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Epidemiological SIR-models for predicting infectious diseases

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02.12.2021

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Background

- COVID-19 pandemic still has a huge effect on the world
- Non-pharmaceutical intervention (NPI) strategies and vaccines are being used across the globe
- How to estimate the impact of these intervention and vaccination strategies

Goals

- SIR-modeling and COVID-19
- How informative is SIR-modeling as a prediction tool
- Study how extended SIR-models that are used to model vaccination
- Understand the limits of simple modeling (Lahtinen et al. 2017)

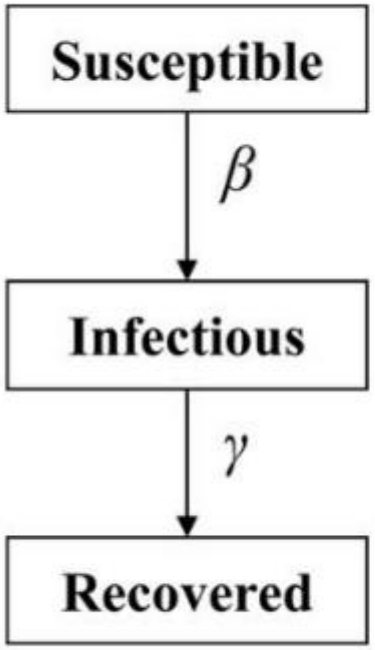
Methods

- Detailed review of 8 research papers
- Illustrative SIRV-model implemented in MATLAB

Research	Model	Main problem
Giordano et al. (2020)	SIDARTHE	Modeling the COVID-19 epidemic and implementation of population-wide interventions
Moein et al. (2021)	SIR	Problems with forecasting the COVID-19 epidemic with SIR-modeling
Ghostine et al. (2021)	SEIQRDV	Forecasting the COVID-19 epidemic with an extended SEIR-model
Berkane et al. (2021)	SIRV	Predicting the evolution of COVID-19 epidemic in Canada
Bubar et al. (2020)	SEIRV	Quantifying the impact of COVID-19 vaccine prioritization strategies
Yu et al. (2016)	SEIRV	Efficient intervention strategies to control an epidemic
Agarwal et al. (2021)	SEIR	Trade-off between vaccination prioritization and vaccination speed
Karaivanov et al. (2020)	SIRD	Estimating the impact of public policy measures on the spread of COVID-19

Table 1: Main models used in the research papers listed and the main problems the research is trying to tackle

Basic SIR-model



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

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

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

Luz et al. 2010

Extended SIR-model(s) 1/2

- Extended SIR-models cover additional phenomena
- Implemented by adding one or more compartments with respective differential equations and transition rates
  - Common ones are E(exposed), Q(quarantined), V (vaccinated), D(dead)

Extended SIR-model(s) 2/2

- Limitations of basic SIR-models can be addressed by extending them
- Predictions using SIR-models work short term but inaccurate predicting over longer periods of time
- Vaccination policies matter
  - Vaccine prioritization vs vaccination speed (Agarwal et al. 2021)
  - Vaccine efficacy (Bubar et al. 2020)
  - Vaccine release time (Yu et al. 2016)

Illustrative modeling example

- SIRV over 300 days, 50 infected at day 0, total population 5,5 million, parameters constant
- Vaccine efficacy 100%, one dose guarantees protection, no delay from vaccination to effect
- 4 vaccination scenarios
  - Upfront (vaccinating on day 1)
  - Periodical (vaccinating on 4 occasions)
  - Constant (vaccinating everyday)
  - Response (vaccinating as a response to a infection peak)

Results

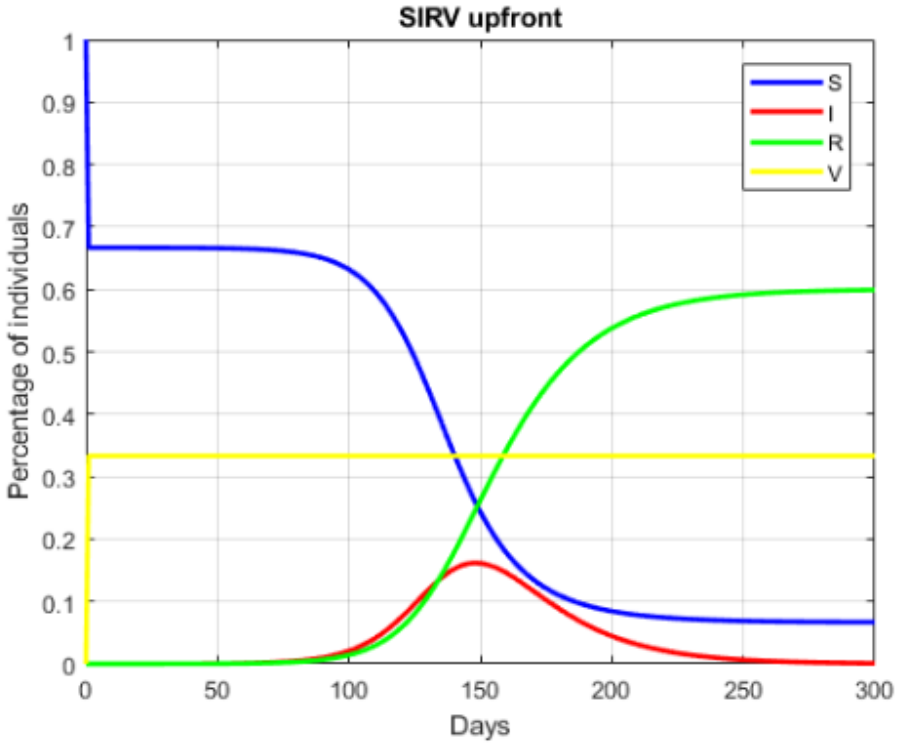


Figure 1: Result of the simulation when vaccinating on day 1

Results

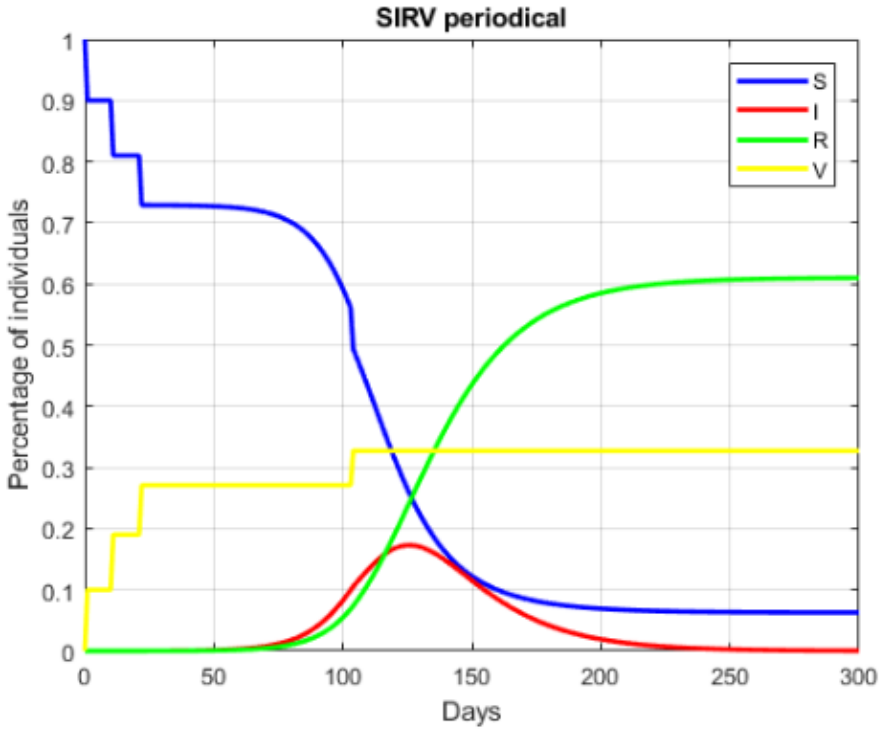


Figure 2: Result of the simulation when vaccinating on 4 occasions

Results

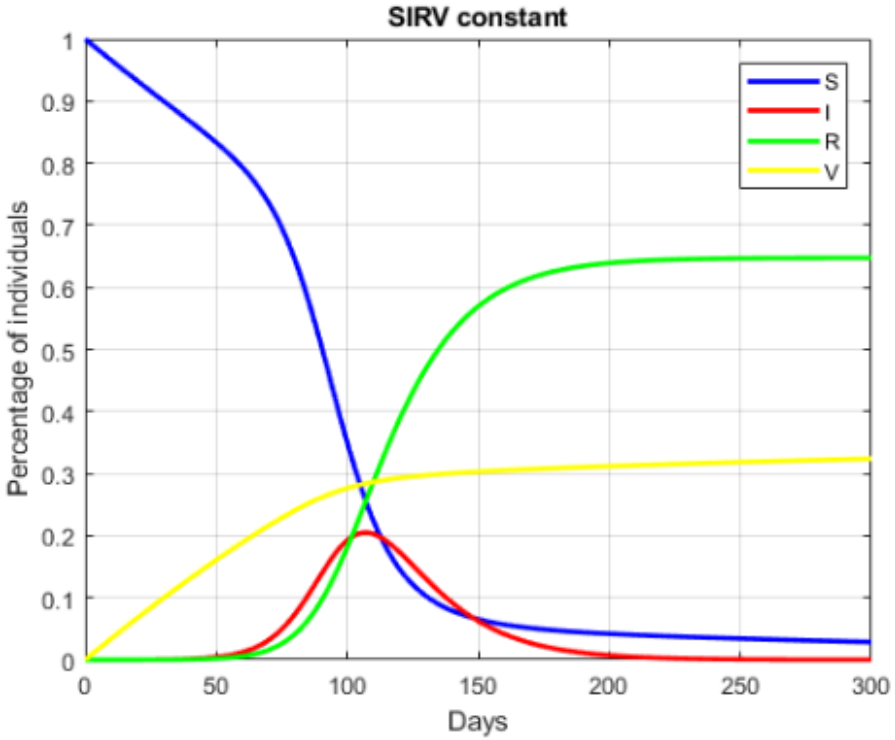


Figure 3: Result of the simulation when vaccinating every day

Results

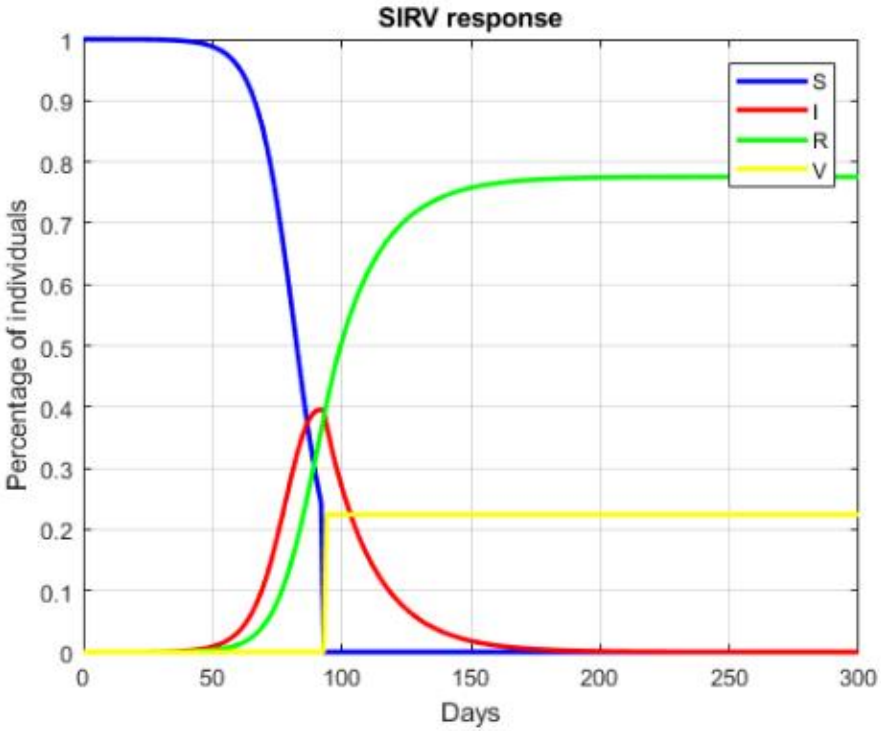


Figure 4: Result of the simulation when vaccinating as a response to a infection peak

Summary

- SIR-modeling is a flexible and a simple tool
- SIR-models describe the main features in the evolution of infectious diseases
- ”All models are wrong but some are useful” (George Box)
- Improvements or alternatives to SIR-modeling
  - IBM (Individual-based models)
  - Hybrid models

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