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Disaster Rescue Simulation based on Complex Adaptive Theory

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Abstract

Disaster rescue is one of the key measures of disaster reduction. The rescue process is a complex process with the characteristics of large scale, complicate structure, non-linear. It is hard to describe and analyze them with traditional methods. Based on complex adaptive theory, this paper analyzes the complex adaptation of the rescue process from seven features: aggregation, nonlinearity, mobility, diversity, tagging, internal model and building block. With the support of Repast platform, an agent-based model including rescue agents and victim agents was proposed. Moreover, two simulations with different parameters are employed to examine the feasibility of the model. As a result, the proposed model has been shown that it is efficient in dealing with the disaster rescue simulation and can provide the reference for making decisions.

Keywords: *disaster rescue, complex adaptive theory, agent*

1. Introduction

China is one of the countries which are most affected by natural disasters. According to the International Disaster Database statistics, there are 24 times and 17 times of disasters, respectively, occurred in China among the top 100 natural disasters which caused largest number of deaths and direct economic losses in the 20th century. In recent years, although disaster reduction capacity is strengthening, natural disasters are still the major issues which impact economic construction and social development. The situation is extremely severe in face of natural disasters. The positive and effective rescue is an important means to reduce disaster losses. Disaster rescue involves social factors such as government, social organizations, victims, time factors such as occurrence time, disaster duration, spatial factors such as occurrence place, weather conditions, and also resource factors such as basic rescue facilities, relief supplies. These factors form a heterogeneity, difference, diversity, sudden, randomness system. Therefore, disaster rescue system is a complex adaptive system.

The theory of complex adaptive system has been applied in various fields such as manufacturing, medical science, engineering, etc. and one of the important areas lies in the multi-agent system (MAS) simulation. Qinglin Guo and Ming Zhang [1] proposed architecture consists of various autonomous agents that are capable of communicating with each other and making decisions based on their knowledge to form a architecture of multi-agent-based Intelligent Manufacturing System. Arend Ligtenberg et al. [2] explored the use of MAS to simulate spatial scenarios based on modeling multi-actor decision-making within a spatial planning process. Bonnie Rubenstein Montano et al. [3] presented a Bayesian learning approach for a multi-agent system which learned to identify an appropriate agent to answer free-text queries and keyword searches for defense contracting. Kevin F.R. Liu [4] introduced an agent-based environmental emergency management framework as a loosely coupled collection of agents that can cooperate to achieve a common goal preparedness for and response to environmental emergency situations. KaiYing Chen and ChunJay Chen [5] used multi-agent technology to construct a multi-section flexible manufacturing system (FMS) model, and utilized simulation to build a manufacturing environment based on JADE framework for multi-agent to combine with dispatching rules. Jie Lin and Qingqi Long [6] presented a multi-agent-based distributed simulation platform to support the extremely complex semiconductor manufacturing

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analysis. The platform development and the design of graphical user interface were also exploited in that paper.

As a research of disaster rescue process, this paper uses complex adaptive system theory to establish a model contains rescue agents and victim agents. Based on the full analysis of the behavior and influencing factors in the rescue process, a model including judgments of the rescue members, behaviors among victims and the impact of relief supplies is established. In this article, the disaster rescue model has the following features:

(1) Simulation of disaster environment: Using the agent simulation technology to create a virtual disaster environment. Victims and rescue members are mapping as agents.
(2) Simulation of relief supplies: Relief supplies play a very important role in the disaster rescue. In the rescue process, not only to consider the interaction of supplies between the rescue agent and victim agent, but also to include the interaction model between the victims.
(3) Simulation of the search action: The search operation is the first step in the rescue process. Rescue agents need to determine the next course of action according to the current circumstances. This requires the simulation model can provide accurate judgment and rapid response capability of rescue agents under different situations.
(4) Simulation of the rescue process: The rescue process is the core of disaster relief, but also the most complex step. The rescue process involves the ability to deal with a variety of different situations, the match of different materials requests and the collaboration of different agent groups.

The rest of this paper is organized as: Section 2 provides the theory of complex adaptive system and its relation with the disaster rescue process. In Section 3, we apply the proposed multi-agent model to simulate the rescue process on the Repast platform. Finally, Section 4 is the conclusion of this paper.

2. Research Method

2.1. Complex Adaptive Analysis of the Disaster Rescue Process

The theory of complex adaptive system has seven relevant concepts: aggregation, nonlinearity, mobility, diversity, tagging, internal model and building block. The first four are certain characteristics of the individual which will play a role in the adaptation and evolution; the latter three are the mechanism of interaction between the individual and the environment. Disaster rescue system is a complex adaptive system because the system also has the following characteristics of complex adaptive systems:

(1) Aggregation: In the disaster rescue process, we regard victims as victim agents, rescue teams as rescue agents, which has made the model has the aggregation characteristic. The victim agent doesn’t mean just one of victims in the general sense, but a group of victims which can seek relief, help each other, as well as make decisions. The rescue agent is also an aggregate in a certain sense. It doesn’t mean just the rescue team which can offer relief supplies, but a group which can rescue buried person, provide medical assistance in the broad sense. Therefore, in the disaster rescue process, the interaction between agents promotes the evolution of the system.
(2) Nonlinearity: In the disaster rescue process, the interaction between the various agents of the system does not meet the homogeneity principle. In addition, the interaction between agents is not simply a passive one-way causal relationship, but a complex adaptive relation.
(3) Mobility: In the disaster rescue process, high resource mobility exists between rescue agents and victim agents. These resources contain human resources, material resources and information resources. Human resources refer to the collection of workers involved in the rescue process, such as medical rescue, distribute aid and command staffs; Material resources include rescue funds and relief supplies; Information resources provide information services, including all types of communication, distress signal for rescue, etc.
(4) Diversity: Each rescue team has its unique technology, supplies and service characteristics. Meanwhile there are differences between the different teams which have the same kind of rescue techniques. Therefore, not only types of agents are diverse, but also agents in the same class are diverse. With the advance of the rescue process, the

various agents change their behavior to adapt the mutative situation, which opens up the possibility for further diversity.
(5) Tagging: Tagging can be tangible or intangible, such as team banner, volunteer's dress and Slogans.
(6) Internal model: The rescue agent will choose the way to implement the rescue according to the information of rescue objectives and operational mechanisms and rules. The rescue agent will change its internal structure to adapt the new situation when necessary.
(7) Building block: isaster rescue personnel, funds, relief supplies and equipment, rescue knowledge, on-site information, the rescue team management and operational mechanism are building blocks in the disaster rescue process. Different combinations of these building blocks establish different internal models and produce different behavior results.

In summary, the disaster rescue system has the seven general characteristics and mechanism of the complex adaptive system, and so be seen as a complex adaptive system.

2.2. Formal Description of Victim Agents

Disaster rescue model virtualizes disaster environment to a flat space which is meshed uniformly and each grid corresponds to 0.5 * 0.5m space. According to the actual situation of environmental disasters structure, the attribute value of each grid is assigned as follows: victims, rescue members or null.

This model will define each victim as an agent:

Victim Agent = < St, E, V >

St is the state collection of agents at time t; E is the collection of external events that can stimulate the state and behavior of agents; V is a collection of agent behaviors, including all the acts taken spontaneously or inspired by external events.

St = < loc, c, q >

Loc is grid coordinates of the agent at time t; c is the current health state of the agent; m is current quests of the agent.

2.3. Formal Description of Rescue Agents

In this model, every rescue member (or rescue team) is defined as an agent.

Rescue Agent = < St, E, V >

St is the state collection of agents at time t; E is the collection of external events that can stimulate the state and behavior of agents; V is a collection of agent behaviors, including all the acts taken spontaneously or inspired by external events.

St = < loc, v, dir, m >

Loc is grid coordinates of the agent at time t; v is the instantaneous velocity of the agent at time t; dir records the direction of the agent movement from time t-1 to time t; m is current supplies of the agent.

Standards of rescue agents' behaviors are defined below:
(1) If there is a victim agent in the visible range, then move to it.
(2) If there is no victim agent in the visible range, then choose the direction which has the highest density of victim agents to move.
(3) Material exchange between victim agents and rescue agents. If meet all the demands, then the victim is rescued.

3. Results and Analysis

3.1. Repast Platform

Repast (Recursive Porous Agent Simulation Toolkit) is a simulation-based Agent software architecture of Social Sciences Computing Research Center of the University of Chicago. This architecture provides a series of libraries used to generate, run and display the model and collect the related data. Repast has the abstraction of the underlying structure, strong scalability and good performance ability, and has been applied to all aspects of social simulation. Now Repast has developed into a versatile, multi-agent simulation platform. The Repast Simulation program contains the following parts: agent class, model class, behavior class, data source class.

Table 1. Core modules of the Repast Simulation program

Module	Illustration
Agent class	Define the properties and behaviors of the agent
Model class	Use templates to build simulation model
Behavior class	The decouple between the simulation scheduler and the agent
Data source class	Analyze the simulation program

3. 2 Parameters Initialization

According to the above, the Repast model sets the parameters to be run at a 50 * 50 environment which includes three rescue agents. Parameters of victim agents and rescue agents are shown in Table2 and Table 3.

Table 2. Parameters of victim agents

Parameters	Illustration
State	Two states of the victim agent are included: 0- not rescued and 1- has been rescued. At the beginning of the simulation, they are all marked as 0
Service ID	Three services are included: 1-water, 2-tents and 3-food. At the beginning of the simulation, they are randomly assigned.
Request number	The amount of service request that victim agent asked. At the beginning of the simulation, they are randomly assigned
Health degree	health conditions of victims
Coordinates	Coordinates of the victim agent. They are randomly assigned at the start
Color	The color of the victim agent is designed as follows: white for the agents that are not rescued. All the colors are initially white

Table 3. Parameters of rescue agents

Parameters	Illustration
Storage	Material reserves of each rescue agent. This model sets three kinds: drinking water, tents and food
Coordinates	Coordinates of the victim agent. They are randomly assigned at the start

There are many factors affecting the rescue routes: types of rescue services the rescue agent can offer; the quantity of equipments and materials the rescue agent can carry; the distance between the rescue agent and the victim agent; health conditions and aggregation density of victim agents.

3.3 Model Simulation Process

(1) As every cycle begins, the victim agent generates a request.
(2) The rescue Agent searches whether there is a victim agent in the adjacent grids. If there is, rescue the victim agent. If it meets all the demands, the victim agent is rescued; if it only satisfies k kinds of the demands, adds k to the health degree of the victim agent and deducts the relief supplies of the rescue agent. If not, the rescue agent determines the movement direction according to the weight value of victim agents’ number in the visible range and their health degree.
(3) The victim agents’ activity: adjacent victim agents share supplies. If meet k kinds of the demands, the healthy degree plus k.
(4) If not rescued, the health degree of the victim agent subtracts one.
(5) When the rescue number reached 95%, the simulation ends.

3.4 Experimental Analysis

According to parameters of the simulation model as well as mutative conditions during the actual rescue process, this paper set two experiments with the different number of victim agents (500 and 250 victim agents).

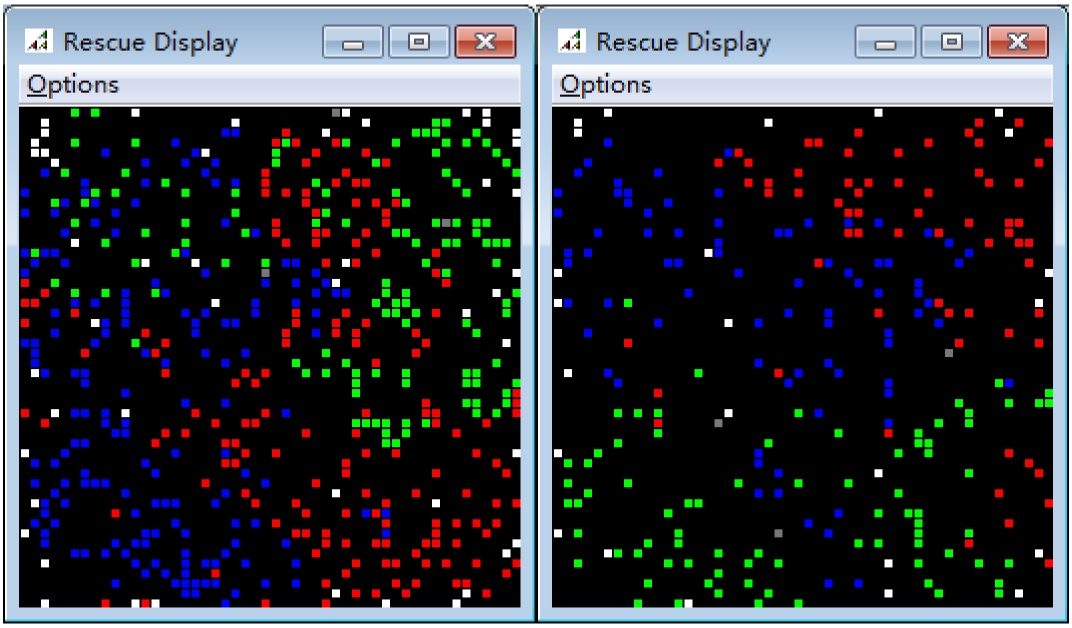

Figure 1. The Repast simulation display

In Figure 1, the simulation runs at a 50 * 50 environment including three rescue agents. The left experiment sets 500 victim agents while the right sets 250 victim agents. Grey grids are original locations of three rescue agents. Red, green and blue colors respectively represent victims which have been rescued by three rescue agents, while white represents the victim which has not been rescued. To a certain extent, victims of the same color substantially cluster together. This is due to the judgment of the distance between the rescue agent and the victim agent in decision-making criteria. Meanwhile other criterion is also included (such as health conditions, etc.), thus causes the distance between some victims of the same color is so far.

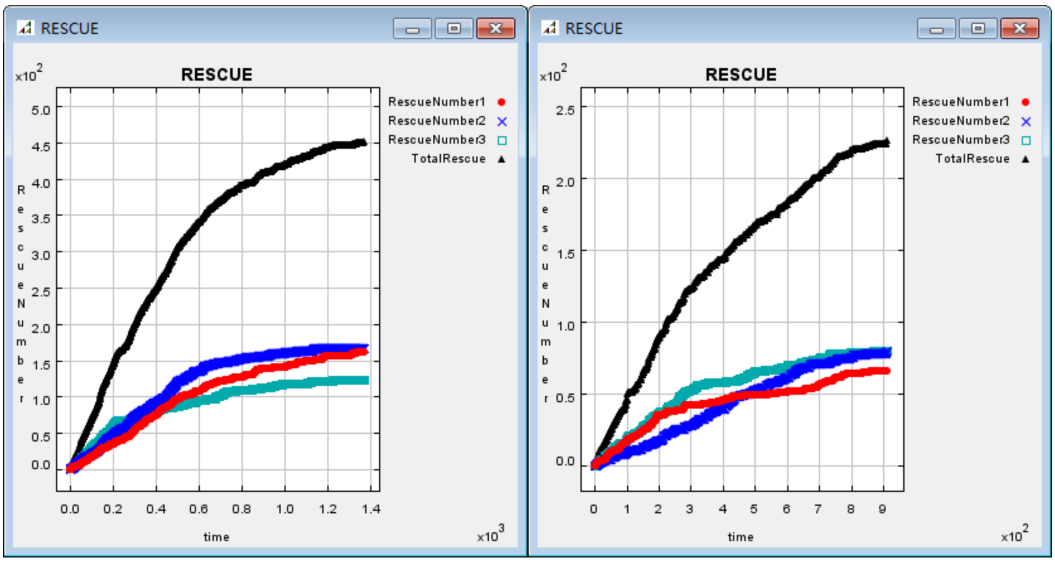

Figure 2. Numbers of rescued victims

Figure 2 shows the fluctuations of rescued victims' number over time. The results of two experiments are almost the same. From the graph we can see the number of rescued victims is rising fast in the beginning. But as time goes on, the curves of rescued victims' number show a relatively stable trend till the number of rescued victims reaches 90% of the number of total victims. This is because each agent materials reserve is enough in the early rescue operations, generally meet the current request of the victims. However, in the later period, due to the reduction of the materials reserve, the rescue agents can't satisfy the requests of victims. So in each cycle the chance of the rescue agents which do not participate in the rescue process increases, that causes the curve approaching on a stable. In a cycle of this model, a rescue agent doesn't take the rescue operations can be summarized as the following two situations: The material storage can't satisfy the request of the current victim agent; the distance between the rescue agent and the nearest victim agent is too far.

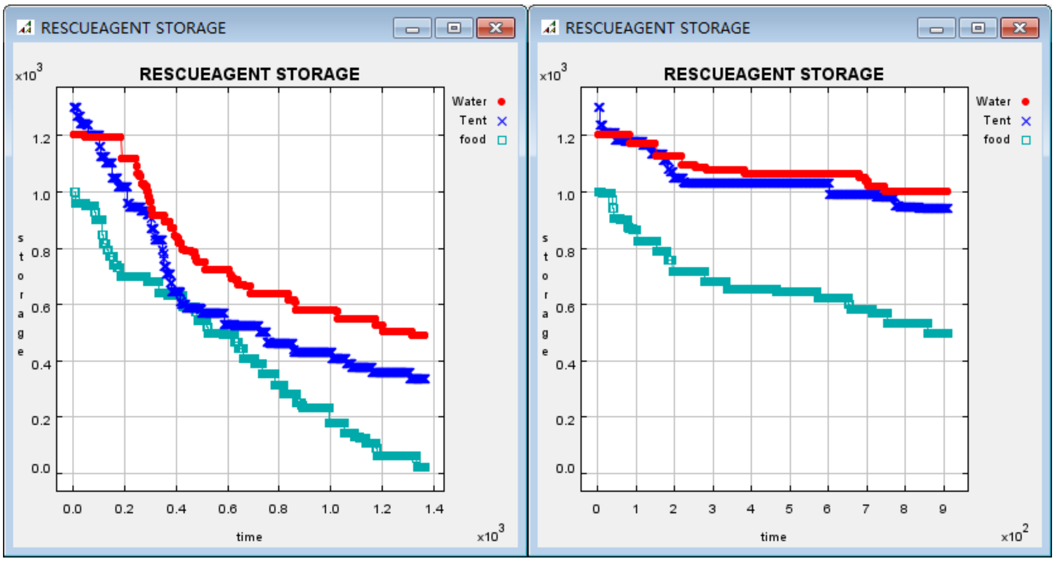

Figure 3. Storages of No.1 rescue agent

Figure 3 shows the material storage change of No.1 rescue agent. This model has three kinds of relief supplies: drinking water, tents and food, respectively, marked with a different notation in the figure. The left curve is decreasing fast while the right curve remains relatively stable. Since the left experiment has 500 victim agents while the right has 250, the density of victim agents of the left is much more than the right one. This causes rescue agents rescue more victims while consume more relief materials.

4. Conclusion

This paper uses complex adaptive and multi-agent theory as the basic idea to analyze the disaster rescue process. A multi-agent model contains rescue agents and victim agents has been proposed on the Repast platform and has been shown that it is efficient in dealing with the disaster rescue simulation. Therefore, this approach may give experts a more credible and informative suggestion to make better decisions.

Future research may focus on how to make it closer to the human way of thinking and how to make it more suitable to describe the human decision-making process in the interaction of social groups. Furthermore, environment changes may be considered in the future model, such as adding weather or terrain parameters.

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