Research on Modeling of Complicate Traffic Simulation System

Jiankun Wu[1], Linpeng Huang[1], Jian Cao[1], Minglu Li[1], Dejun Wang[1], and Mingwen Wang[2]

[1] Department of Computer Science, Shanghai Jiaotong University, Shanghai, 200240, P.R. China
[2]School of Computer Information Engineering, Jiangxi Normal University, Nanchang 330027, P.R. China
jkwu@sjtu.edu.cn,
{huang-lp,cao-jian,li-ml}@cs.sjtu.edu.cn,
wangdejun@sjtu.edu.cn, mwwang@jxnu.edu.cn

Abstract. With the increasing of traffic complexity, traffic simulation becomes an important approach to deal with the complicated traffic problems; meanwhile, system modeling plays a more and more important role in the simulation systems. Cellular automata provide a simple discrete deterministic mathematical model for physical, biological, and computational systems and are shown to be capable of complicated behavior and generate complex and random patterns, which are very suitable for the description of complicate traffic environment [7]. A simulation model based on agent technology, HLA/RTI technology and expanded cellular automaton is presented in this paper. The simulation model makes the platform expandable and flexible, at the same time, it can provide high-capable computing resources to solve the complex traffic issues. In the traffic entity model aspects, the expanded cellular automata and agent technology were adopted to model the behaviors of passengers, vehicles, traffic signal lights and so on. The optimal scheme for evacuation of traffic disaster, superintendence of large scale activities and design of traffic environment will be obtained through the simulation model.

Keywords: Traffic simulation, Agent, HLA/RTI, Complexity system, Cellular automata.

1 Introduction

With the traffic complexity rapidly increasing, it becomes more and more difficult to obtain the solution of traffic problems in reality, so traffic simulation becomes an effective tool for analyzing traffic states and problems. Based on simulation results, good decisions are made in traffic project and effective traffic guidance are designed.

Currently, traffic simulation research has been carried out in some countries, such as American, England, Germany, Japan and so on [6]. Although with respective advantages on special areas, it is difficult for users to customize the software per their

V.G. Duffy (Ed.): Digital Human Modeling, HCII 2007, LNCS 4561, pp. 1037–1046, 2007.

own needs. Especially, it is not enough in the research on simulation of evacuation of traffic disaster and superintendence of large-scale activities aspects. From the point of view of resource sharing and inter-operation, the description of traffic entity behavior and inter-operation between the sub-systems are inadequate. To solve the above problems, it is significant to propose a new simulation model to make simulation systems flexible and reused.

The accurate description of traffic entities behaviors and system architecture design play an important role in the traffic simulation. In complicated traffic environment, traffic systems become nonlinear due to the existence of random factors like persons. Currently, cellular automata are used as an effective method to solve self-organization and non-balance problems. Any system with many identical discrete elements undergoing deterministic local interactions may be modeled as a cellular automaton. Many complex systems including traffic system can be broken down into identical components, each obeying simple laws. These components that make up the whole system act together to yield very complex behavior [7]. So it is significant to adopt cellular automata with some additional conditions to build abstract traffic simulation model.

In order to make the simulation application and RTI (run-time infrastructure) independent and developed separately, the HLA (High Level Architecture) [1] is selected as the simulation architecture. However, it is somewhat difficult to simulate complicated objects like persons just using cellular automata. Agent is characteristic with autonomy, adaptability, and intelligence, so it is an effective tool that simulates the living objects and other objects that conforms some changing laws [2][15]. That agent behavior based on expanded cellular automata model is selected in this paper is due to two factors: (1) Cellular automata is a simple model that can generate pseudorandom patterns and can be efficiently implemented by hardware. The research on traffic flow and passenger flow based on cellular automata has obtained some useful theoretical models and related analysis; (2) Agent is more flexible and convenient than cellular automata in art intelligence. The model in this paper uses cellular automata to describe the rules of traffic environment and adopts the agent to implement the traffic entities; as a result, the factuality had been improved greatly; (3) Since the behavior description of traditional cellular automata is too simple to describe non-linear behaviors like person's activities, friction and repulsion are introduced in cellular automata to simulate traffic entities more accurately. The simulation technology combined with cellular automata, agent and HLA is effective to simulate the complicate micro traffic.

This research is based on Shanghai Traffic Information Service Grid and the simulation platform and the model built in the project can efficiently solve the problems confronted in traditional simulation systems. The optimal scheme for evacuation of traffic disaster, superintendence of large-scale activities and design of traffic environment will be obtained through the simulation model. The remainder of this paper is organized as follows: In section 2 the system architecture model is described; Section 3 discussed the traffic entity model in detail; Section 4 given the verification of the model; Finally, the summary and future work are given.

2 Simulation System Model

The simulation model presented in this paper is focus on the evacuation of traffic disaster and superintendence of large-scale activities. In the micro traffic simulation, it must pay attention to not only the whole traffic flow state but also the model of traffic entity behavior such as vehicle, passenger, signal light, control center et al. In the following section, all subjects will be discussed.

2.1 System Architecture

Due to the huge number of roads, vehicles and passengers, distributed simulation architecture based on HLA is adopted to improve the expandability and flexibility. In complicated traffic environment, traffic entities have characteristics of autonomy, adaptability, intelligence, so agent is adopted to implement these entities. With HLA and agent focus on different aspects, the simulation application sub systems act as plug-and-play components and the RTI acts as the soft bus.

To describe the model in more details, the simulation architecture and layered sub simulation system will be described respectively. The general architecture of model is showed in Fig. 1.

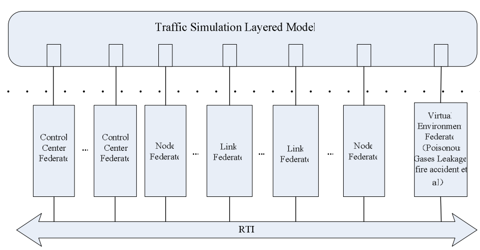

Fig. 1. System simulation architecture

As shown in figure 1, RTI is the run-time infrastructure of HLA. The federation that includes many federates is above the RTI. The federate presented in this paper mainly include control center, road (node federate, link federate) and virtual environment which simulate the poisonous gases leakage and fire accident et al. Publish/ subscribe mechanism is adopted as communications between different federates. The top is the concrete simulation application system.

2.2 Layered Model

The layered micro traffic simulation model is the implementation model of the simulation application system. The federation in the general architecture is the high level abstract of it. The layered model mainly include AE (Agent Entity) layer, road layer and control layer and is shown as Fig. 2.

As shown in figure 2, AE layer represents the traffic entities such as vehicle, passenger and signal light and so on. Those entities have characteristics of autonomy, adaptability, intelligence, which should be considered in the simulation.

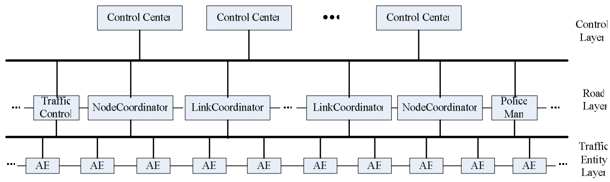

Fig. 2. Layered micro traffic simulation model

The road layer is the most complicated layer, which is responsible for the following: (1) collect the information from the AE layer. Link Coordinator will collect simulation results of link entities such as speed, traffic flow, density, queue length of road cross and so on, Node coordinator will record the crossing time delay. All the information will be transmitted to higher federate through asynchronous communication and exchanged between the federate at the same layer. (2) Another function is responsible for transferring the signal light state information. Signal lights are half- autonomous, so the signal lights are implemented as agent, which can adjust the rule according to traffic states or change the light color per commands from the control center. (3) The third special function is to convey the policeman's command to traffic entities and report traffic environment information to policeman.

The top layer is control layer, which is used to monitor and control the traffic state. It can adjust the signal lights' rule according the traffic flow and inform policeman when traffic accident happens.

2.3 Communication Model and Time Management

There are two communication styles in the model: (1) communications between different layers and different objects at same layer will conform to the agent communication protocol (ACL); (2) Communications between different federates and simulation applications will use the HLA/RTI, which includes synchronization in both time management and simulation result information between federates, the latter is achieved by publish/subscribe style [1].

Time management plays an important role in the simulation, it's important to keep simulation time consistent between components to get accurate simulation results. In our model, HLA implements time management and use Time-Stepped advance style. The simulation procedure will advance to next step when all the simulation computing complete and step length could vary between different steps, it showed as figure 3.

2.4 Abstract Agent Model

An abstract agent model was presented to describe traffic entities and makes the development of agent. The architecture is shown as figure 4.

Abstract model works as following: (1) acquire the environment information through communication; (2) convert the information to the knowledge that could be understood; (3) input the knowledge and self-desire to the BDI reasoning machine

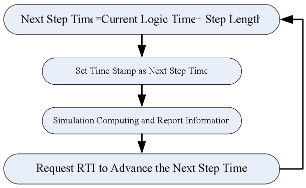

Fig. 3. Advance strategy based on time step

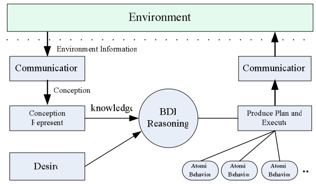

Fig. 4. Abstract model of Agent

[8]; (4) BDI reasoning machine will give a plan which includes a sequence of agent atomic behavior; (5) execute the plan and report the simulation state.

BDI reasoning machine is the core and activity engine of agent. The autonomy, sensation and intelligence characteristics of agent depend on the BDI reasoning machine. The BDI reasoning module makes use of the interior knowledge, self-desire and environment information based on CA to produce a behavior sequence called a plan. CA abstract model will be discussed in section 3.

3 Abstract Theory Model of Traffic Entity

3.1 Introduction of Model Context

The understanding of the traffic entities' behavior holds the balance in building perfect evacuation model and rules. We refer to several related models [9][10][12][13][14] to improve the accuracy of the CA evacuation model. The friction and repulsion are introduced into the CA traffic urgency evacuation model; it is shown as figure 5 and figure 6.

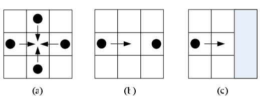

Fig. 5. Three repulsion type

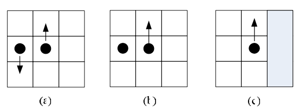

Fig. 6. Three friction types

In the model, complicate traffic environment is divided into uniform grids and each traffic entity's moving obeys simple local rule. The traffic entity is implemented as agent and the behavior of it is adjusted depending on surrounding environment.

3.2 Cellular State Transition Model

Every cellular is occupied by the traffic entity or idle, some traffic entities can occupy more than one cellular. The traffic entity can move to four neighbor cellular with some probability or stay in the original cellular, as shown in figure 7 (downward direction is the progress). When the four direction probabilities are not equal, the phenomenon is called moving with tendency and the entity is called tendency entity.

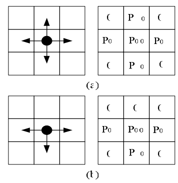

Fig. 7. Mobile styles of traffic entity in cellular automata

In this paper, Von Neumann Neighborhood is used to represent entities' visual field. Each entity tries to reach the destination as quickly as possibly and always avoid the congestion place. We present a hypothesis that traffic entity would abandon competition and select the hypo-optimal place when there are more than two entities to compete to enter same place.

The cellular state aggregate is S and the element is $s_{i,j}, i \in [0, N], j \in [0, M]$, N and M are the grid number of abscissa and ordinate, i, j are the subscript coordinates of abscissa and ordinate. $s_{i,j}$ is an five-unit group:

$$s_{i,j} = (is\_occupied, p_{i,j-1}, p_{i+1,j}, p_{i-1,j}, p_{i,j+1})$$

$is\_occupied$ is a flag indicate if the cellular is occupied. $p_{i,j-1}$ is the probability that traffic entity enter the cellular from the right direction and other three probabilities in the group are similar. The state of each cellular changes as the following format:

$$s_{i,j}{}^{(t+1)} = f(s_{i-1,j}{}^{(t)}, s_{i,j-1}{}^{(t)}, s_{i,j}{}^{(t)}, s_{i+1,j}{}^{(t)}, s_{i,j+1}{}^{(t)})$$

Since the number of traffic entity is very huge and the areas occupied by vehicle and passenger are different, the cellular number occupied by different traffic entities are different. The function is implemented by agent in this research project.

3.3 Mobile Probability of Traffic Entity

As showed in Fig. 6(a), when m(m≥2) traffic entities move to the same object, the repulsion rate which presented by Kirchner et al[11] was considered and the moving probabilities of traffic entity is determined by following formula:

$$p_i = (1 - r_1)/m \qquad (i = 1, 2 \ldots m),$$

The traffic entity stays in the same cellular with probability r_1 and forward to another cellular with probability $1 - r_1$.

For the case of figure 5(b) and figure 5(c), because it is similar to (a) and just the speed of traffic entity and traffic environment obstacle are different, we adopted following formula to determine the moving probability:

$$p_i = 1 - r_2$$

In the formula, the traffic entity stays in the same cellular with probability r_2 and moves with probability $1 - r_2$.

Similarity, we use the following formula to determine the traffic entity moving probability of figure 5(c):

$$p_i = 1 - r_w$$

It states that the traffic entity remains the same point with probability r_w and moves forward to next point with probability $1-r_w$. If the value of r is determined, we could quantitively analyze the repulsion between traffic entity and traffic entity or between traffic entity and traffic environment obstacle.

In order to quantitively analyze the effects of friction, we introduce the friction probability f. In case of figure 6(a), the moving probability is defined as formula :

$$p_i = 1 - f_1$$

It shows that traffic entity will stay in the same point with probability f_1 and move to the next point with probability $1-f_1$.

In the case of figure 6(b), because the traffic entity is affected by the static object's friction, the moving probability is defined as following formula:

$$p_i = 1 - f_2$$

It shows that traffic entity will stay in same point with probability f_2 and move to the next point with probability $1-f_2$.

As considered for figure 6(c), the traffic entity is affected by the static obstacle's friction, the formula for the moving probability will be defined as:

$$p_i = 1 - f_w$$

It means that the traffic entity will stay in the same point with probability f_w and move to the next point with probability $1-f_w$.

Based on the above analysis, we can conclude that if the friction probability f is determined, the affect of friction could be quantitively analyzed.

3.4 Selection of Repulsion Probability and Friction Probability

The existence of repulsion is attributed to the traffic entity's behavior of avoiding hurt. What's the extent depends on the relative speed between traffic entities or between traffic entity and environment obstacle. The traffic entity would be hurt more heavily when relative speed increases and it will tend to avoid with higher probability. So the repulsion probability increases direct proportion with repulsion and will go up when relative speed increases. There is an entity sustainment limitation and once the limitation exceed, the repulsion probability will tend to be 1. As considered that avoiding behavior is reaction of nervous system, the well known Sigmoid function of artificial neural network is adopted to define the repulsion. The repulsion is defined as formula:

$$r = \frac{1 - e^{-\alpha V}}{1 + e^{-\alpha V}}$$

V is relative speed and defined as follows: when there are multi traffic entities moving to each other: V= 2*v; in case of one moving and another static: $V = v$; in case of moving traffic entity and environment obstacle: $V = v$. $a \in [0, \infty]$ is a hardness coefficient and it shows the hurt extent of entity to entity or environment obstacle to entity, such as the wall hardness and roughness.

Friction depends on the contiguity extent, relative speed and friction coefficient between traffic entities or between traffic entity and environment obstacle. In the CA model, because the cellular is uniform, the contiguity content is same when the traffic entities are neighbors. So the friction is defined as formula:

$$f = \theta * V$$

V is relative speed and defined as follows: when there are multi traffic entities move to each other: V= 2*v; in case of one moving and another static: $V = v$; in case of moving traffic entity and environment obstacle: $V = v$. $\theta \in [0, \infty]$ is friction coefficient. It reflects the friction extent between traffic entities or between traffic entity and environment obstacle.

4 Experimental Verification

The simulation platform is based on the grid environment. In our simulation environment, the hard resource includes the Itanium Servers, IBM690 and IBM E1350 for complicate computation. We adopt GLOBUS Toolkit 4.0[5] as the grid middleware to build the runtime environment and implement the grid service conform to WSRF [4]. The entity environment is showed in figure 8. When the environment is built, all the resources include the agent platform register to the WS MDS [5] server.

Jade [3] platform was adopted to implement the traffic entity agent and all the implementations are using java programming language.

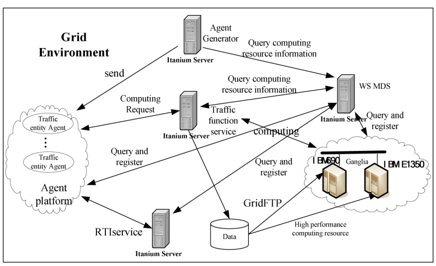

Fig. 8. High performance grid-based simulation environment

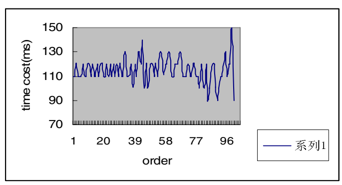

Fig. 9. Synchronization time performance test

In order to test the architecture proposed in this paper, the synchronization time performance test was given and one thousand traffic entities distributing in fifteen sub areas were considered in the test. The computing was carried by ten experimental nodes and the performance curvilinear is showed in figure 10. As showed in figure 9, every synchronization delay time is about 0.1 second. It is satisfied the traffic simulation requirement. From the curvilinear of figure 10, we could conclude that the distributed environment improves the performance greatly.

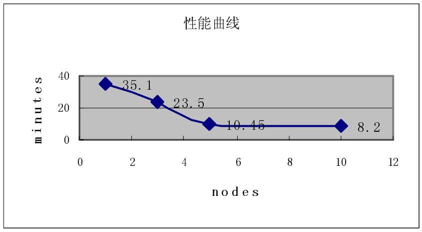

Fig. 10. Performance curvilinear

5 Summary and Future Work

A simulation model of complicate environment is presented in this paper. HLA/RTI and agent technology are the implement carrier of the model and the BDI reasoning machine of agent uses the expanded CA as theory base. Evacuation of traffic disaster, superintendence of large scale activities and design of traffic environment could be solved by the simulation model. Finally, a grid-based simulation environment is given with shanghai south railway station as the simulation background; the model is validated by the simulation platform and obtains well effects.

The future work we plan to do is to enrich the CA-based model; in additional to friction and repulsion, we will consider other factors. We could improve the simulation veracity through the enriched CA-based BDI reasoning machine.

Acknowledgments. This paper is supported by Grand 60673116 of National Natural Science Foundation of China, Grand 2006AA01Z166 of the National High Technology Research and Development Program of China (863), Grand SYSKF0607 of the Foundation of Laboratory of Computer Science, Institute of Software, Chinese Academy of Science.

References

1. IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA)-Frame and Rules [S], IEEE Std 1516-2000, September 2000 (2000)
2. Pan, X., Han, C.S., Law, K.H.: A Multi-agent based Simulation Framework for the Study of Human and Social Behavior in Egress Analysis (2006) http://eil.stanford.edu/ egress/ publications/ASCE_2005_Pan_Han_Law.pdf
3. Jade - Java Agent Development Framework (2006) http://jade.tilab.com/
4. WSRF-The WS-Resource Framework (2006) http://www.globus.org/wsrf/
5. Globus Toolkit 4.0 (2006) http://www.globus.org/
6. Bing, S.H., li, C.Y.: An Overview of Computer Simulation Research on Traffic Systems. Computer Simulation 21(3), 101–104 (2004)
7. Mamei, M., Roli, A., Zambonelli, F.: Emergence and Control of Macro-Spatial Structures in Perturbed Cellular Automata, and Implications for Pervasive Computing Systems. IEEE Transactions on Systems, Man, and Cybernetics 35(3), 337–348 (2005)

8. Bauer, B., Müller, J.P., Odell, J.: Agent UML: A Formalism for Specifying Multi-agent Software Systems. International Journal of Software Engineering and Knowledge Engineering 11(3), 1–24 (2001)
9. Helbing, D., Farkas, I., Vicsek, T.: Simulating dynamical features of escape panic. Nature 407, 487–490 (2000)
10. Kirchner, A., Schadschneider, A.: Simulation of evacuation process using a bionics-inspired cellular automaton model for pedestrian dynamics. Physica A 312, 260–276 (2002)
11. Kirchner, A., Nishinari, K., Schadschneider, A.: Friction effects and clogging in a cellular automaton model for pedestrian dynamics. Physical Review E 67, 56–112 (2003)
12. weiguo, S., yanfei, Y., Tao, C.: Influences of Exit Conditions on Pedestrian Evacuation. Fire Safety Science 12(2), 100–104 (2003)
13. weiguo, S., yanfei, Y., weicheng, F., heping, Z.: An evacuation model based on cellular automaton which pays attention to friction and repulsion. Science in China Ser. E Engineering & Materials Science 35(7), 725–736 (2005)
14. weiguo, S., yanfei, Y., heping, Z.: Evacuation Analysis of a Large Shopping Mall. Engineering Science 7(10), 78–83 (2005)
15. weifeng, F., lizhong, Y., rui, H.: A Multi2agent Model Based on Cellular Automata for Simulating Human Behavior to Assess Building Design Performance. Engineering Science 5(3), 67–71 (2003)