UNIVERSITY OF TRENTO

A New Model to Capture the Impact of Behaviours on the Spread of Infectious Diseases

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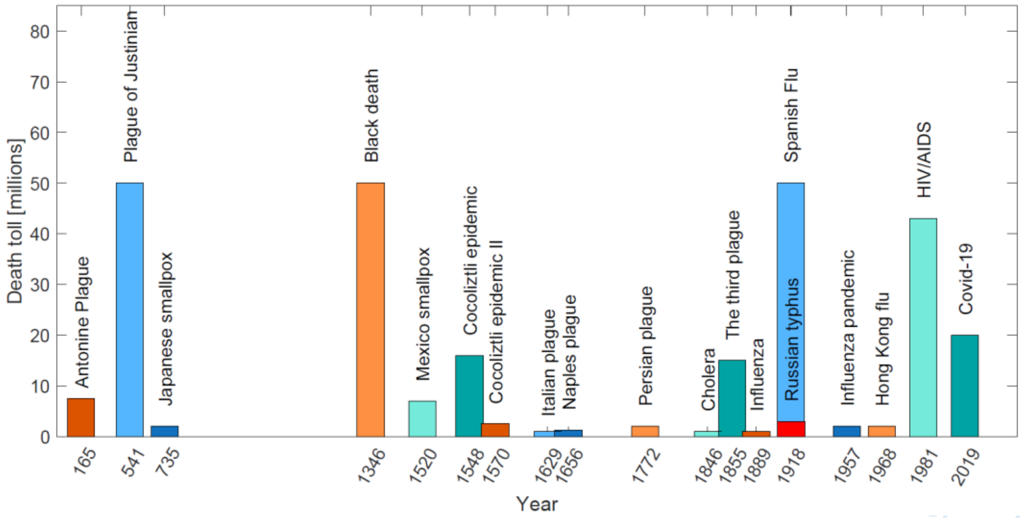
Presentation outlook

01 Introduction: Why studying Epidemiology

- Humanity has faced epidemic throughout its history
- Diseases impact health and social aspects of societies
- Advances in medicine and hygiene, yet new diseases still emerge.



02 Objectives

I. Study **how** behavior can be included in epidemics.

II. Realize the **coupling** of the two phenomena including:
- P2P mechanism
- “fatigue” contribution
- policy effect

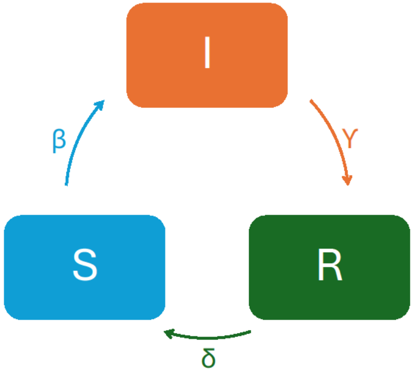
III. Analyse **stability**, **simulate** evolutions and study **Threshold** effect of the proposed model.

03 Definitions: the SIR model class

Mean field approximation

Homogeneous mixing

Population conservation $S + I + R = 1$



Transitions rates

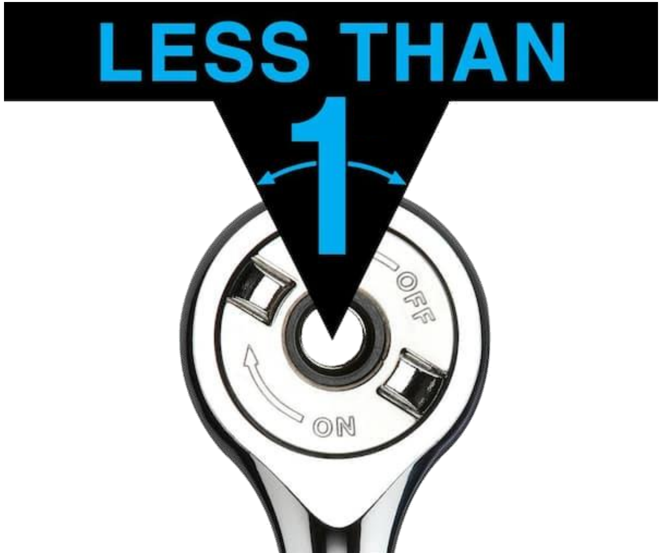
- β transmission rate
- γ recovery rate
- δ immunity waning rate

03 Definitions: key parameters

Basic reproduction number

$$R_0 = \frac{\beta}{\gamma + \delta}$$

"It is the average number of secondary infections caused by one infected person in a fully susceptible population".



Treshold value

- $R_0 > 1$: epidemic outbreak
- $R_0 \leq 1$: disease-free equilibrium

04 SIRS model

epidemic layer

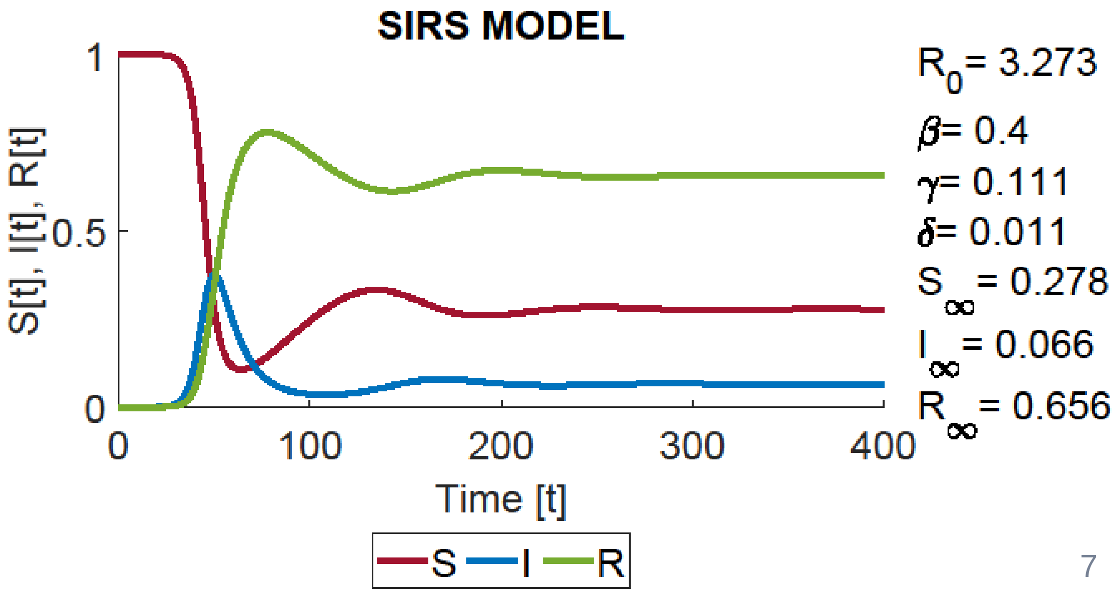
Example: $R_0 = 3.273 > 1$

There is an epidemic Outbreak!

$$\frac{ds}{dt} = -\beta\, s\, i + \delta\, i$$

$$\frac{di}{dt} = \beta s\, i\ - \gamma i$$

$$\frac{dr}{dt} = \gamma i\ - \delta i$$



04 Behavioral model

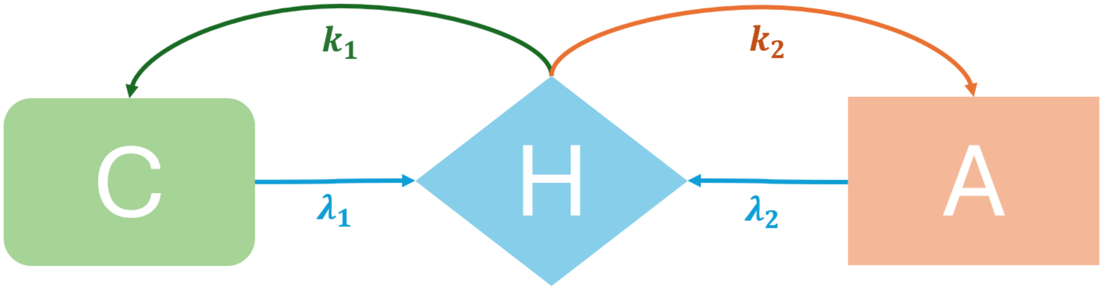
Heedless – Compliant – Against

dynamic

k_1 , k_2 persuasion rate
λ_1 , λ_2 fatigue to maintain behavior
B_1 , B_2 behavior conversion number

$$\frac{dH}{dt} = -k_1 CH - k_2 AH + \lambda_1 C + \lambda_2 A$$
$$\frac{dC}{dt} = k_1 CH - \lambda_1 C$$
$$\frac{dA}{dt} = k_2 AH - \lambda_2 A$$

$$B_i = \frac{k_i}{\lambda_i} \; with \; i = 1,2.$$



04 SAHCIR model

multi-system

Design method:

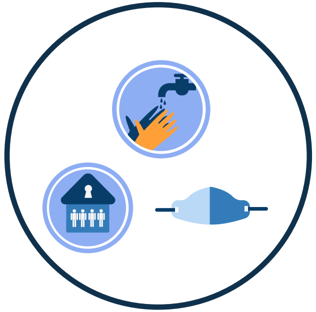
Inspire model choice

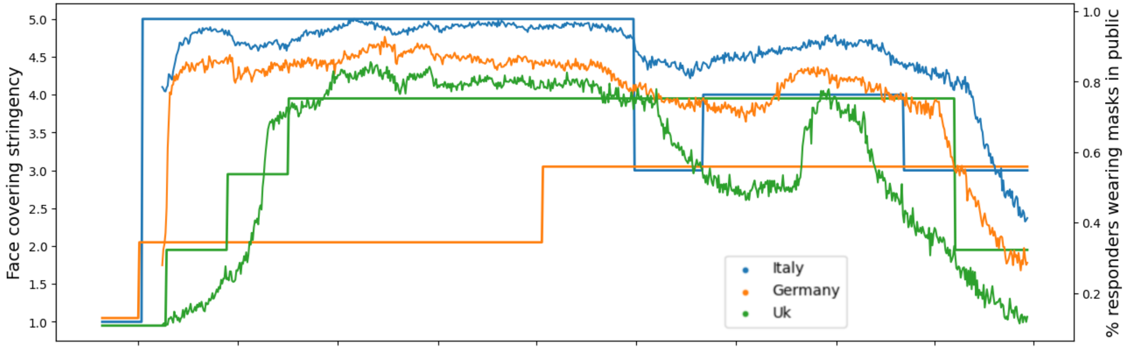
Epi-behavioral data

Epi-behavioral model

Simulate empirical trends

Safe behaviors

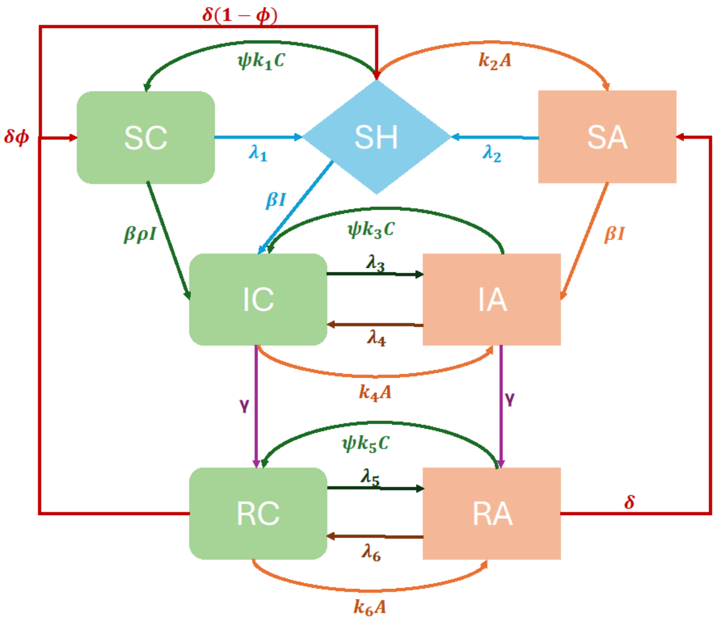




Example: Empirical data of mask wearing in different countries during COVID-19. Figure from [Provebio et al. .](#)

04 SAHCIR model

$$
\begin{aligned}
S_H' &= -\boxed{\psi}k_1 S_H C - k_2 S_H A + \lambda_1 S_C + \lambda_2 S_A + \delta(1-\phi)R_C - \beta S_H I \\
S_C' &= \boxed{\psi}k_1 S_H C + \delta\phi R_C - \lambda_1 S_C - \beta\boxed{\rho}S_C I \\
S_A' &= k_2 S_H A - \lambda_2 S_A - \beta S_A I + \delta R_A \\
I_C' &= \beta\boxed{\rho}S_C I + \beta S_H I + \boxed{\psi}k_3 I_A C - \lambda_3 I_C - k_4 I_C A + \lambda_4 I_A - \gamma I_C \\
I_A' &= \beta S_A I - \boxed{\psi}k_3 I_A C + \lambda_3 I_C + k_4 I_C A - \lambda_4 I_A - \gamma I_A \\
R_C' &= \gamma I_C - k_6 R_C A + \lambda_6 R_A + \boxed{\psi}k_5 R_A C - \lambda_5 R_C - \delta R_C \\
R_A' &= \gamma I_A + k_6 R_C A - \lambda_6 R_A - \boxed{\psi}k_5 R_A C + \lambda_5 R_C - \delta R_A
\end{aligned}
$$



$$
\begin{aligned}
A &= S_A + I_A + R_A \\
C &= S_C + I_C + R_C \\
I &= \boxed{\epsilon}I_C + I_A
\end{aligned}
$$

$$
\begin{aligned}
&0 \le \rho \le 1 \\
&0 \le \epsilon \le 1 \\
&0 < \phi \le 1 \\
&\rho \ge 1
\end{aligned}
$$

05 Epidemic- behavior Reproduction number E_0

Next generation matrix method

$$E_0 = spec(FV^{-1})$$

$$F = \left[\frac{dF_i}{dx_j}(x_0)\right] \text{ with } 1 \leq i,j \leq m$$

$$V = \left[\frac{dV_i}{dx_j}(x_0)\right] \text{ with } 1 \leq i,j \leq m$$

$$x = (x_1, x_2, \dots, x_n)^T$$

$$\frac{dx_i}{dt} = F_i(x) - V_i(x) \text{ for } i = 1,2,\dots,m$$

$$F = \begin{bmatrix} \beta\epsilon(\rho S_C + S_H) & \beta(\rho S_C + S_A) \\ \beta\epsilon S_A & \beta S_A \end{bmatrix} \quad V = \begin{bmatrix} \lambda_3 + k_4(S_A + I_A + R_A) + \gamma - \psi k_3 I_A & k_4 I_C - \lambda_4 - \psi k_3(S_C + I_C + R_C) \\ \psi k_3 I_A - \lambda_3 - k_4(S_A + I_A + R_A) & \psi k_3(S_C + I_C + R_C) - k_4 I_C + \lambda_4 + \gamma \end{bmatrix}$$

Disease Free Equilibria x_0

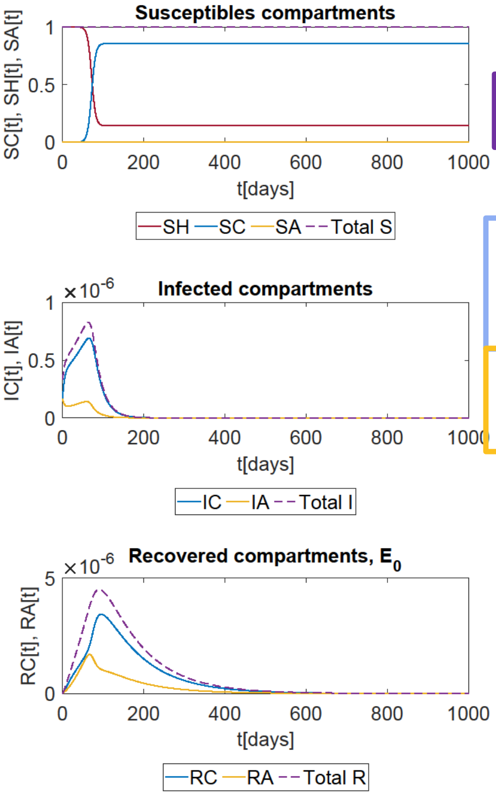
$$I_C = 0, I_A = 0$$

$$R_C = 0, R_A = 0$$

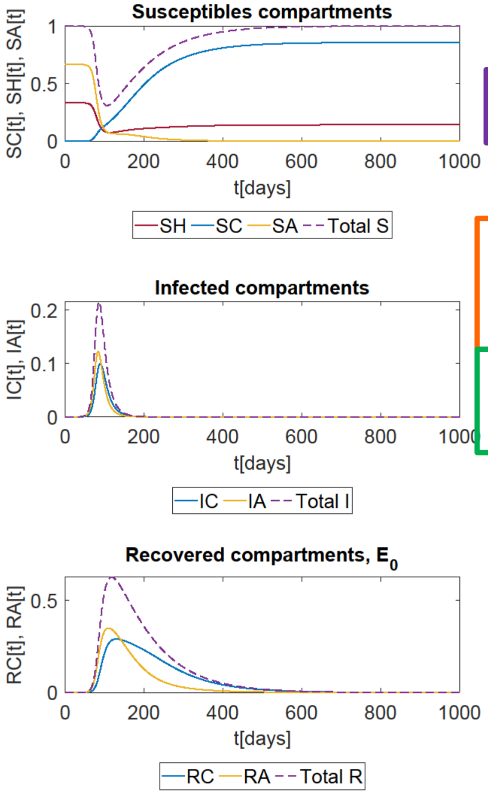
	S_C	S_H	S_A	E_0
type-A	0	1	0	$\frac{\beta}{\gamma}\frac{\lambda_3 + \epsilon\gamma + \epsilon\lambda_4}{\lambda_3 + \lambda_4 + \gamma}$
type-B	0	$\frac{\lambda_2}{k_2}$	$1 - \frac{\lambda_2}{k_2}$	$\frac{\beta}{\gamma}\frac{\gamma + \lambda_3 + \epsilon\lambda_4 + S_H\gamma(\epsilon - 1) + k_4 S_A}{\lambda_3 + \lambda_4 + \gamma + k_4 S_A}$
Type-C	$1 - \frac{\lambda_1}{k_1}$	$\frac{\lambda_1}{k_1}$	0	$\frac{\beta}{\gamma}\frac{(S_H + \rho S_C)(\lambda_3 + \epsilon\gamma + \epsilon\lambda_4 + \psi\epsilon k_3 S_C)}{\lambda_3 + \lambda_4 + \gamma + \psi k_3 S_C}$

05 Results

Simulations with different E_0



$E_0=1.11$
$R_0=3.27$
$B_1=7$
$B_2=3$
$\beta=0.4$
$\gamma=0.11$
$\delta=0.01$
$k_1=0.23$
$k_2=0.1$
$\lambda_1=0.03$
$\lambda_2=0.03$
$S_{C0}=0$
$S_{H0}=1$
$S_{A0}=0$



$E_0=2.63$
$R_0=3.27$
$B_1=7$
$B_2=3$
$\beta=0.4$
$\gamma=0.11$
$\delta=0.01$
$k_1=0.23$
$k_2=0.6$
$\lambda_1=0.03$
$\lambda_2=0.2$
$S_{C0}=0$
$S_{H0}=0.33$
$S_{A0}=0.66$

$k_1 > k_2,$
$\lambda_1 = \lambda_2,$

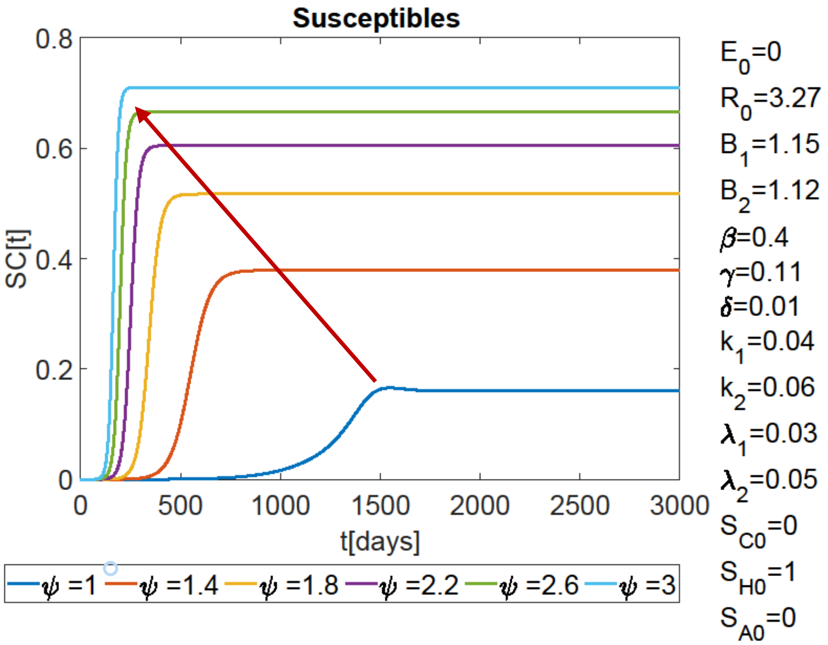
$k_1 < k_2,$
$\lambda_1 \ll \lambda_2,$

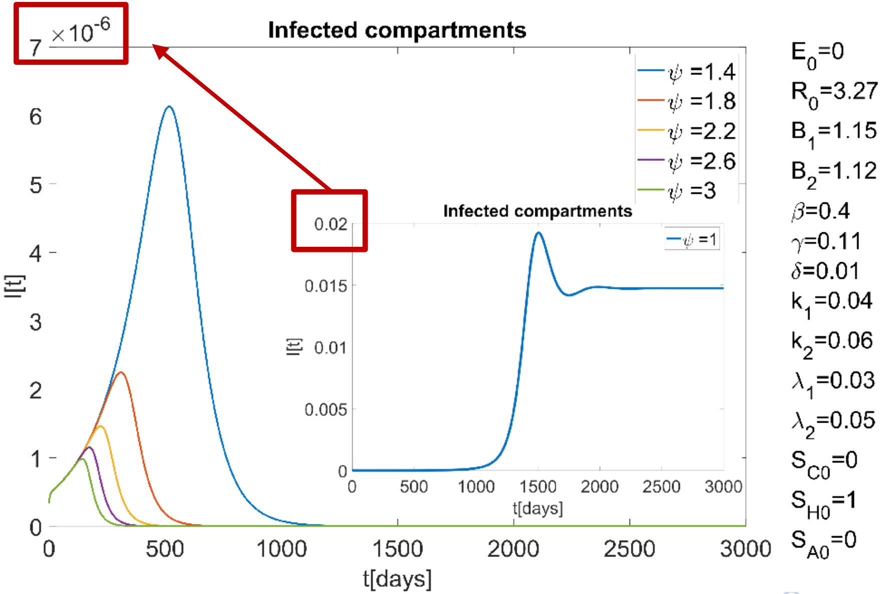
Same B_1, B_2

Different DFE

05 Results

Effect of ψ global mean field agent





06 Conclusion

Thanks!

SAHCIR MODEL

01 **Behavior-Epidemic interactions**

02 **Insights from simulations**

E_0 effective to reproduce epidemic insurgence

03 **Framework flexibility**

Adaptable to different scenarios

04 **Possible limitations**

Homogeneous mixing, H only in S

Future perspective:

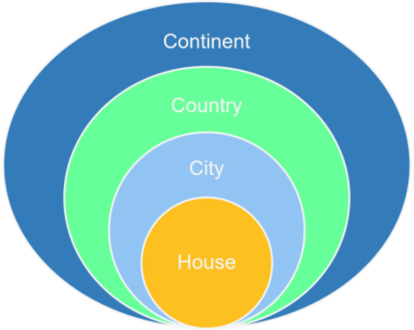
fit empirical data, complex ψ, more investigation on k_i, λ_i

01

Introduction

Epidemic spreading: multiple layers and scales are involved

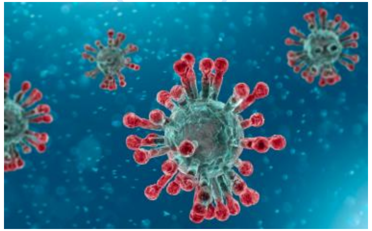
Population interconnections



Model people behavior during an epidemic

Population interactions

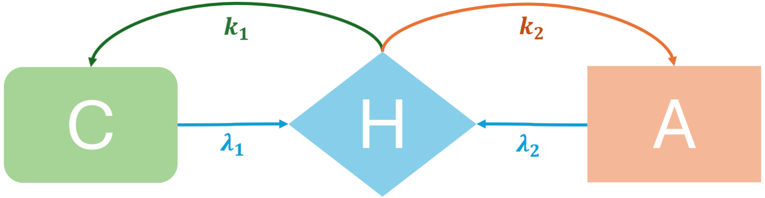
Microscopic, infection dynamic within a host



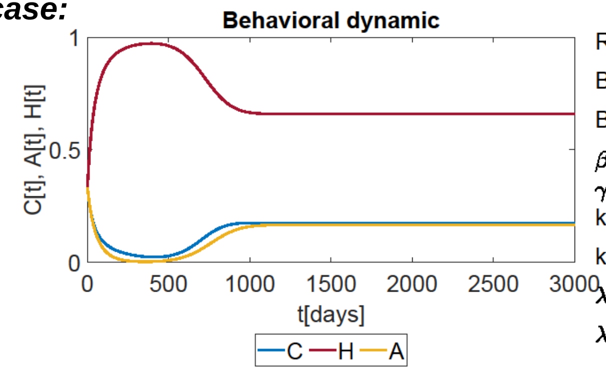
04

Behavioral model

Heedless – Compliant – Against dynamic

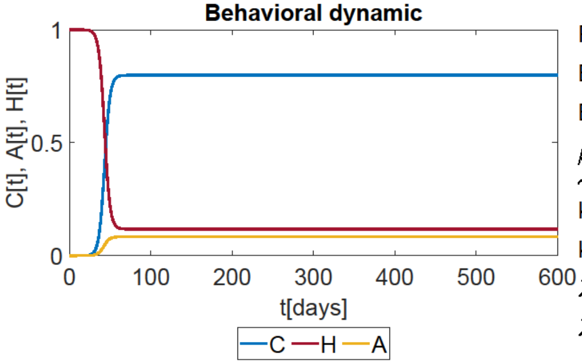


I case:



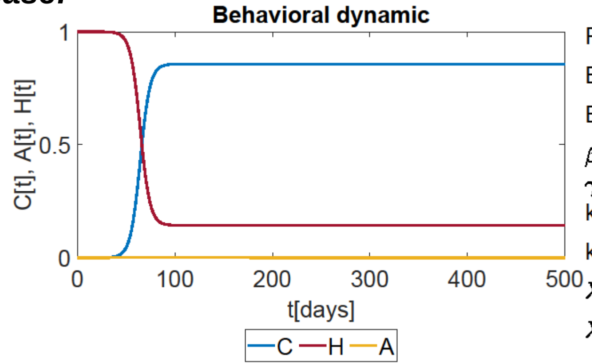
R_0=3.6
B_1=0.89
B_2=0.45
β=0.4
γ=0.11
k_1=0.03
k_2=0.01
λ_1=0.03
λ_2=0.03

II case:



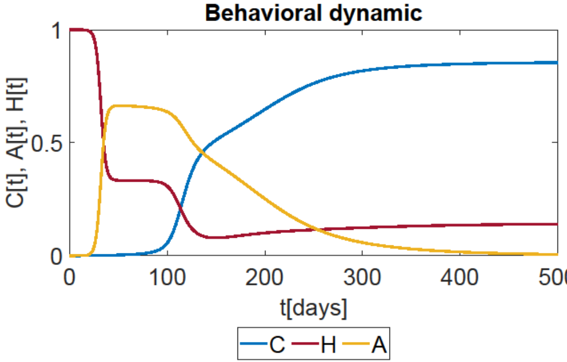
R_0=3.6
B_1=8.5
B_2=8.5
β=0.4
γ=0.11
k_1=0.34
k_2=0.28
λ_1=0.04
λ_2=0.03

III case:



R_0=3.6
B_1=7
B_2=3
β=0.4
γ=0.11
k_1=0.23
k_2=0.1
λ_1=0.03
λ_2=0.03

IV case:



R_0=3.6
B_1=7
B_2=3
β=0.4
γ=0.11
k_1=0.23
k_2=0.6
λ_1=0.03
λ_2=0.2

01 Introduction: Why models

Powerful instruments

Study, understand, reconstruct patterns

Prediction

Generate insight into epidemic dynamics

Stakeholders

Develop policies to minimize human life loss, economic costs, and hospital overcrowding.

Exploring disease incidence

	S_C	S_H	S_A	E_0
type-A	0	1	0	$\frac{\beta}{\gamma}\frac{\lambda_3+\epsilon\gamma+\epsilon\lambda_4}{\lambda_3+\lambda_4+\gamma}$
type-B	0	$\frac{\lambda_2}{k_2}$	1- $\frac{\lambda_2}{k_2}$	$\frac{\beta}{\gamma}\frac{\gamma+\lambda_3+\epsilon\lambda_4+S_H\gamma(\epsilon-1)+k_4S_A}{\lambda_3+\lambda_4+\gamma+k_4S_A}$
Type-C	1- $\frac{\lambda_1}{k_1}$	$\frac{\lambda_1}{k_1}$	0	$\frac{\beta}{\gamma}\frac{(S_H+\rho S_C)(\lambda_3+\epsilon\gamma+\epsilon\lambda_4+\psi\epsilon k_3S_C)}{\lambda_3+\lambda_4+\gamma+\psi k_3S_C}$

Mapping prevalence

Snapshot

Mercury is the closest planet to the Sun and the smallest of them all

Distribution

Venus has a beautiful name and is the second planet from the Sun

Factors

Despite being red, Mars is actually a cold place. It's full of iron oxide dust

Enhancing research credibility

Mercury

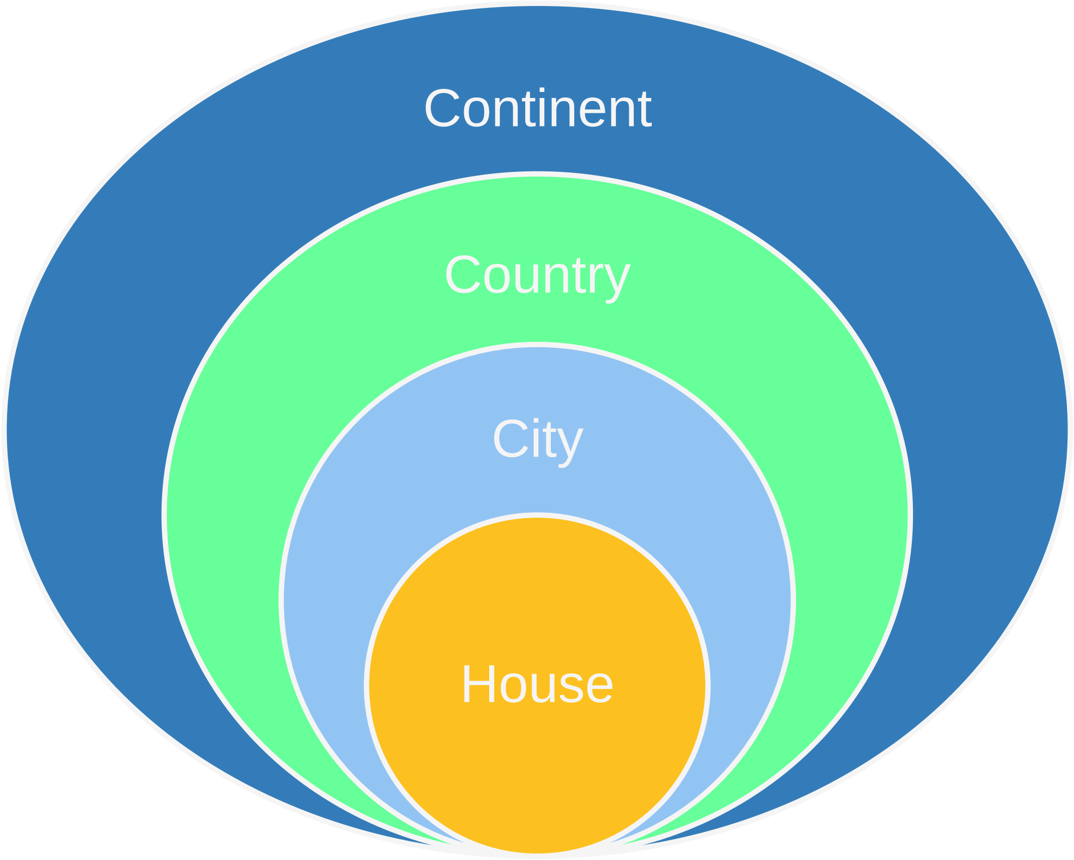
- ✓ Mercury is a small planet
- × Mercury is the closest planet to the Sun

Venus

- ✓ Venus is a very hot planet
- × Venus is the second planet from the Sun

Jupiter

- ✓ Jupiter is a huge gas giant
- × Jupiter is the biggest planet of them all


Continent
Country
City
House

Awesome words

Icon pack