Model M - an agent-based epidemiological model

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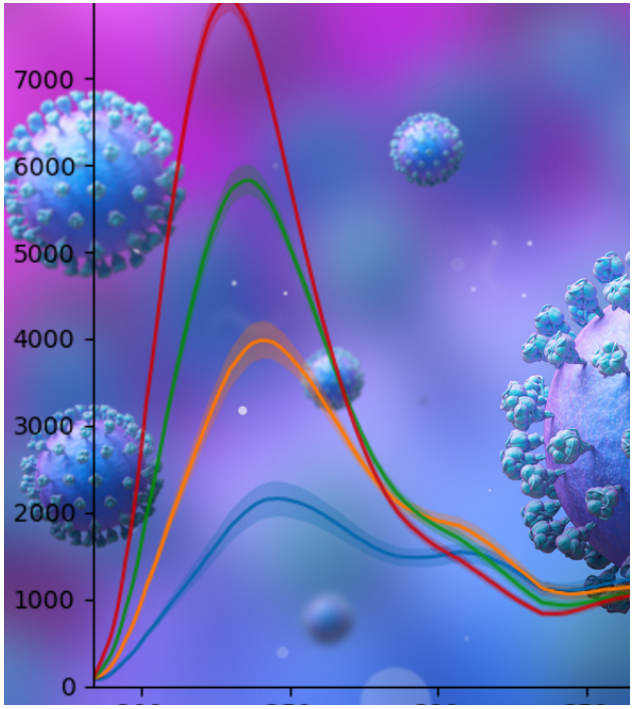
23. 5. 2023

Let's go back in time to 2020 and the start of the pandemic.

Contents



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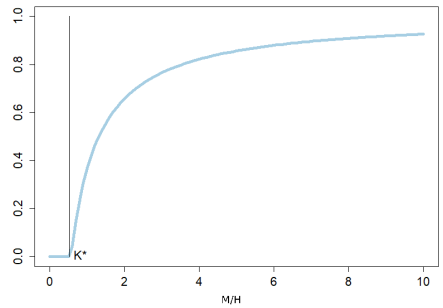
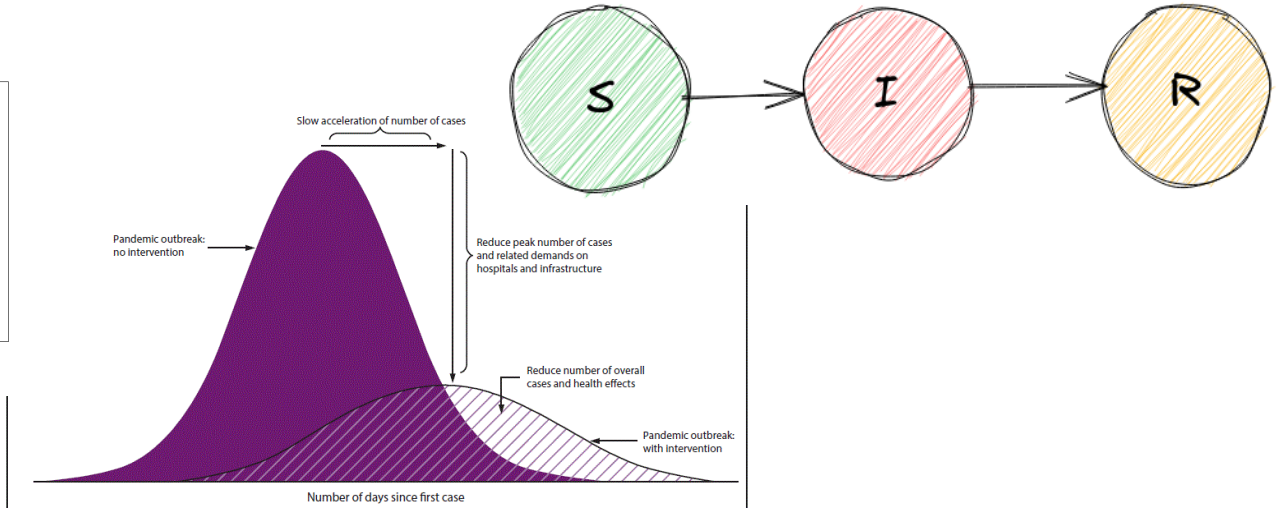
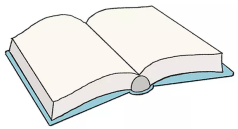
Data from PAQ and MEDIAN.

Epidemiological models





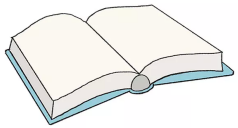


L. Berec: Kapitola 2, str. 19

Model types

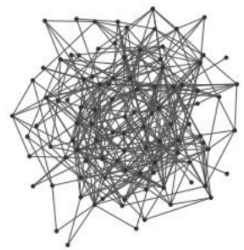
- compartment models - groups, susceptible, infected, recovered
- agent based models - work on individual level

From Compartments to Agents



R. Neruda: Kapitola 3, str. 39

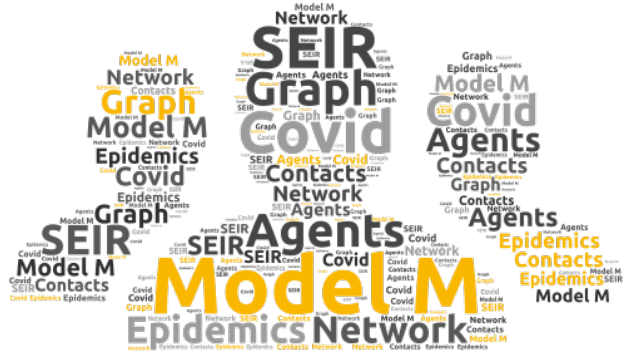
- Compartment models have difficulties in modelling non-pharamaceutical interventions (contact reductions, partial closures)



- Agent models work with a population of individuals
- Agents are connected in a network, i.e. a contact graph

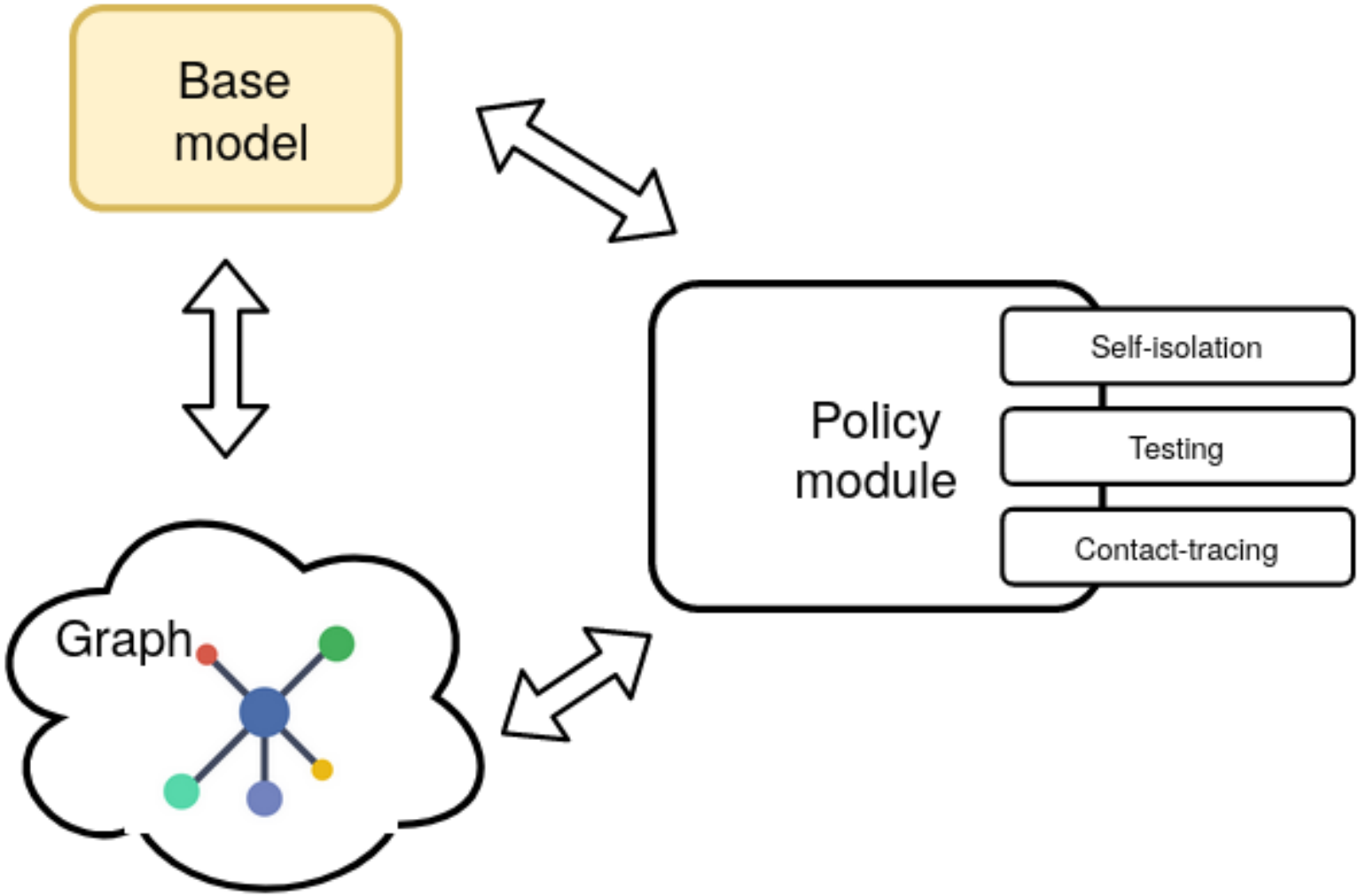
- Agents provide simulation tools for modelling of individual human behaviour
- Enable detailed simulation of various interventions

Model M



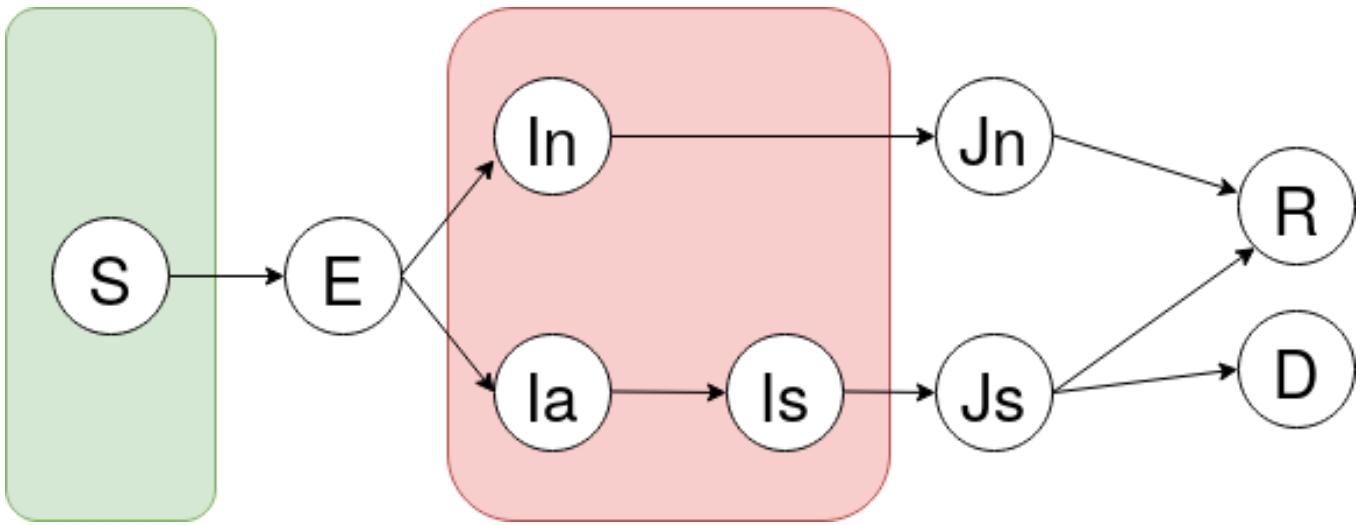
- Agent based model
- Why M? M referes to the world “town” (in Czech “město”)
- Works with a population of individuals (56 000 nodes/agents)
- Uses a realistic contact graph
- The graph models one Czech county
- Focus on comparing interventions (rather than on precise forecasting)
- Enables modelling of non-pharmaceutical interventions
- Simulates quarantines, isolations, flat closures on individual level

Model M


Base model
Policy module
Self-isolation
Testing
Contact-tracing
Graph

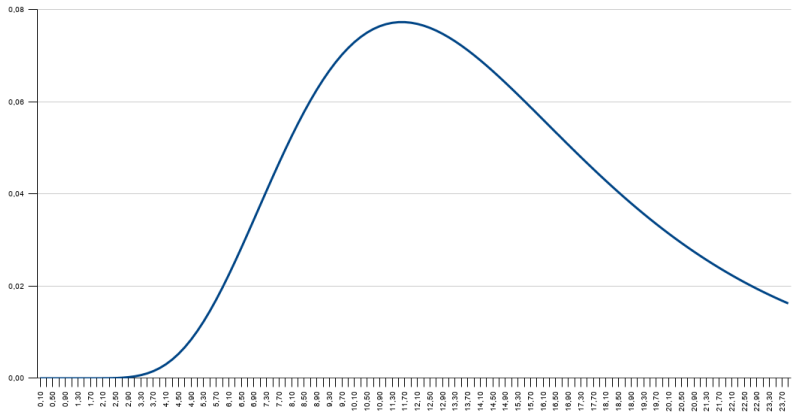
Base model - SEIR model

- Each individual is in exactly one of possible states
- Iterates on a daily basis
- Transition $S \rightarrow E$ is given by β and the contact graph
- Other transitions depends on parameters of the infection only

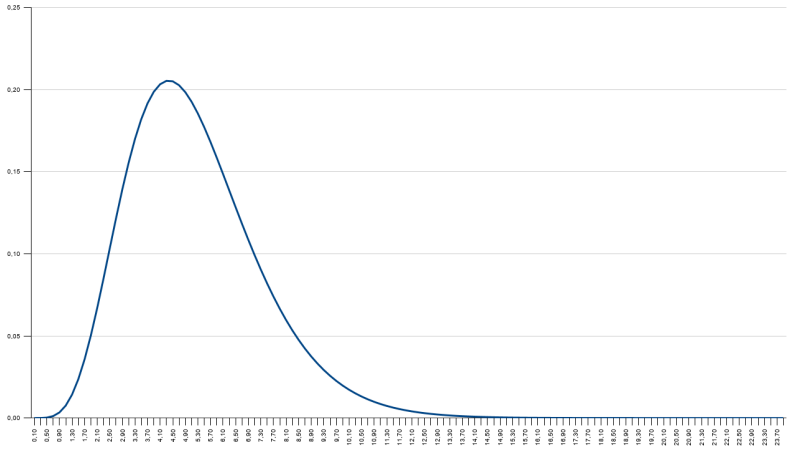


Base model - state durations

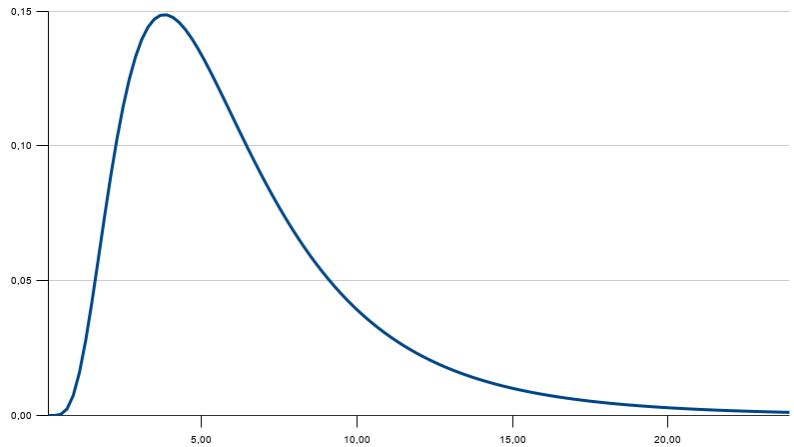
RNA positivity



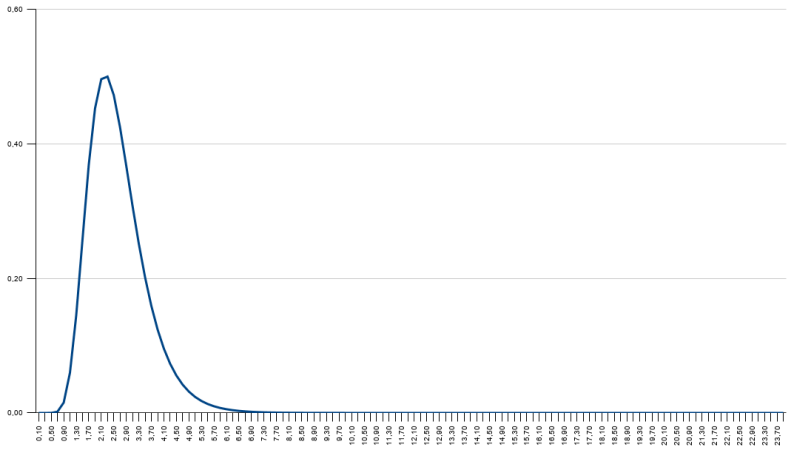
Infectiouness



Incubation

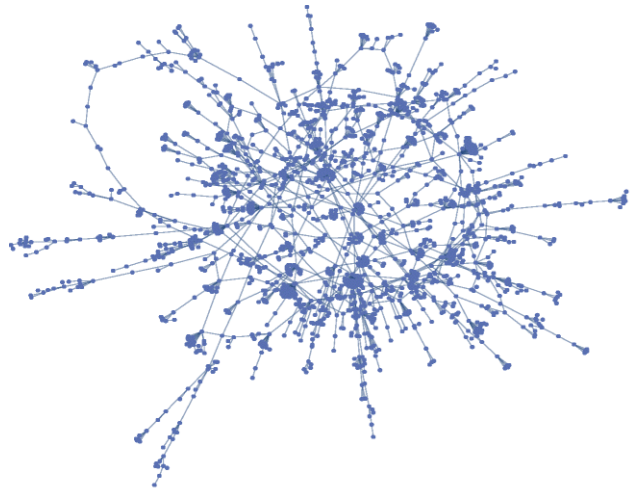


Presymptomatic time

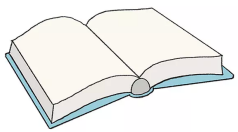


Model M - graph

- Realistic graph
- Model of a real Czech county (Hodonín)
- Models contacts between people
- Multi-graph



- Data sources:
  - Czech Statistical Office
  - State Administration of Land Surveying and Cadastre
  - Ministry of Education, Youth and Sports
  - PAQ research, Median
  - Openstreet map
  - Expert knowledge
- Modified Barabasi-Albert algorithm



M. Zajíček, K. Vrbenský: Kapitola 6, str. 75

Contact matrices

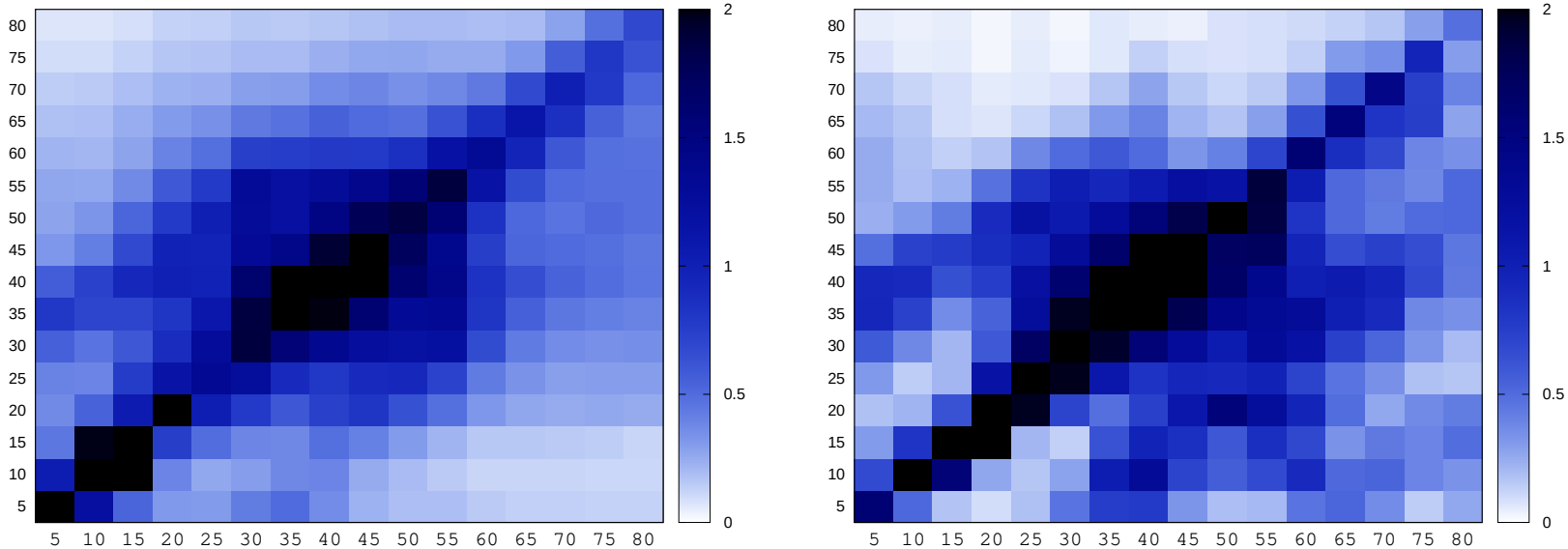
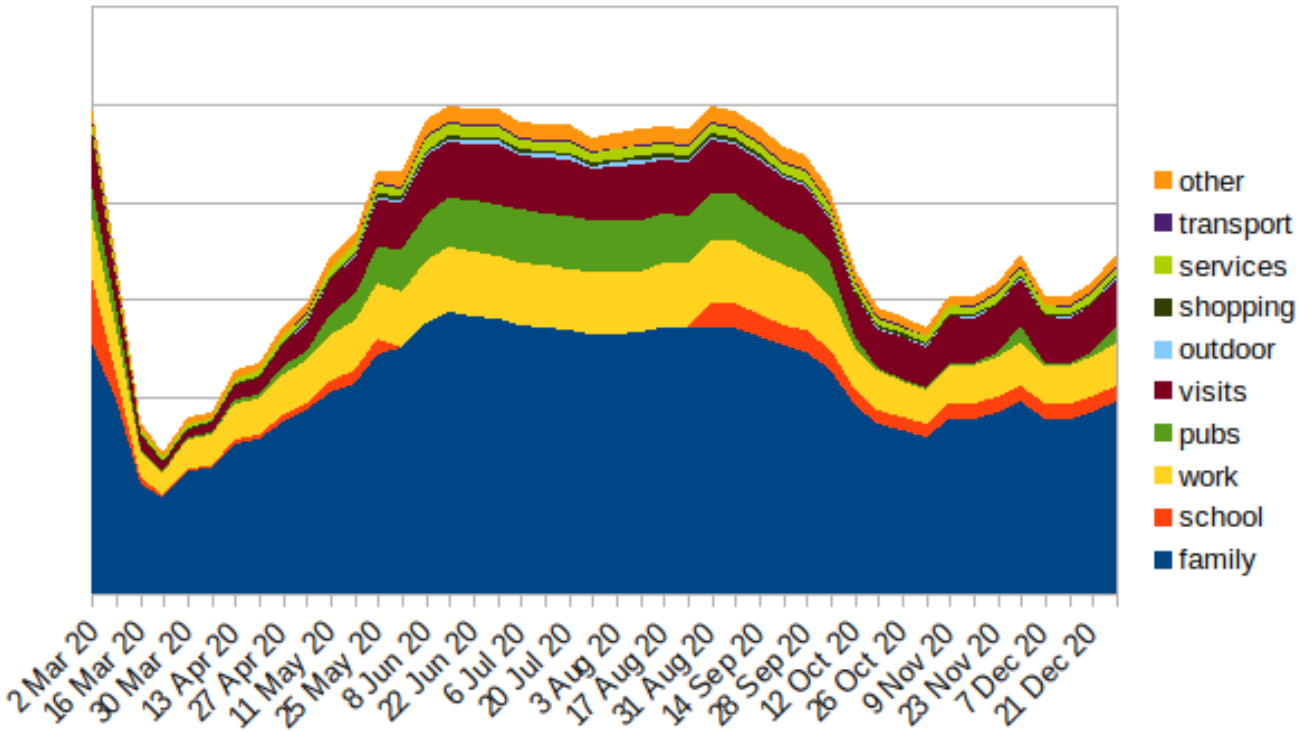
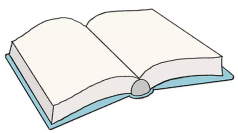


Figure: Frequency matrices for social contacts based on age: Our data (left), Prem et al. 2017 (right)

Contacts in time



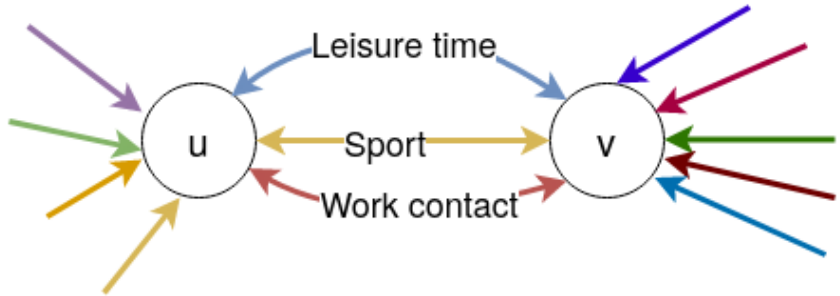
PAQ, Life during pandemic



D. Prokop a spol.: Kapitola 13, str. 161

Model M - graph

- Multi-graph, organised in layers (family, work, school, etc.)
- 56 thousands nodes
- 2.8 millions edges
- 30 layers



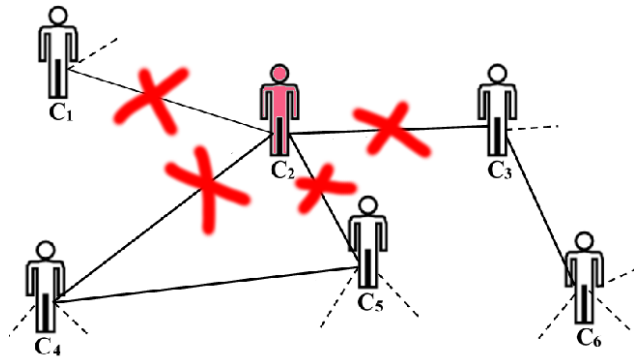
- Edge parameters: contact probability p, intensity i, layer type l

- Each day an edge is activated with the probability $w_l * p$
- Probability of infection transmission

$$p_{S \to E}(e) = \begin{cases} \beta * i & \text{if the edge is active} \\ 0 & \text{otherwise} \end{cases}$$

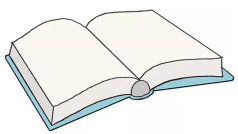
Model M - policy module

- Implements various interventions and changes in people's behaviour
- Invoked on daily basis
- Modifies the graph
- Controls and change model parameters



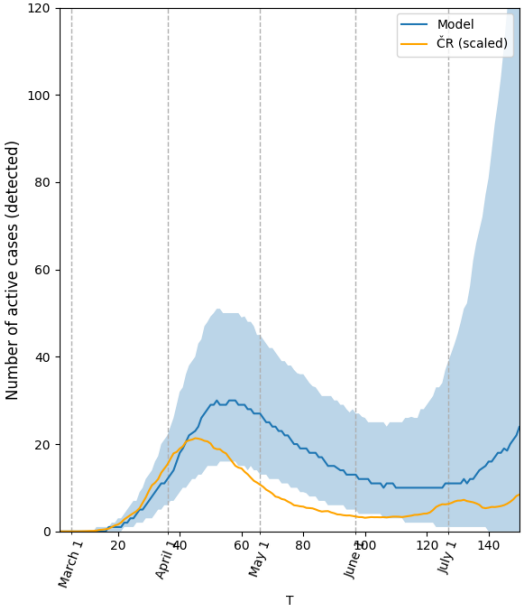
Interventions

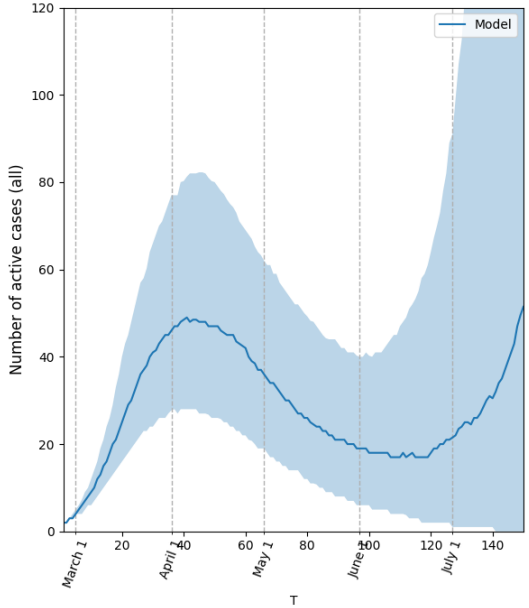
- Protective measures - reduction of β
- Flat contact restrictions - switching off whole layers
- Individual isolation
  - Testing, isolation, contact tracing

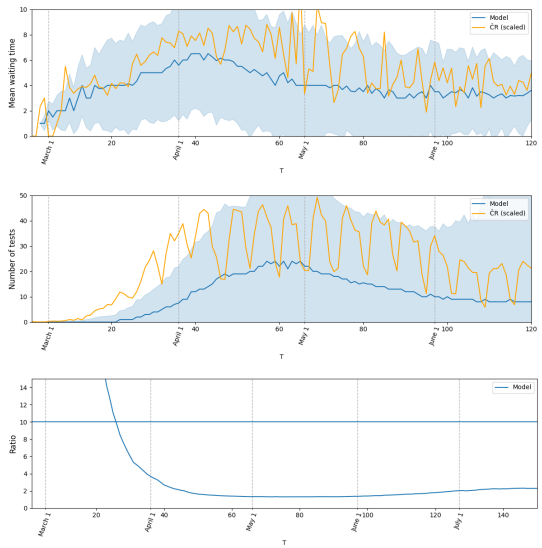


P. Vidnerová, G. Suchopárová, R. Neruda: Kapitola 7, str. 87

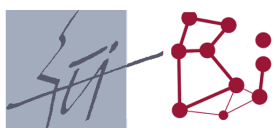
Calibration





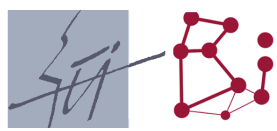


- Finding parameters to fit the history
- Using grid search and CMA-ES

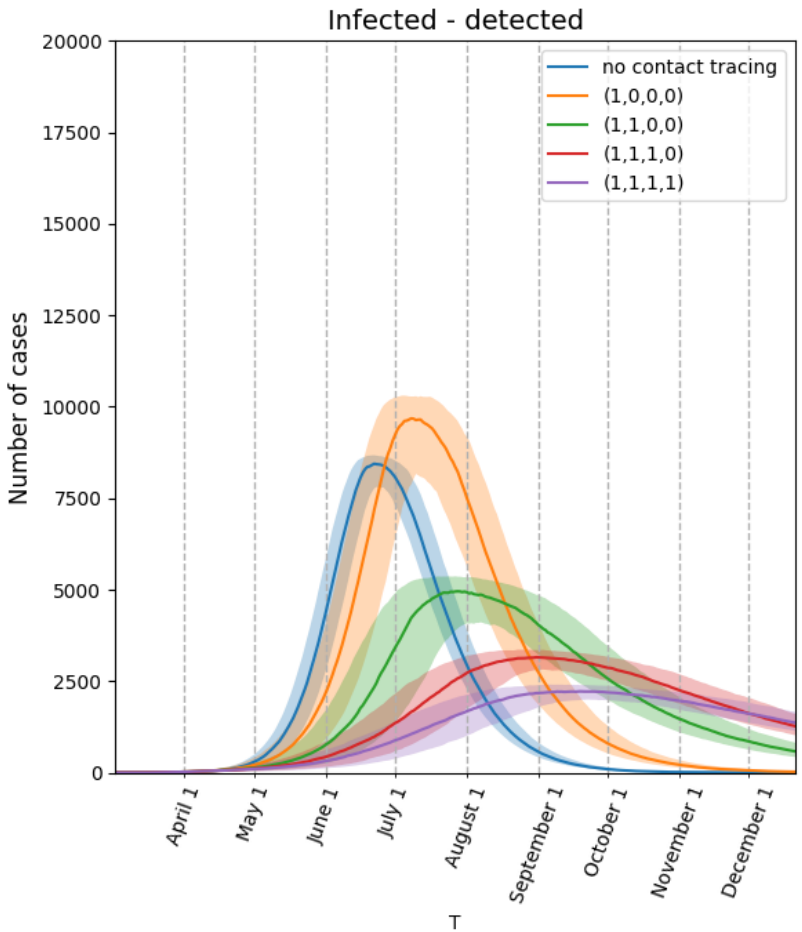


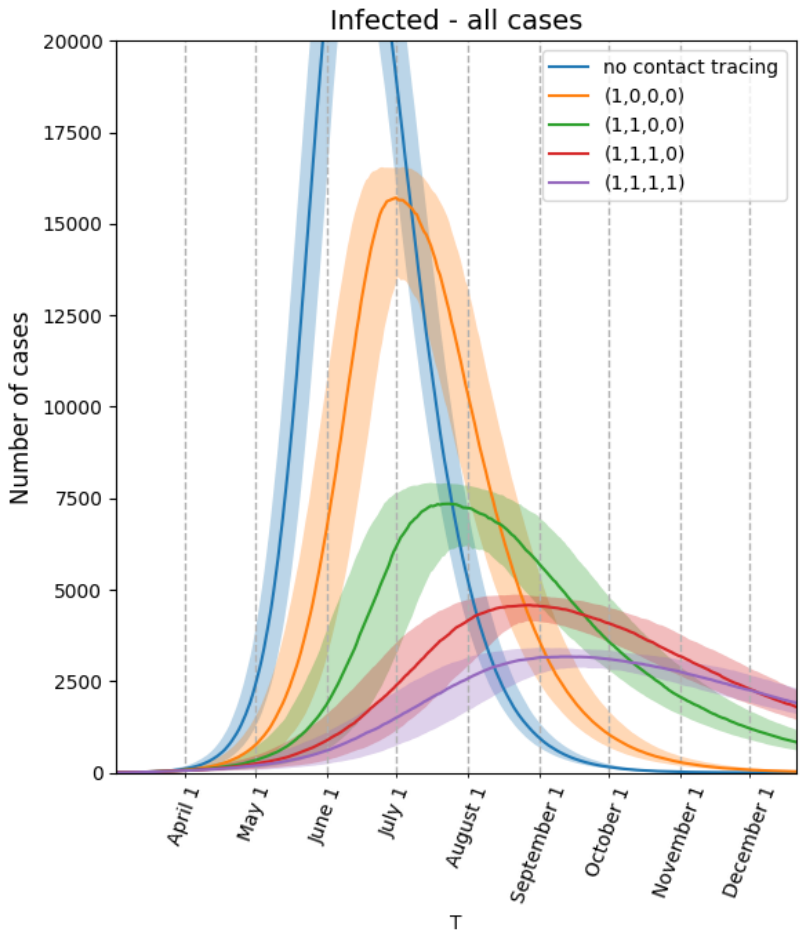
Contact tracing

- Compare different levels of contact tracing – layers (family, school & work, leisure time, others)
- Two scenarios – with and without flat restrictions
- Flat restrictions corresponds to spring 2020 in the Czech Republic
- 1000 simulations for each setup (model is stochastic)

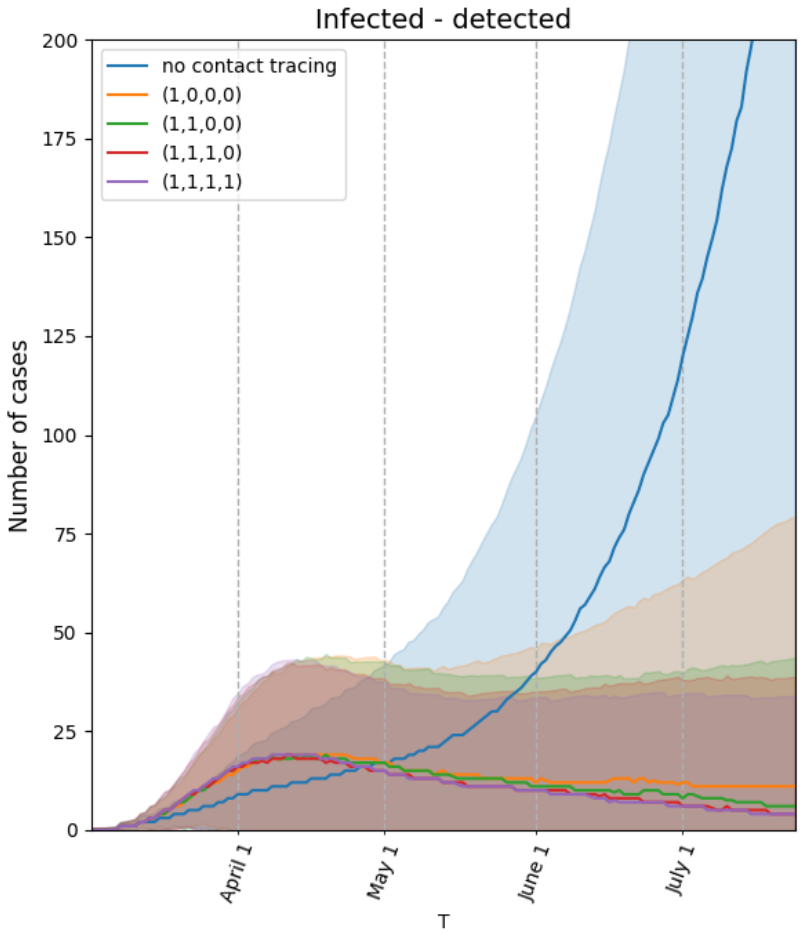


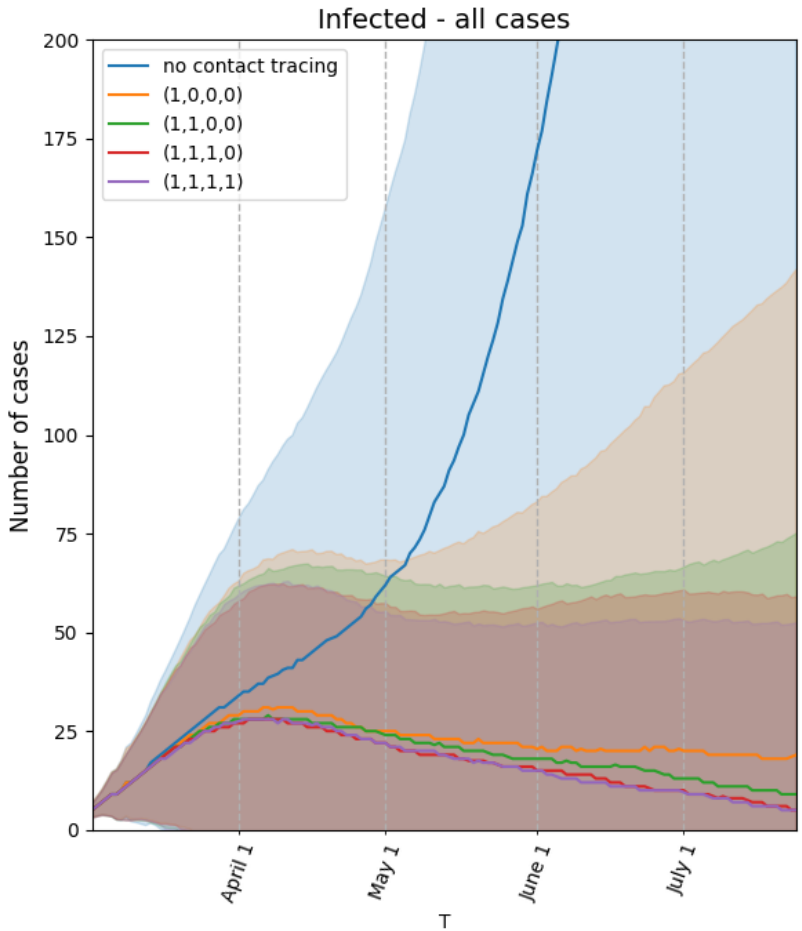
Different levels of contact tracing comparison



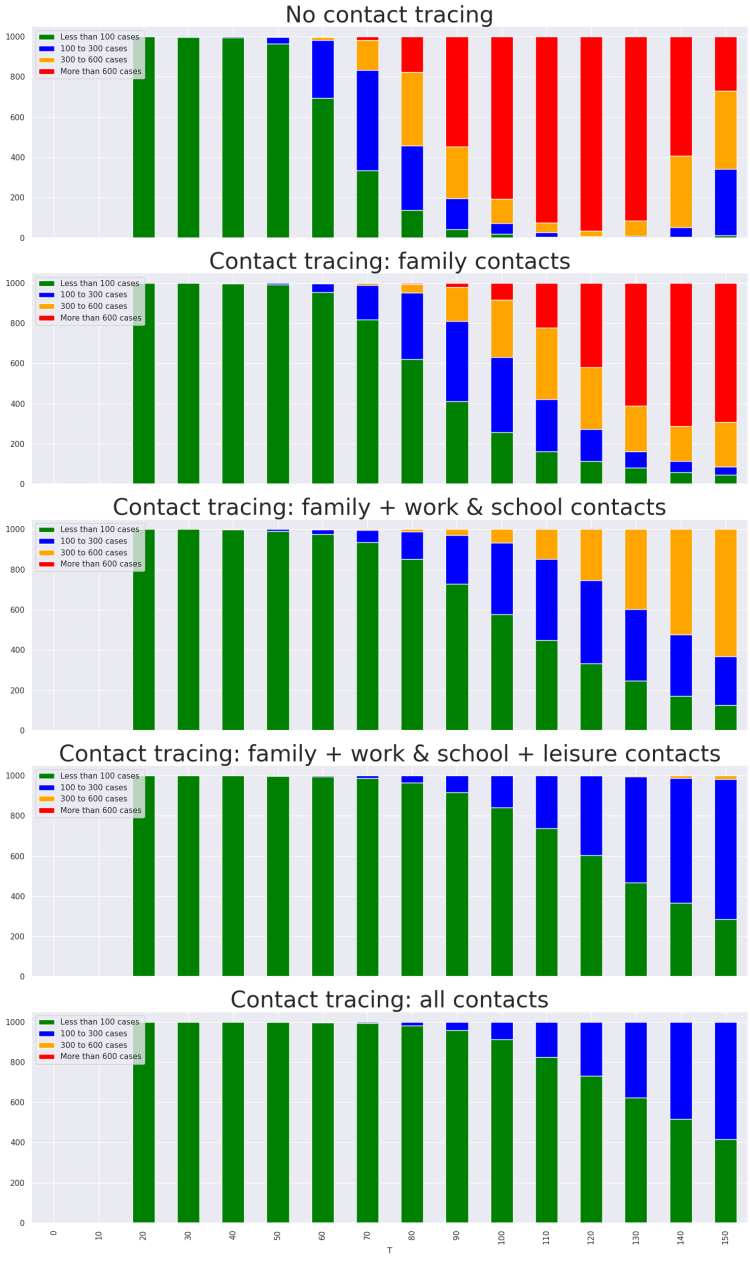


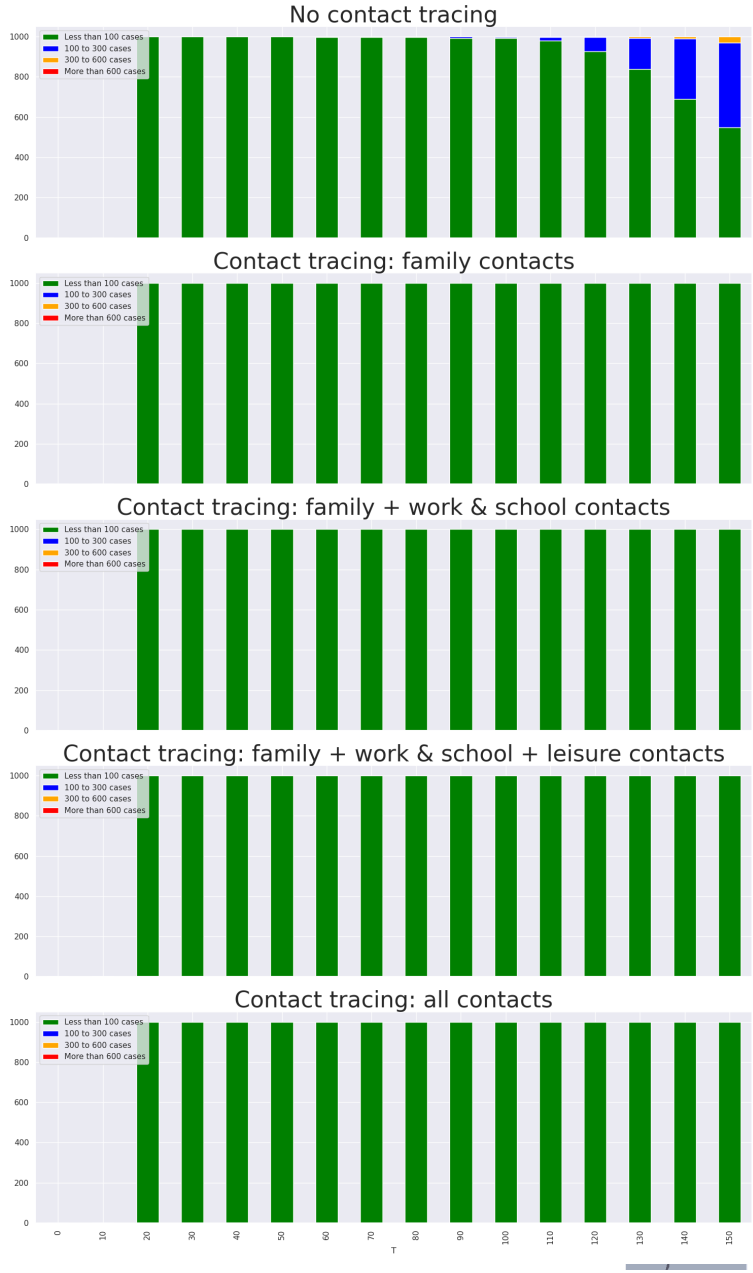
Different levels of contact tracing with flat closures





Distribution of individual simulation runs by epidemic level

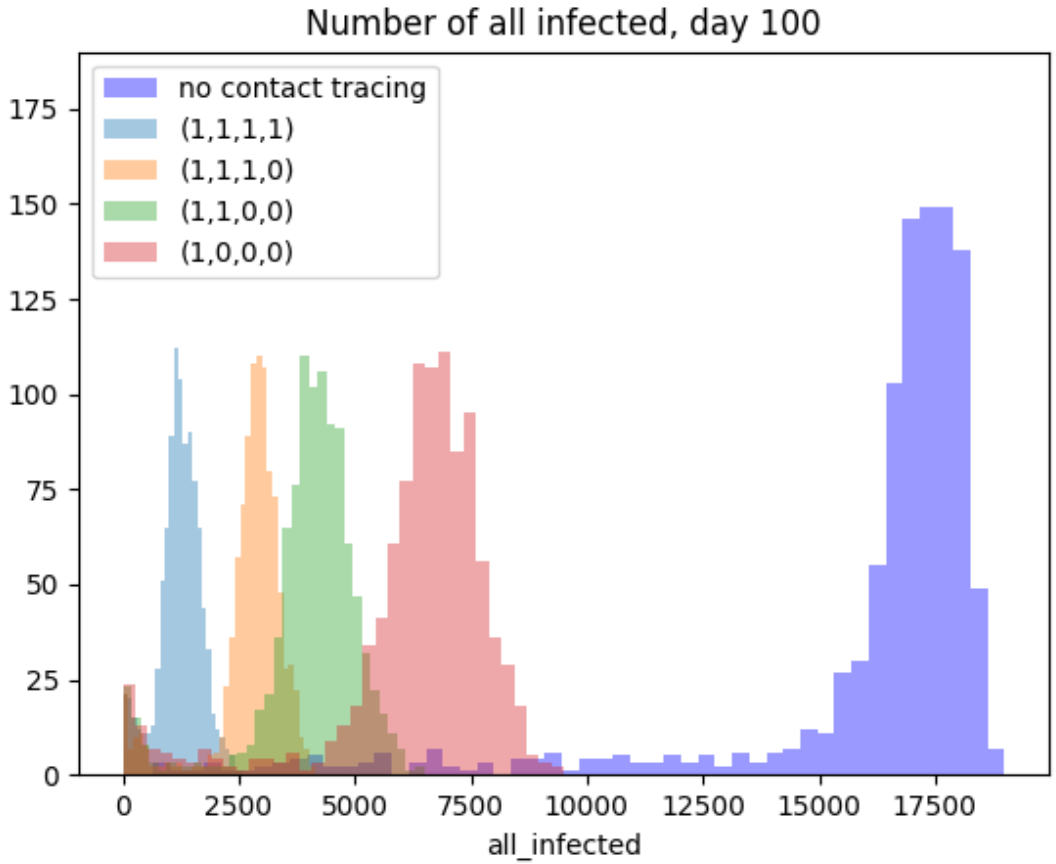




Histogram of simulation runs – scenario with a mass event

Experiment II

- A mass event
- Once a week
- 300 individuals
- 14 000 edges

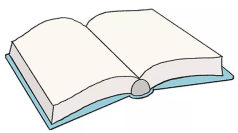


Experiments with school environment

- In cooperation with Ministry of Education, Youth, and Sports
- Need for safe mode of school attandance

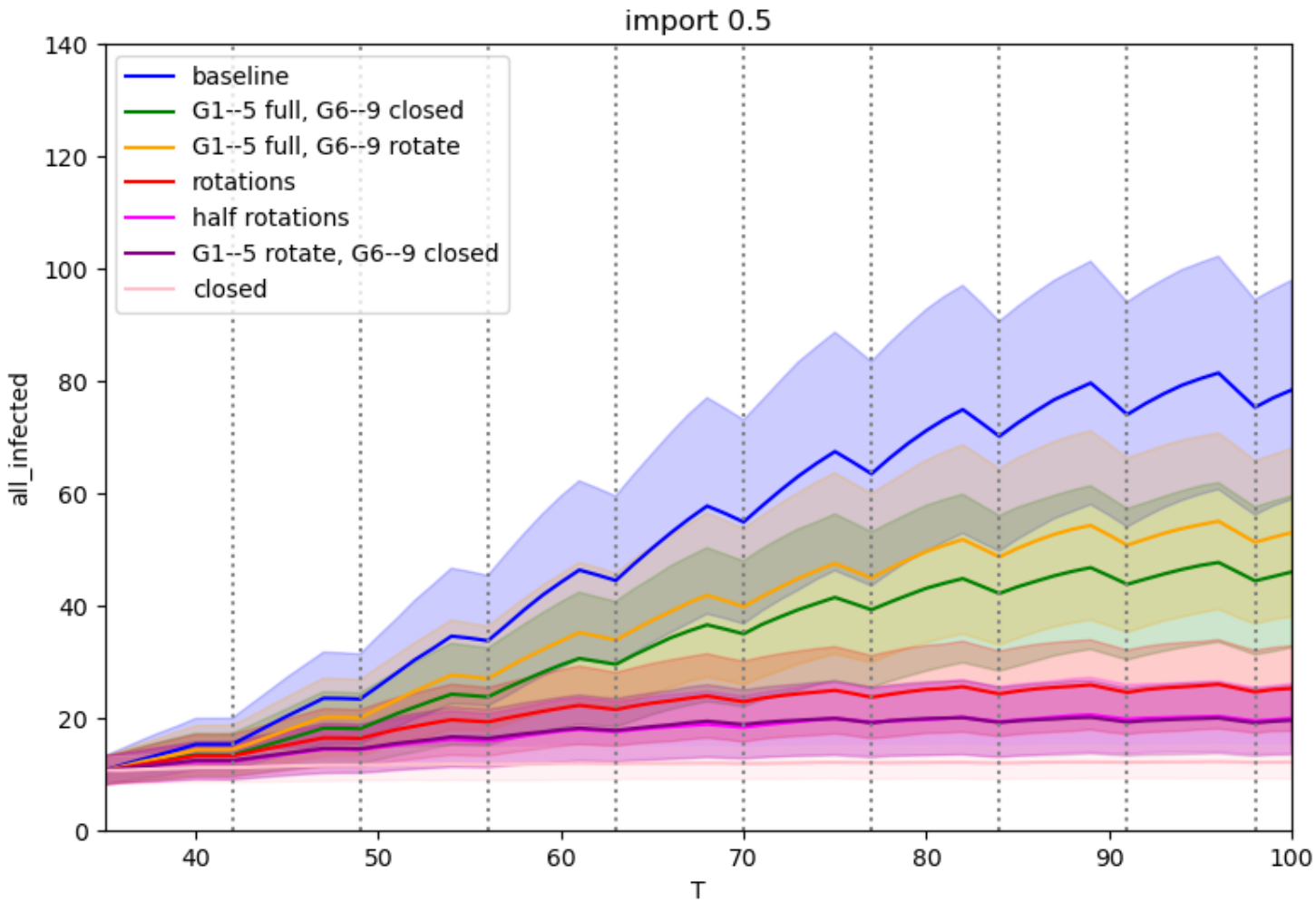
- An alternative graph, model of a real school
- Based on sociological survey
- 650 nodes (teachers and pupils), 70 layers of edges

- Goals is to study various interventions
- Partial closures
- Week alternations
- Testing



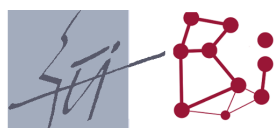
T. Diviák, J. Drbohlav: Kapitola 8, str. 97

Rotation Scenarios

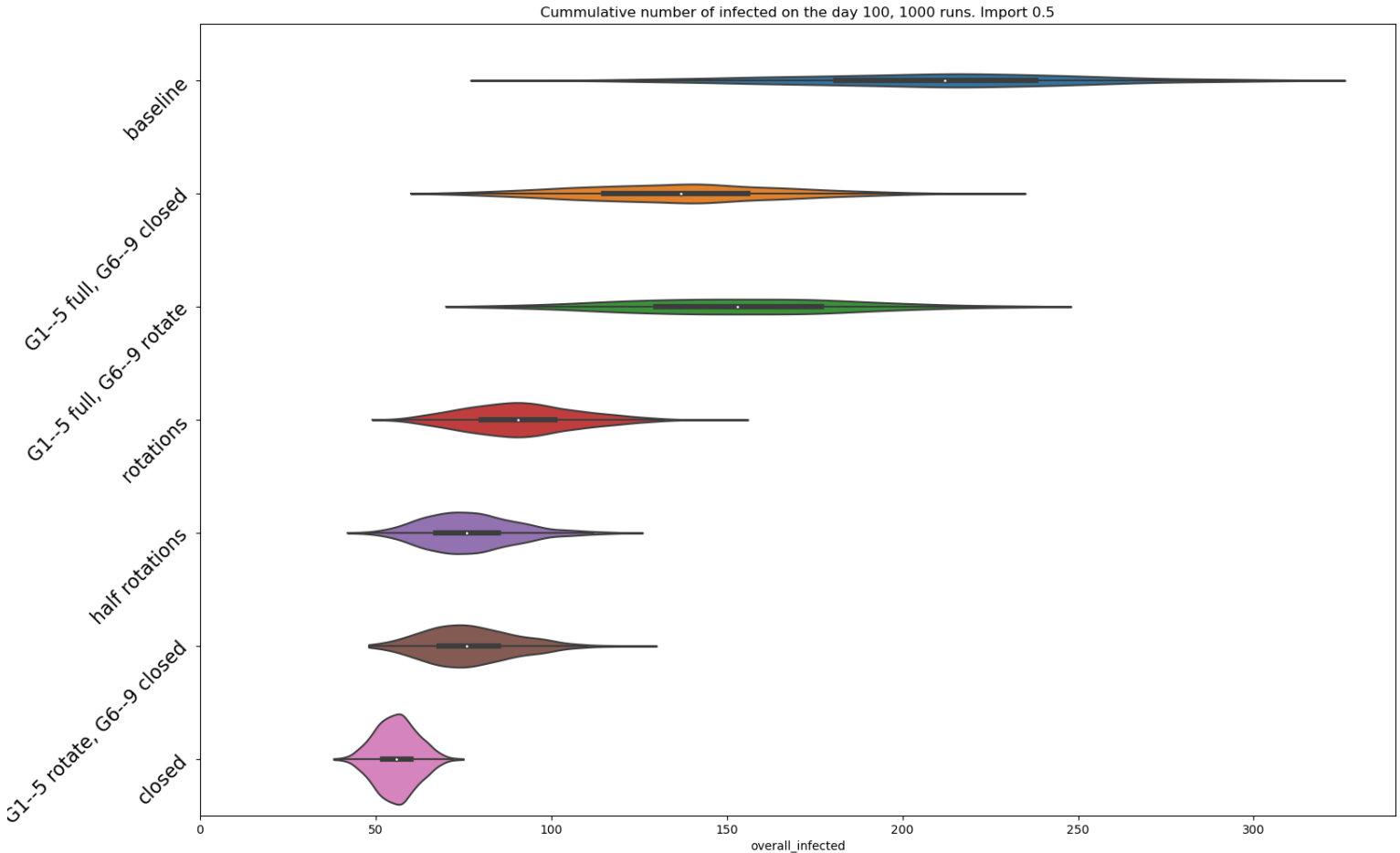


Rotation Scenarios

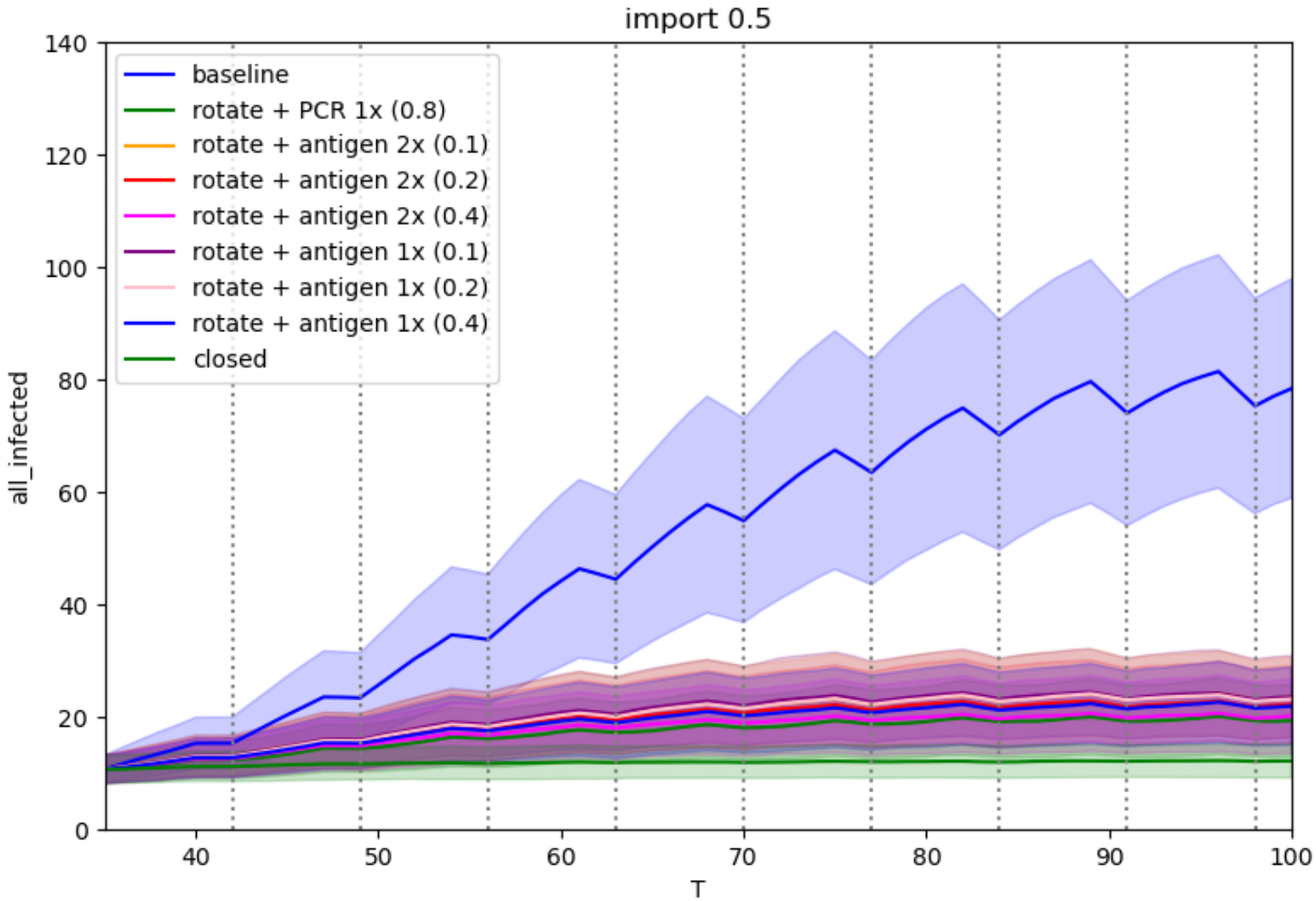
	import			
	0.1	0.25	0.5	1.0
baseline	100.00	100.00	100.00	100.00
G1–5 full, G6–9 closed	50.67	54.67	52.98	54.38
G1–5 full, G6–9 rotate	60.19	63.87	63.92	64.46
rotations	18.93	21.94	22.69	24.79
half rotations	13.18	12.57	14.02	15.42
G1–5 rotate, G6–9 closed	12.17	12.47	13.83	15.32
closed	0.00	0.00	0.00	0.00



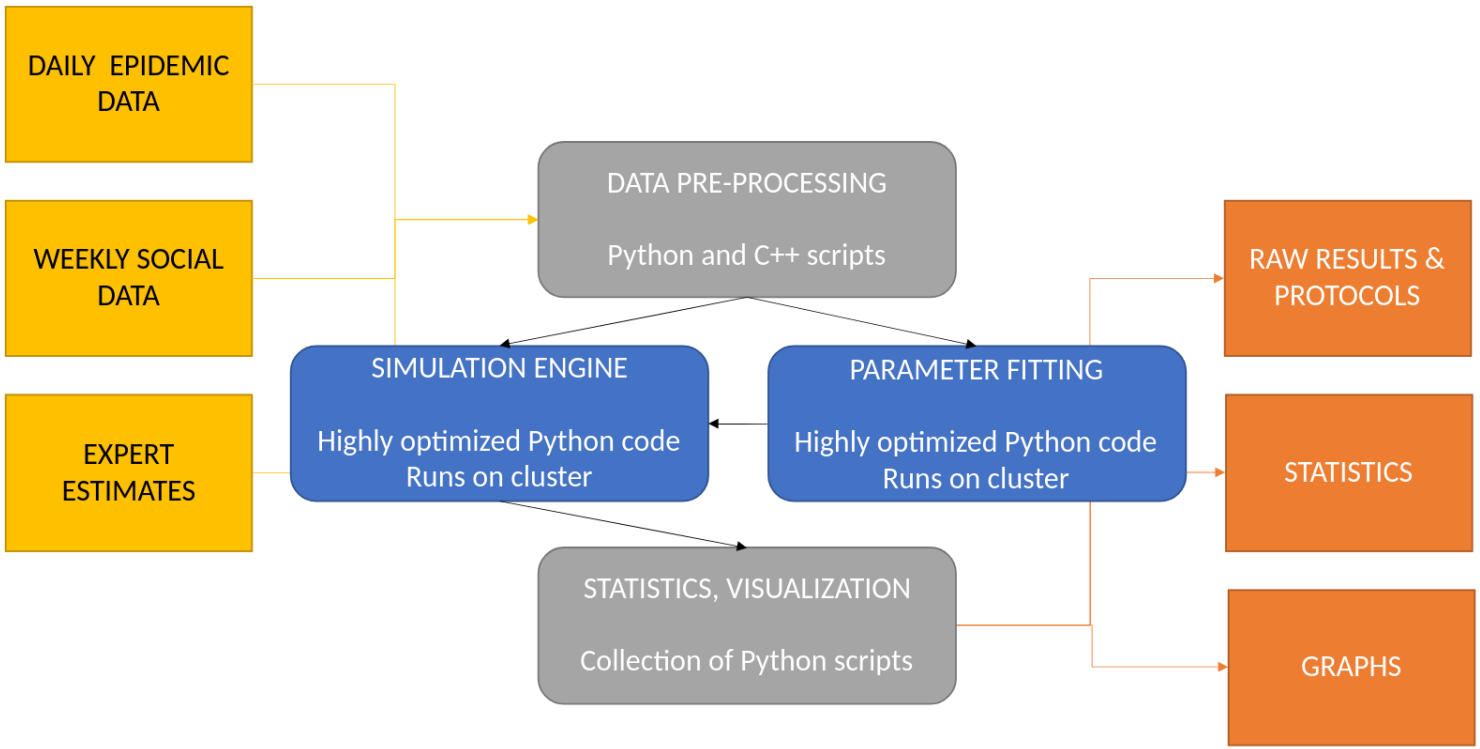
Rotations - violin plots



Rotations + Tests



Software



github.com/epicity-cz/model-m

Conclusion

Summary

- Agent based epidemic model with a realistic graph
- Enables simulation of various interventions on individual level
- Modular and extensible (different graphs, vaccination, etc.)

Reading

- Berec et al. Importance of vaccine action and availability and epidemic severity for delaying the second vaccine dose, Scientific Reports volume 12, Article number: 7638 (2022)
- Berec et al. On the Contact Tracing for COVID-19: A simulation study. Epidemics, Elsevier, Volume 43, 2023.
- Brom et al. Rotation-based schedules in elementary schools to prevent COVID-19 spread: A simulation study.