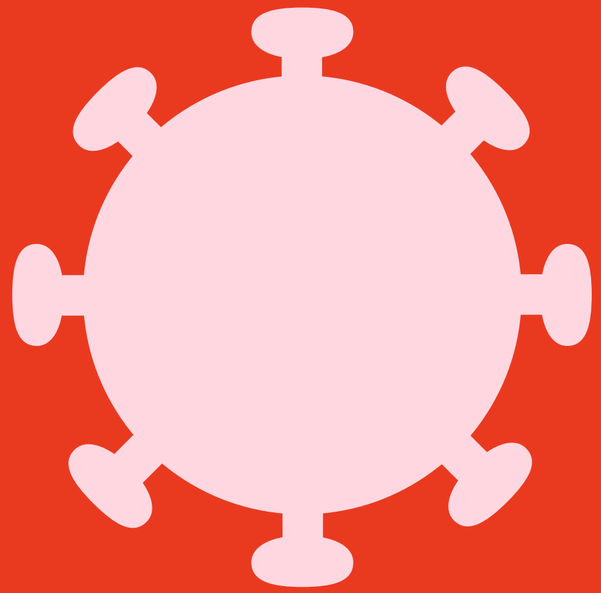
BEHAVIORAL EPIDEMILOGY

MODELING DISEASES AND HUMAN RESPONSE



Alice Oveson

GTM July 2025

WHAT IS IT?

THE STUDY OF DISEASES

THE STUDY HUMAN BEHAVIOR

MATHEMATICAL MODELING

OUTLINE

I. BRIEF INTRODUCTION TO MATH MODELING

Important questions, model types, etc.

II. MODELING DISEASES

Basics, important questions, and three examples

III. MODELING HUMAN HEALTH BEHAVIOR

There are no basics we are literally making this up as we go

MODELING BASICS

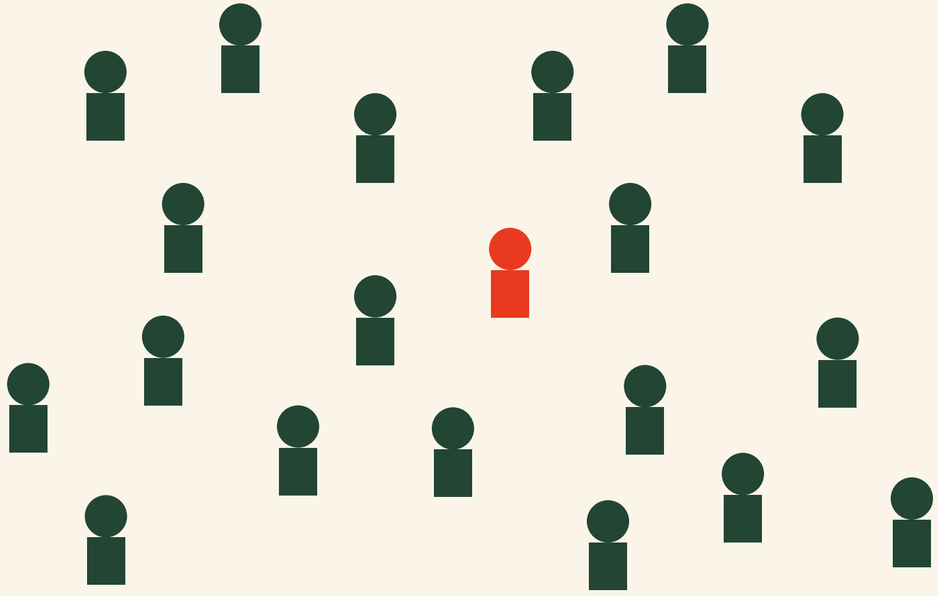
- How can we describe what we see with math?
- Discrete Models
  - $X_{t+1} = f(X_t)$
- Continuous Models
  - $X'(t) = f(t)$
- Compartmental Models: splitting the population by characteristics (location, age, sex, disease state, etc.)

DISEASE BASICS

- How does infection occur? (Respiratory, Sexually transmitted, vector-borne, etc.)
- What are the different stages of the disease? (Uninfected, exposed, (a)symptomatically infectious, recovered)
- What is the timeline like? Is the timescale in days, months, years?
- How bad is it? (Death rate and reproduction number)

REPRODUCTION NUMBER

ON AVERAGE, HOW MANY PEOPLE WILL AN INDIVIDUAL WITH DISEASE X INFECT DURING THEIR INFECTIOUS PERIOD?



Known Reproduction Numbers:

- COVID-19: 3-5 (varies by strain)
- HIV/AIDS: 2-6
- Seasonal flu: 1.3
- Polio: 5-7
- Mumps: 10-12
- Measles: 18

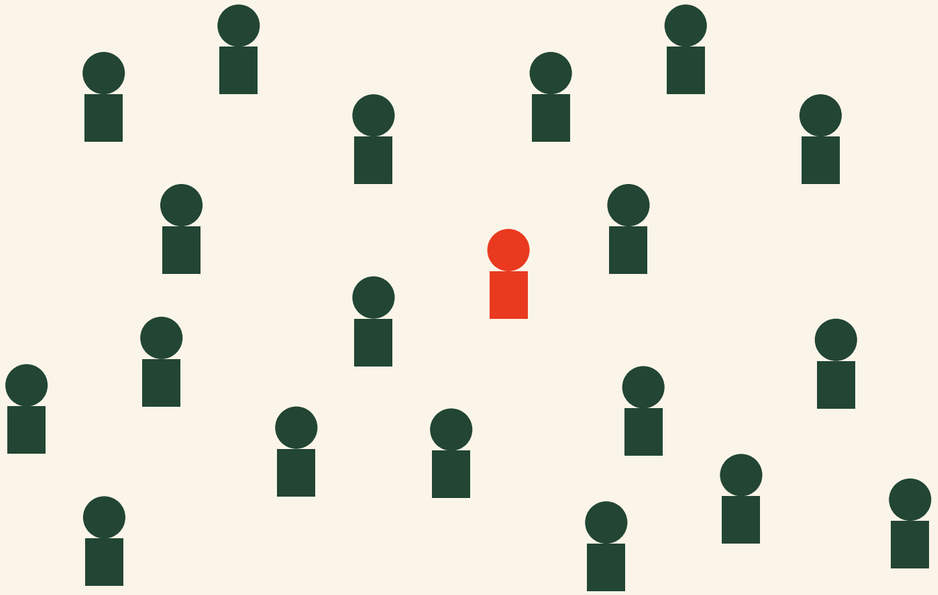
IF THE REPRODUCTION NUMBER IS LESS THAN 1, THE DISEASE WILL DIE OUT.

REPRODUCTION NUMBER

BASIC REPRODUCTION NUMBER

$\mathbb{R}_0$

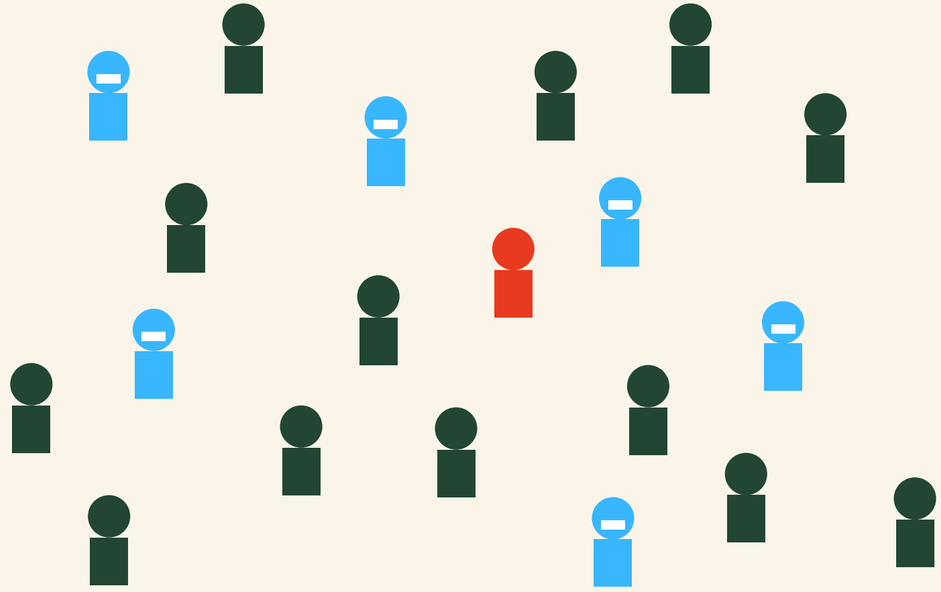
(Totally susceptible population,
does not change)



CONTROL REPRODUCTION NUMBER

$\mathbb{R}_c$

(Partially protected or immune population,
changes as humans adapt)



OUR GOAL IS TO GET THE CONTROL REPRODUCTION NUMBER BELOW 1.

DISEASE MODELING

3 STEPS

STEP 1

Answer the important questions

STEP 2

Make a flowchart to visualize

STEP 3

Build your mathematical model

DISEASE MODELING

3 EXAMPLES: STEP 1

COVID-19

How does infection occur?
What are the stages of the disease?
What is the timeline/scale?

How can we decrease the reproduction number?

HIV/AIDS

How does infection occur?
What are the stages of the disease?
What is the timeline/scale?

How can we decrease the reproduction number?

MALARIA

How does infection occur?
What are the stages of the disease?
What is the timeline/scale?

How can we decrease the reproduction number?

Super quick group discussion: chat with your neighbors.

DISEASE MODELING

3 EXAMPLES: STEP 1

COVID-19

Respiratory transmission (breath, spit, coughs and sneezes)

Disease stages include: susceptible, asymptomatic, symptomatic, recovered, hospitalized (optional)

Infection and recovery happen in terms of days

Masking, vaccination, social distancing

HIV/AIDS

Sexual transmission, needle sharing between drug users, mother to child

Disease stages include: susceptible, acute HIV, chronic HIV, AIDS, treated

Infection and acute HIV stage happen over a few days, chronic HIV and AIDS stages can last for years

Condoms, PrEP, high quality sex ed

MALARIA

Mosquito to human and human back to mosquito via bites

Disease stages include: susceptible (humans), infected (humans), recovered (humans), susceptible (mosquitoes), infected (mosquitoes)

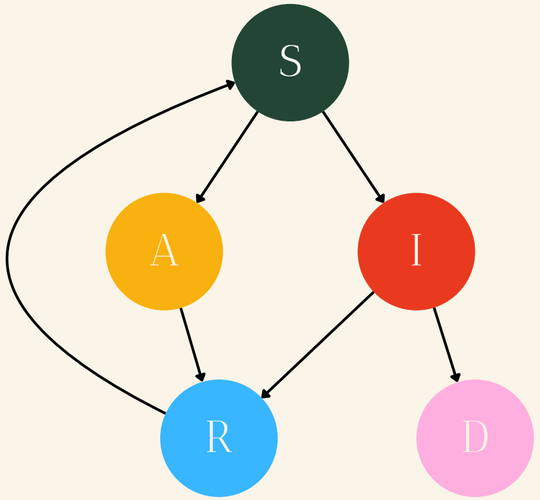
Infection and recovery occur over the course of 2-4 weeks

bug spray, malarial pills, bed nets

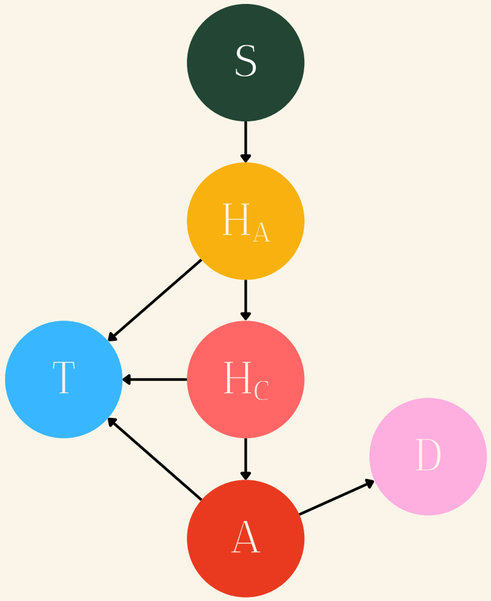
DISEASE MODELING

3 EXAMPLES: STEP 2

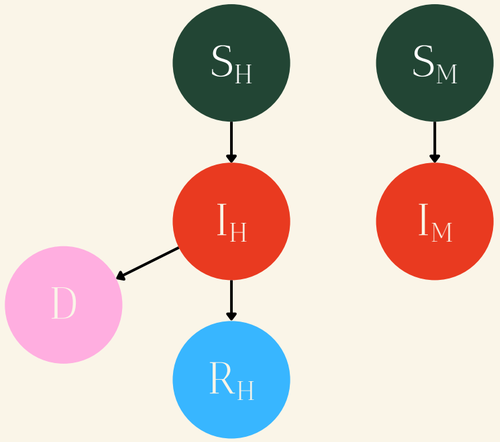
COVID-19



HIV/AIDS

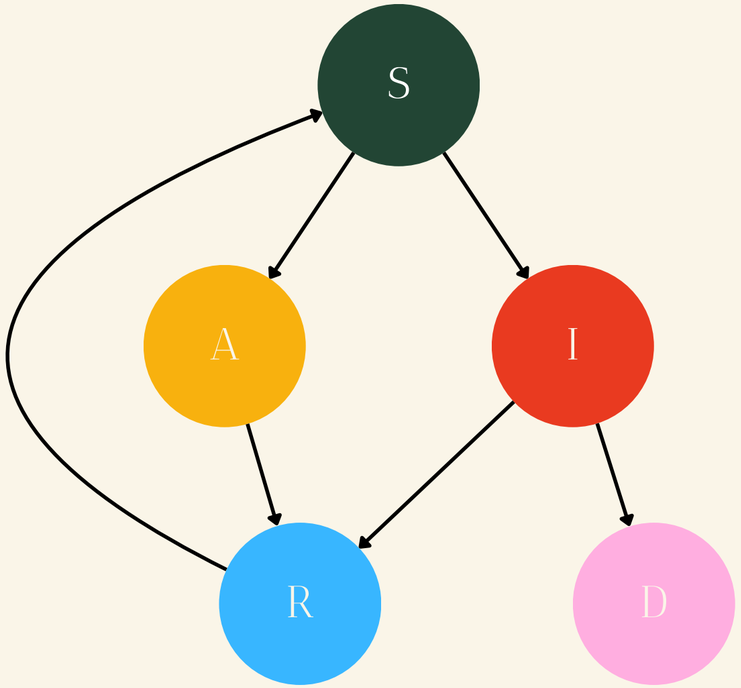


MALARIA



COVID-19 MODELING

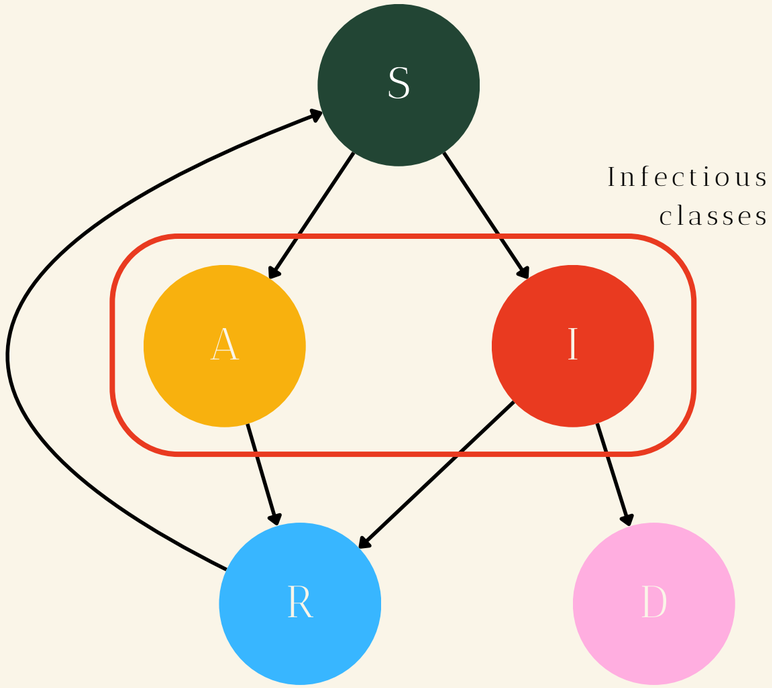
STEP 3



$$S'(t) =$$
$$A'(t) =$$
$$I'(t) =$$
$$R'(t) =$$
$$D'(t) =$$

COVID-19 MODELING

STEP 3



$$S'(t) =$$
$$A'(t) =$$
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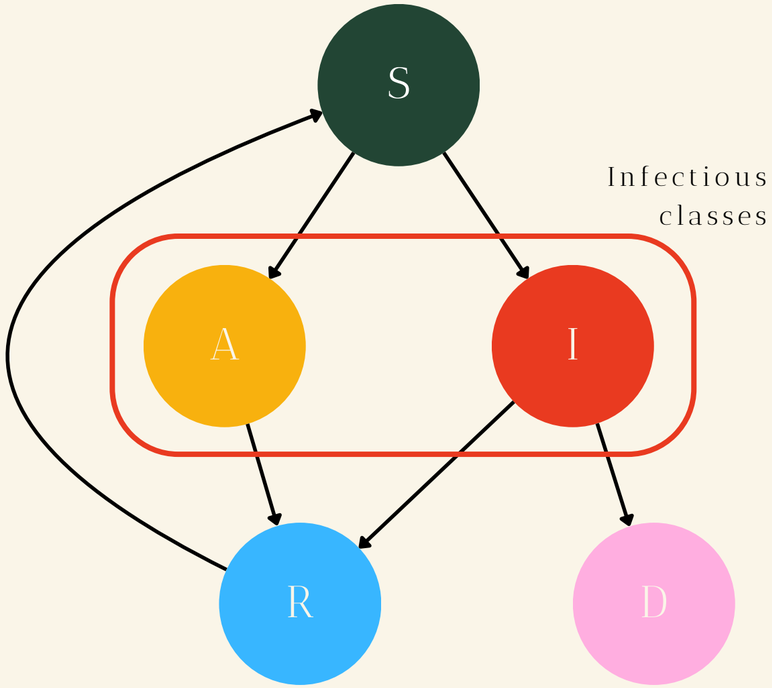
$$R'(t) =$$
$$D'(t) =$$

COVID-19 MODELING

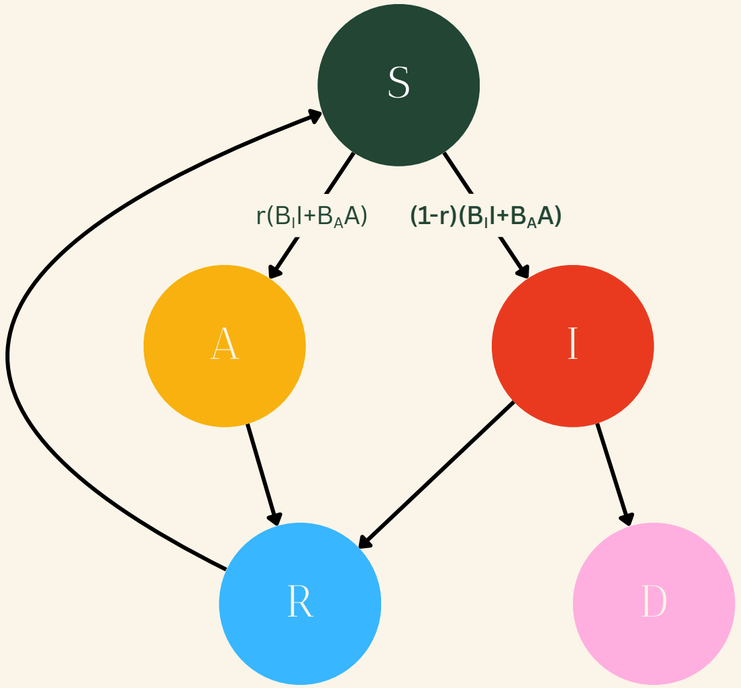
STEP 3



$$S'(t) = -\beta_I IS - \beta_A AS$$
$$A'(t) =$$
$$I'(t) =$$
$$R'(t) =$$
$$D'(t) =$$

COVID-19 MODELING

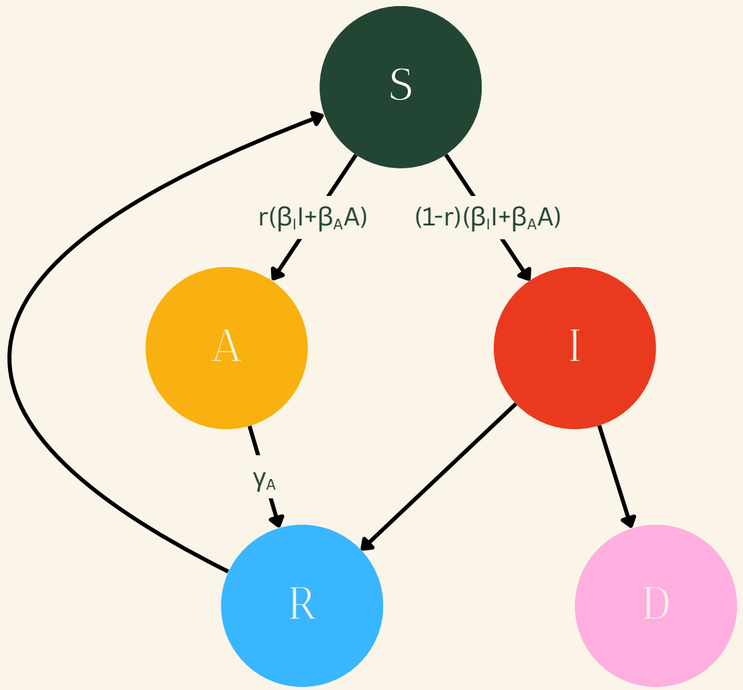
STEP 3



$$S'(t) = -\beta_I I S - \beta_A A S$$
$$A'(t) = r(\beta_I I + \beta_A A)S$$
$$I'(t) = (1-r)(\beta_I I + \beta_A A)S$$
$$R'(t) =$$
$$D'(t) =$$

COVID-19 MODELING

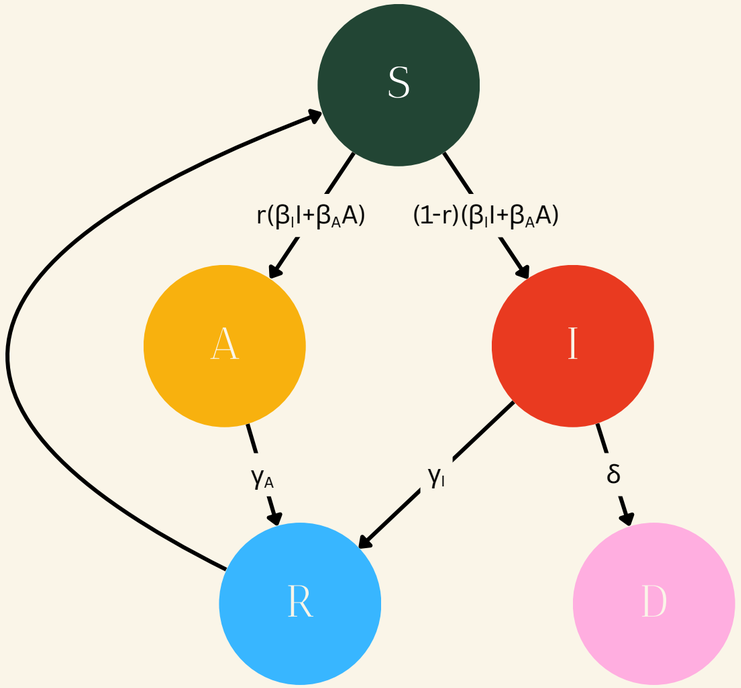
STEP 3



$$
\begin{aligned}
S'(t) &= -\beta_I I S - \beta_A A S \\
A'(t) &= r(\beta_I I + \beta_A A)S - \gamma_A A \\
I'(t) &= (1-r)(\beta_I I + \beta_A A)S \\
R'(t) &= \gamma_A A \\
D'(t) &=
\end{aligned}
$$

COVID-19 MODELING

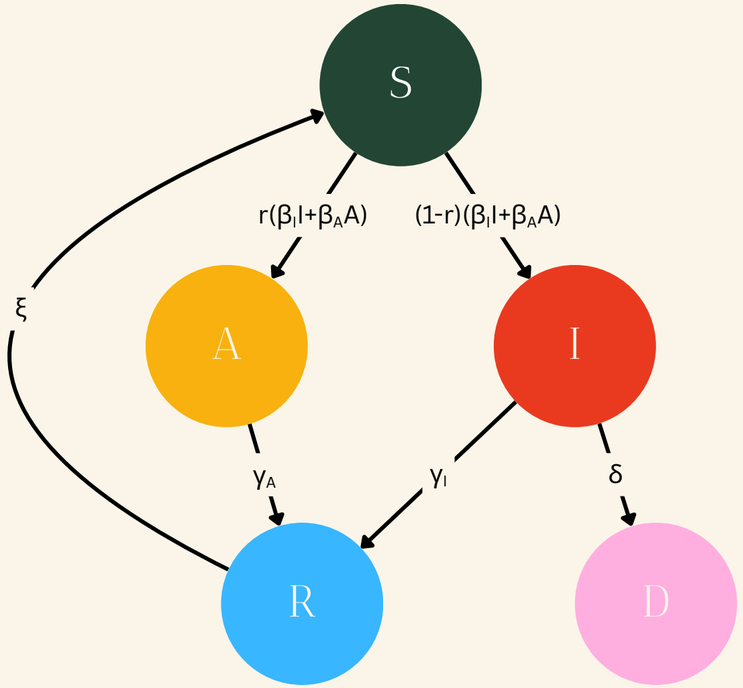
STEP 3



$$
\begin{aligned}
S'(t) &= -\beta_I I S - \beta_A A S \\
A'(t) &= r(\beta_I I + \beta_A A)S - \gamma_A A \\
I'(t) &= (1-r)(\beta_I I + \beta_A A)S - \gamma_I I - \delta I \\
R'(t) &= \gamma_A A + \gamma_I I \\
D'(t) &= \delta I
\end{aligned}
$$

COVID-19 MODELING

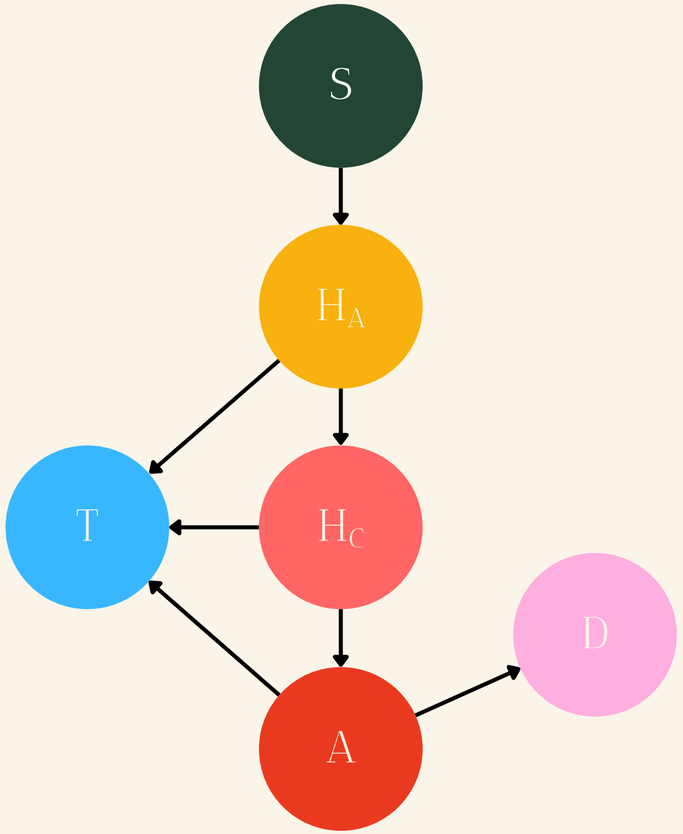
STEP 3



$$
\begin{aligned}
S'(t) &= \xi R - \beta_I I S - \beta_A A S \\
A'(t) &= r(\beta_I I + \beta_A A)S - \gamma_A A \\
I'(t) &= (1-r)(\beta_I I + \beta_A A)S - \gamma_I I - \delta I \\
R'(t) &= \gamma_A A + \gamma_I I - \xi R \\
D'(t) &= \delta I
\end{aligned}
$$

HIV/AIDS MODELING

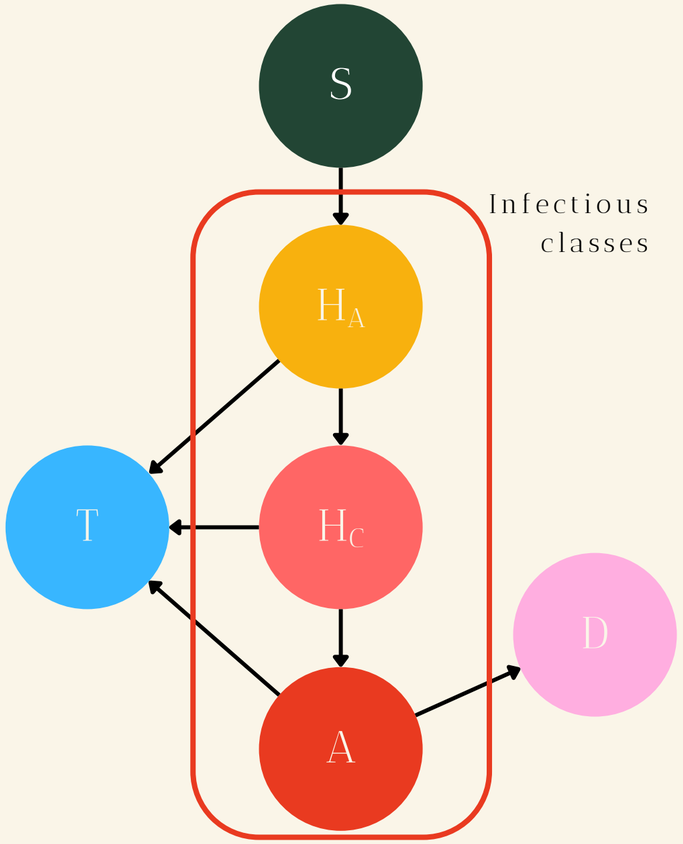
STEP 3



$$S'(t) =$$
$$H'_A(t) =$$
$$H'_C(t) =$$
$$A'(t) =$$
$$T'(t) =$$
$$D'(t) =$$

HIV/AIDS MODELING

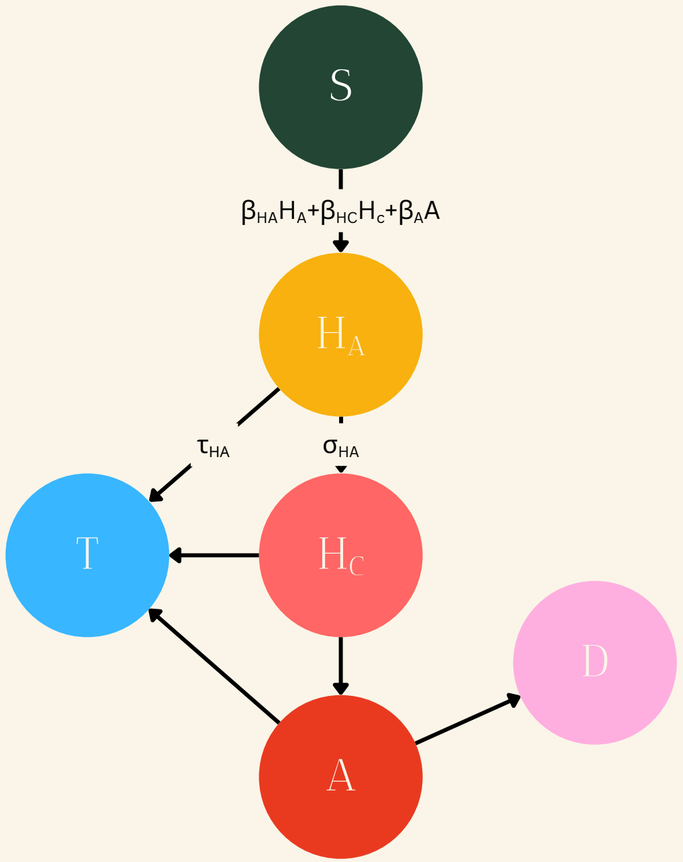
STEP 3



$$
\begin{aligned}
S'(t) &= -\beta_{H_A} H_A S - \beta_{H_C} H_C S - \beta_A A S \\
H'_A(t) &= (\beta_{H_A} H_A + \beta_{H_C} H_C + \beta_A A) S \\
H'_C(t) &= \\
A'(t) &= \\
T'(t) &= \\
D'(t) &=
\end{aligned}
$$

HIV/AIDS MODELING

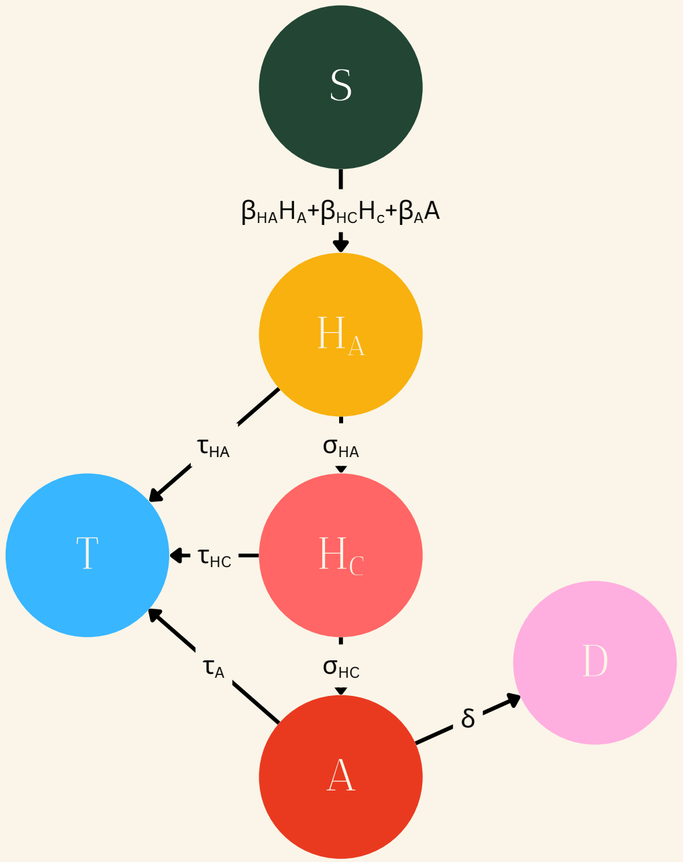
STEP 3



$$
\begin{aligned}
S'(t) &= -\beta_{H_A} H_A S - \beta_{H_C} H_C S - \beta_A A S \\
H'_A(t) &= (\beta_{H_A} H_A + \beta_{H_C} H_C + \beta_A A) S - \tau_{H_A} H_A - \sigma_{H_A} H_A \\
H'_C(t) &= \sigma_{H_A} H_A \\
A'(t) &= \\
T'(t) &= \tau_{H_A} H_A \\
D'(t) &=
\end{aligned}
$$

HIV/AIDS MODELING

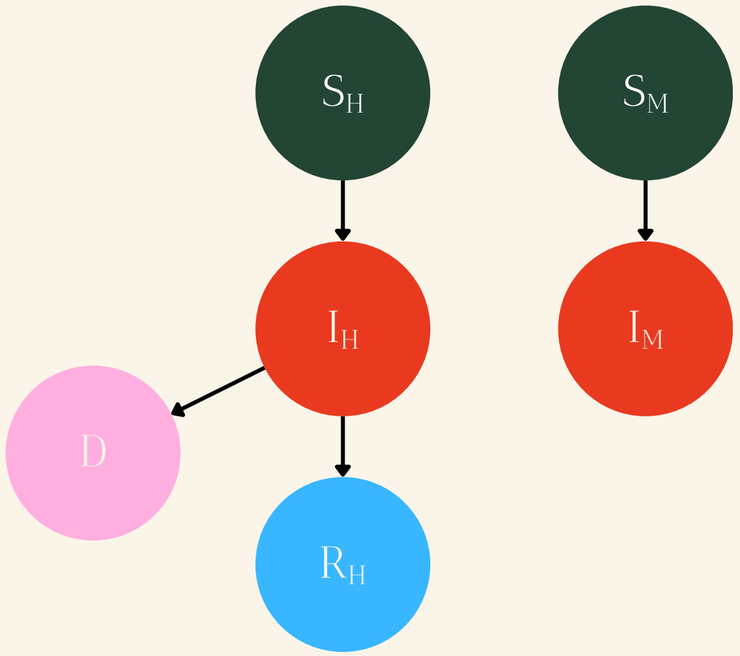
STEP 3



$$
\begin{aligned}
S'(t) &= -\beta_{H_A} H_A S - \beta_{H_C} H_C S - \beta_A A S \\
H'_A(t) &= (\beta_{H_A} H_A + \beta_{H_C} H_C + \beta_A A) S - \tau_{H_A} H_A - \sigma_{H_A} H_A \\
H'_C(t) &= \sigma_{H_A} H_A - \sigma_{H_C} H_C - \tau_{H_C} H_C \\
A'(t) &= \sigma_{H_C} H_C - \tau_A A - \delta A \\
T'(t) &= \tau_{H_A} H_A \\
D'(t) &= \delta A
\end{aligned}
$$

MALARIA MODELING

STEP 3

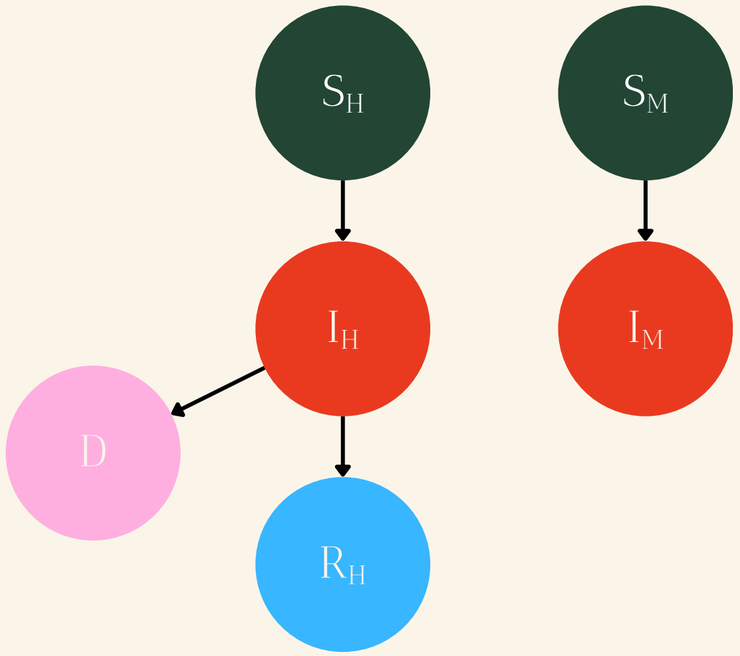


$$S'_H(t) =$$
$$I'_H(t) =$$
$$R'_H(t) =$$
$$D'(t) =$$

$$S'_M(t) =$$
$$I'_M(t) =$$

MALARIA MODELING

STEP 3



$$S'_H(t) = -\beta_{M2H} I_M S_H$$
$$I'_H(t) = \beta_{M2H} I_M S_H - \gamma I_H - \delta I$$
$$R'_H(t) = \gamma I_H$$
$$D'(t) = \delta I$$

$$S'_M(t) = -\beta_{H2M} I_H S_M$$
$$I'_M(t) = \beta_{H2M} I_H S_M$$

OKAY BUT WHAT ABOUT HUMAN BEHAVIOR?

DISEASE-BEHAVIOR BASICS(?)

It does not matter how dangerous the disease is: the only thing that will cause people to change their behavior is how they perceive the disease. This is why making public health information readily available is so important.

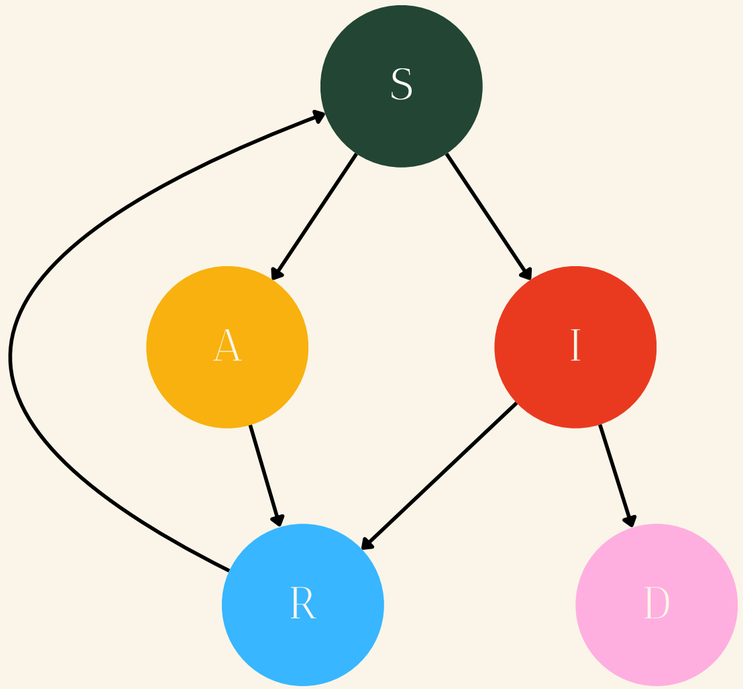
Do they perceive the disease to be a significant threat?

DISEASE-BEHAVIOR BASICS(?)

- How is (mis)information about the disease shared? (social media, news sites, town square notices)
- Do most people trust the information?
- If people do perceive the disease to be a threat, how do they respond? (masking, vaccination, limiting contacts)
- How does the perception of the threat change over time?

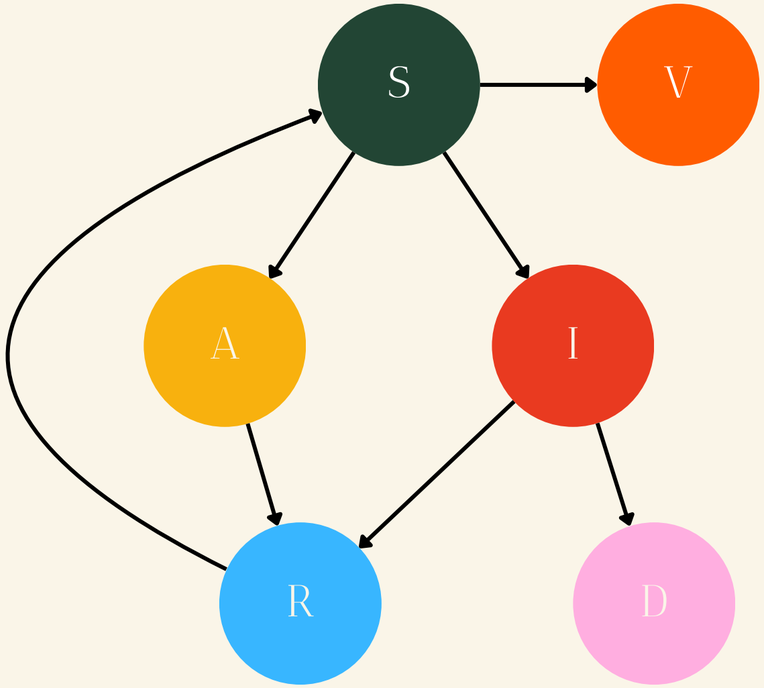
DISEASE MODELING
+ BEHAVIOR!

What does human behavior look like in math/epidemiology terms?

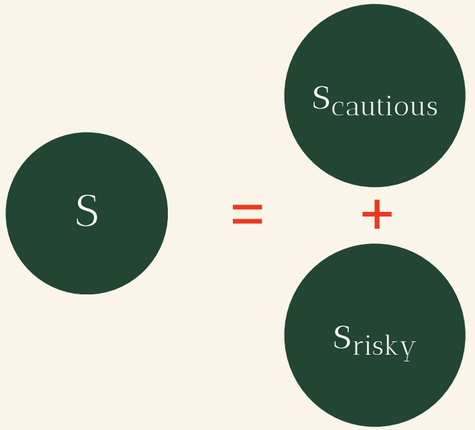


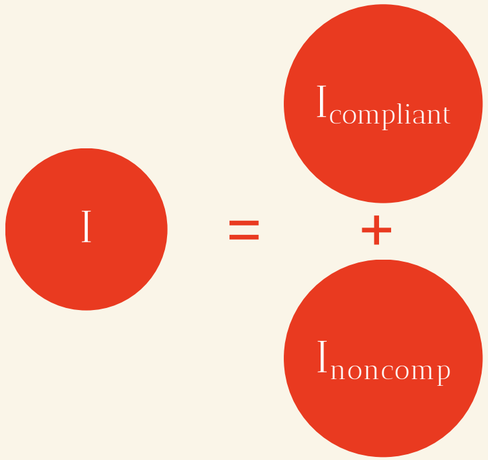
DISEASE MODELING
+ BEHAVIOR!

Adding a vaccination class



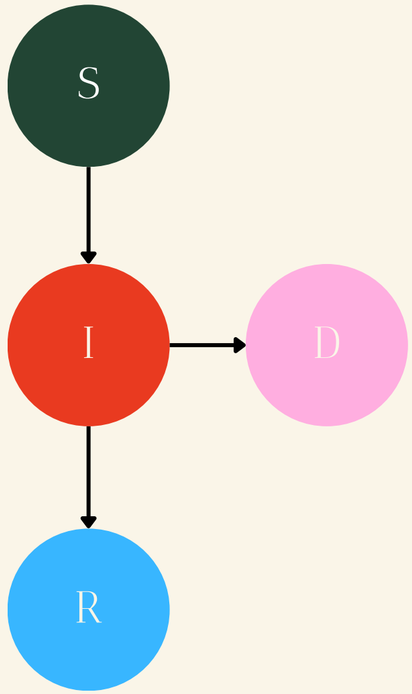
Dividing compartments by behavior





DISEASE MODELING
+ BEHAVIOR!

Including adaptive contact rates



$$S'(t) = -\beta\, c(I) IS$$
$$I'(t) = \beta\, c(I) IS - \gamma I$$
$$R'(t) = \gamma I$$

$$c(I) = e^{-pI(t)}$$

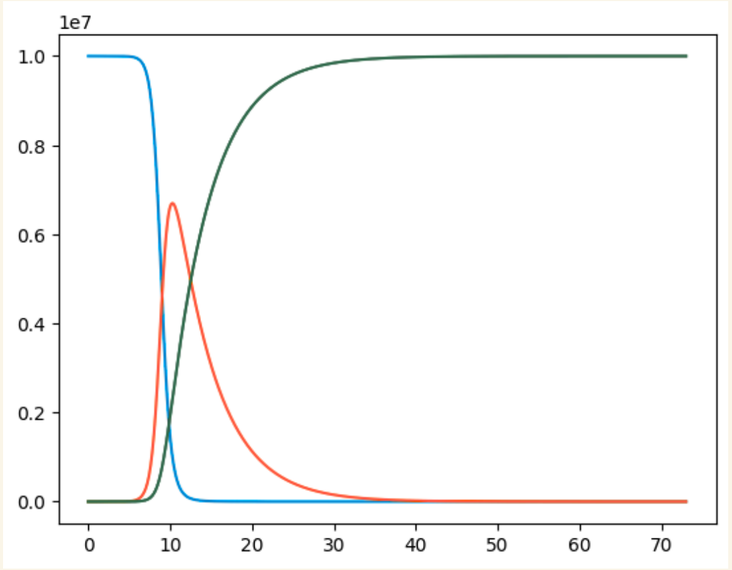
Susceptible individuals decrease contacts as more people get sick

WHAT DIFFERENCE DOES THAT MAKE?

$$S'(t) = -\beta IS$$
$$I'(t) = \beta IS - \gamma I$$
$$R'(t) = \gamma I$$

VS.

$$S'(t) = -\beta\, c(I) IS$$
$$I'(t) = \beta\, c(I) IS - \gamma I$$
$$R'(t) = \gamma I$$
$$c(I) = e^{-pI(t)}$$



S
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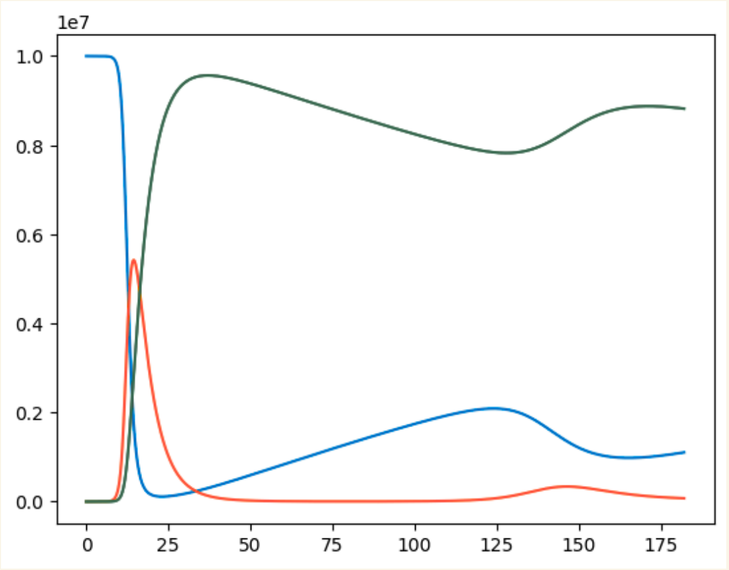

Q&T&F&A

QUESTIONS, THOUGHTS, FEELINGS AND (MAYBE) ANSWERS

THANK YOU

BEING A WOMAN IN MATH IS COOL. YOU ARE COOL.