A collaboration platform for data sharing among heterogeneous relief organizations for disaster management

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ABSTRACT

Recently, we are witnessing the progressive increase in the occurrence of large-scale disasters, characterized by an overwhelming scale and number of causalities. After 72 hours from the disaster occurrence, the damaged area is interested by assessment, reconstruction and recovery actions from several heterogeneous organizations, which need to collaborate and being orchestrated by a centralized authority. This situation requires an effective data sharing by means of a proper middleware platform able to let such organizations to interoperate despite of their differences. Although international organizations have defined collaboration frameworks at the higher level, there is no ICT supporting platform at operational level able to realize the data sharing demanded by such collaborative frameworks. This work proposes a layered architecture and a preliminary implementation of such a middleware for messaging, data and knowledge management. We also illustrate a demonstration of the usability of such an implementation, so as to show the achievable interoperability.

Keywords

Data Processing, Disaster Management, Interoperability, Ontology, Reconstruction and Recovery

INTRODUCTION

In the recent decades, we are witnessing the effects of massive climate changes and terrorist attacks, which caused the occurrence of major harmful events that can be named as large-scale disasters (OECD, 2004), leading to a high number of causalities and damages, implying high costs and efforts of recovery and/or happening in vast geographical areas within a single country or even across different countries. Concrete examples of large-scale disasters are the September 11th terrorist attacks in U.S. in 2001, the Hurricane Katrina in U.S. in 2005, the Sichuan earthquake in China in 2008 and the L'Aquila earthquake in Italy in 2009, just to cite the main ones. All these events have in common the intervention of different and heterogeneous organizations during the after-disaster time, which have to collaborate and be coordinated with or without a centralized management.

Despite differing in many respects, such events also have some similarities, which can help us to understand what are the key issues and requirements in managing large-scale disasters and to provide a framework for facilitating and improving disaster response and recovery (OECD, 2004):

1. Immediately after a disaster, information about the situation in the damaged area is typically incomplete, fragmented and/or hard to interpret. Vital pieces of the overall picture are scattered across different organizations, spanning from central and local government, relief organizations, hospitals, police and fireman authorities and so on. Experience shows that all the involved organizations and individuals to deal with the emergency need to communicate and to co-ordinate their actions.
2. Disasters can overwhelm the response capacities of any single country due to the large scale and causalities, so it is needed to receive some sort of concrete support and aid from foreign countries. Actually, this is a really complex scenario, which requires the creation of coordination and reporting lines between involved stakeholders, such as Humanitarian Coordination Architecture proposed by the Inter-Agency Standing Committee (IASC) (IASC, 2010).
3. In the case of Chemical, Biological, Radiological and Nuclear (CBRN) contamination, it has to be urgently established what the extent of contamination is, and what will be required to restore the situation to a safe environment. Therefore, information about the contaminated areas need to be rapidly, reliably and securely spread so as to activate proper procedures to isolate them, to evacuate the civilians from there and to start assessing the contamination.

To deal with these requirements in the case of large-scale disasters, we have designed and implemented an advanced net-centric information management tool, named DESTRIERO, which structures and presents information to collaborative groups of (international) stakeholder organizations. Such a middleware platform is meant to provide interoperability means to integrate heterogeneous systems and information sources and to support damage and needs assessment as well as recovery planning for coordinated Post-Crisis Needs Assessment (PDNA) and Reconstruction and Recovery Planning (RRP) processes.

BACKGROUND

Our proposed solution to enforce interoperability among heterogeneous relief organizations and to realize the coordination and collaboration required to manage large-scale disasters as recommended by several international regulations, such as the above-mentioned IASC coordination architecture, consists in the adaptation of a middleware solution for Air Traffic Management (ATM), developed by SELEX ES, a FinMeccanica company. Such a solution is named as "System Wide Information Management - BOX (SWIM-BOX), which aims to demonstrate the feasibility of initial system-wide information management functionality for the air transport system. We have extended such a product to the domain of disaster management by building on top of it proper software abstraction for the data management and sharing. SWIM-BOX adopts a layered organization, where at the lowest level there are the essential IT building blocks to realize Internet-scale networking. The higher layer encompasses the core technical services that SWIM provides to all integrated systems. On top of this layer, we have a series of data access services to implement the "SWIM virtual information pool". The last layer contains services for added-value ATM functionality beyond that of the "virtual information pool".

To allow the integration with legacy systems, a software component adapts the interface expected by the legacy system and the one offered by the SWIM-BOX services by resolving technical (i.e., differences in the supporting programming platforms and languages), syntactic (i.e., differences in the data formats and structure) and semantic heterogeneity (i.e., differences in the semantics of the data model). The Adapters have the role to translate data/services among Legacy Systems and other instances of the middleware, and each adapter can be also decomposed in different adapters, each one dedicated to the particular served "Data Domains". All the data domains can rely on core services, which provide the main services of SWIM-BOX and allow different versions of the middleware to interoperate.

RELATED WORKS

The proposed platform will be modeled on the key internationally agreed methodologies, procedures and standards for disaster recovery to support the information needs as well as the decision making and planning processes. In fact, our platform will integrate and support the procedures of the Damage and Loss

Assessment (DaLA) Methodology (ECLAC, 2009), an assessment methodology that is considered a standard de facto, and the Operational Guidance for Coordinated Assessments in Humanitarian Crises (IASC, 2012), a guidance to enhance coordination among international organizations. As such the platform will provide tools that underpin (not replace) project and programme management frameworks and methodologies that are used by coordinating and relief organizations.

Over the last decade, many crisis information systems have been proposed, developed and practically adopted in relief organizations. Such systems guarantee various different interoperability aspects. All of them are based on the syntactic interoperability concept, specified data models and communication protocols, where standards like as XML or SQL are fundamental (Pundt, 2008). However, most of them lack a proper support to semantic interoperability: each relief organization manages information based on its own semantics, thus information sharing among stakeholders requires the definition of a common ontology to overcome heterogeneity in semantics. As a practical example, the recent solution for an interoperable crisis information system from the SPIDER research project (Šubik, Rohde, Weber and Wietfeld, 2010) allows mapping internal onto an external data structures and vice versa for integrated heterogeneous relief organization. This helps in achieving technical and syntactical interoperability, but completely neglects the semantic one. Our proposed solution will take an ontology-based methodology, and as such targets a holistic semantic interoperability, at operational and information level, providing exchange of data, information and knowledge related to the existing assessment tools currently based in different data models. The challenge is to devise a metadata approach to annotate information sources automatically, in a way that its context and reliability are easier to understand for users from other organizations. This approach is required for improving the Situation Awareness and the Common Operational Picture (SA/COP) (Kuusisto, Kuusisto and Armistead, 2005). A SA/COP reflecting all the crisis dimensions is an essential element for supporting the cooperation among different organizations.

The use of ontology for semantic interoperability is a topic receiving a growing interest within the crisis management sector, and some solutions are available; however, as presented in (Liu, Brewster and Shaw, 2013), there are several research challenges that need to be properly handled. First of all, few ontologies for crisis management, very few are formally represented and publicly accessible. Second, these ontologies are typically specific to certain aspects of crisis management, but unable to cover all of them. Last, in the literature there is the lack of a common vocabulary or standard for the domain. Our solution aims to overcome these limitations in the current ontological approaches for crisis management by proposing a standard-based formal and flexible ontological definition of all aspects of crisis management.

PROPOSED SOLUTION

We have inherited from the SWIM-BOX the layered organization of its architecture and the messaging capabilities, but we have re-thought the data management services to better meet the key requirements of the interoperability and collaboration among relief organizations.

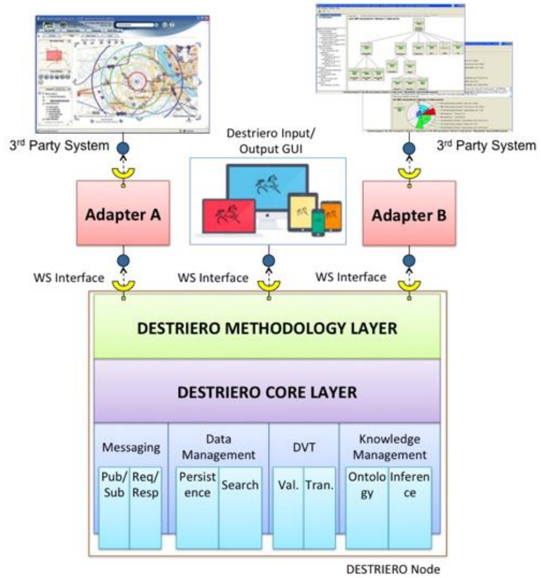

Figure 1. DESTRIERO Layered Architecture

Figure 1 illustrates the architecture of the DESTRIERO platform by means of the so-called DESTRIERO node, organized in three layers:

- The bottom of the architecture is represented by a series of basic services for messaging, data and knowledge management and data transformation;
- The Core Layer is built on top of the basic services, which are generic, and have the responsibility to make the basic services more domain-specific;
- The Methodology Layer is built on top of the previous one to expose the core services by means of proper Web Services, so as to accept requests from the integrated systems and to pass them down to the services at the core layer.

Such architecture can be directly used by applications specifically designed by considering the DESTRIERO guidelines and interfaces. However, also legacy systems can use our platform by realizing proper adapters that third-party systems can use so as to interact with the DESTRIERO solution.

At the moment we have designed and implemented the basic services and part of the core ones, leaving for future work the definition and realization of the rest of the DESTRIERO architecture. Therefore, in this paper we go into the details of these elements of the proposed architecture:

- As for SWIM-BOX, the messaging component allows the communication among remote instances of the DESTRIERO Node by means of two different interaction models: the synchronous request/response and the asynchronous publish/subscribe;
- The data management component is the one responsible for the persistent storage as a relational database and the retrieval of data stored within the DESTRIERO Node.
- The Data Validation and Transformation (DVT) component, used when dealing with a large set of different information with the necessity to provide capabilities that can assure validation and transformation of data.
- The knowledge management component is the one devoted to store the ontology defined within DESTRIERO, instantiate objects from its classes and to infer on the ontology and its instances. An ontology is a formal naming and definition of the types, properties, and interrelationships of the piece of information that relief organizations can exchange.

Due to page limits for this paper, let us restrict our attention to two key components to accomplish the data sharing envisioned for the collaborative management of large-scale disasters, that is, the data management and the knowledge management. The data management component has been realized by means of three main levels, as shown in Figure 2:

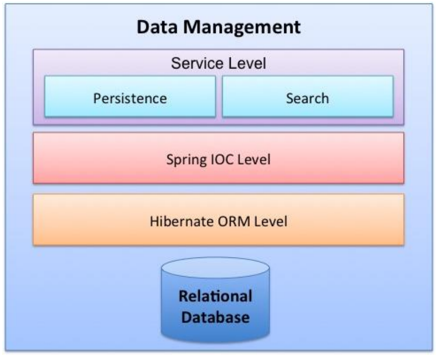

Figure 2. Internal structure of the component for Data Management

- A services level, which is responsible to expose the persistence, and search interfaces to external entities willing to persistently store and retrieve some data;
- A Spring Inversion-Of-Control (IOC) level, which exploits the IOC abstraction offered by the Spring framework (Winterfeldt, 2008) to have Data Access Object (DAO) support that aims at making it easy to work with data access technologies.
- A Hibernate Object-Relational Mapping (ORM) level, which is capable to manage and interact with a configured database thanks to Hibernate (Bauer and King, 2007), an open-source Java persistence framework project for performing powerful object relational mapping and query databases using HQL and SQL.

Also the component for Knowledge Management is composed by levels, as show in Figure 3 and similar to the ones for Data Management. Below the service level we have adopted the Apache Jena (Apache Software Foundation, 2014) for the management of ontologies and inference on them by means of a SPARQL predicate. Jena is an open source Semantic Web framework for Java by providing an API to extract data from and write to RDF graphs. Such graphs are represented as an abstract "model", which can be queried through SPARQL thanks to various internal reasoners, and can be serialized by means of several possible means, among which the mains one are a relational database and a RDF/XML graph.

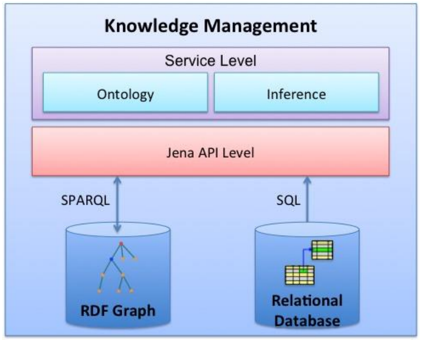

Figure 3. Internal structure of the component for Knowledge Management

The mentioned adapters allows to realize technical and, partially, syntactic interoperability among heterogeneous relief organizations; however to fulfill all the interoperability requirements it is needed to define a common data and information model which specify the common structure of the exchanged data and their semantics by means of a proper ontology. The JC3IEDM data model (MIP, 2012), which has designed by the Multilateral Interoperability Program (MIP) and North Atlantic Treaty Organization (NATO), plays such a role in our project and proposed architecture. Despite being thought for Command and Control Information Systems (C2ISs), we have found that it fits also the typical information exchanged among relief organizations with marginal modifications (i.e., by add functional extensions for accommodating the uncovered aspects).

The ontology for DESTRIERO Common Semantic Data Exchange Model (DCSDEM – URI: http://www.destriero-fp7.eu/ont/DCSDEM) has been created in accordance with two principles: (a) maintain as much as possible the entities defined in the original JC3IEDM model and (b) maintain the ontology as open as possible to enable interoperability with legacy systems and to describe, if needed, different situations and scenarios. The DCSDEM ontology is composed by two OWL files written by using the open-source ontology editor and framework for building intelligent systems called Protégé (Tudorache, Nyulas, Noy and Musen, 2011).

USAGE DEMONSTRATION

A first demonstrating scenario for the use of our solution in post-crisis management is illustrated in Figure 4 and is composed of three instances of a traffic sensor emulator, a legacy system implemented by SELEX ES, the persistence storage of the traffic data generated by the sensor, a third-party GUI and a DESTRIERO-enabled GUI showing the sensor data. In the scenario, we imagine a set of traffic sensors deployed after a disaster in order to monitor the evacuation of the damaged area by the residents; the gathered information can then be useful to guide vehicles on alternative evacuation routes in case of a traffic jam.

The traffic sensor system is a third party system with its own data model structured according to the Sensor Model Language (SensorML), which has to be mapped to the JC3IEDM model in our platform. Specifically, we have mapped SensorML data on a MATERIAL-TYPE instance of JC3IEDM. This model entity is divided in other two sub-categories: EQUIPMENT-TYPE and CONSUMABLE-MATERIEL-TYPE. To fill the gap between SensorML messages and the ELECTRONIC-EQUIPMENT-TYPE entity or others, a proper adapter has been created and instantiated within the SWIM-BOX SMD domain. The purpose of SWIM-BOX Data domains is to create usable functionality for any application or system providing or using a specific data type (SensorML data in this case). SMD aims to provide operations to create, share, filter and delete alert signals from various sensor types.

Figure 4. Demonstrating scenario

When a sensor has correctly advertised itself it is ready to publish alerts. An alert contains three information: (i) who publish the data, e.g. a sensor ID; (ii) when the data is published, typically a timestamp; and (iii) the observation of the sensor. Each sensor publication is seen, considering the JC3IEDM model, as an ACTION-EVENT and is mapped on its sub entities.

The execution of this scenario is illustrated in Figure 5. The first step is to launch the two DESTRIERO nodes composing our demonstrator, characterized by two JBOSS instances (hosting the EJB of our solution) identified by different port numbers. Once the DESTRIERO nodes are running, we have to execute the traffic emulator. After the traffic emulator has been initialized, test sessions could be started by clicking "Advertise Phase", which generates seven advertises, created by the traffic sensors located in different geographical points. The produced advertises are then correctly stored locally in the reference DESTRIERO node, and distributed towards the other nodes, through a publish/subscribe paradigm, that will persistently store them, too. Once subscriptions are done based on the received advertisements, the "Publish Phase" could be started.

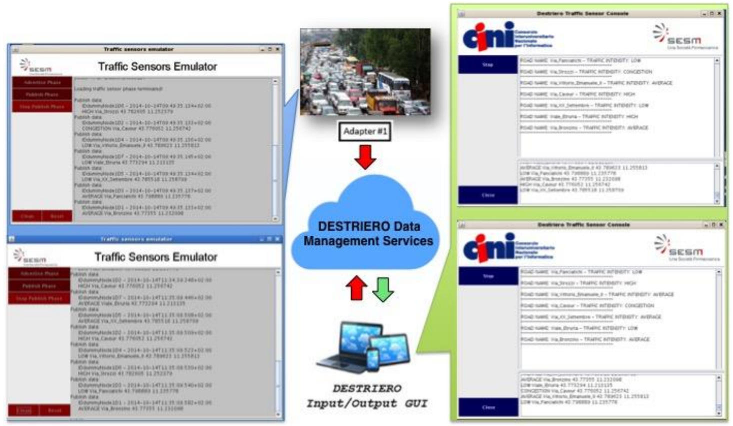

Figure 5. Validator run

CONCLUSIONS

In this paper, we have described a middleware solution, and its preliminary implementation, for data sharing among heterogeneous relief organizations and we have highlighted the key ICT technologies we have adopted in order to resolve the technological, syntactical and semantic heterogeneity occurring among such organizations. As future work, we have planned to continue the design and implementation of the remaining parts of the DESTRIERO architecture that have not been the object of this paper. Moreover, we have also plan to investigate the reliability, security and collaboration issues within this application domain by proposing innovative solutions to tolerate possible faults without compromising the overall DESTRIERO infrastructure, by presenting countermeasures to protect the infrastructure against possible violations and threats so as to achieve an high security degree, and by studying means for an efficient placement of data so as to reduce un-needed replication (which require heavy consistency) and enforce promptly data retrieval. Last, we will evaluate the usability and effectiveness of the DESTRIERO architecture and platform within the context of a large-scale disaster. Specifically, the envisioned scenario is composed by three different events that are combined through a cascade effect and are able to affect a huge number of people and infrastructures within a large area:

- A big earthquake occurs within an area characterized by a dam;
- The damages caused by the earthquake to the dam makes possible a big flood;
- The flood hits a nuclear plant (as happened in Fukushima), and a CBRN contamination incident happens.

Such a complex scenario justifies the use and deployment of a system such as the one partially presented in this paper, to help coordinating the different activities of a large number of entities and authorities involved in the recovery and reconstruction phase. Such a scenario will be adopted within the context of the experimental testing to validate capabilities, properties and the match of the proposed solution with the overall needs of relief organizations when dealing with large-scale disaster management.

ACKNOWLEDGE

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