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ARCHITECTURE USING JINI TECHNOLOGY FOR SIMULATION OF AN AGENT-BASED TRANSPORTATION SYSTEM

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ABSTRACT

This paper describes an architecture for the simulation of a transportation system that uses agent technology to deliver people and goods from their origins to their destinations. The intent of the architecture is to analyze incremental changes to the existing transportation paradigm to determine what type of system we could plan for in the future. Each entity within the system that has computational power is simulated as an agent. This architecture is useful for experimenting with many different algorithms and strategies for improving transportation systems.

1 MOTIVATION

Congestion costs the U.S. one hundred billion dollars in lost productivity every year (Ben-Akiva 1992). Urban areas across the country are experiencing increasing travel demands resulting in traffic congestion. This is placing a tremendous burden on existing highway infrastructure. Due to latent demand and growth in population and employment, building wider freeways rarely solves this congestion problem (Haboian 2001).

To achieve a significant increase in the efficiency of a transportation system, we must exploit technology and change the paradigm of the current transportation system. Envision a system in which a person loads goods, or himself, into an agent-like "transporter" that will take him or the goods to a destination. When the item to be transported enters the transporter, the user swipes a credit card to pay the fare and types the address of the destination. Then the transporter-agent's computing power calculates the route and joins the rest of the transporters within the system in a train-like fashion. When the transporter arrives at its destination, the contents are unloaded and the transporter becomes available for other people or goods to use to transport themselves to their desired destination.

Of course considering the current infrastructure, it would be a long time before a system such as this would be fully functional, if it would ever be implemented at all. However we can experiment with the feasibility of incremental changes to the current system such as communication among cars and trucks to avoid collisions, a concept currently being addressed in telematics research projects by car manufacturers.

The technology for the hardware exists to support such a distributed system. The technology that would need to be developed is the system architecture, software, and algorithms. Simulation analyses are necessary to evaluate different system architectures and agent algorithms to determine how and if such a system would be feasible. Jini technology is useful in developing a prototype distributed system to simulate agent-based communication. Jini supports serendipitous interactions among services and users of those services. Jini also supports redundant infrastructure to reduce the probability that services will be unavailable if machines within the Jini community crash (Edwards 1999).

2 PROBLEM DEFINITION

The purpose of the work done for this paper was to develop an architecture for the simulation of a distributed system that uses agent technology to transport people and goods from their origins to their destinations. The architecture is used to experiment with designs for incremental changes in the existing infrastructure to determine the feasibility of each change. The simulation would focus on the algorithms required by the agents, such as dispatching or navigation algorithms. As shown in Figure 1, the system design includes people, hardware, and software.

Each of the components shown in Figure 1 have several items to consider, thus the architecture must include characteristics to enable simulations that consider experimentation with these items. These items are listed in Table 1.

3 PROJECT CONTEXT

Much work has already been done towards developing pieces of an advanced transportation system. The simulation within the architecture is aimed at fitting all the pieces into a distributed agent-based system. Some of these pieces

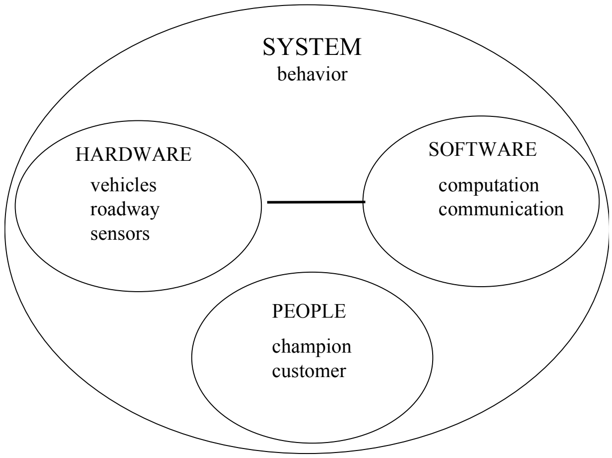

Figure 1: Agent Transportation System Architecture

Table 1: Characteristics of an Agent Transportation System

People	User characteristics (e.g. elderly, commuters)
	Desired services
Software	Computational algorithms
	Information shared electronically among agents
	Information required from sensors, versus information required from electronic communication (the link between hardware & software)
Hardware	Capabilities of roadway links and nodes
	Capabilities of transporters
System	Physical interaction of roadway devices and transporters
	Communication among roadway devices and transporters

include dispatching (Taghaboni and Tanchoco 1988), platooning, automated cars, car sharing, small cars, inter-vehicle communication, and other remote communication.

3.1 Advanced Transportation Systems

Research has been done at the University of California Berkeley PATH (Partners for Advanced Transit and Highways) program in the area of Automated Highway Systems (AHS). Shladover (1991) has been working on research projects toward the development and implementation of AHS. Some of his work involves research on platooning, which is the concept of grouping vehicles into train-like arrangements. The purpose is to utilize roadway more efficiently without introducing risks of high-impact collisions. These studies use magnets or computer vision to guide the automated vehicles.

Shaheen *et al.* (1999) are working on a car-sharing program in the San Francisco Bay area in which people pay a monthly fee to use cars owned by the program. Cars are available in a lot near their homes and driven to the BART station. Then the car is left in the BART parking for someone else to use. When users arrive at their destination BART station, they take another car owned by the program to work.

Corbin Motors manufactures small vehicles designed for carrying one passenger during a short commute. The vehicles operate on battery power which lasts for approximately 40 miles per charge. Other motor companies are experimenting with inter-vehicle communication.

3.2 Architecture

Great effort has been spent on developing a national Intelligent Transportation Systems (ITS) Architecture (USDOT 2000). ITS projects requesting federal funding are required to use relevant portions of the ITS architecture. The ITS architecture does not (and should not) define a specific system to work toward.

Tambe *et al.* (2000) developed a teamwork-based agent integration framework to encompass several heterogeneous agents within one system. Their framework is designed to build teams of agents that can accomplish team goals in a computational environment. Martin *et al.* (1999) developed an open agent architecture framework for constructing multiagent systems. The open agent architecture makes it possible for services to be provided through cooperative efforts of distributed autonomous agents. Guessoum (2000) presents a multi-agent framework that has a modular architecture which reuses artificial intelligence methods and has a discrete event simulator.

Schaefer (2000) presents an object-oriented architecture for implementing simulations of agents to analyze their emergent behavior. Schaefer's architecture is a framework that can be used for experimenting with variations of rule sets to assist in discovering a rule set that results in desirable system-level behavior.

4 SIMULATION ARCHITECTURE

Jini supports serendipitous interactions among services and users of those services. (Edwards 1999) Agents in a network send messages to register themselves with Jini services.

Each portion of the architecture described below addresses the system components shown in Figure 1. Figure 2 depicts the simulation architecture in which each segment represents a hardware entity with embedded software used by people, the three components in Figure 1. For the simulation, each transporter, location service, and user interface are agents on their own virtual machines. The system represented in Figure 2 is one Jini community that exists in a system of many communities. All agents within a given vicinity belong to the same community. A vicinity may represent a traffic intersection or a neighborhood of street-links. The three agent types, transporter, location service, and user interface, are described below.

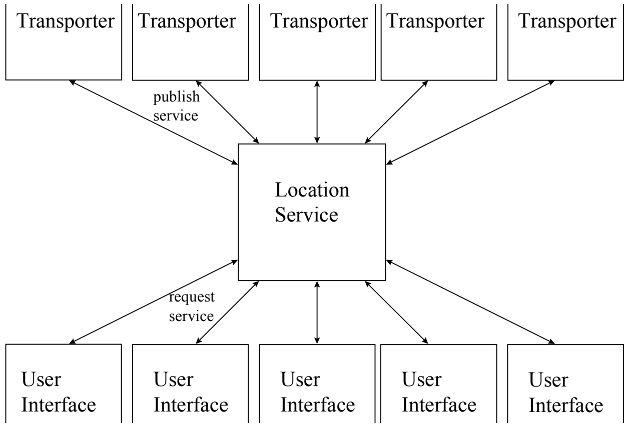

Figure 2: One Community of Transporters and Interfaces within the same Vicinity

4.1 Location Service

In this architecture, the location service is the link to communication among all members of a Jini community of agents. The location service serves one vicinity of a traffic intersection or a neighborhood. When a transporter enters the boundaries of the location service's vicinity, the transporter broadcasts a message to register with the location service. The location service detects the transporter signal and sends information back to the transporter. Figure 3 shows the attributes and methods of a location service.

ATTRIBUTES
Boundaries
List of members
Local map
METHODS
Optimization

Figure 3: Attributes and Methods of Location Service

4.2 Transporter

The transporter would be a car-like entity, thus in a simulation, the transporter agent must have some knowledge of the physics of the entity, such as acceleration and braking. As the transporter enters the boundaries of a new location service, it gathers information about the map of the vicinity and other nearby transporters so the transporters can negotiate directly with each other for lane or intersection priority. The attributes and methods of transporters are shown in Figure 4.

ATTRIBUTES
Destination
Current location
Speed
Acceleration capabilities
Braking capabilities
Current map
Current route
METHODS
Route selection
Navigation rules
Check if maintenance required
Negotiate for lane or intersection priority

Figure 4: Attributes and Methods of Transporter

4.3 User Interface

In a futuristic scenario, the user interface would be a button that sends signals to request a transporter to the person's current location. Merely a push-button would not be relevant in a near-term scenario, thus if simulating a less futuristic scenario, the interface may require more interaction from the user, such as current driving tasks. Figure 5 shows the attributes and methods of a user interface.

ATTRIBUTES
Location
METHODS
Dispatching rules
Navigation rules
Route calculation

Figure 5: Attributes and Methods of User Interface

4.4 System

Figure 6 shows a transporter leaving a community and driving into another adjacent community. When this happens, the transporter broadcasts a message to register itself with the community it just entered. Each community has boundaries within which it contains the interfaces and transporters. The transporters are able to communicate with each other through proxies obtained by the location service when it registered with the service.

Figure 7 shows what this scenario may look like in the actual system, with the paradigm of streets with intersections, lanes, and car-like transporters. Interfaces could be cellular phones. Intersections are numbered corresponding to location services in Figure 6. Note the transporter leaving the vicinity of the intersection on the lower left and entering intersection 4, also as in Figure 6.

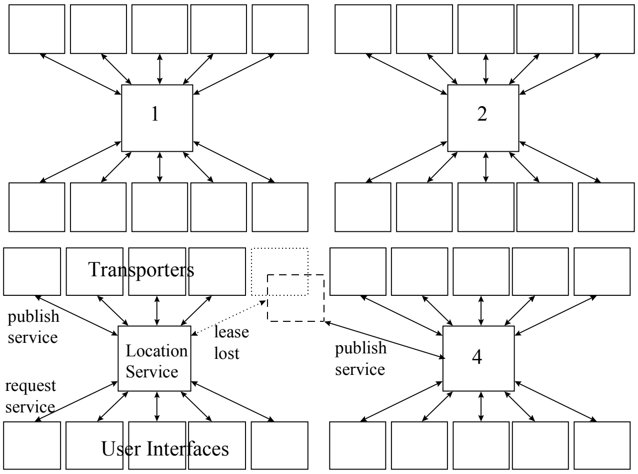

Figure 6: Simulated Adjacent Communities

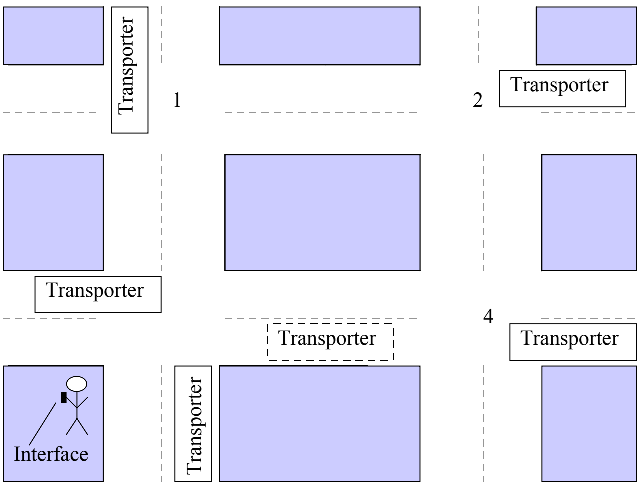

Figure 7: Possible Actual System Represented by Figure 6

4.5 Simulation Algorithm

There are three steps within the simulation: initialization, simulation, and feasibility analysis. The events which occur during the three steps are outlined below.

4.5.1 Initialization

To start the simulation, the machines representing the transporters, location service, and user interfaces must be running. The location service is given boundaries and interfaces are given logical locations. Transporters are given locations on transportation links. Transporters broadcast a registration message which is picked up by the machine for the vicinity which the transporter is located in. The location service then registers the transporters as members of the Jini community.

4.5.2 Simulation

Transporters change their locations at each time step according to their accelerations and velocities. If they enter a new vicinity, they broadcast a registration message. The vicinity computer registers the transporter with the new vicinity they entered. A period of time after a transporter leaves a vicinity, its registration expires with the previous vicinity.

4.5.3 Feasibility Analysis

Any data collected during the simulation can be analyzed to answer a variety of questions. Several questions are discussed in the following section.

A preliminary agent simulation was performed to answer questions such as:

1) How crowded can a vicinity become before congestion becomes a problem?
2) Which system characteristics affect inefficiency?

The analysis proved that if the system is crowded, navigation will be inefficient. Thus it would be useful to experiment with a system that uses platooning. The analysis also proved that a crowd traveling in varying directions will navigate inefficiently. Thus modeling a system in which transporter agents navigate along rails may be useful.

5 FUTURE EXPERIMENTS

Many more experiments that could be performed within this architecture come to mind. A few of them are described here.

Experiments could be performed to determine feasible steps to implementing a truly futuristic transportation system. In the initial steps, the transporter would have the same capabilities of today's car. Successive steps would experiment with vehicle to vehicle communication for collision avoidance, vehicle to vehicle to vicinity communication with a location service to decide who has priority in the intersection, varying percentages of vehicles with communication capabilities, a dedicated lane for transporters with advanced capabilities, and partial control by the driver. Studies addressing some issues similar to these have been done at the California PATH project.

One could also experiment with various algorithms for agents such as platooning, routing, dispatching, maintenance scheduling, negotiation, and intersection optimization strategies. An analysis could be performed to determine appropriate information transfer among agents and the amount of collaboration that would be desired. It may be possible that the location service should be responsible for some optimization computation.

Systems issues need to be considered such as timing or transmission problems with broadcasting signals and robustness if a transporter or interface loses its registration. Other system issues include special links or times for large trucks transporting goods and keeping a large family together during transport.

6 DISCUSSION

If a new transportation system is going to become reality, society must change its paradigm and engineers must plan for integration. Simulation experiments must be done during the research phase before design can commence and the physical system can be developed. We could destroy the whole transportation infrastructure and start over from scratch, like the Japanese had to do with their manufacturing infrastructure after World War II. But they had to endure 40 years of hardship while rebuilding (Hopp and Spearman 1996). Destroying the current transportation infrastructure so things would be more efficient in many years would not be desirable. It would take longer to rebuild the transportation infrastructure in the United States than to rebuild factories in Japan. Thus the current system must be our starting point and we can plan how to incrementally change the system. It may be best to try a pilot study in developing countries with dense populations and little infrastructure.

Although this paper focused on systems with the functionality of cars or public transit, the architecture could be useful in material handling robot or unmanned military vehicle scenarios.

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