ONTOLOGY-BASED TECHNOLOGIES FOR DISASTER PREPAREDNESS, RESPONSE AND RECOVERY

Panagiota Masa[1], Georgios Tzanetis[2], Spyridon Kintzios[3], Georgios Meditskos[4,5], Stefanos Vrochidis[6], Iosif Vourvachis[7], Lorenzo Nerantzis[8], Ioannis Kompatsiaris[9]

[1,2,3,4,6,9] *Information Technologies Institute, Centre for Research and Technology Hellas, (Greece)*

[5]*School of Informatics, Aristotle University of Thessaloniki, Greece*

[7,8]*Hellenic Rescue Team*

(E-mail: gmasa@iti.gr, tzangeor@iti.gr, sp.kintzios@iti.gr, gmeditsk@csd.auth.gr, stefanos@iti.gr, i.vourvachis@hrt.org.gr, l.nerantzis@hrt.org.gr, ikom@iti.gr)

ABSTRACT

Natural disasters such as forest fires, earthquakes, floods and heat waves have a tremendous impact on the economy, the environment and the people. Every year, manmade and natural disasters lead to human and property losses and resettlement, the disintegration of infrastructures and degradation of society's resilience. The key role in the efficient management of such a crisis is information and knowledge management. The fusion of heterogeneous information, sensors and data processing is the stepping stone for every system architecture. This paper proposes the use of ontology-based technologies for disaster preparedness, response and recovery to ensure effectiveness. Innovative semantic structures that have been used in relevant EU projects are explored and adapted in the respective framework.

Keywords: Semantic Web, Ontology, Semantic Reasoning, Decision Support, First responders.

1. INTRODUCTION

Natural and manmade disasters are becoming more frequent and more devastating. The use of technology could leverage the response and make societies more resilient. Data acquisition, taxonomy and fusion from multimodal services (video and image analysis, Earth Observation-EO tools, social media, weather forecasts, wearables, etc.) can provide an advantage for crisis management. Decisions could be supported by facts and analysis (even trial and error) instead of being intuitive. Human fatigue and limited cognitive could be overpassed by Disaster Management Systems (DMS) and Disaster Support Systems (DSS). Early warning messages provide alerts to prepare and protect citizens and first responders. Meanwhile, wearable equipment monitors first responders' status and reflects the feasibility to fulfill their missions.

A promising approach to building complex systems is the use of Semantic Web technologies [1]. These technologies, with their ability to integrate heterogeneous data from various sources, offer a significant amount of potential to extend the information available on the Web by giving the information an understandable meaning that can be used by applications for assisting emergency management. Information is represented via ontologies while semantic reasoning schemes run on top of the ontologies and facilitate situational awareness and analysis for decision support. The use of semantic technologies for disaster management has been used in different disaster cases, e.g. earthquakes [2], in order to reduce the response time in disaster detection scenarios, and wildfires [3], in order to enhance knowledge dissemination and operational stakeholder preparedness. The inference process is essential wherever there is a need to identify potential data inconsistencies, evaluate data, identify new relationships, and build new knowledge.

In this paper, we present a framework for combining heterogeneous data from multiple sources, by using a unified ontology model for disasters. This framework can be used in each domain (disaster management, sensing and observation, emergency response, etc.) to support decision-making for the relevant stakeholders. To achieve this goal, we use the OWL2 language to create interoperable Knowledge Graphs (KGs) and semantic reasoning techniques capable of assisting decision support. In addition, we use real-world data to illustrate use cases and highlight how our framework supports various stakeholders.

2. ONTOLOGY-BASED FRAMEWORK

The proposed semantic-based framework (Figure 1) acts as a middleware between the multimodal content analysis inputs from the acquired data and the generated output services. During the semantic analysis process, the heterogeneous analysis results are captured, interlinked and transformed in RDF structures, and stored in a semantic database (TripleStore). The population of these data is based on specific ontological frameworks, which facilitate the semantic reasoning process; the main tool for inferring high-level information to feed the decision-making process is in the form of alerts and reports.

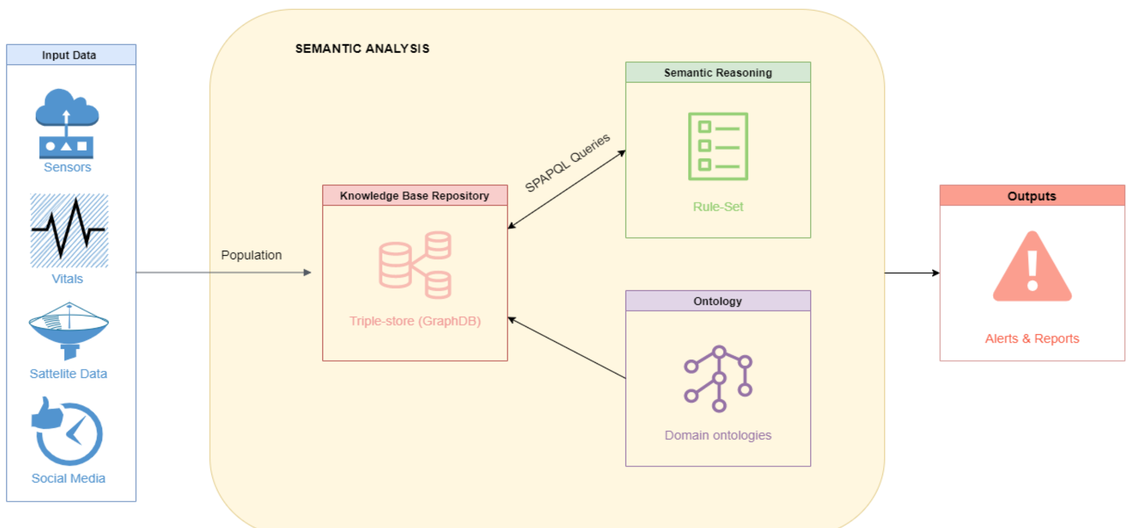

Figure 1. The position of semantic analysis in a high-level architecture.

2.1. Ontologies

The design of specific ontological structures, which can address the abundance of data that need representation in each respective domain, while also being easily adjustable and reusable, is a complex process and can be divided into three phases. The first phase includes the construction of the Ontology Requirements Specification Document (ORSD) [4] by understanding the user requirements and use case for the optimal matching with the ontology requirements. After the acquisition of the ontology requirements, in the second phase, the development of an initial ontology takes place using generic (e.g., SSN [5]) or domain dependent ontologies (beAWARE [6]). In Figure 2, a sample high-level ontology is depicted containing some of the fundamental concepts that are found during a crisis management situation. Some of these concepts are: the Disaster (e.g. manmade or natural), the Stakeholders (e.g. FR, citizens), the Equipment (e.g. wearables, assets), the Sensors (each module that makes an observation) the Impact, etc.; for simplicity, we have omitted data type and inverse properties, as well as extensive class hierarchies. Finally in the third phase is the enrichment of each respective framework with sophisticated design patterns and inclusions of the inferred knowledge from the semantic reasoning.

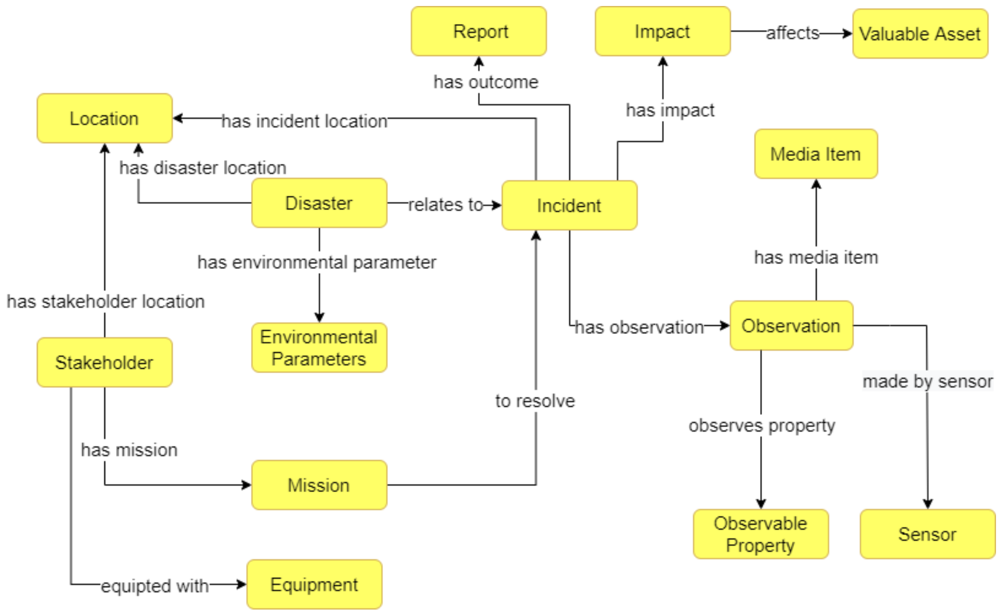

Figure 2. A high-level overview of initial disaster management and response ontology.

2.2. Reasoning component

The semantic reasoning component is responsible for inferring implicit knowledge from explicitly asserted facts existing in the ontology and detecting connections between ontology objects and concepts [7]. Data from multiple sources such as weather forecasts, earth observations, sensors, cameras, wearable technology and social media are integrated into the reasoning component. Moreover, SPARQL queries over OWL 2 ontologies have been used to create the reasoning mechanism. These queries traverse the ontology to identify situations of interest, e.g. alerts that are stored back to the Knowledge Base (KB), providing useful information and assisting end-users in evaluating alternatives and making decisions.

A rule-based interpretable technique is implemented that searches for relationships between data set attributes and class labels and extracts a set of rules. For instance, the weather conditions like wind, temperature and moisture can indicate the potential fire ignition in a specific forest location. The warmer and windier conditions associated with CO_2 emissions are a scenario that produces fires that burn more intensely and spread more quickly in most locations [8]. In this situation, the semantic reasoning module retrieves information regarding the weather forecast variable Fire Weather Index (FWI), which is one of the most popular techniques for predicting the risk of forest fires [9], analyzed the relative data and through the assistance of the SPARQL queries, create early warning messages to inform the citizens and the first responders. The early warning rule is shown in Table 1. Another rule example is presented in Table 1 in which real-time monitoring of the condition of the FR is needed. The vitals that are measured through wearable sensors are combined with other modalities (boots for FRs that recognize their motion status and personal info), and the rule generates pertinent alerts if the conditions are met.

Table 1. A sample of rules for early warning and real-time FR health condition monitoring.

Early warning Rule	FR Condition Rules
IF (FWI >21.3 and FWI<38) THEN PROBABILITY OF FIRE IS VERY HIGH and RECOMMENDATION IS SENT TO CITIZENS "*Do not burn litter, dried grass and small branches in open air.*"	IF (BODY TEMPERATURE >=41) and(DURATION >=1') THEN SEVERE HEATSTROKE IF (HEART RATE <=60) and (BOOTS == IMMOBILIZED) and (DURATION>= 1') THEN FR IN SERIOUS DANGER

3. CONCLUSION

In this short paper, we have presented the ontology-based framework for knowledge discovery to facilitate the decision support during disaster incidents. Having the right information at the right time is essential and crucial while managing a disaster event. Situational analysis and the combination of all information in a more productive manner is a key fundamental for raising situational awareness while handling a major event. Therefore, the overall goal is to increase the efficiency of the decision-making process while reducing the required time. The proposed semantic framework and the respective domain ontology aim to enhance the management of all incoming information from various sources that will support authorities and first responders in addressing disasters in a more effective way. Future work includes the validation and evaluation of these techniques in real situations which will take place in different pilot areas.

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