Extensive Epidemic Spreading Model Based on Multi-agent System Framework

Chunhua Tian, Wei Ding, Rongzeng Cao, and Shun Jiang

IBM China Research Laboratory, Beijing 100094, China
{chtian,dingw,caorongz,jshun}@cn.ibm.com

Abstract. In current epidemic spreading study, continuous system dynamics model and discrete agent model are often regarded as two types of incompatible models. However these two types of models may coexist in large-scale epidemic simulation. A multi-agent based framework for such coexisting is proposed in this paper consisting of location agents with hierarchical structure, participant agents to denote host, pathogen, or medium, and event agent to model the epidemic outbreak, control policy, etc. Transformation algorithm is provided for the communication between locations with different types of epidemic models. Such a framework is illustrated by SARS (Severe Acute Respiratory Syndrome) outbreak case.

Keywords: Epidemic Spreading Model, Epidemic Simulation, Multi-Agent System.

1 Introduction

Epidemics spreading simulation is an important approach for epidemics control policy analysis. Currently there are two types of models [1], continuous system dynamics model (i.e., continuous differential equation) and purely discrete agent model with great difference in state variables. States variables in system dynamics model are the size of the groups, while that in multi-agent model are health state of agents.

From SIR (Susceptible, Infective, Recovered) model, many extensional system dynamics model are developed, such as SIS, SEIR ('E' denotes "Exposed"), MSEIR ('M' denotes "maternal antibody protection"), etc. All these models assume that the population being affected by a disease is "well mixed" and either not distributed or geographically distributed in a uniform manner.

With the application of computer simulation, more complicated and practicable models are proposed considering spatial dimension, traffic network, diversity of population and many other important factors in epidemic spreading. EpiSims [2] is an agent-based modeling platform, which relies on TRANSIMS (TRanportation Analysis SIMulation System) to emulate social behavior and traffic flow. However this approach often requires large amounts of computing resources even for small city scenario. To avoid such disadvantage, in STEM (Spatial and Temporal Epidemiological Modeler) by Ford et al. uses continuous modeling for large areas while agent based model for specific areas [3].

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In current application, either continuous or discrete model is adopted in simulation. However, there are many scenarios requiring the coexisting of both types of models. For example, data availability (city vs. countryside), monitoring focus, multiple epidemics outbreak at the same time. The purpose of this paper is to propose a hybrid model for the common simulation platform.

2 Epidemic Spreading Model Framework

2.1 Epidemics Outbreak Scenario

The system architecture for epidemics simulation is shown in Fig. 1. At the core, there are "participant" model to emulate the behavior of host, pathogen, and medium. "Location" model to describe the geographic feature. Another key model is "social contact network" model to describe the interaction between participants and location-based activities. For modern society, transportation network has been a key channel for local epidemics to become pandemics. So the traffic model is often a key data source to construct social contact network. Demography data is used to construct participant distribution in geography, age, sex and other factors which may be needed in participant modeling. Outbreak scenario includes the flowing 3 types of factors. 1) Epidemics outbreak event to describe when certain or several types of epidemics outbreak. 2) Pathogen evolution event. 3) Environment change event such as weather, nature disaster, etc, which may impact on host/vector behaviors or epidemic spreading. Control policy event to describe the detailed policy and when it is put into action. The first three factors are often called as outbreak scenario.

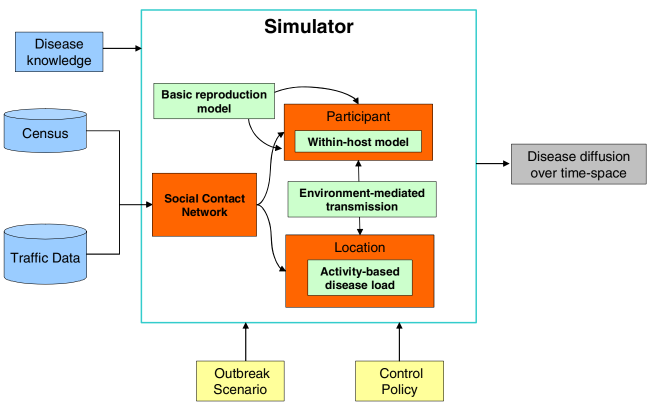


Fig. 1. Epidemic Simulation Architecture

2.2 Multi-agent Framework

Participant agents can be divided into two categories, individual or aggregate. Continuous epidemics model is often applied to aggregate participant agents, where each agent denotes a group of host, pathogen, mediums in a location. Discrete epidemic model is correlated with individual participant agent.

However, the computation of these two types of models differs a lot. In multi-agent, there is an identifier with each agent. While system dynamics model only cares about the size of each group. So when these two types of models coexist, the transformation method is needed.

1) An agent moves from a location with discrete model to a location with continuous model

The group corresponding to the agent's state size increases 1. As long as the agent stays at the location, during each period update, the state of the agent is determined according to uniform probability. The travel behavior of the individual agent is not depended on the aggregate agents.

2) A unit flow from a location with system dynamics model to a location with multi-agent system

Generate a virtual agent with state as the flow state. Its behavior is configured according to the aggregate agent. When virtual agent leaves for another location with multi-agent model, it remains the same. When virtual agent leaves for another location with system dynamics model, it is annihilated in corresponding state group.

2.3 Metamodel

To support the co-existing and extensibility of continuous and discrete model, interface breakdown hierarchy shown in Fig. 2 is adopted. At the top of the hierarchy is the interface IDiseaseModel. It represents the abstract idea of a model of a disease process. In particular, it contains the state transition diagram although no detailed computational process that generates the transitions from one state of a particular disease model to another. IDiseaseModel is extended by the interface ISDDiseaseModel for continuous model and IMASDiseaseModel for discrete model, which expands abstraction by introducing the state transition computation process.

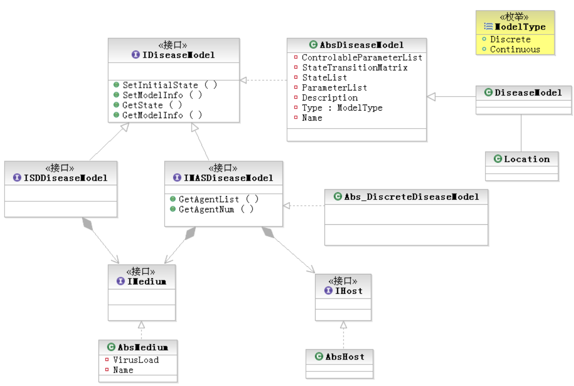
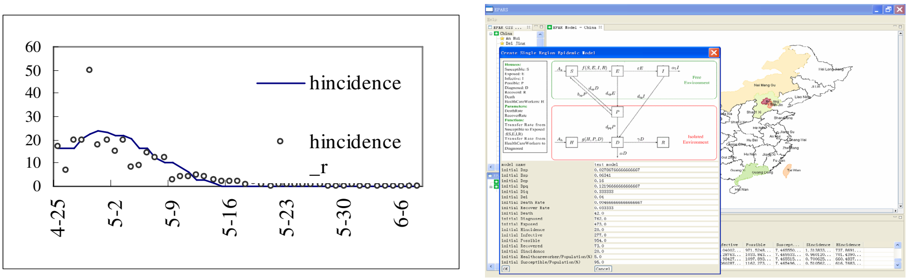


Fig. 2. Metamodel of Epidemic Spreading Model

3 Illustration

SARS outbreak case in 2003 is adopted to illustrate different modeling technologies. At first, the continuous model, BloComp(2,7) model proposed by Zhang et al. [4] is adopted to study SARS spreading dynamics in Beijing. Based on our adaptive parameter estimation algorithm, the simulation results (solid curve) have high approximation to the reported data (dotted curve) from Chinese Minister of Health [5], just as Fig. 3(a) on the incidence of healthcare workers. The difference of most days is kept within 15% except a big error in April 30.



(a) Simulation result of incidence number of healthcare workers

(b) Simulation tool snapshot

Fig. 3. SARS Spreading Simulation Tool & Result

Since most public SARS data are reported at the administration level of provinces. In the study the SARS spreading process across the China show in Fig. 3(b), Beijing is model as an agent model, while other provinces are modeled by continuous model. In the agent model, social network is generated according to the demography data such as age, job, and activity models. The people contact is stochastically generated according to the social network and agent activity model. Unfortunately traffic data across provinces is not directly available to us. For illustration purpose, national statistics on annual people transportation volume is adopted. Average daily traffic volume between two provinces is generated according to their population. The distribution in each state (that is, susceptible, exposed and infectious in free environment) is generated according to their proportion in the total population.

4 Conclusion

Due to the heterogeneity of data availability, the co-existing of continuous differential model and agent model is inevitable in epidemic simulation. Based on multi-agent framework, the architecture, method and model synthesizes the types of models are proposed in this paper. SARS outbreak case is adopted to verify the feasibility of such an approach.

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