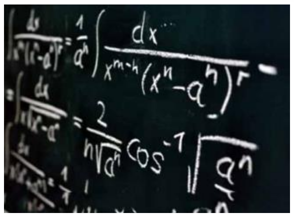
De verspreiding van COVID-19 begrijpen: de rol van AI

Robert Kooij

2 November 2020

Who am I ?

TU Delft



1988 - 1993

1994 - 1996

kpn

Royal Dutch Telecom

1997 - 2003

TNO 2003 - 2018

TU Delft 2005 - ...

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN 2018 - 2020

Do you know who this is?

- Prof. Neil Ferguson
  - Mathematical epidemiologist at Imperial College London
  - Scientific Advisor to UK Government

16 March 2020 *Imperial College COVID-19 Response Team*

Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand

Neil M Ferguson, Daniel Laydon, Gemma Nedjati-Gilani, Natsuko Imai, Kylie Ainslie, Marc Baguelin, Sangeeta Bhatia, Adhiratha Boonyasiri, Zulma Cucunubá, Gina Cuomo-Dannenburg, Amy Dighe, Ilaria Dorigatti, Han Fu, Katy Gaythorpe, Will Green, Arran Hamlet, Wes Hinsley, Lucy C Okell, Sabine van Elsland, Hayley Thompson, Robert Verity, Erik Volz, Haowei Wang, Yuanrong Wang, Patrick GT Walker, Caroline Walters, Peter Winskill, Charles Whittaker, Christl A Donnelly, Steven Riley, Azra C Ghani.

Prediction: based upon mathematical models

No action taken → 500.000 deaths in UK!

MATHEMATICS

exponential growth

R_0

the R-number

moving averages

flattening the curve

Importance of understanding spread

- Intervention policy
- Healthcare allocation
- Economic impact
- Mental well-being

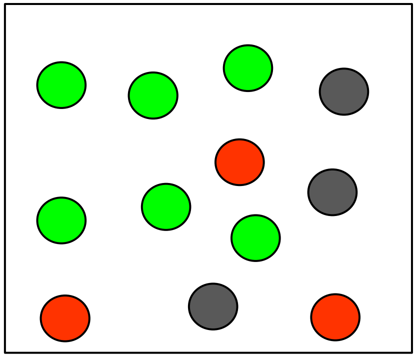
Two types of approaches

- Approach 1: Compartmental models
  - Population divided into categories

- Equation based

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

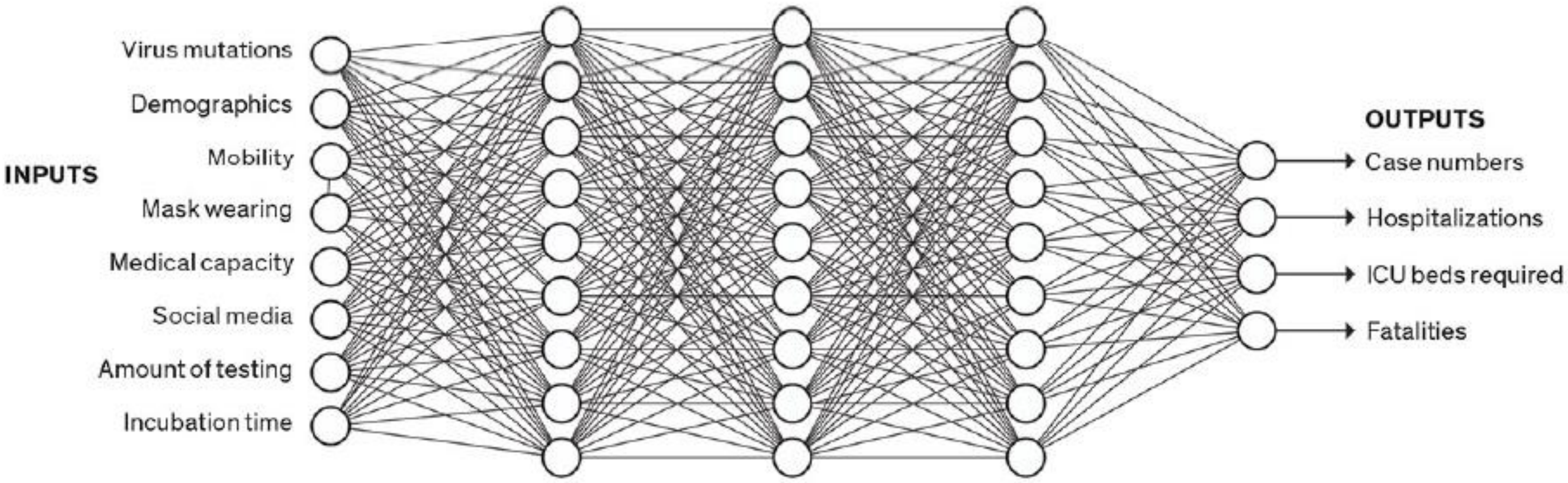
- Agent based



TU Delft

Two types of approaches

- Approach 2: AI-driven models



Overview

- Compartmental models: Equation Based
- Compartmental models: Agent Based
- AI-driven models
- Comparing the approaches
- Equation based approach on networks
- TU Delft COVID-19 Digital Campus
- Wrap-up

Compartmental models: equation based

- **SIR - model**

- No births or immigration
- Curing leads to immunity
- Fixed infection rate per day: β
- Fixed recovery time: $1/\gamma$
- People are well-mixed

Compartmental models: equation based

- S: fraction of population that is **Susceptible**
- I: fraction of population that is **Infected**
- R: fraction of population that is **Removed**

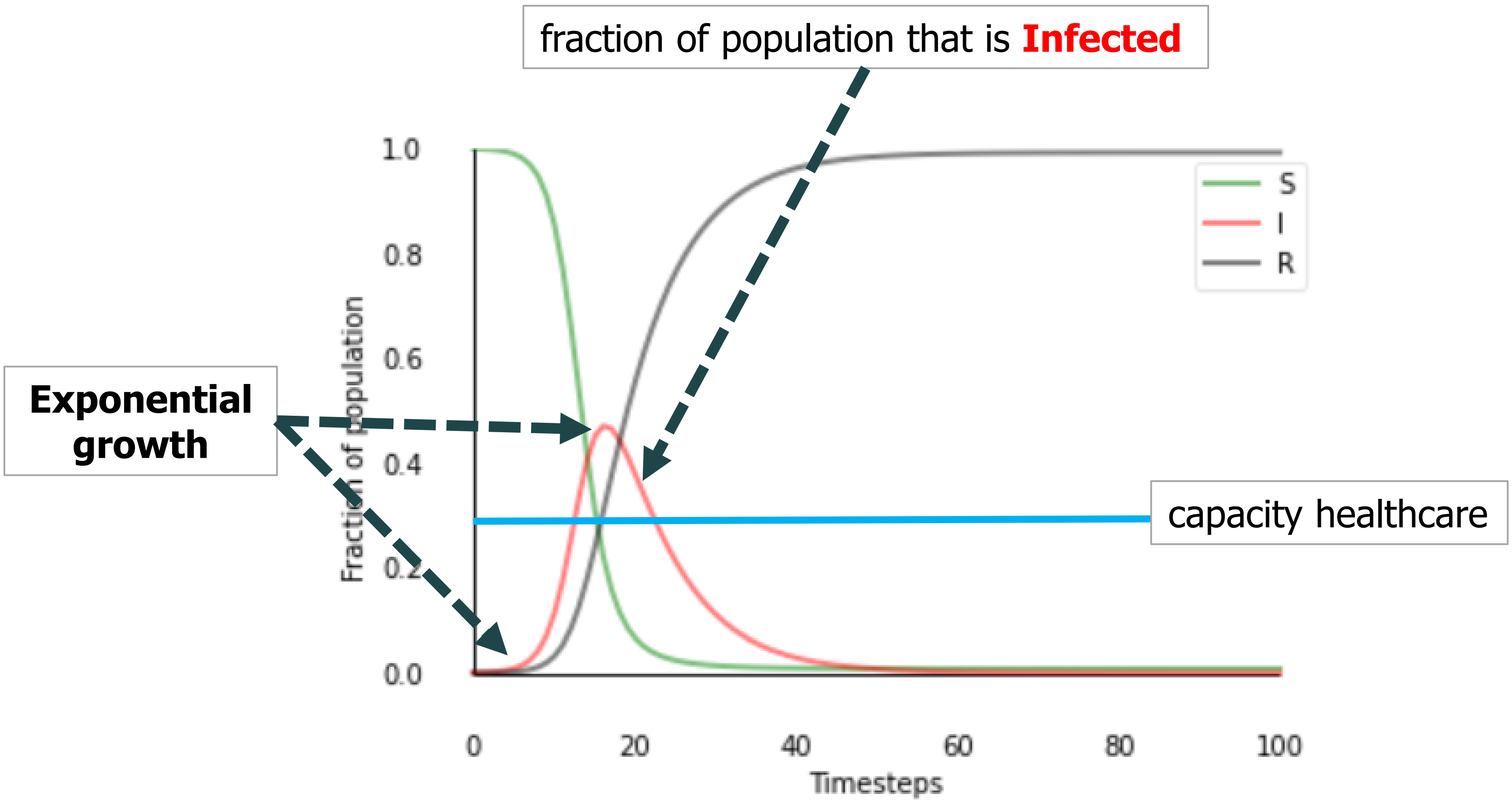
$$\frac{d\boldsymbol{S}}{dt} = -\beta \boldsymbol{S}\boldsymbol{I}$$

$$\frac{d\boldsymbol{I}}{dt} = -\gamma \boldsymbol{I} + \beta \boldsymbol{S}\boldsymbol{I}$$

$$\frac{d\boldsymbol{R}}{dt} = \gamma \boldsymbol{I}$$

W.O. Kermack and A.G. McKendrick, 1927, A contribution to the mathematical theory of epidemics, Proc. R. Soc. Lond. A, 115, 700–721.

Compartmental models: equation based



Compartmental models: equation based

- Growth governed by R_0: **basic reproduction number**
- R_0: # of new infections due to first infection
  - $R_0 > 1$ exponential growth # of infections
  - $R_0 = 1$ # of infections stays constant
  - $R_0 < 1$ # of infections decreases fast to 0
- **Flattening the curve**: lowering R_0

Compartmental models: equation based

$$R_0 = \frac{\beta}{\gamma} = p \cdot c \cdot \frac{1}{\gamma}$$

Probability of infection per contact

Number of contacts per day

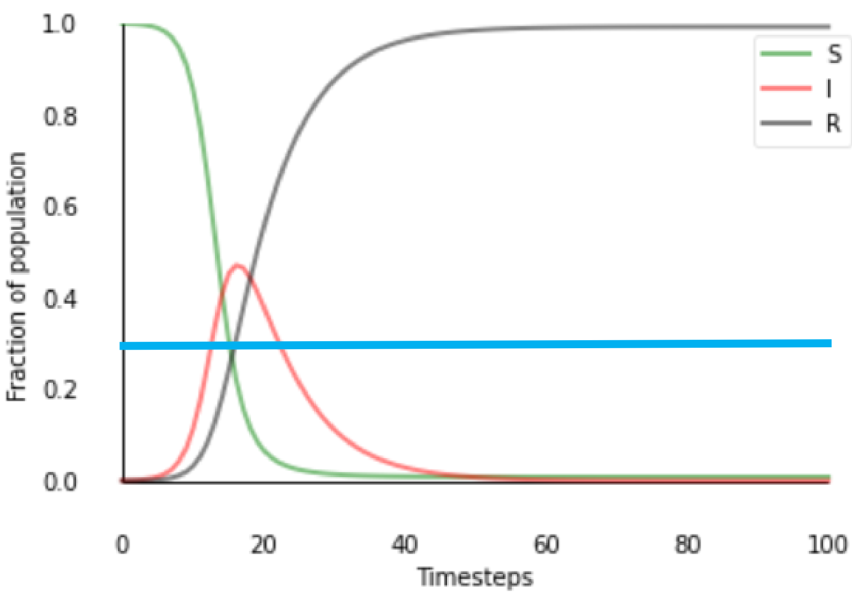
Duration of infection

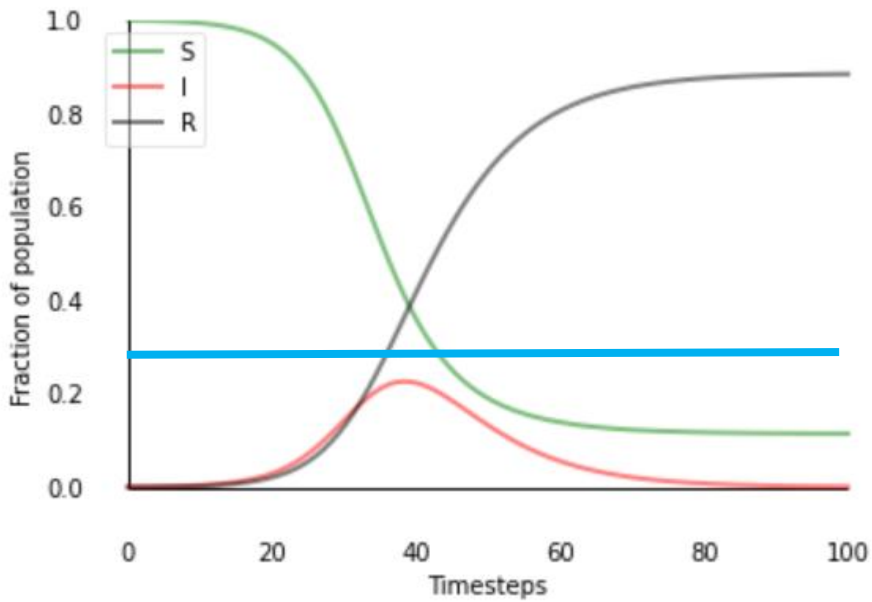
Mask wearing

Social distancing

Better treatment

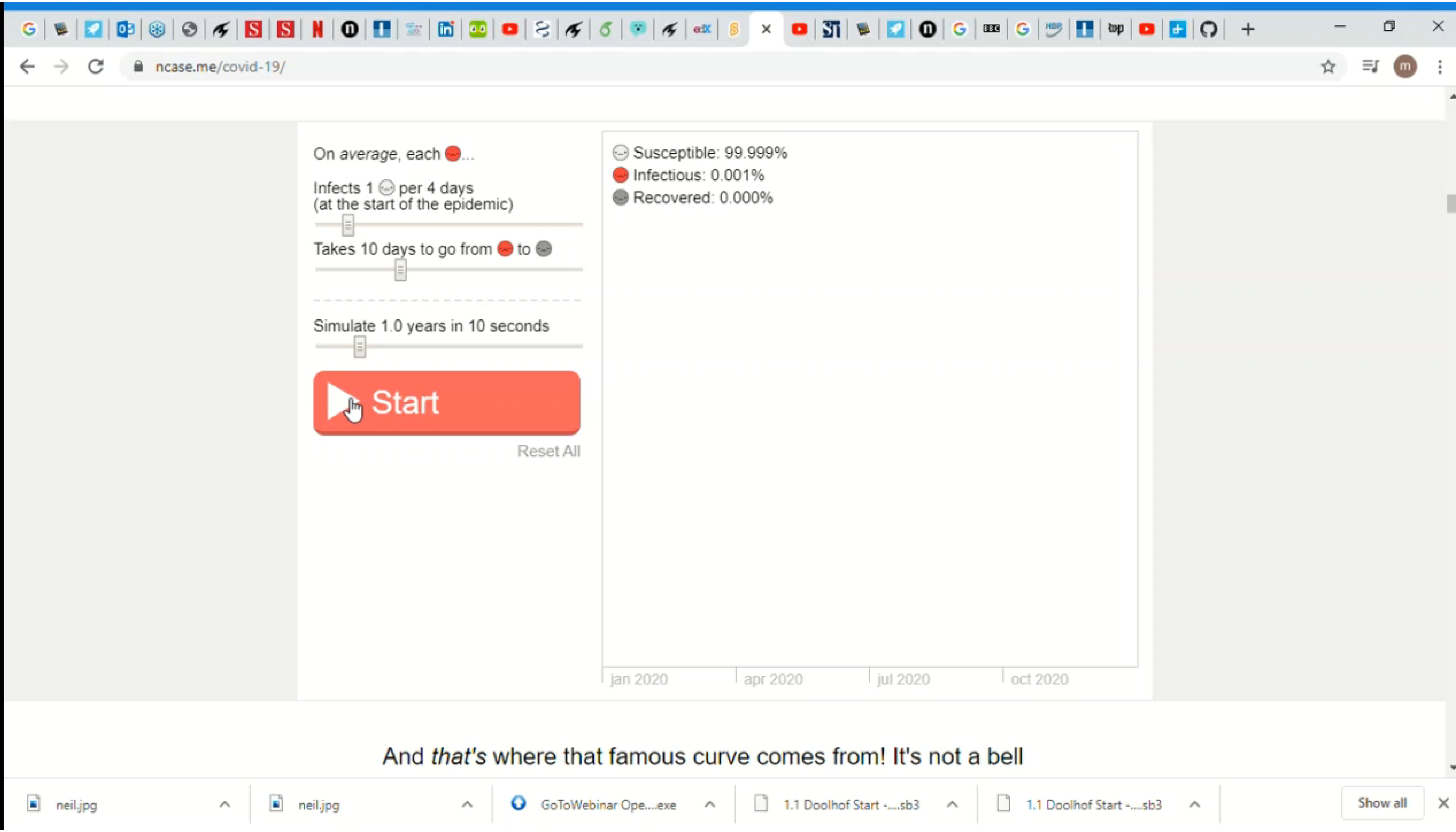
Compartmental models: equation based





- Reduce number of contacts per day by 50%

Compartmental models: equation based

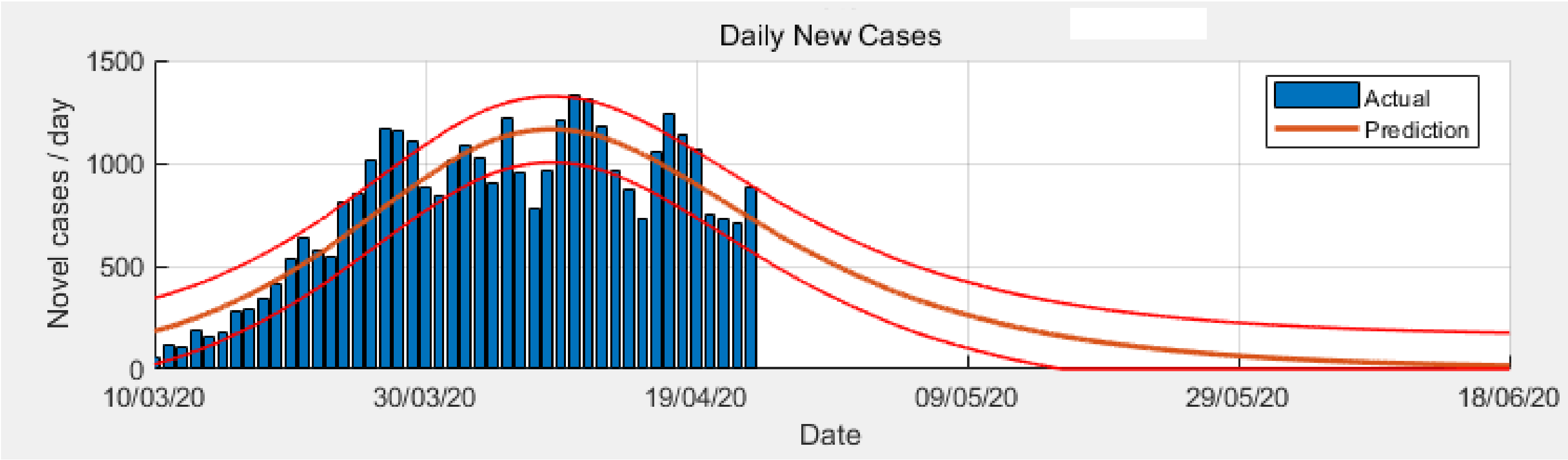


https://ncase.me/covid-19/

Compartmental models: equation based

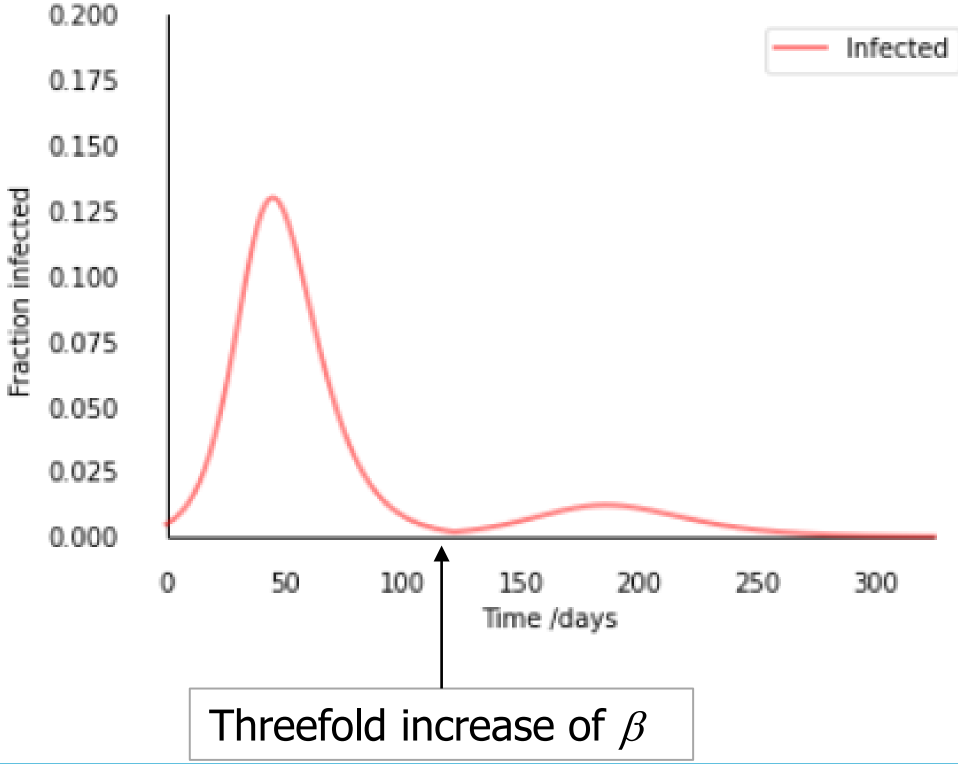
Predictive Monitoring of COVID-19
Jianxi Luo, Singapore University of Technology and Design, May 2020

- Use data on daily number of infections
- Estimate β and γ by using AI



Compartmental models: equation based

- Infection rate β increases after relaxation interventions

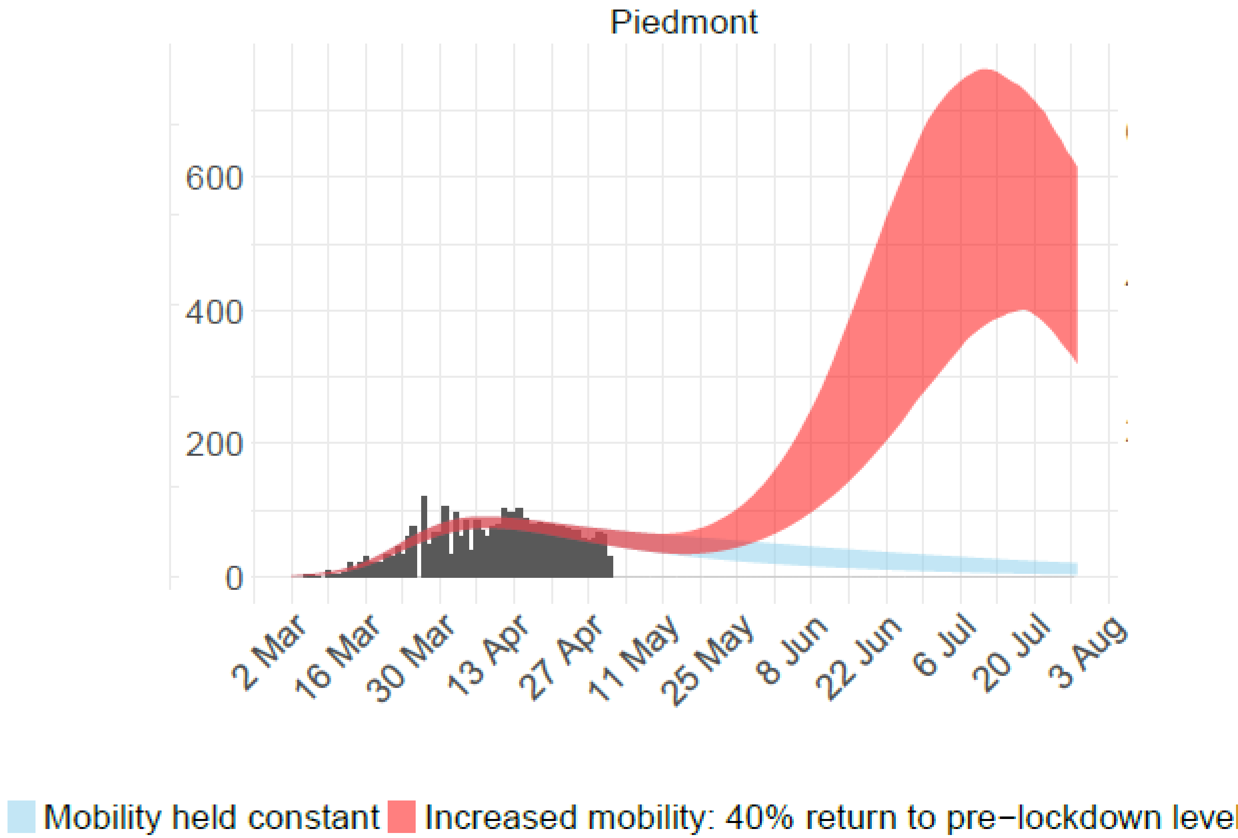


TU Delft

Compartmental models: equation based

4th May
Imperial College COVID-19 Response Team

Report 20: Using mobility to estimate the transmission intensity of COVID-19 in Italy: A subnational analysis with future scenarios



Compartmental models: equation based

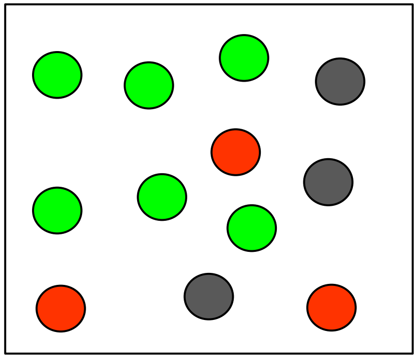
- Parameters are not constant
- Availability and quality of data
- Undetected cases
- Infection delay
- Duration immunity
- Seasonal variation
- Heterogeneous mixing
- Human factors

?

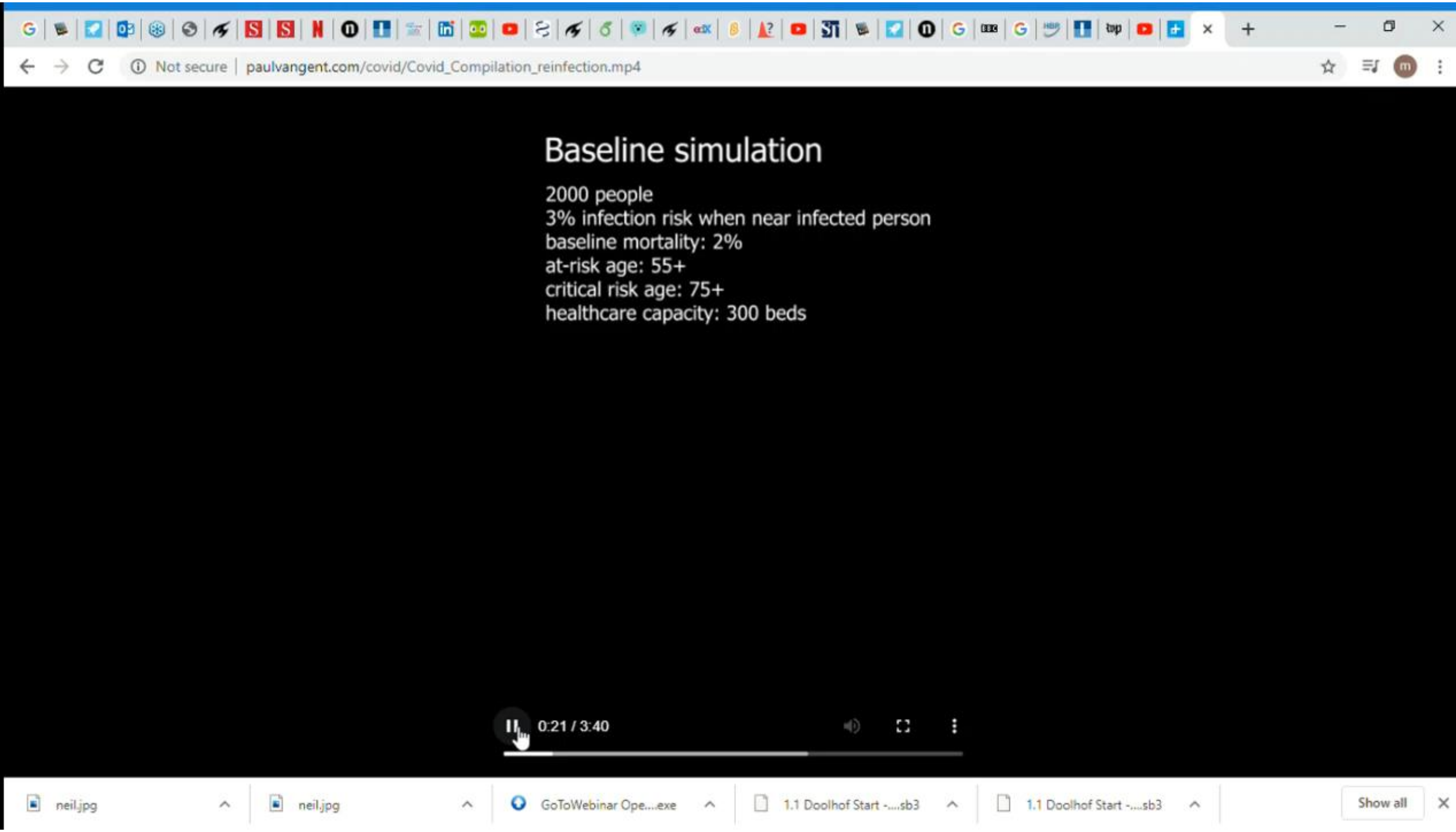
TU Delft

Compartmental models: Agent Based

- Each individual (agent)
  - Moves around
  - Is in one of the **S**-**I**-**R** states



Compartmental models: Agent Based



- **Paul van Gent:** post-doc at Faculty of CiTG
  https://github.com/paulvangentcom/python_corona_simulation

Compartmental models: Agent Based

Modelling transmission and control of the COVID-19 pandemic in Australia

Sheryl L. Chang[1], Nathan Harding[1], Cameron Zachreson[1], Oliver M. Cliff[1], and Mikhail Prokopenko[1,2,*]

[1] *Centre for Complex Systems, Faculty of Engineering, University of Sydney, Sydney, NSW 2006, Australia*
[2] *Marie Bashir Institute for Infectious Diseases and Biosecurity, University of Sydney, Westmead, NSW 2145, Australia*
[*] *Corresponding author: mikhail.prokopenko@sydney.edu.au (ORCID: 0000-0002-4215-0344)*

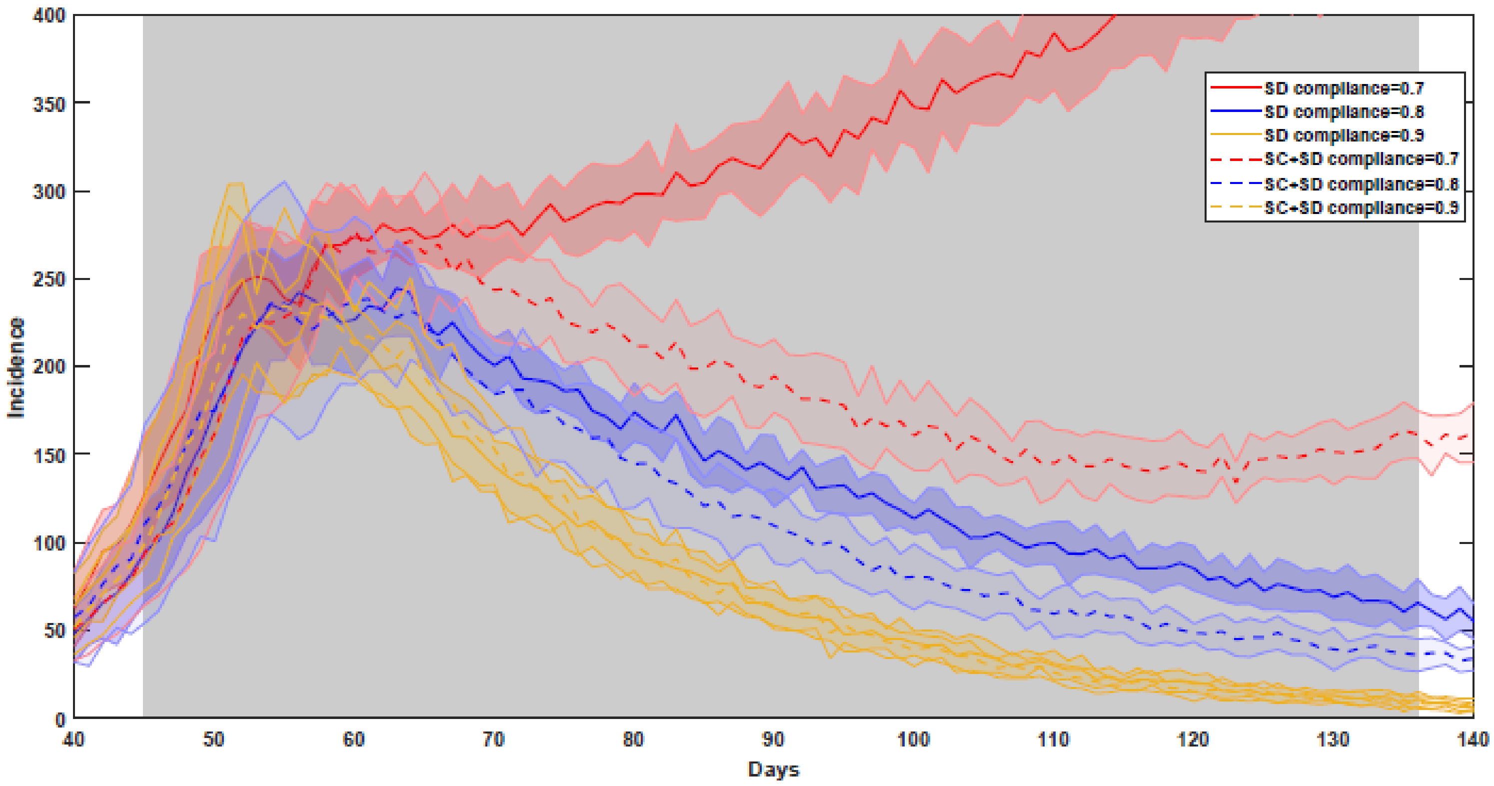
- Virtual Australia with 24 million agents
  - Demography
  - Mobility
  - Disease

Compartmental models: Agent Based

- Requires massive computation power
- Hard to calibrate

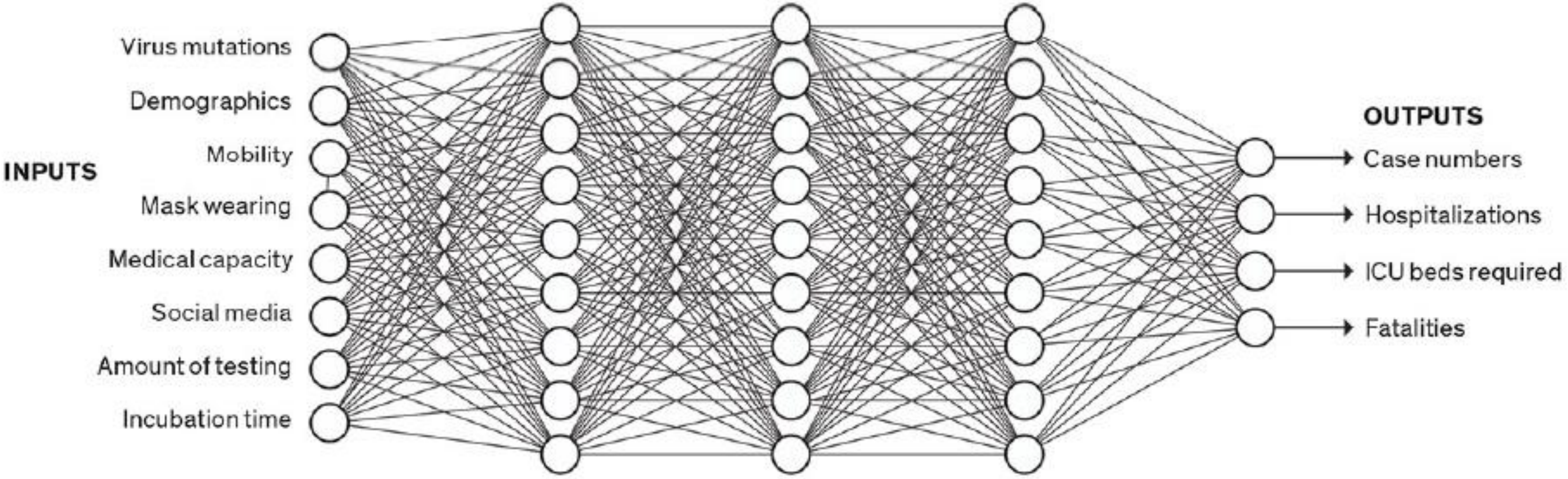
- Once the model is calibrated
  - Relate interventions to changes in infection rates
  - Assess impact of several interventions

Compartmental models: Agent Based



TU Delft

AI-driven models



AI-driven models

394,088 views | Feb 5, 2020, 12:14pm EST

AI Predicts Coronavirus Could Infect 2.5 Billion And Kill 53 Million. Doctors Say That's Not Credible, And Here's Why

AI-driven models

IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received August 21, 2020, accepted August 25, 2020, date of publication August 28, 2020, date of current version September 14, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3019989

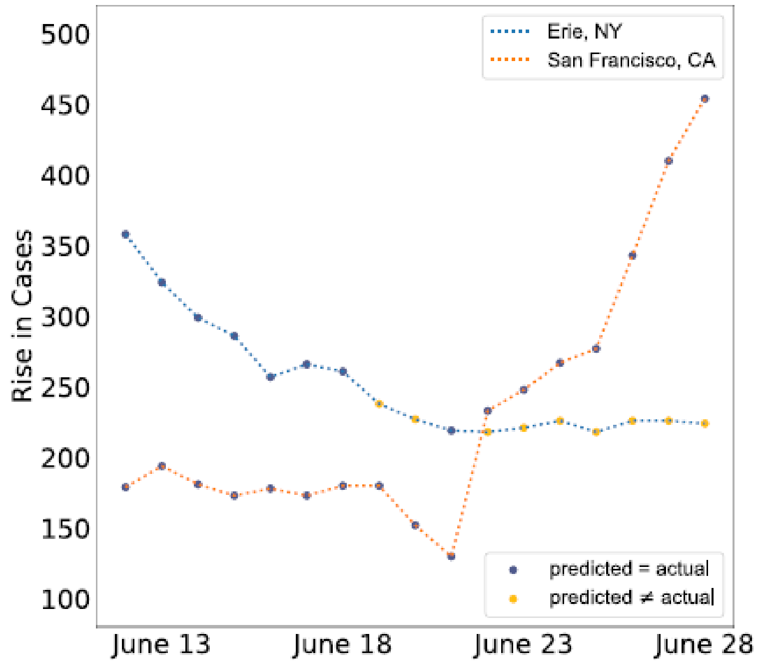
DeepCOVIDNet: An Interpretable Deep Learning Model for Predictive Surveillance of COVID-19 Using Heterogeneous Features and Their Interactions

ANKIT RAMCHANDANI[1], CHAO FAN[2], AND ALI MOSTAFAVI[2]
[1]Department of Computer Science and Engineering, Texas A&M University, College Station, TX 77840, USA
[2]Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, TX 77840, USA

AI-driven models

- Obtain data
- Selecting features
  - Population attributes
  - Population activities
  - Mobility
  - Disease spread attributes
- Build Deep Learning model (LSTM)
- Evaluate performance of model

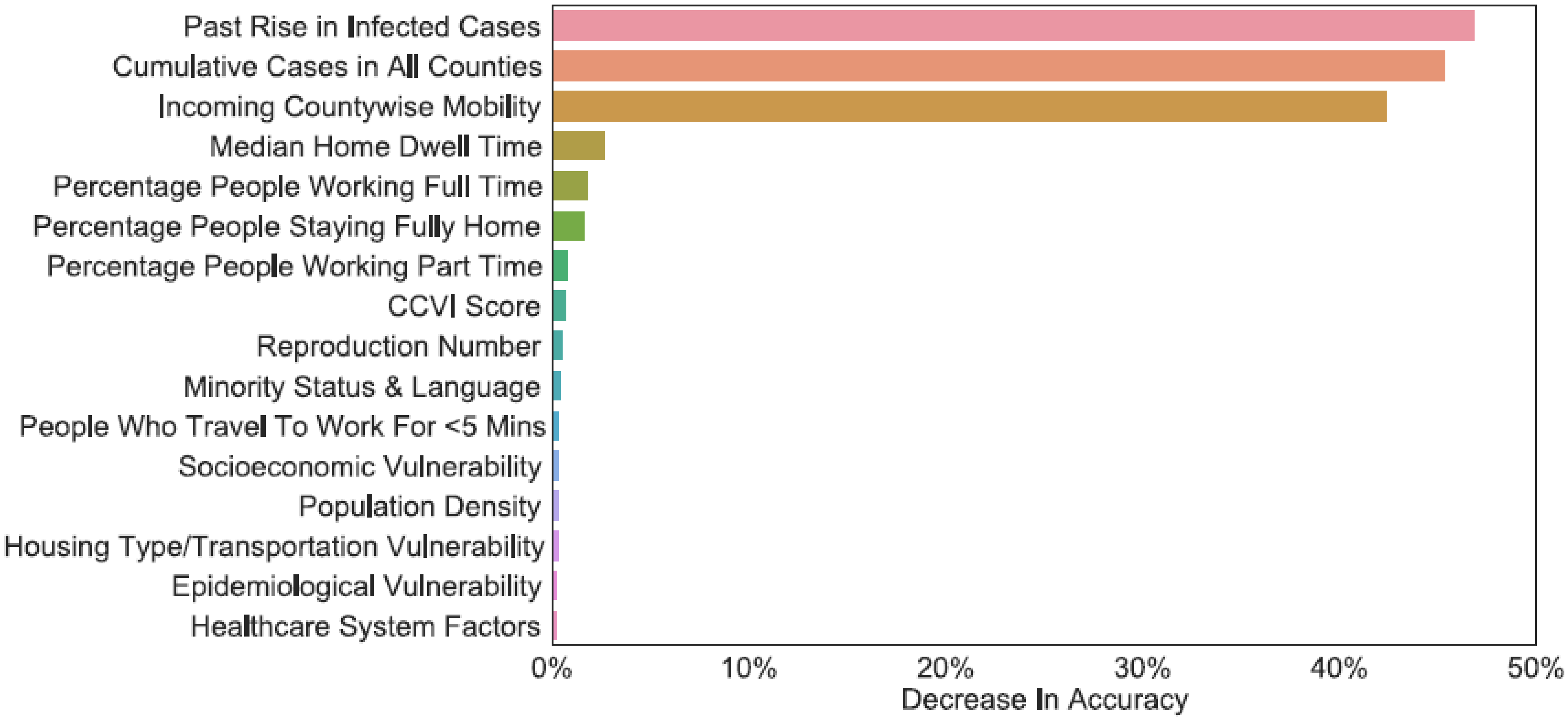
AI-driven models



- Predictive performance: 7 days

TU Delft

AI-driven models



- Identification most influential features

Comparing the approaches

- Compartment Models
  - Relatively simple tool for long-term forecasts
  - Parameter estimation
- Agent Based Models
  - Lot of work to build
  - Tricky to calibrate
- AI-driven models
  - Short-term predictions
  - Unreliable when conditions change

Comparing the approaches

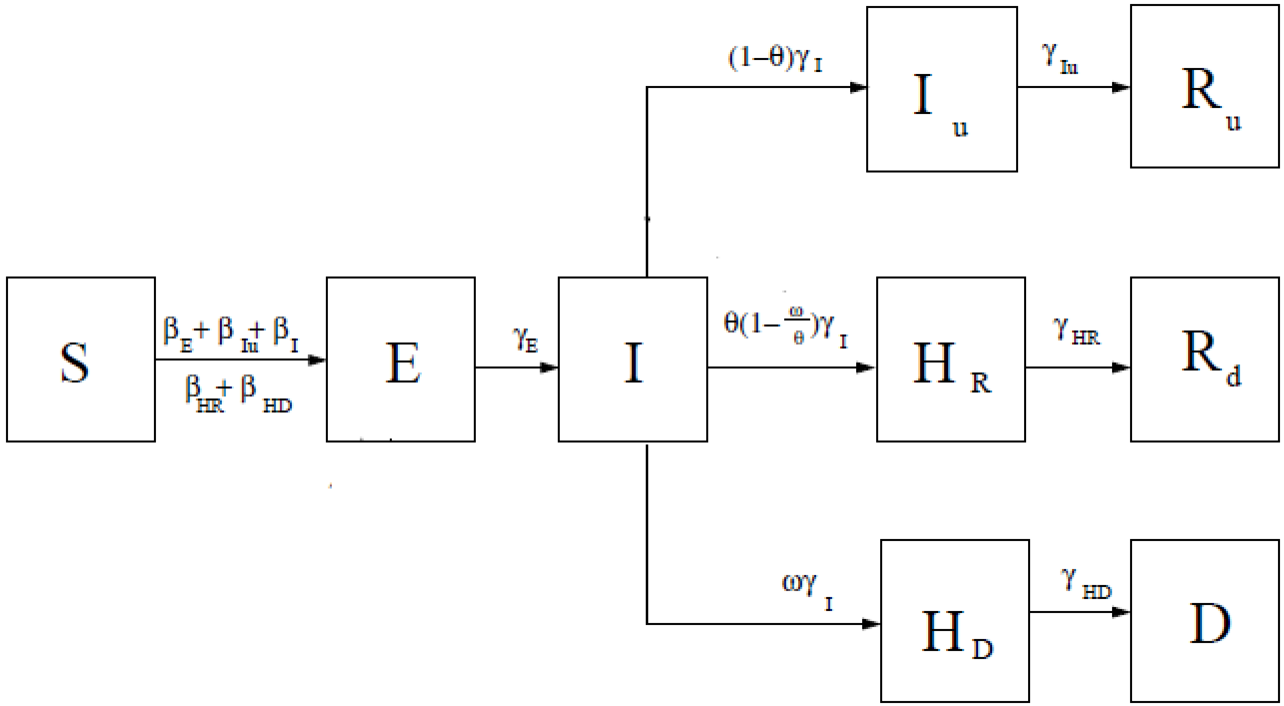
- Hybrid models
- More compartments
  - Undetected cases
  - Hospitalization
  - Incubation delay
- Time dependent control measures
- Parameters estimated through AI

Commun Nonlinear Sci Numer Simul. 2020 Sep; 88: 105303.

Mathematical modeling of the spread of the coronavirus disease 2019 (COVID-19) taking into account the undetected infections. The case of China

B. Ivorra,[a] M.R. Ferrández,[b] M. Vela-Pérez,[a] and A.M. Ramos[a,*]

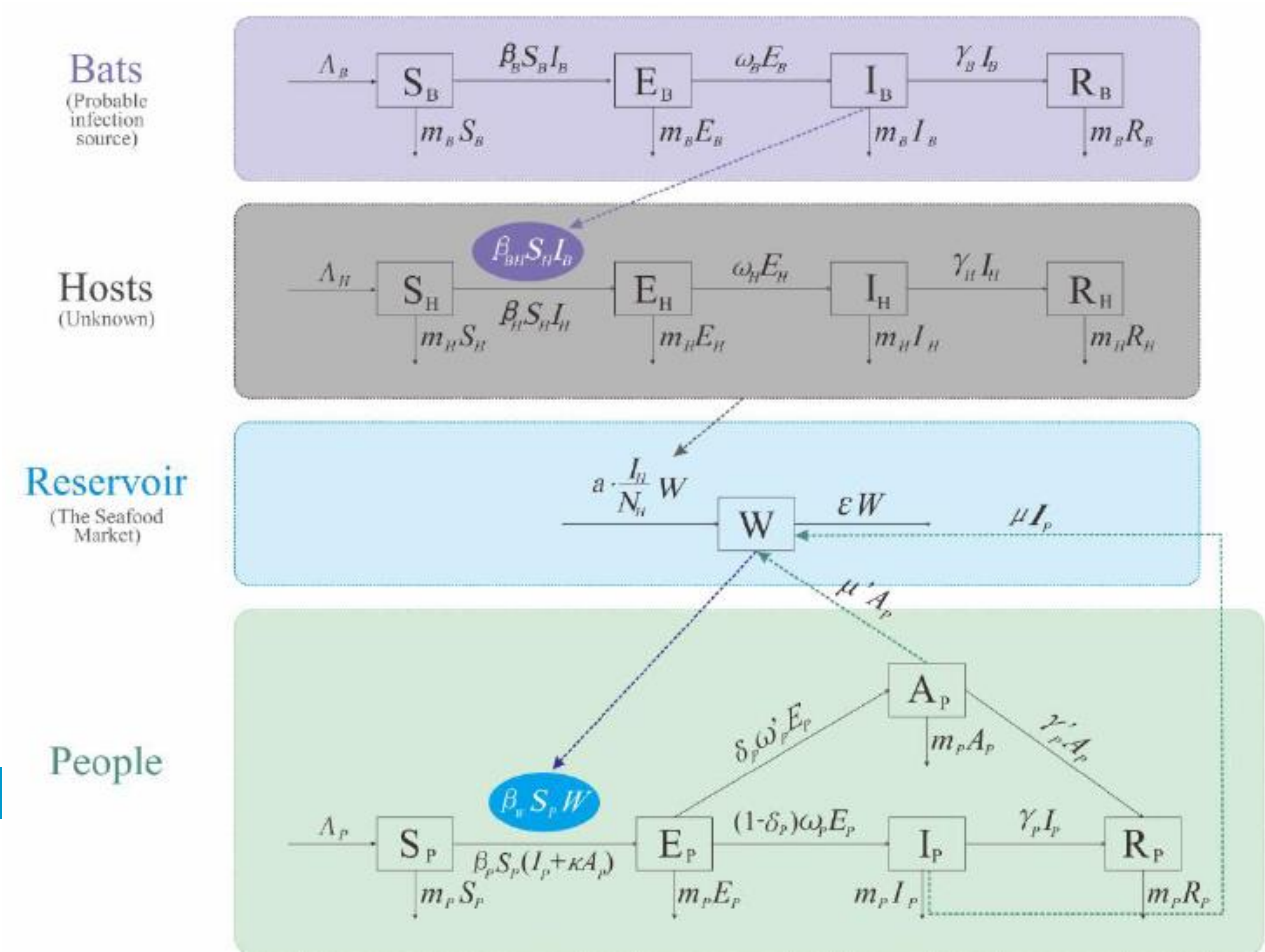
Comparing the approaches



Comparing the approaches

$$
\begin{aligned}
\frac{\mathrm{d}S}{\mathrm{d}t}(t) &= -\frac{S(t)}{N}\Big(m_E(t)\beta_E E(t) + m_I(t)\beta_I I(t) + m_{I_\mathrm{u}}(t)\beta_{I_\mathrm{u}}(\theta(t))I_\mathrm{u}(t)\Big) \\
&\quad -\frac{S(t)}{N}\Big(m_{H_R}(t)\beta_{H_R}(t)H_R(t) + m_{H_D}(t)\beta_{H_D}(t)H_D(t)\Big), \\
\frac{\mathrm{d}E}{\mathrm{d}t}(t) &= \frac{S(t)}{N}\Big(m_E(t)\beta_E E(t) + m_I(t)\beta_I I(t) + m_{I_\mathrm{u}}(t)\beta_{I_\mathrm{u}}(\theta(t))I_\mathrm{u}(t)\Big) \\
&\quad +\frac{S(t)}{N}\Big(m_{H_R}(t)\beta_{H_R}(t)H_R(t) + m_{H_D}(t)\beta_{H_D}(t)H_D(t)\Big) - \gamma_E E(t) + \tau_1(t) - \tau_2(t), \\
\frac{\mathrm{d}I}{\mathrm{d}t}(t) &= \gamma_E E(t) - \gamma_I(t) I(t), \\
\frac{\mathrm{d}I_\mathrm{u}}{\mathrm{d}t}(t) &= (1-\theta(t))\gamma_I(t)I(t) - \gamma_{I_\mathrm{u}}(t)I_\mathrm{u}(t), \\
\frac{\mathrm{d}H_R}{\mathrm{d}t}(t) &= \theta(t)\left(1 - \frac{\omega(t)}{\theta(t)}\right)\gamma_I(t)I(t) - \gamma_{H_R}(t)H_R(t), \\
\frac{\mathrm{d}H_D}{\mathrm{d}t}(t) &= \omega(t)\gamma_I(t)I(t) - \gamma_{H_D}(t)H_D(t), \\
\frac{\mathrm{d}R_\mathrm{d}}{\mathrm{d}t}(t) &= \gamma_{H_R}(t)H_R(t), \\
\frac{\mathrm{d}R_\mathrm{u}}{\mathrm{d}t}(t) &= \gamma_{I_\mathrm{u}}(t)I_\mathrm{u}(t), \\
\frac{\mathrm{d}D}{\mathrm{d}t}(t) &= \gamma_{H_D}(t)H_D(t).
\end{aligned}
$$

Comparing the approaches



TU Delft

Equation based approach on networks

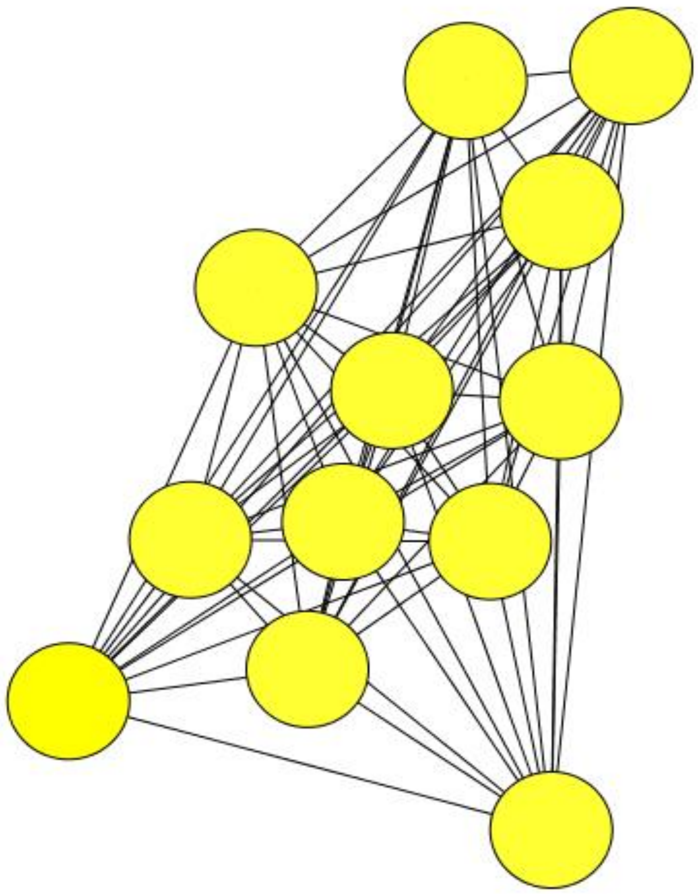
4th May
Imperial College COVID-19
Response Team

Report 20: Using mobility to estimate the transmission intensity of COVID-19 in Italy: A subnational analysis with future scenarios

occur, the number of deaths averted is likely to be considerably lower in both scenarios. It should be noted that in our model we do not account for cross-region movement, which, given increased mobility, is likely to increase infections and subsequently deaths, in regions not experiencing major epidemics.

TU Delft

Equation based approach on networks



https://www.nas.ewi.tudelft.nl/index.php/coronavirus

TU Delft

Equation based approach on networks

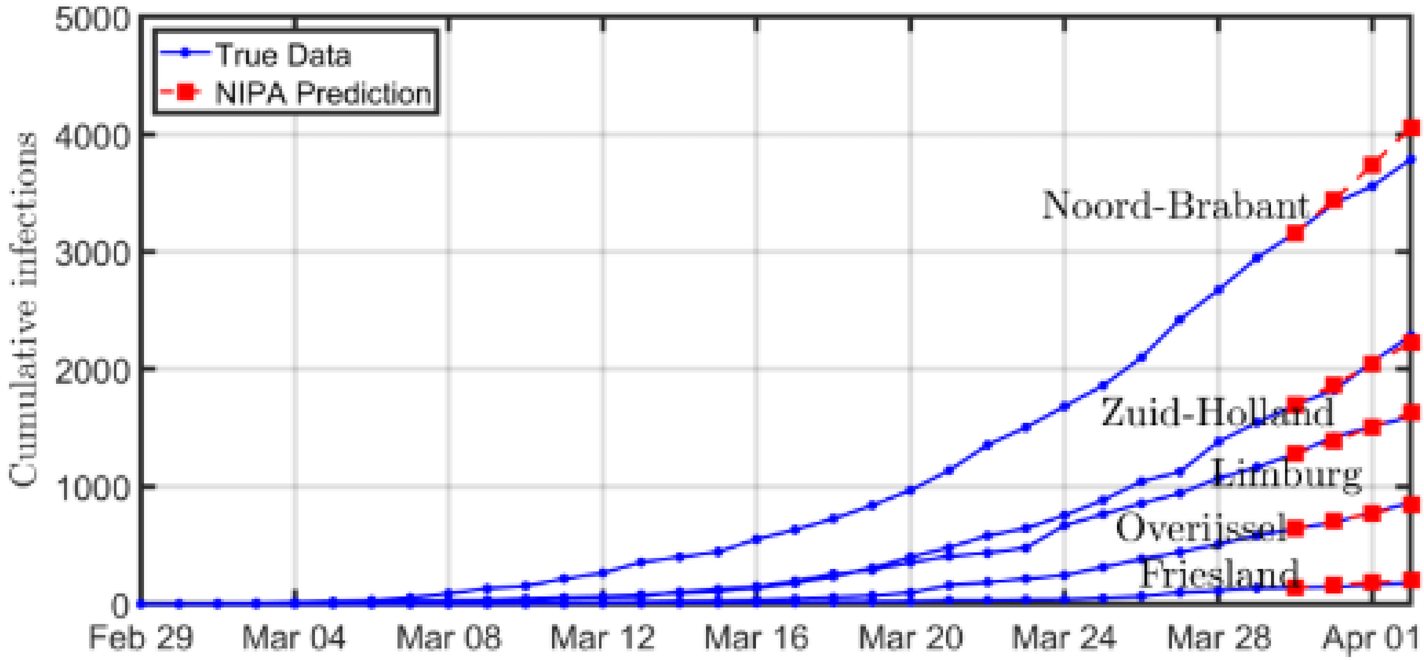
- NIPA = Network Inference-based Prediction Algorithm

- For every province estimate
  - Self-infection and curing rate
  - Infection to other provinces

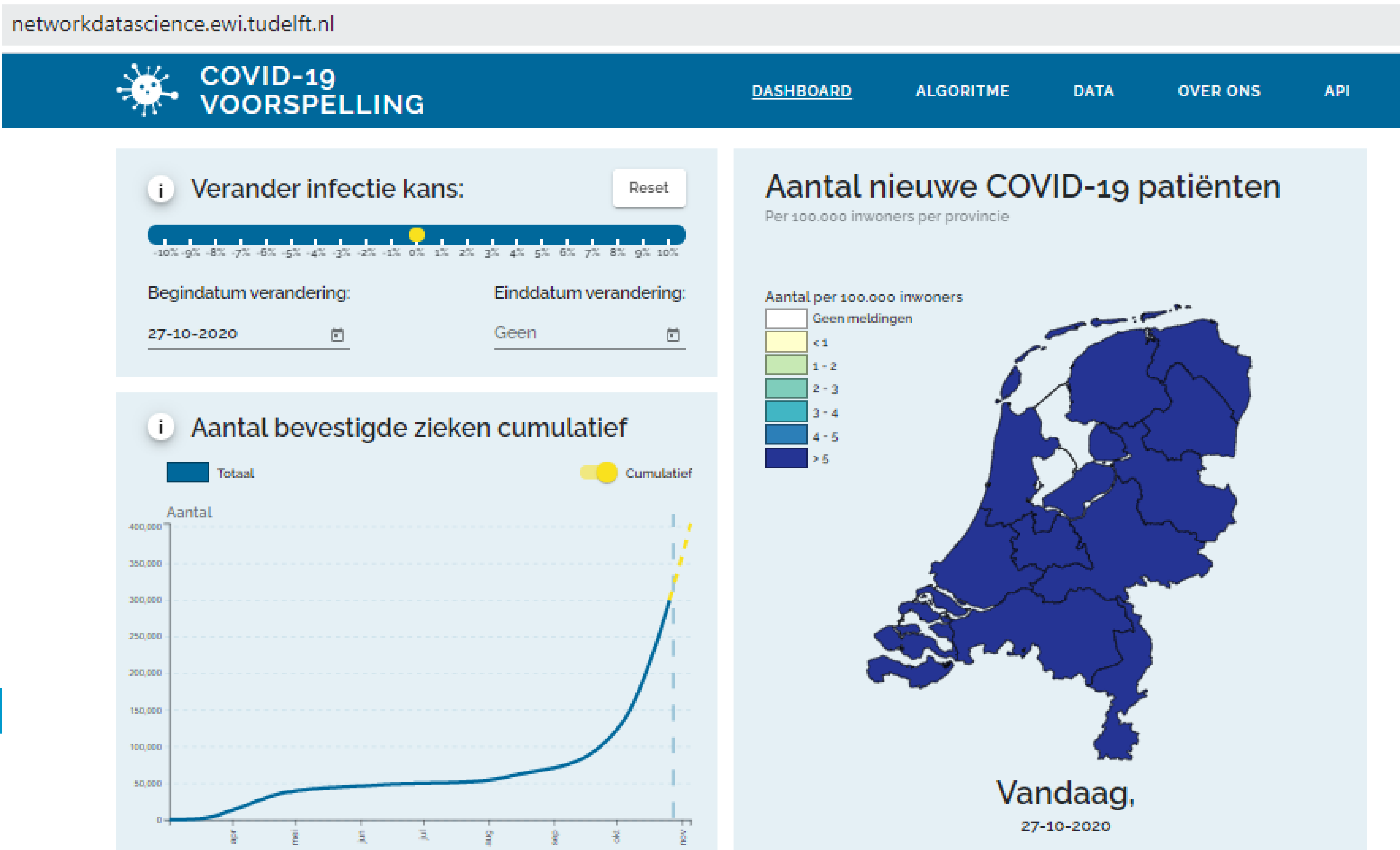
156 parameters!

Estimated using AI

Equation based approach on networks



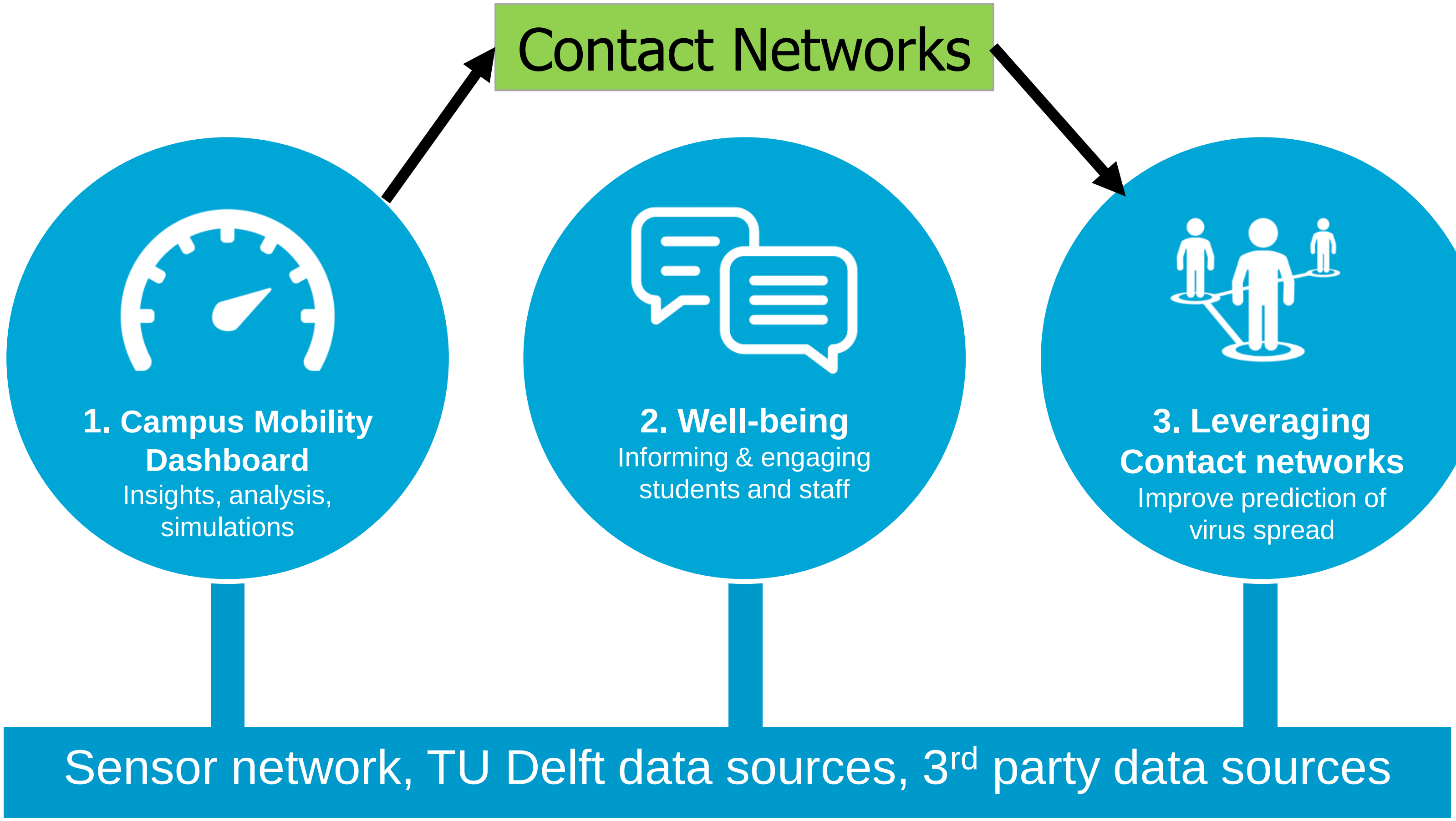
Equation based approach on networks



TU Delft – COVID-19 Digital Campus

TU Delft

TU Delft – COVID-19 Digital Campus



https://www.tudelft.nl/en/covid/

TU Delft

Wrap-up

- Importance of understanding COVID-19 spread
- Equation based approach
- Agent Based approach
- AI-driven approach
- Hybrid models
- COVID-19 Digital Campus

Wrap-up

29 October 2020 *Imperial College COVID-19 response team*

Report 34: COVID-19 Infection Fatality Ratio: Estimates from Seroprevalence

Nicholas F Brazeau[1], Robert Verity[1], Sara Jenks[2], Han Fu[1], Charles Whittaker[1], Peter Winskill[1], Ilaria Dorigatti[1], Patrick Walker[1], Steven Riley[1], Ricardo P Schnekenberg[3], Henrique Hoeltgebaum[4], Thomas A Mellan[1], Swapnil Mishra[1], H Juliette T Unwin[1], Oliver J Watson[1], Zulma M Cucunubá[1], Marc Baguelin[1], Lilith Whittles[1], Samir Bhatt[1], Azra C Ghani[1], Neil M Ferguson[1], Lucy C Okell[1+].

Thanks for your attention!

r.e.kooij@tudelft.nl