# RoboCupRescue 2007 - Rescue Simulation League Team <Hinomiyagura (JAPAN)> <Agent Competition>

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**Abstract.** Our team has developed tools to support decision support at local governmental departments. At 2006, our team compared RCRS's result with data in the published report by generating maps from open XLS GIS data. This year, universal method to analyze agent behaviors is one of research themes. A method based on probability model is proposed and has been implemented in 2007 Hinomiyagura center agents.

## Introduction

**•background of our team's policy**
Rescue work in the real world is important in saving human lives and consists of a lot of agents. Simulations involving human behavior and its interaction with different environments will provide useful tools and data for local governments to improve decision making. The objectives of the RoboCup Rescue Simulation(RCRS) Project are

- to apply agent technologies to social problems, ultimately to save human lives,
- to promote research collaboration via competition.

The following is the score formula used in ranking teams in the rescue league.

$$V = (P + \frac{H}{Hint}) \times \sqrt{\frac{B}{Bmax}} \quad (1)$$

where $P$ is the number of living civilian agents, $H$ is HP (health point, how much stamina agents have) values of all agents and $B$ is the area of houses that are not burnt. $Hint$ and $Bmax$ are values at start. It is a metric of the overall rescue performance and its higher scores show that rescue agents operate better. Participants develop rescue agents or agents' collaboration architectures to increase $V$.

Local governmental agencies are potential users of the simulation systems. We showed that RCRS results of our town have a good correlation with data in the

**Table 1.** Changes of $V$ scores for sensing abilities

| sensing condition | team X | team Y | team Z |
|---|---|---|---|
| Base | 78.92 | 97.69 | 88.24 |
| Eyesight | 78.92 | 35.41 | 83.30 |
| Voice | 79.92 | 83.49 | 51.45 |
| Both | 78.91 | 90.87 | 45.76 |

fire department report [3]. The following are comments from local governments when they were asked about the possibility of using RCRS's results as one of their tools.

– there are no applicable precedents,
– there are no theoretical backgrounds, [1]
– the simulation size is far from a real one, because the number of agents is small compared to the real world.

While RCRS (in a broad sense, ABSS) has many points that need to be improved for practical usages, we think it is necessary to show the validity of simulation results to persuade local governments to use systems such as RCRS as disaster management tools.

**•Analysis of simulation results and limits of $V$ as performance index**
The output is analyzed with two different views. One is a microscopic level estimation. Agents are evaluated in terms of how well it performs a task according to one or more metrics. The other is a macroscopic level in which the outputs are evaluated in terms how well it mirrors the system it simulates. In the rescue domain, metrics, such as $V$ or $B$, are the microscopic level. Comparison between RCRS' results and data of the fire department report are the macroscopic level estimation. Local governmental people want to know why team X is more robust than other teams. To answer these questions, it is necessary to interpret the behaviors of the specified agents from ABSS's output and to express them in a level between the microscopic and macroscopic levels.

In 2004, the Rescue Simulation League organized a special session to test the robustness of rescue operations [2]. Teams do rescue operations with varying sensing conditions on the same disaster situations. The first run (labeled *Base* in Table 1) was a simulation result by agents with normal conditions. The second was that the visual ability of agents was set at half of the normal visual ability and the hearing ability of agents was set at half for the third run. Both visual and hearing ability were set to half for fourth run (labeled *Both*). Teams with less variation in scores for changes in sensing conditions were defined as to be robust. Team X was the most robust one, while team Y performed better at base

[1] Fire spread simulator in RCRS (Ver.46) was programmed according to models that have been used by many local governments, however there is no model as a comprehensive simulator.

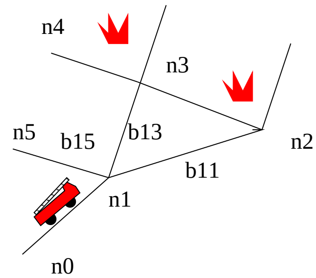



**Fig. 1.** Property model of agent next motion selection

conditions. This agrees with remarks of Kaminka who analyzed the robustness using the log files of three years of Soccer Simulation League's evaluation sessions and found some interesting features, such as multi agent teams exhibit a clear performance-robustness tradeoff, etc [1].

**•Our Idea: Agent behavior analysis based on probability model**

Figure 1 shows a situation in which a rescue agent comes from $n_0$ to extinguish fires. It knows there are two fires near $n_2$ and $n_3$. At crossing $n_1$, the agent determines which fire to extinguish and selects whether it will go forward, turn right or do something else.

Behaviors of agents with the same aim will select similar actions. However, they do not necessarily act in the same way because their internal states, such as the history of their actions and their information, are different. Their behaviors at state $i$ are presented as a set of $\{p_{ij}\}$ where $p_{ij}$ is the probability that the agents will take an action that causes it to be at state $j$ at the next time. In the case of Figure 1, the rescue agent behaviors are observed as $P_1 = \{p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}\}$ where $p_{1j}$ is the probability that the agents will be at $n_j$ at the next step. By assuming the followings, rescue agent behaviors are described with probability model.

**Assumption 1** *Agents are programmed to select actions to reach their goal efficiently and promptly.*

**Assumption 2** *States that agents are more often are more important than other states.*

**Assumption 3** *Difference between actions with good performance and bad performance are represented as differences in their probabilities.*

We propose a new method to analyze agent behaviors based on a probability model and interpretations of simulation results. The method indicates differences among simulation results and gives hints to users in a way that they can recognize the differences precisely. The transition probability can be approximated by taking the ensemble average of how many times agents change states from $i$ to $j$ from ABSS's output. $p_{ij}$ is the probability that the agents at state $i$ will be at state $j$ after one time step.

**•Task independent interpretation based on stochastic matrix**

When tasks are presented as stochastic processes, theorems and methods developed can be used in analyzing behaviors of agents. A stochastic matrix $\mathbb{P} = \{p_{ij}\}$ is a matrix with $p_{ij} \geq 0$ and $\sum_j p_{ij} = 1$ for all $i$. There are some problems in applying a stochastic matrix directly to interpret agent behaviors:

- states of agents are required to be known before analyzing behaviors (we don't know interanl states of the agents),
- $\sum_j p_{ij} = 1$ for all $m$ means there are transitions to any state (there may be some states that are not be transited by other states).

We use a frequency matrix, $\mathbb{F}$ where $p_{ij}$ are normalized as $\sum_{ij} f_{ij} = 1$, instead of $\mathbb{P}$ [2]. $\mathbb{F}$ has features as a directed graph, and when $\mathbb{F}$ is reducible it shows that the areas that agents move are separated. $\mathbb{F}$ has the following properties:

**Property 1** *$\mathbb{F}$ presents agents' behavior. Rank of $\mathbb{F}$ is proportional to the range of agents' motions.*

**Property 2** *Large elements of dominant eigenvectors correspond to places that are important in social simulation (in rescue domain, to protect a town from disasters).*

**Property 3** *When agents move in separate areas, components of eigenvectors are also divided.*

**•Illustation of our approach**

Figure 2 shows a pattern of rescue agent actions in which two fires break out at two places, B1 and B2, and two agents are at A1 and A2 initially. According to assumption 1, reasonable fire brigade agents move to fires and extinguish them. In this example, the places are thought to represent the state of the agents namely, when the agent is at Bs, the agent is assumed to be the extinguish fire state.

$$
\begin{array}{c|ccccc}
 & A_1 & B_1 & A_2 & B_2 & C \\
\hline
A_1 & & 1/m & & & \\
B_1 & & 10n/m & & & n/m \\
A_2 & & & & 1/m & \\
B_2 & & & & 10n/m & n/m \\
C & & n/m & & n/m &
\end{array}
\xrightarrow{n\to\infty}
\begin{pmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 10/24 & 0 & 0 & 1/24 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 10/24 & 1/24 \\
0 & 1/24 & 0 & 1/24 & 0
\end{pmatrix}
$$

Let the tank of the fire engine become empty by ten consecutive extinguish actions and it move to a water station, C, with a cost of one time step. The left shows $\{f_{ij}\}$ after repeating $n$ times of extinguishing and watering its tank and $m = 24n + 2$. Repeating the action patterns, factors corresponding to key states become dominant while others become less significant. The right is a

[2] Let $N_i$ be a number that agent are at state $s_i$ and $N$ is $\sum_i N_i$. Then $f_{ij} = \frac{N_i}{N} p_{ij}$.

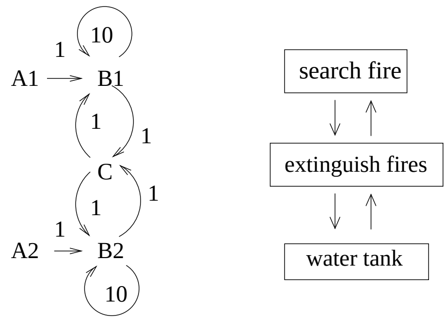



**Fig. 2.** Action pattern of fire brigade agent and its state transition

matrix after $n$ goes to infinity and its rank is 3 that corresponds to the number of dominant places; B1, B2 and C. $0.425, 0.417$ and $-0.008$ are eigenvalues of $\mathbb{F}$ and $(0, 0.7, 0, 0.7, 0.14)^t$, $(0, 0.7, 0, -0.7, 0)^t$ are eigenvectors of the first and second dominant eigenvalues. Major components of the eigenvectors correspond to the place of fires where agents go frequently.

**•Analysis Results of 2004 Challenge Games**

The 2004 Challenge session mentioned before was done on a virtual map. The map has 1065 roads, 1015 nodes and 953 buildings and $\mathbb{F}$' size is 3033. Rescue simulations were done with 13 fire brigade agents, 12 police agents, 6 ambulance agents and 89 civilian agents. Table 2 is the results of analyzing the 13 fire brigades behaviors. The table shows following interesting futures that cannot be gained only by $V$ in Table 1.

– Changes in moving areas to sensing abilities are different for teams. Even team X, whose $V$ scores are similar ones in four cases, moves differently. At half visible sensing ability, it moves wider than the normal ability and it moves less at half hearing sensing ability. On the other hand, team Y moves in a broader area in the three conditions with worse sensing condition than the normal case and team Z behaves conversely.
– Ratios of the dominant eigenvalue to the 2nd one and the 3rd one become close to 1.0 when sensing conditions become worse. It means that agents move inconsistently when sensing conditions become worse. For example, agents of team Y are thought to move mostly according to the dominant eigenvalue at the normal sensing condition. At both half sensing conditions, the agent behaviors are thought to be divided into three patterns as magnitudes of the dominant, the 2nd and the 3rd eigenvalue are equal.

**•Analysis of 2006 Games**

Figure 3 shows snapshots of simulations on the Kobe map that consists of 820 roads, 766 nodes and 754 buildings. The size's $\mathbb{F}$ is $2322 \times 2322$ and 13 fire fighter agents, 7 ambulance, 11 police and 85 civilians are involved in this simulation.

(a) Initially, three fires break out at locations, B1, B2 and B3.

**Table 2.** Size of matrix and ratio 2nd & 3rd eigenvalues to 1st eigenvalue

| Sensing | team X | | | team Y | | | team Z | | |
|---|---|---|---|---|---|---|---|---|---|
| Condition | Size/Rank | 2/1:3/1 | | Size/Rank | 2/1:3/1 | | Size/Rank | 2/1:3/1 | |
| Base | 899/820 | 0.38 | 0.25 | 342/254 | 0.27 | 0.27 | 433/391 | 0.49 | 0.21 |
| Eyesight | 920/867 | 0.31 | 0.19 | 650/563 | 0.85 | 0.73 | 372/297 | 0.58 | 0.43 |
| Voice | 787/649 | 0.80 | 0.69 | 626/552 | 0.85 | 0.39 | 372/316 | 0.69 | 0.12 |
| Both | 685/592 | 0.85 | 0.78 | 575/484 | 0.96 | 0.93 | 332/284 | 0.79 | 0.78 |

**Table 3.** Time sequence of burning rate, size of matrix and eigenvectors

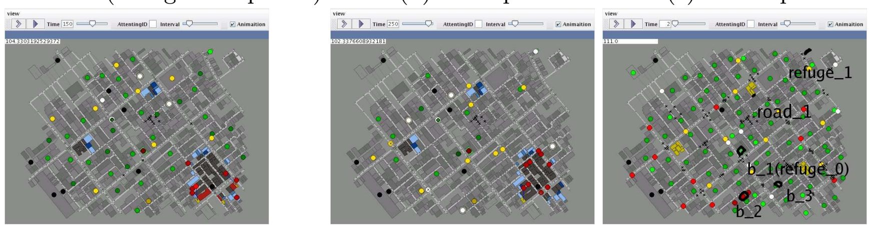
| step | burning rate | matrix | | | key locations corresponds to component of dominant e.vectors | | |
|---|---|---|---|---|---|---|---|
| | | | ratio of E.V.s | | | | |
| | | size/rank | e.v(2/1) | e.v(3/1) | 1st | 2nd | 3rd |
| 50 | 2.6% | 155/135 | 0.38 | 0.38 | b_1 | b_2 | road_1 |
| 100 | 4.0% | 246/217 | 0.11 | 0.10 | b_1 | road_1 | b_2 |
| 150 | 4.9% | 300/271 | 0.06 | 0.06 | b_1 | road_1 | b_2 |
| 200 | 5.0% | 355/325 | 0.05 | 0.04 | b_1 | road_1 | b_2 |
| 250 | 5.0% | 422/388 | 0.04 | 0.04 | b_1 | road_1 | b_3 |
| 300 | 5.1% | 484/442 | 0.03 | 0.03 | b_1 | b_3 | road_1 |

(b) At 50 steps, fires at B1 and B2 are extinguished while the fire at B3 spreads. (In Figure 3, part drawn black indicates the area that is burned.)
(c) Agents collect to extinguish at B3.
(d,e) After 150 steps, spreading of the fire is prevented by fire fighting actions.

Table 3 shows the time sequence changes of burning rate and $\mathbb{F}$ of fire brigade agents - size, rank and coefficients of dominant eigenvectors. It shows the followings that $\mathbb{F}$ indicate more than the change of burning rate.

- The rank of $\mathbb{F}$ becomes large as simulation steps. It indicates that the range of the fire brigade agents becomes wider.
- Seeing the ratio of the 1st eigenvalue to the 2nd and 3rd eigenvalues becomes more dominant over time. The 1st to 2nd ratio is 0.38 at 50 steps and it decreases to 0.03 at 300 steps. It indicates that agents moved separately at first and they behave similarly as simulation proceeds.
- The following changes in components of dominant vectors correspond to the changes in the snapshots.
  - refuge_0 is the key building all steps,
  - from 100 and 250 step, a place(road_1) near the fire (B1) is the second dominant,
  - form 250 step, a place(b_3) near other fire (B3) appears as key place and becomes the 2nd one.


(a) start time (Bs: ignition points) (b) 50 steps (c) 100 steps




(d) 150 steps (e) 300steps (f) key locations

**Fig. 3.** Time sequences of disaster simulations and snaps

## 1 Team Members and Their Contributions

– Tomoichi Takahashi

## 2 Agent communication

Ideas mentioned in the introduction is implemented Hinomiyagura 2007. Mobile agents send their present locations and ID to center Agents. Center agents calculate $\mathbb{F}$ and send target zone information to the mobile agents.

## 3 World modeling

Yabi worldmodel class is a base model. $\mathbb{F}$ and the eigenvectors are used as indexes to show the level of importance.

## 4 Agent skills and action selection

Mobile agents use a simple selection rules - setTarget, move & do rescue operation. In setTarget, the target zones are selected using indexes of $\mathbb{F}$.

## 5 Disaster Prediction, Vision and parameter learning

Figure 4 shows our image that RCRS will be used at local government. At headquarter, RCRS will be used to check the usefulness of their plans before command real rescue people. In such situations, commands to agents are required compatible with synthetic and real ones. We assume that the predictions of disasters such as fire spreading etc. are assumed to task at headquarter.

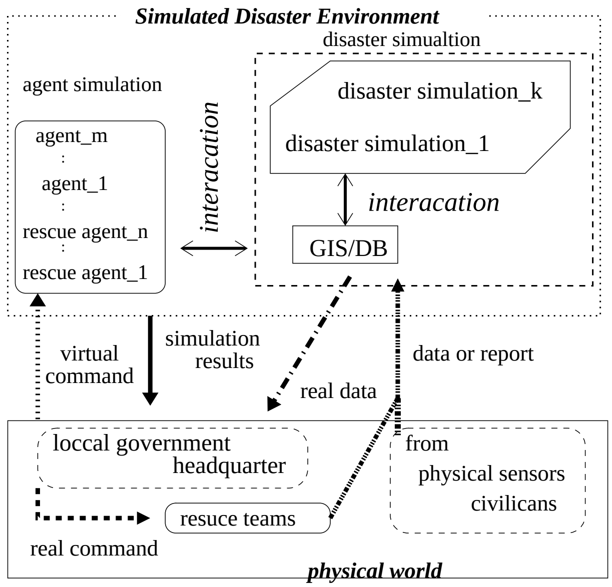



**Fig. 4.** Disaster Rescue Management System

## 6 Agent coordination

Mobile agents do no coordinate directly among them, however, do coordinate indirectly via their center agent. By July, center agents will coordinate among them via $\mathbb{F}$.

## 7 Data visualization

Data visualization is one of key points to persuade the potential users to use RCS as their tools. Interpretation of results in a form of eigenvectors is one of data visualizations.

## 8 Possibility for Practical Application to Real Disaster Site

We believe our method provide a practical tool and an analysis tool of other social simulation results.

## 9 Lessons Learned

The scores of 2006 top teams showed similar trend like the 2004 Challenge session. The tactics of rescue operations adopted by team are assumed to be different each other, however it is difficult to distinguish the differences among them. Our team thinks that a tool to analyze them with universal methods are necessary to our community.

## 10 Acknowledgements

We thank teams and committee members for their contribution to RSL.

## References

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