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Analysis and Simulation of the HIV Transmission among Homosexual Based on Agent Dynamical Small World Network

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Abstract

This paper proposes a multi-agent dynamic small world network approach for constructing Human Immunodeficiency Virus (HIV) dynamic propagation model for men who have sex with men (MSM), which combines small world networks and multi-agent systems. In order to adapt to the dynamic characteristics of social network for HIV transmission, this model considers steady and casual partnership between 2 agents of sexual contacts and demographic dynamics. It also considers the effects of autonomy and protective measures such as testing and usage of condoms on HIV transmission. In addition, it introduced the progression of HIV and disease parameters.The results of this simulation make it clear that this model can fairly reflect the effects of dynamic social network and individual autonomy behaviour on HIV transmission.

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Keywords: Multi-agent system（MAS）; Small world network; Autonomy behavior; HIV transmission;

1. Introduction

In China, the spread of Human Immunodeficiency Virus (HIV) has become a serious public health and social issue. Developing the dynamics simulation model of HIV is an important method for people to study the mechanism of epidemic propagation. By using the model to research HIV transmission trend, we can be more effective to carry out the intervention of social behavior, guide our government looking

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for effective blocking strategies, and give important reference method for other spread of the related disease issues. At present , Multi-Agent Systems (MAS) and Complex Networks (CN) are often used separately to model and simulate epidemic propagation process.

MAS is a kind of microscopic simulation technology, it can flexible establish simulation model, properties and behaviours of individual is not restricted. In recent years, it has caused the attention of some researchers who study the transmission mechanisms and control strategies of HIV. Kretzschmar and Morris earlier used the modelling method based on agent to study the research of HIV spread through sexual network [1]. Xuan HuiYu et al. proposed a CA-based heterogeneous epidemic model for HIV transmission [2]. But this kind of constructing social network method is not suitable for the populous cities and regions. It lacks the generality, and also does not show advantages of complex network model in researching social network.

Network-based simulations are proving successful for exploring epidemic dynamics and assessing intervention strategies among large and varied populations. Compared with agent-based simulations, network-based simulations have a stronger focus on relationships between individuals. In social networks, nodes represent individuals and link their various relationships types. By using complex network approaches, Bai WenJie et al. present a complex network model for the spread of HIV [3]. Sloot et al. put forward a general model, which used dynamic complex network for research of HIV transmission and control [4]. But there's also obvious deficiency. As the evolution rules of network nodes are too simple, factors, including personal attributes and behavior rules which greatly affect the transmission of HIV, response of individuals to the environment and measures of treatments, preventions and controls are not to be considered. The complex network model can express various channels for horizontal transmission, but for vertical propagation is difficult to achieve.

So, when studying HIV transmission in complex social system, it is necessary to combine agent method with complex network method. The complex agent network approach takes the MAS and complex network to model and simulate epidemics on individual and population scales, respectively [5]. Researchers have carried on the preliminary attempt on it. These researches suggest us that combining microscopic simulation method with complex network model to study epidemic transmission dynamics in a complex social system is a new research topic. However, there are only some preliminary researches about it and many scientific problems need further research.

In this paper we present the agent dynamic small world network approach for constructing HIV dynamic propagation model for men who have sex with men (MSM).The proposed agent small world network will differ from the above models for :(1)Extending traditional epidemic spread model (SIR), describing the main stages process of epidemic by different individual states, and including more people groups (2) In order to adapt to the dynamic characteristics of social network for the spread of HIV , considering steady partnership links and casual partnership links between 2 agents of sexual contacts and demographic dynamics, (3)Considering agent adaptation of the agent to its different control strategies and its environment ,(4) Considering the effects of usage of condoms and HIV tests control strategies on the spread of the disease.

2. Multi-agent Dynamic Small World Network

2.1. small world network

In recent years, statistic data shows that the social network model should be a small world network model. Small world network can be transformed from regular network to random network by regulating a parameter P . The constructing algorithm of small world network is setting an annular regular network which contains N points. Each point can get K edges by connecting with K adjacent points, and meet $N >> K >> \ln(N) >> 1$. Then, rewire each clockwise edge of each node with a probability P . With repeating this step we can get the small world networks at last.

2.2. Combined mechanism of MAS and small world network

S.Mei et al. proposed a combined mechanism of MAS and complex network [5].This paper used the combined mechanism for reference to realize the combination of MAS and small world network. This interaction at both the individual and population levels is depicted in Fig. 1[5].

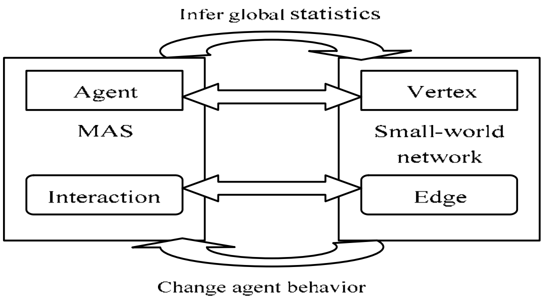

Fig. 1 Co-evolution of MAS and small world network

To combine the MAS and small world network we map agents and their interactions in MAS to vertices and edges in a small world network, respectively, as shown in Fig. 1 Agents provide personal autonomy, heterogeneity and local disease progression on an individual scale. Networks continuously help to calculate the values of epidemic-related variants by collecting agents' statuses, for the sake of mimicking virus propagation on population scale.

3. Generating Model of Multi-agent Dynamic Small World Network

A social network was regarded as a multi-agent dynamic small world network whose generative process has been demonstrated as the following steps:

- Generating regulation network. When $P = 0$, each agent only associates with the adjacent agent and a regulation network is developed.
- Generating small world network. Since the social network is a complex crisscross network, the condition of $P = 0$ does not accord with the actual situation. Suppose $0 < P < 1$, the link of an agent in the network disconnected with the probability P , while the agent connected with other irrelevant agent. As a result, a small world network is formed.
- Generating dynamic small world networks. Social network is not static. In social contact activities, there are casual partnerships and steady partnerships for MSM. Each individual can randomly create casual partnership with another individual, however, steady partnership is built based on casual partnership with a certain probability fp (fp denotes the probability of steady partnership). Casual partnership corresponds to free-links of the network and isn't stable and whether it can be changed depends on the variable dp (dp denotes the dynamic-variation probability in small world network). When a free-link is disconnected, the agent which loses track of his partner will create a new free-link with an irrelevant agent. However, the steady partnerships correspond to fix-links, and it is stable. In this model, the duration of steady partnership is set to 0.6 year. During this period, fix-links will not be disconnected with each other. When the time is more than the deadline, fix-links will be changed into

free-links and disconnected with the probability of dp . Fig.2 shows the network distribution at two different moments. The grey lines denote free-links, while the yellow lines represent fix-links.

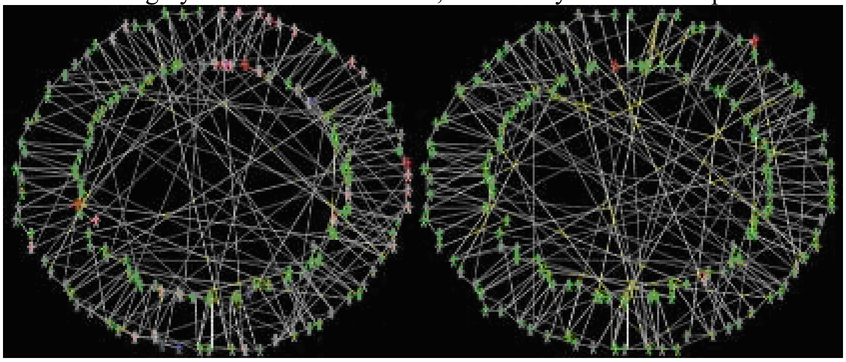

Fig.2 The network distribution at two different moments （a） Network distribution at t_1 ; （b） Network distribution at t_2

- The entering and exit of agents from the system. Sickness and death of human society, and immigration and emigration of people also reflect the dynamics feature of small world. First of all, the new-born replace the death individuals. An infected individual will be sure to die in 1 to 2 years after showing the symptoms, if an infected individual dies and exit from the system, then a healthy new-born must enter instead of the infected individual. Furthermore, the immigrations replace the emigrations. The properties of the emigrations and immigrants are both random in the system, it may be healthy or infectious etc. From the perspective of the overall, the numbers of agents entering and exit are almost equal in this system, we approximately believe that regional population is constant whereas the properties of the node agent are dynamic in the small world network.

Compared with the original small world network model, the multi-Agent dynamic small world network model can embodies more complexity and variability of social networks. The dynamic characteristics of small world network are more realistic and worthwhile research.

4. Disease Progression of Agents and Disease Parameters

The pathological progression of HIV is a process of multiply stages, and each stage shows a different morbidity. Fig. 3 shows the whole changes of agent.

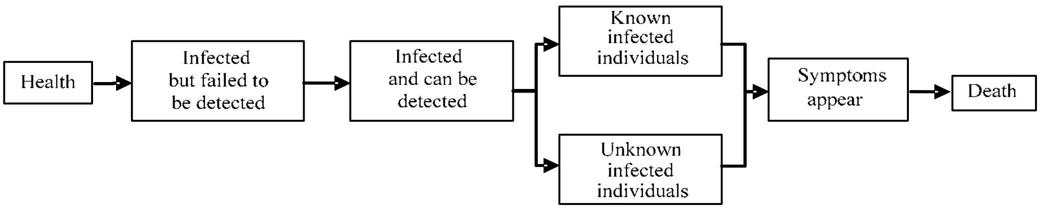

Fig.3 The changes of HIV progression

Clinical studies have shown that a newly infected agent is unable to be detected HIV virus until seroconversion. It's the early stages of HIV infection. Let T_1 denote the duration of this period. Anderson et al. [6] report T_1 to lie between 40 and 60 days in transfusion-induced HIV cases. In our model we assume that T_1 is a random variable following a normal distribution with the mean μ_1 and the variance σ_1^2. After T_1, if the infected agent is sent to hospital for medical examination, the doctor could check out HIV antibody positive from his blood, indicating that the agent has been infected with HIV virus, he is known infections. If the infected agents do not be detected, because it does not show any symptom, he still does not know that he has been infected with HIV virus. The duration during which an infected is infectious but not yet symptomatic is called incubation period. We let T_2 donate the period. Empirical work suggests an average incubation period of around 4 to around 15 years[6-7].For simplicity, we take T_2 as a real number drawn from a normal distribution with the mean μ_2 and the variance σ_2^2.During the T_2 period, HIV virus in the victim's body are constantly cloning themselves and eventually the immunity system collapses. At this point, the victim starts to show some symptoms. As usually, let T_3 denote the duration of this period. Rothenberg et al. [8] report 5-7 year survival rates among 1660 IDUs (Intravenous Drug User) in New York City and find a median time of survival of 282 days. Similarly, we assume T_3 follows a normal distribution with the mean μ_3 and the variance σ_3^2. At last, the victim sure to die. Table 1 lists the parameters chosen for the normal distribution [2].

Table 1. The parameters for the normal distribution

Parameters	Mean of T_1 (μ_1)	Variance of T_1 (σ_1^2)	Mean of T_2 (μ_2)	Variance of T_2 (σ_2^2)	Mean of T_3 (μ_3)	Variance of T_3 (σ_3^2)
Value	10	1	500	100	400	50

5. The Autonomy Behaviors of Agents

The autonomy behaviors of agent reflect in the adaptability to the environment. In the actual social, the individual decision-making behavior that affects the spread of HIV is often ignored in other models. When the proportion of individuals who infected with HIV is more than H, people will take some protective measures to prevent infection. Through the autonomy behaviors of agent, people could control the speed of HIV transmission.

The agent of dynamic small world networks does not have the integrity of global view in the system. It means that it is impossible for the individual to obtain the global and accurate cognition about the epidemic, but only to make some autonomy behavior to avoid the spread of HIV according to its own local information and the rough global information.

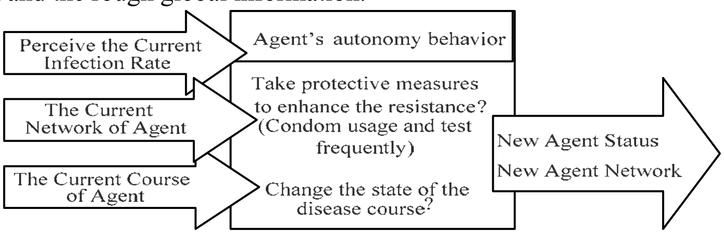

Fig.4 Agent autonomy behavior model

Fig.4 describes the structure of the autonomy behaviors of agent in detail. With the spread of HIV, agent can perceive the local infection rate by agent sensor .When the perception of the infection rate is more than a given percentage (the panic threshold *H*), then agent will take some protective measures to reduce the probability of infection. When the infection rate is lower than *H*, agent will recover the normal behavior. If a person has been infected with HIV, others will consciously keep a distance with him, so that the person is unable to transmit HIV virus, and eventually dies and withdraw from the system, and is to be replaced by a new individual.

Based on individual cognition of the epidemic, the model can set the decision-makings and behaviors to avoid HIV transmission according to infection rate, then make the simulation experiment of virus transmission. The decision-makings that healthy individuals utilize to avoid transmitting HIV are illustrated in Table 2.

Table 2.Decision-makings for healthy individuals to avoid transmitting HIV

The percentage of infected	Decision-making behavior to avoid HIV infection
[0%—10%)	No specific measures
[10%—20%)	Reduce their own sexual behaviors and increase usage of condom
[20%—100%]	Increase the frequency of regular tests

6. Simulation results and analysis

This paper adopts development tool of Netlogo 4.1 [9] based on agent to complete the simulation. Values of various parameters under fixed standard are given. The number of agents （ n ） is 200. Initial infection rate (σ) is 8%. The probability of generating steady partnership (fp) is 0.2. Time of keeping steady partnership (t) is 0.6 year. Condoms utilization rate (cp) is 0.3. Virus infection rate (f) is 0.2. Periodical test rate (tp) is 0.45 times per year. Rewiring probability in small world network (rp) is 0.25. Dynamic-variation probability (dp) is 0.3.

6.1. Influence of agents autonomy behavior on propagation process

In order to facilitate observation, all the parameters are remained unchanged. And two changing situations, including one with autonomy behaviors and one without autonomy behaviors, are compared in Fig. 5 which shows the simulating results.

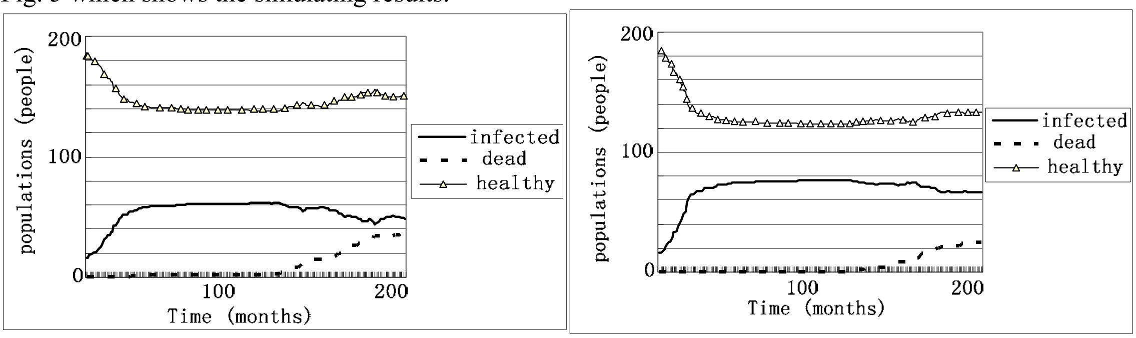

Fig.5 Autonomy behavior of agent's effect on transmission (a) With autonomy behavior; (b) Without autonomy behavior

At the early stage of infection, HIV gradually spread out, thus infected individuals increase. When the increasing number reaches to a peak, symptom of the infected individuals reveals and deaths begin to appear. Because of both the entering and exit of individuals, numbers of infected individuals and healthy ones in this system eventually tend to be relatively steady.

From Fig.5, it can be obviously observed that agent spread relatively slowly at the first situation with autonomy behaviors. On the other hand, when without autonomy behaviors, agent spread faster among individuals. From this aspect, autonomy behaviors play an important role in controlling HIV transmission.

All the following simulation results are considered the autonomy behaviour.

6.2 Influence of rewiring probability (rp) in small world network on transmission

There is a very important parameter in the formation of small world network: Rewiring probability (rp). Changing rp can turn the regular network (rp =0) into random network (rp =1).However, it will also affect the spread of HIV in small world network. Other parameters remain unchanged; we now take simulation under two different values of rp , 0.15 and 0.5.

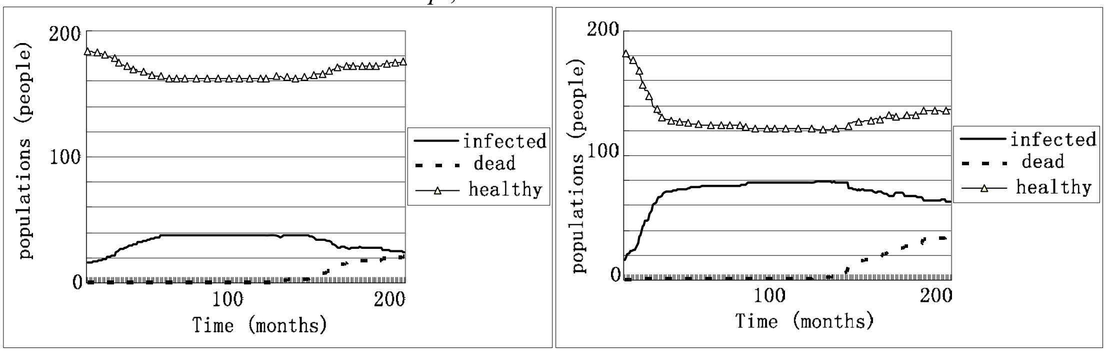

Fig. 6 Populations of all kinds of people under different (a) rp =0.15; (b) rp =0. 5 rp

As shown in Fig. 6(a) the value of rp is 0.15; the number fluctuation of all kinds of people is little. The infected number gradually increased and reached a relatively low peak. Healthy individuals decrease in a small number .However, because of the new-born and immigration individuals, healthy individuals then gradually increased. While in Fig. 6(b) the value of rp is 0.5. Infected individuals increased rapidly and reached a relatively high peak. Meanwhile, healthy individuals decreased rapidly. And the number reaches the lowest point when infection numbers arrive at peak. Later the deaths increased dramatically. This phenomenon shows that the larger rewiring probability is, the more quickly HIV spreads.

6.3 Influence of dynamic-variation probability (dp) in small world network on transmission

Dynamic-variation of small world network refers to the changing rate of casual partnership. Bigger dp shows bigger number of agents who an agent contacts with. In this way, dp influences the transmission rate of HIV in small world network. Keeping other parameters unchanged, set two values of dp as 0.1 and 0.5, and observe the simulation results.

Comparing the two figures (a) and (b) in Fig.7, we can find that when the value of dp is 0.1, the spreading range of HIV is relatively small and the number of infected individuals increased slowly. However, when the value of dp is 0.5, the spread of HIV is rapid and all kinds of individuals fluctuate markedly. From these results, we come to the conclusion that the larger dynamic-variation is, the more quickly HIV spreads.

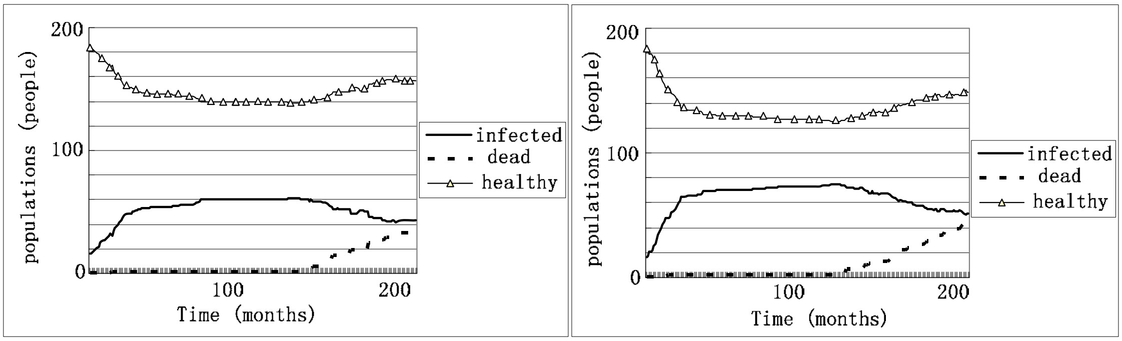

Fig.7 Populations of all kinds of people under different dp (a) dp =0.1; (b) dp =0.5

7. Conclusions

This paper proposes a multi-agent dynamic small world network model. It combined the multi-agent systems and small world network systems together, and endowed the system with dual characteristics of the small world network and agent. It also expressed the progression of HIV and the autonomy behaviors of agent. The design of the whole model solves the issue of HIV transmission in complex social networks. Simulation results of the model are consistent with the conclusions of the actual situation. This article provides a new platform for researches of HIV transmission in complex networks.

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