Planning interventions in a controlled pandemic

SCUDO Scuola di Dottorato – Doctoral School
WHAT YOU ARE, TAKES YOU FAR
XXXVI Cycle

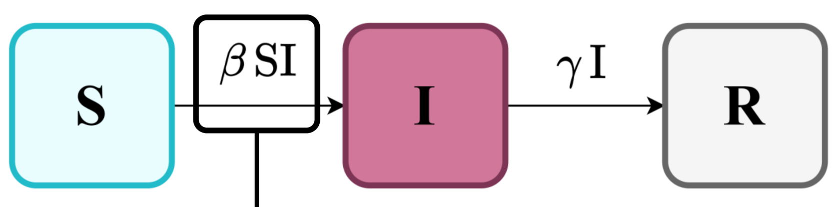
Franco Galante

Supervisor: Prof. Emilio Leonardi

Research context and motivation

COVID-19 triggered worldwide efforts to **control & predict** virus spread

SIR model (**S**usceptible **I**nfected **R**emoved) has been the most employed



- SIR models have been used also in opinion dynamics to model **innovation adoption**

law of mass action: encounter between individuals depends on the fraction in the classes

γ: rate of recovery (or death) of individuals
β: mean # of contacts per person per time

Compartmental Models – **Extension**

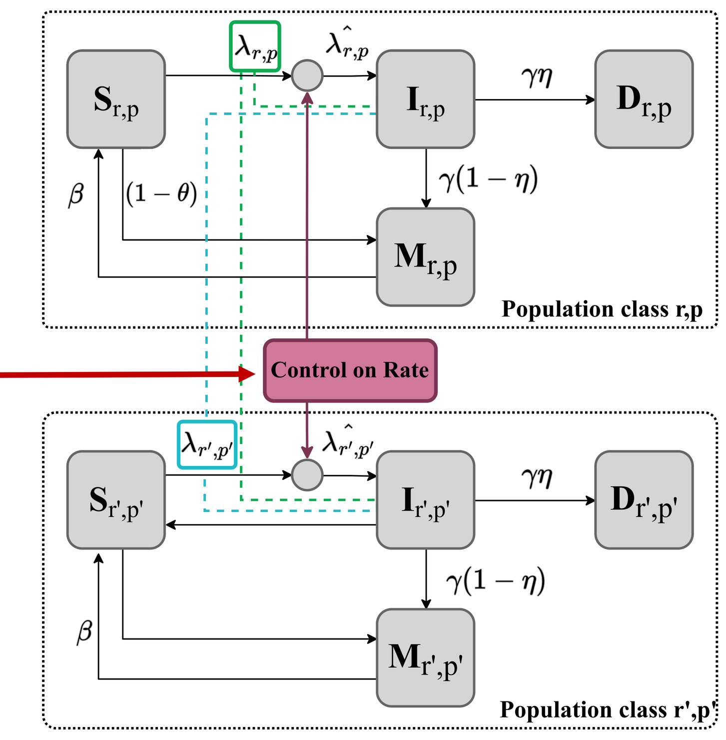
- Individuals progress between **compartments** at certain **rates**
- **Exposed** to the virus but not yet able to transmit (SEIR)
- distinguishing Deaths and iMmune (SIMD)

- Need to devise **efficient strategies** to control the spread of the disease — **Disease Control**
- Approaches including those exploiting **optimal control** theory are daunting to be implemented. Simple strategies and effective representation of the population are needed

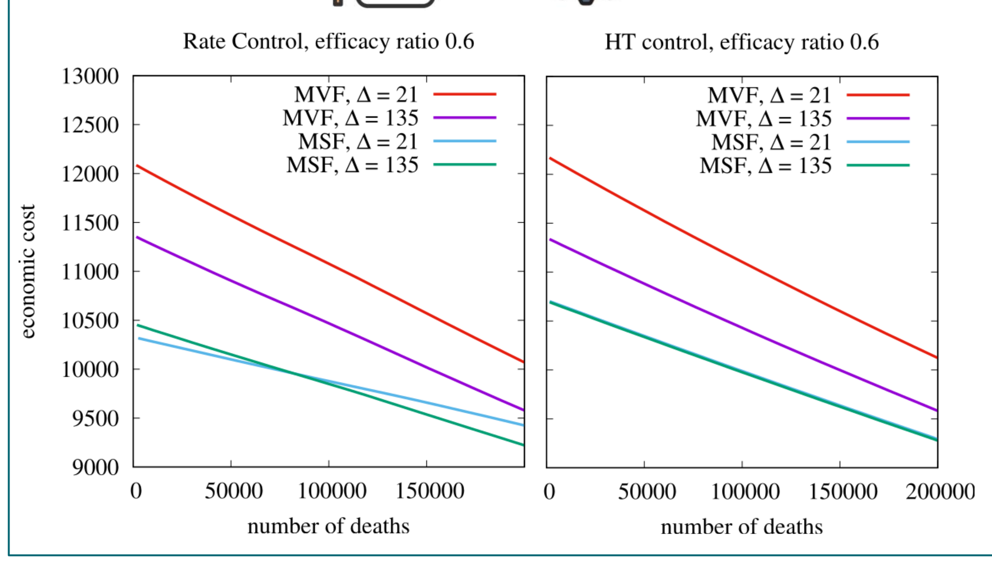
Novel contributions

Theoretical

Model framework in a **tightly controlled** regimen capturing social interventions (i.e. DPI, social distancing, governmental interventions)



- Represent social **heterogeneity** with $f_{r,p}$
- Stability, introducing **delay** in the feedback loop

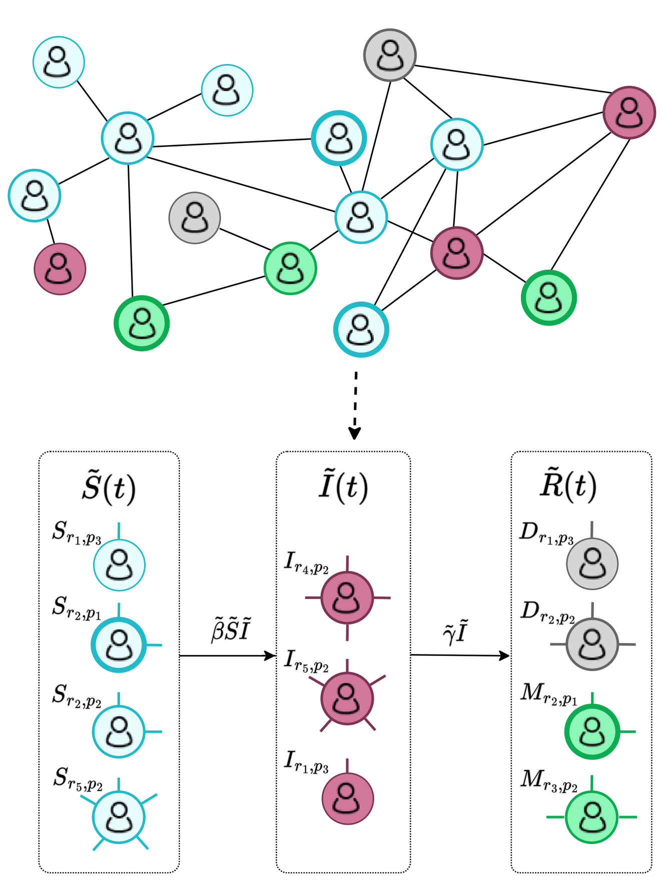


Numerical Solution

- Vaccination strategies considering both individual's **mobility** and **vulnerability**

Targeting individuals with a **high** # of contacts **reduces** the economic cost

Addressed research questions/problems

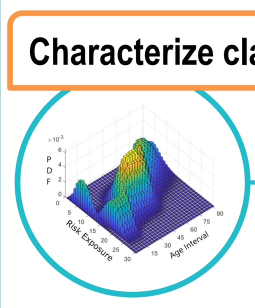


- Development of a model which naturally encompasses:
  1. **Flexibility** in population representation
  2. Governmental **social interventions**
- Quantify both a social cost and an economical cost
  - \# of deaths
  - cost of the countermeasures
- A control exerted on **hospitalizations** and **ICU occupation** introduces a delay in the control loop.
  - How does this delay affect **stability**?
- Vaccines introduced early with **scarce supply** and **uncertain efficacy.**
  - Considering a 2-dose vaccination consider: (a) different efficacy ratios between doses and (b) administration intervals.
- Strategies prioritizing those **most exposed to infection** may be better — **Priority to Social?**

MSF Most Social First vs **MVF** Most Vulnerable First

Adopted methodologies

Characterize class r,p



Mean-Field

$$\dot{S}_{r,p}(t) = -\lambda_C(t) + \mu M_{r,p}(t)$$
$$\dot{I}_{r,p}(t) = \lambda_C(t) - \gamma I_{r,p}(t)$$
$$\dot{D}_{r,p}(t) = p \cdot \gamma I_{r,p}(t)$$
$$\dot{M}_{r,p}(t) = (1-p) \cdot \gamma I_{r,p}(t) - \mu M_{r,p}(t)$$

- **Stability** by linearizing around equilibrium points
- Numerical solution of the system of non linear ODE
- **Generalization** considering healthcare system, vaccines

Infection Rate

$$\lambda_C(t) = \rho(t) \cdot \sigma \sum_{r,p} r I_{r,p}(t) \frac{r S_{r,p}(t)}{\sum_{r,p} r N f_{r,p}}$$

Control: (1) New infections, (2) ICU occupancy

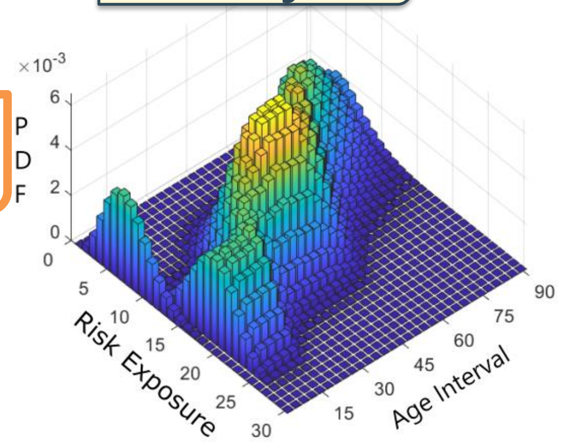
Cost-optimal Strategy

- To keep infections under a threshold ⇒ keep **constant rate** λ_C
- Consider a **convex** economic cost and use Jensen's inequality

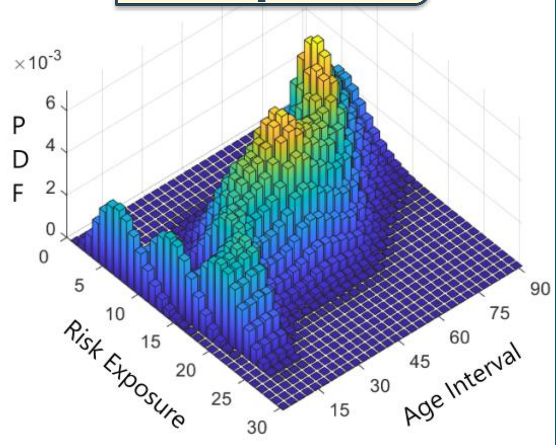
A data-driven approach

- Characterize the population
  - **Risk Exposure**
  - **Vulnerability**
- **Negative correlation** between age and risk exposure

Italy



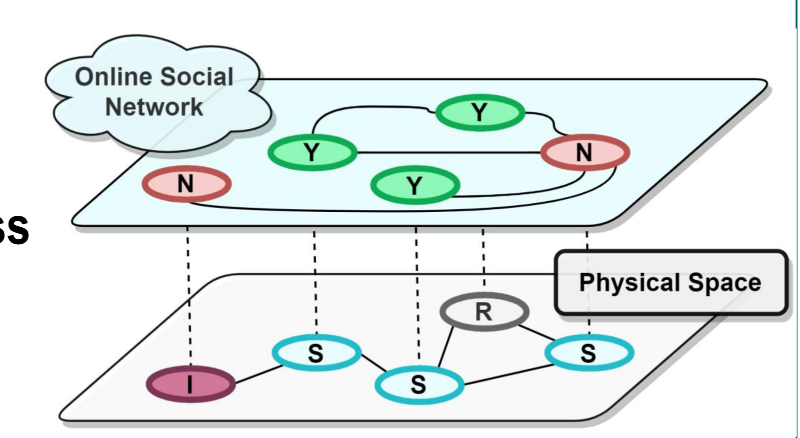
Japan



Future work

Opinions — interplay — **Epidemics**

- How does (online) **vaccine awareness** influence the spreading of disease? [1]
- Effect of **echo chambers** on epidemics?



[1] Granell,C., Gómez,S., Arenas,A., "Dynamical interplay between awareness and epidemic spreading in multiplex networks"-Physical review letters,2013

Submitted and published works

- Galante, F., Ravazzi, C., Garetto M., and Leonardi, E., "Planning interventions in a controlled pandemic: the COVID-19 case", IEEE Transactions on Automatic Control (submitted)

List of attended classes

- 01ROOKG - Introduction to belief propagation (May 22, 2CFU)
- 01TRARV - Big data processing and programming (Mar 22, 4CFU)
- 01QTEIU - Data mining concepts and algorithms (Feb 22, 4CFU)
- 01DNKRT - Nonlinear network systems (Jan-Apr 22, 6CFU)
- 01TUUOD - Fisica dei sistemi complessi (Mar-Jun 21, 6CFU)
- 01DNKRT - Scienza dei dati applicata alle reti complesse (Jun 21, 4CFU)
- 01TSGKG - The Monte Carlo method (Apr-Jun 21, 6CFU)
- 02SFURV - Programmazione scientifica avanzata in matlab (Feb 21, 6CFU)
- 01QFFRV - Tecniche innovative per l'ottimizzazione (Jan 21, 4 CFU)