Simulating COVID-19 Spread Using a Markov Random Walk Model

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Team 1

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Background and Motivation

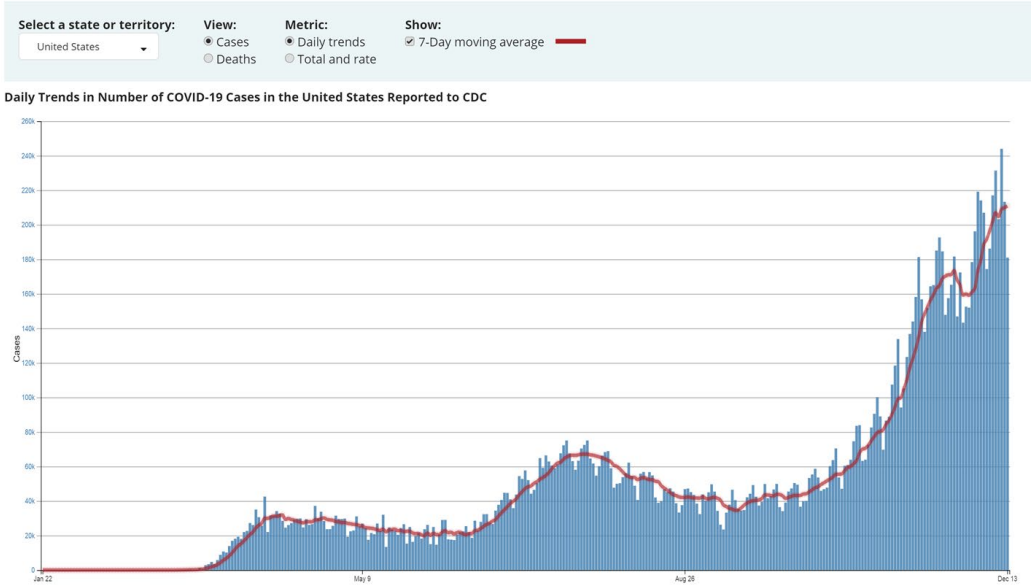
- SARS-CoV-2, or Covid-19, has caused a global Pandemic since late 2019

- Ever since the Pandemic started, numerous research efforts have been devoted to studying the transmission dynamics

- Many models have been developed to study transmission dynamics:
  - Deterministic: Using ODEs, such as the SIR model
  - Probabilistic: Using Markov random walk model

- Many government guidelines have been posted:
  - wearing mask, social distancing, and limiting large gathering
  - Some have questioned the effectiveness of such measures

- In this study, we use a Markov random walk model to investigate the effects of the three measures mentioned above

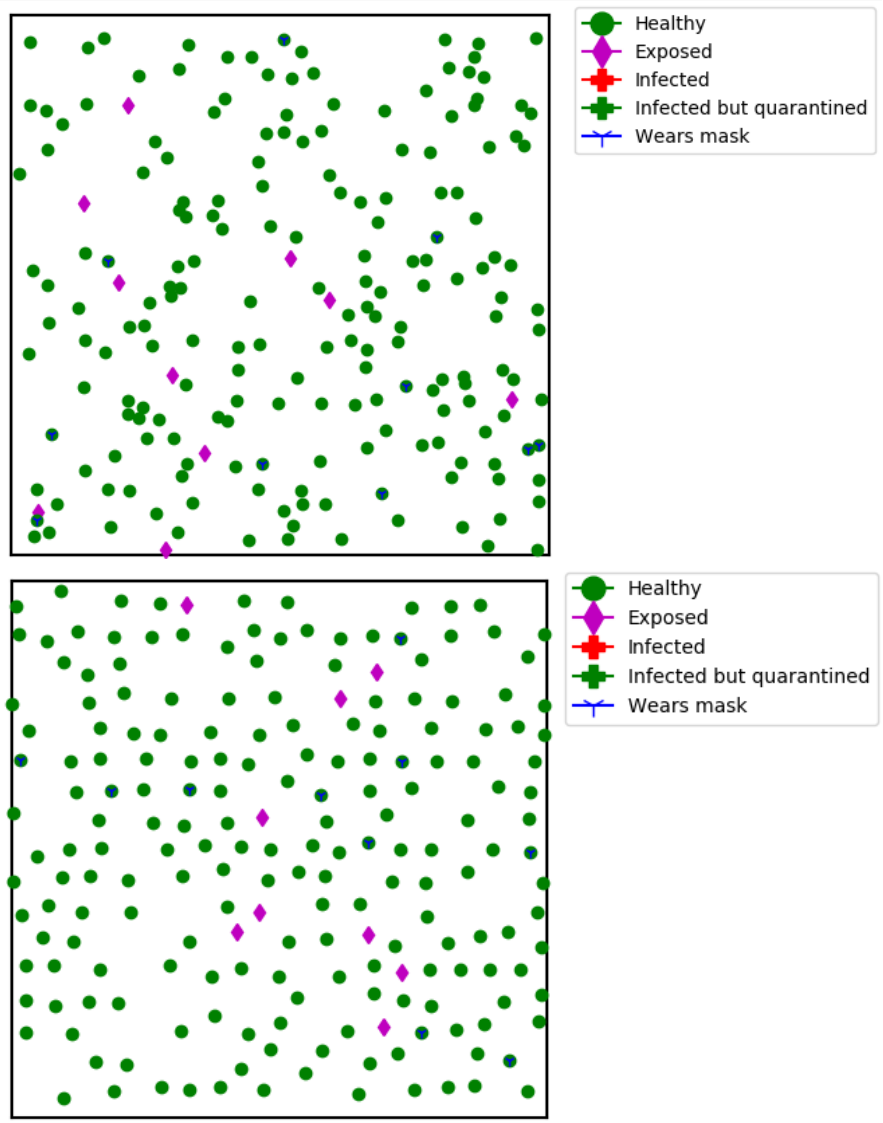


Covid-19 is still spreading throughout the U.S.

Method

- Initial condition:
  - Assign agents to random grid points
  - Move agent positions without transmission
  - Sample walking direction from a uniform distribution, distance from a Gaussian distribution
  - Check for overlap, or enforce social distancing
  - Randomly select a list of initial infectors and mask wearers

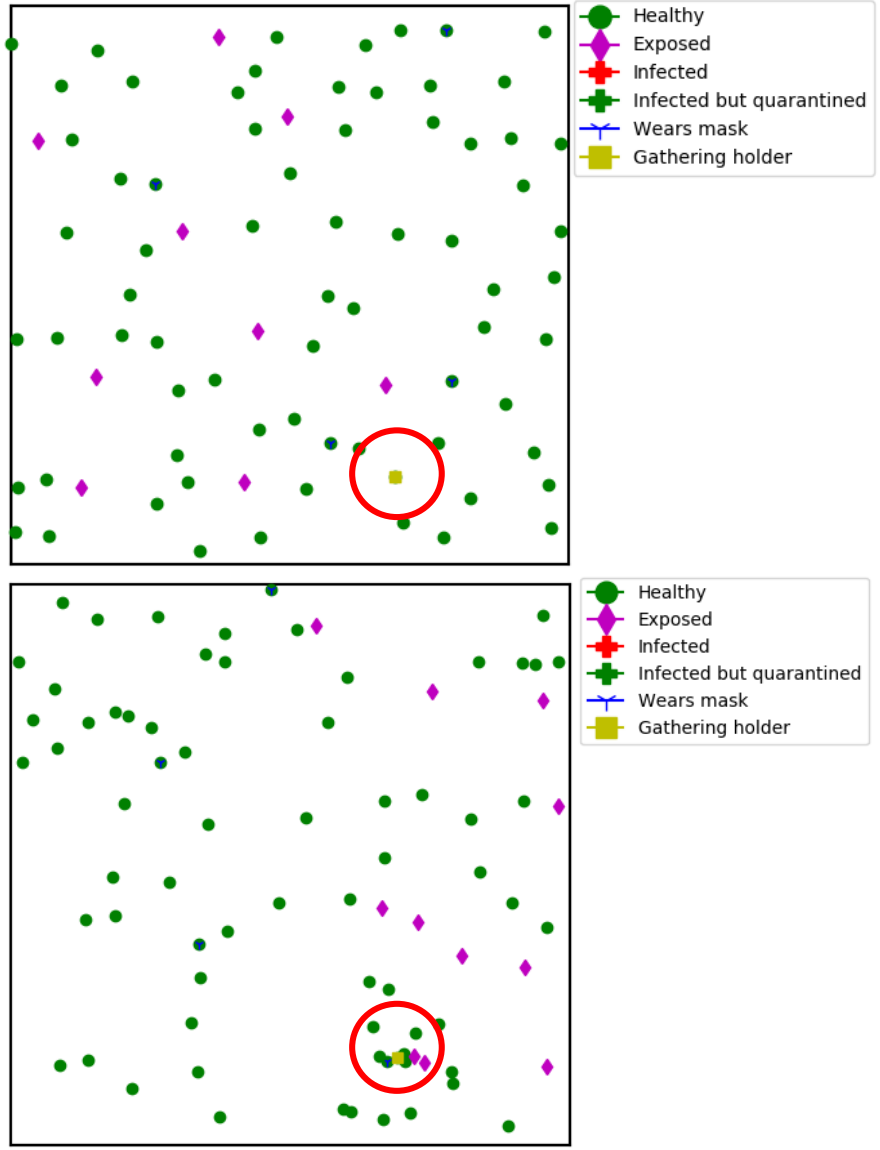
- Social distancing:
  - Obtain minimal distance to infected/exposed agents via KD tree
  - If no social distancing, reject the move if min dis. < 1.5ft
  - If social distancing, reject the move if min dis. < 6ft
  - Otherwise, accept the move with probability $P_{acc} = \exp\left(-\frac{d_m}{2}\right)$
  - Top: no social distancing, Bottom: social distancing



Method

- Holding gatherings:
  - Accomplished by a special move
  - Agent is to join the gathering if distance to host is less than a user tolerance
  - Agent coordinates updated as $X_{new} = X_{center} + \Delta d$
  - Δd is sampled from a Gaussian distribution, with maximum displacement limited
  - No social distancing enforced during gatherings
  - Top: Initial condition, Bottom: After 10 steps

- Susceptible to exposed:
  - Probabilistic, based on nearest distance to exposed agent
  - Minimal distance to exposed/infected agent is obtained from KD tree
  - Probability of being exposed is calculated as:
  - $P_{exposed} = C_{mask} P_0 [1 - tanh(\frac{d_c}{d_{ref}})]$
  - C_{mask} describes how much safer you will be with mask on
  - P_0, d_{ref} are to be calibrated to fit available data

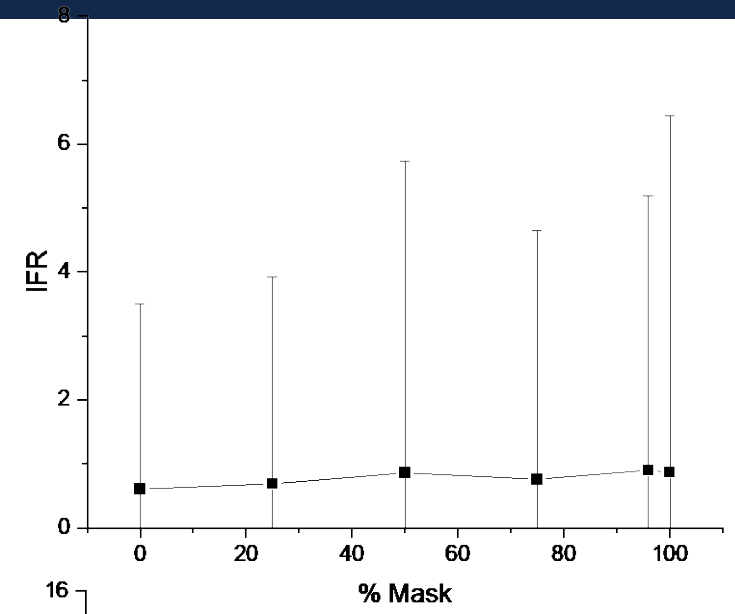


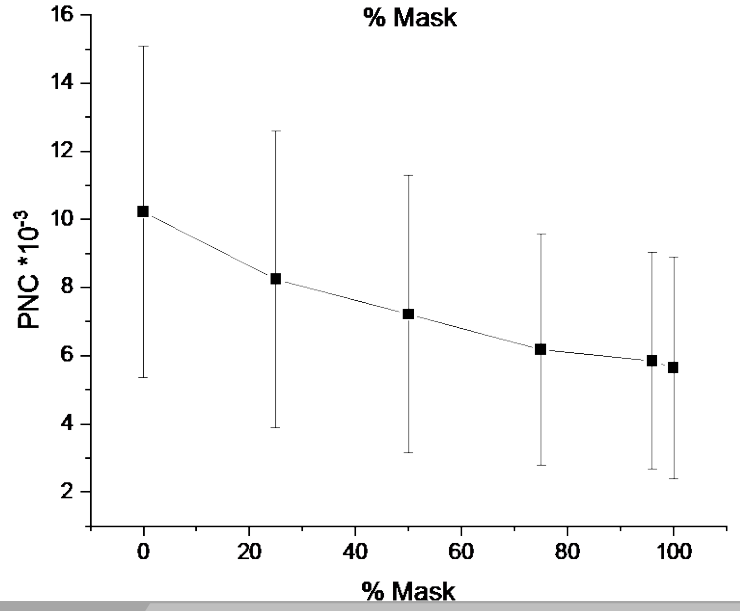
Results: Mask wearing percentage

- Simulations were repeated for 1000 runs, each run consisted of 150 time steps

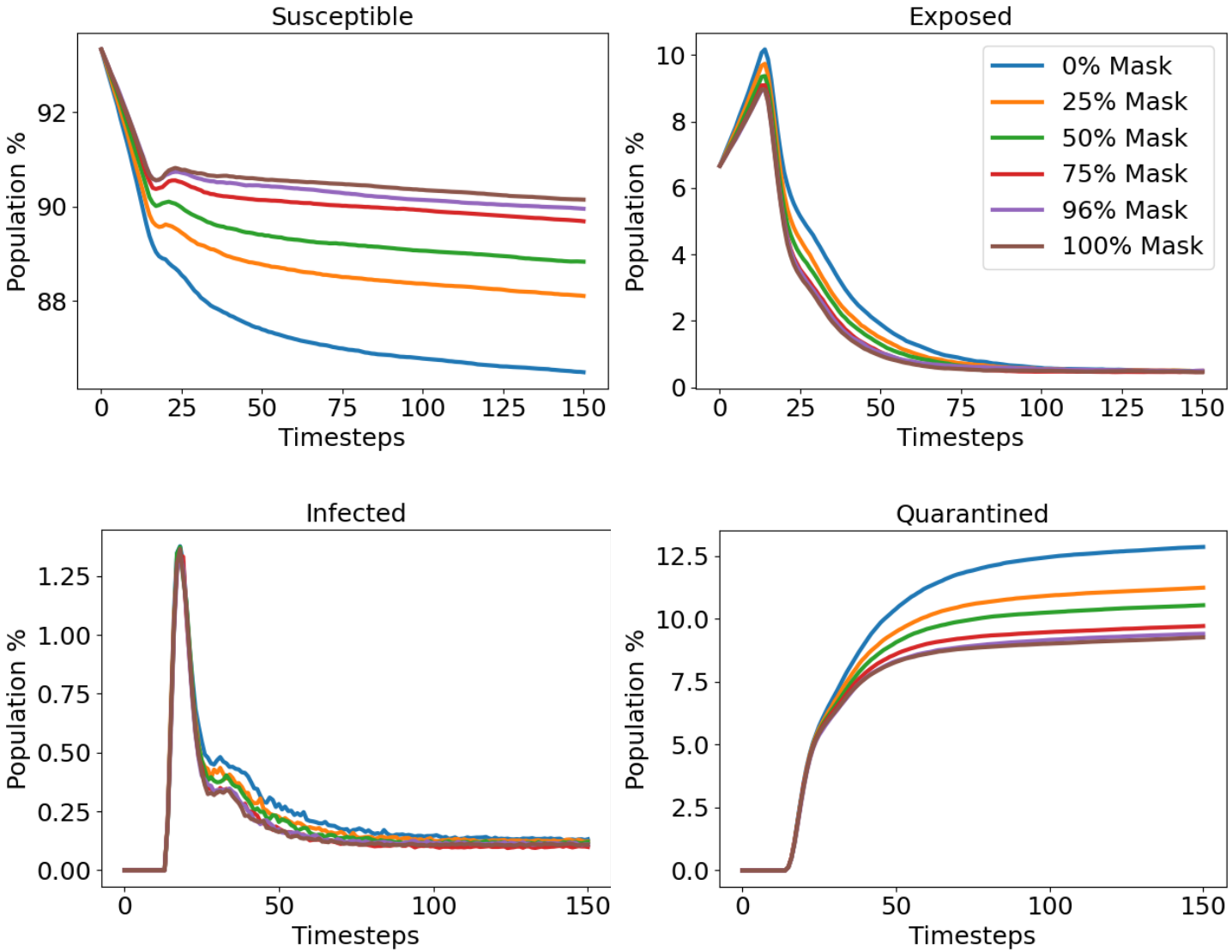
- Important metrics
  - Infection fatality rate, $IFR = \frac{Confirmed\ Deaths}{Confirmed\ Cases}$
  - Population normalized cases, $PNC = \frac{Total\ Cases}{\#\ of\ Agents}$

- Higher mask wearing rate means:
  - Lower PNC
  - Higher IFR (What????)
  - PNC decreases faster than the increase in IFR, so the population normalized death count, PNC*IFR, is lowered





Results: Mask wearing percentage



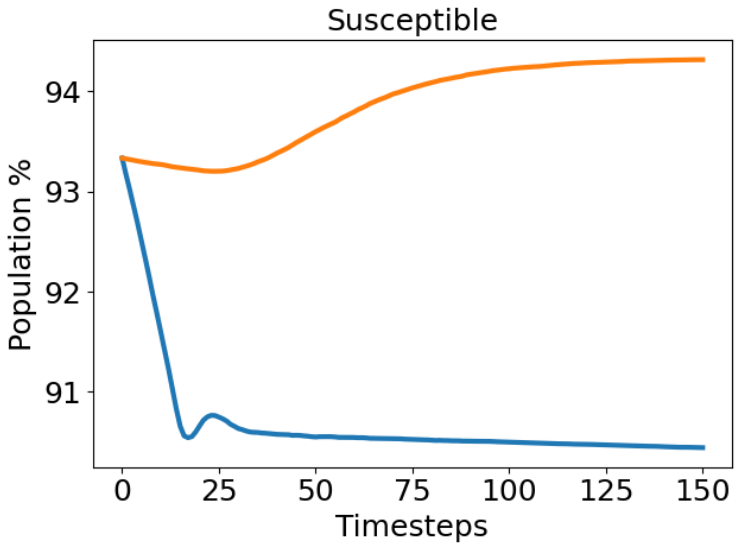
- Higher mask wearing rate means:
  - More agents remain healthy at steady state
  - Fewer exposed cases at peak
  - Lower quarantine and death rate
- All these metrics indicate that wearing masks is an effective way to slow down virus transmission

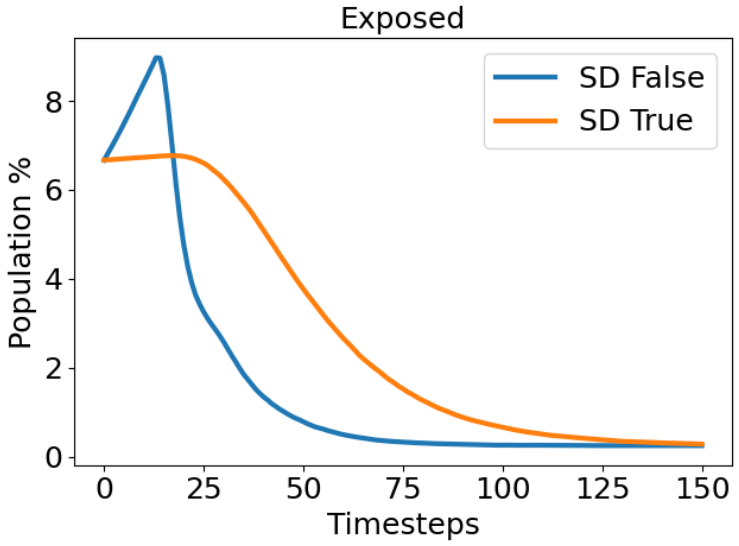
Results: Social distancing

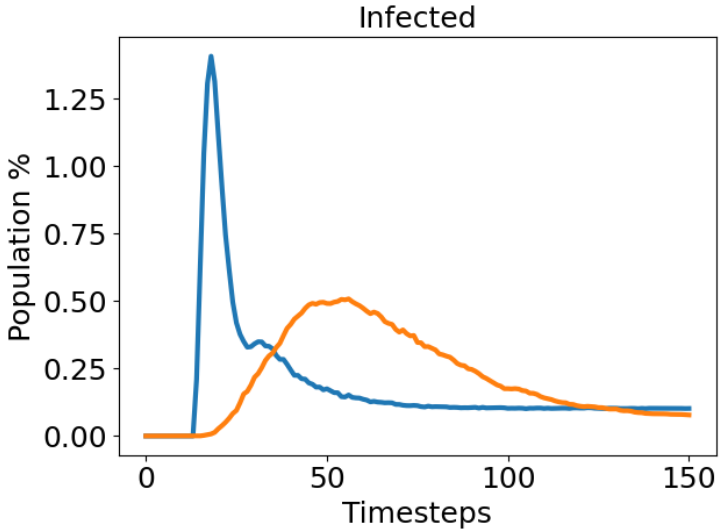
Table 1. Effect of Extreme Social Distancing on IFR and PNC				
Social Distancing	IFR (%)	IFR SD	PNC (%)	PNC SD
FALSE	**1.02**	3.54	**6.25**	3.78
TRUE	**~0***	~0*	**0.39**	0.55
***Values were less than 10^{-2}%**				

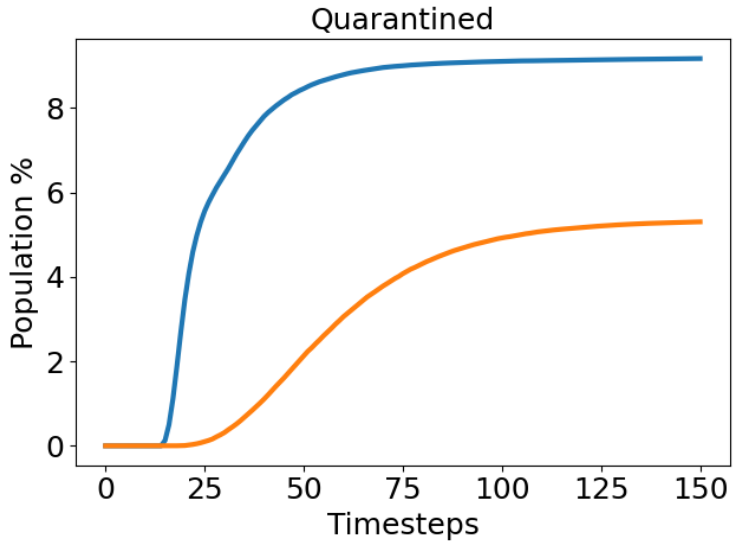
- Simulations were repeated for 3000 runs, each run consisted of 150 time steps
- Social distancing means:
  - Lower IFR (fewer deaths)
  - Much lower PNC (fewer cases)

Results: Social distancing









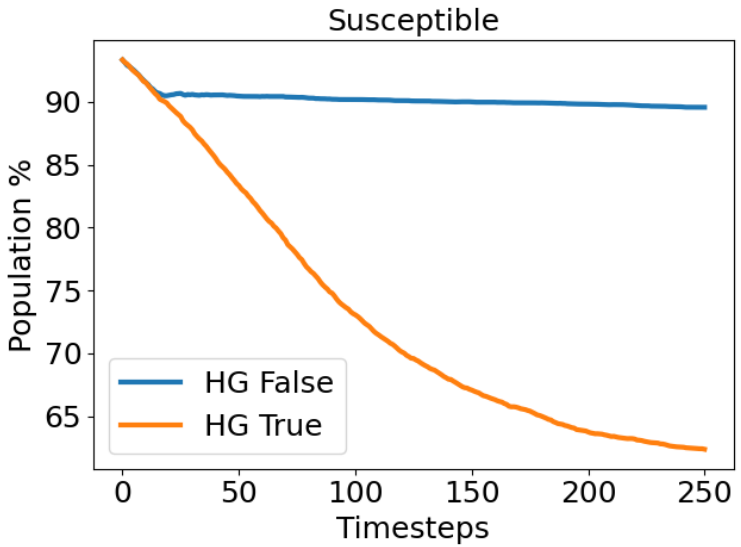
- Social distancing means:
  - Much, much more agents remain healthy at steady state
  - Fewer exposed cases at peak
  - The infected curve is efficiently flattened
  - Lower quarantine and death rate
- Social distancing works as an effective measure to slow down the spread and flatten the curve!

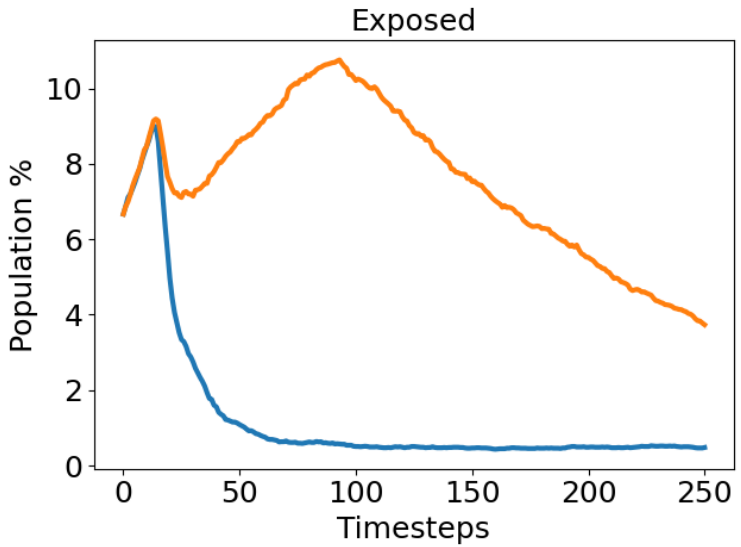
Results: Large social gatherings

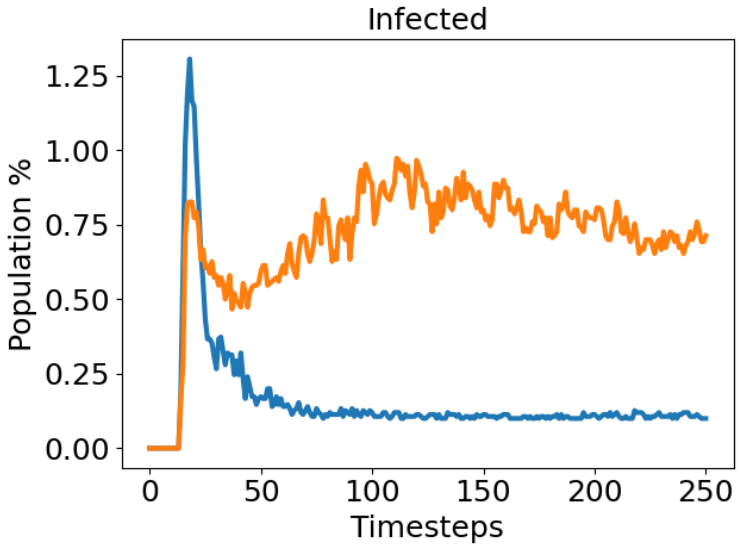
Table 2. Effect of Gatherings on IFR and PNC				
Gatherings	IFR (%)	IFR SD	PNC (%)	PNC SD
FALSE	**1.44**	5.72	**6.39**	4.28
TRUE	**0.36**	1.1	**39.8**	22.85

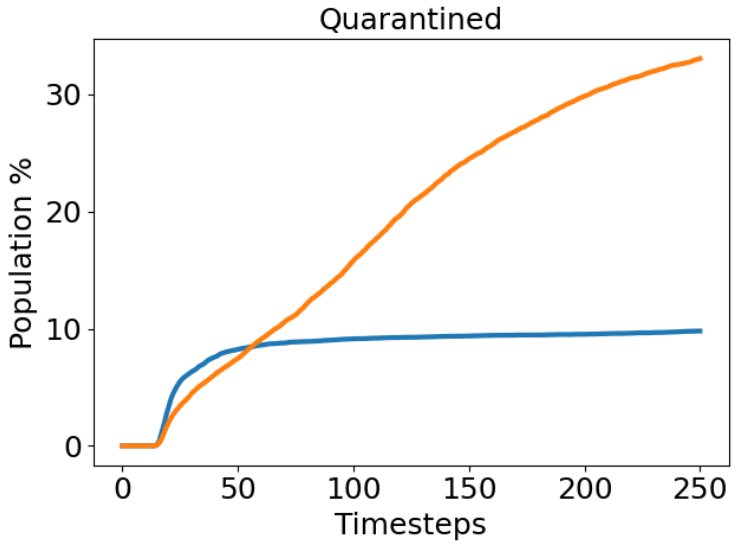
- Simulations were repeated for 3000 runs, each run consisted of 250 time steps
- One gathering was introduced
- Having large gatherings means:
  - Lower IFR (Good thing??)
  - Much higher PNC
  - Overall, leads to more deaths

Results: Large social gatherings









- Having large gatherings means:
  - Much, much more agents fall sick
  - First peak of exposed cases is similar, but having gathering leads to a second peak
  - The infected curve fails to decrease after initial peak
  - Quarantine nearly triples
  - Almost double the death rate
- Having large gatherings without obeying social distancing rules can very likely lead to super-spreader events!

Conclusion

- Implemented a Markov random walk model to simulate transmission dynamics of Covid-19
- Social distancing introduced through a distance-based rejection technique, large gatherings emulated through a special move function
- Probability of getting exposed is distance-based, with distance calculated by a KD tree
- Mask wearing slow downs the transmission, leads to more healthy agents and fewer deaths
- Social distancing is effective in flattening the curve, and lowering the death rate
- Having large gatherings without social distancing leads to more cases and possible even a second peak in exposed cases

Thank you!

Questions?

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