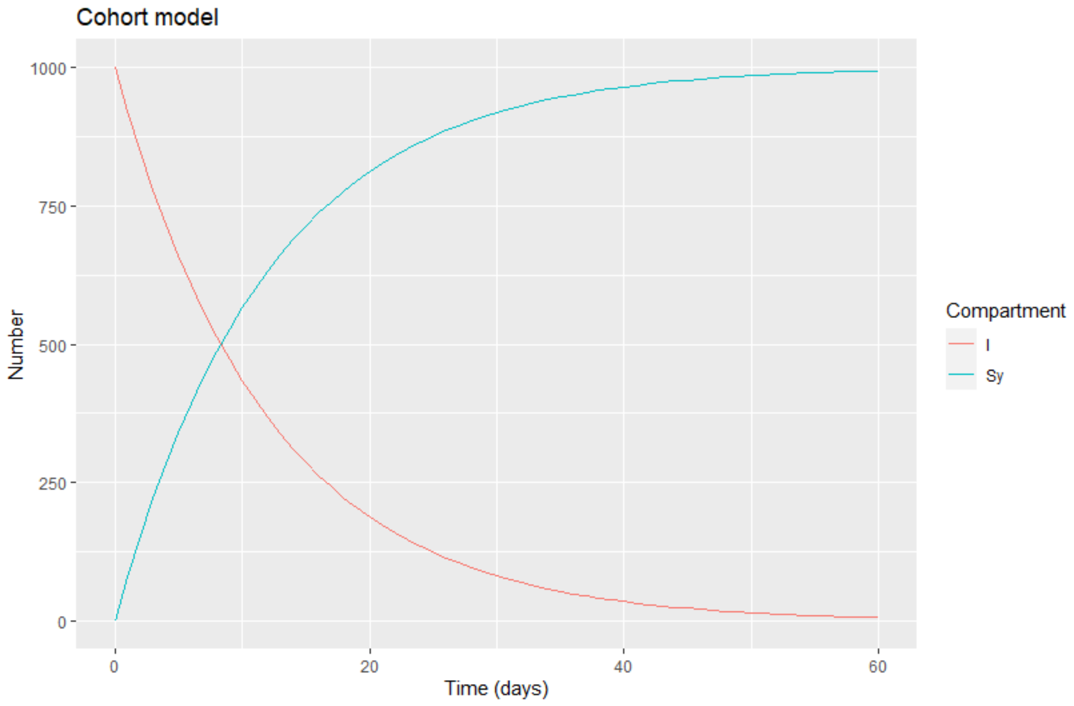
How we produce model output ?

- Back to our previous system

$$\frac{dI}{dt} = -I(t)\theta$$

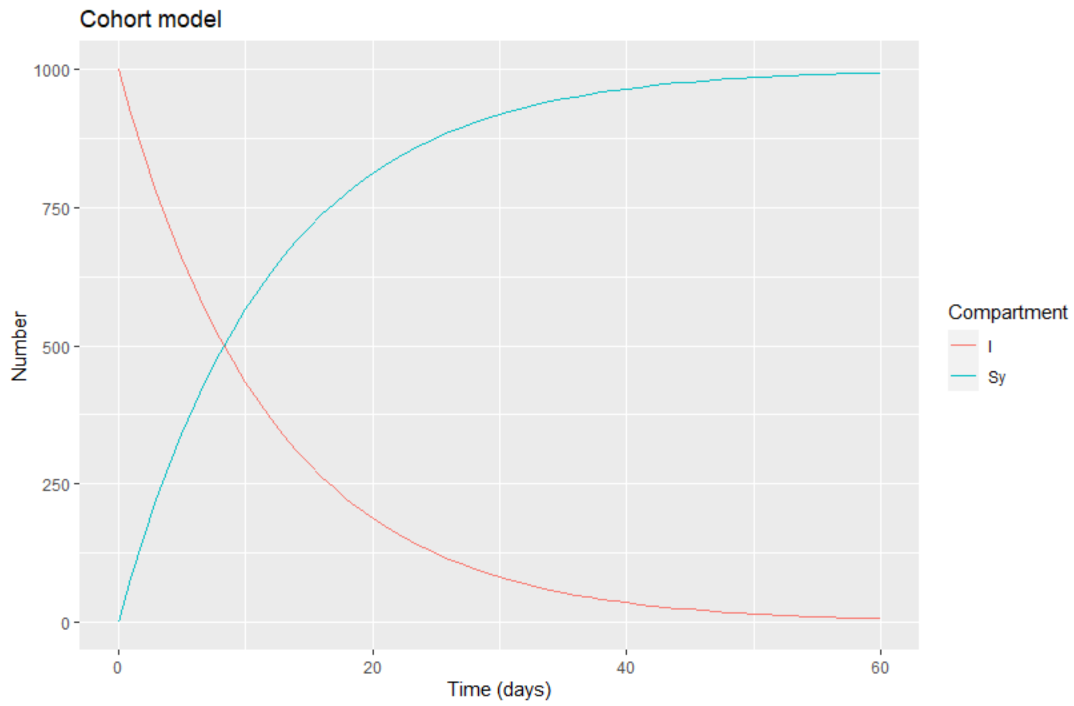
$$\frac{dS}{dt} = I(t)\theta$$

Numerical integration using a software , R !

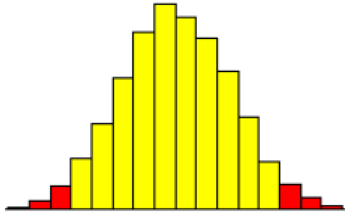


What is the output?

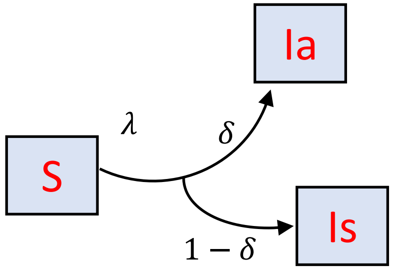
- Is the integration of our system over a time period
- We ***project*** the value of our state variables (*I* and *Sy)* over 60 days
- We don't ***predict*** since our results come from a simplified systems and assumptions
- Prediction is for statistics!



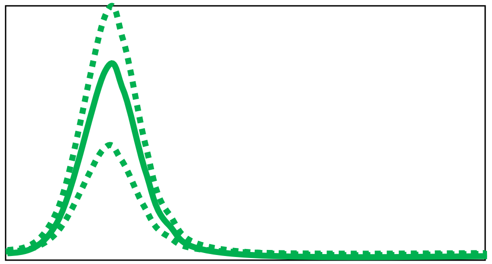
What about uncertainty in our results?



Uncertainty
in the inputs



Uncertainty
in the system



Results in uncertainty around our projections

We can explore this range by calibrating our parameters

If we introduce stochasticity

Types of mathematical models

- **Deterministic**
- A same set of model parameters will **always** produce the same results
- The results are strictly determined by the parameter values given a system
- E.g., an infected individual will always develop symptoms at an average rate θ.
- We will focus on these !!

- **Stochastic**
- A same set of model parameters can produce **different** results
- The results combine the input and randomness in the events of transition
- E.g., an infected individual can or cannot develop symptoms out of chance.

Types of mathematical models

- **Compartmental**
- Describe the system of interest at the population level
- Are good to understand the average behaviour of a phenomenon
- Easier to interpret
- Sometimes hard to code!

- **Individual**
- Simulate individuals
- Easier to code
- Harder to interpret
- Computationally expensive
- Require much more data

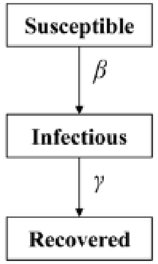
Focus in this short course

- We are interested in public health, not in maths!

- We want to apply mathematics and statistics to understand infectious diseases

- These methods have a strong role in the current landscape of public health and can help improve global health!

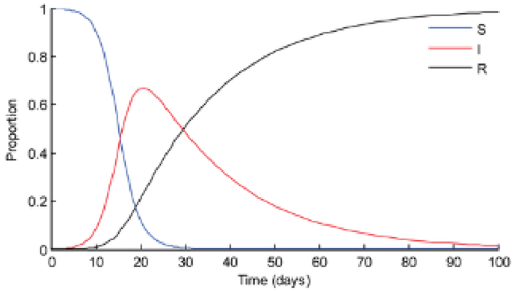
Roles of transmission models in public health



$$\frac{dS}{dt} = -\beta SI$$

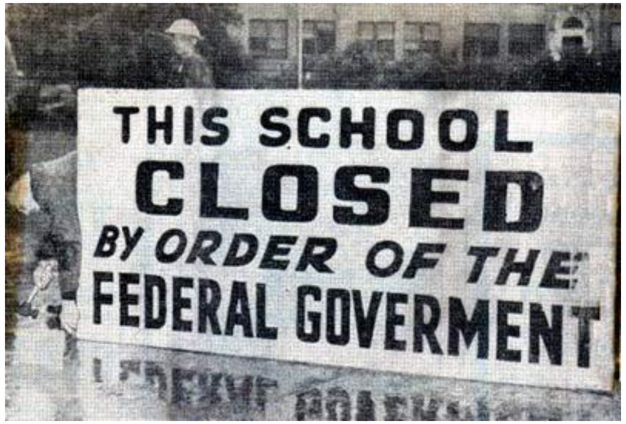
$$\frac{dI}{dt} = \beta SI - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$



Supporting healthcare delivery

Informing decision-making



Basic science: contributing to evidence base for policy

What we should know by now

- What is a mathematical model
- What are the building blocks of models
- What are the basic maths for describing a model
- What types of mathematical models there are
- How can models contribute to public health