Life Data Epidemiology - Project 3

SIR model with fear and age-structured contacts

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Introduction

Part 1 *SIR fear models*

Perra N, Balcan D, Gonçalves B, Vespignani A - *Towards a Characterization of Behavior-Disease Models* (2011)

Part 2 *Introducing age groups and different types of contacts*

Part 3 *Simulation of possible public health interventions*

Goals:

- Build models to simulate an SIR epidemic including the spreading of the fear
- Analyze how the spreading of the fear can affect the epidemic evolution
- Include in the model a division in class by ages, considering different matrices for face-to-face and online average daily number of contacts
- Study the trend of the epidemic for the different groups
- Hypothesize some measures to contain the epidemic and understand their impact

Basic SIR fear model

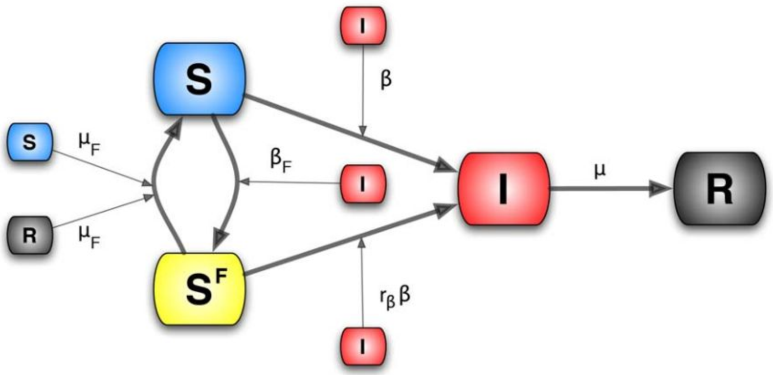
Model 1 - Local, prevalence-based spreading of the fear of the disease

$S^F \rightarrow$ susceptibles with fear of the disease

$\beta_F \rightarrow$ fear transmission rate

$\mu_F \rightarrow$ fear recovery rate

$r_\beta \rightarrow$ reduction in the disease transmission rate



[Perra N, Balcan D, Gonçalves B, Vespignani A (2011)]

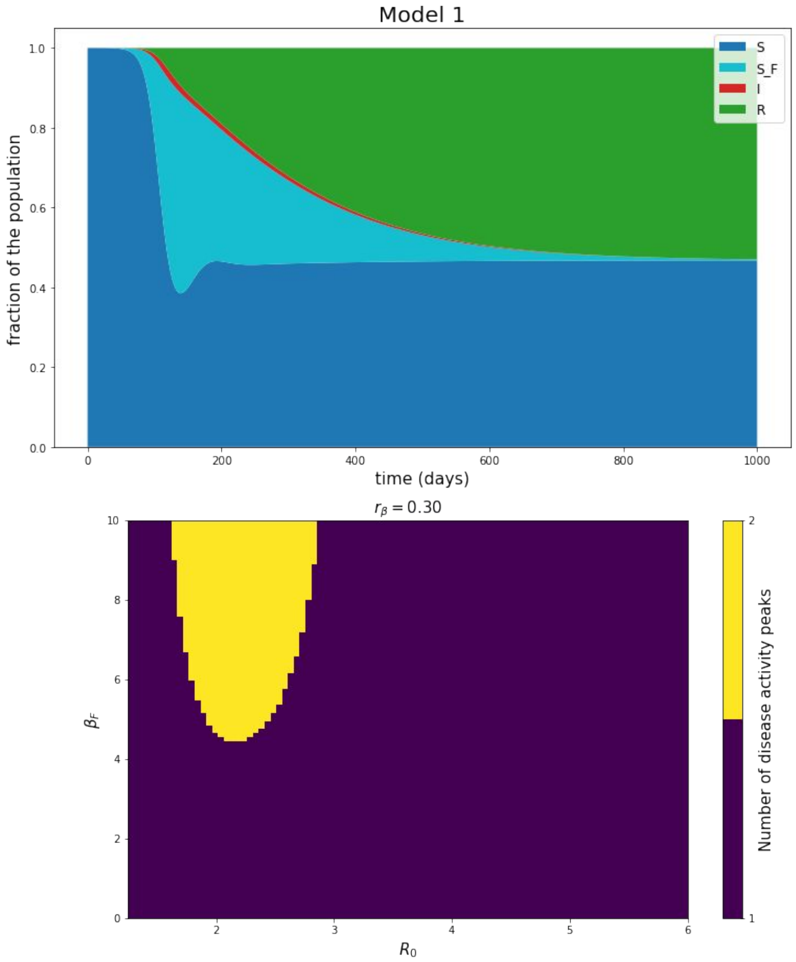
Stationary solution: $\longrightarrow$ NO ENDEMIC FEAR

$$(S^*, S^{F*}, I^*, R^*) = (N - R_\infty, 0, 0, R_\infty)$$

Epidemic threshold depends on how many fearful susceptibles are present at the begin:

- $R_0 = \dfrac{\beta}{\mu} > 1$ if $S^F << 1$
- $R_0 = r_\beta \dfrac{\beta}{\mu} > 1$ if $S^F >> 1$

Presence of multiple peaks in the prevalence for specific values of R_0 and β_F , depending on r_β



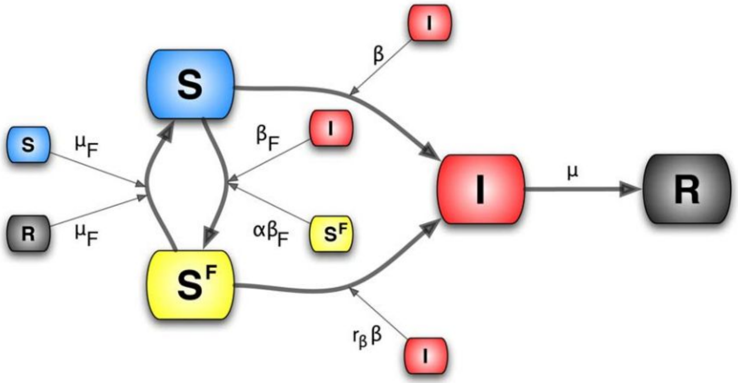
Improved SIR fear model

Model 3 - Local, belief-based spreading of the fear of the disease

$\alpha \rightarrow$ reduction in the fear transmission rate, a person is more likely to get afraid when is in contact with an infected then with a fearful individual

Without the disease, we have a SIS epidemic of fear

$R_F = \alpha \frac{\beta_F}{\mu_F} \rightarrow$ basic reproduction number of fear



[Perra N, Balcan D, Gonçalves B, Vespignani A (2011)]

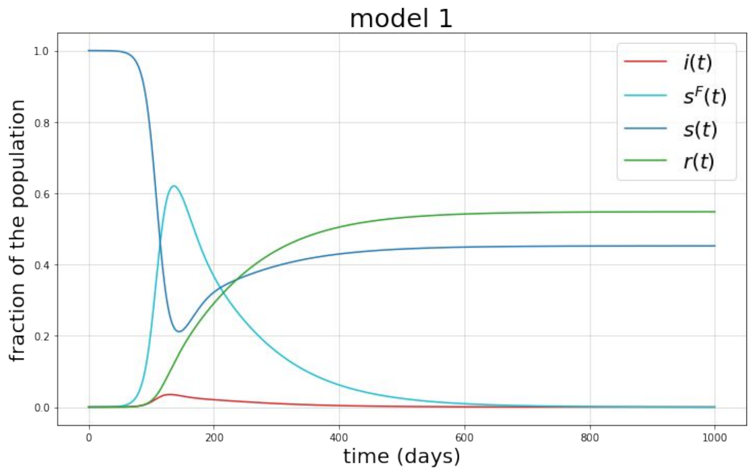
Comparison

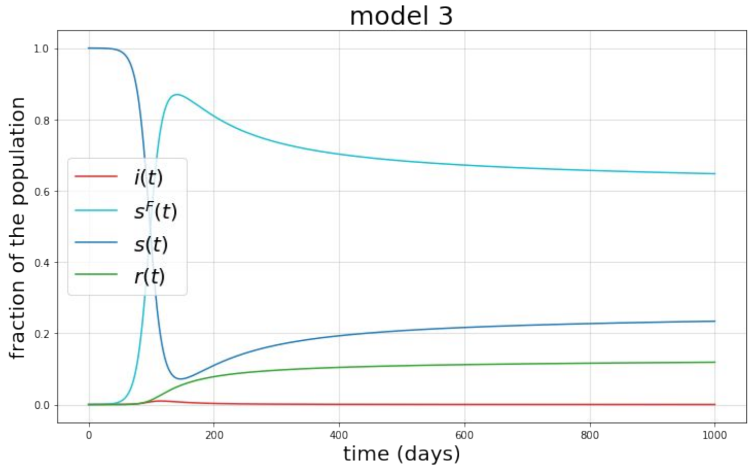
Same model parameters for the two SIR fear variants

The only difference is in the presence of the α parameter in model 3, set to the value:

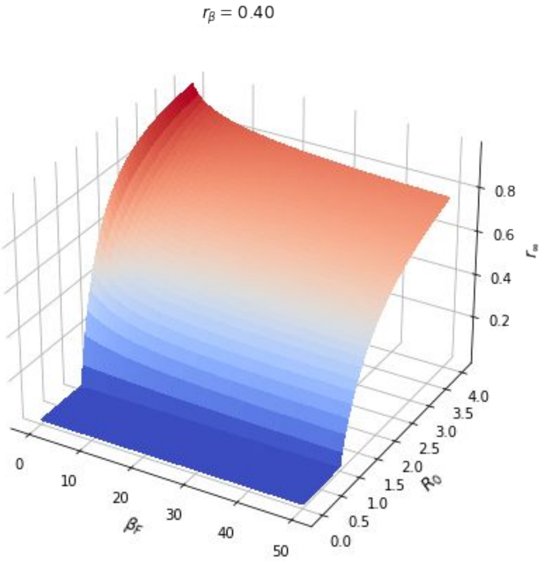
$$\alpha = 0.05$$

Huge difference on the final attack rate





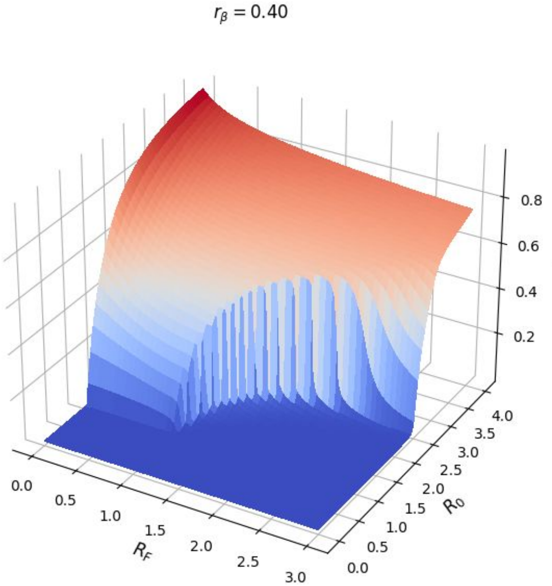
Outbreak regions in phase space



Model 1

Final number of total infected individuals for the two models

Introduction of fear self-reinforcement leads to first order phase transition phenomena



Model 3

Improved SIR fear model with age groups including also online contacts

$$\frac{dS_i}{dt} = -\beta S_i \sum_j k_{ij}\frac{I_j}{N_j} - \beta_i^F S_i \left[\sum_j k_{ij}\frac{I_j}{N_j} + \alpha \sum_j (k_{ij}+\gamma M_{ij})\frac{S_j^F}{N_j}\right] + \mu_F S_i^F \sum_j (k_{ij}+\gamma M_{ij})\frac{(S_j+R_j)}{N_j}$$

$$\frac{dS_i^F}{dt} = -r_\beta \beta S_i^F \sum_j k_{ij}\frac{I_j}{N_j} + \beta_i^F S_i \left[\sum_j k_{ij}\frac{I_j}{N_j} + \alpha \sum_j (k_{ij}+\gamma M_{ij})\frac{S_j^F}{N_j}\right] - \mu_F S_i^F \sum_j (k_{ij}+\gamma M_{ij})\frac{(S_j+R_j)}{N_j}$$

$$\frac{dI_i}{dt} = -\mu I_i + \beta S_i \sum_j k_{ij}\frac{I_j}{N_j} + r_\beta \beta S_i^F \sum_j k_{ij}\frac{I_j}{N_j}$$

$$\frac{dR_i}{dt} = \mu I_i$$

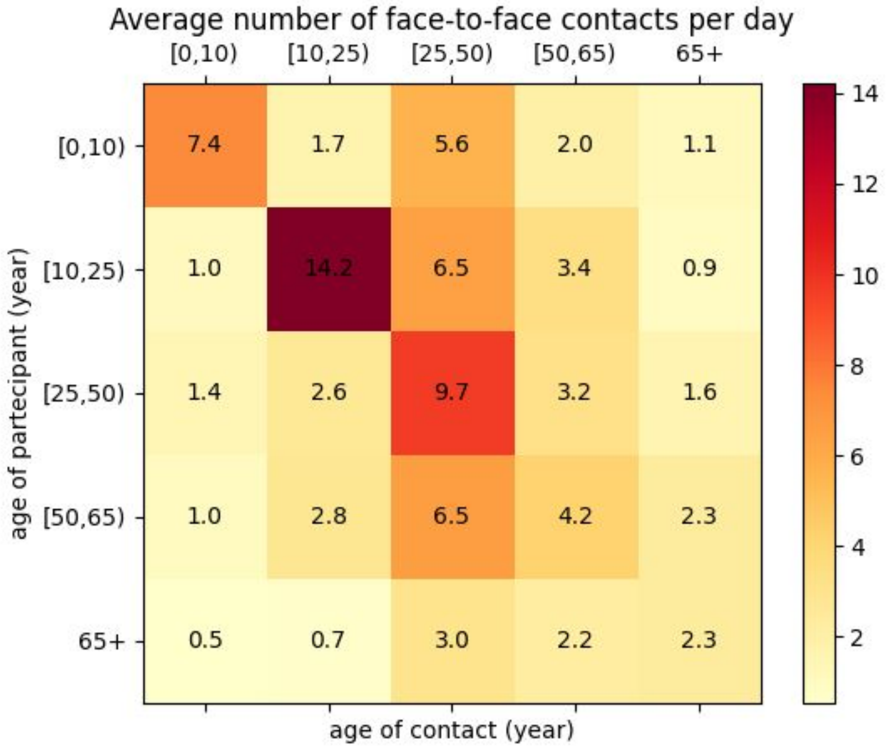
$$\sum_{i=1}^{N_{groups}} X_i = X$$

$k_{ij} \rightarrow$ face-to-face contacts matrix by age

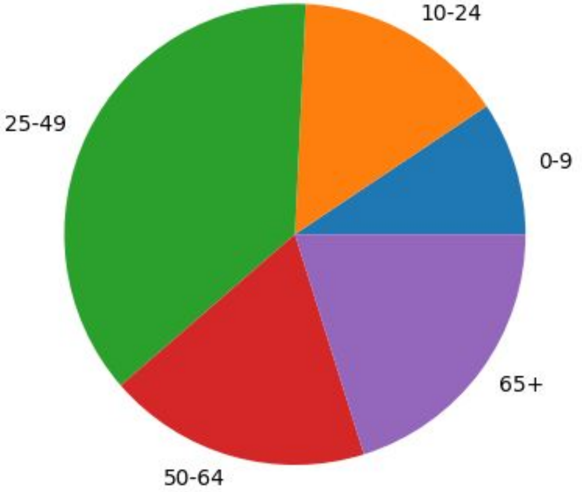
$M_{ij} \rightarrow$ online social connectivity matrix by age

$\gamma \rightarrow$ weights the possibilities of getting fear between in person and online contacts (it can assume values between 0 and 1)

Face-to-face contacts matrix k_{ij}

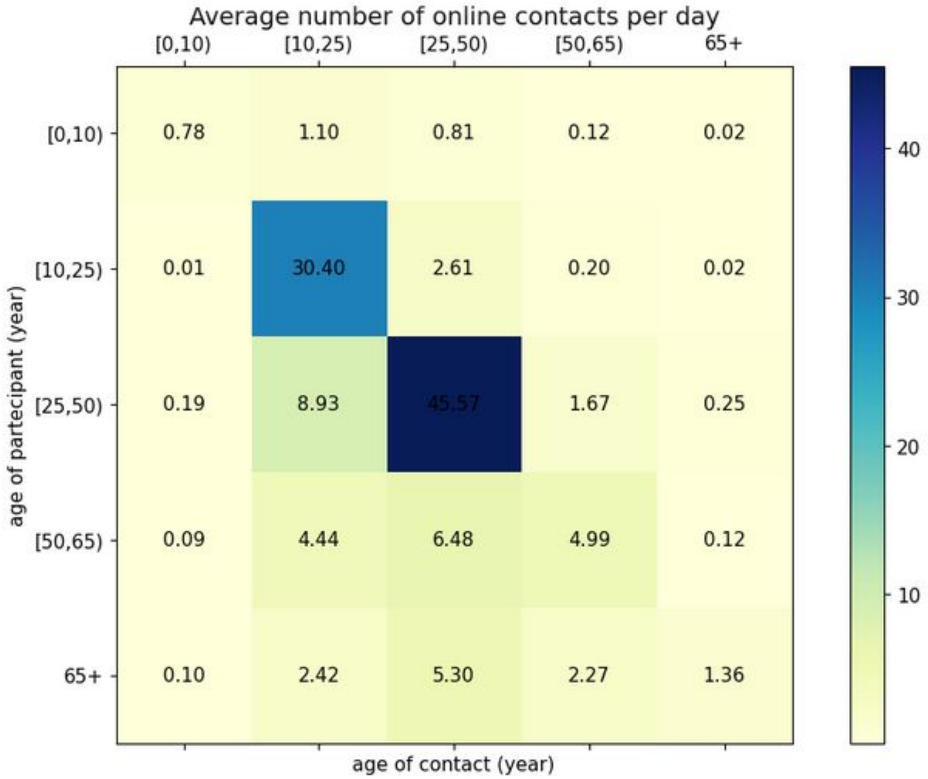


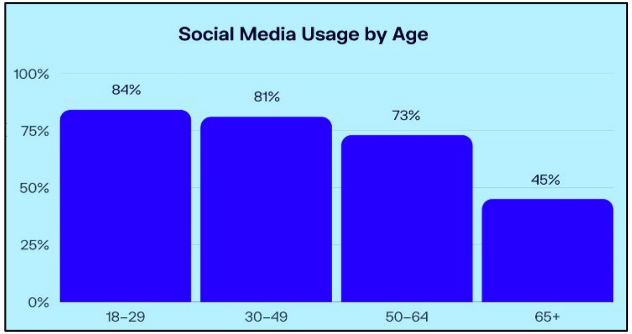
source: www.socialcontactdata.org/socrates

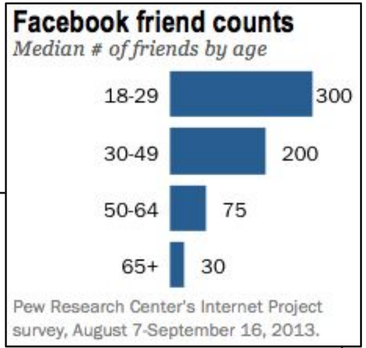


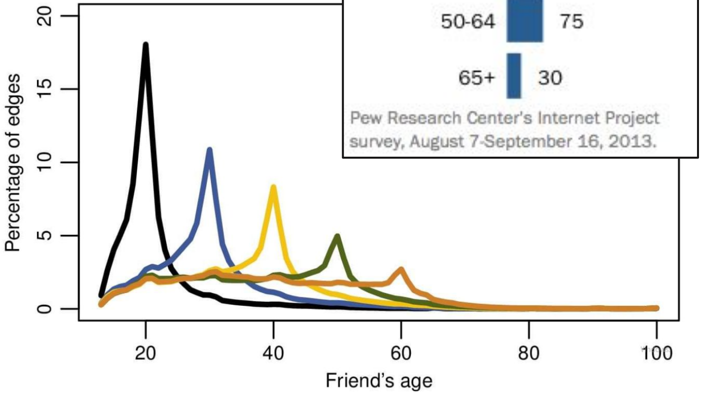
Population of Italy 2008
(source: ISTAT)

Online social connectivity matrix M_{ij}









Application for Covid-like disease

Last model can be used to characterize the spread of a Covid-like disease in a fully susceptible population.

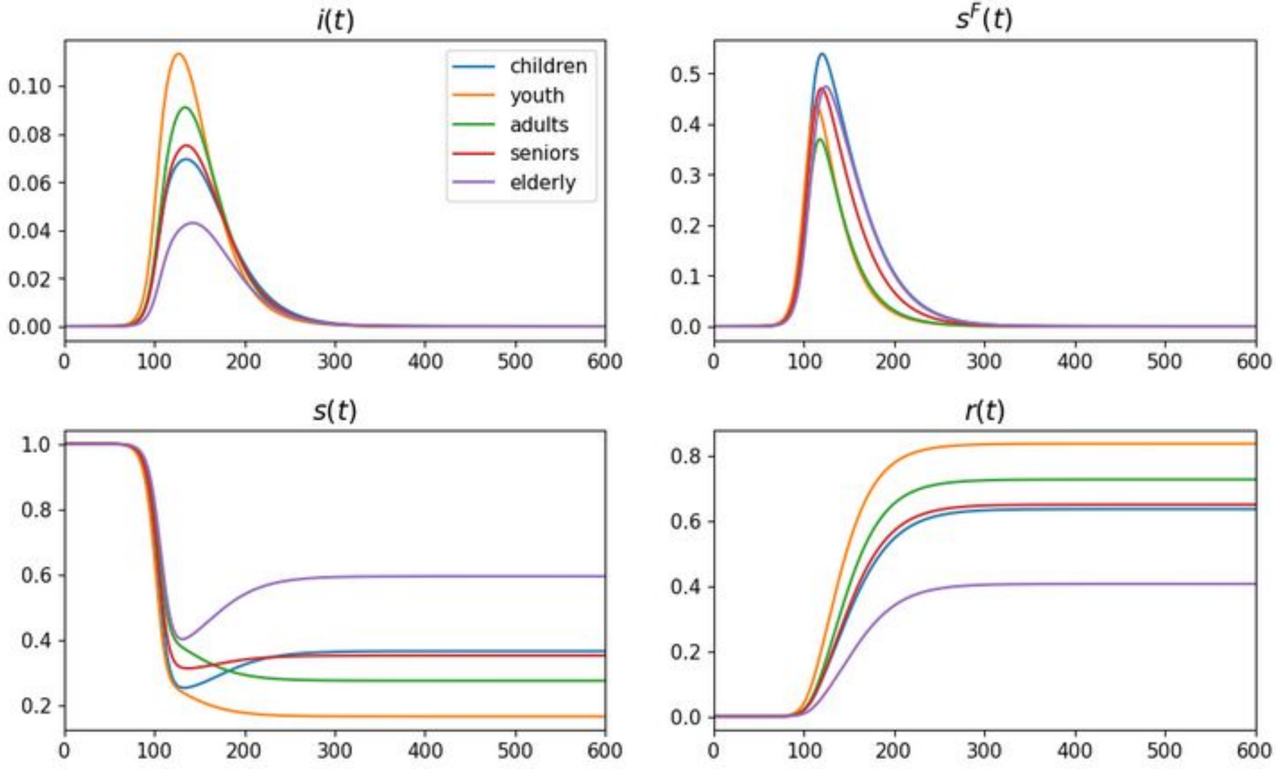
It's necessary to identify a reasonable set of parameters:

- $R_0 = 2.5$ $\rightarrow$ estimate from the early spread of Covid
- $\mu = 1/10$ $\rightarrow$ average disease duration of ten days
- $\beta_F = 1.5$
- $\mu_F = 1/7$ $\rightarrow$ average fear duration of a week
- $\alpha = 0.05$ $\rightarrow$ set to the same value of reference paper [1]
- $r_\beta = 0.3$ $\rightarrow$ estimate for mask protection [9]
- $\gamma = 0.7$

Simulations

Elderly class has the lowest percentage of infected individuals, this is due to its low face-to-face contact rate

Children class has the highest percentage of fearful individuals… not expected



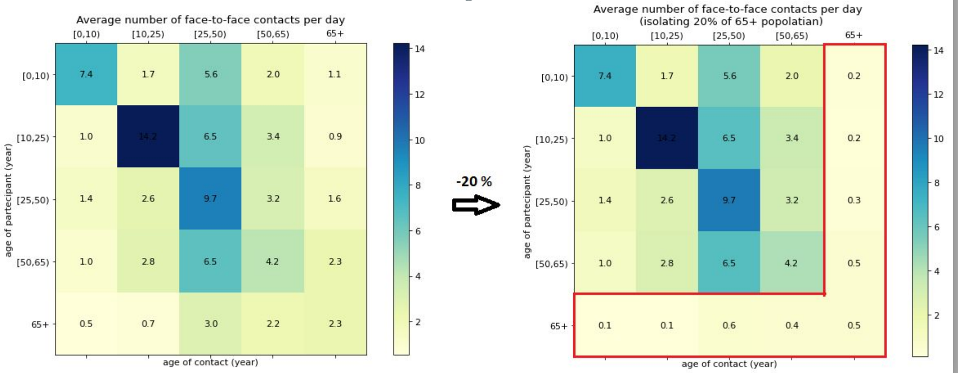
Possible interventions

The goal is to reduce the impact of the epidemic in the society:

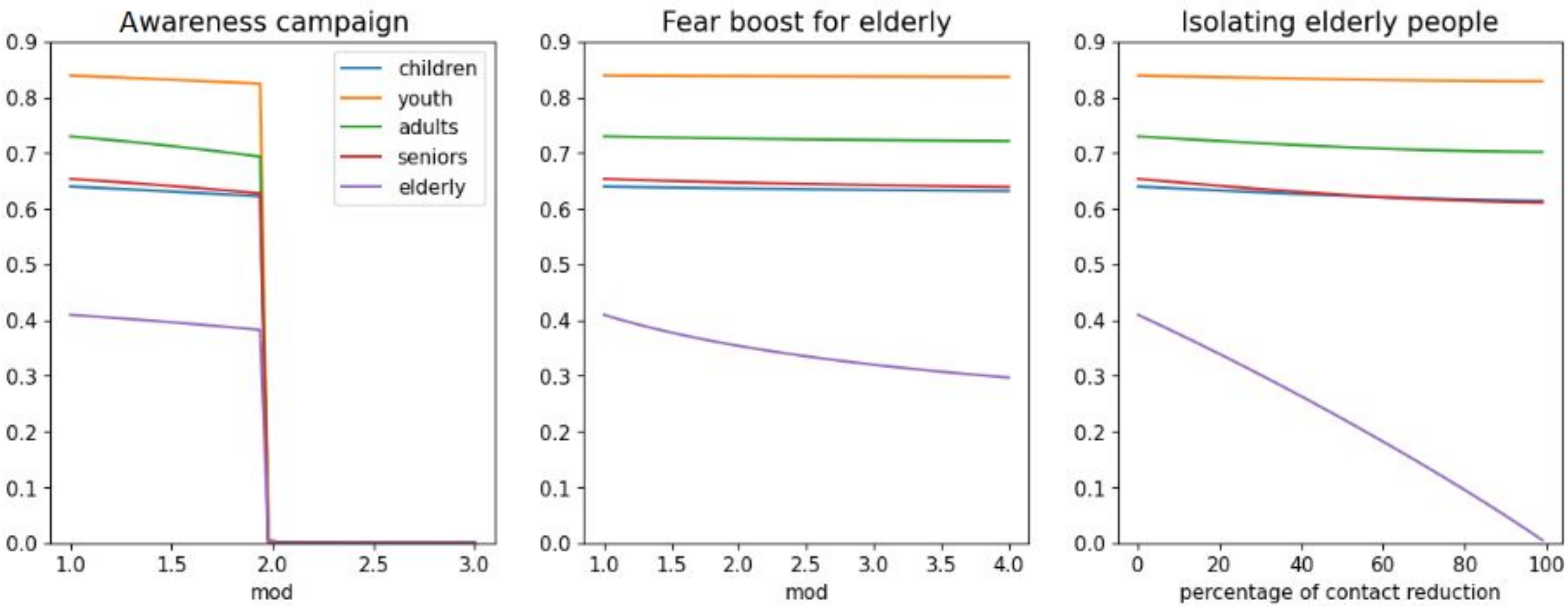
- Awareness campaign
  $\alpha \rightarrow \alpha * mod$
- Fear boost in elderly (increase fear transmission in age class 65+)
  $\beta_F[elderly] \rightarrow \beta_F[elderly] * mod$
- Isolating elderly people (cutting a fraction of their contacts by modifying k_{ij})

Measurements for the effect of the intervention

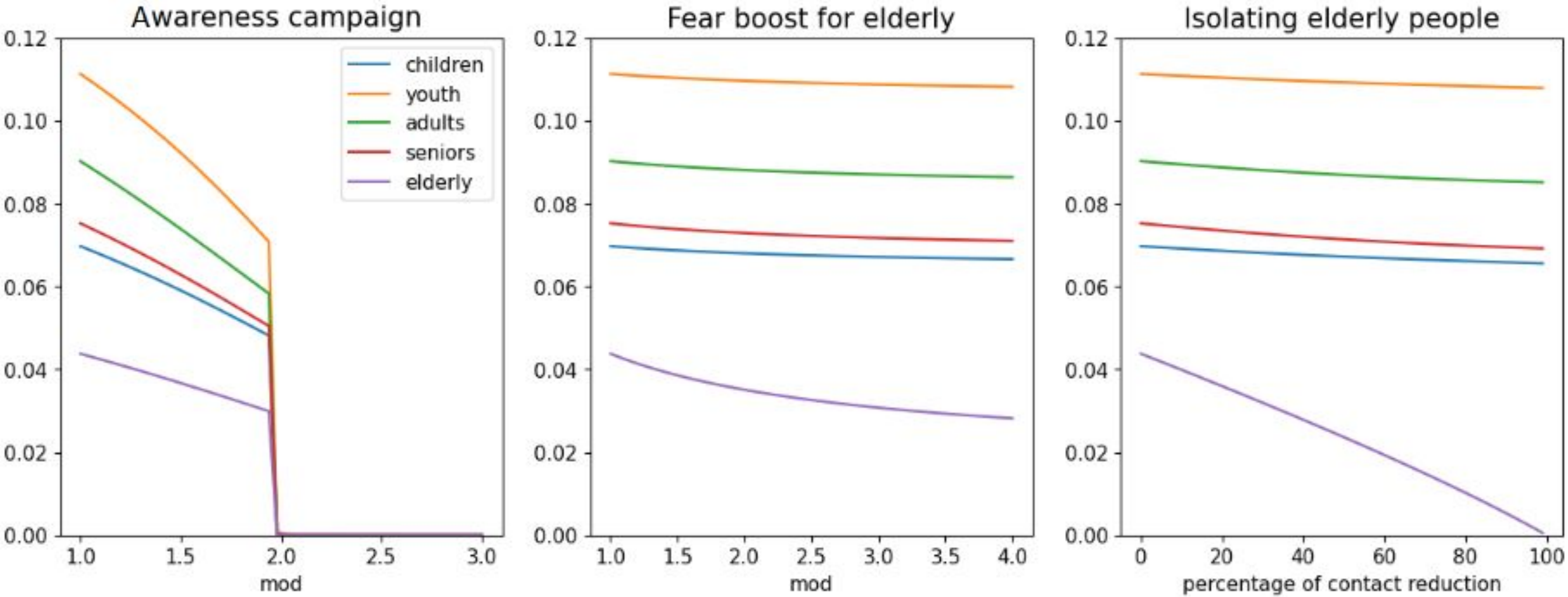
1. Final size of the epidemic
2. Peak prevalence
3. Outbreak length (time to extinction)



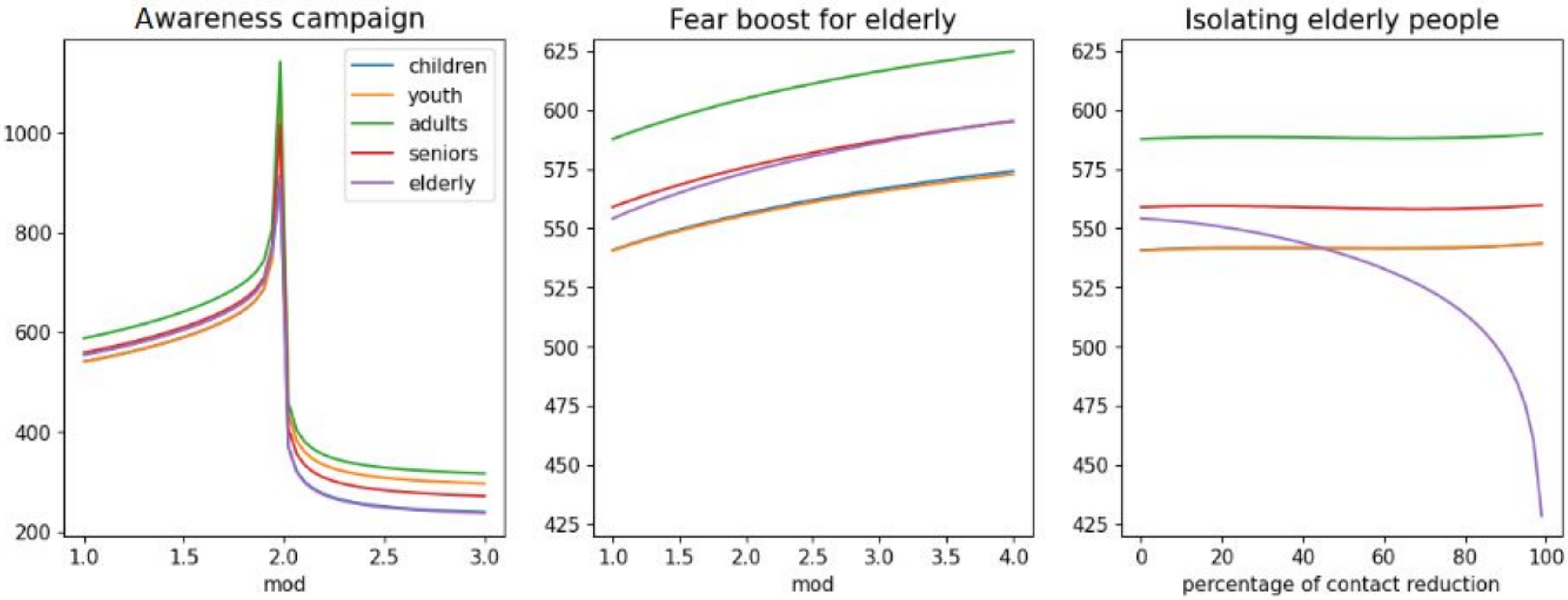
1. Final size of the epidemic



2. Peak prevalence



3. Outbreak length



Discussion and Conclusions

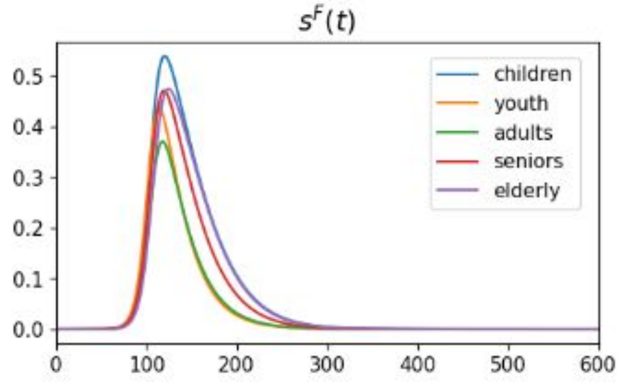
➢ Interventions

➔ what we want to achieve with an intervention
➔ focus on elderly people vs spread awareness across all population

➢ Limitations of the model

➔ the model does not include fear spread by other mass media a part from contacts on social media

➔ unexpected behaviour of the fear in children –> alternative model?



References

[1] Perra et al - *Towards a Characterization of Behavior-Disease Models*

[2] www.socialcontactdata.org/socrates/

[3] De Luca et al - *The impact of regular school closure on seasonal influenza epidemics: a data-driven spatial transmission model for Belgium*

[4] Mossong et al - *Social Contacts and Mixing Patterns Relevant to the Spread of Infectious Diseases*

[5] Willem, Torneri, Hens- *Social contact data analysis: participant weights*

[6] www.pewresearch.org/

[7] Ugander et al - *The Anatomy of the Facebook Social Graph*

[8] Backstrom et al - *Four Degrees of Separation*

[9] https://www.cdc.gov/mmwr/volumes/71/wr/mm7106e1.htm

Backup slides

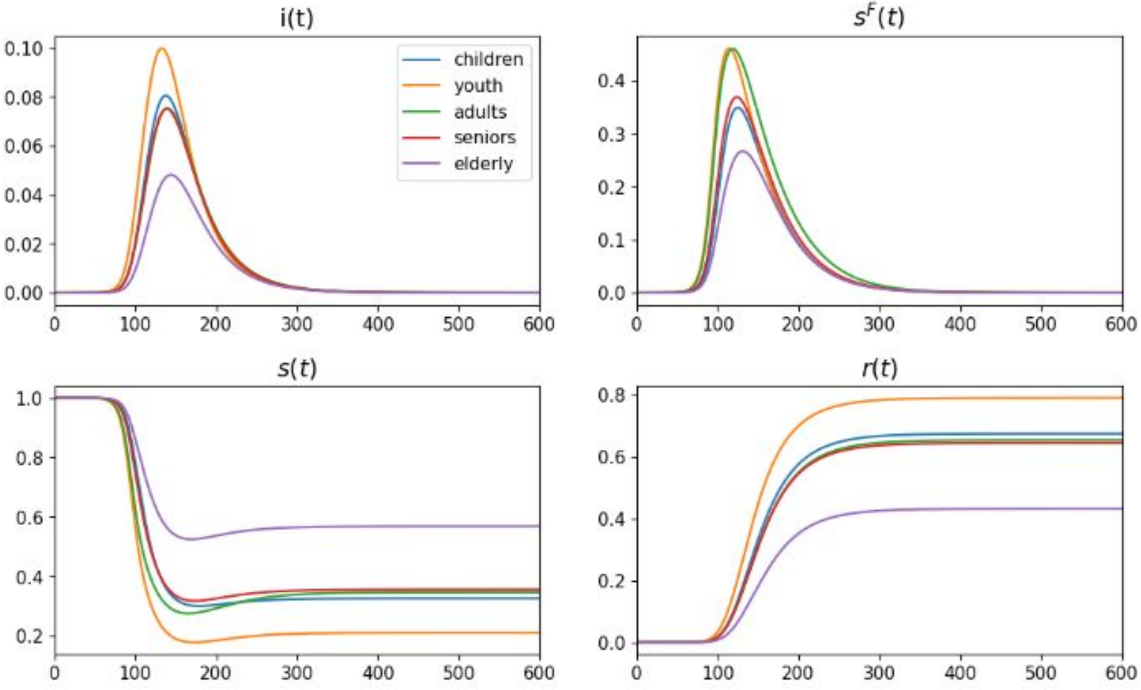
Alternative model

$$\frac{dS_i}{dt} = -\beta S_i \sum_j k_{ij}\frac{I_j}{N_j} - \beta_i^F S_i \left[\sum_j k_{ij}\frac{I_j}{N_j} + \alpha \sum_j (k_{ij} + \gamma M_{ij})\frac{S_j^F}{N_j}\right] + \boxed{\mu_F S_i^F}$$

$$\frac{dS_i^F}{dt} = -r_\beta \beta S_i^F \sum_j k_{ij}\frac{I_j}{N_j} + \beta_i^F S_i \left[\sum_j k_{ij}\frac{I_j}{N_j} + \alpha \sum_j (k_{ij} + \gamma M_{ij})\frac{S_j^F}{N_j}\right] - \boxed{\mu_F S_i^F}$$

$$\frac{dI_i}{dt} = -\mu I_i + \beta S_i \sum_j k_{ij}\frac{I_j}{N_j} + r_\beta \beta S_i^F \sum_j k_{ij}\frac{I_j}{N_j}$$

$$\frac{dR_i}{dt} = \mu I_i$$



Different fear transmission parameter for each age group