Disaster Evacuation Guide: Using a Massively Multiagent Server and GPS Mobile Phones

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Abstract

The ubiquitous environment enables us to build systems that provide individual users with personalized navigation services in cities. In developing such a system, it is necessary to estimate the influence and the movement of its users and to get feedback. However, it is difficult to perform tests on such a system given the large number of human subjects involved and its scale, which matches that of a major city. One possible solution is proposed herein, the augmented experiment; it combines a multiagent simulation with a small-scale experiment performed with human subjects. In the experiment, the movements of agents that simulate users are shown to human subjects in order to give them the impression that the environment is populated with a large number of users. In this research, we build a evacuation guide system based on GPS-capable cellular phones and perform an augmented experiment wherein human subjects and evacuee agents are directed while the status of the simulation is passed to the human subjects. Interviews of the human subjects confirmed that the augmented experiment successfully gave the impression that a large number of users were present.

1. Introduction

Due to the popularity of and improvement in mobile phones, environments that support ubiquitous computing are spreading. In traditional information services, the user accesses the services desired via a terminal fixed in a room. However, in the ubiquitous environment, each user has his/her own portable device and accesses the services desired from any location via the wireless network. Because each person has his/her own device such as a mobile phone, it is possible to show different information to each user. In addition, GPS (Global Positioning System) and RFID (Radio Frequency Identification) tags enable devices to get information of the location and the situation of the user. In such an environment, it is possible to provide services that suit the properties, the purpose, the location and the context of each user. Navigation in public spaces is one such service [6][8].

Current navigation services simply broadcast the same instructions over a large area, but what is needed is a system that can provide individualized instructions to each person. The use of GPS-capable cellular phones enables the provision of personalized navigation instructions to suit the user's characteristics, city-supplied evacuation targets, and the surrounding environment.

To know the behavior of such social systems, it is desirable to perform confirmation experiments with a large number of human subjects. Unfortunately, cost and safety concerns preclude such experiments from being performed on a realistic scale. The solution is the augmented experiment approach; multiagent simulations are combined with small-scale experiments in the real world [4][5].

Any large-scale evacuation guide system must be verified from the macro standpoint and the micro standpoint. The former is concerned with whether all citizens can take refuge efficiently. The latter addresses how citizens use the system. Verification will be accurate only when the human subjects feel as if their environment is populated with an adequate number of participants. Our goal is to devise a process for verifying city-wide navigation services. In this research, we confirm that the combination of multiagent simulation and GPS-capable cellular phones can create a situation in which human subjects feel like they are participating with a large number of humans.

Section 2 explains augmented experiments. In Section 3, we describe the scenario description language and the massive multi-agent platform as the fundamental technology. Section 4 introduces our large-scale evacuation guide system for augmented experiments. In Section 5, we explain the setting of an initial experiment and its results.

2. Augmented Experiment

A city-wide evacuation guide system is a large-scale social information service where a large number of users interact with each other. Testing the system requires analyzing the movement of crowds and the usability of the system. These analyses need human subjects who feel as if they are participating together with a large number of humans. Unfortunately, real-world experiments with many people are too expensive and rather dangerous.

The Augmented Experiment was proposed to test large-scale ubiquitous computing systems [5]. A real-world experiment with a small number of human subjects is enhanced by a large-scale multiagent simulation.

Figure 1 illustrates how an augmented experiment for a city-wide navigation service is realized. The augmented experiment system lets human subjects perceive the results of the simulation performed in the virtual space concurrently with the real-world experiment. The human subjects are made to feel that they are participating with many other humans. This approach yields data comparable to that by performing real-world tests with a great many human subjects. In addition, comparing the movements of the human subjects with those of the agents can enable us to refine the user models of the agents.

The augmented experiment for the navigation service proceeds as follows. The real-world experiment and the simulation in a virtual space are executed concurrently. A user agent in the simulation sends its location to a guide agent, who gives navigation instructions to the agent. The user agent determines his behavior considering the instructions and the agent's situation in the virtual space. The human subject, on the other hand, sends his location to the navigation service and the subject's position is projected into the virtual space. The guide agent for the subject sends navigation instructions and the status of the virtual space including positions of other evacuees to the subject.

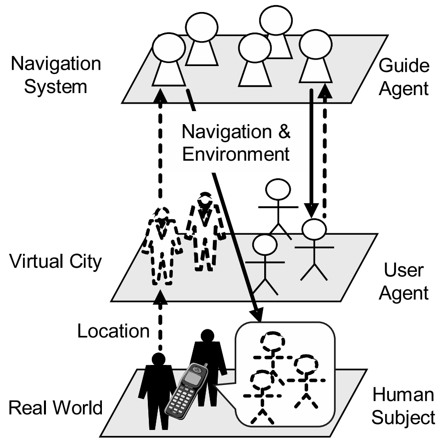

Figure 1. Example of Augmented Experiment for Navigation Service

Participatory simulations are another method that allows the actions of human subjects in a virtual space to be extracted [?].In a participatory simulation, some agents are replaced by human-controlled avatars. A participatory simulation is performed in virtual space, and the avatars are controlled by human subjects sitting in front of their computers. Participatory simulations are particularly useful, but sometimes fail to give valid results. To understand how users really respond to socially embedded systems, real world experiments are often required.

3. Fundamental Technologies

We have combined the scenario description language Q [3] with a large-scale agent server Caribbean [10] to build a platform for large-scale multiagent simulations. Below, we describe the two technologies and the massively multiagent platform that we developed by combining them.

3.1. Scenario Description Language Q

Q[1] is an interaction design language that describes how an agent should behave and interact with its environment including humans and other agents. For details see [3]. In modeling human actions, it has been shown that the Q approach, describing the interaction protocol by scenarios, is more effective than alternative agent description methods that simply describe the appearance of human beings [?].

1 Q is available from `http://www.ai.soc.i.kyoto-u.ac.jp/Q/index_e.htm`

The features of the Q language are summarized as follows.

- **Cues and Actions**
An event that triggers an interaction is called a cue. Cues are used to request agents to observe their environment. A cue has no impact on the external world. Cues keep waiting for the event specified until the observation is completed successfully. Actions, on the other hand, are used to request agents to change their environment. Cue descriptions begin with "?" while action descriptions begin with "!".

- **Scenarios**
Guarded commands are introduced for the case wherein we need to observe multiple cues in parallel. A guarded command combines cues and actions. After one of the cues becomes true, the corresponding action is performed. A scenario is used for describing state transitions, where each state is defined as a guarded command.

- **Agents and Avatars**
Agents, avatars and a crowd of agents can be defined. An agent is defined by a scenario that specifies what the agent is to do. Avatars are controlled by humans so they do not need any scenario. However, avatars can have scenarios if it is necessary to constrain their behavior.

In addition, a tool called Interaction Pattern Card (IPC) is introduced into Q to support scenario descriptions. Even computer novices can easily describe scenarios by using this tool.

3.2. Agent Server Caribbean

Caribbean[2] is a large-scale agent server implemented in Java. Caribbean manages agents as objects. There are two types of objects in Caribbean: service objects and event driven objects. Objects in Caribbean communicate with each other using the Caribbean messaging facility. Service objects can be run at any time and are used for implementing modules such as databases with common information which are accessed frequently. In contrast, event driven objects run only when they receive messages from other objects. The Caribbean scheduler allocates threads to event driven objects based on messages. Most modules in a Caribbean system are implemented as this type of object.

2 Caribbean is available form `http://www.alphaworks.ibm.com/tech/caribbean`

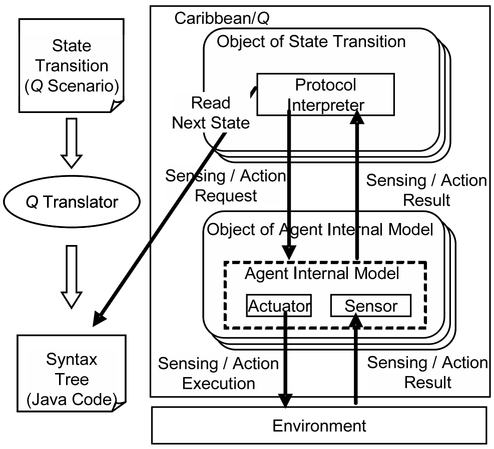

Figure 2. Overview of Massively Multiagent Platform Caribbean/Q

Using the naive method of assigning one thread to each object and running them concurrently limits the system to only several hundred objects. Caribbean does not run all objects concurrently, and assigns threads only to those event driven objects that have to work. This makes it possible to run a much larger number of objects.

Caribbean limits the number of the objects that can call on memory and controls the consumption of memory by shuttling objects between memory and external storage. When the number of objects that call on memory exceeds a limit, Caribbean moves inactive objects to external storage. When another object sends a message to an object in external storage, the object is restored to memory and the message is processed. This swapping means that Caribbean can manage many more agents than would fit directly into memory.

3.3. Massively Multiagent Platform Caribbean/Q

We developed a large-scale multiagent Caribbean/Q system, by combining scenario description language Q and large-scale agent server Caribbean. A key point is that it realizes the separation of protocol design and agent development and scalability. Figure 2 outlines the system.

A Q scenario describes an interaction protocol between an agent and the outer world. A protocol is given as a state transition description. The conventional processor of Q language, which is implemented in Scheme, cannot control enough agents to realize the massive

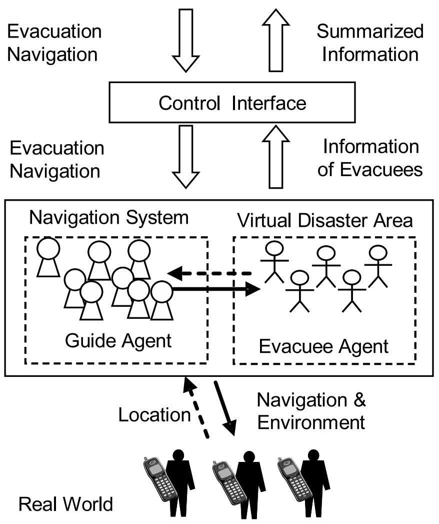

Figure 3. Overview of Evacuee in Augmented Experiment for Large-Scale Evacuation Guide System

scale needed. Therefore, we developed a new processor of Q language that runs on the agent server Caribbean.

In Caribbean/Q, the Q translator takes a Q scenario as input, and converts it into a syntax tree that is read by the state machine object in Caribbean. The state machine executes the converted syntax tree stepwise, by which the protocol given in Q is executed. The scalability of Caribbean is thus fully exploited by importing the Q processing system as an event driven object in Caribbean.

MACE3J [1], MadKit [2], Robocup Rescue [7] are other large-scale multiagent platforms. These platforms provide no explicit separation between protocol description and agent development. In contrast, the Caribbean/Q architecture is aimed at separating protocol design from agent development, which enables the experts of different domains to cooperatively and efficiently develop large-scale multiagent systems.

4. Large-Scale Evacuation Guide System for Augmented Experiment

We produced a large-scale evacuation guide system as a good test of the augmented experiment approach. Figure 3 depicts the structure of the system.

The system commander assigns evacuation destinations and evacuation directions through the control interface shown in Figure 4. The commander issues high level instructions to the guide agents using a map and the guide agents, assigned to evacuees on a one-to-one basis, provide individual navigation instructions. These instructions are sent to the evacuees via GPS-capable cellular phones.

Each guide agent navigates its user with consideration of the user's surrounding environment. The positions and movements of other evacuees are shown on the navigation map. In this way, human subjects can feel as if they are participating with a large number of humans.

4.1. Control Interface

Transcendent communication is proposed as the method for navigation in public spaces [9]. We implemented the control interface based on this architecture. In transcendent communication, the distribution of evacuees in the real space is reproduced on the virtual space as human figures that mirror the positions of evacuees; the positions of the subjects are acquired by sensors.

By running multiagent simulations, the commander can develop and optimize evacuation instructions as if he were interacting with a large number of human subjects. The commander views the virtual space via transcendent communication and treats real evacuees and virtual evacuees in the same way.

The current state of the virtual space is displayed as a birds-eye view on the monitor of the control center, so that the commander can grasp how evacuees are moving in the real world. In addition, the commander can instruct individual evacuees by clicking on the human figures on the screen. The system passes the instructions to the appropriate evacuees via their registered phone numbers or e-mail addresses. The use of transcendent communication, make sit possible to grasp the situations of all evacuees while providing local navigation instructions as needed.

In a large scale disaster, the commander should not be trying to provide detailed instructions to each evacuee. The solution is for the commander to group evacuees in certain areas and send rough instructions to them as shown in Figure 4. However, such rough instructions can't provide enough information to the evacuees. Therefore, the guide agents acquire the rough instructions from the commander and send personalized navigation to their users by interpreting it as shown in Figure 5.

The commander tells the guide agents the direction to be taken to evacuate through the control interface. The interface provides a complete map of the disaster area so that the commander can discern the current locations of almost all evacuees. The commander

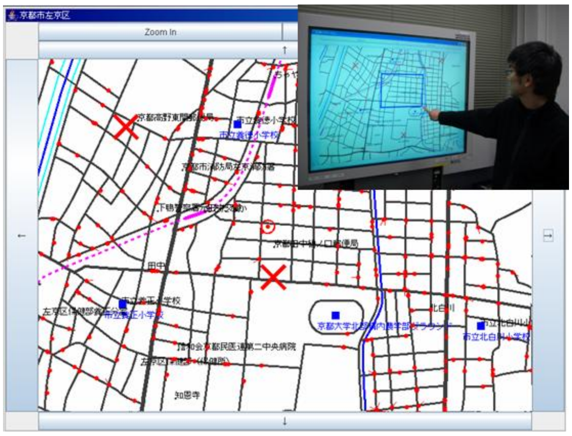

Figure 4. Transcendence Interface for Commander

Figure 5. Evacuee in Augmented Experiment and GPS-capable Cellular Phone

can also assign evacuation sites, set places of shelters, and record the information about dangers such as fires.

This system places geographical information of the disaster area into the virtual space by accessing a database holding numerical maps (1/25000) issued by the Geographical Survey Institute. Evacuation guides and disaster situations that are entered through the control interface are recorded in this database at regular intervals.

4.2. Massively Multiagent System

Agents on Caribbean/Q act as event-driven objects. Caribbean/Q can operate both guide agents and simulation agents simultaneously. Both guide agents and simulation agents are implemented as extensions of the event-driven object of Caribbean and agent behaviors are controlled via Q scenarios. They get information of dangerous sites and shelters from the same environment database.

Guide Agents:
Guide agents provide individual navigation instructions to each evacuee using information of the evacuee's position, navigation targets set by the commander, and the environmental situation.

A guide agent sends a surrounding map centered on the user's location upon receiving location information from the user's GPS-capable cellular phone. The map shows locations of dangerous sites such as fires, shelters to evacuate to, and the direction of safety are described. The user can send his location and get a new map whenever he wants to.

An agent is instructed on the evacuation direction by the control center. The agent retrieves shelters around the user, and selects a destination according to the ordered direction and distance between the user and each shelter. If the destination is changed, the agent notifies the user. If there is a person who needs help, his location is given to neighboring evacuees.

Evacuee Agent:
The positions and movements of other evacuees are provided to the human subjects through their navigation maps. The positions of the human subjects are captured by GPS and plotted in the virtual space. Evacuee agents determine their behavior after consideration of this data.

Evacuee agents behave as navigated users and act in the virtual space according to their scenario. An evacuee agent requests its guide agent to send a navigation map and uses the map in determining its movements. The scenario of an evacuation agent is shown in Figure 6.

Human users move in the real space following the maps sent by their guide agents and naturally cannot break the laws of physics. The agents, on the other hand, must be provided with geographic data to prevent them from ignoring reality. In the current system, simulation agents can move only along “roads”. Road data is prepared for them in the virtual space. This data is composed of intersections (nodes) and segments (edges) connecting intersections. Taking account of shelters, dangerous sites, and the given direction, a simulation agent evacuates along the fixed roads on the virtual space.

One cycle of an evacuee agent is as follows. First, the evacuee agent decides his goal. The agent checks if the current heading direction has become incorrect due to the emergence of dangerous sites or the disap-

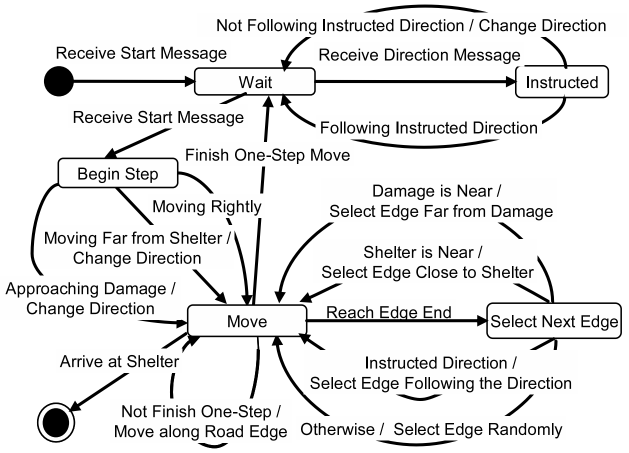

Figure 6. Scenario of Evacuation Agents

pearance of shelters. If the heading direction should be changed, the agent turns to new direction. Next, the agent starts to move along a road segment. If it reaches an intersection, it selects the next intersection and moves along the segment to the intersection. When it selects the next intersection, it obeys rules such as not to approach dangerous sites, to select an intersection close to a shelter, to follow the direction set by the control center.

In this experiment, all guide agents are controlled with the same scenario. However, by creating various scenarios, it is possible to develop a system that navigates users in various scenes or to conduct simulations with different properties and goals.

5. Augmented Experiment: Evacuation Guide

We executed an augmented experiment for the evacuation guide system described in Section 4. This experiment was conducted in order to test how human subjects responded to the simulated crowd.

5.1. Setting of Augmented Experiment

The experiment was conducted around Kyoto University. The area had a side length of 4 km. About 10 human subjects (13 in the first phase, 10 in the second phase) and 3, 000 simulation agents were evacuated together. 5 shelters were dispersed throughout the area in advance.

The system was accessed via web browsers of current mobile phones. Each mobile phone determined its location with GPS and sent it to the system every minute automatically. In addition, human subjects could send their location manually whenever they needed a new map. Upon receiving location information, a guide agent would send a map that showed dangerous sites, shelters, and the direction to be followed its user.

One person played the role of the commander. He viewed the virtual space displayed on the monitor in the control room, and instructed both guide agents and simulation agents on the directions to be taken.

Although the human subjects were told about the virtual refugees before the experiment, they were given no instructions about responding to them such as following them or avoiding them.

The experiment proceeded as follows. When a disaster warning was issued for the area around Kyoto University, the commander started the evacuation guide. The commander grasped the disaster scene through the transcendence interface, selected groups of agents, and give them rough directions for safe shelter or evacuation. The guide agents received the location information from the GPS-capable cellular phones and sent navigation maps to the users. When a second disaster occurred, it was displayed to the commander. The commander changed the navigation instructions the evacuees impacted by the second disaster. The commander could also provide personal navigation instructions to evacuees via e-mail.

5.2. Result of Augmented Experiment

Our purpose was to discern if human subjects would participate in the navigation experiment as if they are in the midst of a large crowd. In this experiment, each navigation map showed the directions to shelters, locations of dangerous sites, and the positions and movements of simulation agents.

In the experiment, the subjects were made aware of the presence of the simulation agents via the maps displayed on their mobile phones. After the experiment, five human subjects were asked how they felt about this approach. All of them said that they had formed their evacuation plans after considering the virtual refugees. While some of them followed the virtual refugees, other avoided them. This shows that even a simple graphic representation notification of the virtual evacuees can influence human behavior.

One purpose of the augmented experiment is to refine the models of simulation agents based on the models of human beings extracted from data captured during the experiment. Since the human subjects were dispersed widely across the test area, the data that could be captured was limited to just the time and location at which each subject requested a new map. This was supplemented by replies to questionnaires and interviews performed after the experiment. More detailed behavior of human subjects can be collected from small real-world experiments and participatory simulations. In small real-world experiments, the behavior of human subjects can be recorded by cameras. In participatory simulations, behavior can be reproduced from the histories of avatars.

6. Conclusion

To develop a navigation service for humans with mobile terminals, it is necessary to test the system with a large number of human subjects. However, any experiment in the real world with many human is too expensive and rather dangerous. Thus we took the augmented experiment approach which uses a multiagent simulation to expand a real-world experiment with a few subjects.

We produced a city-wide evacuation guide system assuming the use of GPS-capable cellular phones. In this system, each user receives updated maps and instructions from his/her own guide agent. We subjected this system to an augmented experiment.

In the augmented experiment, the positions and movements of simulated users was shown on the navigation maps sent to each subject. Interviews of the human subjects confirmed that the system successfully gave the impression to the human subjects that they were participating with a large number of users. The results of this experiment give some indication of the possibility of using augmented experiments to refine city-wide navigation services.

Future works included determining how to extract models of human subjects from the results of augmented experiments and how to use the models to enhance simulation accuracy.

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