Comparing Agent-Based and Continuous Compartmental Epidemiology Models

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computational epidemiology research

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Background

Agent-based epidemiology models are increasing popular in application where random mixing assumptions are unreasonable. One such scenario is when structural or architectural constraints preclude the possibility of mixing randomly, as in the modeling of nosocomial infection. We investigate the differences between an agent-level epidemiology model and a compartmental differential equation model, with specific interest investigating the effect of patient churn and data degradation on the spread of nosocomial infection.

Both the agent-level and the continuous model assume knowledge of contact behaviours of the population in question. In this study, we draw contact information from two sources: first, contacts recorded from shadowing personnel of the University of Iowa Hospitals and Clinics, and second, a contact network constructed from access to Electronic Medical Records from the University of Iowa Hospitals and Clinics. The agent-level model generates a contact network with node populations and edge distributions consistent with recorded data. The compartmental model used is given here:

$$\frac{d}{dt}S_i = -\sum_j \left[s_i \frac{S_i}{N_i} C_{ij} \frac{e_j E_j + i_j I_j}{N_j} \right]$$

$$\frac{d}{dt}E_i = \sum_j \left[s_i \frac{S_i}{N_i} C_{ij} \frac{e_j E_j + i_j I_j}{N_j} \right] - \frac{1}{\tau_E} E_i$$

$$\frac{d}{dt}I_i = \frac{1-q}{\tau_e} E_i - \frac{1}{\tau_I} I_i$$

$$\frac{d}{dt}R_i = \frac{q}{\tau_e} E_i + \frac{1}{\tau_I} I_i$$

- S_i, E_i, I_i, and R_i represent the number of Susceptible, Exposed, Infected, and Recovered agents of type *i*, respectively.
- N_i denotes the total population of agent type i.
- s_i, e_i, and i_i denote susceptibility of class S_i and infectiousness of classes E_i and I_i, respectively.
- C_{ij} denotes the number of contacts expected between agents of type i and j in one unit of time.
- τ_E and τ_I denote the incubation and recovery periods, respectively.
- q denotes a rate of quarantine.

Experiments

First, we examine the baseline comparison of the agent-level simulator and the continuous model in the context of nosocomial infection. We use assume a fixed population of 18 personel types plus patients, with infection parameters based on influenza. The results are show in Fig. 1.

In practice, contact recording techniques are flawed or imcomplete. The effect of data loss, in terms of quality and/or grainularity, plays an important role. We investigate the effect of such data loss, comparing the effect of using contact models based on differing length-of-contact thresholds. Such data loss may be expected in passive monitoring systems, where length-of-contact may correlate to quality of data. Results are show in Fig. 2.

While fixed population models are reasonable for infections that are quick relative to population change, such as nosocomial infection in long-term caregiving units, the effect of "patient churn" may play an important role. The results are given in Fig. 3.

Results

We see that the estimations made by the differential equations models are consistently higher than the discrete models. This may be due to the fact that at the discrete level, certain individuals may act as gateways between groups of contacts; as these agents are vaccinated, the discrete graph becomes disjointed and transmission is stayed. This is most notable in Fig. 2, where the loss of data and subsequent disconnection of the graph drives infection to near-zero regardless of vaccination rates.

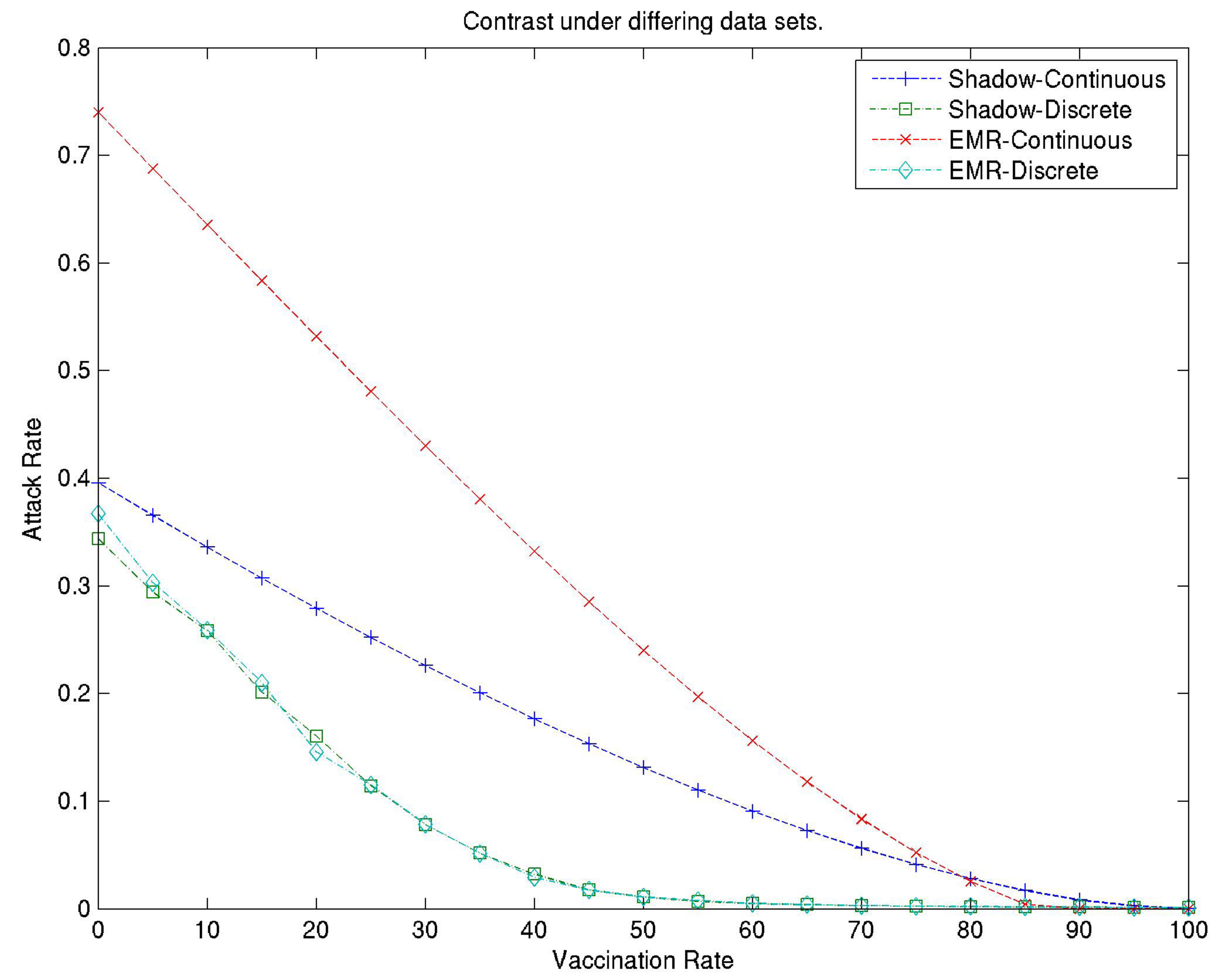

Fig. 1.
A comparison of each model under two data sets:
While the agent-based simulator behaves consistently across each data set, the continuous model sees a large increase in infection. This may be due to the EMR-network having may more contacts per unit time; in the severe case, initial infection can progresses to all immediate neighbors. However, in an agent-based simulator, this is a small subset of the population as a whole, whereas the continuous model will assumes complete connection of the entire population.

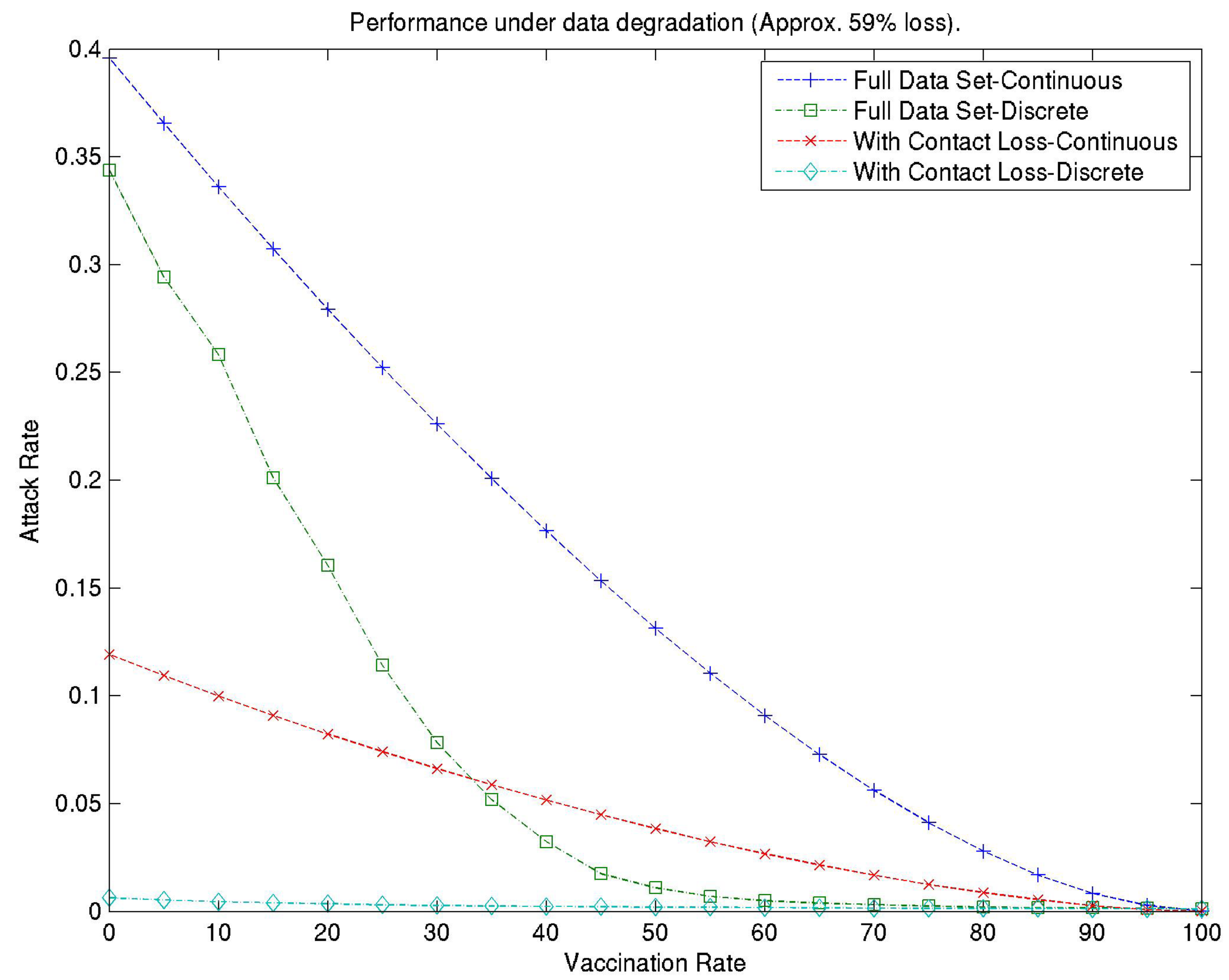

Fig. 2.
Performance under data degradation:
Contacts recorded in the shadowing dataset include a measure of the duration of contact. Here, we compare the two sets of finest grainularity. Approximately 59% of all contacts were among the shortest designation. This severly fractures the agent-based contact network, resulting in no transmission regardless of vaccination rate.

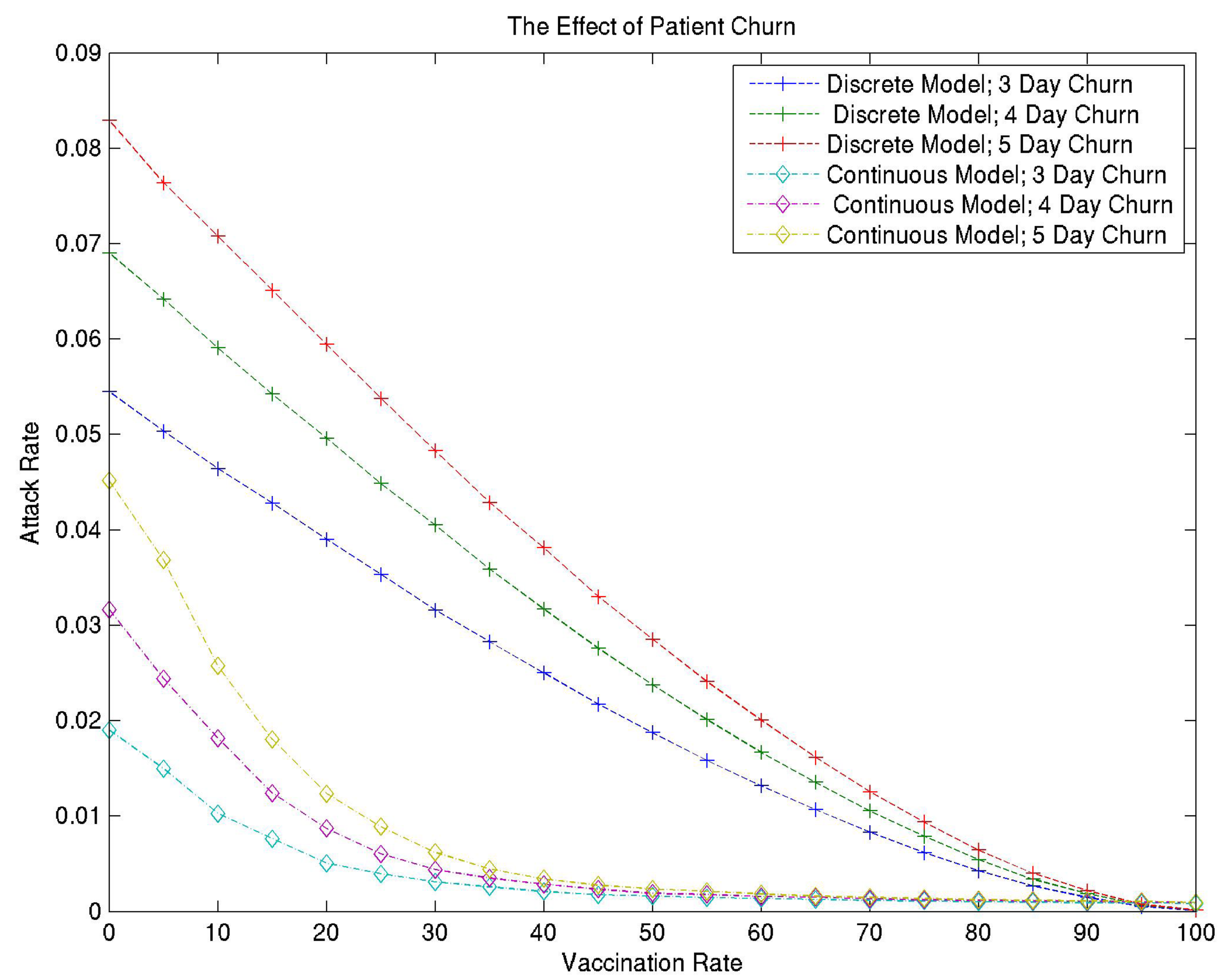

Fig. 3.
The effect of patient churn:
Here, we see attack rates using the two models under differing expected lengths of stay. In both models, attack rates decrease with expected lengths of stay, likely because we may discharge an exposed individual before infection becomes apparent and before the individual can significantly spread infection.

Third International Confernce on Infectious Disease Dynamics (Epidemics^3)
[P1.97] Comparing the Performance of Agent-Based Epidemiology Models with Continuous Compartmental Models