

Social and Information Networks

Tutorial #9: Disease Modelling

University of Toronto CSC303

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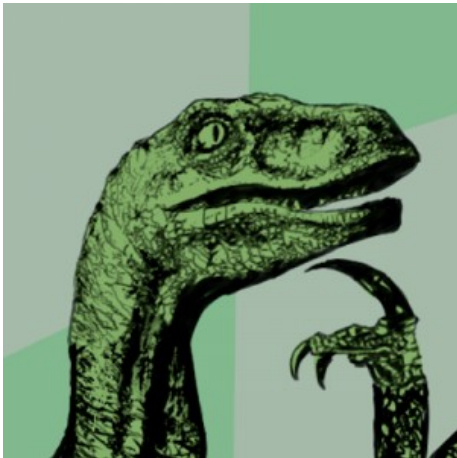
Week 10: Mar 21-25 (2022)

Today's agenda

Today:

- Questions from Lecture
- Real world modelling of COVID-19
- Quercus Quiz

Questions?



Modelling COVID-19

- Today we'll be looking at *real* research modeling the spread of COVID under various strategies, published March 2020 in the Lancet [https://doi.org/10.1016/S2468-2667\(20\)30073-6](https://doi.org/10.1016/S2468-2667(20)30073-6)

The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: a modelling study



Kiesha Prem*, Yang Liu*, Timothy W Russell, Adam J Kucharski, Rosalind M Eggo, Nicholas Davies, Centre for the Mathematical Modelling of Infectious Diseases COVID-19 Working Group†, Mark Jit, Petra Klepac



- Prem et al.'s work uses a modification of the SIR model discussed in class

SEIR

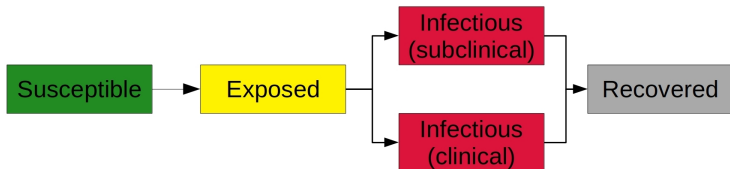
- The SEIR model has four states:
 - ▶ Susceptible
 - ▶ Exposed
 - ▶ Infectious
 - ▶ Recovered



- During the *Exposed* state, a node has been infected, but is not yet infectious

SEIR with asymptomatic (subclinical) infection

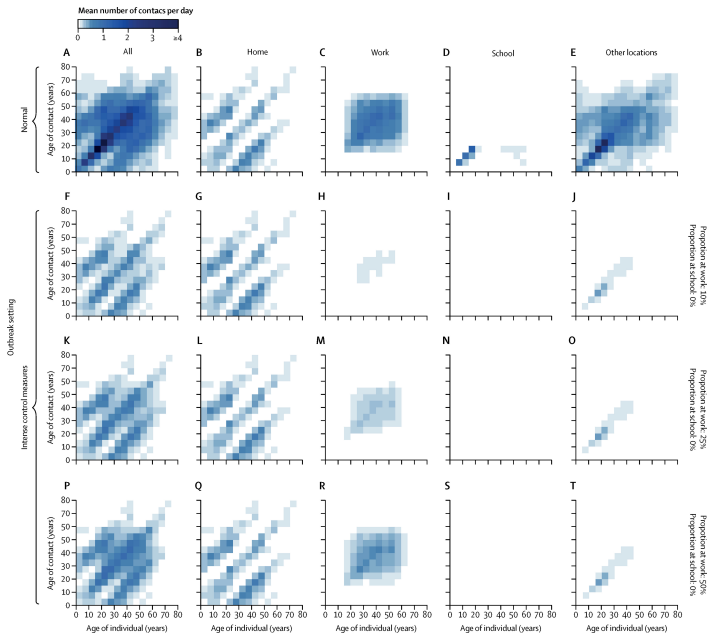
- To further model asymptomatic (subclinical) vs symptomatic (clinical) cases, the authors divided the infectious state into I^{sc} and I^c



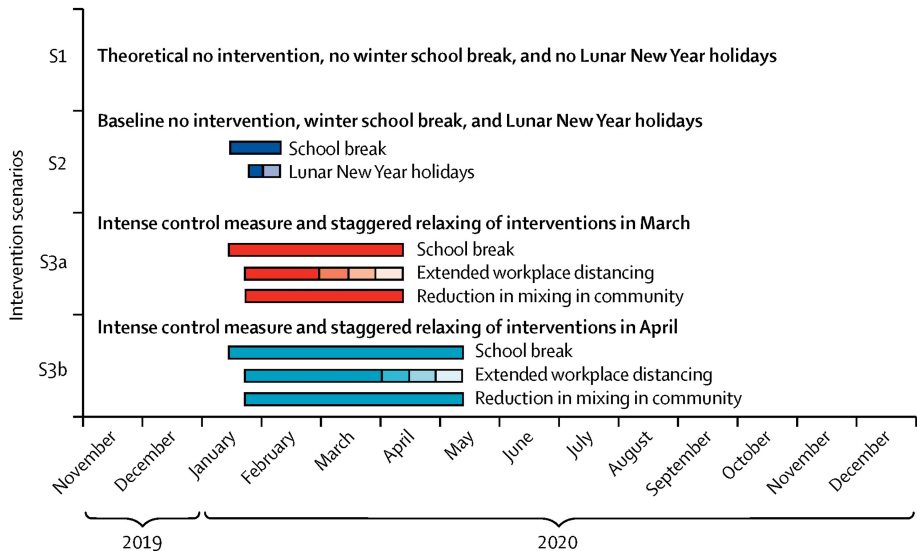
- During the *Exposed* state, a node has been infected, but is not yet infectious

Spread between age groups

- In class we modeled individuals, instead Prem et al. modelled age groups
 - ▶ In part this was to account for different probabilities of being asymptomatic based on age
- Instead of contact networks at the level of individuals like we saw in class, Prem et al. instead produced a weighted graph of exposure between different age groups under various physical distancing scenarios
- These weights were produced by combining the weights estimated for 4 key environments: Home, Work, School, and “Other”
- As these scenarios used different restrictions over time, the weights changed over time
- The weight between age groups i and j adjacency matrix at time t was dubbed $C_{(i,j),t}$. This is the average number of people of age j that a person of age i is exposed to, on day t



[From Prem et al.]



[From Prem et al.]

Spread between age groups

- As Prem et al. did not model individuals, they instead tracked the variables $S_{i,t}$, $E_{i,t}$, $I_{i,t}^C$, $I_{i,t}^{SC}$ and $R_{i,t}$
- Here i is the age group (in buckets of 5 year ranges, and 75+), and t is the day
- Each variable is the average number of people in this state

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$$S_{i,t+1} = S_{i,t} - \left[\beta S_{i,t} \sum_{j=1}^n C_{(i,j),t} I_{j,t}^C + \alpha \beta S_{i,t} \sum_{j=1}^n C_{(i,j),t} I_{j,t}^{SC} \right]$$

- β is the transmission rate, scaled based on R_0
- α is a discounting factor to adjust for asymptomatic individuals being less infectious

Spread between age groups

$$E_{i,t+1} = (1 - \kappa)E_{i,t} + \left[\beta S_{i,t} \sum_{j=1}^n C_{(i,j),t} I_{j,t}^c + \alpha \beta S_{i,t} \sum_{j=1}^n C_{(i,j),t} I_{j,t}^{sc} \right]$$

- κ is the probability of an exposed individual becoming infectious within a day
 - ▶ Based on the exponential distribution, $\kappa = 1 - \exp(-1/d_L)$ where d_L is the average incubation period in days

Spread between age groups

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- κ is the probability of an exposed individual becoming infectious within a day
 - ▶ Based on the exponential distribution, $\kappa = 1 - \exp(-1/d_L)$ where d_L is the average incubation period in days
 - ★ $P(X \leq x) = 1 - e^{-\lambda x}$

Spread between age groups

$$I_{i,t+1}^c = \rho_i \kappa E_{i,t} + (1 - \gamma) I_{i,t}^c$$

$$I_{i,t+1}^{sc} = (1 - \rho_i) \kappa E_{i,t} + (1 - \gamma) I_{i,t}^{sc}$$

- ρ_i is the probability that an infectious individual in age group i is symptomatic
- γ is the probability that an individual recovers in a day or less
 - ▶ Again by the exponential distribution, $\gamma = 1 - \exp(-1/d_I)$ where d_I is the average duration of infection in days

Spread between age groups

$$R_{i,t+1} = R_{i,t} + \gamma I_{i,t+1}^C + \gamma I_{i,t+1}^{SC}$$

- γ is the probability that an individual recovers in a day or less

Source of Parameters

- The $C_{(i,j),t}$ values were synthetic
- Other parameters were estimated based on published research

	Values	References
Basic reproduction number, R_0	2.2 (1.6–3.0)*	Kucharski et al ¹⁴
Average incubation period, d_i	6-4 days	Backer et al ¹⁶
Average duration of infection, d_i	3 days or 7 days	Woelfel et al ²²
Initial number of infected, I_0	200 or 2000	Abbott et al ¹⁵
Pr(infected case is clinical), ρ_i	0 or 0.4, for $i \leq 4$	Bi et al ¹⁰
Pr(infected case is clinical), ρ_i	0 or 0.8, for $i > 4$	Davies ²¹
Pr(infection acquired from subclinical), α	0.25	Liu et al ¹⁹

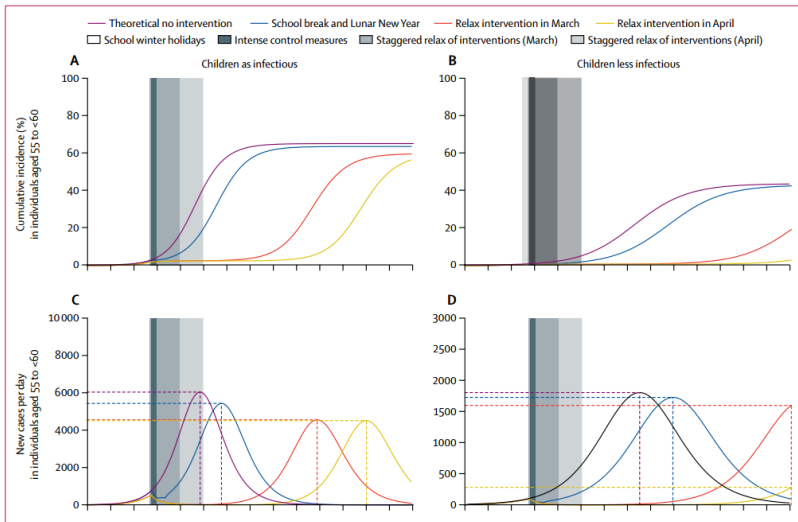
*Data are median (IQR). Pr represents the probability of an event. The parameters d_i and d_i represent the mean incubation period and duration of infectiousness, respectively.

Table: Parameters of the susceptible-exposed-infected-removed model

[From Prem et al.]

- Model parameters were validated by comparison with the number of confirmed cases in Wuhan from 16th January to 12th February
- Prem et al. considered two scenarios, one where children were more likely to be asymptomatic, and one where children were equally likely to be asymptomatic

Results



[Modified From Prem et al.]

Conclusions

- The authors concluded that measures that reduced social mixing were effective at reducing the magnitude of an outbreak, and at delaying the peak
- They found the effect of the measures varied by age group, with the largest impact on children and older individuals, and the least impact on working-age individuals
- They found that whether children were more likely to be asymptomatic had a large impact
- The incubation period was found to be critical to when measures can be relaxed
 - ▶ under an incubation period of 3 days measures could be relaxed in March, to produce the same effect under an incubation period of 7 days measures had to be lifted a month later in April

Quercus Quiz