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COVID-19 Scenarios

8-10 minutes

This web application serves as a planning tool for COVID-19 outbreaks in communities across the world. It implements a simple SIR (Susceptible-Infected-Recovered) model with additional categories for individuals exposed to the virus that are not yet infectious, severely sick people in need of hospitalization, people in critical condition, and a fatal category.

The source code of this tool is freely available at github.com/neherlab/covid19_scenarios and we welcome contributions in any form: comments, suggestions, help with development. For example, you can:

- ask a question or post a comment in the General Discussion Thread
- report a bug or propose an improvement by openning a New Issue
- directly propose changes in code, documentation or data by Forking our repository on GitHub, commiting changes to your new fork and opening a Pull Request, so that we could review and merge the changes.

Basic assumptions

The model works as follows:

- susceptible individuals are exposed/infected through contact with infectious individuals. Each infectious individual causes on average R_0R0 secondary infections while they are infectious. Transmissibility of the virus could have seasonal variation which is parameterized with the parameter "seasonal forcing" (amplitude) and "peak month" (month of most efficient transmission).
- exposed individuals progress to a symptomatic/infectious state after an average latency
- infectious individuals recover or progress to severe disease. The ratio of recovery to severe progression depends on age
- severely sick individuals either recover or deteriorate and turn critical. Again, this depends on the age
- critically ill individuals either return to regular hospital or die. Again, this depends on the age

The individual parameters of the model can be changed to allow exploration of different scenarios.

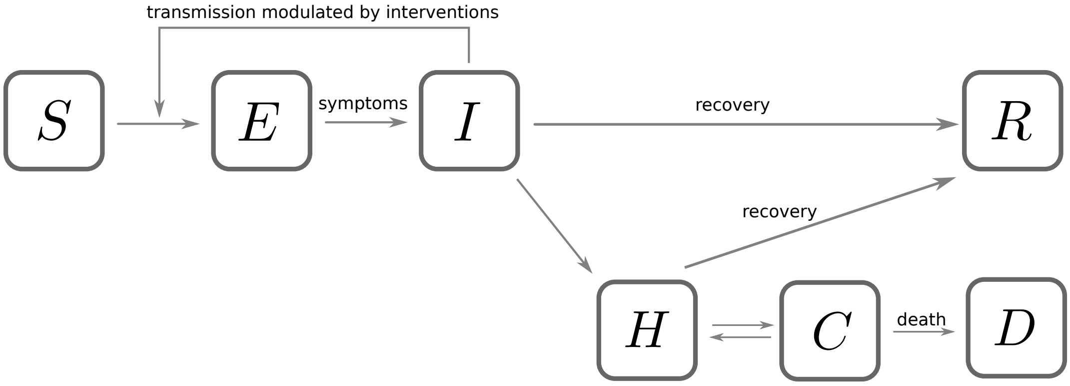

Figure 1. A schematic illustration of the underlying model. S corresponds to the 'susceptible' population, E is 'exposed', I is 'infectious', R 'recovered', H 'severe' (hospitalized), C

'critical' (ICU), and D are fatalities.

COVID-19 is much more severe in the elderly and proportion of elderly in a community is therefore an important determinant of the overall burden on the health care system and the death toll. We collected age distributions for many countries from data provided by the UN and make those available as input parameters. Furthermore, we use data provided by the epidemiology group by the Chinese CDC to estimate the fraction of severe and fatal cases by age group.

Seasonality

Many respiratory viruses such as influenza, common cold viruses (including other coronaviruses) have a pronounced seasonal variation in incidence which is in part driven by climate variation through the year. We model this seasonal variation using a sinusoidal function with an annual period. This is a simplistic way to capture seasonality. Furthermore, we don't know yet how seasonality will affect COVID-19 transmission.

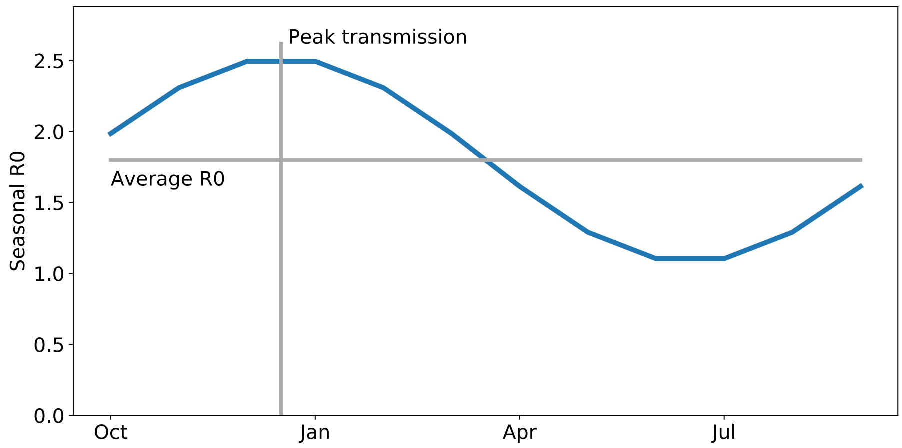

Figure 2. Seasonal variation in transmission rate is modeled by a cosine. The model allows to specify the average R0, the amplitude of the cosine (seasonal forcing), and the month of peak transmission.

Transmission reduction

The tool allows one to explore temporal variation in the reduction of transmission by infection control measures. This is implemented as a curve through time that can be dragged by the mouse to modify the assumed transmission. The curve is read out and used to change the transmission relative to the base line parameters for R_0R0 and seasonality. Several studies attempt to estimate the effect of different aspects of social distancing and infection control on the rate of transmission. A report by Wang et al estimates a step-wise reduction of R_0R0 from above three to around 1 and then to around 0.3 due to successive measures implemented in Wuhan. This study investigates the effect of school closures on influenza transmission.

Details of the model

Qualitatively we model the epidemic dynamics with the following subpopulations:

- Susceptible individuals [SS] are exposed to the virus by contact with an infected individual.
- Exposed individuals [EE] progress towards a symptomatic state on average time $t_l$tl
- Infected individuals [II] infect an average of R_0R0

secondary infections. On a time-scale of $t_i$ti, infected individuals either recover or progress towards hospitalization.

- Hospitalized individuals [HH] either recover or worsen towards a critical state on a time-scale of t_hth.
- Critical individuals [CC] model ICU usage. They either return to the hospital state or die [DD] on a time-scale of $t_c$tc
- Recovered individuals [RR] can not be infected again.

Subpopulations are delineated by age classes, indexed by a a, to allow for variable transition rates dependent upon age. Quantitatively, we solve the following system of equations to estimate hospital usage:

$$
\begin{aligned}
\frac{dS_a(t)}{dt} &= -N^{-1}\beta_a(t)S_a(t)\sum_b I_b(t) \\
\frac{dE_a(t)}{dt} &= N^{-1}\beta_a(t)S_a(t)\sum_b I_b(t) - E_a(t)/t_l \\
\frac{dI_a(t)}{dt} &= E_a(t)/t_l - I_a(t)/t_i \\
\frac{dH_a(t)}{dt} &= (1-m_a)I_a(t)/t_i + (1-f_a)C_a(t)/t_c - H_a(t)/t_h \\
\frac{dC_a(t)}{dt} &= c_a H_a(t)/t_h - C_a(t)/t_c \\
\frac{dR_a(t)}{dt} &= m_a I_a(t)/t_i + (1-c_a)H_a(t)/t_h \\
\frac{dD_a(t)}{dt} &= f_a C_a(t)/t_c
\end{aligned}
$$

dtdSa(t)dtdEa(t)dtdIa(t)dtdHa(t)dtdCa(t)dtdRa(t)dtdDa(t) =−N−1βa(t)Sa(t)b∑Ib(t)=N−1βa(t)Sa(t)b∑Ib(t)−Ea(t)/tl=Ea (t)/tl−Ia(t)/ti=(1−ma)Ia(t)/ti+(1−fa)Ca(t)/tc−Ha(t)/th=caHa(t)/th

−Ca(t)/tc=maIa(t)/ti+(1−ca)Ha(t)/th=faCa(t)/tc

The parameters of this model fall into three categories: a time dependent infection rate $\beta(t)$β(t) time scales of transition to a different subpopulation $t_l$tl, $t_i$ti, t_hth, $t_c$tc, and age specific parameters $m_a$ma, $c_a$ca and $f_a$fa that determine relative rates of different outcomes. The latency time from infection to infectiousness is $t_l$tl, the time an individual is infectious after which he/she either recovers or falls severely ill is $t_i$ti, the time a sick person recovers or deteriorates into a critical state is t_hth, and the time a person remains critical before dying or stabilizing is $t_c$tc. The fraction of infectious that are asymptomatic or mild is $m_a$ma, the fraction of severe cases that turn critical is $c_a$ca, and the fraction of critical cases that are fatal is $f_a$fa.

The transmission rate $\beta_a(t)$βa(t) is given by

$\beta_a(t) = R_0 I_a M(t)(1+\varepsilon\cos(2\pi(t-t_{max})))/t_i$βa(t)=R0Ia M(t)(1+εcos(2π(t−tmax)))/ti

where I_aIa is the degree to which particular age groups are isolated from the rest of the population, $M(t)$M(t) is the time course of mitigation measures, εε is the amplitude of seasonal variation in transmissibility, and t_{max}tmax is the time of the year of peak transmission.

Parameters

- Many estimates of R_0R0 are in the range of 2-3 with some estimates pointing to considerably higher values.
- The serial interval, that is the time between subsequent

infections in a transmission chain, was estimated to be 7-8 days.

- The China CDC compiled extensive data on severity and fatality of more than 40 thousand confirmed cases. In addition, we assume that a substantial fraction of infections, especially in the young, go unreported. This is encoded in the columns "Confirmed [% of total]".
- Seasonal variation in transmission is common for many respiratory viruses but the strength of seasonal forcing for COVID19 are uncertain. For more information, see a study by us and by Kissler et al.

University of Basel

COVID19-scenarios is developed at the University of Basel.