Multi-agent Animation Techniques for Traffic Simulation in Urban Environments

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ABSTRACT

This paper presents a traffic simulation system based on multi-agent animation method. The behaviour model of individual virtual agent defines the driving characteristics of the vehicle agent and cell-based configurations allow real-time dynamic path planning and efficient traffic flow simulations. By incorporating the advantages of discrete cellular automation algorithms and the continuous model of fluid dynamics, our 3D virtual reality traffic simulation system achieves realistic and accurate simulations in virtual environments.

Keywords
Multi-agent behaviour modelling, Computer Animation, Traffic simulation in virtual environments.

1. INTRODUCTION

Traffic simulation for urban environments has an important role in meeting future urban development and planning. In the context of traffic simulation, numerical results can provide useful and detailed quantitative descriptions of a traffic network, while 3D virtual environments of the simulation demonstrates the overall performance of specific traffic flow situations visually, from which a trained operator can quickly access the dynamic changes within a road network and select plans to enable the network to adapt the situations. For example the operator can specify traffic light signal timing to ease congestions at a particular location point of the network during rush hours or when an incident occurs [van Katwijk and Koningsbruggen 2002]. As the simulation system deals with large numbers of social agents (cars, pedestrians, motorcycles, and bicycles) and each of them has its own behaviour characteristics, the challenge is to model the massively distributed parallel behaviours [Reeves 1983, Metoyer and Hodgins 2000]. However, individual characteristics of traffic elements including human factors, vehicle specifications and dynamics, could be very difficult to model using traditional traffic flow theories or macroscopic simulation approaches []. The multi-agent traffic simulation system for urban environments described in this paper is capable of modelling large volumes of traffic in response to current network loading at the time of interest. The responsive simulation system calculates traffic control management and operations according to different traffic flow situations. The system models the motion behaviours of each individual vehicle agent using a set of object-orientated simulation components, which acts upon the vehicle agents to manage the behaviours of the agents during the simulation. Based on an origin-destination matrix, the system is capable of providing an accurate description of the expected traffic flows using a real-time path-planning algorithm, which estimates route choices and the effect of unexpected congestions.

We present a multi-agent 3D simulation system, in

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which a roadway network is represented as strings of cells and vehicles in the roadway-network are modelled as a continuous flow. The discrete space for the roadway network provides a framework for high-speed system update and traffic management registration, while a continuous space and time for modelling vehicle dynamic movements produces realistic traffic flow. Therefore the approach takes the advantage of discrete models at the same time maintains the features of fluid dynamic models. The model is capable of taking into account the human factors for more accurate simulation results. Compared with existing systems, which are mainly two-dimensional simple graphical representations [Nagel and Schreckenberg 1992], a three-dimensional visualisation system is developed based on the approach. At the current development stage, our system is able to simulate small and medium scale traffic flows of urban environments.

2. CONFIGURATION OF TRAFFIC NETWORK

A traffic network in the simulation system is modelled as a connection of desecrated cells. Each road configuration maintains a table of these cells. As shown in Figure 1, a vehicle agent is an individual element, which travels from one location to another via a route with dynamic velocity V through a list of cells along the roadway network to destination. Figure 2 shows a snapshot of the roadway network in the simulation system for a housing estate.

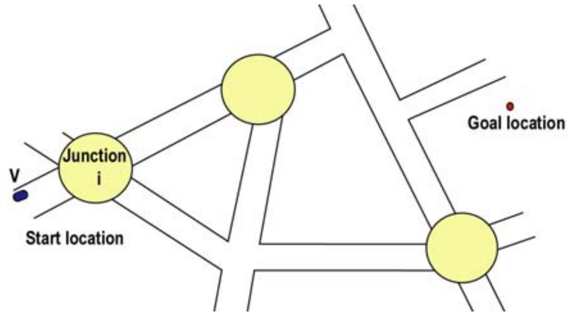

Figure 1. Description of a roadway network system

Figure 2. A screen capture of the roadway network in the simulation system

Traffic congestion and uncertainty will occur when traffic demand is higher than usual supply, which brings inefficiency to all road users. During the simulation, the state of each cell is updated according to the traffic flow. A cell is registered as occupied when there are vehicle in the cell. Otherwise it is registered as an empty cell. There will be no difference for the vehicle's exact position to the road situation as long as the vehicle is in the area defined by the cell configuration at the period of interest. The network configuration for a particular urban environment is loaded from the configuration map of the network at the initialisation stage.

3. PATH PLANNING

Based on an origin-destination matrix for the period of interest, the system is capable of providing an accurate description of the expected traffic flow using real-time A* path-planning algorithm, which estimates route choices of the vehicle agents.

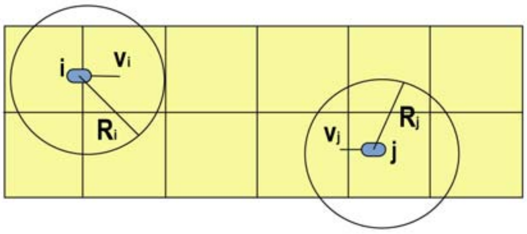

Figure 3 Description of the perception of virtual vehicle agents: Vi – velocity of vehicle i, Ri-perception radius of i, Vj- velocity of vehicle j, Rj-perception radius of j.

The average travel time for a vehicle traversing a specific route can be calculated. Upon arrival of an individual vehicle, the traffic stream is split to follow routes according to the cost value of the chosen route. The vehicle will choose the least cost route to travel. Each vehicle in the system has been assigned a circular vision zone representing the views of mirrors and of the front screen.

At time t, the position of a vehicle moving along a roadway is designated $x_0(t)$, then its velocity is $dx_0(t)/dt$, and its acceleration $d^2x_0(t)/dt^2$. With N vehicles in the system, there are N different velocities, each depending on time, and the velocity of each vehicle is designated $v_i(t)$, i=1,…,N. At time t and position x, the velocity of the vehicle i can be expressed as a point in space of a velocity field:

$$v_i(x_i(t),t) = v_i(t) \qquad (1)$$

In order to measure the traffic, the traffic flow q, which is the average number of vehicles passing per lane per unit time, say per hour, is defined. The number of vehicles in a given length of roadway, which might be converted into the number of vehicles per unit length (per lane), is called the density of vehicles p. The general relation of the three variables is:

$$q = p \cdot v \qquad (2)$$

The dynamics of an individual moving vehicle must follow the basic laws of motion, which may be represented as a set of general ordinary deferential equations with delay. The behaviour of each vehicle is modelled in relation to the vehicle ahead. This is refereed as car-following models []. This model captures individual driver's reaction to the road conditions ahead. Although drivers will decelerate and accelerate quite differently, the driving behaviour also depends on the distance to the preceding vehicle. The closer the driver is, the more likely the driver is to respond strongly to an observed relative velocity. Therefore, the sensitivity is inversely proportional to the distance ahead.

$$\frac{d^2 x_n(t+T)}{dt^2} = c \cdot \left(\frac{dx_{n+1}(t)}{dt}\right)^m \cdot \frac{\left(\frac{dx_n(t)}{dt} - \frac{dx_{n-1}(t)}{dt}\right)}{\left[x_n(t) - x_{n-1}(t)\right]^l} \qquad (3)$$

where T is the reaction time between stimulus and response, which summarizes all delay effects such as human reaction time or time the vehicle mechanics need to react to input, c is a chosen constant, which can be interpreted as the velocity corresponding to the maximum density p_{max}. The constant m describes the perception-reaction time and various responses to the movement of other vehicles including individual driving attitudes, while constant l expresses the road conditions and other related factors. Important human performance characteristics can therefore be added into the formulation although no clear solution has yet been found. We consider two general cases. First, Equation 3 applies for high densities of a roadway. Second, Equation 4 is for small densities. Because for small densities of a roadway, the speed changes of a vehicle are more likely influenced by the speed limit, say 30 miles per hour for residential areas. Therefore, $v = v_{max}$, and the velocity at the maximum flow is:

$$v\left(\frac{p_{\max}}{e}\right) = c \qquad (4)$$

The system updates the internal state of each agent of the network consistently. Agents are maintained by Finite State Machines (FSMs). At each simulation frame, the state of an agent has a specific set of outputs.

4. SIMULATION RESULTS

The traffic management module of the system carefully controls the traffic flows for vehicles both entering and leaving a roadway of the network. If the flow exceed the designed capacities of that roadway, congestions and delays are introduced. Figure 4 shows the virtual vehicles agents arriving at a roundabout.

Figure 4. Vehicles approaching a roundabout

The design of the network must take into account the congestion and queuing at junctions. The system uses the average number of arrivals per unit time for each junction. There is a maxim queue length beyond which the change of traffic signal is enforced. It is desirable for junctions of the network to be in equilibrium so that the entering and leaving of the traffic flow of a roadway are the same. This process can be summarised by Figure 5 for a traffic light controlled junction.

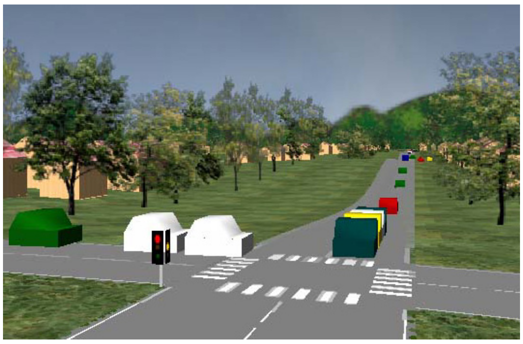

Figure 5. A queuing system of a traffic light controlled roadway.

Traffic jam occurs when the flow of input is greater the throughput.

Figure 6. Traffic jam at roundabout during morning rush hours of a residential housing estate

It is very common in reality that there are vehicles waiting at traffic lights and roundabouts. A long-lived queue is considered as congestion, if the delay time of a vehicle at a junction is greater than expected Figure 6 demonstrates a traffic jam at a roundabout of a residential area in the morning rush hours.

Cells of the roadways are used as sensors for detecting congestion in different regions of the network. Information will be posted to inform the following vehicles on the same roadway of the congestion. These vehicles would change routes by re-planning a path from their current position to destinations.

As the behaviour modelling in our simulation is an individual agent based approach, it enables good capture of stochastic characteristics of traffic in reality. For a period of interest, the system subdivides the time period into short measuring intervals.

In ambient traffic situations, a roundabout is assumed more efficient than a traffic light controlled junction if the design of other sections of the roadway remains the same. However, in an ill-designed roadway network, a roundabout can cause traffic congestion very quickly in heavy traffic. The simulation for the large residential area as shown in above figures runs at 13 to 15 frames per second for 500 moving vehicles, which is near real-time visualisation.

5. CONCLUSION AND FUTURE WORK

Using a computer animation approach, we have simulated a large complex roadway network with different designs and configurations in a 3D visualisation of a housing estate. Users of the system can populate the network during the simulation to test the roadway traffic flow. Users can set the origin -destination matrix of the vehicle agents. Timing of the traffic signals can also be altered in the event of a traffic jam. New network design and alterations of junctions including the type and control management of the junctions can be loaded from a design map before a simulation. We are able to simulate a large number of vehicles in the environment effectively with different traffic situations and conditions, and the results agree well with the reality of similar situations.

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