# COVID-19 modelling efforts in advice to Luxembourg government

Atte Aalto and Jorge Gonçalves

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UNIVERSITÉ DU LUXEMBOURG

LCSB

# Covid-19 task force in Luxembourg

- WP 1: Cross-sectional study on infection prevalence in Luxembourg
- WP 2: Predictive markers for COVID-19 severity
- WP 3: Interventional clinical trial with existing drugs
- WP 4: Diagnostic capacity and large-scale testing strategies for Luxembourg
- WP 5: eHealth solutions for hospitalised and ambulatory patients
- WP 6: Statistical pandemic projections
- WP 7: Gauging economic impact of the COVID-19 outbreak
- WP 8: Mobilising volunteers for support of hospital emergency services
- WP 9: Mobilising and coordinating private partner initiatives
- WP 10: COVID-19 centred communication
- WP 11: Evidence-based review team in the outbreak context
- WP 12: Ideas for new initiatives in the pandemic context
- WP 13: Supply chains and logistics

# WP6: Statistical pandemic projections

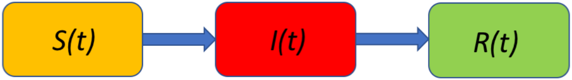
- Led by Alexander Skupin and Rudi Balling (LCSB)
- Members from different institutions of University of Luxembourg and elsewhere
- Consists of several different approaches:
  - Statistical curve fitting
  - Machine learning
  - Differential equation models (with parameter estimation using MCMC, optimisation, or Kalman filter)
  - Agent-based models

# SIR model

Population (of size $N$) is divided into susceptible (S), infected (I) and removed (R), whose dynamics are given by

$$\begin{cases} \frac{d}{dt}S(t) = -\beta S(t)I(t)/N \\ \frac{d}{dt}I(t) = \beta S(t)I(t)/N - \gamma I(t) \\ \frac{d}{dt}R(t) = \gamma I(t) \end{cases}$$

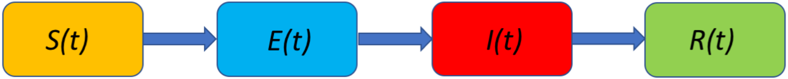
Note that the right side sums to zero, and so $S(t) + I(t) + R(t) = N$.



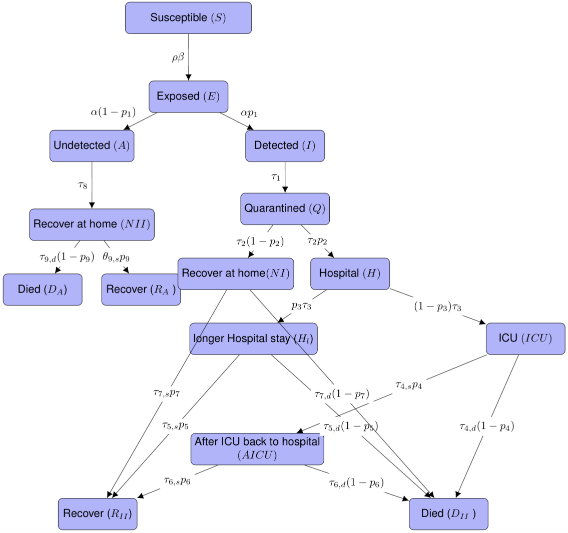
# SEIR model

Population is divided into susceptible (S), exposed (E), infected (I) and removed (R), whose dynamics are given by

$$
\begin{cases}
\frac{d}{dt}S(t) = -\beta S(t)I(t)/N \\
\frac{d}{dt}E(t) = \beta S(t)I(t)/N - \mu E(t) \\
\frac{d}{dt}I(t) = \mu E(t) - \gamma I(t) \\
\frac{d}{dt}R(t) = \gamma I(t)
\end{cases}
$$



# ODE model for short-term projections[1]



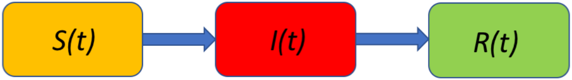

[1] Françoise Kemp and Stefano Magni et al. www.medrxiv.org/content/10.1101/2020.12.31.20249088v1

# Stochastic SIR model

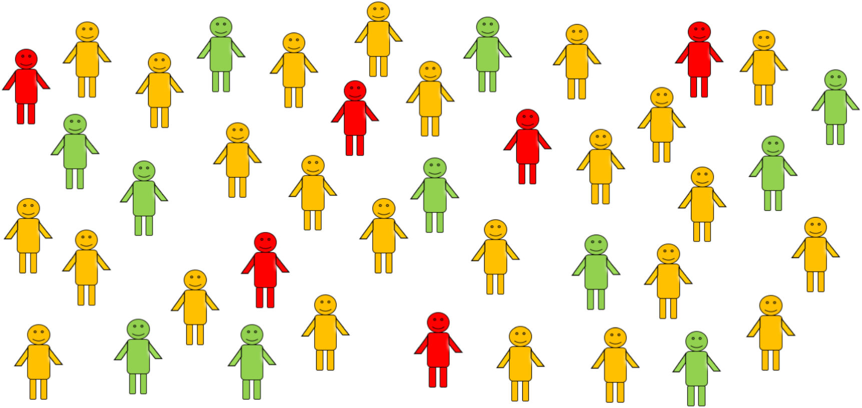
$$\begin{cases} \frac{d}{dt}S(t) = -\beta S(t)I(t)/N + \sqrt{\beta S(t)I(t)/N}\,w_1(t) \\ \frac{d}{dt}I(t) = \beta S(t)I(t)/N - \gamma I(t) - \sqrt{\beta S(t)I(t)/N}\,w_1(t) + \sqrt{\gamma I(t)}\,w_2(t) \\ \frac{d}{dt}R(t) = \gamma I(t) - \sqrt{\gamma I(t)}\,w_2(t) \end{cases}$$

where $w_1$ and $w_2$ are independent white noise processes.

Note that $S(t) + I(t) + R(t) = N$ still holds.

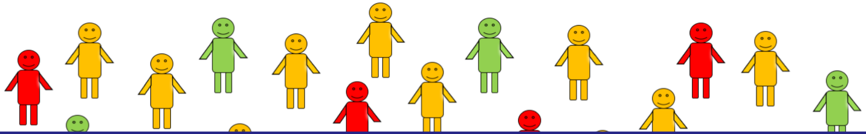


# Simple agent-based SIR



- Each susceptible person has a probability $\beta I(t)/N \cdot \Delta T$ to be infected during a time interval $\Delta T$.
- Each infected person has a probability $\gamma \Delta T$ to recover during a time interval $\Delta T$.

# Simple agent-based SIR



**Note!**

- This formulation assumes a homogeneous and perfectly mixed population.
- In general, an agent-based model is not bound to this limitation.

- Each susceptible person has a probability $\beta I(t)/N \cdot \Delta T$ to be infected during a time interval $\Delta T$.
- Each infected person has a probability $\gamma \Delta T$ to recover during a time interval $\Delta T$.

# ODE vs. Agent-based models

## ODE

- \+ Easy/fast to tune
- \+ Out-of-the-box tools exist
- − Limited heterogeneity
- − Limited interventions

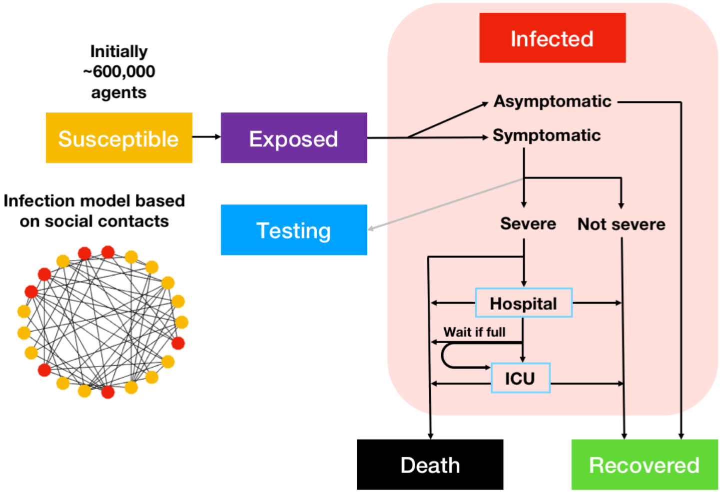
**Ideal for short-term projections and simple phenomenological studies**

## Agent-based

- \+ Population heterogeneity
- \+ Different types of contacts with varying infection risk
- \+ Realistic interventions
- − High number of parameters
- − Complexity
- − Tuning is difficult/ time-consuming

**Ideal for "What if..." scenario simulations**

# Agent-based model for Luxembourg[2]



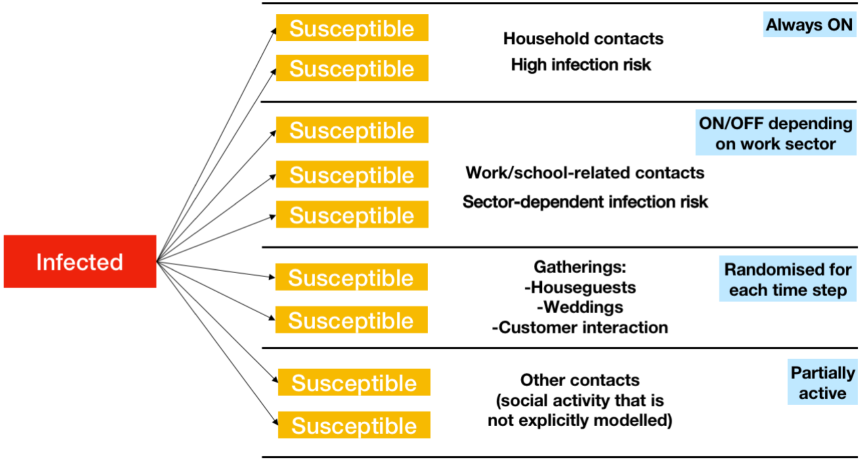

[2] Atte Aalto, Laurent Mombaerts, Laurent Heirendt, Daniele Proverbio, Françoise Kemp, Christophe Trefois, Jorge Gonçalves, and Alexander Skupin doi.org/10.17881/q3g1-7a85

# Model evolution

"Sailing and building the boat at the same time" — Rudi Balling

- Version 1 (March–April):
  - One social network (with age-dependent contact structure)
  - Crude model for workplaces and schools
- Version 2 (April–May):
  - Schools and workplaces in different economic sectors
  - Cross-border workers included as simplified agents
  - Contact tracing
  - Customer interaction (v2.1)
- Version 3 (June–):
  - Households
  - Household, school, and workplace data from social security system
  - Private gatherings
  - Large-scale testing
  - Location-specific contact structure

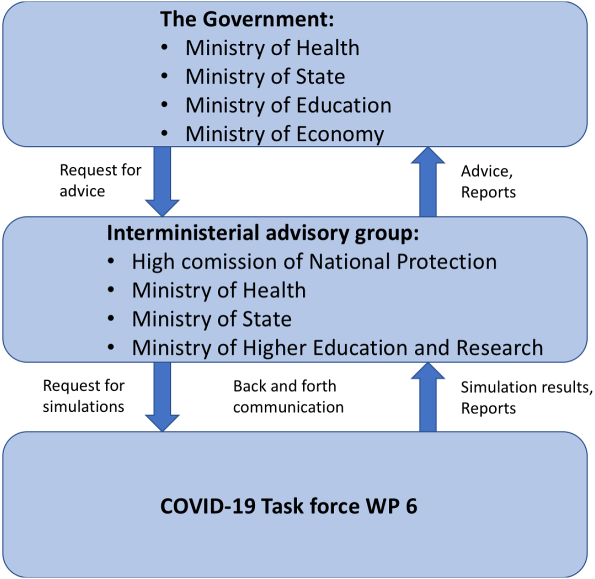
# Infection model



# Contact structure


Average numbers of contacts between people of different ages.

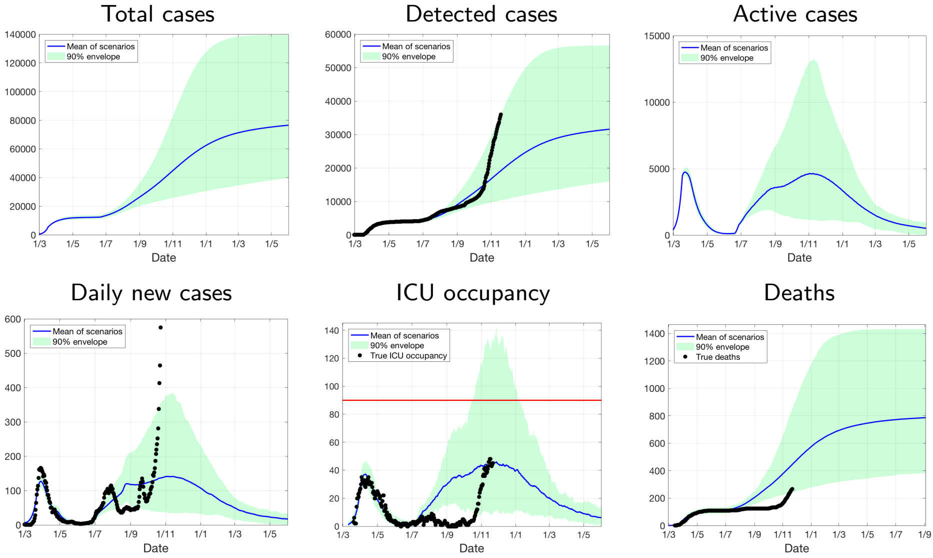
# Organisation



# Simulation topics

- Continued lockdown
- Full exit
- Retail and RDV services opening on different dates
- Different levels of other social interaction
- Isolation of 65+ aged people
- Houseguest scenarios
- Different restaurant scenarios
- Contact tracing (with varying capacity)
- Full / split classes at school for next school year
- Large gatherings, such as weddings
- Large-scale testing (with different targeting strategies)
- App-tracing

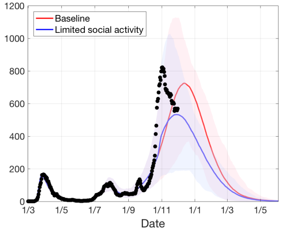
# Simulation from early July on the effect of large-scale testing



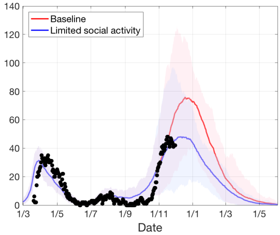
# Simulation from mid-October on the third wave

Limited social activity: 50% reduction in frequency of private gatherings and restaurant visits, and increased capacity in large-scale testing

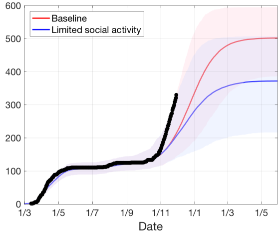
Daily new cases




ICU occupancy



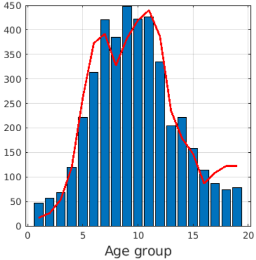

Deaths



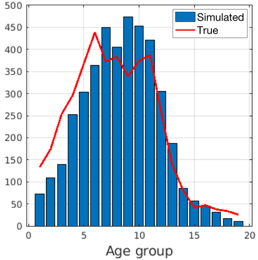
# Other outputs (examples)

Age distribution of infections

## 1st wave

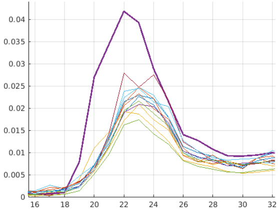



## 2nd wave

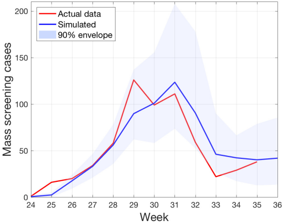



2nd wave analysis

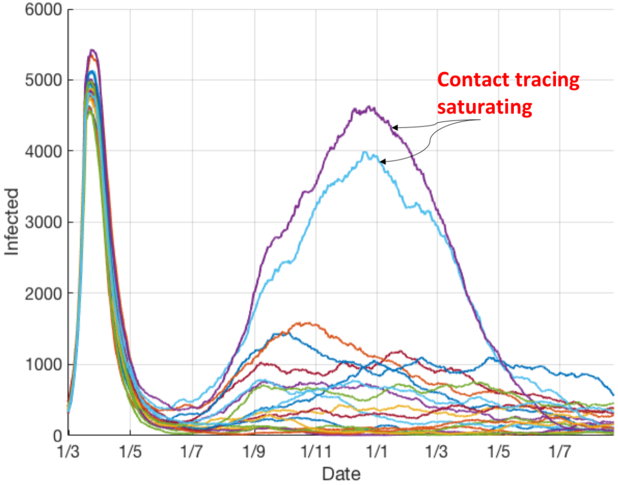
## Regional prevalence




## Cases found by LST

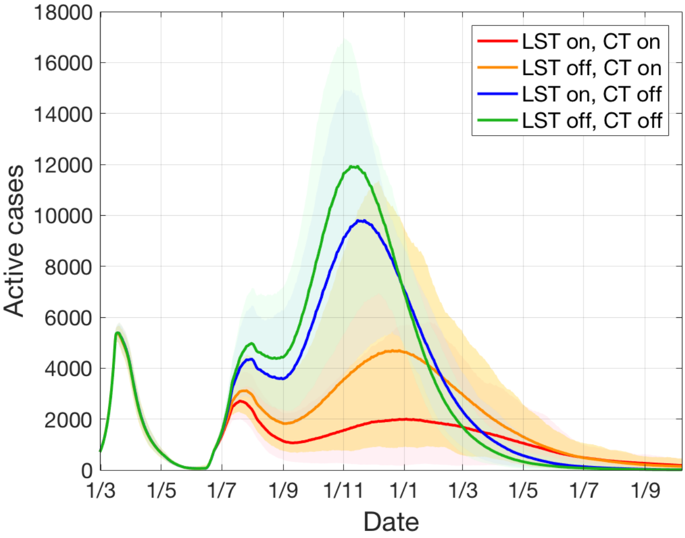


# Contact tracing capacity effect




20 random replicates of the same scenario

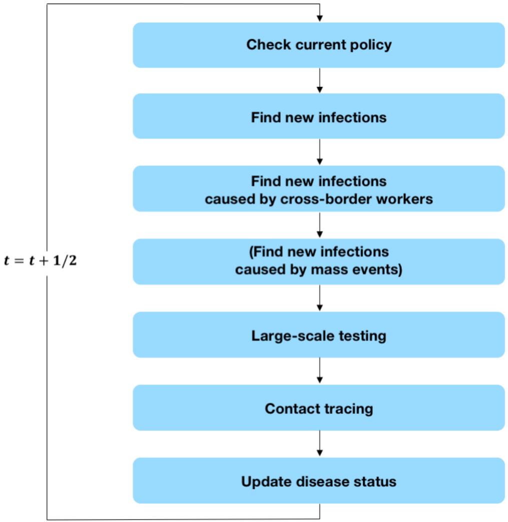
# Large-scale testing effect



# Code structure

MATLAB

- Custom-built code
  - + More freedom
  - − Not very user-friendly
- Simulation time: 5–15 minutes for a scenario (40 replicates run in parallel)
- ∼400 scenarios simulated



# Discussion

- A model is not a crystal ball;
- Higher complexity allows more detailed simulations, but requires more guesswork;
- Long-term predictions are impossible. Results should be considered as possible scenarios;
- Challenges:
  - Disentangling different effects on the observed numbers (testing strategy, public reaction, etc.)
  - Ensuring coherent data streams (many institutions involved, data protection issues,...)
  - Communication to the public
  - Dealing with unrealistic expectations (we cannot really model the effect of wearing masks, keeping 2 meter distance in restaurants, etc.)