YabAI
The First Rescue Simulation League Champion

Takeshi Morimoto, Kenji Kono, and Ikuo Takeuchi

Department of Computer Science, University of Electro-Communications,
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan,
morimoto@takopen.cs.uec.ac.jp,
http://ne.cs.uec.ac.jp/∼morimoto/

Abstract. RoboCupRescue project aims to simulate large urban disasters. In order to minimize damage resulting from disasters, various rescue agents try to accomplish their missions in the disaster space in the simulation system. Ability of an individual agent, however, is utterly insufficient. Agents need to cooperate with other same and different types utilizing as little communication as possible under stringently limited visual sensory information. Our YabAI team, however, successfully implemented effective cooperations under this limitation.

1 Introduction

RoboCupRescue project aims to simulate large urban disasters. Rescue agents such as ambulance teams, police forces, and fire brigades act on the disaster space in the simulation system. Buildings and houses collapse and burn, and roads are blocked in the disaster space. So number of civilian agents are sacrificed and injured. In order to minimize damage resulting from disasters, these agents have to try to accomplish their missions.

This paper, at first, briefly describes the outline of the disaster space, the simulation system, and agents. Then it describes technical problems which researchers and developers encounter, and some of the relevant research issues and innovations that lead YabAI team to the success.

2 Disaster Space

Building collapses, fires and blockage of roads occur in the disaster space by a large earthquake as was recently experienced in the Hanshin-Awaji Earthquake which killed more than 6,500 citizens. Many agents such as civilians, ambulance teams etc. lived in the disaster space. Soon after the large earthquake, buildings collapse, many civilians are buried in the collapsed buildings, fires propagate, and it becomes difficult for agents to move roads because these are blocked by debris of buildings and something else.

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The objective of agents is, collectively, to minimize casualties. The behavior and performance of agents are evaluated by the following equation in the RoboCupRescue competition.

$$V = DeathToll + \frac{TotalDamage}{TotalLifePoint} \cdot \frac{BurnedSquare}{TotalBuildingSquare} \quad (1)$$

represents the degree of damage resulting from the disaster. The less is V, the higher is the evaluation. Note that the second term is less than or equal to 1.

The size of the disaster space used in the first competition is 500m × 500m. Within this area there are 740 buildings, 820 roads, 97 agents, etc. The simulation

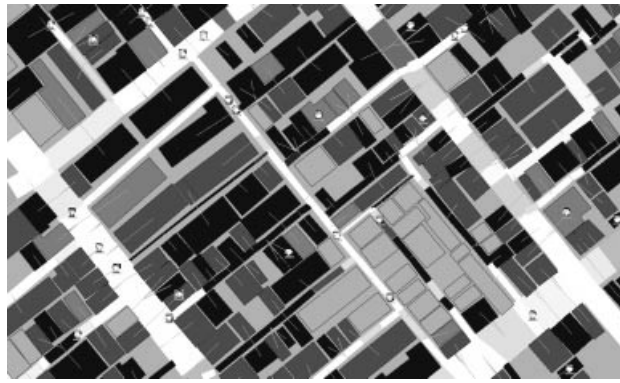

Fig. 1. Disaster space

system simulates 5 hours, or 300 minutes of the disaster space after an earthquake occurs. One minute in the disaster space is referred to as one turn. At each turn, each agent decides its action, and the simulation system reflects these actions if possible, action cannot be always carried out in the disaster space.

2.1 Simulation System

The simulation system consists of several disaster sub-simulators, the GIS (Geographical Information System), the viewer and the kernel. In addition, civilian agents are also regarded as a part of the simulation system in the competition. The simulation system is managed by the kernel. and The kernel proceeds the simulation as follows.

1. The kernel sends individual sensory informations to all the agents in the simulation world.
2. Agents submit their action command to the kernel individually.
3. The kernel sends agents' commands to all relevant disaster sub-simulators.

4. Sub-simulators submit updated states of the disaster space to the kernel.
5. The kernel sends updated states to the viewer.
6. The kernel advances the simulation clock in the disaster space.

The simulation system repeats this loop 300 times. Typically it takes a few seconds to simulate one turn. All the agents must decide an action for a few seconds.

For more details of the simulation system, refer to [2000].

2.2 Types and Abilities of Agents

Types of Agents: In the disaster space, there are seven types of agents; civilian, ambulance team that rescues injured persons and take them to refuges, fire brigade that extinguishes fires and arrests the spread of fires, police force that repairs blocked roads, ambulance center, fire station, and police office. Agents are classified to three kinds; civilians, platoons, and centers.

Some of civilian agents are buried, injured or sacrificed. Other civilian agents probably go to refuges or places safer than their current position. some of them panic, and cause traffic jams perhaps. Because civilian agents are regarded as a part of the simulation system in the competition, agent developers need not develop them.

Ambulance team agents, fire brigade agents and police force agents are platoon agents. A platoon agent consists of several people. They can move by a vehicle and have special skills according to their agent type.

Ambulance center agents, fire station agents and police office agents are center agents. Center agents represent buildings and have the ability of people who work there. They only communicate with same type platoons and other type centers.

In the first RoboCupRescue Simulation League, there are initially 72 civilian agents, 5 ambulance team agents, 10 fire brigade agents, 10 police force agents, 1 ambulance center agent, 1 fire station agent and 1 police office agent in the disaster space.

Abilities of Agents: Each agent has abilities according to their type (Table 1). Platoon agents can sense visually information about buildings, roads, other agents and etc. within a radius of 10m, and fires of any distance. Center agents cannot sense information visually.

Any agent can communicate with other agents. When an agent says a message by voice, the message is immediately heard by agents within a radius of 30m. When an agent tells a message by electrical communications devices, the message is immediately heard by agents whose type is the same as the speaker's. Furthermore, when a center agent tells something, the message is transferred to other type centers, too (Fig.2). The number of Say, Tell and Hear commands that can be issued by an agent in one turn is limited. An agent can say or tell up to four messages in a turn, and can hear four messages in a turn. Information amount of messages is measured by the number of sentences involved. When an

Table 1. Ability of agent

Type	Ability
Civilian	Sense, Hear, Move, Say
Ambulance team	Sense, Hear, Move, Say, Tell, Rescue, Load, Unload
Fire brigade	Sense, Hear, Move, Say, Tell, Extinguish
Police Force	Sense, Hear, Move, Say, Tell, Clear
Ambulance center	Hear, Say, Tell
Fire station	Hear, Say, Tell
Police office	Hear, Say, Tell

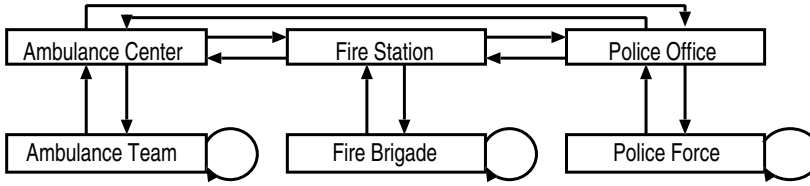

Fig. 2. Tell by Electrical communication

agent receives hear information from the simulation system, the agent may select whether it hear individual messages or not by checking who is the speaker.

3 Problems

This section describes technical problems researchers and developers will encounter when they develop agents.

Causes of casualties are mainly the damage by burial on land and fire. Almost all of civilian agents which are buried in collapsed buildings are injured, and become weaker as time goes by. Furthermore, when they are enveloped in fire spreading, they suffer from a fatal injury. In order to rescue and extinguish, ambulance team and fire brigade agents must go to the scene of the accident. It is, however, difficult for those agents to reach there, because many roads are blocked.

In order to minimize casualties, not only rescue operation by ambulance team agents but also extinguishing operation by fire brigade agents and road repairing operation by police force agents are necessary.

Agents must try to accomplish their missions under stringently limited conditions. Ability of an individual agent is insufficient against the scale of disasters. Agents can only get visual sensory information within a radius of 10m in the large disaster space which has an area of 500m $\times$ 500m. They have not enough

ability to cope with disaster alone. Furthermore, it is stringently limited for agents to communicate with each other.

Cooperation among Same Type Agents: Single agent can hardly be useful. It takes a long time to rescue a buried civilian by single ambulance team agent. Single fire brigade agent can hardly extinguish a fire. Single police force agent lag demand. Consequently, platoon agents need to cooperate with other agents of the same type.

Cooperation with Different Type Agents: The ability of each agent is complementary to each other, so agents need to cooperate with agents of different types. Police force agents clear blocked roads for other types, or agents cannot go through these roads. Fire brigade agents extinguish fires and arrests the spread of fires for buried agents, or they are enveloped in fire. Ambulance team agents are not possible to rescue buried agents without these cooperations by other types.

Cooperation under Stringently Limited Communications: Rescue agents need to communicate with each other in order to accomplish their missions efficiently. However it is difficult to communicate, because they can speak only four messages and hear only four messages in a turn. There is a dilemma. In order to communicate enough, agents want to speak many messages. However, if agents speak many messages, it increases the likelihood that other agents miss the messages. For example, when ten fire brigade agents and one fire station agents speak four messages respectively in a turn, they receive 40 messages except for four messages of their own and then they must select four messages from 40 messages by only relying on the information who is the speaker. In this case, each message can be heard by others with only 10% probability. Agents need to hold speaking messages in bare minimum. Agents are required cooperating strategies with minimum communication.

Above problems are summarized as follows. In order to minimize casualties, rescue agents need to cooperate with same and different types with as little communication as possible under stringently limited visual sensory information.

4 Modularization of Fundamental Functions

We developed YabAI in incremental steps. First, we modularized several fundamental functions. Second, we developed agents which act without cooperation, and improved fundamental abilities such as an advanced world modeling and a reliable routing ability. Finally, we introduced several cooperation strategies; a fire brigade distribution strategy, a blocked road reporting strategy etc.

4.1 Modules

In order to develop agents efficiently, we modularized several fundamental functions;

- communication function between the simulation system and agents,
- world modeling function,
- world condition describing function,
- object extracting function,
- routing function,
- communication function among agents in the simulation system, and
- visual debugger.

Agent developers can concentrate all of their energies on the development of agent intelligence by using these modules. We chose JAVA as description language. Almost all intelligent parts of YabAI are described as a production system. For example, an agent intelligence that finds fires and goes there is described as follows:

$$
\begin{aligned}
&\mathit{isBurning} := \mathit{FIERYNESS\_F} \geq 1 \quad \wedge \quad \mathit{FIERYNESS\_F} \leq 3 \\
&\mathit{fireSet} := \{b \in \mathit{buildingSet\ in\ world} \mid \mathit{isBurning}(b)\} \\
&\mathit{route} := \mathit{route\ from\ here\ to\ fireSet\ minimizing\ costFunction} \\
&\mathit{move\ along\ route}
\end{aligned}
$$

we can easily describe a program by using the modules as follows.

```
Predicate isBurning = FIERYNESS_F.gte(1).and(FIERYNESS_F.lte(3));
Set fireSet = world.buildingSet().get(isBurning);
Route route = router.get(self.position(), fireSet, costFunction);
move(route);
```

4.2 Visual Debugging Module

It is impossible to develop agents without viewing various information about agents;

- an internal world model of individual agent,
- action which an agent did,
- a route which an agent wanted to go along,
- messages which agents spoke, etc.

We introduced a visual debugger into YabAI. Visual information is much more easily handled than text information. Agent developers can get information visually as they wish by using the visual debugger (Fig.3).

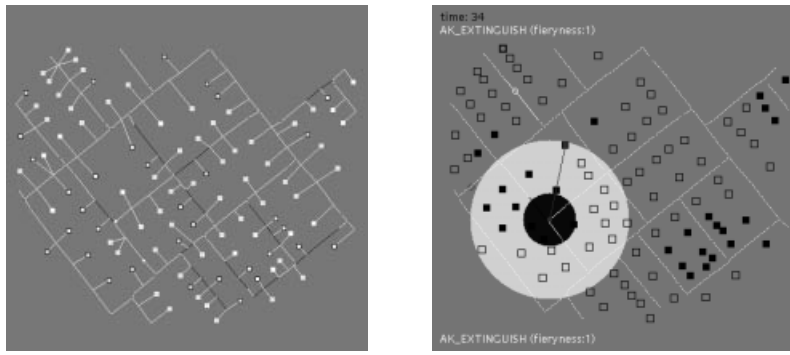

Fig. 3. Default Viewer (left) & Visual debugger (right)

5 Fundamental Abilities

Agents need to have well-tuned fundamental abilities in order to act efficiently. Mechanisms for multi-agent cooperation are of no use unless the individual agents can do their low level tasks properly. There are inseparable two fundamental abilities which intelligent agents must have; one is the ability of an appropriate perception of the current situation, and the other is the ability to decide an appropriate action according to the current situation. If agents does not have an appropriate perception, they cannot decide an appropriate action, and vice versa.

In RoboCupRescue, agents must have two fundamental abilities in particular; the advanced world modeling ability and the reliable routing ability.

5.1 Advanced World Modeling Ability

The disaster space changes every moment. Injured persons becomes weaker. Fires spread. Other agents move from space to space. Agents can not pass through even the roads which they have passed before, because of a traffic jam. On the contrary, agents could pass through the roads which they have never passed before as a result of clearance by police force agents. Agents have only a narrow range of view, so they can hardly grasp perception of the whole disaster space. However, agents can get more information within their range of view by observing others. Agents can get informations from visible others; their type, position, life point, damage, route along which they came from other place etc. By taking advantage of such route information, YabAI infers that these route are passable. This technique is highly effective, and is a base for all actions.

5.2 Reliable Routing Ability

The ability by which agents reach destination in a short time is very important for any agents. Especially when there are mortally wounded persons and early

fires, even slight delay turned out to be a fatal mistake. Agents must route so as to move surely. YabAI becomes possible to move fast and surely by using certainty factor based on the above-mentioned advanced world modeling ability. To be specific, YabAI gets routes by using the routing module with the following cost function:

$$costFunction = actualDistance \times \begin{cases} 1 & movable \\ 10 & not\ \ confirmed \\ 100 & unmovable \end{cases}$$

6 Cooperation Strategies

6.1 Ambulance Team

Ambulance team agents search for injured persons in a distributed manner, and concentrate to rescue them together with others by using communication. Ambulance team agents can hardly grasp states of all injured persons, because there are many injured persons and they are often appear suddenly, for example, by the spread of a fire. So it is nearly impossible to optimize a rescue plan. Ambulance team agents put a premium on the certainty, and rescue injured persons soon after they decide it is necessary to rescue just now. In order to restrict rescue operation from which no pay-back can be expected, they divide injured persons into four rescuing priorities; "need immediately", "need", "no need" and "abandon".

6.2 Fire Brigade

Fire rapidly changes its condition, so it must be especially rapidly coped with. It may not be difficult to extinguish an early fire for even a few fire brigade agents. On the contrary, it is very difficult to extinguish a late and big fire for even many. Time is valuable very much. It is better that individual fire brigade agent selects fire on its own arbitrarily, than spending time to communicate with others.

There are four tactical points about fire fighting;

- give early fire top priority,
- barricade by extinguishing edges of spread of fires,
- concentrate flashing power as possible, and
- distribute power as far as possible finally.

It is wasteful that many fire brigade agents extinguish a small-scale fire, and it is ineffective that a small number of agents extinguish a large-scale fire. However, under a situation where fires are scattered, it is a formidable task to balance concentration and distribution of flashing powers.

YabAI becomes possible to distribute fire brigade agents efficiently by estimating the priority of fires based on three criteria; (Fig.4)

– state of the fire, especially burning duration,
– surrounding circumstances of the fire, and
– distance from the agent to the fire.

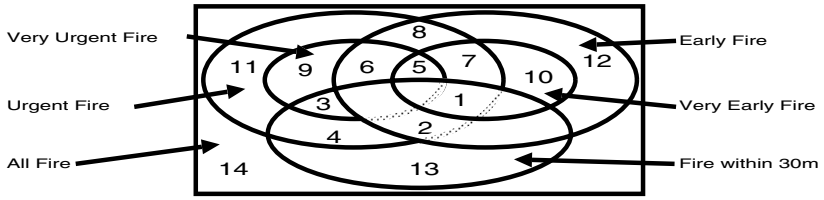

Fig. 4. Priority of fire

Fire brigade agents look at the surrounding circumstance of the fire to estimate whether fire spreading can be blocked by extinguishing it. If extinguishing the fire is useful for blocking of fire spreading, then it is valuable. The value of fire extinguishment is calculated with the numbers of unburned buildings, extinguished buildings and fires around it. To be specific, the fire around where has many unburned buildings and few fires is valuable to extinguish, that is, urgent. Fire brigade agents should extinguish such urgent fires rapidly, or the fires probably propagate to the surroundings.

Fig.4 shows the priority of fires which is described by numeric character. For example, the first priority the smallest the integer is given to a fire which is very early and located within a radius of 30m.

6.3 Police Force

Police force agents repair blocked roads through which others need to pass. Other types are often put in a situation that they cannot reach any destinations because routes are cut off. Though they are able to calculate optimal routes, they cannot reach any destinations in such a situation. As previously mentioned, agents must reach their destinations as soon as possible when they need to be there. Activity of police force agents especially affects others'. It is, however, difficult to get a criterion which roads they had better to repair first.

YabAI mainly repairs roads requested by others, at this point. This strategy is effective, but it takes time for others to be able to pass. In order to save others' time, it is necessary to repair important roads in advance. After a number of trials and errors, we introduced two strategies without using communication. One strategy is to make a route from the passable police force agent to the nearest fire brigade agent. This strategy has two merits. First, the police force agent can go to the fire brigade agent soon after being requested to repair a road. Second, this produces an optional route for the fire brigade agent. The

other strategy is to make a route passable from the police force agent to fires. This also produces optional routes for fire brigade agents who want to go to those fires. These two strategies are implemented in a trivial short-range planning, but these are effective them expected.

6.4 Center Agents

Center agents only hook up communication with other type center agents, now. There may remains room for improvement about selection of messages to be spoken or heard.

7 Results

At the RoboCup-2001 competition, YabAI won the champion.

In the preliminaries there were seven games. All participants contested in the same disaster space at each game. At every game, they were placed in order, and got a point according to their order. Top four placings in total point passed the preliminaries. YabAI became 1st in 3 games, 2nd in 2 games, 4th in 1 game and 6th in 1 game. YabAI became 4th and 6th unfortunately, because of the simulation system's malfunction. YabAI was 2nd place in the preliminaries.

At the semifinal YabAI won all 2 games over Rescue-ISI-JAIST (3rd place).

At the final YabAI won all 2 games over Arian (2nd place). YabAI got overwhelming victory because of the remarkable activity of ambulance team agents at the first game, and won the second game which was very close by virtue of our early extinguishment.

It can be said that YabAI overwhelmed other teams except Arian.

8 Conclusions

In RoboCupRescue, agents try to accomplish their missions in order to minimize casualties. Ability of an individual agent is limited compared with the scale of disasters. Agents need to cooperate with same and different type agents without communication as far as possible under stringently limited visual sensory information.

YabAI shows effective cooperation based on well-tuned fundamental abilities such as the advanced world modeling ability and the reliable routing ability. Ambulance team cooperates by using communication with other ambulance teams in order to search and rescue injured persons efficiently. Fire brigade cooperates without communication with other in order fire brigades to extinguish fires surely and efficiently. Police force cooperates with agents of other types in two ways; one uses explicit communication with others to facilitate their requests, the other does not use communication, but implicitly cooperates by clearing important routes in advance.

The success of YabAI due to the effective cooperations with minimum communication.

For a more thorough understanding of the implementation details, the reader is encouraged to scrutinize the algorithms described here by looking at the YabAI source code [2001]

References

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