Mathematical Modelling and Simulation

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Modelling the spread of SARS-CoV-2:

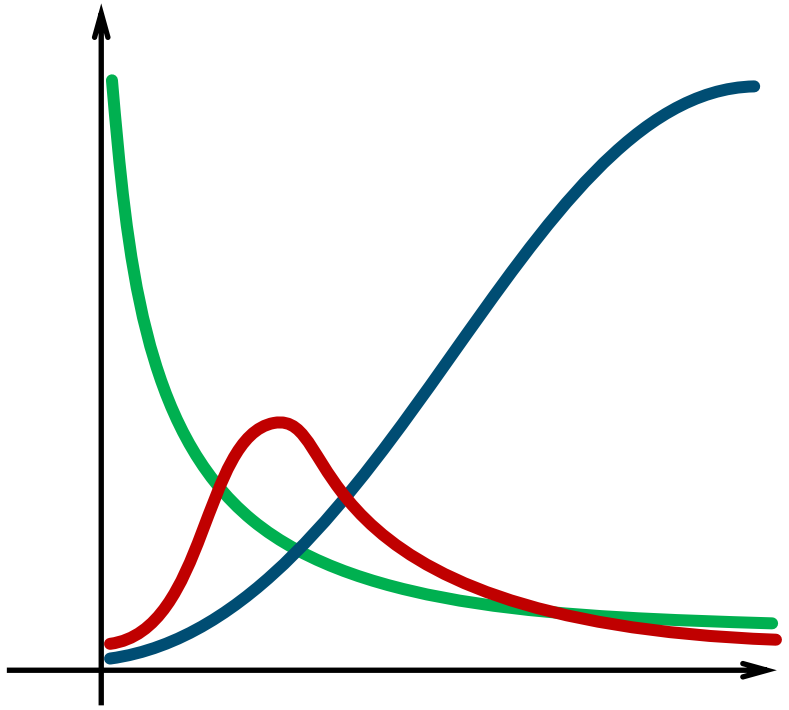
How reliable are simulated forecasts?

Dr. Martin Bicher [1,2]

[1]TU Wien, Institute for Information Systems Engineering
[2]dwh GmbH, dwh simulation

Overview

- What is and why do we need mathematical modelling and simulation?
- What's the secret behind epidemiological models?
- What's the uncertainty of epidemiological models?



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What is and why do we need

MATHEMATICAL MODELLING AND SIMULATION

Mathematical Modelling and Simulation

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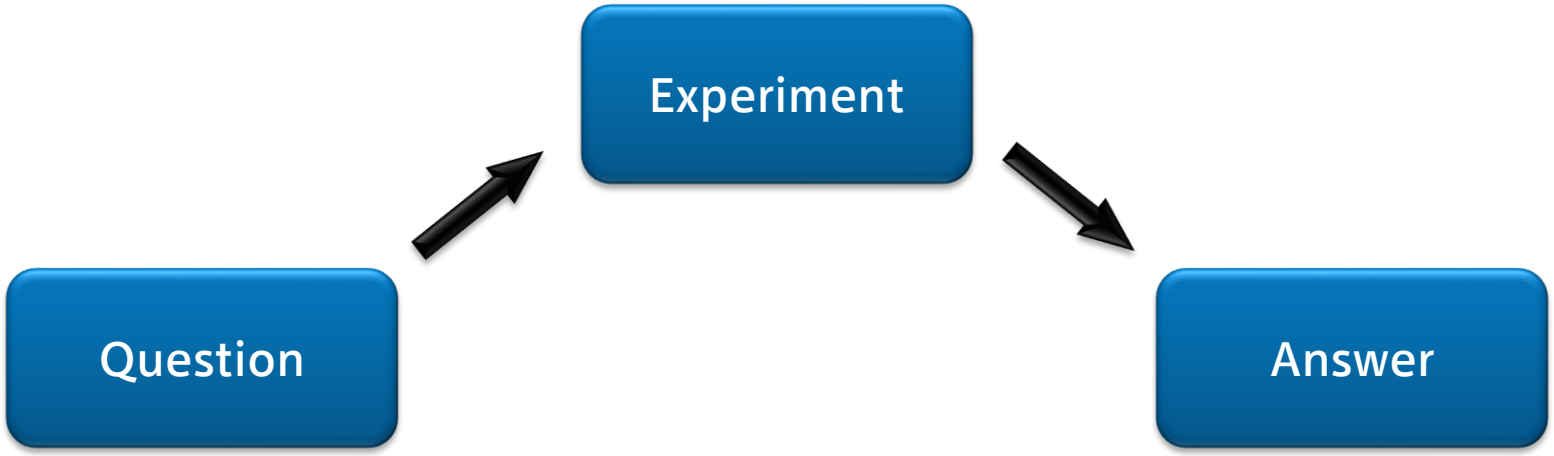

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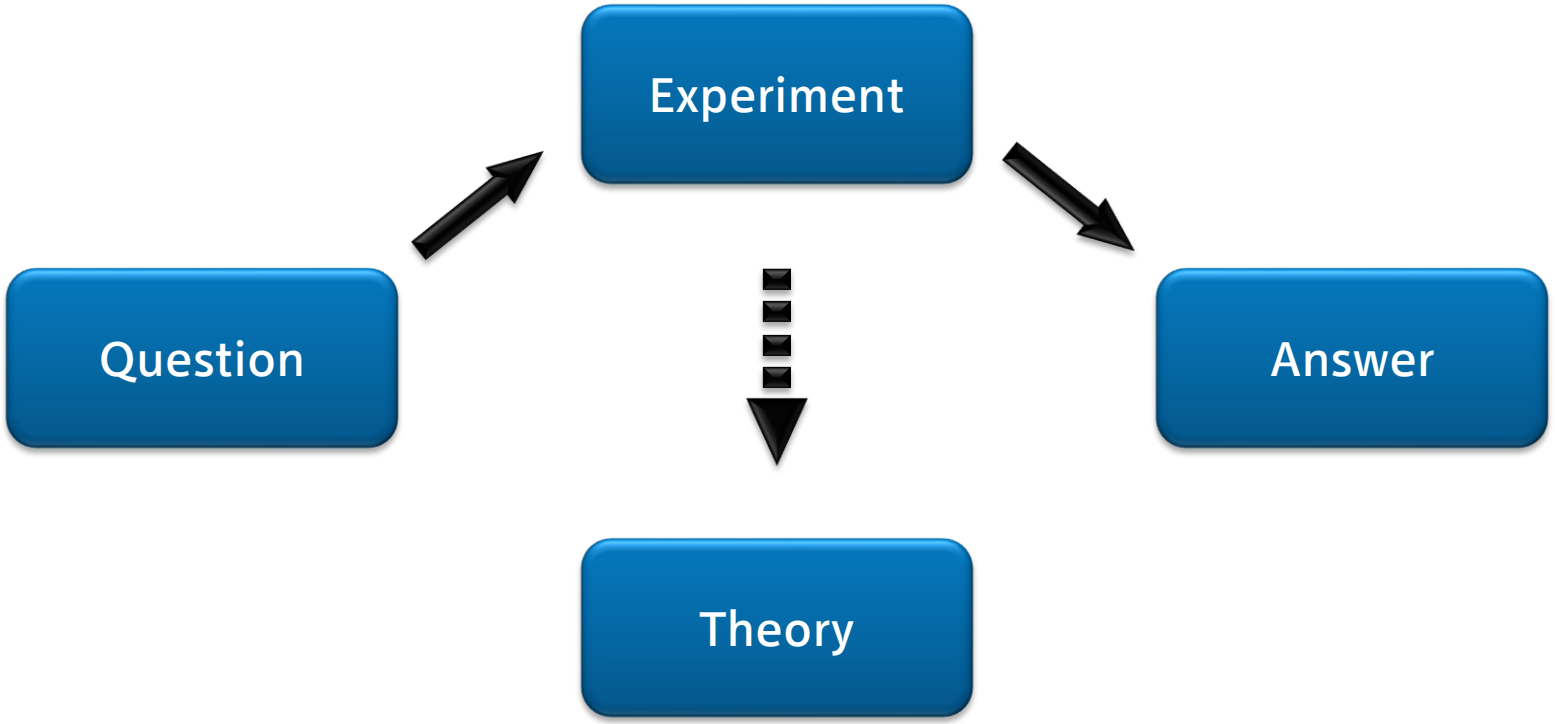

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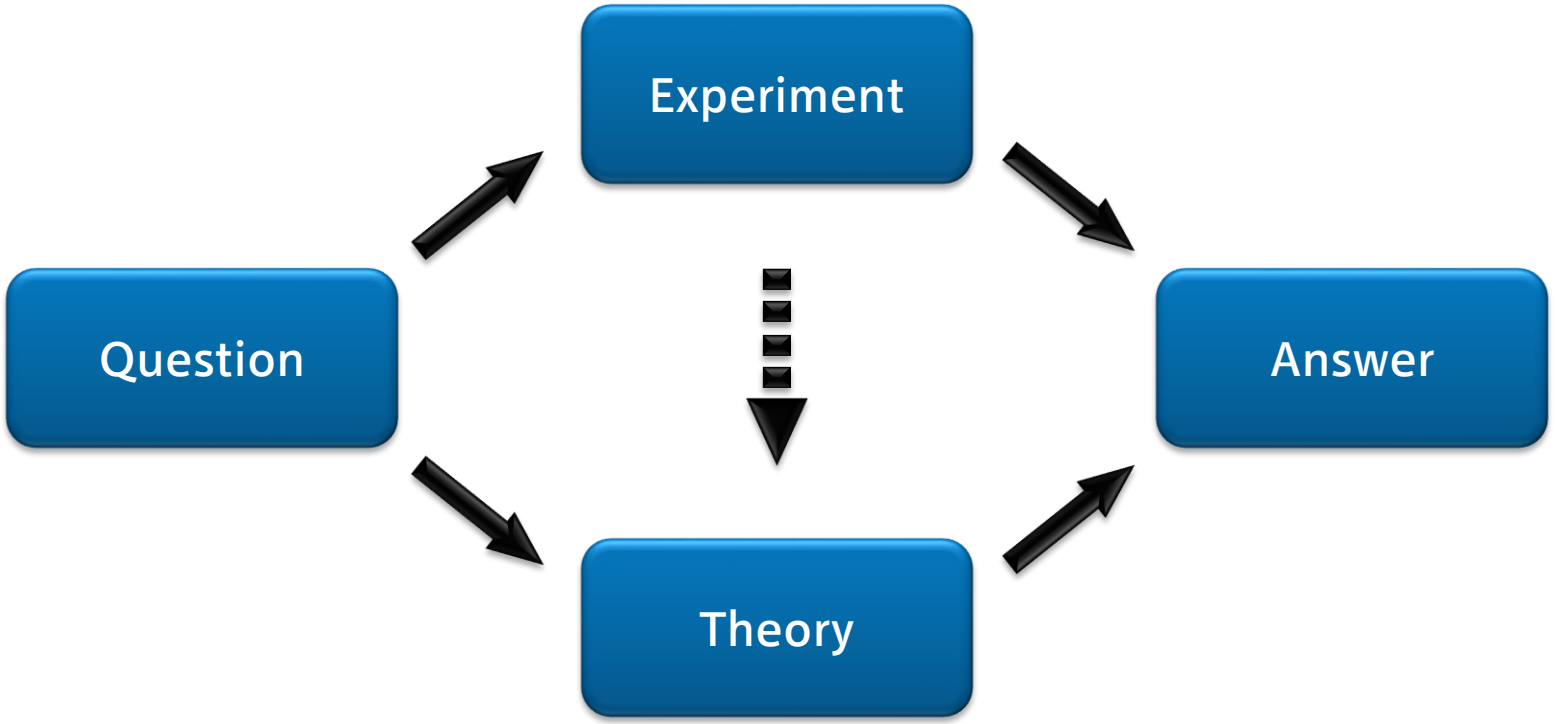

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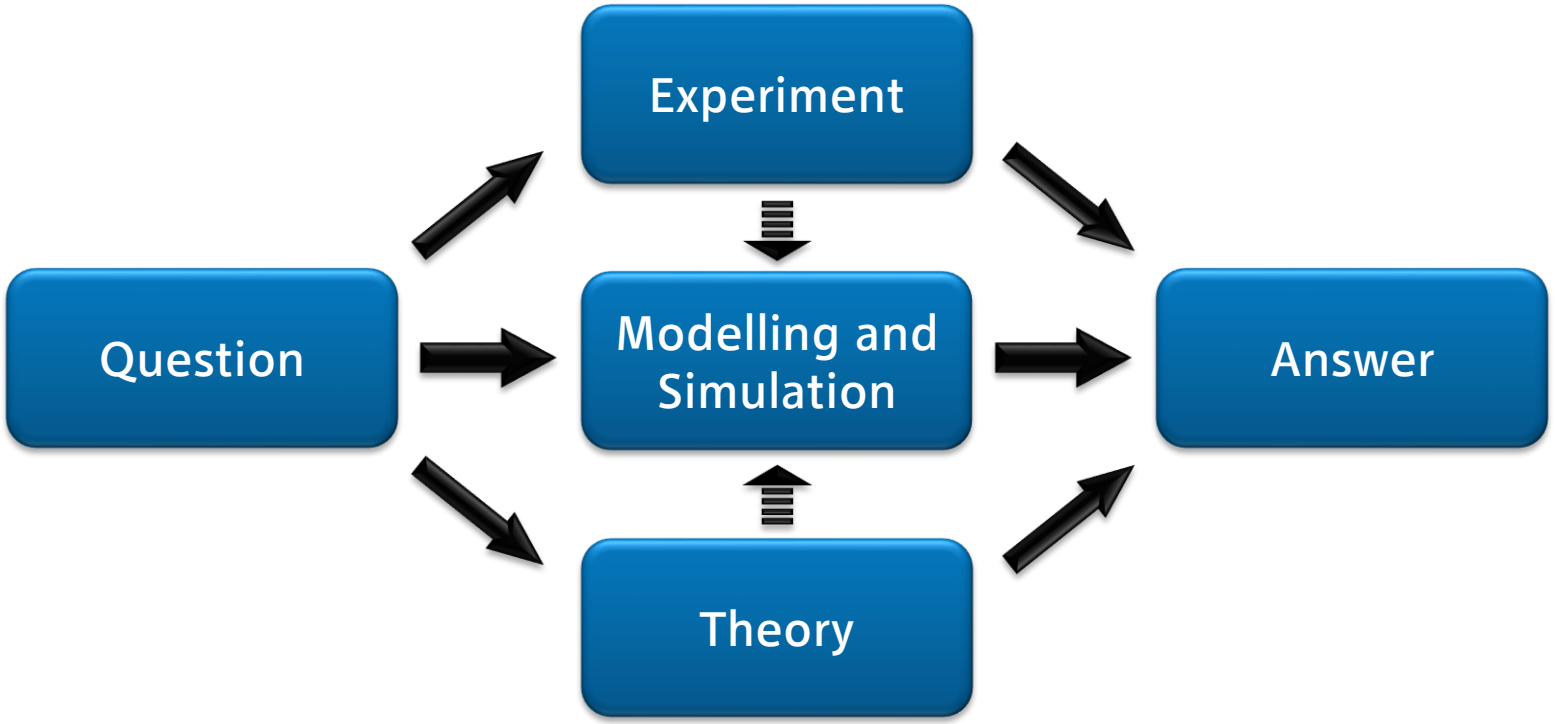
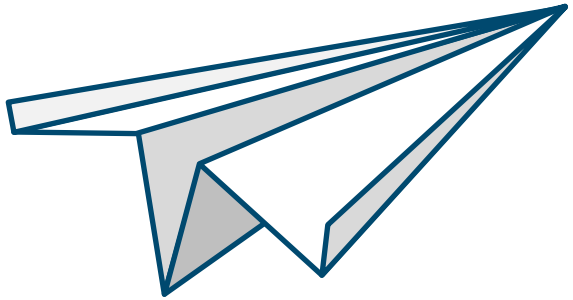


Mathematical Modelling and Simulation
Abstract Example

Does the paper plane fly further than 5m?



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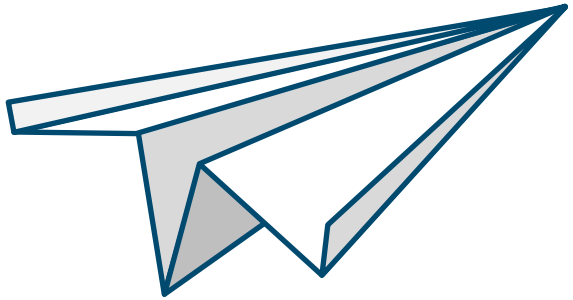
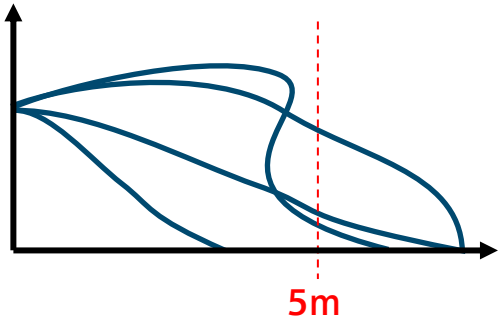


Experiments



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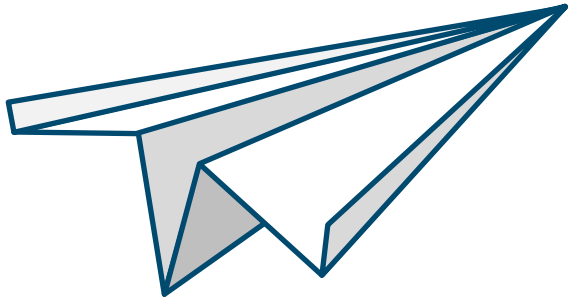

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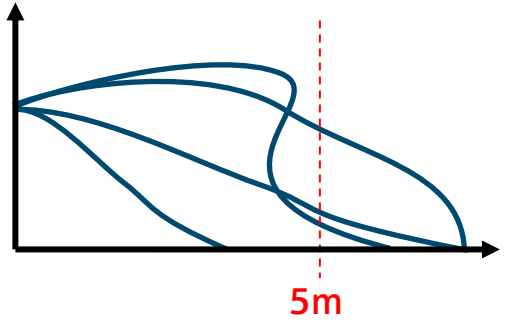

In 80% of all cases.

Mathematical Modelling and Simulation
Abstract Example

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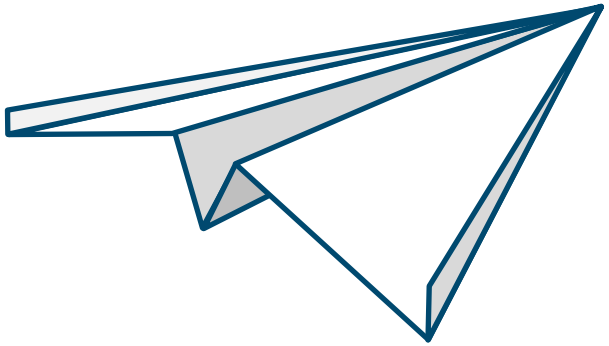

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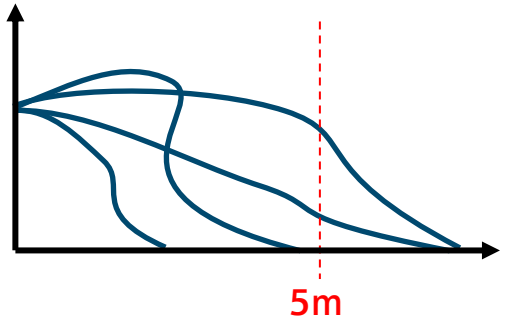

In 70% of all cases.

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Abstract Example

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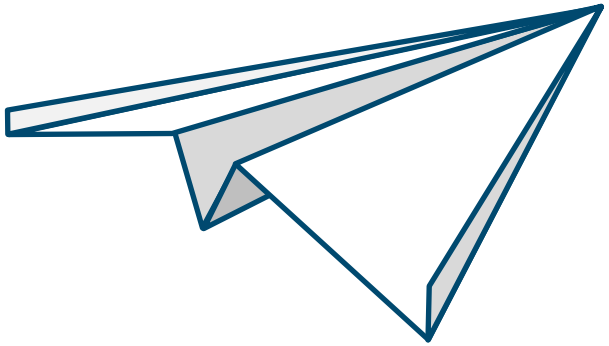

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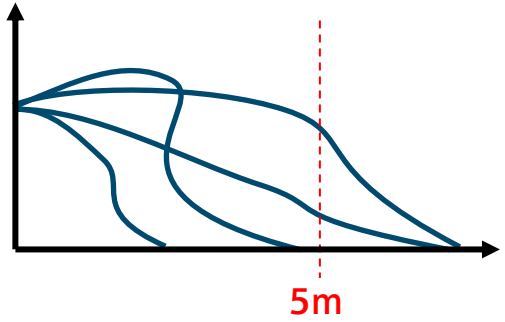

In 70% of all cases.

General Paper Plane Theory:
„Arrow-type paper planes fly ... dependent on their wing span...“

Mathematical Modelling and Simulation
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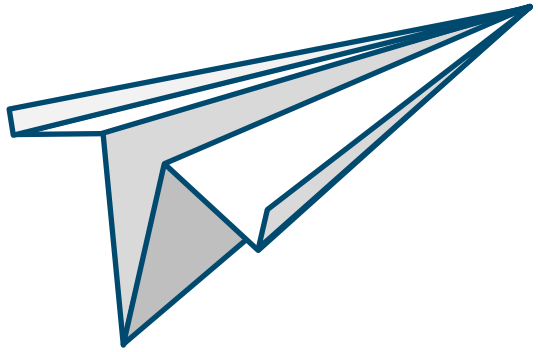

General Paper Plane Theory:
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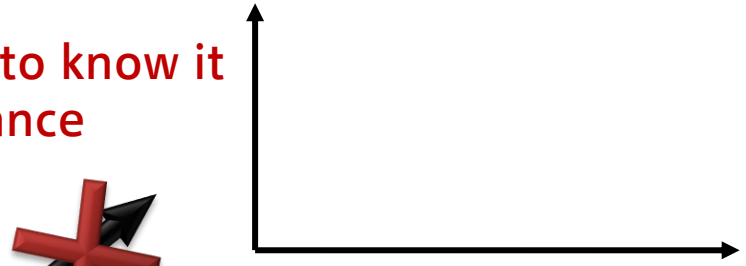
In 90% of all cases.

Mathematical Modelling and Simulation
Abstract Example

I need to know it in advance



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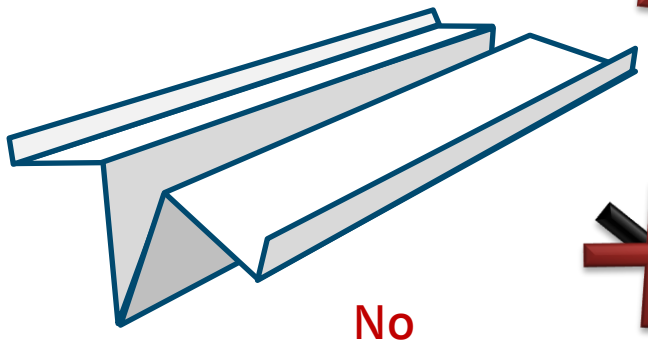

No arrow-type

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Mathematical Modelling and Simulation
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Mathematical Modelling and Simulation
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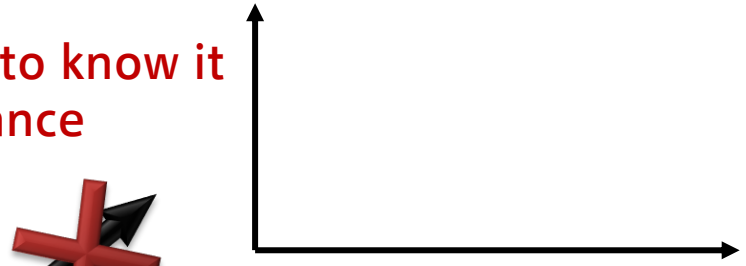

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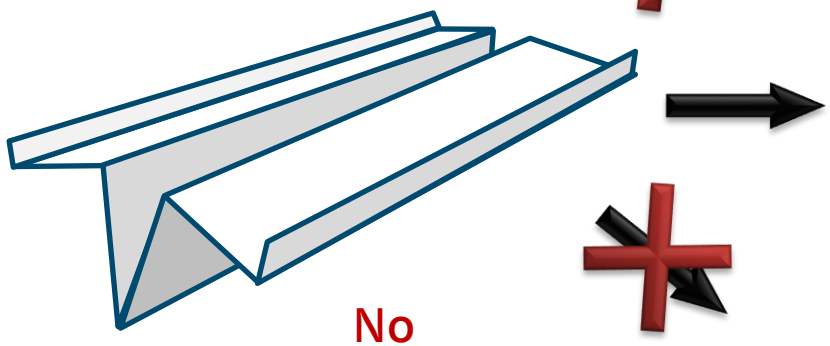

No arrow-type

Mathematical paper plane model

$$e = \frac{u^2}{2} + \frac{p}{\rho} + gz$$

- Findings from „ General Paper Plane Theory“
- Data from experiments
- Additional knowledge like Physikal laws, ...

General Paper Plane Theory:
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Mathematical Modelling and Simulation
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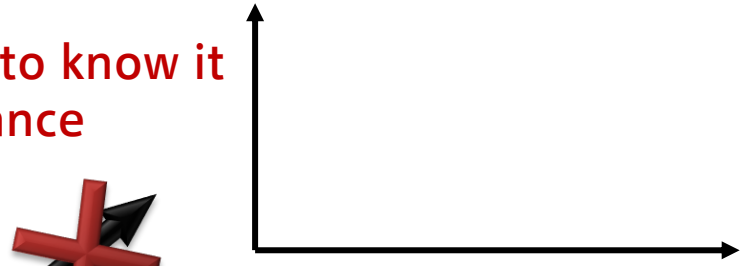

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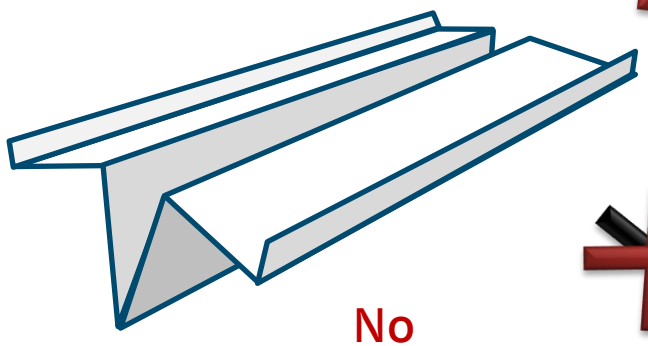

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Mathematical paper plane model

$$e = \frac{u^2}{2} + \frac{p}{\rho} + gz$$

Simulation → In 2% of all cases.

General Paper Plane Theory:
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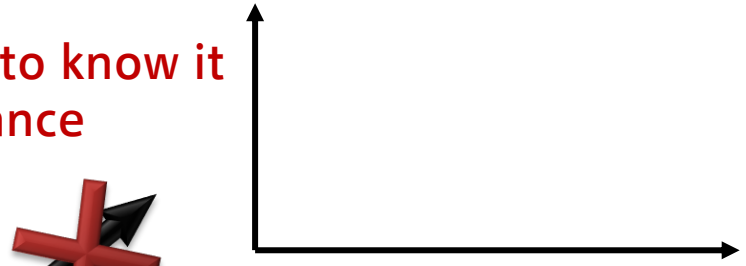

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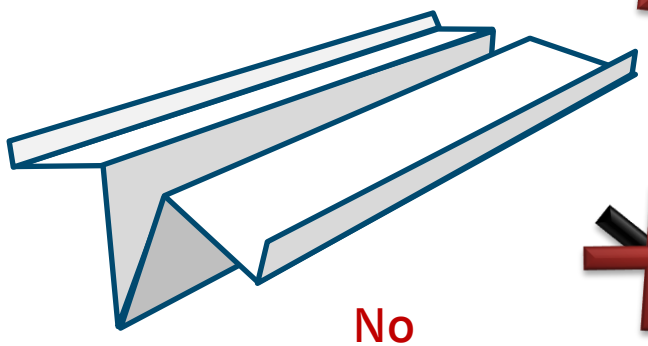

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Mathematical paper plane model

$$e = \frac{u^2}{2} + \frac{p}{\rho} + gz$$

Simulation

→ In 2% of all cases... probably

Model Uncertainty:

- Previous knowledge cannot be used directly
- Impossible to model all influence factors
- ...

General Paper Plane Theory:
„Arrow-type paper planes fly ... dependent on their wing span...“

Mathematical Modelling and Simulation
COVID-19

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How is SARS-CoV-2 going to spread in Austria? What consequences will the epidemic of COVID-19 have on the population?

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COVID-19

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- Italy ≠ Austria

Unintentional „experiments“: data from countries in which the virus has started spreading earlier

How is SARS-CoV-2 going to spread in Austria? What consequences will the epidemic of COVID-19 have on the population?

- SARS CoV-2 ≠ Influenza

General knowledge about Influenza, other corona viruses, and the health care system

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COVID-19 simulation model

e.g.:

$$S' = -\alpha IS$$
$$I' = \alpha IS - \beta I$$
$$R' = \beta I$$

- Information / data from countries with more „COVID-19 experience“
- General knowledge about the spread of infectious diseases in Austria
- Additional causal knowledge about the spread of infectious diseases (SIR)

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COVID-19

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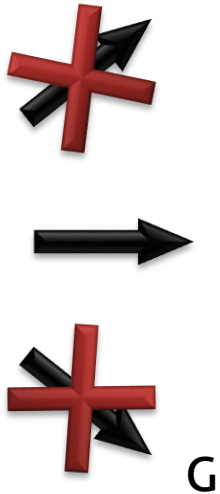

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Model Uncertainty ?

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Short introduction into

EPIDEMIOLOGICAL MODELS

What are the secrets behind epidemiological models?

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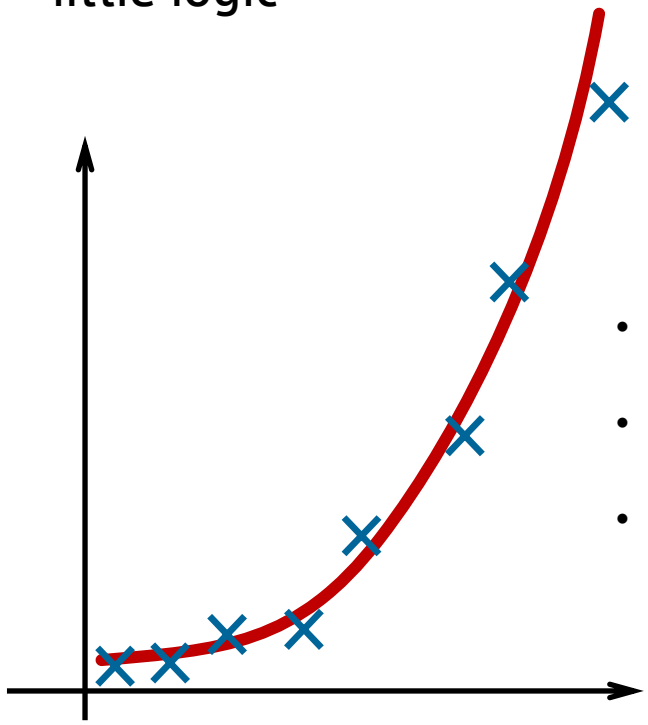
data based models

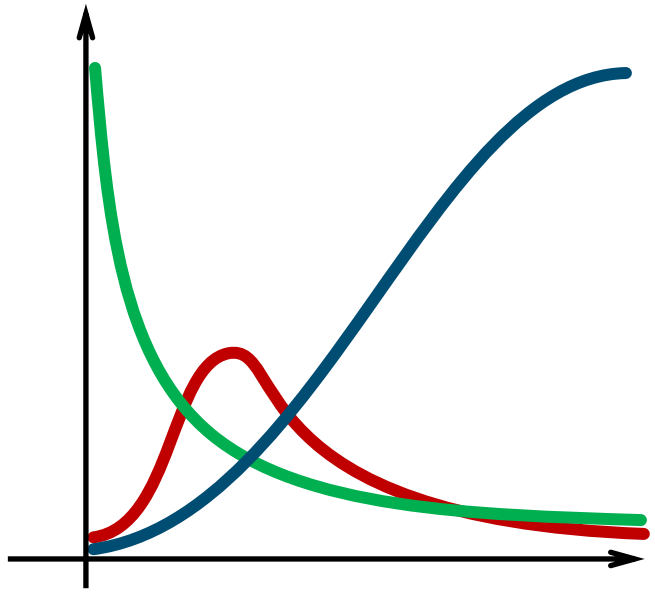
- much data
- little logic



- extrapolation of current trends
- good fit of current numbers
- statistical methods, machine learning, ...

causal models

- (a little bit) less data
- much logic



- good qualitative forecasting capabilities
- Status quo more difficult to fit
- uses meta information about the system

What are the secrets behind epidemiological models?

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data based models

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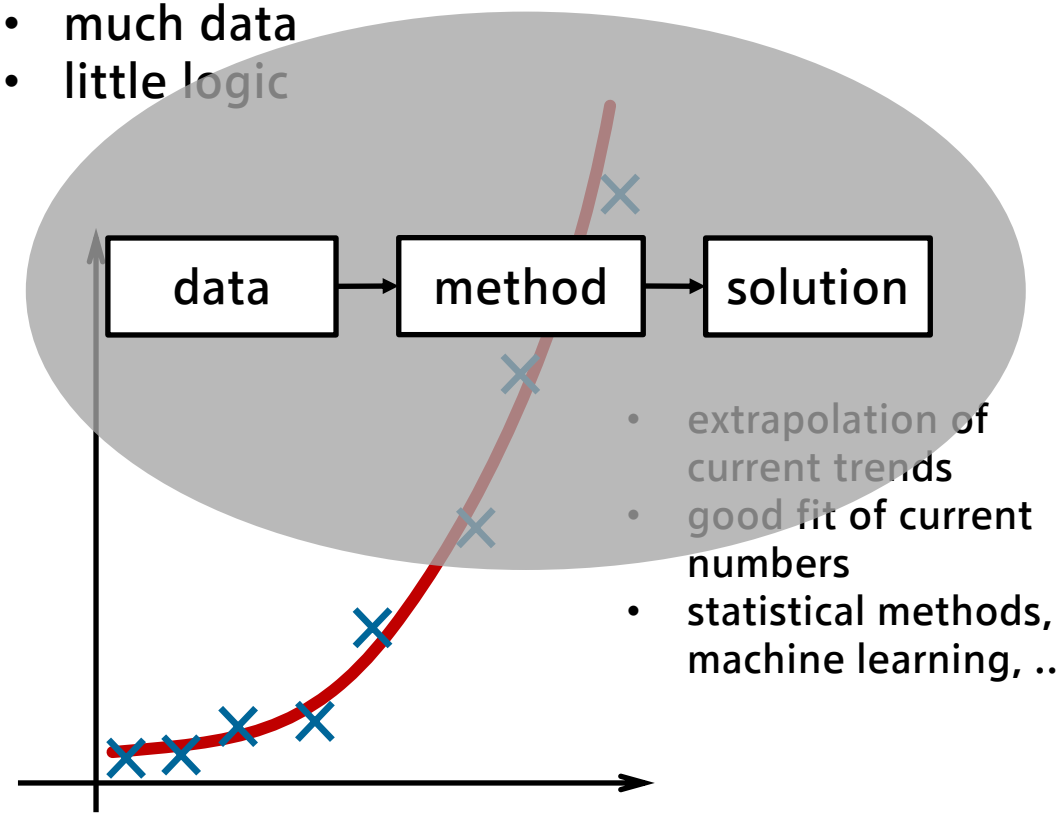

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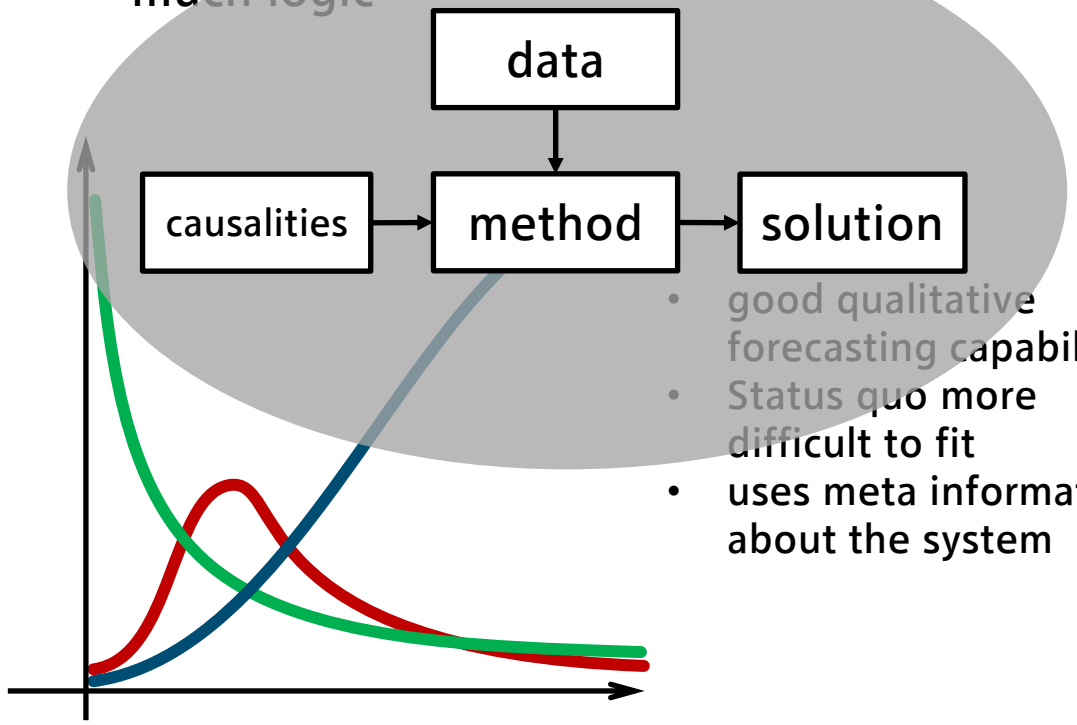

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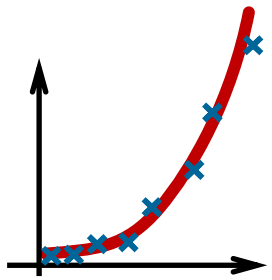
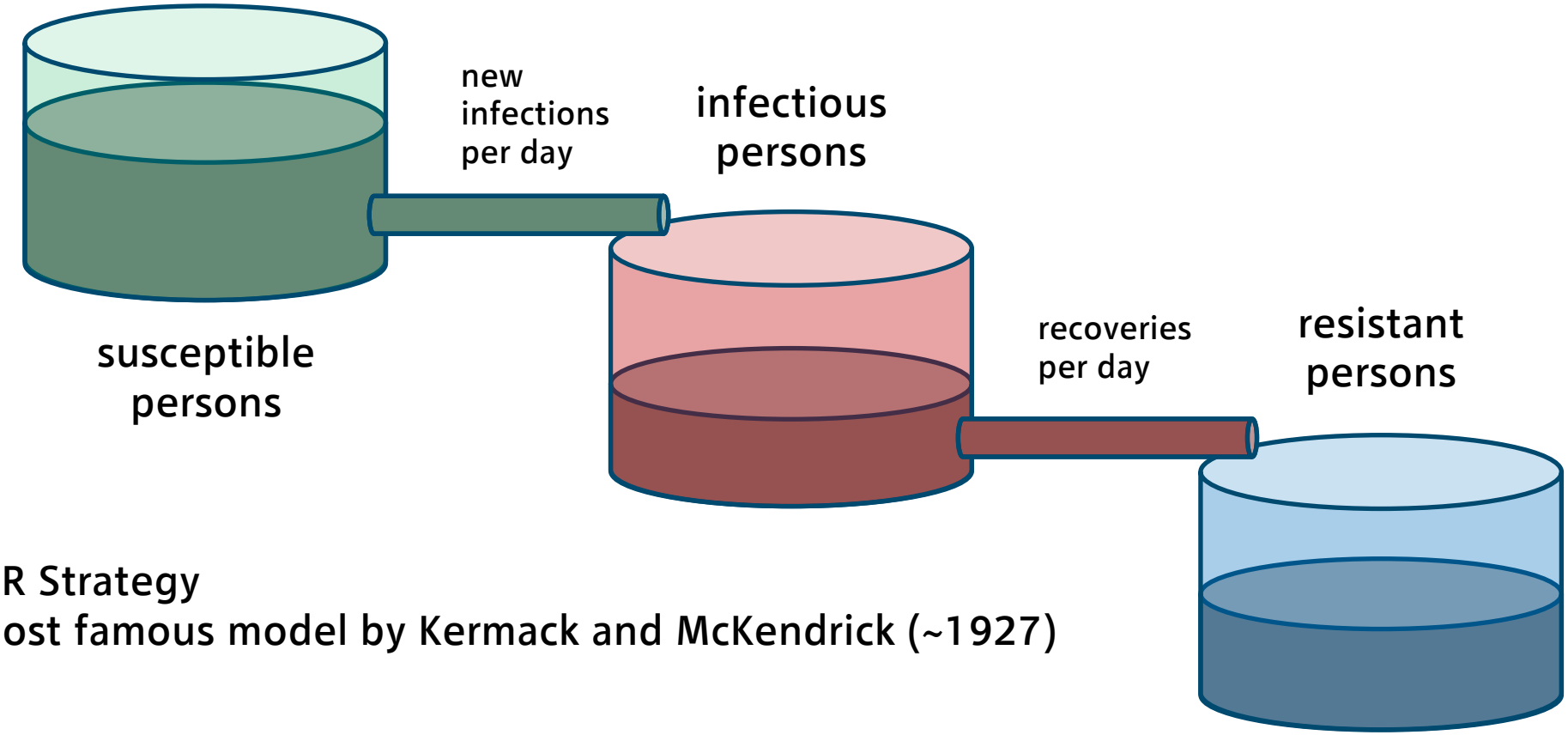


causal models

macroscopic/aggregated models



- SIR Strategy
- Most famous model by Kermack and McKendrick (~1927)

What are the secrets behind epidemiological models?

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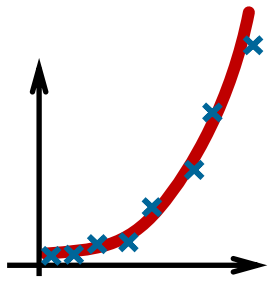
data-based models



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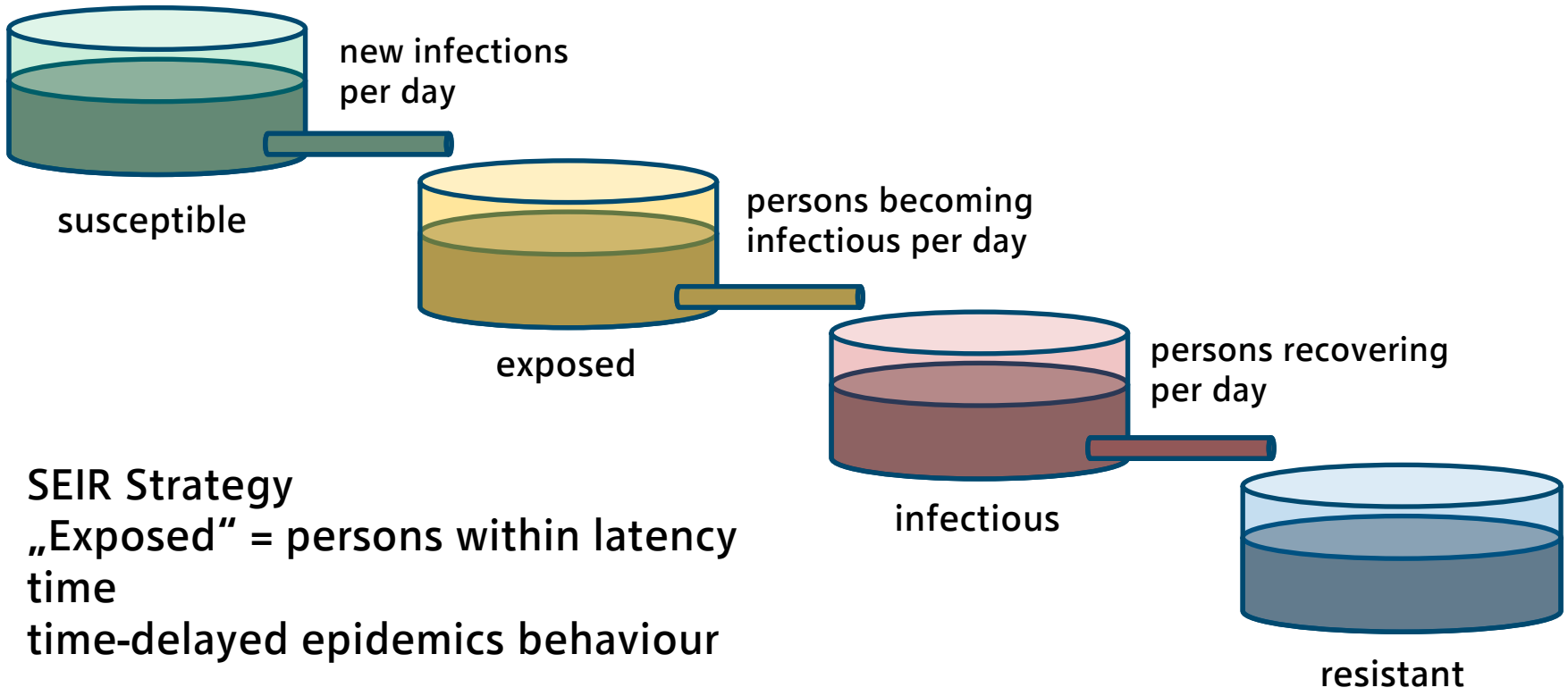

- SEIR Strategy
- „Exposed“ = persons within latency time
- time-delayed epidemics behaviour

What are the secrets behind epidemiological models?

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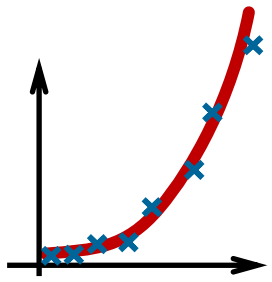
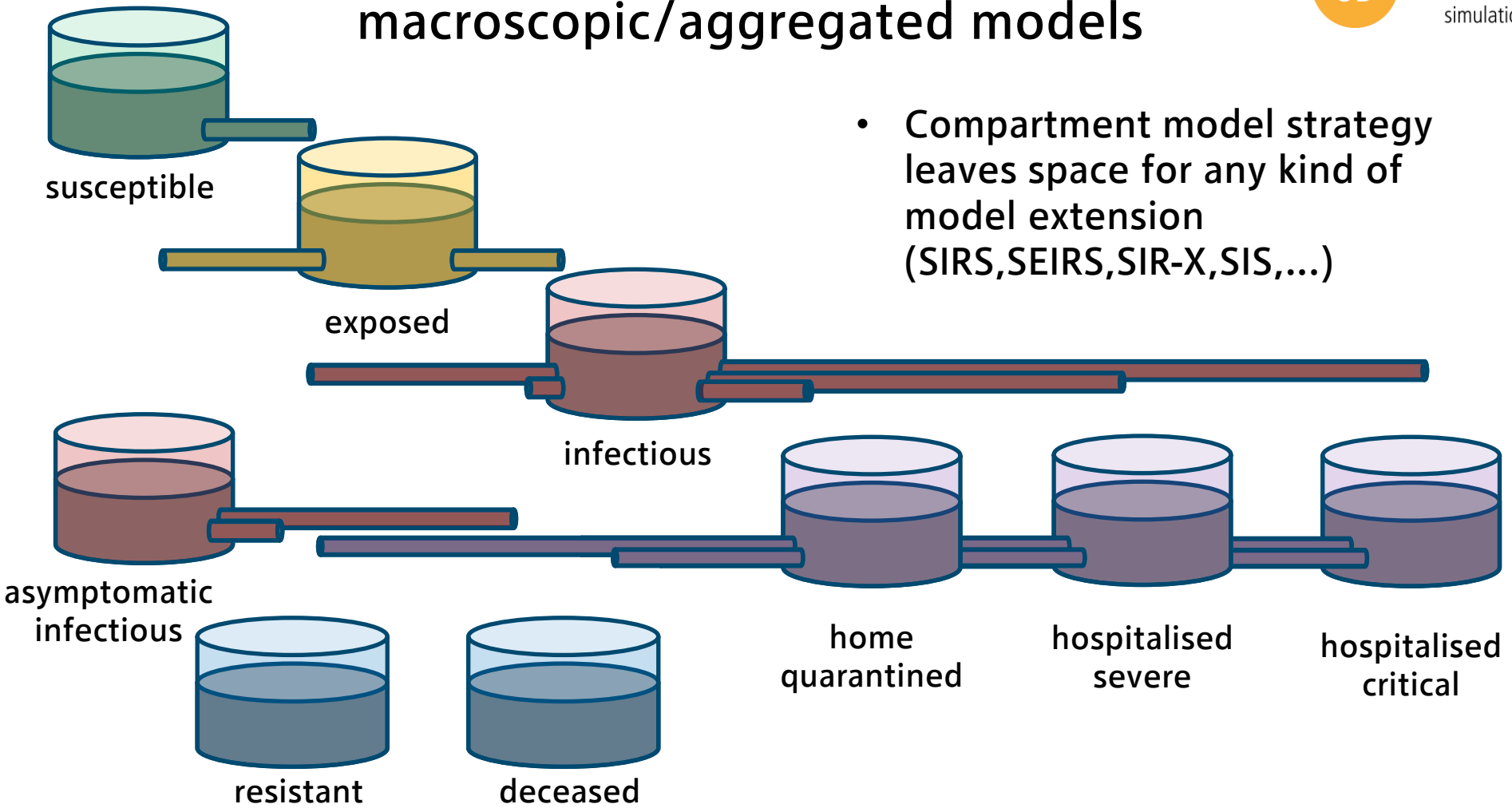
data-based models



macroscopic/aggregated models

- Compartment model strategy leaves space for any kind of model extension (SIRS,SEIRS,SIR-X,SIS,...)



What are the secrets behind epidemiological models?

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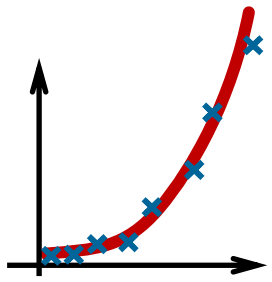

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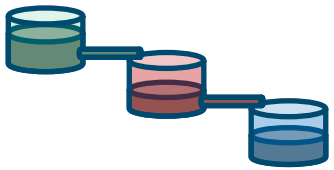
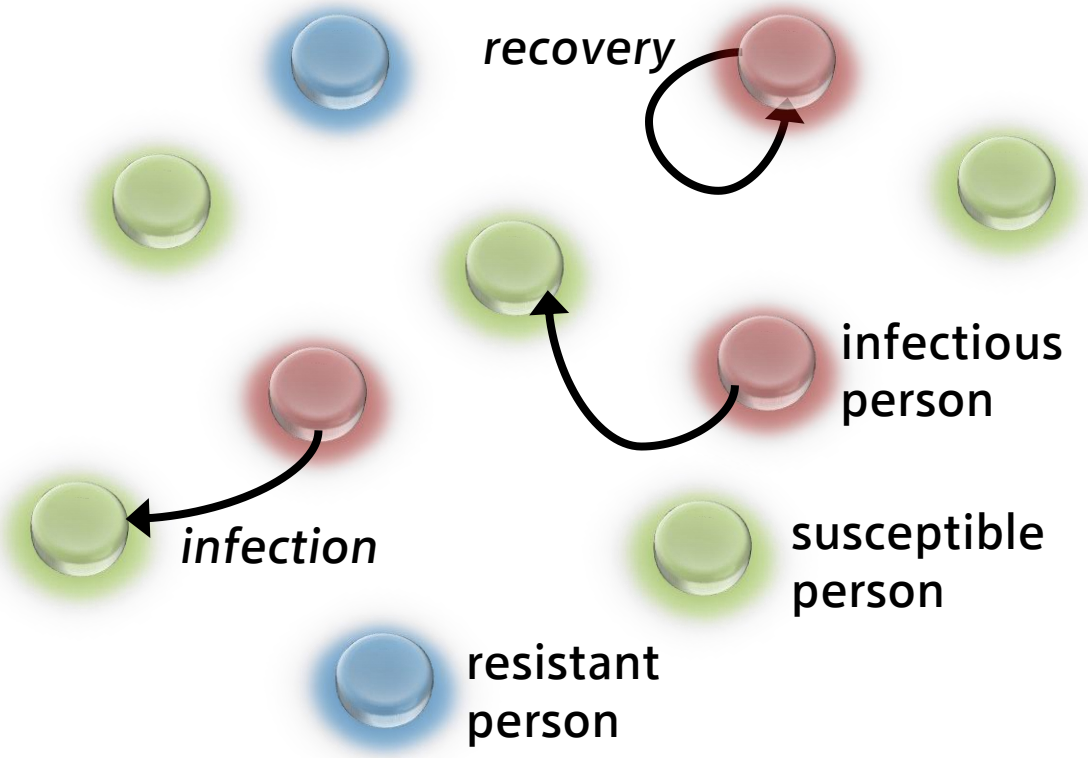
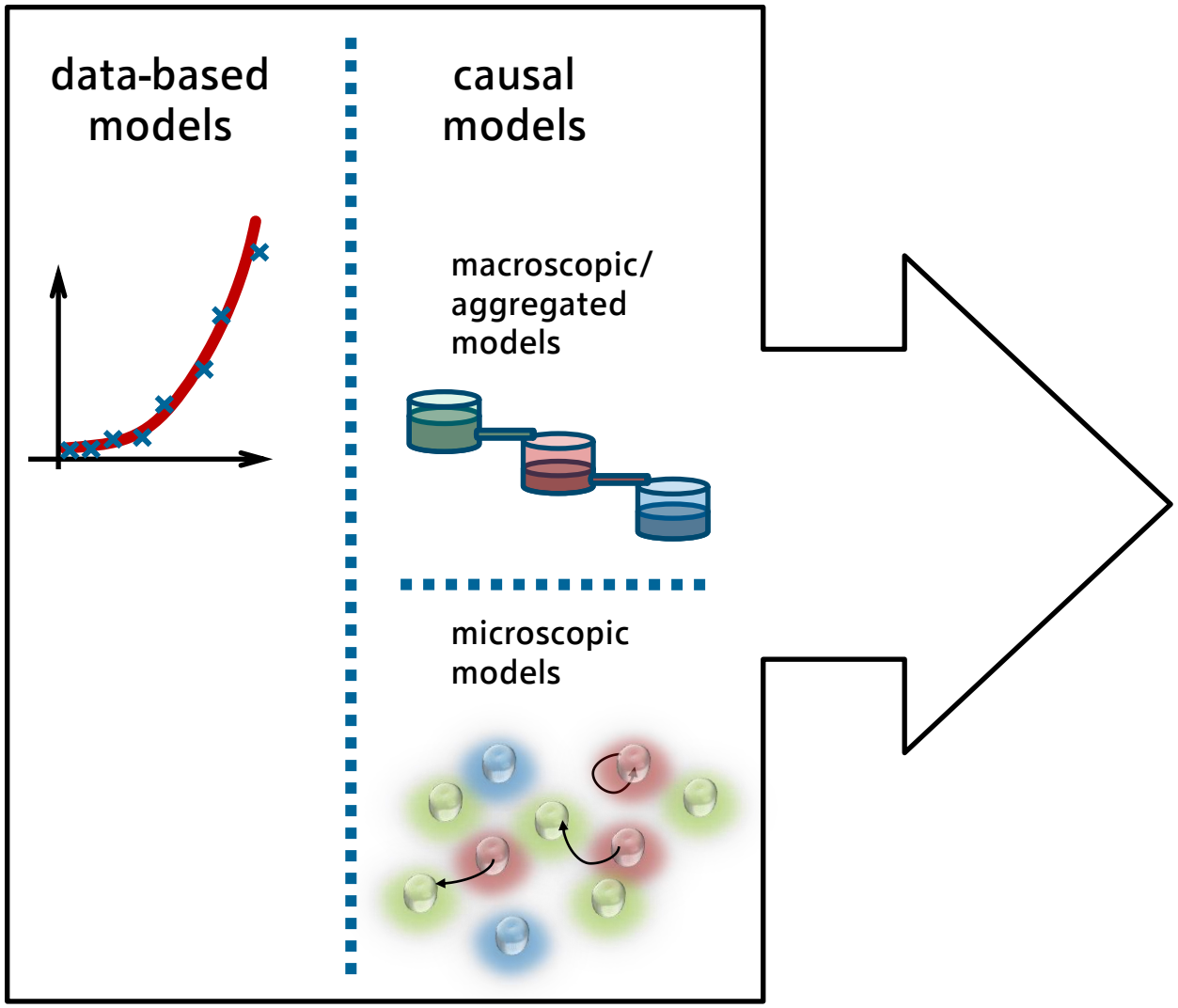


microscopic models (microsimulations)



- agent-based models
- Markov Models
- DES Models

What are the secrets behind epidemiological models?



- ***„No-Free-Lunch“***
  All model types have advantages and disadvantages

- ***Every model is developed for a certain purpose***
  It should only be used for this purpose and only within its range of validity

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COVID-19 Model

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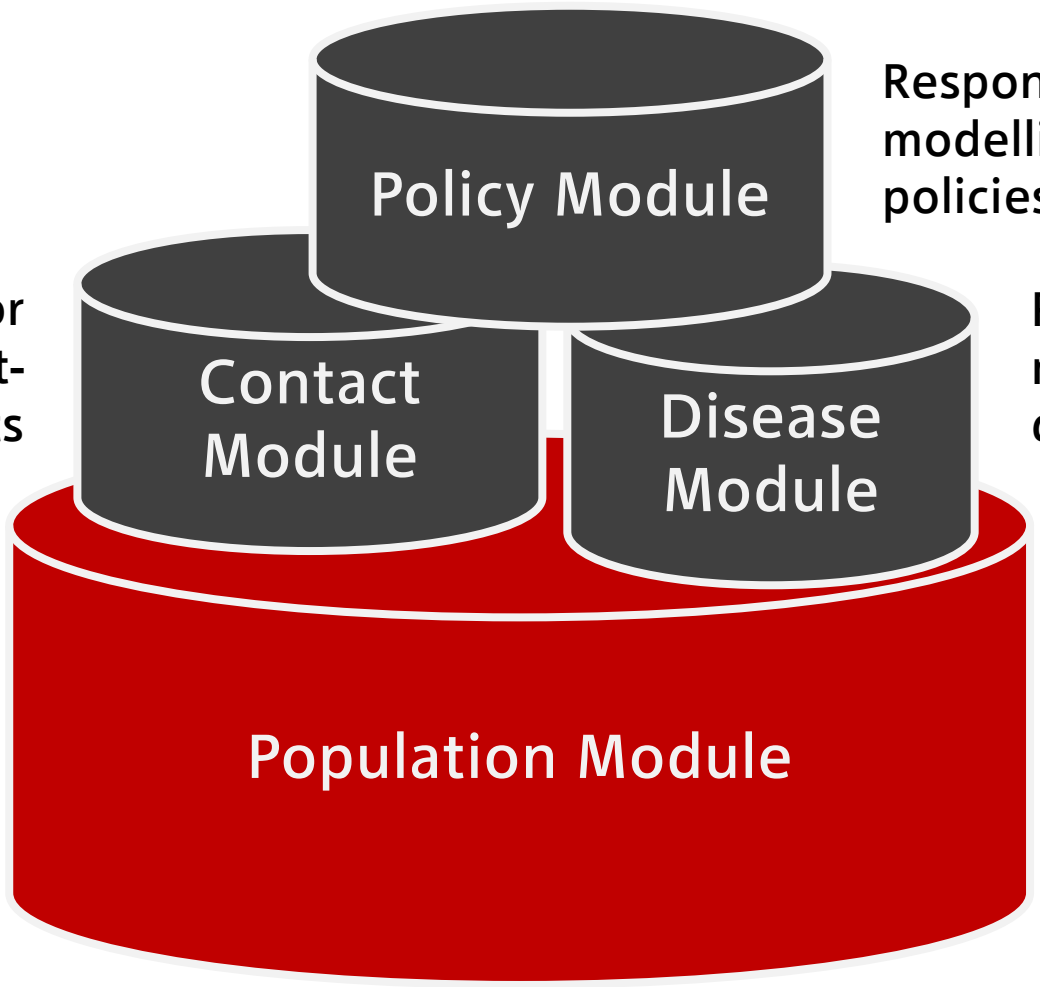

Responsible for modelling of policies

Responsible for creating agent-agent contacts

Responsible for modelling the disease progression

Responsible for creating and managing agents as well as death and birth processes

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COVID-19 Model

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Key concept:
Every real inhabitant is repesented by a statistically representative virtual inhabitant (a so called agent)

Sampling

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COVID-19 Model

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Sampling

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COVID-19 Model

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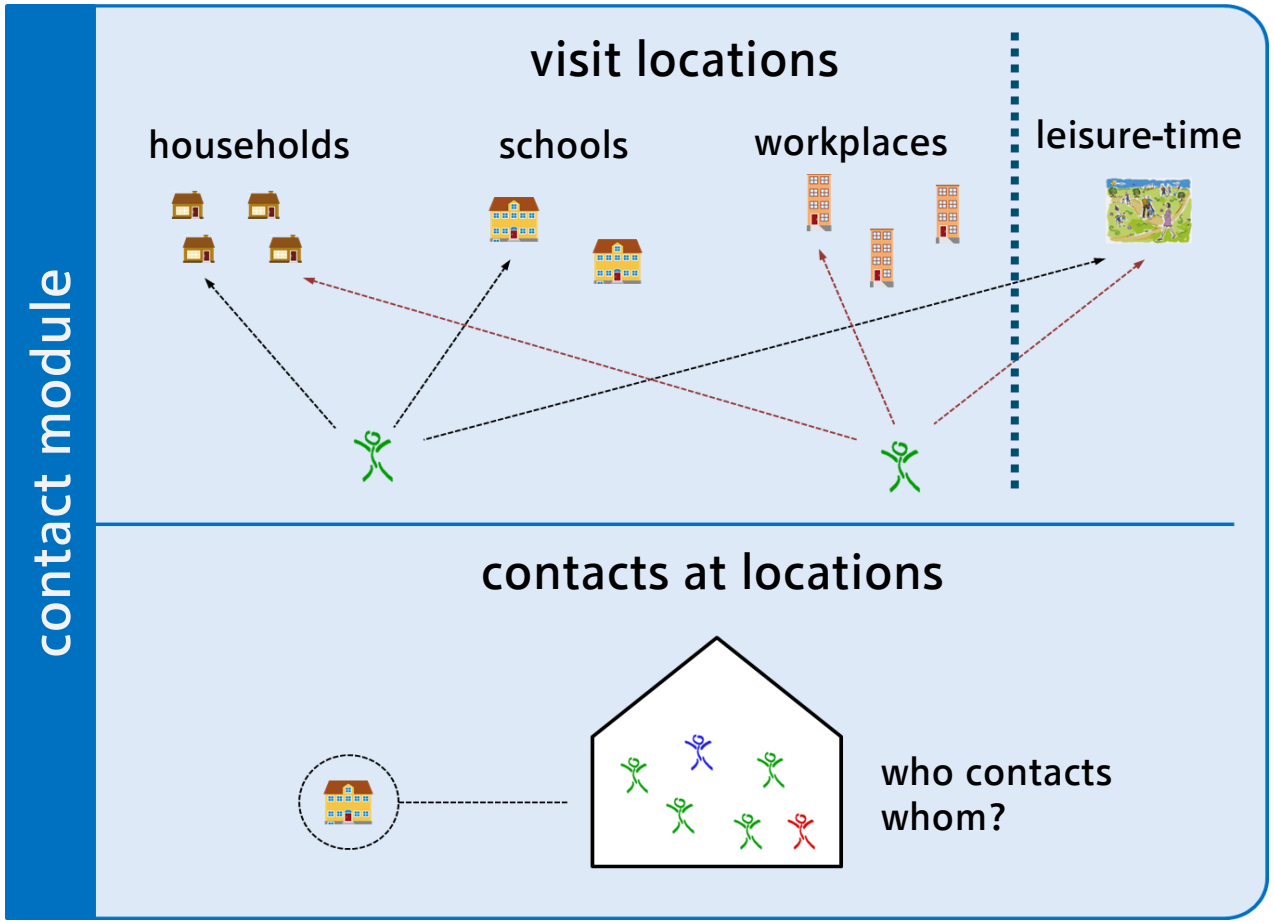
- Contacts between agents are not direct but **agent-location-agent** contacts
- Location types: **households, schools, workplaces**
- Additonal **agent-agent** leisure time contacts



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COVID-19 Model

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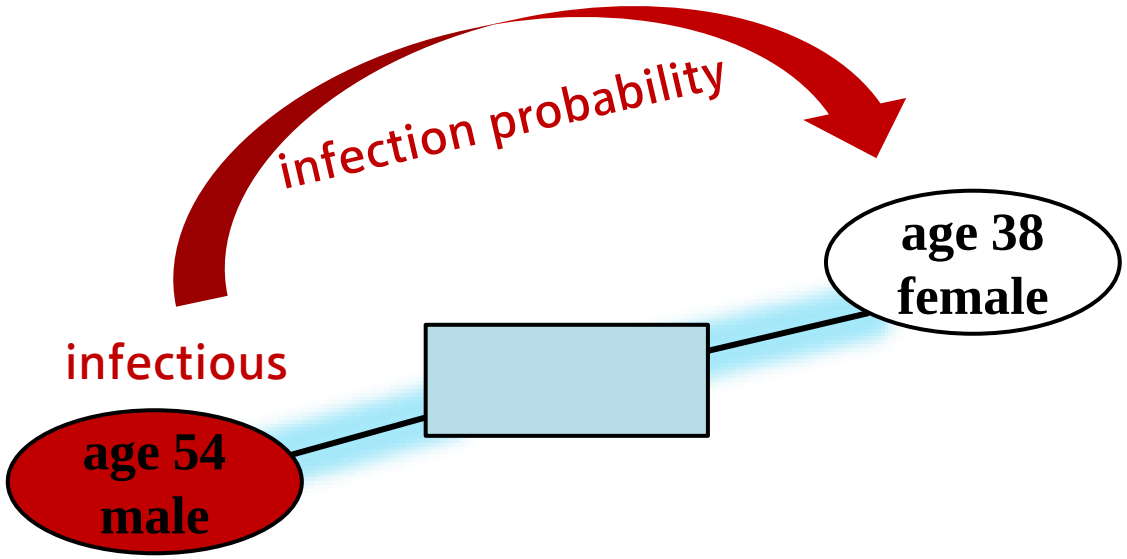
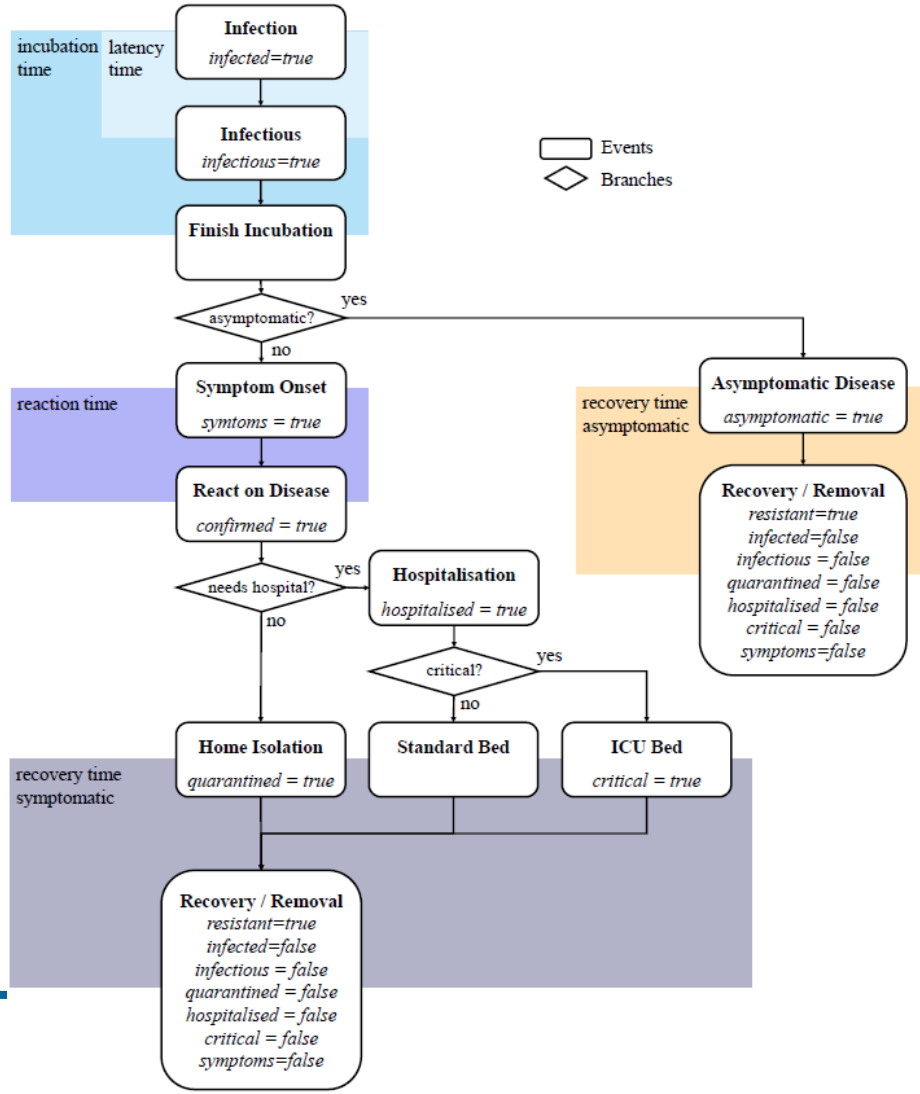
- Disease progression is handled in form of a flow-chart
- Each agent uses is own discrete-event simulator





How about uncertainty?

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Unintentional „experiments“: data from countries in which the virus has started spreading earlier

How is SARS-CoV-2 going to spread in Austria? What consequences will the epidemic of COVID-19 have on the population?

COVID-19 simulation model

e.g.:

$$S' = -\alpha IS$$
$$I' = \alpha IS - \beta I$$
$$R' = \beta I$$

- Information / data from countries with more „COVID-19 experience“
- General knowledge about the spread of infectious diseases in Austria
- Additional causal knowledge about the spread of infectious diseases (SIR)

- SARS CoV-2 ≠ Influenza

General knowledge about Influenza, other corona viruses, and the health care system

Model Uncertainty ?

How about uncertainty?

Mathematical Modelling and Simulation

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Model Uncertainty

Model Errors.

- Every model is a simplified version of reality:
  potentially important mechanisms might not included or insuffiently known

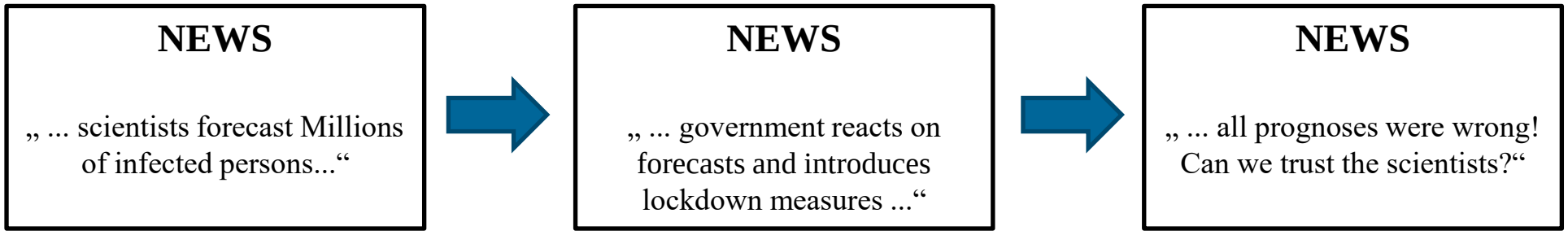
Data Errors

- All data sources for COVID-19 are heavily biased

Forecast Uncertainty

Feedback Loop.

- Every forecasts is only valid for a system that does not change
- Even published forecasts might change the system behaviour



Summary

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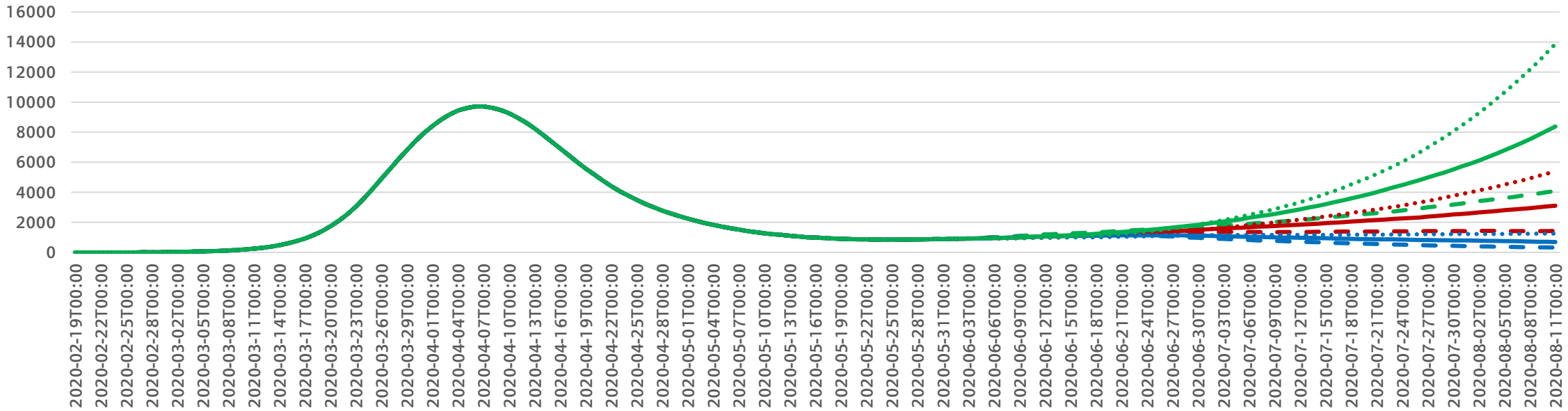
Though the uncertainty is huge, computer models and simulations are currently our only way to get an idea of what lies ahead of us.
Consequently they are and will remain a vital element for decision support of COVID-19 policy makers



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Modelling the spread of SARS-CoV-2:

How reliable are simulated forecasts?

Thank you for your attention

Dr. Martin Bicher [1,2]

[1]TU Wien, Institute for Information Systems Engineering
[2]dwh GmbH, dwh simulation