CX4230 - Computer Simulation

Project 3B - Zika Virus Propagation - The Plan

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Literature Review:

One example of a model we found that is related to the work we want to accomplish for this project is found at this link: https://github.com/nicholasyager/airport-disease-modeling/. The aforementioned model is called Edge-based control of disease propagation through the world-wide airport network. The model simulated the spread of a pathogen through air routes and a directed network was made using current airports as vertices and their respective routes as edges. Airports were infected at random and then were set to recover. The model implemented multiple strategies to thwart the number of infected airports by canceling flights based on edge betweenness centrality and a clustering coefficient, which they have defined in their model. This model is close to what we want to accomplish with the model we are planning to make.

For our model, we are thinking about extending this model by first, removing all the airports and just having the airports in the US. Second, we are going to display a map of the US instead of a globe as the model has done. Third, include the major interstates that will act as additional pathways or routes to spread the Zika virus. Fourth, we are planning on adding agent-based modeling by having patches of mosquitoes infect humans (other agents) and see how it affects the spread of the Zika virus. We are planning on using this model found on GitHub and extending it to have a model that suits our creativity. Further details on the conceptual model are described in the conceptual model section with some simulation experiments that we are planning on running.

Another paper/model we found that could be usefule for our project is found here: https://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072X-8-50. The paper is called an agent-based approach for modeling dynamics of contagious disease spread; it deals with how diseases are propagated through an agent-based model where the humans are the agents. The objective of the model was to use an agent-based modelling approach that integrates geographic information systems (GIS) to simulate the spread of the measles disease in an urban environment, as a result of individuals' interactions (which act as the agents) in a geospatial context (the urban area). Individuals in a closed population are explicitly represented by agents associated to places where they interact with other agents. The agents are given mobility through a transportation network that allows them to move freely giving the model some complexity in terms of the propagation of the disease. Due to its ability to depict the disease progression based on the agents' interactions, the results of the model provide insights into the application of the model to calculate ratios of susceptible and infected in specific time steps and urban environments. It is portrayed in the model that the spatial interactions within the population lead to high numbers of exposed individuals who perform stationary activities in areas after they have finished commuting. Thus, due to this, the sick agents are conglomerated in locations like schools and universities. This could apply to our model because most of the sick agents are probably going to be concentrated in major cities and not minor ones. Basically, this agent based model designed in this paper can be easily used/customized to study the disease spread dynamics of any other contagious disease by simply adjusting the modeled disease timeline and/or the infection model and modifying the transmission process, which is what were are planning on doing for our Zika virus propagation model. We will be modifying the transmission process, which will happen through two types of agents: humans and mosquitoes. We are also planning on adjusting the infection model by implementing a way to stop the propagation of the disease by possibly shutting down certain flights/routes.

One other paper that was reviewed was the network-patch model located here: http://www.tandfonline.com/doi/pdf/10.1080/17513758.2015.1005698 . This paper was based on making a hybrid modeling system of networked and agent-based modeling that contains habitats that are represented by patches and humans allowed to move within and between these networked patches. The main thing that was gleaned from this paper was that modeling individual mosquitoes or even patches of mosquitoes is overly complicated based on all the dynamics of how the mosquitoes take blood meals, how often are the blood meals, vegetation, temperature, and etc. This was good insight because initially the model was going to include mosquitoes as agents or some form of patch work of mosquitoes that would could scale possibly, but a simpler approach after talking to Jordi was to model the humans first and make sure that modeling approach works first and then make the model simulation more complicated if time permits.

Another paper that the network-patch model references is the model about human movement and the impact of it on vector-borne disease located here:

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0006763 . This paper provides a lot of good background on general parameters of the dynamics of mosquitoes and humans including mosquito biting rate and human recovery rate that can possibly be used or similar parameters be used in our final model. This paper will be similar to our model in that it looks at the system as a network of patches, which is similar to our concept of a network of cities or hubs. Where our model will be different is that we consider the dynamics of the road and airlines for propagation and run many more simulations on a multitude of scenarios.

In addition, we looked into some statistics on the Zika virus to understand it better for modeling purposes. This website http://www.wpro.who.int/mediacentre/factsheets/fs_05182015_zika/en/ provided some helpful history on the virus, but more importantly, how long the incubation is (2-7 days). Another website http://ecdc.europa.eu/en/healthtopics/zika_virus_infection/factsheet-health-professionals/Pages/factsheet_health_professionals.aspx provided additional incubation period of 3-12 days with recovery within 4-7 days. This data will assist in building out the model with appropriate parameters to create a realistic simulation.

Conceptual Model:

Zika Propagation in the US Task:

The problem we are modeling and simulating is the potential propagation of the Zika virus through the US via network-based and agent-based modeling.

Model Customer:

The hypothetical "customer" would be the Center for Disease Control (CDC), which is based out of Atlanta. This model could be useful for the CDC to see where the Zika virus has the potential to spread and the CDC could also use this model to see what preventative methods they can take to help decrease the propagation of the Zika Virus.

Modeling Approach:

This Zika propagation model can be abstracted as both a network-based and agent-based modeling problem. The network-based modeling portion will be via the road interstates and airline travel routes. The agent-based modeling portion will initially be via humans only.

1. We will build the network by creating nodes that represent the major cities or hubs in the US. These nodes will contain population data in the near vicinity of these hubs. Two datasets (interstates and flight routes) will be overlaid together to create the edges of the network. Interstate edges and flight routes will contain average number of humans traveling along those pieces.
2. Mosquito dynamics will be modeled at each major city or hub. We are proposing on obtaining general mosquito population data throughout the year for at least one city and creating a synthetic distribution for simplicity to be used for all cities for the rate of infection. The synthetic normal distribution graph will be lowered or raised based on any other data we can find to simulate the seasons of potential mosquitos in the area of each city or hub. One way to represent the mosquitoes is to have an array of 12 points for each city (to represent the year) with a so called mosquito infection rate for that month.
3. Major cities or hubs will be considered anything over a certain population or number of cities to keep the model manageable.
4. Boundary limits of infection will be limited to maximum area that the particular mosquito Aedes Aegypti can live in during any part of the year. Any infections that spread to cities or hubs outside of these limits will not propagate for this simulation.
5. For the beginning of this project, humans will be carriers of the zika virus and every time step in the simulation and based on the probability of infection from mosquitoes at different cities or hubs, will determine if they become infected.
6. Additional nodes intermediately may be added as an additional feature if time permits for additional propagation.
7. Mosquitoes may be added later as additional agents, but as of right now, the model seems already complicated enough.

Software Implementation:

For this model, we are planning on using Python and NetworkX, which is a Python package for the creation, manipulation, and study of the structure, dynamics, and functions of complex networks. Since the simulation will be stochastic, i.e., use random numbers to model unpredictable elements of the system, we will be using an existing random number generator library. We will be using a network of all the major cities connected via their respective airplane and major interstate routes. We will also have a global dictionary noting what the current state of each city is i.e. how much of they city has been infected.

Simplifications:

Some simplifications are made for our model. Since It is both unnecessary and difficult to take some details into consideration in our model, we make the following simplifications:

1. We are only having the major cities, airports, and interstates.
2. A certain number of cities (cities with airports/interstates that are in high-degree/busier) will be started as infected in the simulation.
3. The time to travel via plane or car will be a constant rate speed multiplied by the distance of travel.   The time will be measured in days.
4. Assume time step, vary time, set minimum
5. Routes are directional. Based upon the degree of the source and destination airports, each edge is weighted to represent the probability of carrying infectious individuals.
6. To properly model the flow of individuals around our cancellations, edge weights are recalculated after each cancellation strategy

Assumptions:

Some data about our simulation is hard to collect. So we need to make some assumptions to process our model.

1. Airports/interstates are used as proxies for individuals harbored within the city. This assumption is held with the understanding that transient passengers are able to infect permanent residents of the city. These residents are then able to pass the infection on to other individuals in the city through mosquitoes.
2. There is no record for an infectious person's behavior. Thus, we treat all infectious persons as unaggressive/inhumane people, and then we induce no one will help propagate the disease faster by purposely infecting others.

3. On the other hand, mosquitoes will be aggressive and will infect whomever randomly and at a quicker pace than humans.

Experiments:

The following are different scenarios we will experiment with:

1. Start infections at different hubs (airports, cities) and run simulation to determine worst cities that could be infected so that preventive measures could be started now
2. Change infection rates, movement rates, vaccination rates (assuming a vaccine is created)
3. Shutdown different hubs to minimize infection
4. Determine if infection could be stopped through all out preventative measures
5. Look at the infection rate within a city and also see how critical a city is in spreading the Zika virus by looking at the incoming edges for that city.
6. Our goal is to model as many cities as possible and see which cities are critical in spreading the virus so someone like the CDC knows which cities it needs to quarantine.

<u>Implementation Plan:</u>

- Implementation checkpoint C - Monday, April 11
  - Obtain updated airport dataset for major airports in the US
  - Obtain number of flights and passengers per route
  - Obtain interstate dataset for the US
  - Obtain interstate travel data
  - Obtain population data for all major cities in the US
  - Obtain seasonal boundaries for where mosquitos that can carry the Zika virus can live throughout the year, population data
  - Figure out mosquito reproduction dynamics
  - Figure out all parameters that we need for varying modeling simulations
  - Confirm graphic software to demonstrate model (NetworkX)
  - 1 page summary complete

- ❖ Implementation checkpoint D - Monday, April 18
  - ➢ Draft network and agent-based model complete
  - ➢ 1 page summary complete
- ❖ Implementation checkpoint E - Monday, April 25
  - ➢ Final network and agent-based model complete
  - ➢ Final analysis complete
  - ➢ 1 page summary complete
  - ➢ Draft Poster complete
- ❖ Implementation checkpoint F - Wednesday, May 4, 8:00-10:50am
  - ➢ Final Poster complete
  - ➢ Print out poster by Monday, May 2

References:

https://github.com/nicholasyager/airport-disease-modeling/

https://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072X-8-50

http://www.simondobson.org/complex-networks-complex-processes/epidemic-spreading.html

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http://www.tandfonline.com/doi/pdf/10.1080/17513758.2015.1005698

http://arxiv.org/pdf/cond-mat/0205009.pdf

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0006763