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Applying Semantic Web Technologies for Decision Support in Climate-Related Crisis Management

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KEY POINTS

- *During climate-related crises vast volumes of heterogeneous multimodal information are generated.*
- *Meaningfully processing and communicating this information for efficient decision support is a key challenge.*
- *The paper describes applying Semantic Web technologies for decision support during such crises.*
- *We are proposing the application of these technologies in the whole "sensor to decision chain".*
- *This approach is being tested within the beAWARE EU project, with contributions by domain experts.*

1 INTRODUCTION

The efficient management of climate-related crises poses several challenges to authorities, the most important of which arguably concern the exchange of vast volumes of heterogeneous, multimodal information coming from citizens (e.g. through social media posts), machines (e.g. deployed sensors), and other stakeholders (e.g. weather forecasting services). State-of-the-art Semantic Web technologies provide an excellent means towards alleviating the burden of processing, integrating, and meaningfully making use of all this information, as they provide the required infrastructure for ensuring enhanced data integration and information interoperability across different stakeholders (Sikos, 2015).

There have been several recent attempts of deploying Semantic Web technologies for climate-related crisis management. Approaches typically either (a) propose common semantic representation models, or, (b) deliver crisis management systems based on Semantic Web technologies. The most prominent approaches belonging to the former group include the works by Limbu (2012), Babitski et al. (2011), Liu et al. (2014), Lauras et al. (2015), and Mescherin et al. (2013). As for the latter group, Pandey & Bansal (2017) developed a system based on semantic technologies for monitoring social media for earthquake reports and weather alerts, and for notifying the public in case of an emergency. Moreover, Burel et al. (2017) propose the encapsulation of a layer of semantics into a deep learning model for automatically classifying information from social media posts. Poslad et al. (2015) developed an IoT early warning system for environmental crisis management, where the use of semantics facilitated sensor and data source plug-and-play, simpler, richer, and more dynamic metadata-driven data analysis and easier service interoperability and orchestration.

The main drawback of the above approaches is their narrow focus on specific parts of the pipeline of processes from sensor data capturing, analysis, semantic representation and fusion, to reporting and decision making. In contrast, we recently proposed the "*sensor to decision chain*", namely, a holistic framework for facilitating decision support by data integration via sensors and semantic data analysis (Moßgraber et al., 2018). In this paper, we focus on the application of Semantic Web technologies in all the phases of this framework, capitalizing thus on the significant benefits brought forth by these technologies. By using Semantic Web technologies we aim to support crisis management systems in the domain of situational awareness. Situational awareness refers to being able to accurately determine what has happened so far during a crisis, what is happening now, and what will come next, all in order to plan and coordinate the most effective response possible with the resources available. The framework is being tested within the beAWARE EU-funded project (http://beaware-project.eu/).

2 DEPLOYED SEMANTIC WEB TECHNOLOGIES

Figure 1 illustrates the steps of our Semantic Web technologies-enabled "*sensor to decision chain*" framework towards managing a natural disaster crisis: Data coming from artificial and human sensors (1) is fed to respective analysis components (2), and the analysis results are semantically integrated into a semantic knowledge base (KB). The KB performs semantic reasoning (3) and forwards its outputs to a reporting module, which provides authorities and decision makers with the appropriate information in natural language (4) for facilitating decision support during the crisis.

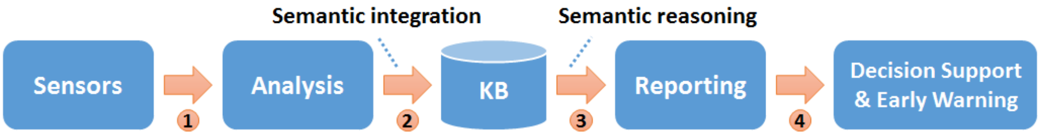

Figure 1. Application of Semantic Web technologies in the sensor to decision chain.

2.1 The Semantic knowledge base

The backbone of the deployed technologies is a semantic knowledge base (KB), which is formalized as an *ontology* (Fensel, 2001) that semantically integrates all the pertinent information: (a) natural disasters and respective climate parameters; (b) analyzed sensor data; (c) rescue unit assignments (Kontopoulos et al., 2018). For example, a video analysis algorithm may detect that a street is flooded and that several cars are partially submerged. A corresponding flood incident is created in the ontology and is linked to the affected objects, in this case the cars. Based on that, the system generates automated suggestions to the decision maker; e.g. to check for people who might get trapped in a submerged car.

2.2 Semantic integration and semantic reasoning

System components perform analysis upon various resources (e.g. audio, text, images, videos and social media posts) and submit their results to the KB. These analysis results are *semantically integrated* within the ontology schema, and can, from now on, be treated by the authorities as homogeneous information, although they originate from different sources. Figure 2 displays an indicative example of analyzed sensor data, namely an image analysis instance, where a potentially injured person is detected in the flood.

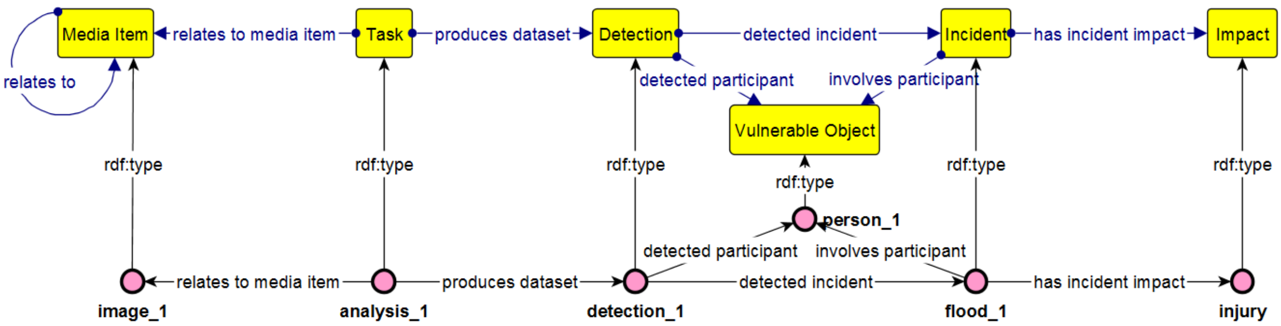

Figure 2. Representation of analyzed data in the ontology.

A *semantic reasoning mechanism* integrated in the framework further facilitates decision support. This mechanism consists of a SPARQL-based ruleset[1], and is capable of inferring underlying knowledge (e.g. establish implied interconnections of detected entities, incidents, etc.) from the semantically fused data generated by the analysis components. The newly inferred knowledge is appended back into the ontology.

An indicative task handled by the reasoning mechanism involves the spatial clustering of incidents during a crisis. Incoming information items (e.g. from social media) can refer to the same incident, and thus need to be clustered based on their location. Our reasoning mechanism classifies all recorded incidents into groups within a certain user-defined radius, protecting the end user from information overload. This process can be enriched with other semantic criteria, such as temporal information and incident importance.

[1] *SPARQL* (Harris et al., 2013) is a semantic query language for ontologies in the Semantic Web.

Additional semantic reasoning examples include: (a) the dynamic (re)calculation of incident severities, e.g. incidents of high risk involving human beings should be classified as “severe” in order to attract the most attention by authorities and decision makers (see Figure 3); (b) the monitoring of safe locations and relief spots. Regarding the latter, during a crisis, citizens could be notified about the existence of such locations, safe detours etc. The reasoner is responsible for inferring the availability of these spots and for determining optimal alternatives in case of low availability. For example, if a bridge is reported to have collapsed during a flood, the closest safest river passage should be calculated and announced to the citizens.

```
DELETE { ?incident :hasIncidentSeverity ?previous_severity }
INSERT { ?incident :hasIncidentSeverity "severe" }
WHERE {
    ?incident rdf:type :Incident .
    { ?incident :isOfIncidentType :flooding } UNION { ?incident :isOfIncidentType :fire } .
    ?participant :participantIsInvolvedIn ?incident .
    ?participant rdf:type :Population .
    OPTIONAL { ?incident :hasIncidentSeverity ?previous_severity . }
}
```

Figure 3. SPARQL rule for calculating incident severity.

2.3 Reporting

The various customized alerts and knowledge gained through semantic integration and reasoning about the unfolding crisis is communicated to authorities and decision makers via a *verbalization framework* that translates the information contained in the ontology to multilingual natural language descriptions. The translation extends our previous work (Mille & Dasiopoulou, 2017) and is realized in two steps. First the semantic ontological representations are mapped to abstract linguistic predicate-argument (*predArg*) representations that serve as language-independent lexicalization templates. Then, the *predArg* structures are mapped to sentences through a sequence of processing tasks that is grounded in the Meaning-Text Theory (Mel’cuk, 1988) and consists in: the mapping from the abstract *predArg* meanings onto lexical units of the target language, the syntacticization of predicate-argument graphs, the introduction of function words, and finally the linearization and retrieval of surface forms.

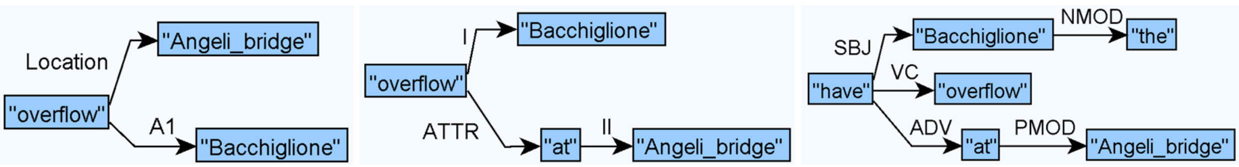

Figure 4. Predicate-argument, deep-syntactic and surface-syntactic structures produced during the generation of the sentence “The Bacchigilone has overflowed at Angeli bridge”.

Figure 4 illustrates some of the intermediate structures, which are generated as part of the English verbalization pipeline, given a KB with appropriate assertions that encapsulate the overflowing of the Bacchiglione river at Angeli bridge. *Angeli bridge*, denoting a location, is associated with the preposition *at* in the deep-syntactic structures and, being a member of the class “*Bridge*”, no determiner is introduced; on the other hand, *Bacchiglione*, as a member of the class “*River*”, is assigned a definite determiner (i.e. *the*). As first argument of the predicate *overflow*, *Bacchiglione* becomes the subject of the corresponding active sentence. The relations of the surface-syntactic structure are used to determine the order and the morphological agreements (e.g. *has*) between the words. If *Bacchiglione* was to be pronominalized, the pronoun *it* – as opposed to *he*/*she* – would be selected.

3 CONCLUSIONS AND FUTURE WORK

In this paper, we described the application of key Semantic Web technologies for facilitating decision support during climate-related crises. Contrary to other related approaches, we proposed the application of these technologies in the whole “sensor-to-decision chain”: the representation of all pertinent aspects is implemented through a semantic KB; the analysis of information coming from sensors and social media is realized through semantic integration mechanisms; semantic reasoning processes facilitate decision support for authorities, while communication to decision makers is achieved through a semantic verbalization framework that translates the KB encoded information to multilingual natural language reports. Based on the above aggregation of multimodal information, our work contributes to the disaster management procedures (such as crisis classification) in all the phases of a crisis. Moreover, it provides the foundations for the decision support services to the authorities and can be integrated in relevant disaster management systems.

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