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Agent-oriented modeling and development of a system for crisis management

Iván García-Magariño [a,*], Celia Gutiérrez [b]

[a] Departamento de Ingeniería Informática y Organización Industrial, Facultad de Enseñanzas Técnicas, Universidad a Distancia de Madrid, Collado Villalba 28400, Spain
[b] Department of Software Engineering and Artificial Intelligence, Facultad de Informática, Universidad Complutense de Madrid, Madrid 28040, Spain

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ABSTRACT

The management of crisis situations has been a challenging problem from different points of views, such as communication efficiency and avoiding casualties. This paper presents a novel approach that includes an interaction organization pattern for Multi-agent Systems (MASs) in crisis management, abstracted from several existing case studies in which the agents follow a sequence of interactions and the organization must optimize the use of human resources. The pattern considers an emergent organization of peers that adopt different roles according to the circumstances. The key features of the organization are its robustness, scalability (in terms of both agents and roles), flexibility to deal with a changing environment, and the efficient use of resources. In order to validate the organization, the paper presents its modeling and development with the Ingenias methodology, conforming the corresponding MAS. This development follows a model-driven approach, which allows a smooth transition from the specification to the code, and a low-cost testing of the system with different settings. Another key aspect is the application of metrics for validating and improving the MAS in terms of response time. The MAS has been tested with 600 agents representing 200 citizens, showing its performance.

1. Introduction

Researchers have taken into account the management of different kinds of crisis situations for a long time. For instance, Tsang and Ngai (1996) proposed an expert system for decision-making in order to guarantee safety in a gas company. Then, Engestrom (1999) considered the involvement of large groups of people in crisis situations, and indicated that the key for success in crisis management is a proper combination of knowledge-based actions, planning, flexible adaptation, critical analysis, and group interaction. Bearing these features in mind, the Artificial Intelligence (AI) community, and in particular the Agent community (Kitano & Tadokoro, 2001), has considered scenarios involving these situations of crisis as an ideal testbed for their techniques. This field is generally denoted as *crisis management*. One can mainly observe four kinds of scenarios in crisis management: search and rescue robots (Davids, 2002); crowd simulators (Murakami, Minami, Kawasoe, & Ishida, 2002); contingency management systems (Sheremetov, Contreras, & Valencia, 2004); or crisis response (Kitano & Tadokoro, 2001). Among all of these, the study of crisis response scenarios has drawn more the attention of MAS developers.

In the scenarios of crisis response, there is usually a catastrophe where several groups of agents with specific skills must be coordinated to assist the victims. These assistant agents collect information of the environment while working, and autonomously solve emerging issues. This kind of problem has several features that make of MASs a proper tool for its analysis. First, it has a clear identification of agents, roles and groups. In addition, agents have to interact with a customizable and changing environment. The solution of the problem needs collaboration between the involved agents. Moreover, the scenario offers a clear statement of the goals to satisfy both at the individual and group levels. This relevance has lead to the development of common implementations of the scenario, like RoboCup Rescue (Kitano & Tadokoro, 2001) and DrillSim (Balasubramanian, Massaguer, Mehrotra, & Venkatasubramanian, 2006).

General lessons can be extracted from the implementations made for the crisis response scenario, that is, to try to extract interaction patterns for MASs from this experience. These patterns can provide useful insights for the design of the communication of systems with similar requirements and expected benefits. This work focuses on the description and implementation of one of such patterns, specifically focused on organizational issues of the MAS. Its main requirements are the following. It considers several groups of agents with different capabilities and goals, mainly citizens and specialists, like medical doctors and firefighters. Each of these groups shares some common goals, although individual persons have specific goals

* Corresponding author. Tel.: +34 687031935; fax: +34 918561997.
E-mail addresses: ivan.garcia-magarino@udima.es (I. García-Magariño), cegutier@fdi.ucm.es (C. Gutiérrez).

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and behave autonomously in the field responding to their specific situations. The use of resources (like communications, movements, or medical supplies) must be planned and optimized as much as possible given their scarcity. The current approach states the solution in case an agent fails, which corresponds to the failure of the node where it resides. Finally, the overall success of the system is regarded as the fast communication to reduce the casualties and, if possible, the damaged infrastructures and properties.

A MAS is presented to achieve the proper communication in the aforementioned scenario. In this MAS, people, both citizens and specialists, are supported by agents playing two roles: *InformationR* for those reporting some information or asking for help; and *NetworkR* for optimization of the network use. The agents of reporter role process the results sent by the agents of other roles by means of a distributed database. The networker considers issues such as traffic balance, network fault tolerance, or message addressing to the potentially proper receivers. Both citizens and specialists have a limited radio of communication and knowledge about the situation. To coordinate the different services, the people are coordinated by means of the coordinator agents, playing the *CoordinatorR* role. Each of these agents represents a person and it is running in its smartphone or tablet.

In particular, the current approach is practiced in the following specific crisis response scenario. A poisonous material has been accidentally released into a city. The number of affected people is very high to be managed only with a centralized solution at hospitals. In addition, the official medical services are overwhelmed to be able to assist affected people at their own locations. Thus, a distributed solution where people on the ground collaborate is necessary. The citizens with medical capabilities (i.e. the specialists) will help affected citizens (i.e. the citizens in the general pattern) who are close enough to them. Citizens will be warned as soon as possible of the infected locations to avoid these. The central official system (i.e. the coordinators) must be informed of all the infected locations. The communications should be efficient, as the communication network is almost collapsed. It is remarkable the fact that, in this scenario, each citizen has been assigned to an agent for coordination with other citizens. The corresponding MAS has been tested with 600 agents representing 200 people on the ground, and with different configurations of numbers of citizens asking for assistance and citizens with medical capabilities, showing the performance of the system.

There are several possible Agent-oriented Methodologies (AOMs) that could have been used for implementing the presented pattern for crisis-management. In particular, Isern, Sánchez, and Moreno (2011) present an analysis of the most relevant AOMs extracting their support and possibilities for modeling organizational structures with different levels of complexity. This analysis guides developers in selecting the most appropriate AOM for a given MAS for solving a particular problem. The presented pattern for crisis-management needs coalitions, teams and congregations. According to the study and these organizational structures, the presented pattern could be implemented with Extended Gaia, Multiagent systems Software Engineering (MaSE), Ingenias, and Agent-oriented Software Process for Engineering Complex Systems (ASPECS). The authors preferred the AOMs that include recent principles of Model-driven Development (MDD) (Schmidt, 2006), since this allows a rapid construction of MASs from models facilitating the implementation of the pattern. From these AOMs, both ASPECS and Ingenias included recent MDD principles. On one hand, ASPECS (Cossentino, Gaud, Hilaire, Galland, & Koukam, 2010) has the advantage of including support for holarchies. On the other hand, Ingenias (Pavón, Gómez-Sanz, & Fuentes, 2005) provides its tool support, called Ingenias Development Kit (IDK) (Gómez-Sanz, 2013). Since this pattern does not need holarchies in its current version and since the IDK tool support facilitates the development of MASs, the Ingenias AOM has been selected for implementing this pattern. However, this pattern may include holarchies in the future, and consequently ASPECS would be used for its implementation.

Therefore, both the description of the pattern and its implementation adopt the Ingenias AOM and its support tool, IDK. Ingenias covers most of the concepts required for the description of the pattern, with an important focus on the mental state of agents, their interactions, and their organizations. For now, it only considers basic definition of the space and time features of the environment, but this is planned to be enhanced as future work, especially with the inclusion of smart cities, as further described in Section 7. The IDK provides support for modeling, refinement, verification, and code generation with different target platforms. The current case study uses the Ingenias Agent Framework (IAF), distributed as part of the IDK and built on top of the Java Agent DEvelopment Framework (JADE) platform (Bellifemine, Bergenti, Caire, & Poggi, 2005).

A prototype of the current application was previously introduced in our work (García-Magariño, Gutiérrez, & Fuentes-Fernández, 2009), as an application of the IDK. However, the current work is extended by presenting the complete application and determining more aspects, such as the definition of the interaction between the coordinator and networker, and the tasks related to the Networker–Coordinator interaction. The current work now also indicates how the development of this application can be adapted in different crisis management scenarios. In addition, the application have been measured and optimized in order to increase its efficiency, which is achieved by changing the agent selection mechanism for starting interactions. Moreover, a new test has been added to assure that simultaneous requests can be attended by the same person one by one, if necessary, and all the tests are checked with a higher number of agents, specifically 600 agents instead of 21. Finally, the work now contains an extended analysis of related works, including a detailed comparison with the most similar work, which is RoboCup Rescue and its platform project.

The remainder of the paper further explains the pattern and its implementation. Its organization is as it follows. The next section analyses the related works mentioning the improvements of the current work over the existing ones. In particular, the next section also presents a detailed comparison of the current work with the framework RoboCup Rescue, as it is considered relevant for the presentation of the current work. Section 3 describes the requirements of the proposed scenario with more details. After that, Section 4 shows the complete design of the pattern with Ingenias. Section 5 presents the development of the platform specific models that contain the additional information for code generation, and the running system is validated with several tests described in the same section. In Section 6, one can observe some experimental results that compare response times. Finally, Section 7 discusses the main features of the pattern regarding experimentation and considers some future work.

2. Related works

Works collected from literature show that there are many works regarding the simulation of crisis scenarios. Due to the different nature of the goals, the first subsection makes a study depending on the scope of the scenario. In addition, RoboCup Rescue has set a milestone in the crisis management by the use of the combination of AI and robotics, so another subsection compares this with the current work.

2.1. Scenarios of crisis management

Crisis management can be regarded in several scenarios. The first one is the use of search and rescue robots. Davids (2002)