Imperial College London

MACHINE LEARNING & GLOBAL HEALTH NETWORK

Practical 3: Designing a model of HIV

Modern Statistics and Machine Learning for Population Health in Africa

27th March 2025

(with thanks to Imperial College London MRC Centre for Global Infectious Disease Analysis and University of Bristol for initial ideas)

In this practical we will design and understand a basic model flow chart of HIV infection. Then we will incorporate increased model complexity by expanding the model flow chart. This forms the first step of model creation and fitting it to data that we will investigate tomorrow.

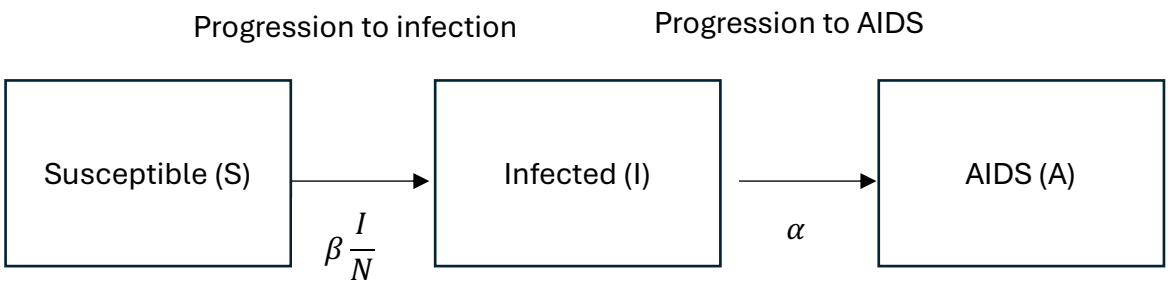
Introduction to HIV

Human immunodeficiency virus (HIV) is a blood-borne virus that had infected 39.0 million [33.1–45.7 million] people by the end of 2022, with two thirds (25.6 million) being in the WHO African Region. It can be transmitted via the exchange of a variety of body fluids from people living with HIV, such as blood, breast milk, semen and vaginal secretions. HIV can also be transmitted during pregnancy and delivery to the child. If untreated, HIV infection can progress to acquired immune deficiency syndrome (AIDS). There is no cure, but effective lifelong treatment by antiretroviral therapy (ART) can halt the transmission potential of HIV and disease progression, with HIV-infected individuals living normal lifespans.

Model 1: Simple model

A simple HIV model structure the contains the main aspects of HIV include three compartments: Susceptible (S), Infected (I), and AIDS (A). Susceptible persons can become infected and can subsequently progress to AIDS. We do not include births and non-HIV-related deaths.

1) Draw a flow chart diagram explaining the transmission described in the model 1 description. Using similar notation to the lecture, use symbols to describe the transmission and define them.



β is the contact rate, α is the progression rate to AIDS, I is the number of infected individuals and N is the total population

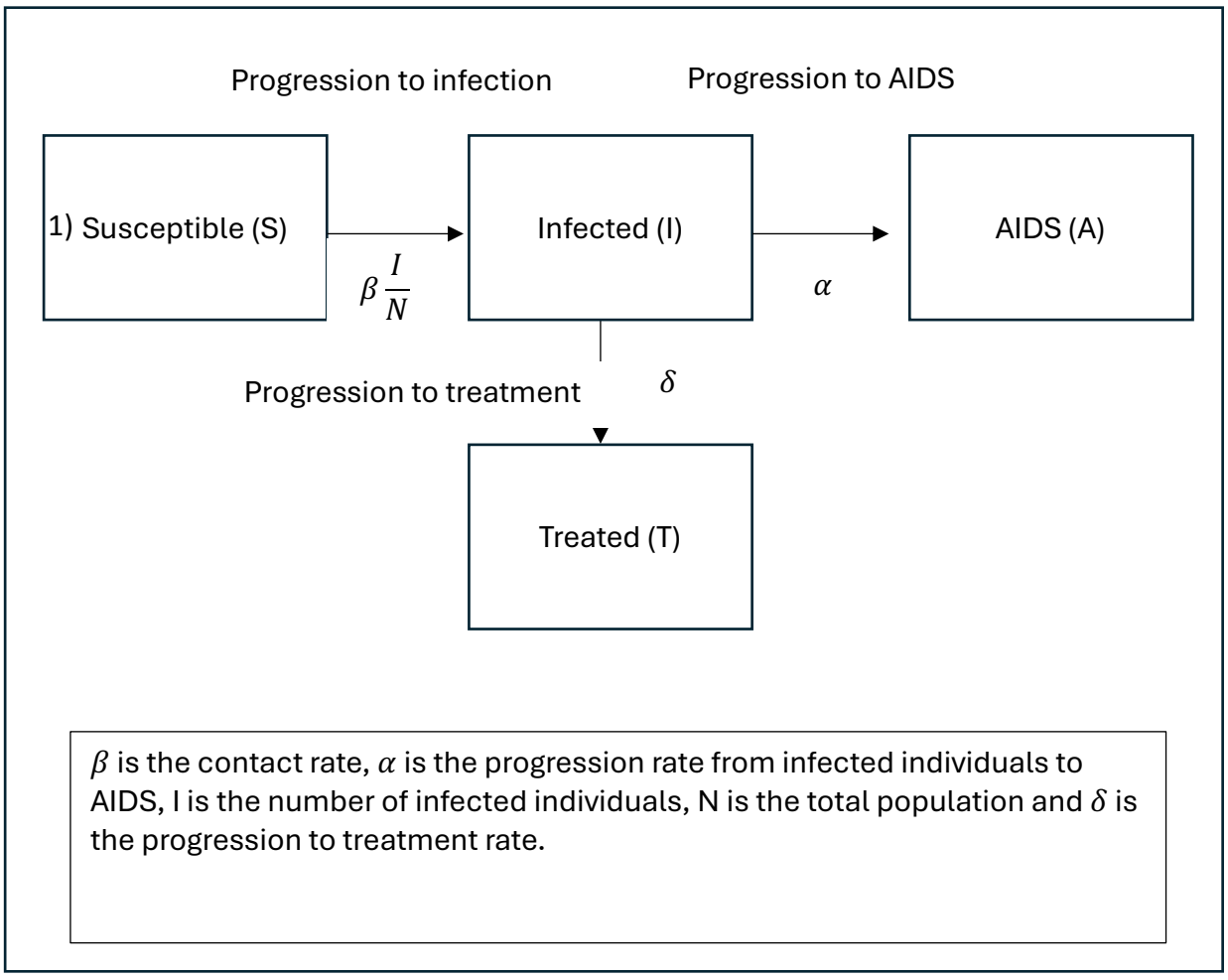
2) Write down the ordinary differential equations (ODEs) that explain this model. You may find it helpful to write the equations out in words depending on your familiarity with ODEs.

$$\frac{dS}{dt} = -\beta \frac{I}{N} S$$
$$\frac{dI}{dt} = \beta \frac{I}{N} S - \alpha I$$
$$\frac{dA}{dt} = \alpha I$$

This assumes that a person who has AIDs is too ill to infect people. If you didn't want to make this assumption you could change the transmission rate to $\beta \frac{(I+A)}{N}$.

Model 2: Incorporating antiretroviral therapy (ART).
ART has been shown to reduce HIV transmission to negligible levels from infected to susceptible individuals and slow down the progression to AIDS and reduce AIDS mortality rates. Infected individuals can start treatment, and in this model, we assume once they are treated, they achieve viral suppression and are not infectious, remaining in the treated compartment whilst taking medication.

3) Draw a flow chart diagram explaining the transmission described in the model 2 description.



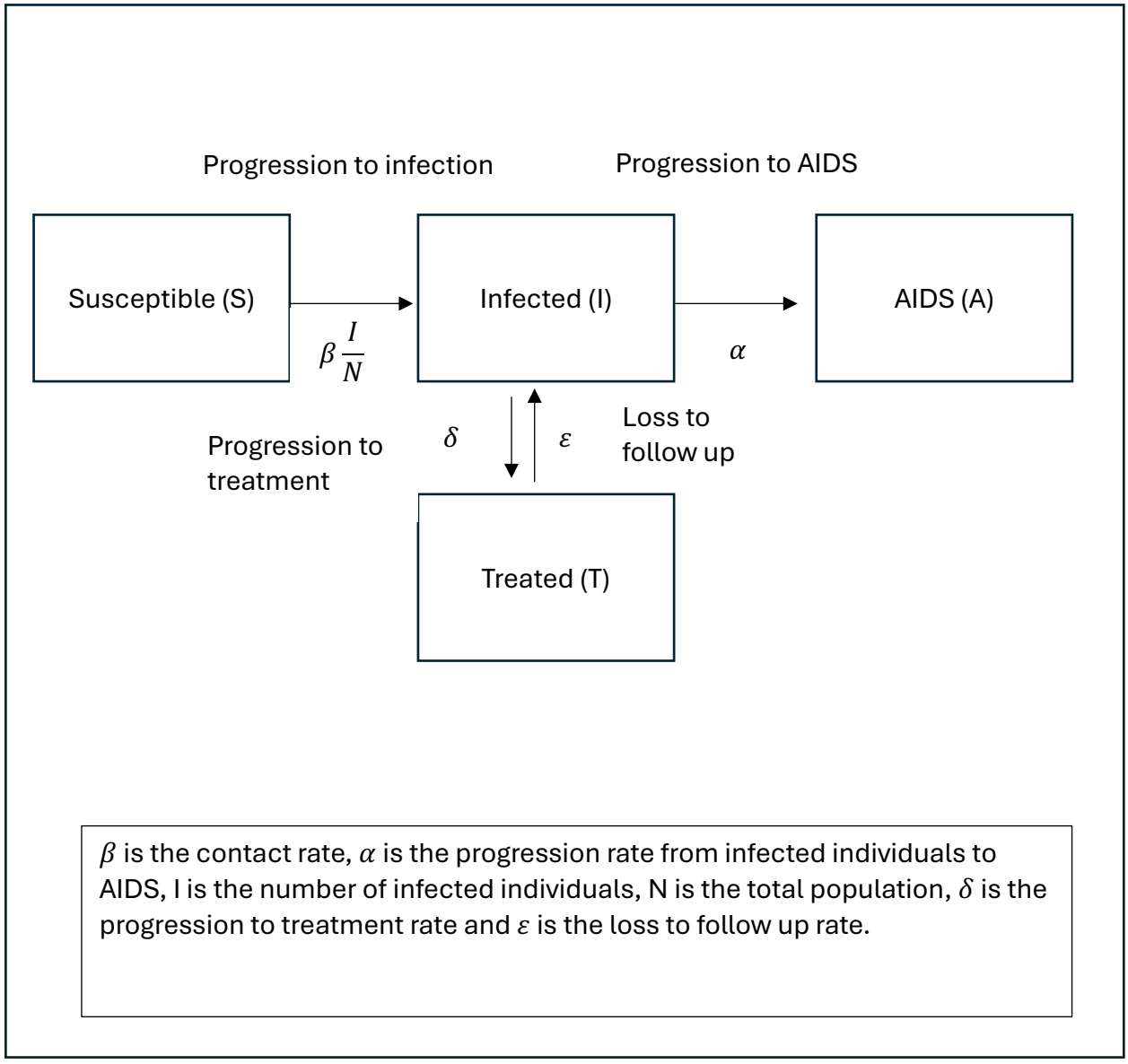
β is the contact rate, α is the progression rate from infected individuals to AIDS, I is the number of infected individuals, N is the total population and δ is the progression to treatment rate.

4) Write down the ordinary differential equations (ODEs) that explain model 2.

$$\frac{dS}{dt} = -\beta \frac{I}{N} S$$
$$\frac{dI}{dt} = \beta \frac{I}{N} S - \delta I - \alpha I$$
$$\frac{dT}{dt} = \delta I$$
$$\frac{dA}{dt} = \alpha I$$

Model 3: Loss to treatment.
Another feature of long-term treatment is that individuals stop following the recommended programme and are "lost to follow up". These people move back from the treated compartment to the infected compartment.

5) Draw a flow chart diagram explaining the transmission described in the model 3 description.



β is the contact rate, α is the progression rate from infected individuals to AIDS, I is the number of infected individuals, N is the total population, δ is the progression to treatment rate and ε is the loss to follow up rate.

6) Write down the ordinary differential equations (ODEs) that explain model 3.

$$\frac{dS}{dt} = -\beta \frac{I}{N} S$$

$$\frac{dI}{dt} = \beta \frac{I}{N} S + \varepsilon T - \delta I - \alpha I$$

$$\frac{dT}{dt} = \delta I - \varepsilon T$$

$$\frac{dA}{dt} = \alpha A$$

7) If you have any additional time, use your own knowledge, what the demonstrators can tell you and do some research to add some other factors that could improve your model of HIV.