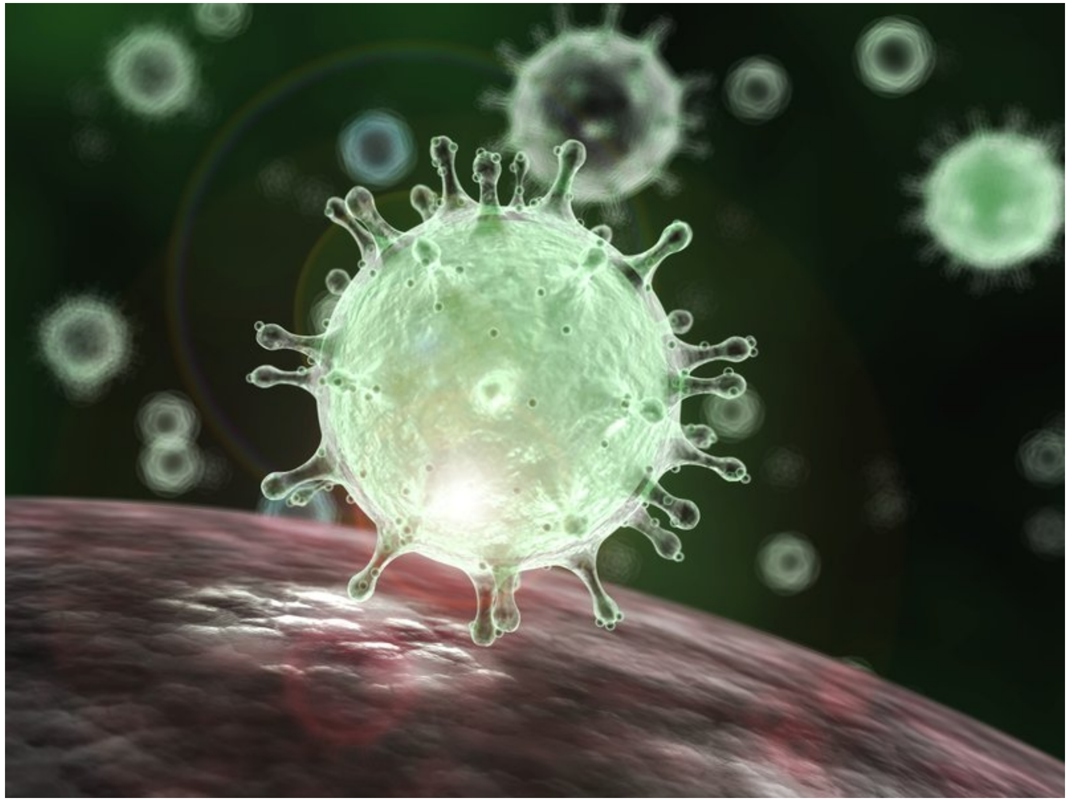
Simulation Modeling of COVID-19: Global Spread and Short-Range Contamination



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SPECIAL COLLOQUIUM ON COMPUTATIONAL ENGINEERING MATHEMATICS (CEM) AND DATA SCIENCE

UNITED STATES MILITARY ACADEMY (USMA), WEST POINT, NY

NOVEMBER 18, 2020

HTTP://APPSCEM.COM/USMA_CEM_COLLOQUIUM_FLYER2020.PDF

Simulation Modeling Tools for COVID-19 Pandemic

- Topic A: Computer modeling of regional, national, continental, and global infection spread
  - Spread of infection vs. time
  - Number of deaths vs time
- Topic B: Computer modeling of short-range virus spread from person A to person B
  - Atmospheric dynamics of liquid droplets

Why COVID-19 is so bad?

- Severe Acute Respiratory Syndrome coronavirus SARS-CoV (2002-2003) was more deadly (9.6% fatality rate vs. COVID-19 1.4%) but not easily spread
- Middle East Respiratory Syndrome MERS (2020) has a fatality rate of 34% but is not easily transmitted
- Swine flu, a new version of the H1N1 influenza virus spread easily in 2009 with an R0 = 1.4-1.6 vs COVID-19 R0 = 1.5-3.5 (R0 is a measure of how many people an infectious person could infect). But the fatality rate was smaller, less than 0.1%
- Ebola (1976) had a 50% fatality rate but was not easily transmittable
- Therefore: COVID-19 is bad mostly because of its R0 = 1.5-3.5 ➔ person to person infection

Topic A

Computer modeling of regional, national, continental, and global infection spread

- Epidemiological computer models are indispensable tools to
  - Estimate trends of infections and deaths
  - Evaluate “what if” or “must do” scenarios to possibly reduce infections and deaths
- Problems:
  - Sensational death estimates ➔ alarmism
    - E.g., forecasts from Neil Ferguson's team at Imperial College London (https://www.spectator.co.uk/article/six-questions-that-neil-ferguson-should-be-asked/amp)
  - Underestimation of danger

The Basics of Coronavirus Modeling

$N_{dead} = N_{susceptible\ population} \times \text{infection rate} \times \text{fatality rate}$

- Understand/quantify how people move between different areas and how quickly
- Individuals are either susceptible (S) to the virus; have become infected (I); and then either recover (R) or die (D)
- The R group is presumed to be immune to the virus. People with natural immunity would also belong to this group
- Simplest models ➔ basic assumptions, such as that everyone has the same chance of catching the virus from an infected person and that people with the disease are all equally infectious until they die or recover
- More-advanced models ➔ subdivide people into smaller groups – by age, sex, health status, employment, number of contacts, and so on – to set who meets whom, when and in which places, i.e., measuring social mixing at home, work, school, and other locations
- Important assumptions: R0, death rate, incubation period of infection, degree of natural immunity, etc.

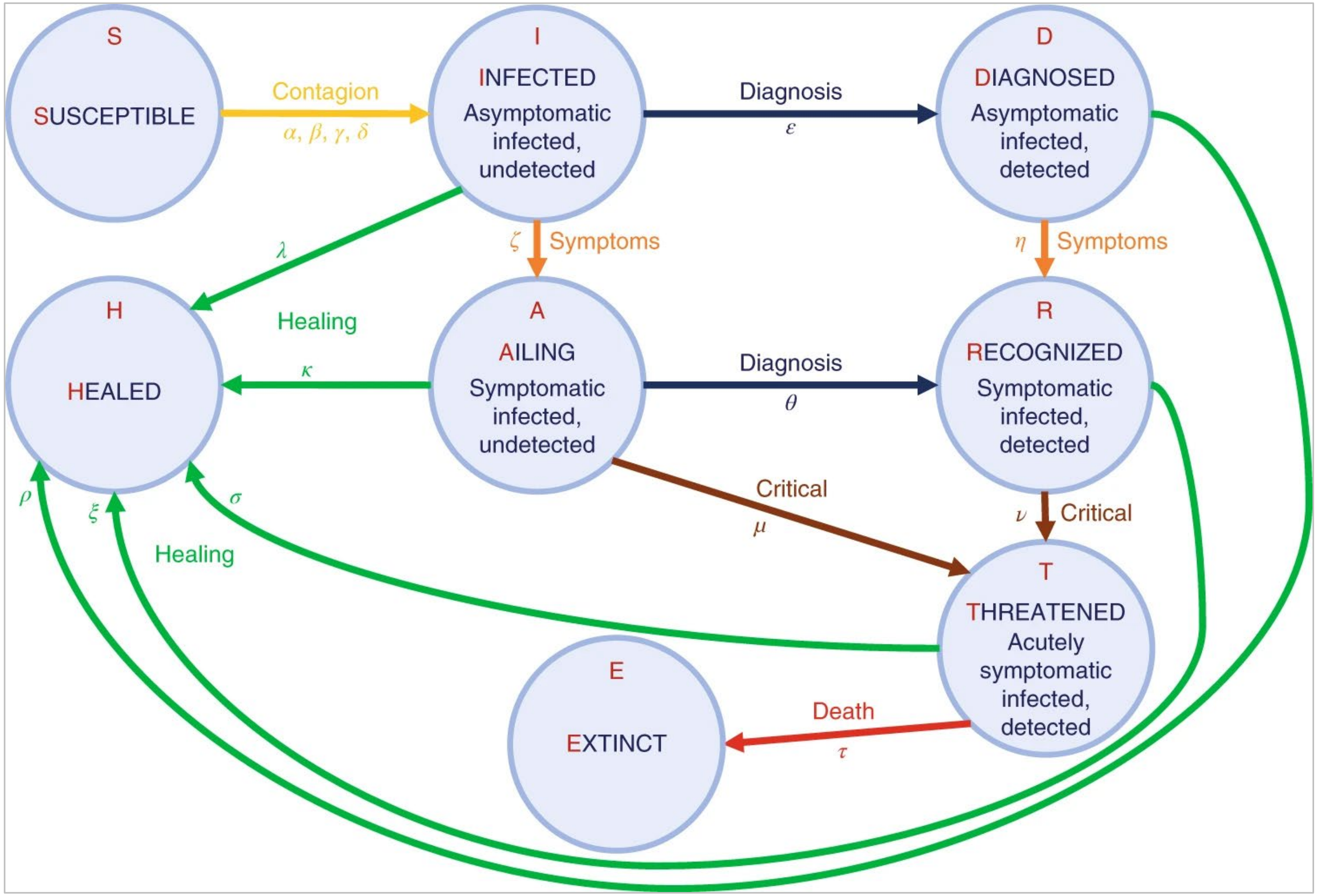
Simple Model: The SIR model

Susceptible, Infected, Recovered (SIR) model. Main assumptions (from https://towardsdatascience.com/modeling-the-spread-of-diseases-821fc728990f):

- Population is divided into three groups: the susceptible individuals (**S**), the infected individuals (**I**), and the recovered individuals (**R**).
- **Recovered indicates** individuals that may have **healed** and developed an immunity or may have **died**, but in any case, they can no longer be infected.
- The **susceptible group is closed**: no one joins it. Therefore births and immigration are ignored; moreover, people can be infected only once. Therefore, the only way an individual leaves the susceptible group is by becoming infected. Consequently, infected individuals can only go into recovered group.
- All individuals in the population have the same probability to contract the disease and their age distribution is uniformly distributed between 0 and the life expectancy L (this assumption is justified especially for developed countries).
- Homogeneous mixing of the population: the contacts of an individual with the rest of the population also follow a uniform distribution, i.e. individuals are not part of smaller groups. This hypothesis is less plausible because of the social structures usually present, but it is necessary to keep the model tractable.

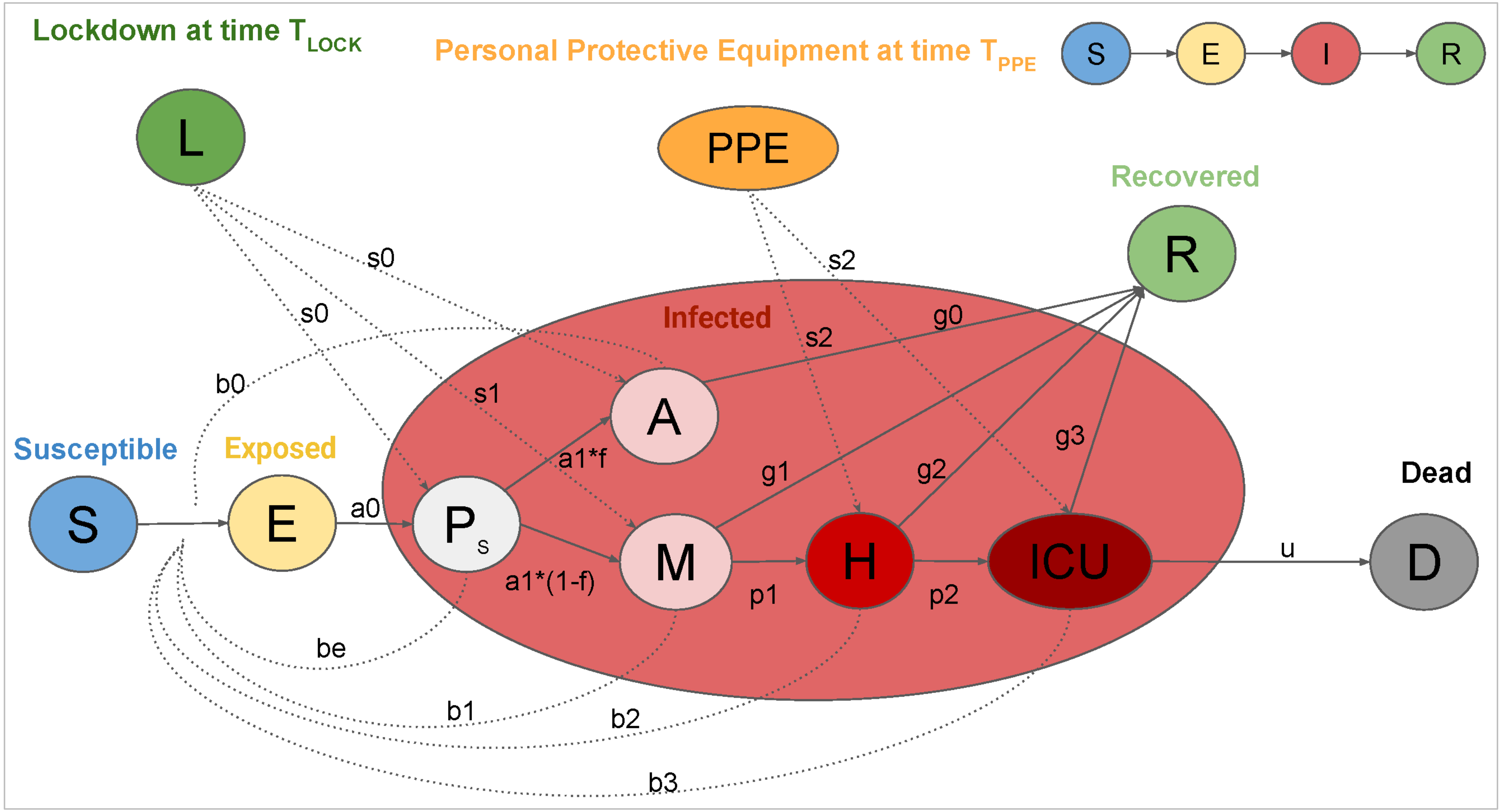
More complex models (Example 1)

From Giordano, G., Blanchini, F., Bruno, R. et al. Modelling the COVID-19 epidemic and implementation of population-wide interventions in Italy. Nat Med 26, 855–860 (2020). https://www.nature.com/articles/s41591-020-0883-7



More complex models (Example 2)

From Antonini, C.; Calandrini, S.; Stracci, F.; Dario, C.; Bianconi, F. Mathematical Modeling and Robustness Analysis to Unravel COVID-19 Transmission Dynamics: The Italy Case. Biology 2020, 9, 394. https://www.mdpi.com/2079-7737/9/11/394/htm



Software for modeling the spread of a disease

STEM: The Spatiotemporal Epidemiological Modeler Project (https://www.eclipse.org/stem/).
The STEM software is used by a global community of researchers and public health officials working to track and, when possible, control outbreaks of infectious disease in human and animal populations.
Additional information available in this paper: https://www.liebertpub.com/doi/full/10.1089/hs.2019.0018

GLEaMviz: The Global Epidemic and Mobility Modeler (http://www.gleamviz.org/)
Additional information available in:

- https://bmcinfectdis.biomedcentral.com/articles/10.1186/1471-2334-11-37
- https://bmcmedicine.biomedcentral.com/articles/10.1186/1741-7015-7-45

Example image from http://www.gleamviz.org/

US current deaths = 241K (Nov 13) - Forecast below for Dec 19:

• Johns Hopkins Univ.	258K-271K
• Iowa State	270K-278K
• Georgia Tech	258K-266K (Dec 5)
• Univ. of Texas	261K-268K (Dec 5)
• MIT	277K-287K
• UCLA	271K-289K
• Institute for Health Metrics and Evaluation	281K-304K
• Northeastern Univ.	260K-285K (Dec 5)
• Univ. of Arizona	243K-247K (Dec 5)
• Los Alamos	275K-333K
• Univ. of Mass.	265K-309K (Dec 5)
• Columbia Univ.	270K-314K (Dec 5)
• U.S. Army	370K-388K

Latest COVID-19 Modeling Predictions (Nov 13)

https://projects.fivethirtyeight.com/covid-forecasts/

Topic B

How does person A infect person B?

Many "theories" are found in the scientific literature and the media (Last one I read: imported frozen foods…)

There seems to be a consensus that liquid droplets from coughing and sneezing are a major (perhaps the dominant) cause of **SARS-CoV-2** infection

I would add shouting and chanting because →

THE WALL STREET JOURNAL.

WORLD

The Soccer Match that Kicked Off Italy's Coronavirus Disaster

Decision to hold Atalanta-Valencia Champions League match in February accelerated spread of pandemic

On Dec. 1, 2019, a patient in Wuhan, China, started showing symptoms of what doctors determined was a new coronavirus. Since then, the virus has spread across the world. Here's how the virus grew to a global pandemic. Photo: Alberto Pizzoli/Agence France-Presse/Getty Images

By *Joshua Robinson*
Updated April 1, 2020 2:32 pm ET

PRINT TEXT 130

On the afternoon of Feb. 19, Andrea Pontiggia was heading from Bergamo, Italy, to the biggest soccer match of his life—along with 40,000 of his closest friends.

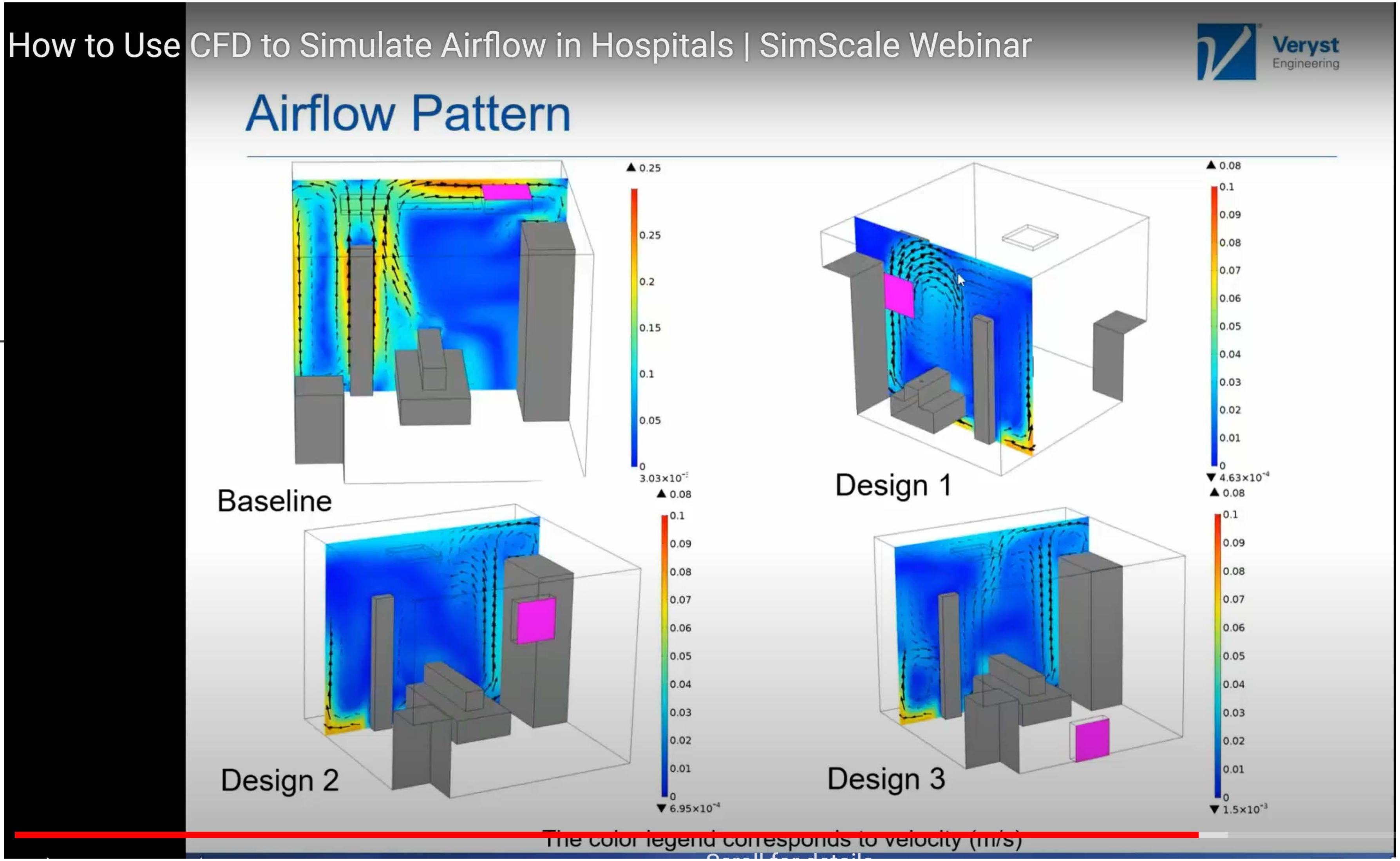
Computer Simulation of Atmospheric Trajectories of Droplets

1. Indoor vs. Outdoor
2. Emission of droplets from Person A
3. Simulation of the main 3D Air Flow
4. Addition of turbulent fluctuations (mostly outdoor)
5. Gravitational settling, as a function of diameter and density of the droplet
6. Partial evaporation (change in droplet diameter)
7. Deposition of droplets; contact / inhalation by Person B

3D Air Flow Indoor

E.g.: How to Use CFD to Simulate Airflow in Hospitals | SimScale Webinar

https://www.youtube.com/watch?v=dWQPDy87skQ



3D Air Flow Outdoor

Meteorological models are available to simulate the main air flow, e.g.:

CALMET (diagnostic) http://www.src.com/

WRF (prognostic) https://www.mmm.ucar.edu/weather-research-and-forecasting-model

For microscale effects of obstacles, CFD models can be used, e.g.:

FLUENT (expensive)

https://www.ansys.com/products/fluids/ansys-fluent

OpenFOAM (open source)

https://openfoam.com/

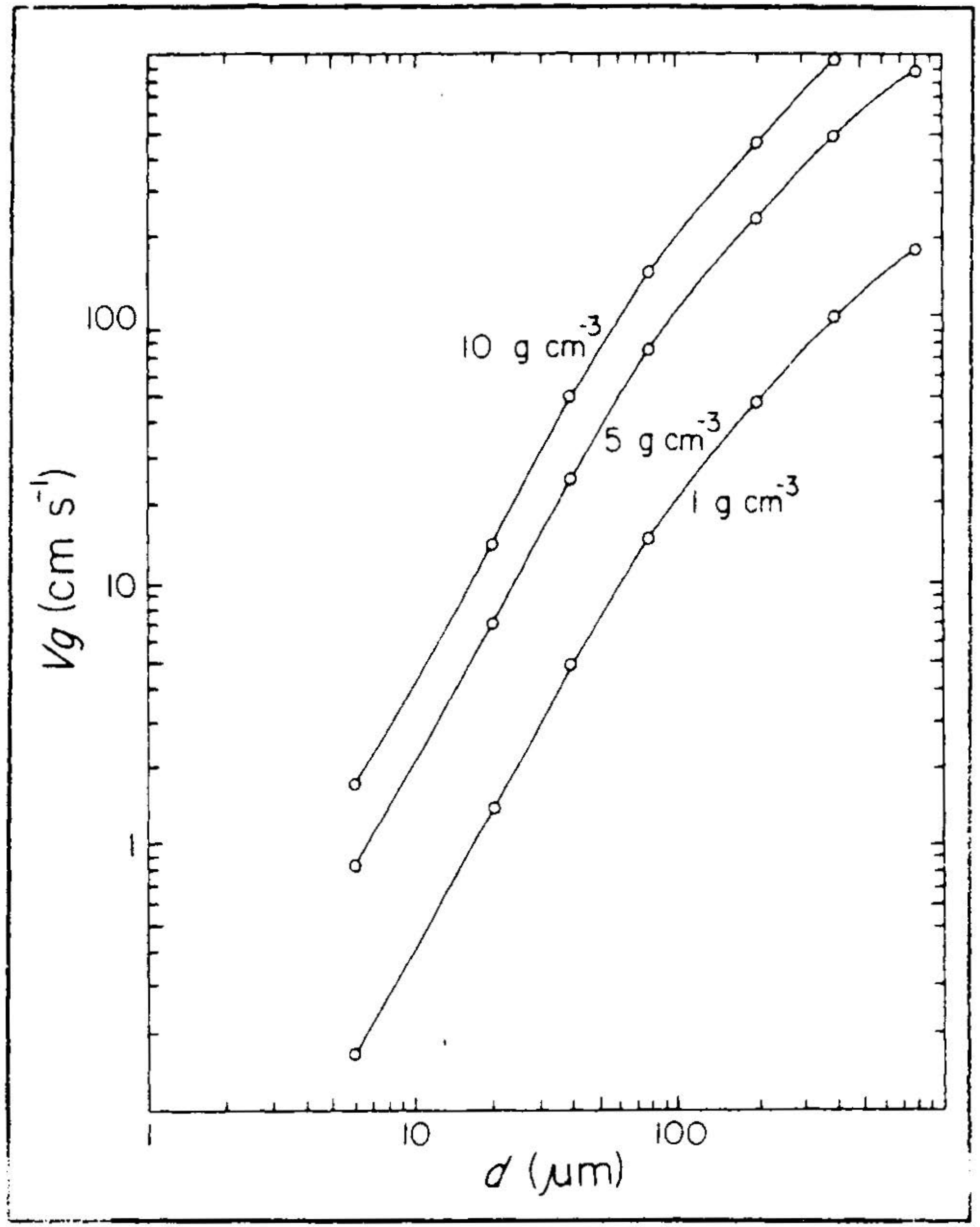
https://www.openfoam.com/news/openfoam-covid-response.php

Atmospheric Turbulence (Outdoor)

Turbulent dispersion can be simulated by adding semi-random wind fluctuations calculated with Monte-Carlo computer methods. E.g., see the LAPMOD system

https://www.enviroware.com/lapmod/ (open source)

Gravitational Settling Velocity - depending on diameter and density of the droplet



Further Complication: EVAPORATION

Liquid in a droplet may evaporate → change in droplet diameter → change in gravitational settling velocity

Evaporation formulas/algorithms are available, e.g., those developed for aerial spray of pesticides (AgDRIFT and AGDISP)
https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment

Evaporation rate depends upon ambient temperature and relative humidity

Videos of Computer Simulations

TOP: coughing without a mask

BOTTOM: coughing into a cloth mask

https://play.vidyard.com/z4hoghY3GpSQa7Vcu5GTSV

A person coughs in a grocery store

https://youtu.be/WZSKoNGTR6Q

Running

https://youtu.be/99yx2wScgJA

CONCLUSIONS – Topic B

- GOOD: We possess the mathematical/numerical tools to simulate all the physical phenomena
- BAD: Uncertainties are very large, e.g.:
  - Number of droplets emitted and size distribution
  - Infectious SARS-CoV-2 dose of each droplet
  - Initial & Boundary conditions (especially indoor)
- WE CAN ONLY SIMULATE HYPOTHETICAL SCENARIOS – Modeling validation & calibration seem very difficult to perform

Thanks!

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Additional Links – Forecasting Models

https://gkpolicybriefs.com/briefs/covid-19-forecasting-models

https://www.sciencedirect.com/science/article/pii/S2468042720300397

https://www.sciencedirect.com/science/article/pii/S2468042720300336#bbib9

https://www.sciencedirect.com/science/article/abs/pii/S0960077920301636?via%3Dihub

https://www.sciencedirect.com/science/article/abs/pii/S0048969720323342

https://www.journalofinfection.com/article/S0163-4453(20)30095-5/fulltext

https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-020-05415-7

COVID Internet Resources, including models

https://github.com/soroushchehresa/awesome-coronavirus#models

Online Model

https://covid19-scenarios.org/

A comment on premature mortality numbers…

An important parameter not often discussed is the Years of potential life lost (YPLL)

In Italy, for example:

- 93,300 people die every year because of tobacco smoking https://tobaccoatlas.org/country/italy/
  - If the average YPLL is 20 years (?), the total YPLL for tobacco smoking is 1,800,000
- 3,400 people died of traffic accidents in 2017

https://www.statista.com/statistics/914470/number-of-deaths-in-road-accidents-in-italy-by-region/

  - If the AVERAGE YPLL is 45 years (?), the total YPLL for traffic accidents is 153,000

These numbers can be compared with 50,000 (?) COVID deaths in 2020, with the average life expectancy of 5 years (?): the total YPLL is 250,000 for COVID

Total Deaths/1M population (on Nov 17)

https://www.worldometers.info/coronavirus/#countries

Belgium	1259
Spain	891
UK	775
Italy	769
USA	766
France	708
Sweden	615
Netherlands	502
Switzerland	422
Portugal	349
Hungary	340
Poland	287
Austria	215
Germany	158

Do we have any explanation for these numbers? E.g.:

- Belgium vs. Germany !?! One order of magnitude!
- Sweden !?!

Additional Information

Airborne Transmission of SARS-CoV-2: A Virtual Workshop

The National Academies of Sciences, Engineering, and Medicine

Aug 26 - 27, 2020

https://www.nationalacademies.org/event/08-26-2020/airborne-transmission-of-sars-cov-2-a-virtual-workshop