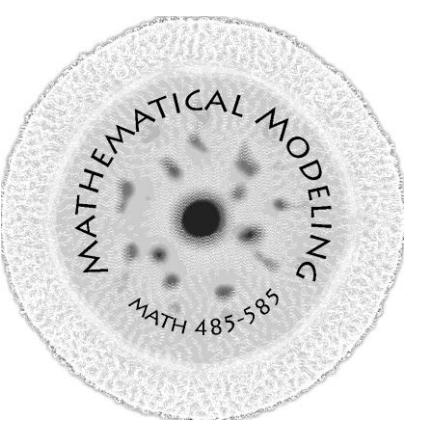




# Epidemics with Pathogen Mutation on Small World Networks



## Abstract

- Bit-string model emulates pathogen mutation.
- Agent based model combines bit-string and SIRS in a realistic socio-spatial network called a small world network.
- Study the spread of pathogens in a realistic setting.
- Guide implementation of eradication methods effectively and efficiently.
- Increase realism through parameter modification of mutation and immunity data.

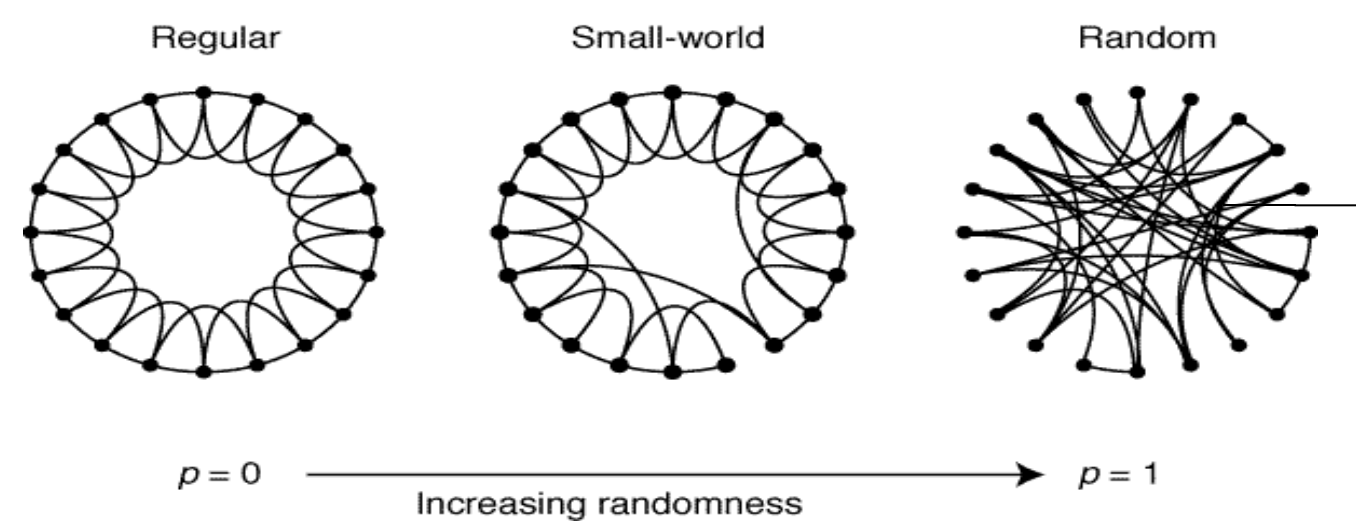
## Scientific Challenges

- Mathematical models can help predict the behavior of infectious agents.
- Accounting for pathogen mutation and time-dependent immunity within the small-world paradigm leads to a more realistic model.

## Potential Applications

- Improved vaccination methods and eradication programs.

## Methodology



Random rewiring procedure for interpolating between a regular ring lattice and a random network

D.J. Watts and S.H. Strogatz p. 440

- A **Small World Network** of  $N$  nodes models a socio-spatial network. Connections between nodes are rewired, with probability  $p = .01$ , creating a clustered and connected graph.
- Pathogens are represented by 10 digit bit-strings
- The **Immunity Repertoire** stores a node's history of infection.
- The epidemic begins with one random node infected with the initial pathogen strain [0000000000].
- Each infected node sends challenge strains to its neighbors.
- Infection occurs if the minimum Hamming-distance between the challenge strain and strains in immunity repertoire exceeds the cross-immunity threshold,  $h_{thr} = 2$ . Mutations occur with probability  $\mu = 0.005$ .
- Normal nodes infectious for Infection Duration,  $T_I = 1$ . **Population at Risk** nodes are infectious for  $3T_I$ . Thereafter, strains remain in the Immunity Repertoire for Immunity Duration,  $T_R = 150$ .
- Model run numerically for each set of parameters over ten different networks with at least fifty runs per network. Graphs are averaged data sets.

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## Results

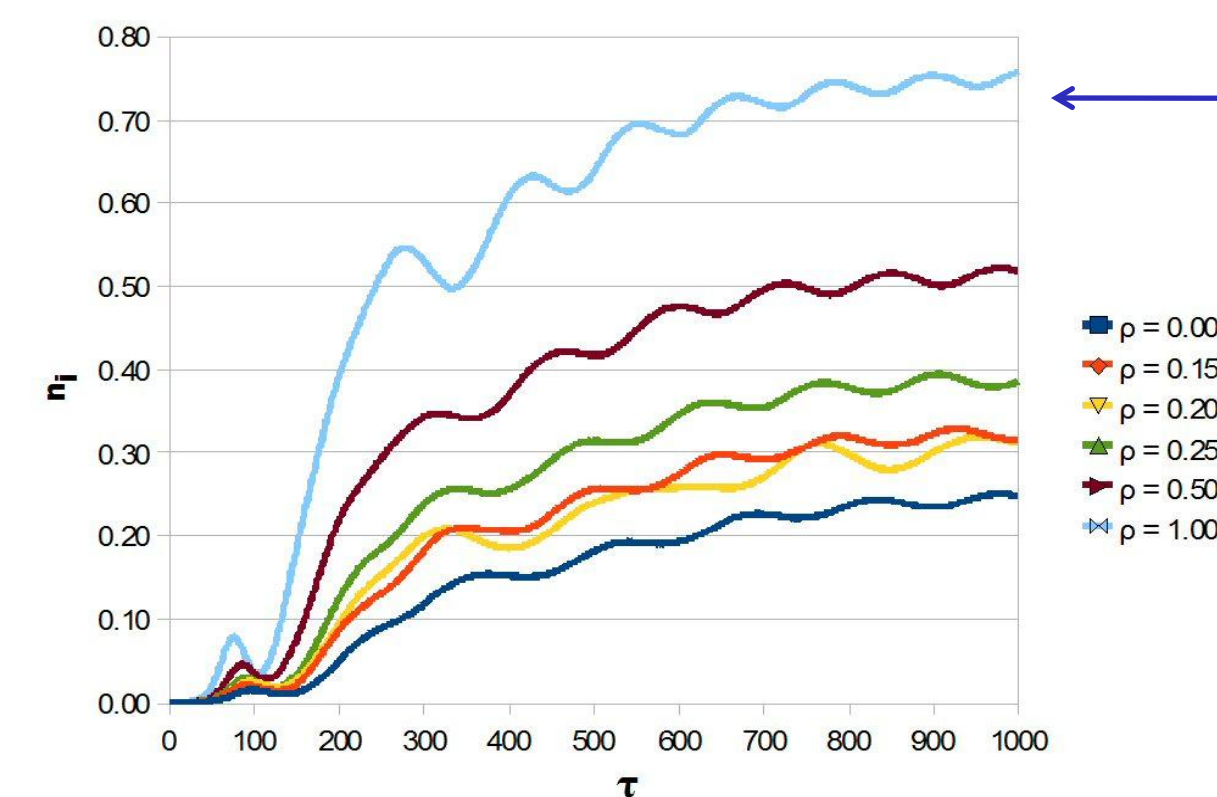


Fig. 1 Fraction of infectious individuals,  $n_I$ , as a function of time step,  $\tau$ , for various proportions,  $\rho$ , of the total population, representing the **Population at Risk**.

- Maximum cost-effectiveness of vaccination schemes achieved when approximately 20%-30% of population is vaccinated.

- Vaccination event. Vaccine composed of original strain, plus 1<sup>st</sup> and 2<sup>nd</sup> generation mutations.

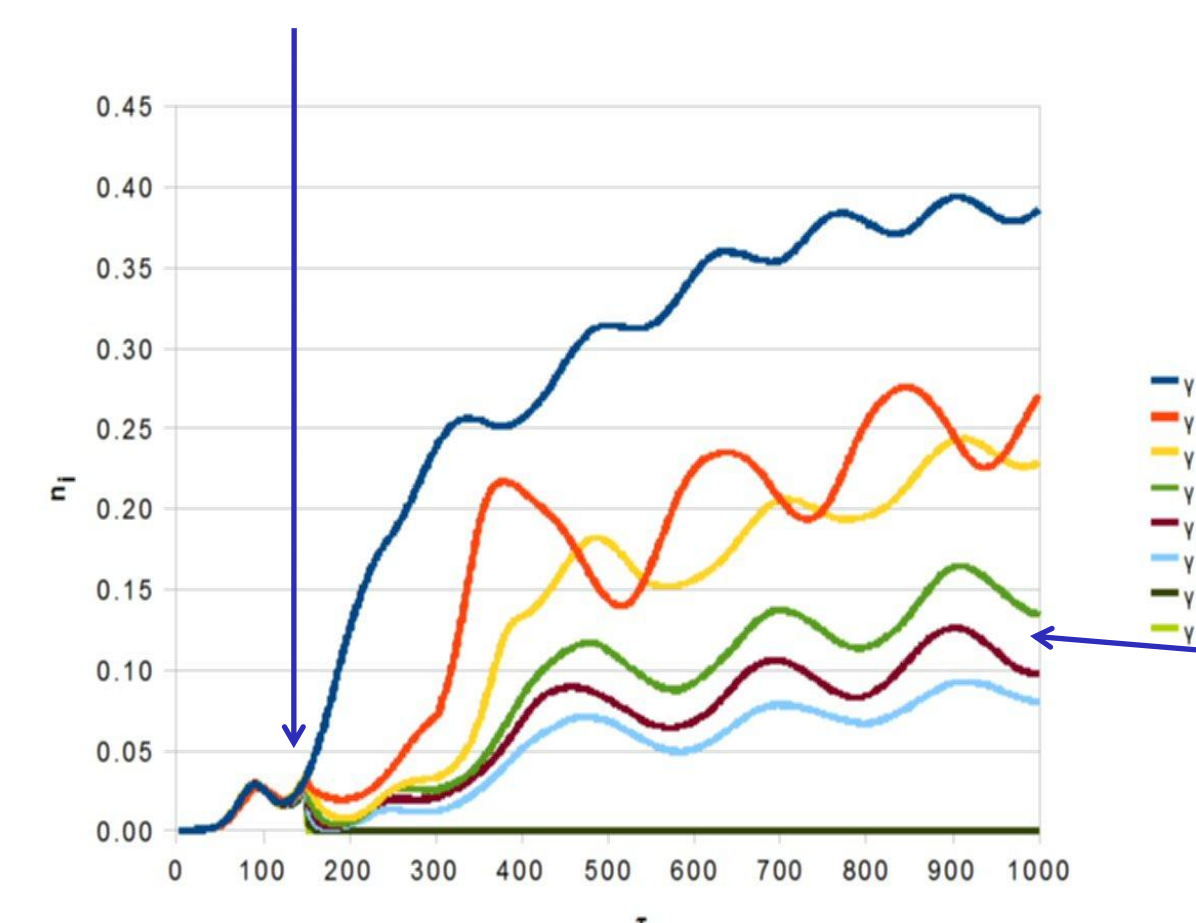


Fig 3. Fraction of infectious individuals,  $n_I$ , for various proportions,  $\gamma$ , of a random selection of the population.

- As the **Population at Risk** becomes a larger proportion of the total population, the fraction of infected individuals saturate at higher levels.

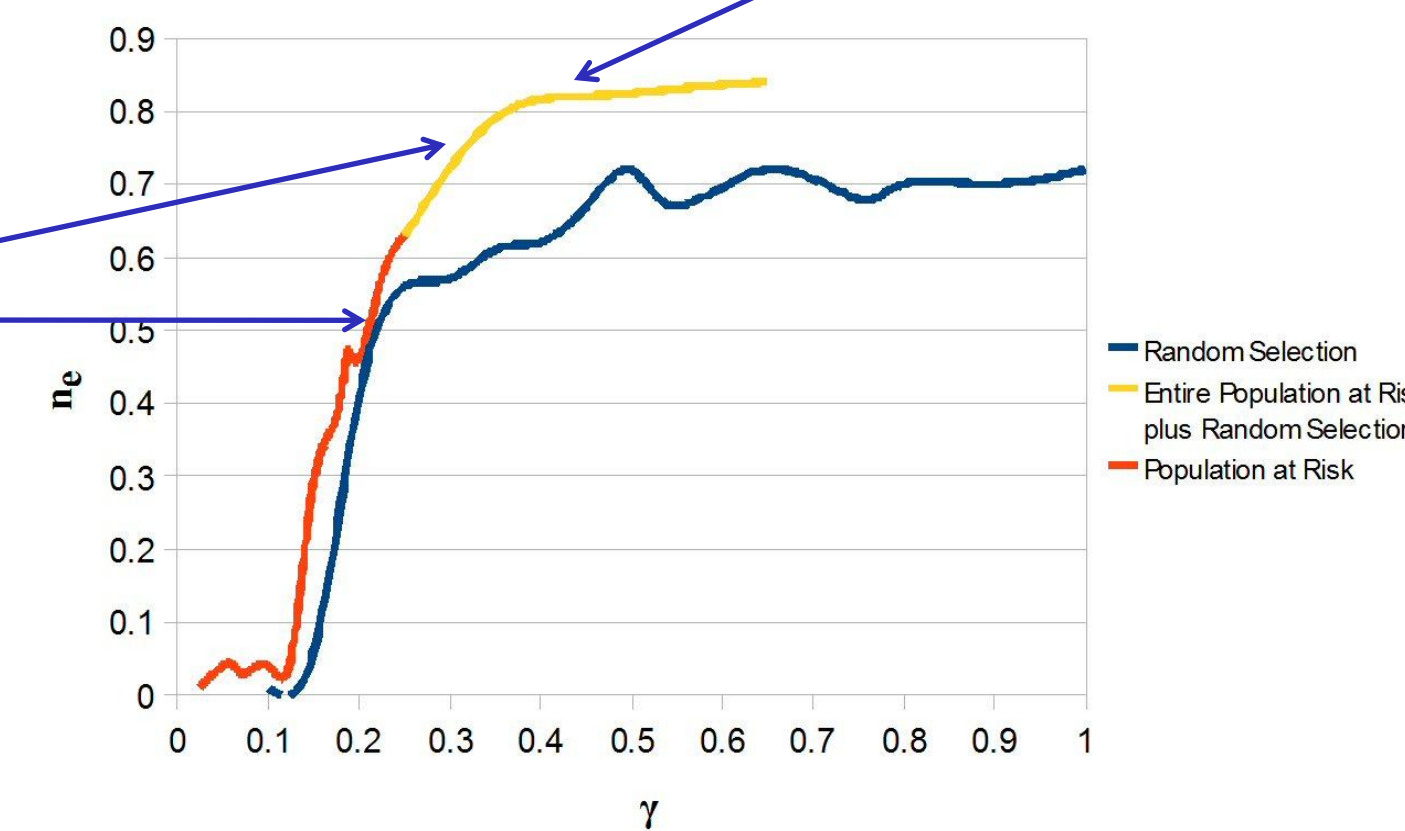


Fig 2. Fraction of trials,  $n_e$ , which led to extinction of all pathogen strains from the population for various proportions vaccinated,  $\gamma$ . Here,  $\rho = 0.25$ , which is typical of influenza-type pathogens.

- Typical time-dependent behavior of some trials vaccinating a random proportion of the population.

## Summary

- The inclusion of a sub-population, the **Population at Risk**, with more severe and longer-lasting symptoms, modeled with a longer Infection Duration, results in a more realistic model of pathogen spread.
- Short term behavior post-vaccination: drastic reduction of the number of infectious individuals.
- Long-term behavior depends on success of vaccine. Pathogens may be eradicated from the population, or lead to a second wave of epidemic.
- Even when large proportions of the population are vaccinated, pathogens may persist due to mutation.
- Targeting vaccinations to the **Population at Risk** is more effective in combating an outbreak.

## Glossary of Technical Terms

- $N$ : Population size
- $2k$ : Average number of neighbors
- $p$ : Network randomness (probability of node connections rewiring)
- $T_I$ : Infection Duration
- $T_R$ : Immunity Duration
- $\mu$ : Mutation probability
- $h_{thr}$ : Cross-immunity threshold (antigenicity)
- $l$ : Pathogen representation length
- $\rho$ : Proportion of the population representing the **Population At Risk**
- $\gamma$ : Proportion of the population vaccinated at time, 150.
- SIRS**: susceptible to infection S, infected I, and immune R
- Immunity Repertoire**: A node's history of infections
- Population At Risk**: Sub-population more heavily impacted by an outbreak.

## References

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1. D.J. Watts and S.H. Strogatz, *Collective dynamics of 'small-world' networks*, Nature **393**, 440-442 (1998).

## Acknowledgments

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