Using Cellular Automata to Model the Spread of HIV among Injection Drug Users

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HIV

Vancouver's Downtown Eastside, one of the poorest neighborhoods in Canada, is home to over 5000 injection drug users and has high rates of HIV infection. About 30% of the Downtown Eastside population has HIV. Needle sharing among injection drug users is one of the predominant reasons for the spread of the virus. Once an individual becomes infected with HIV, they progress through the following stages:

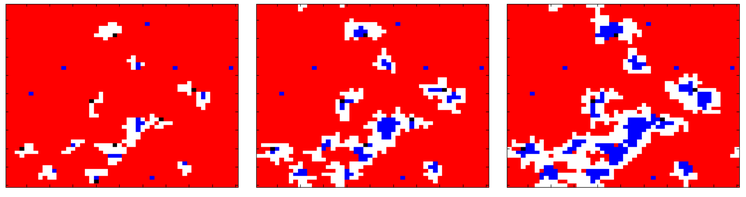
- Initial Stage - highly infectious - 2 months
- Clinical Latency Stage - less infectious - 8 to 10 years
- AIDS Stage - highly infectious - 1 to 2 years

HAART Treatment

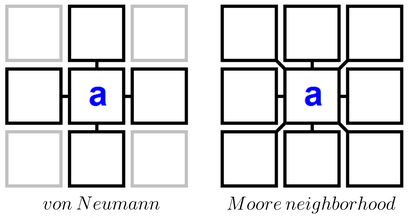
Highly Active AntiRetroviral Therapy (HAART) is a treatment for infection by retrovirus, such as HIV. Individuals undergoing treatment take a combination of drugs at several times throughout the day. HAART does not cure an individual of HIV, but general health and quality of life are typically improved among HIV infected individuals. If the right treatment is followed, HAART has been shown to boost the life expectancy of patients to 32 years from the time of infection. However, there are some issues with HAART. Side-effects from the treatment can be grueling and daily regimens can be tough for patients to follow.

Cellular Automata

A cellular automaton is a discrete model made up of a grid of cells, each one in one of a finite number of states. The grid can be any finite number of dimensions. The model is run for a certain number of steps, with the grid being updated at every step. Each cell interacts with other cells in the model and is updated according to this interaction. Cellular automata models are useful because they allow us to look at the global impact of local interactions.



To model an interaction, we must define two things for each cell. First we must define each cell's neighborhood. A neighborhood is simply a list of cells that a given cell will interact with, and will typically be the cells immediately surrounding the given cell, though we are free to define it however we wish to (see figure below). We must also assign a rule for updating. A rule will consider some or all of the interactions a given cell has made at a time step and will either change the state of the given cell or leave the given cell in the same state depending on these interactions. In most cellular automata models, the rule doesnt change over time and is the same for each cell. Moreover, it is usually applied to the entire grid at once.



von Neumann neighborhood *Moore neighborhood*

Goals of the Model

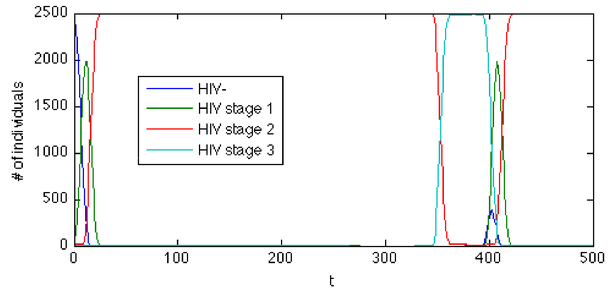
- To understand how the HIV epidemic evolves among needle-sharing injection drug users
- To evaluate the impact of treatment programs such as HAART on the epidemic

Setting Up the Model

Where applicable, we will use data taken from the Downtown Eastside in our model. We begin by creating a two-dimensional grid such that every cell on the grid represents an individual. Every individual in our model will be an injection drug user who shares needles. Each individual is either HIV- or in one of the three stages of HIV infection. We define each individual's neighbors to be those within the individual's von Neumann neighborhood. At each time step, which we have chosen to correspond to one week, every individuals shares a total of 30 needles with his/her neighbors. If an HIV- individual shares a needle with an HIV+ individual, then there is a certain probability p that the HIV- individual will become infected. p is based on which stage of infection the HIV+ individual is in.

HIV stage	p
Initial stage	0.05
Clinical latency stage	0.001
AIDS stage	0.01

The life expectancy of an HIV- injection drug user is 50 years. We consider every individual in our model to be over the age of 14, so HIV- cells in our model live for about 36 years, if they manage to stay HIV-. A cell that is HIV+ will progress through the stages of infection and die at the end of the final stage, about 8 years later, should the individual not exceed 36 years of age.



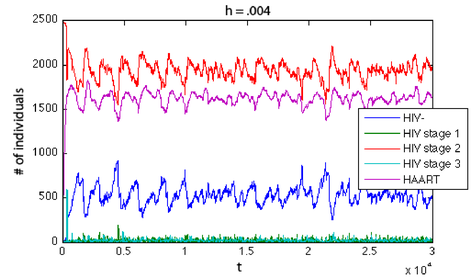
When we run this model, the rate of HIV infection is so high that the entire population becomes infected with HIV in a short amount of time. The graph above will continue to cycle for as many time steps as we run the model for.

Adding HAART

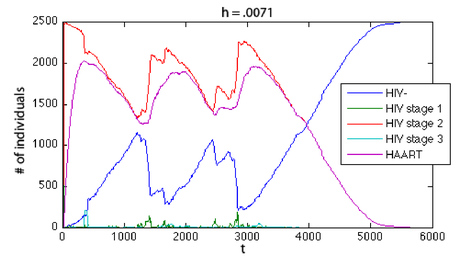
We must make several assumptions about how HAART works in the model. Firstly, we assume that once an individual is placed on HAART, his/her needle sharing behaviour continues at the same rate. Secondly, we assume HAART is effective every time an individual enters treatment. This means that individuals on HAART cannot infect HIV- individuals and that those on HAART will have a normal life expectancy for an injection drug user. We also assume that every individual who begins HAART treatment will not abandon treatment, though this assumption is not particularly reasonable (see Further Research).

We are now free to choose a way to put people on HAART. In this model, we prompt all cells in the second stage of HIV infection to be put on HAART with probability h. We then vary h and find which values of h drive HIV infection out of the population.

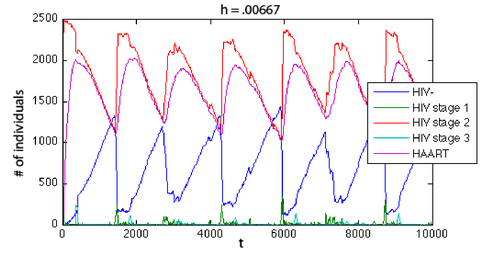
Results



In the above simulation, our value of h is too low to drive out the HIV infection. The virus is endemic.



In this simulation, our value of h is large enough to push the HIV infection out of the population. We note that the number of HIV- individuals cycles before reaching a fixed point, as does number of individuals in stage 2 of infection. As we decrease the value of h, the graph tends to cycle more times. If we increase the value of h, the graph will cycle fewer times.



In this simulation our value of h is too small to push the HIV infection out of the population in a meaningful amount of time. For this particular value of h the HIV infection will eventually die out, but it takes about 100,000 time steps, which corresponds to about 2000 years.

Further Research

One major component yet to be introduced to the model is that of adherence. Given the sometimes complicated regimen that individuals on HAART must follow, it is unrealistic to expect all individuals to stay on HAART once treatment begins. Adherents must take several pills at various points throughout the day and this can be problematic given the lifestyle of the population we are considering. A thorough analysis on the model's behaviour is also needed.