Agent Based Approach in Disaster Rescue Simulation - From Test-Bed of Multiagent System to Practical Application -

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Abstract. We apply multi-agent approach to search and rescue in a large-scale domain. The simulator is designed to simulate various domain specific simulation and human behaviors. Kobe-Awaji earthquake data is used as disaster scenarios and a prototype system was made open at RoboCup 2000. A rescue team composed of heterogeneous agents, – fire brigades, ambulances, and polices –, takes active part in the disastrous situation where about 100 civilian agents move autonomously. By comparing with rescue operations of two teams, we showed that the search and rescue in disasters can be used as a test-bed for multi-agent systems. The comparing experiments made clear that rescue task is not well defined in spite of its practical importance, and planning based on multi-perspectives on disaster losses is necessary. It points that the rescue problem is not only a test-bed for multi-agent system but also for laboratory work for practical system.

1 Introduction

Society consists of multi/heterogeneous entities. Simulating activates in the society requires handling social structures that is difficult to handle systematically. Multi-agent system is one of methods to simulate such human activities. Casti presented that behaviors of individual change traffic condition of a city [1].

Management of environmental emergency is concerned as one of application fields of multi-agent system [7]. Cuena and Ossowski handled a flood management with four types of agent - Local Emergency Management Agent, Dam Management, Fire Brigade Management Agent, and Transport & Ambulance Management Agent.

The agents decide their actions to save victims according to disaster situations. Escape problem from a theater has been studied as application field of multi-agent learning [9]. The problem consists of two phases. The first is that agents search for a button to open doors and one agent pushes it. Other agents can escape from doors after that. Their field is 8×8 mesh world with one exit.

A. Birk, S. Coradeschi, and S. Tadokoro (Eds.): RoboCup 2001, LNAI 2377, pp. 102–111, 2002.

Earthquake at urban areas causes various disasters, such as, fire, building damages, disruption of roads and life lines - electricity, water supply, gas - etc. Fire brigades extinguish fires, ambulance teams bring victims to hospitals, while civilians seek refuge and ask for help.

RoboCup - Rescue is proposed to develop a series of technologies that can actually save people in case of large-scale disasters [2,4,3]. The simulation Project that applies multi-agent research to search and rescue domain, is composed of disaster simulations, rescue people, and residents in that area.

In this paper, we first describe rescue operations in disaster simulation. Secondly, what urban disasters are is described, and the prototype system of *RoboCup - Rescue* is outlined. Simulations of rescue agent behavior and the simulated world is demonstrated in the third section. Problems that were made clear in applying multi-agent system to rescue domains are discussed in fourth section. Finally, points to be studied in future are presented.

2 Disaster & Rescue Simulation Task

At January 17, 1995, a large earthquake of a moment magnitude 6.9 hit Kobe City, Japan. Over 6,000 people were dead, at least 300,000 were injured, and more than 100,000 buildings were collapsed. Similar tragedies also took place in California, Turkey, Taiwan, and other places.

2.1 Rescue Domain Characteristics as Multi-agent Task

Domain characteristics of soccer, and rescue are illustrated in Table 1. In rescue domain, there are heterogeneous agents - civilian, fire fighter, ambulance, police, city offices - to act autonomously. Some of them have hierarchical structure in themselves, for example, fire fighters are composed of fire brigades and fire office. Fire office agents can order fire brigade agents.

	Rescue (Prototype)	Soccer
Number of Agents	100 or more	11 per a team
Agents in the team	Heterogeneous, Hierarchical	Homogeneous
Logistics	Major Issue	No
Information Access	Very Bad	Reasonably good
Representation	Symbolic & Non-Symbolic	Non-Symbolic
Control	Distributed/Semi-Central	Distributed
Filed structure	dynamic (GIS)	static (goal, line)
motion	only move along roads	can move to any point in xy plane

Table 1. Features of Rescue and Soccer

2.2 Fire Department Decisions in Disaster

When a fire occurs, a fire station receives calls from residents. The fire office deploys fire brigades to put off the fire effectively. One of the deployment policies is that extinguish power of fire engines suppress the fire, $\sum_i extinguish\_power(i) > fire$.

On the other hand, an earthquake occurs at urban area, various disasters - fire, collapses of buildings and roads, damages of electric powers and telephone lines - occurs simultaneously over the area. The power of fires all over the area is more than extinguish powers of fire engines. $\sum_i extinguish\_power(i) < \sum_j fire(j)$. And roads covered with debris may disturb fire engines' move and the flow of civilians who refuge from damaged areas makes situations worse.

According to Tokyo Fire Department, their main office controls their fire engines. In a case of big fires, they change their strategies from extinguishing fires respectively to not spreading the fires. Fire engines are deployed around the fires to make water wall. And in a case of worse disaster where there may be troubles in communication, they suppose the center-controlled system will not work well. At that time, local fire stations are permitted to control their fire engines at their decisions.

2.3 *RoboCup - Rescue* Simulation Prototype System

RoboCup - Rescue has been undertaken to put large-scale simulations in use in the domain of search and rescue for large-scale disasters [5].

specification The prototype simulator was designed based on Kobe-Awaji earthquake's case.

- **target area:** Nagata Ward was one of the most damaged area. The area was 11.47 km^2 and 130,466 people (53,284 households) lived there.
- **simulation period:** The purposes of rescue activities change as time passes. The rescue activities are classified into five stages: chaos stage, initial operation stage, recovery stage, reconstruction stage, and normal stage. At the first chaos stage, there is no aid from outside, and the main purpose is saving the victims using local facilities. Considering that survival rate of buried people decreases rapidly after a few days, the period to be simulated is set to first 72 hours.
- **rescue agents:** When earthquakes occur, there are many calls asking for fire fighters. So local rescue agents will do the first rescue actions. There were a total of 7 rescue agents at Nagata fire office.
- **space resolution:** Representing disaster situations or rescue activities requires displaying items at the size of cars. GIS (Geographic Information System) data is maintained with a resolution of 5 m.

architecture The simulator is designed to combine various disaster simulations and human behaviors, and to present them as coherent and comprehensive scene. Disaster simulators are fire, building and road collapse. Human behaviors are rescue activities and evacuation to safe places, etc. Traffic simulator manages the movement of human agents.

A kernel of the simulator combine all information and up-date the status of the simulated world. Several domain specific simulators are connected to the kernel. Information on an entire disaster field is stored in geographic information system (GIS).

Numbers of agents are deployed in this simulation environment to test strength and weakness of the search and rescue strategies.

3 Rescue Scenarios

3.1 Model of Agent Behaviors

In simulation, statistics data will help to model human activities in disasters. Disaster simulators such as fire or collapse have been designed so that results of simulations match the real disasters data. Statistics data on human, such as White paper of National Land Agency, Japan, says that 88% of the cause of death was crushed to death, 10% people were burned to death, and others by fall of things, etc. The data are used to set initial conditions, however, it is very difficult to model human behavior during the simulation.

The behavior model how a civilian acts in emergency or how people act collectively in evacuation will be needed in simulation of rescue operations and their estimation.

3.2 Agents and Their Hierarchy

The word *agent* is used to refer to autonomous entity in the simulated world. Figure 1 shows agents prepared in the prototype system.

Agents – Civilian, Car, Fire Brigade, Ambulance, Police – can move in the area. Civilian represents a resident in that area, and Car represents a resident in a car and can move faster than Civilian. Fire Brigade is a fire engine, Ambulance can bring civilians to a refuge, and Police can repair collapsed roads. All agents have properties such as damage of body, stamina. The properties affected by disaster simulations determine agents' life and death.

Fire Station, Ambulance Center, Police Office, Refuge are building objects and represent functions of people in the building provide. Fire Station, Ambulance Center, and Police Office can instruct corresponding agents. When buried civilians are brought to a refuge, they can receive medical treatments. Otherwise their health point decreases with time, and they will be dead as time passes.

Agents take actions against disastrous situations. The situation changes with time and is changed by the agent rescue operations. Using predefined protocols, the agents

see situations around them with `sensory information` sent from kernel. The information is objects within a certain radius around the agent,
hear voices that other agents ask for help,
plan next actions according to their objectives such as, to search for victims, to rescue them, to evacuate them to safe places, etc.,
send their actions to the kernel as `act` command. It consists of `extinguish` *Target*, `rescue` *Target*, `load` *Target*, `unload`, `open` *Target*.

The kernel gathers all messages sent from agents, and broadcasts them to the component simulators. The component simulators individually compute how the world changes its internal status. These results are sent back to the kernel.

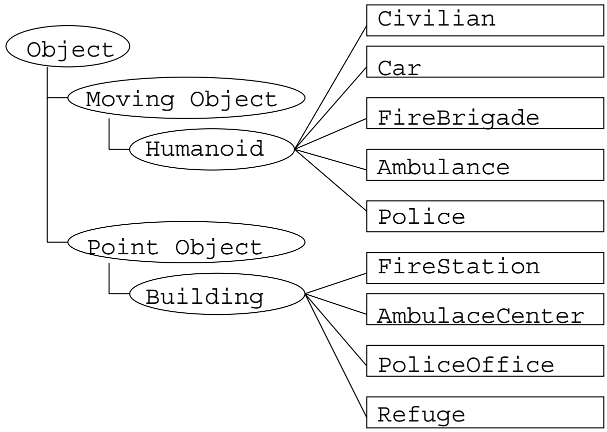

Fig. 1. Hierarchy of rescue agents

3.3 Collaboration among Rescue Agents

The above agent's communication must be done within one simulation step, otherwise the agent stays with doing nothing,

And agents communicate each other using the communication to collaborate in rescue operations. The following are types of collaboration that should be appeared in rescue domain.

type I: collaboration among homogeneous agents.
The first task is n Fire Brigade agents extinguish fires that break out at m places. Using 1/10 scale mode with $m = 3, n = 1 \sim 9$, Ohta showed that extinguishing task has a feature that collaboration among n homogeneous agents obtains more than n times results [8]. And his simulation showed it better to deploy fire brigades intensively to an ignition point than to deploy them widely to ignition points. This corresponds to one of fire departments' methodologies of extinguishing.

type II: collaboration among homogeneous agents with hierarchy.
Fire departments consist of fire brigades and stations. Fire brigades extinguish fires based on local information that they can get within the field of their vision, while fire stations may grab global situation from civilians reports. Fire stations instruct their fire brigades to minimize loss caused from fires. For example, fire stations decide to change their strategies from extinguishing fires to preventing their spread. This hierarchical structure exists in ambulance agents, police agents, etc.

type III: collaboration among heterogeneous agents.
It is very important for fire brigades to go quickly to fires. Earthquakes cause traffic troubles as collapses of roads and buildings, civilian's evacuate-flow. Police agents get rid of debris from roads and make fire brigades or ambulance moves swiftly. Collaboration among police agents and fire brigades is necessary to rescue effectively.

Fig. 2. snapshot of simulation at time=5

4 Simulation Experiments

4.1 Simulation of Rescue Operations

Table 2 shows GIS data that was used in our experiment. $1/1$ scale model is a square area 2,217 m on a side. The numbers of agents and objects are real ones except civilian's number. The real number of civilians, which is 100 times this number, is too large to simulate at this time.

Figure 2 shows a snapshot of a 2D viewer. The legible part in the center is the area selected as 1/10 scale model. The blocks are buildings and the lines are roads. The color of buildings is green, and buildings turn red when they burn.

Table 3 shows the results of two teams rescue activities. Both teams have 10 fire brigades, 5 ambulances, and 10 polices. Team A's fire agents are programmed to look for fires individually by walking randomly. On the other hand, the agents of team B are programmed to rush fires after looking around them. Ambulance and police agents provided as sample agents were used for both teams [6].

An earthquake occurred at time=1, more than 740 houses were collapsed. The collapsed houses buried citizens who were accidentally near them. The buried citizens are alive at first, however their physical strength is decreased with time. If rescue agents save the buried citizens, they will lose their lives. Figure 3 shows the number of dead people during the first 50 steps. After that period, the numbers remain the same.

Table 2. Numbers of agents and objects used in test

	autonomous agents				GIS objects		
scale	1/100	1/10	1/1		1/100	1/10	1/1
Civilian	8	76	934	road	125	818	9,776
Ambulance Team	2	5	5	node	119	765	9,143
Fire Brigade	2	10	10	building	99	778	9,357
Police Force	2	10	10	area size (m)	160	521	2,217

Table 3. Statistics on rescue operations

time	dead /living	buildings on fire	buildings burnt	buildings ext. †	road collapsed
5	1/98	1	0	0	28
team A					
50	16/83	29	2	2	27
100	17/82	48	12	5	25
150	17/82	61	47	10	24
200	17/82	81	84	12	24
250	17/82	102	136	13	24
300	17/82	77	216	15	23
team B					
50	18/81	17	0	8	28
100	18/81	18	4	13	26
150	18/81	3	15	22	26
‡ 200	18/81	1	15	23	24

† extinguished and saved buildings
‡ the data is the same from 200 to 300

The number of collapsed roads at time=5 shows that road collapse simulator worked and the number of burning houses increases as fire spreads. Team A could not extinguish fires, while team B put off at time=200. The number of burnt houses by team A is more 10 times than by team B. However team A saved more people than team B. Figure 4, 5 show the simulation results of team A and B respectively.

4.2 Estimation of Rescue Operations

The rescue operations are estimated from how many lives or houses are saved, not form how well their simulations fit the real one. It is important to validate whether the simulation results can be applied to the real situations. Different from physical phenomena, we cannot experience earthquakes repeatedly to collect data that show some relationship between rescue operations and damages. The disaster data we can get are the total number not as a form of time sequence [10]. The fire and road collapse simulators

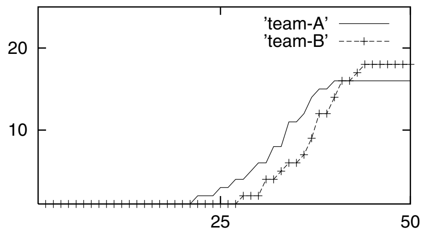

Fig. 3. time sequence of the number of dead people

are adjusted to produce the reported numbers, while other simulators have no reliable models.

There are many indexes that show how large the disaster damaged the society. The indexes are loss of human life, loss of lost buildings, or the money required to restore , etc. It is difficult to say which index is the best or how to combine the indexes to estimate rescue operations. Moreover the rescue agents cannot calculate their values to optimize their behavior when they are in action.

The right window in Figure 4, 5 indicates the losses over the area that is total of all rescue operations at each simulation step. The indexes are the same ones in Table 3 and the values at the final step are used to estimate rescue operations. Actions of agents can be rephrased as teamwork. Although we implemented only type I collaboration at present, it is important to evaluate teamwork as rescue activities. From this point, team-B is better than team-A. However, their evaluations change places form saving human lives.

5 Discussion and Conclusion

Applying multi-agent system to rescue operation in large disaster made clear the following problems, in addition to themes of information engineering that makes simulators stable to move over 10,000 agents;

- Rescue activities are so closely related with human activities, that are easy to express with task-level language but are hard to describe them as command-level operation.
- Objectives of rescue operations come from different fields. And they change with time. Different form other fields, such as soccer that can be scored as goals, rescue operations include something mental aspect like victims' feeling. Attentions from sociological aspect must be paid to refer to disaster victims.

Even though the rescue domain is one of the most serious social issues, goals of rescue simulation are not well defined as in Shakey's world, wumpus world, etc. Besides representing state space of rescue, our first simulation presents new themes;

- In order to represent a civilian as an individual agent, ontology is necessary to communication among agents and representing their feel of the place [11]

– There are numbers of search and rescue scenario in city offices. Human planners will do political decisions and social decision that are not easily incorporated into automated planning of agents. As a way of interactions with real world, planning with human interaction will be necessary.

Search and rescue problem in disasters is an ideal platform for practical application of multi-agent system. We hope our research will not only provide many research themes but also help real rescue operations.

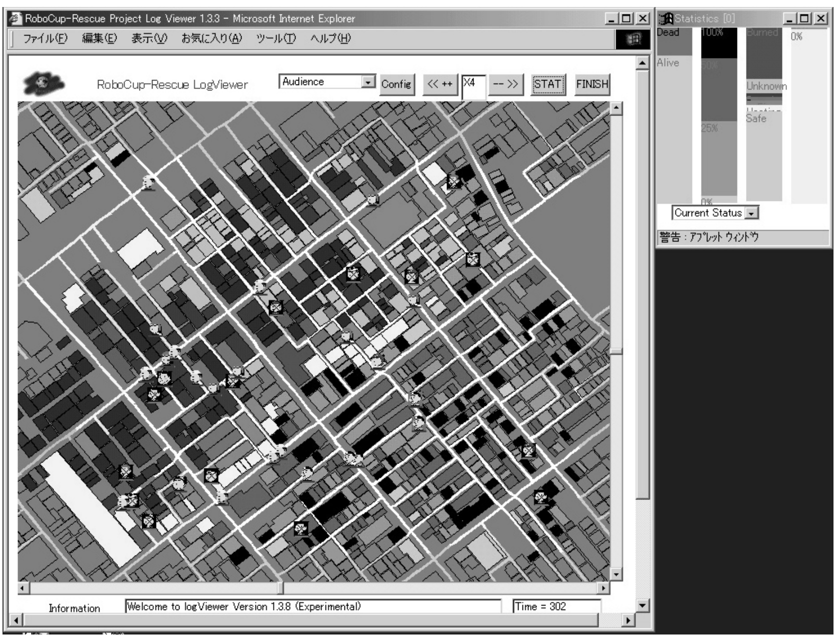

Fig. 4. snapshot of Team A at time=300

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Fig. 5. snapshot of Team B at time=200

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