A Cellular Automata Model of the Spread of HIV in a Community of Injection Drug Users

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Background

Intravenous drug users (IDU) sharing needles for injecting illicit drugs are highly vulnerable to HIV infection because transmission of the virus via contaminated needles is very efficient. The spread of HIV infection in an IDU community additionally depends on the social context for contact patterns among drug users. We present a preliminary version of a general cellular automaton model for the impact of social influences on the spread of HIV/AIDS through sharing contaminated needles within an IDU community.

The model uses a novel approach of *social counters* to track positive and negative social influences with respect to drug use among groups of individuals. Groups are defined based on drug use, attitudes to drug use and HIV status (see below). While sharing of contaminated needles is a social interaction, actual transmission of the virus depends on physical and biological constraints. Therefore, an IDU in contact with HIV-infected neighbours, can contract the HIV virus according to an estimated per contact probability of viral transmission through contaminated needles.

As shown in the figure to the right, all individuals can influence others in the community, and, with the exception of "Stayers", all individuals can be influenced by their peers. For the sake of simplicity, Stayers in this model can only exert a positive influence — either discouraging their peers from initiating drug use or encouraging them to quit. However, Susceptibles, IDU, HIV-infected IDU, and HIV-infected individuals who are not using drugs have the capacity to both encourage their peers to initiate or continue to use drugs or discourage them from doing so. Social influences can also occur within a particular group. These can be envisioned as influences of group members on each other, combined with the risk behaviour strategy of each individual in the group. This general model incorporates behavioural flexibility and a broad range of interactions so it can easily be modified to test various social scenarios.

With the appropriate modifications, the model can be used to study the HIV epidemic in Vancouver's Downtown Eastside (DTES), which has the largest IDU community in Canada. 30-40% of IDU in the DTES are estimated to be infected with HIV [1]. The DTES is the poorest neighbourhood in Canada and struggles with persistent social problems including homelessness, unemployment and crime. Despite the successes of harm reduction programs, such as the Supervised Injection Facility, Insite, HIV prevalence remains high in the DTES. Cellular automata offer a means of exploring the dynamics of the spread and persistence of HV in this complex community.

Description of the Model

AGENTS

Stayer is someone who will never use drugs. Once a cell is initialized as a stayer it is fixed and cannot change state. Stayers exhibit positive influences on their neighbours encouraging them away from drug use.

Susceptible is someone who does not currently use drugs via injection, but could become an injection drug user (IDU) at some time in the future. The only state that a susceptible can transition to is an IDU. Susceptibles may exhibit positive or negative influences on their neighbours.

IDU is an injection drug user who does not carry the HIV virus. An IDU could possibly contract HIV from one of its IDU-HIV neighbours thus transitioning to the IDU-HIV state. An IDU could also decide to quit using drugs and thus transition to a susceptible. IDUs may exhibit positive or negative influences on their neighbours.

IDU-HIV is an injection drug user who carries the HIV virus. An IDU-HIV who quits using drugs becomes an HIV. IDU-HIVs may exhibit positive or negative influences on their neighbours.

HIV is someone who contracted the HIV virus through injection drug use and then stopped the use of drugs. At any point an HIV can be influenced to start using drugs again thus making the transition back to IDU-HIV. HIVs may exhibit positive or negative influences on their neighbours.

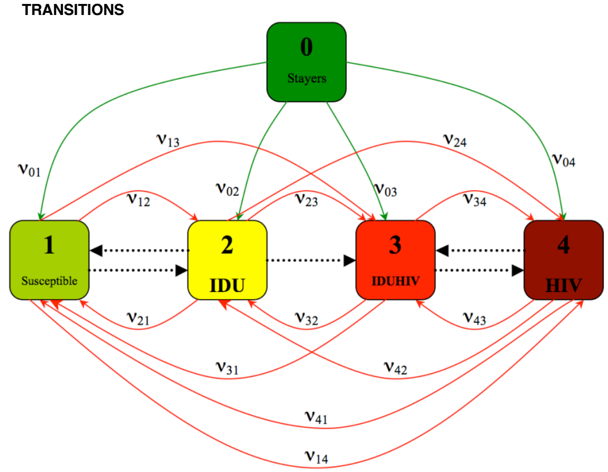
COUNTERS

This model aims to represent the social relationships amongst a community of IDUs. Therefore all updates that occur are time dependent. For example, a person is more likely to experiment with drug use after a prolonged relationship with an IDU. To represent this time dependency, a counter, which records the influences of one's neighbours on a cell, is associated with each cell. The equations of the counters are as follows: (Note: there is no counter for stayers because they cannot change state.)

$$C_1(t) = C_1(t-1) + R_0 v_{01} + R_1 u_1 + R_2 v_{21} + R_3 v_{31} + R_4 v_{41}$$
$$C_2(t) = C_2(t-1) + R_0 v_{02} + R_2 v_{12} + R_2 u_2 + R_3 v_{32} + R_4 v_{42}$$
$$C_3(t) = C_3(t-1) + R_0 v_{03} + R_1 v_{13} + R_2 v_{23} + R_3 u_3 + R_4 v_{43}$$
$$C_4(t) = C_4(t-1) + R_0 v_{04} + R_1 v_{14} + R_2 v_{24} + R_3 v_{34} + R_4 u_4$$

where $0 \le R_i \le 8$ and u_i is the influence that a particular group has upon themselves for i = 0,…,4

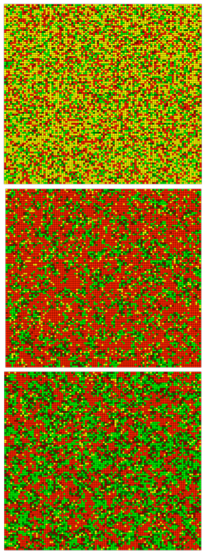
SOCIAL INTERACTIONS AND TRANSITIONS



RULES

1) Update of a susceptible:
   a) a susceptible dies after τ_1 time steps. A dead cell re-enters the system as any one of the five states with unequal probabilities as determined at initialization.
   b) if $C_1 \le -1$ then the susceptible becomes an IDU.
   c) otherwise it remains a susceptible.
2) Update of an IDU:
   a) an IDU dies after τ_2 time steps. A dead cell re-enters the system as any one of the five states with unequal probabilities as determined at initialization.
   b) for each IDU-HIV in its neighbourhood the IDU has probability $p = 0.67\%$ of contracting the disease and becoming an IDU-HIV for each risky needle exchange.
   c) if the IDU does not contract HIV and $C_2 \ge 1$ then the IDU becomes a susceptible.
   d) otherwise it remains an IDU.
3) Update of an IDU-HIV:
   a) an IDU-HIV dies after carrying the disease for τ_3 time steps. A dead IDU-HIV re-enters the system as any one of the five states with unequal probabilities as determined at initialization.
   b) if the IDU-HIV does not die and $C_3 \ge 1$ then the IDU-HIV becomes an HIV.
   c) otherwise it remains an IDU-HIV.
4) Update of an HIV:
   a) an HIV dies after carrying the disease for τ_4 time steps. A dead HIV re-enters the system as any one of the five states with unequal probabilities as determined at initialization.
   b) if the HIV does not die and $C_4 \le -1$ then the HIV becomes an IDU-HIV.
   c) otherwise it remains an HIV.

Simulation of a Possible Social Scenario in Vancouver's Downtown Eastside



ASSUMPTIONS

When available, parameter estimates were drawn from published sources [2, 3]. The community is composed of 70% IDU, with 35% of these infected with HIV, 20% susceptibles; 5% non-drug user HIV+ individuals and 5% stayers.

All individuals in the model are older than 15 years of age. Mortality is incorporated by using the average DTES life expectancy of 75 years for any person not infected with HIV. HIV-infected individuals have a life expectancy of 3 to 8 years from the moment of infection. Any person that dies in the simulation is replaced according to the initial proportions of individual types defined above.

At the start of the simulation agents are considered to have a "history" of HIV infection, with a randomly assigned length of 1 to 96 months (8 years). Each IDU is assumed to inject on average 3.6 times / day. 40% of IDUs are considered to share needles. The probability of transmission of the HIV virus through a contaminated needle is taken to be 0.67% [4].

Stayers exert the strongest positive social influence on their peers of 1/50. Susceptibles and non-user HIV infected persons exert a weaker but still positive influence on their peers of strength 1/100. In contrast, Both infected and non-infected IDUs exert a negative influence of strength -1/100.

OBSERVATIONS

The figures to the left show simulation results for the DTES scenario. The top square shows the initial conditions, the middle one is the result after 100 time steps and the bottom one is the final result after 200 time steps (months). This scenario results in an initial explosion of the HIV epidemic (middle square). Loss of HIV infected individuals through death follows in subsequent steps . At the end of the simulation we observe very few non-infected IDUs (yellow cells) and a majority of susceptibles (light-green) cells, demonstrating the impact of reducing IDU behaviour and HIV prevalence due to the positive social influence existing in this simulated community.

Conclusions

We show how cellular automata can be used to model the impact of social interactions on the spread of HIV in a community of injection drug users. Future work will focus on developing the DTES scenario further with more realistic assumptions.

One advantage of cellular automata models is the potential to represent social phenomenon in space. In the model presented here cells represent individuals. However, the model can be developed so that cells represent geographic units, such as city blocks. The spatial dimension is important in the DTES example because drug-related activity is known to be non-randomly associated with certain landmarks.

One of the main new ideas in this work is the combined use of the social counter and the transition probability to account for both social and biological transition processes.

References

[1] Vancouver Coastal Health (2003). Injection Drug Use in the DTES. *News Release, September 15, 2003*

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Acknowledgments

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