From Cyber Space Opinion Leaders and the Spread of Anti-Vaccine Extremism to Physical Space Disease Outbreaks

Overview, Design Concepts, and Details (ODD)

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This document provides an overview of the model and detailed model elements and structure based on the ODD protocol developed by Grimm et al. (2005).

1. Overview

Measles is a highly contagious disease and poses serious danger to communities around the world. Even if a safe and cost-effective vaccine is available, we are still experiencing Measles outbreaks every year around the globe. In developed countries, one of the serious causes of Measles outbreak is the disease being carried from overseas to vulnerable communities. In many communities of the US, the vaccine refusal rate is getting higher in the last few years as the non-medical exempt policies being implemented. When unvaccinated population is clustered together, it becomes vulnerable to contagious diseases. In the context of Measles outbreak in the US, the "clustering of exemptions" is playing an important role in creating disease vulnerable clusters and cause disease outbreaks (May & Silverman, 2002; Eames, 2009). Therefore, how anti-vaccine parents formed negative opinions and how to prevent more parents from the distrust of vaccination have become questions worth exploring. Meanwhile, with more prevalent online information seeking and knowledge acquiring, Internet is playing a role in shaping the tendency of vaccine refusal. The paradigm of health communication has shifted from doctor-patient to a more disseminated and individual-based one (Kata, 2012). Online communities, opinion leaders play an import role shaping others opinions. In the realm of social network, opinion leaders don't have to be celebrities in real life, but are structurally the same as "hubs" in a scale-free network.

An agent based model (ABM) is develop in NetLogo to explore how anti-vaccine opinion leaders in a scale-free network spread their extremism and how it changes the degree of disease outbreaks. Figure 1 is the graphical user interface (GUI) of the model. The source code and data of the model is on openABM archive (https://www.openabm.org/model/5509).

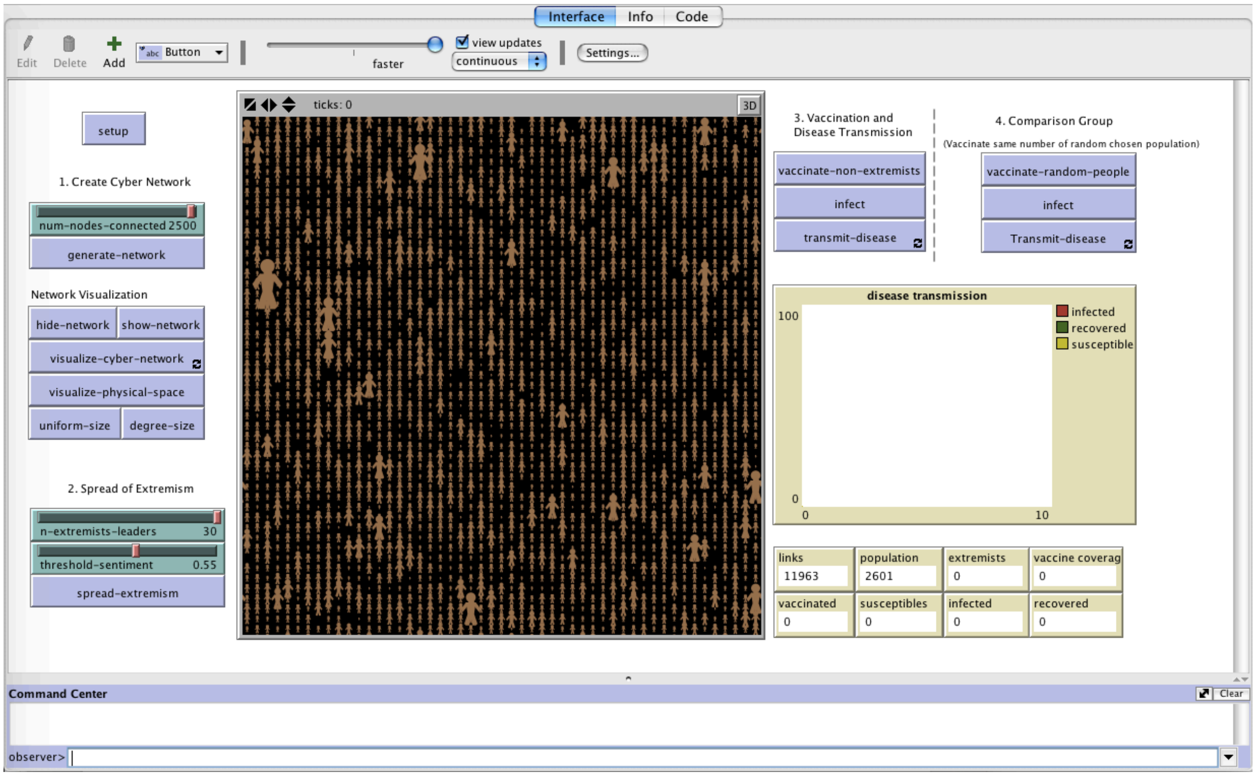

Figure 1: The model's GUI with visualization of local space and cyber space (not shown in the screenshot), input parameters, and output monitors.

1.1 Purpose

The purpose of this model is to model the process of how the public with high anti-vaccine sentiments become anti-vaccine extremists in cyber space under the influence of anti-vaccine opinion leaders in social media where agents are connected in a scale-free network and how such anti-vaccine extremism is spread locally in physical space where agents are located in eight-neighbor grids. In addition, the model aims to test the hypothesis that under such social influence process, disease outbreak will be higher because of the anti-vaccine extremists clustering together.

1.2 Entities, State Variables, and Scales

The agents are heterogeneous individuals with different levels of anti-vaccine sentiment level, physical locations, connection status in the cyber network and other attributes in Boolean logic format – extremist or not extremist, vaccinated or not vaccinated, susceptible or not susceptible, infected or not infected, recovered or not recovered. The environment of the model is two folded: physical space and cyber space. Agents, therefore, are connected differently in either space. In physical space, I use grids to represent physical locations and one individual is located on each grid. All the grids/patches are all occupied. This model does not consider different population density. The world is wrapped both horizontally and vertically. Additionally, I define the neighborhood using Moore neighborhood that each individual has eight neighbors who are located in the most adjacent eight grids. The length of each tick doesn't represent a specific length of time. After constructing the cyber network and after the spread of extremism, there's buttons in the model that can change the visualization. When showing the network, the patches do not represent any geographical environment and the links between agents represent their cyber network connection; otherwise, the patches represent physical locations, which does not represent any real world geographical area but only an abstraction.

1.3 Process Overview

The process of the model run and its scheduling is shown in Figure 2. There are five modules of procedures processed one by one for each run as shown in the flowchart:

(1) cyber network creation: in a scale free network, not every node is connected (isolated node). To limit the scope of this project, I only analyzed the scenario where 2500 out of 2601 individuals are connected (has at least one degree of connection). In each experiment, the 2500 connected nodes are randomly picked and different from each run. But the model has the capability to run and test scenarios with different number of connected and isolated individuals. After the network is constructed, the N of most connected individuals are picked as anti-vaccine opinion leaders. N is the parameter of the model and can be manipulated by users. The model results and effects of different number of opinion leaders are tested in the experiments as well.

(2) Spread of extremism on cyber network: those who connected directly with opinion leaders in the cyber network and also have an anti-vaccine sentiment higher than a threshold become extremists. By "directly connected" I mean one-degree connection in the network. The threshold is also a parameter that users can manipulate. Note that this process only executed once in the model for each run because the assumption is that the model only counts the influence of opinion leaders to its followers. Followers of followers, for instance, do not get influenced by opinion leaders in the cyber network.

(3) Spread of extremism on physical space: After the spread on cyber space, those who are extremists influence its local neighbors in this step. Local neighbors are only the 8 von Neumann patch neighbors in the "physical environment" of the model. Just as last step, this step only executed once for each run.

(4) Vaccination: After two-step spread of extremism, those who are extremists are treated as those who are not willing to get vaccines. The rest of the population gets vaccines and become immune from the disease to be transmitted. Those who are not vaccinated are the "susceptibles".

(5) Disease transmission: in this step, the model uses SIR (Susceptible-Infectious-Recovered) disease transmission model. Those who are not vaccinated in the last step are treated as susceptible. Those who are vaccinated and those who are recovered are all treated as forever immune from the disease. For each tick, not everyone who are susceptible and have infected neighbors will be infected, but only happen under certain probability/rates. There's also a recover rate for infected agents (see details in Section 4.4). The model does not consider death from the disease.

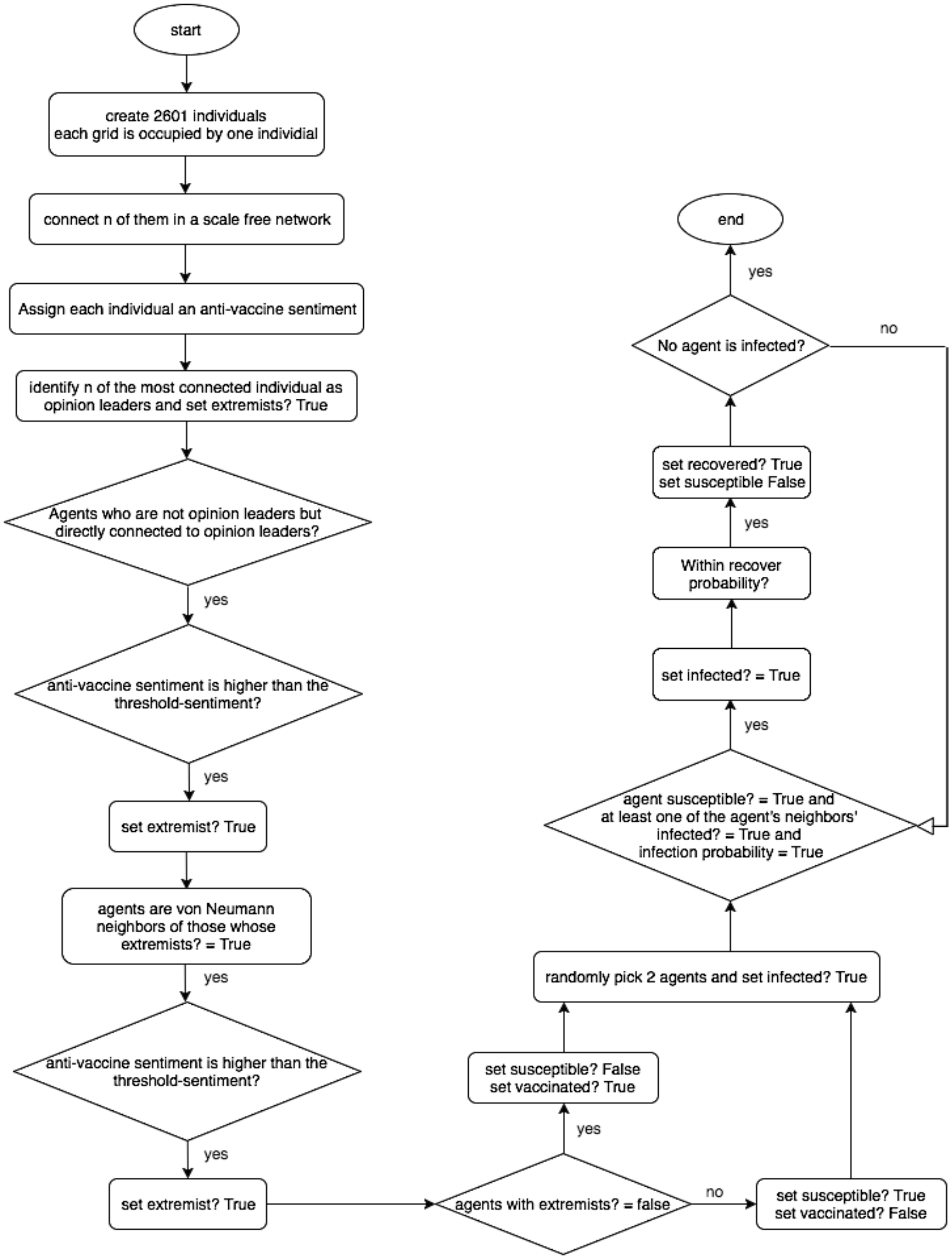

Figure 2: Flowchart of the model process and logic

The model stops when nobody is and will be infected any more. “Ticks” are not counted until the model enters disease transmission part. Each tick, the model makes a record of the number of infected agents, susceptible agents, and recovered agents for further analysis.

2. Design Concepts

The design concepts will be described in aspects as following:

2.1 **Emergence:** As one of the most distinctive features of agent based modeling, emergence comes from the non-linear interaction between autonomous agents. It’s the result on the system/macro level. In this model, the emergent phenomenon is that because of the spread of extremism, the maximum number of people infected in disease outbreaks is higher than that without the spread of extremism. The emergent behavior comes from the opinion clustering that anti-vaccine extremists who are not vaccinated are clustered in geographical space and increases the number of infected people in disease outbreaks. This result, however, is not new and the prototype model has also proved it. This model also shows an emergence that with small number of opinion leader (1 or 2), and with high sentiment threshold (95% percent of the agents who would *not* be turned into extremists), the model still shows that the number of people infected in outbreaks are more than the condition without spread of extremism, with the same rate of vaccination (see details in “results”). The potential of the dissemination of extremists is actualized by the characteristic of scale free network typology and geographical proximity. The model assumes that only when those agents who have a high level of “anti-vaccine-sentiment” can be influenced. The result emerges from network effect (opinion leader’s disproportional influence) and agents’ uncertainty and distrust about vaccination.

2.2 **Adaptation:** The behaviors of the agents in the spread of extremism part can be summarized as influencing others and being influenced by others. The change of state from a potential extremist to a real extremist depends on whether the agent has a connection to opinion leaders or whether the agent has local extremist neighbors and the anti-vaccine sentiment is high enough. The spread of extremism from cyber network have the impact on the behavior change to the next step. Also, the infected rate depends on how many neighbors are infected.

2.3 **Fitness:** This term can be misleading but Grim et al. (2006) explained that in agent based models that do not address animals or plants, instead of fitness, other “objectives” should be considered here. There is no clear objective for agents in the model to achieve but derived from their behavior, the “objective” of extremists is influence and turn potential extremists into real ones.

2.4 **Sensing:** The agent’s influence on others’ opinions is limited. In the cyber network, only one-degree away from the opinion leaders can be influenced by them and in physical space, the influence limit is 8 neighbors. The reason to setup this limit is that the goal of the model is to test the power of opinion leaders, and if the influence of opinion leaders can be carried to the second or more degree of connection, it’s hard to define whether the result is more from the opinion leaders themselves or the network structure.

2.5 **Interaction:** The interactions are in the spread of extremism and the spread of disease. The interaction rules are specified in the flowchart.

2.6 **Stochasticity:** The "randomness" is in the model as: who is connected in the cyber network and who is not are randomly picked; the 2 infected agents are randomly picked in the start of the disease transmission; although the anti-vaccine opinion value is assigned based on normal distribution but essentially, it's randomly assigned.

2.7 **Collectives:** There's no well-defined groups in the model. However, clusters are vaguely defined in the model, that is the geographical area that has dense unvaccinated agents.

2.8 **Observation:** The output data of the model is the peak number of infected population for each run. Experiments are conducted to test different scenarios. Under each scenario, 100 experiments are done and the mean and standard deviation of the output value is calculated to compensate randomness of the agent behavior (i.e. the start of the disease transmission is by randomly selecting two among all as infectious agents).

3. Details

The detail of the initialization value and sub-model design is as follows.

3.1 Initialization

In the initial state of the model, 2601 (51*51) grids and individuals are set up. Each grid is occupied with one Individual (agent) with their attributes set in default values. The attribute "anti-vaccine-sentiment" follows a normal distribution with a mean of 0 (overall the sentiment is neutral) and a standard deviation of 1 with an upper bound 1 and a lower bound -1. If it's positive, it means that this agent is *oppose* to vaccination and negative means supportive. All the agents are initialized as non-extremists and all their attributes related to disease transmission, "vaccinated?", "susceptible?", "infected?", "recovered?" are set as false.

In addition, the infection rates and recover rates *functions* are also set up as the model initiated (the values change as the model runs but not the function itself). For each agent, the infection rates are calculated based on the exponential function:

$$f(i)=1-\exp(-\beta i)$$

The function is from the prototype model by Salathe and Bonheoffer (2008). In all the simulations, ß=0.05 and *i* represents the number of neighbors that are infected. Because exponential distribution is fat-tailed, the infected probability will increase faster as the number of infected neighbors gets more and more. The recover rate is 0.1% for all agents. The start of the disease transmission is always from 2 random susceptible agents.

Three parameters need to be specified to initialize the model: number of individuals connected in the network, number of opinion leaders, and the sentiment threshold. Number of opinion leaders and sentiment threshold will be the two primary parameters to test in the experiments. For all the tests and experiments, the number of individuals connected in the network remains the same: 2500.

3.2 Sub-models

Two sub-models used in this model. This section discusses the background and justifications of the two sub-models.

3.2.1 Modeling opinion dynamics

Modeling opinion dynamics has been an active area of research. It originates from two mathematical models developed independently by Krause and Hegselmann and by Deffuant and Weisbuch et al. (Lorenz, 2007; Hegselmann & Krause, 2002; Amblard & Deffuant, 2004). Despite variations of research on opinion dynamics, the most basic rule is “bounded confidence”, inspired by Axelrod’s (1997) model dissemination of culture. The assumption of bounded confidence is that people are only willing to communicate with others with “similar enough” opinions. Whether it’s “similar enough” depends on a parameter that’s usually named “uncertainty interval” (Gomez-Serrano et al., 2010). How much that the agents would like to change their opinion depends on “converge parameter”.

Inspired by bounded confidence, the sentiment diffusion process in the model follows the behavioral rule that people will only be turned into extremists if they have high sentiment values. The model, however, unlike opinion dynamics models, only include one-time and one-way opinion change (from non-extremists to extremists).

3.2.2 Modeling disease transmission

Epidemic modeling is an area that studies the mechanism of the transmission of infectious disease through individuals (Vynnycky, 2010). In agent based modeling, two kinds of model are often used: Susceptible-infectious-recovered (SIR) and susceptible-exposed-infectious-recovered (SEIR) model. SIR has three classes and stages of infectious disease transmission. SEIR model adds exposed phase to the model, referring to individuals who are infected with the infectious disease but not yet able to transmit that to others. As the purpose of this paper is to connect opinion clustering to disease outbreaks, a prototype model must be mentioned-- Salathe and Bonhoeffer’s (2008) model in the effect of opinion clustering on disease outbreaks. The mechanism was simple in their model: 100 agents are created in a lattice network, in which everyone has 10 connections, everyone is assigned a vaccination opinion (either support or oppose). After the opinion formation process, people with same opinion are clustered together. Those with opinions opposed to vaccinations do not get vaccinated and thus when they are clustered together, infectious diseases transmit very quickly in these clusters. Their model demonstrated well that a small clustering effect would increase probability of disease outbreaks to a relatively great level. The opinion formation process in Salathe and Bonheoffer’s (2008) model is probability based, whereby an agent choice for support/oppose is decided by two factors: how many neighbors have the opposite opinion (dissimilarity index) and a parameter called the strength of opinion formation. My model substitute this probability based opinion formation process with one on the opinion diffusion in networks triggered by opinion leaders.

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