Use of Linked Data in the Design of Information Infrastructure for Collaborative Emergency Management System

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***Abstract*—The evolution of communication channels and social networks proliferation through the web are inspiring and enabling the construction of collaborative environments. This article proposes an architecture of processes that aims to identify information responsibilities within a general emergency scenario, considering a new way of data provenance: citizens and government agencies. Citizens, who experience as victims a chaotic scenario, can also act as collaborators, providing relevant and useful information for the decision-making process. Today, they already do this informally, sharing public interest information through social networks, such as the Tweeter. The architecture also provides procedures for treating reliability and credibility of the information, provided by the so-called "anonymous officials", subjecting it to a filtering and verification process. The heterogeneity of information formats is a well-known problem that affects organizations and communities that wants to access public data. The architecture includes a Linked Open Data (LOD) approach for acquisition and integration of data maintained by government agencies that adopt different publishing standards. A solution to this problem is of particular importance to emergency response organizations that need access to all information available to better respond to disasters and crisis.**

Keywords-Emergency Management, Linked Open Data, Collaborative Decision Making

I. INTRODUCTION

Information is the most valuable resource during emergencies or disasters. It is the basis for coordination and decision making during the emergency response. It is an essential aspect of an organization's ability for gaining (or losing) visibility and credibility. It has a powerful impact on how national and international resources are mobilized. Above all, information is necessary for providing rapid and effective assistance to those affected by a disaster. It is also essential for after-action analysis, evaluation, and lessons learned.

Public and social communication and media have become key elements for efficient emergency management. Operations in highly sensitive political and social situations must be accompanied by good public communication and information strategies that take all stakeholders into account. One of the main challenges is the design of communication and information management that contributes to more effective and timely emergency response. Another challenge is the adequate organization of command and operational activities to reduce the bad impact of disasters and emergencies and consequently improve the life quality of affected populations [1].

This article proposes a scheme for collecting available data from government agencies, such as departments of health, transport, works, that can supply information needs during an emergency response operation. In addition to public information from government agencies, the scheme also includes the treatment and integration of voluntary collaborative data, i.e., data coming from citizens and public media, involved in the emergency settings. The scheme is based on the Linked Open Data (LOD) approach that provides an appropriate solution to manage heterogeneous data from different public sources. The scheme makes use of mobile devices, such as smartphones and social networks to transmit useful information. We focus on the integration and analysis of both static (previously available) and dynamic (current) information. The scheme also combines official (coming from official sources) and unofficial (coming from voluntary sources) information. We also discuss the need for developing treatment and validation methods for information originated from unofficial sources.

Nowadays, the fast evolution of communication resources, particularly the social networks, has made the volume of data available enormous. The Twitter, for instance, is used by many people as a direct channel of information. Some government agencies (e.g. traffic department) are using this channel for promoting almost in real time the latest events happening in the city. However, the challenge today, in all kinds of social networks, is how to separate the true from fake information. In a recent case of a police occupation of a community dominated by drug dealers, criminals posted messages in the Tweeter, using fake profiles, to deviate police attention while they were escaping through another route.

In case of government information, coming directly from its own public channels, for example, websites, main concerns are not about validating the data veracity. In this case, the challenge is the creation of a common protocol to be applied to all government sectors. A solution to this problem would allow changing information without generating inconsistencies. The growth of e-government programs is rapidly growing the volume of data available for citizens, although, data and access heterogeneity creates difficulty for their integration.

The linked open data (LOD) initiative, incorporated in this scenario, allows the interconnection of data, using standards in the context of the semantic web approach. In ideal conditions, government agencies publish their public data, thus allowing the use of automated data concerned consumers, whether they are other government agencies or citizens. Today, most public agencies provide access to their data, but the great majority is unreadable by automated mechanisms, even when they in digital formats (doc, pdf, xls, images, etc.) and without even a dictionary meaning for the published content. These raw data sets and documentation structure should be reliable, otherwise its utility is null.

However, efforts aimed to link government data are growing in some countries around the world. Interesting examples are given by Britain, the United States and Spain. In 2009, the British government began to adopt Linked Data as official standard for publication of public domain data[1]. During the elections of May 2010, British authorities were encouraged to publish the results in the form of Linked Data[2]. In the future, it is expected that data on education, justice, finance, among others are progressively made available and linked following this pattern.

This paper is divided as follows. Section 2 emphasizes the importance of information management in emergencies, characteristics and sources of previous and context current knowledge in emergency response. Section 3 presents an overview of Linked Data. Section 4 is dedicated to propose an architecture applying previous and current data connected through Linked Data. The two last sections show current efforts, conclusions, benefits that could be provided by the new architecture and next steps to be done.

II. Previous and Current Contextual Knowledge in Emergency Response

According to Diniz et al. [2], an emergency event can be chronologically divided into three phases: prevention, response and investigation. During the first phase, preventive measures are followed and plans are elaborated, in case the emergency occurs. The response phase starts when an abnormal incident is communicated. This phase comprises actions aimed to reduce the bad effects of the emergency, notably loss of lives and property. Finally, the investigation starts at the very first moment of the emergency, but lasts until the causes of the emergency and its effects have been identified. Other classifications include two other phases: preparedness and recovery. In the first, a detailed action plan is designed in view of an emergency situation is expected to take place in the near future. This is the case, for example of hurricanes moving towards a region. The recovery is the phase, during which measures are adopted to bring the situation to normal, when the emergency no more exists.

[1] http://data.gov.uk/
[2] http://openelectiondata.org/

Information Management plays an important role in all phases of an emergency. Some information is more static but a high flow of information can dynamically emerge depending on the situation. The need for a combined usage of different types and sources of information makes the information management a complex task, particularly during the response phase when time pressure and information overload are common.

An emergency response activity usually involves several teams from different organizations working cooperatively for the purpose of saving lives or properties. These teams have to make many decisions under time pressure to accomplish their goals. Most decisions require contextual knowledge coming from the emergency settings, including those which report the activities of other emergency teams.

Diniz et al. introduced a conceptual map (Figure 1) that organizes three types of knowledge that the command team, designated to manage an emergency, uses for decision making and for directing field team operations. These decisions are based on combinations of three types of knowledge: the previous (Personal and Formal) knowledge and the current contextual knowledge [2].

Previous Personal Knowledge: It is the knowledge that each member of this team develops over time and experience from previous operations, including training. Generally, people who integrate this team are experienced, having worked in many previous missions, and who understand and have control of the entire emergency process.

Previous Formal Knowledge: General information originated from government agencies not necessarily designed for emergency use. It usually refers to information about an affected area that is considered useful to command decision-making. Data such as road maps, number of hospital beds, construction plants and water supplies can be relevant to assess the emergency situation. A critical aspect is the reliability of this information, especially regarding the question of time stamping. In many cases, the information is outdated and therefore useless. Another related aspect is the lack of standardization. Different formats create difficulties in information sharing and integration, as well as updating. If govern departments do not adopt a common standard, each piece of information has to be processed differently creating barriers to its universal use.

Current Contextual Knowledge: This is information generated during the emergency evolution process. Situation assessment done by field agents, including information about victims and damages, orders issued by the command and their effects are examples of current contextual knowledge. When this information is combined with previous knowledge it builds what is called "Combined Knowledge" in the diagram of Figure 1, which helps the Command decision-making. This knowledge is very dynamic. It changes all the time and therefore it has to be constantly updated. Most updates come from field agents, but it can also be enriched by voluntary workers, directly involved in the emergency or not. The advances of mobile communication devices and the spread of social networks can turn common citizens into "field agents". They can report their perceptions from the current emergency scenario via text and multimedia, on the fly, through mobile devices. The Tweeter, for instance, that are used as an important way of collaboration among citizens to alert about traffic conditions, violence risks and weather conditions, can also be used to report victims or risks of an emergency scenario, thus helping in building a more accurate current contextual knowledge.

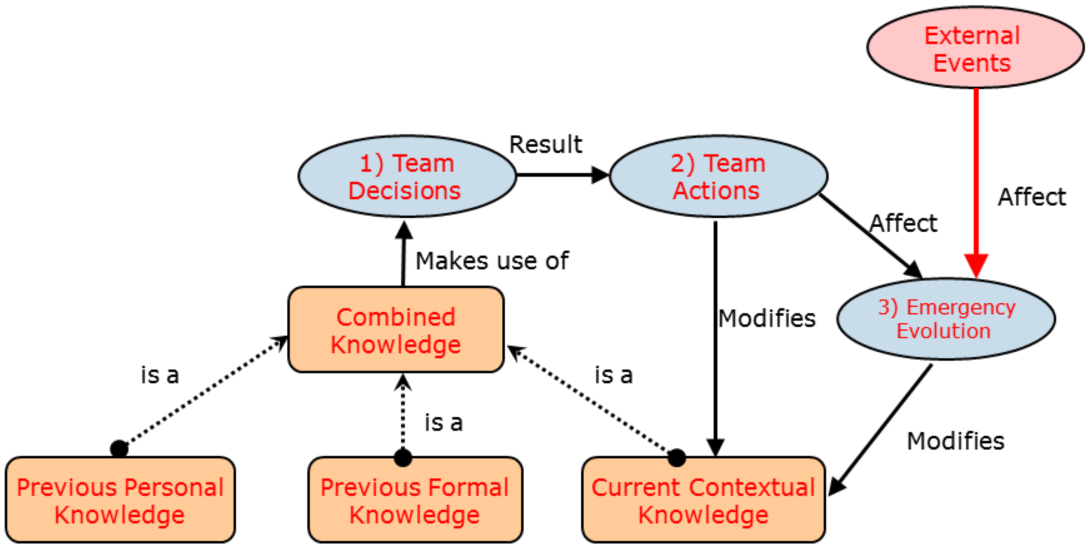

Figure 1 - Conceptual map of knowledge support during an emergency response phase [2]

III. LINKED DATA: AN APPROACH FOR INTERRELATING HETEROGENOUS DATA

The web emerged as a distributed hypermedia that allows interlink between documents, designed for human consumption, with low degree of structures in its objects and implicit semantic of content and links. The result is a "Web of Documents", a huge amount of publish data available as silos of information [3].

In 2006, Tim Berners-Lee posted, on his W3C´s design issues site, some statements on the realization of the semantic web vision, in what is called Linked Data [4]. He argued that "The Semantic Web isn't just about putting data on the web. It is about making links, so that a person or machine can explore the web of data." The proposal of a "Web of Data", considers connecting related data, not originally associated, across the web, using URIs (Uniform Resource Identifier), HTTP and RDF.

RDF (Resource Description Framework) is at the heart of this proposal, as a well-established specification consisting of a suite of W3C Recommendations, published in 2004. It consists basically of a triple-based representation formalism, supporting connections between resources and as well as their description. Among its advantages, it facilitates interoperability, allowing the use of multiple vocabularies and mappings between them.

An RDF triple contains three components [5]: the subject, which is an RDF URI reference or a blank node; the predicate, which is an RDF URI reference; the object, which is an RDF URI reference, a literal or a blank node. An RDF triple is conventionally written in the order subject, predicate, object. The predicate is also known as the property of the triple.

A. *Basic Linked Data Publishing Process*

To take advantage of the Linked Data paradigm, it is necessary to follow some recommended best practices for exposing, sharing, and connecting pieces of data, information, and knowledge on the web, as a combined effort from both producers and consumers of data. The producers have to expose their raw data on the web to feed a process of publishing that filters, cleans and converts data to RDF triples (building the datasets).

The conversion task not only transforms data to RDF format, but also includes the use of terminologies, controlled vocabularies and ontologies to describe triples attributes in a systematic way and as reference conceptual models, to support an integrated view of data and semantic interoperability between datasets. This process unlocks and increases the data sets value. Many tools have already been developed to implement these mappings [6][7], including special support to geo-spatial data [8]. After that, the triples are interlinked using RDF URI Reference. In this case, different approaches and tools to discover and automate the association process are available [9][10].

As the exposed data usually comes from multiple sources, an important issue must be handled: provenance tracking, since it helps to determine the quality and trust of the data [11]. Zhao et al. [12] identify two major constituents of provenance annotations attached to resources (in structured, semi-structured, or free text format), and derivation paths (from a workflow, query or program). They describe [12][13] a dynamically generated hypertext of provenance documents, data, services and workflows. A provenance model [14] for the web of data has been proposed to represent both data creation and access, which can be used by systems to generate provenance graphs for data items. In collaboration environments that support the decision-making process, both ontologies and provenance metadata are a critical issue, especially in Emergence Response scenarios, due to the various sources of data and domains involved.

Finally, the consumers have to use appropriate engines to explore the Linked Data. As data are exposed, many links can be pointed to them, and many applications to explore these data can be built to take advantage of the interlinked data [15][16].

Using the Linked Data publishing process, structured and semi-structured data can be mixed, exposed, and shared across multiple applications in different domains [5]. But integration of datasets still represents a major challenge. Some researchers are proposing approaches to deal with it, focusing on instance integration, schema integration or both.

Scharfe, Liu and Zhou, [17] proposed RDF-AI, a framework and a tool composed of five modules for pre-processing, matching, fusing, interlinking and post-processing datasets. The same authors [18] also proposed an experimental fusion algorithm, which takes into account both the similarity of literal contents and the graph structure of the dataset. Nikolov et al. [19] argued that automatic schema-matching techniques have to be utilized before proceeding with data-level alignment, given that datasets are often structured using different ontologies. KnoFuss, a data integration architecture that implements ontology schema matching was also proposed [20], supporting flexible selection and tuning.

The approaches to integrate data are supported by ontologies and vocabularies. In the Emergency Scenario, some vocabularies [21], domain ontologies [22],[23] and core ontologies have been developed [24]. Core ontologies are basic ontologies containing general concepts associated to a particular subject, and they can be further specialized for more specific domains.

B. Linked Open Data

The appeal for the government to open and expose data to the public as Linked Data became known as Linked Open Data (LOD). With the growth of e-government programs, the available data to citizens is growing in volume every day, but to make it a useful source of information, to be referenced and integrated more easily by different applications, it should to be published according to the best practices of Linked Data.

Efforts aimed to interlink government data are growing in some countries around the world. Interesting examples are given by the British Government, the United States and Spain. In 2009, the British Government began to adopt Linked Data as the official standard for publication of public domain data [25]; it is expected that data on education, justice, finance, among others, are progressively made available and linked following this standard. During the elections of May 2010, British authorities were encouraged to publish the results in the form of Linked Data [26].

Initiatives such as the Data-Gov Wiki [3] (Rensselaer Polytechnic Institute) and GeoLinkedData [4] (University of Madrid) are also efforts to extend the use of Linked Data, transforming public government data, such as National Statistics Institute (INE)[5] and National Geographic Institute of Spain (IGN-E)[6], available in several formats, to Linked Data standards.

C. Linked Data Perspectives

The current status of the Linked Open Data cloud includes 203 datasets, approximately 27 billion triples and 400 millions of RDF outgoing links. Outgoing links refer to the links that are set from data sources within a domain to other data sources [3]. Another recent fact is the approval of the European project LOD Around The Clock (LATC) Support Action [7] to support institutions and people in publishing and consumption of Linked Open Data.

Due to the growth of the Linked Data initiative, in September 2010, the European Union started the LOD2 project [27] to handle some challenges of the LOD paradigm associated to intelligent information management: the exploitation of the web as a platform for data and information integration in addition to document search. Some of their main concerns are related to: coherence and quality of data published on the web, establish trust on the Linked Data Web, methodologies for exposing, high-quality multi-domain ontologies, automatically interlinking and fusing data, standards and methods for reliably tracking provenance, ensuring privacy and data security as well as for assessing the quality of information.

D. Collaboration with Linked Data

An aspect about Linked Data that is of special interest in the context of this work is the interface for collaboration. Davies et al. [30] report a controlled experiment in which novices attempted to use a prototype Linked Data interface. They suggest several specific design approaches for Linked Data authoring environments. Luczak-Rosch and Heese [29] developed an application, called Loomp that allows Linked Data Authoring by non-experts, enabling them to produce and publish semantically annotated content as easy as formatting text in word processors. Passant and Laublet [28] introduced MOAT, a lightweight Semantic Web framework that provides a collaborative way to let Web 2.0 content producers to give meanings to their tags in a machine readable way. Some features and recommendations of these works are used in the interface design proposed in this paper, which implements collaboration software for the Reliable and Social Network Clients in the emergency response scenario, as detailed in section 4.

Although several studies have been made to address issues associated with linked data, there is still lack of work on how to support collaboration in this scenario: how to facilitate the publication and linking of user´s contributions.

[3] http://data-gov.tw.rpi.edu/wiki

[4] http://geo.linkeddata.es

[5] http://www.ine.es

[6] http://www.ign.es

[7] http://latc-project.eu

With all these features and perspectives in mind, we propose an approach to use LOD in the process of combining previous knowledge with current contextual knowledge in a dynamic way, supporting collaboration during emergency response. This proposition is detailed in the next section.

IV. Capturing, Integrating and Displaying Current Contextual Knowledge as Linked Data

Collaborative Knowledge Management Systems in Emergency Response face many challenges, especially those related to the information infrastructure, which must support information dynamics, trustee and integration. The Linked Open Data paradigm can address some of these challenges in order to make available current contextual information, originated from different sources, such as citizens, emergency teams and journalists, combined with previous knowledge.

To do so, we propose an architecture, illustrated on Figure 2, comprising mechanisms to deliver relevant and reliable information to support decision making, avoiding, as much as possible, information starvation or overload during the emergency response phase. The main components of each layer and their functionality are detailed in the following sections, organized according to the Linked Data cycle (expose, publish and consume): a collaborative interface to capture the current contextual data, a process to publish and integrate them to the other assets, and special display features to allow for linked data exploration. Besides, all layers are support by a semantic layer witch provide an environment to storage the ontologies and vocabularies used on the Linked Data cycle.

A. Expose Data by a Collaborative Interface

The current contextual data is captured through an interface designed for collaboration which is prepared to receive information independent of its structure. This interface can be used by the emergency team and other people like citizens and journalists interacting through their own mobile devices. The emergency team can feed the system with contextual data combined with previous personal knowledge through the Reliable Network Client interface, specially designed to receive these information with high level of trustee (a). Citizens and journalists can collaborate with information about the scenario using the Social Network Client interface (b) that is more flexible to allow an easy input of facts and special situations, as current contextual data, such as the one usually posted on social networks, like Tweeter.

B. Publishing Current Contextual Data

The current contextual information captured through the collaborative interface is stored in the Data Layer. The structure of this new information might have been planned in the schema design of the knowledge base or not. If it has been expected, the new information will be *triplified* as an individual in an existing RDF schema. If not, the new information will be *triplified*, with its own structure, and interlinked with other triples using the RDF URI reference.

After that, the data is processed by the "Raw to Linked Data Processing Layer" where filtering, conversion, cleaning, provenance and many other tasks might be executed (c). After being converted to RDF, they are recorded in a triple store, where previous knowledge is already stored (d). Both previous and current contextual knowledge can then be interlinked, using RDF URI reference, no matter if the structures differ. Besides that, the new interlinked triples can be out-linked to others triple stores on LOD Cloud. All these steps are supported by ontologies and vocabularies, as described in section 3. Domain ontologies for the emergency area can be reused and emergency core ontologies can be used as a reference model to support integrations.

The Raw to Linked Data Processing Layer has some features that are of special importance to emergency scenarios. Some data checking and validation can be done on this layer, using: provenance metadata. The georeference, timestamp and device´s MAC address of the current contextual data are the input for such validation, that identifies the citizen collaborator and classifies his data quality and trustee. These derived data can be used to dynamically rank the reputation of the collaborator over time. All these information can be linked to the previous knowledge to support manager´s decisions in a Linked Data environment, using mash-up map applications. These approaches can reduce the overload of information.

Another important role of geolocation [31] is that this type of information can act as a validator about the provenance information. For example, if a citizen posts a note about anything on a particular site, his geolocation (that cannot be changed by him), is to be sent along attached to the post, which can confirm if this rapporteur is actually in the location that he judges to be. In this case the architecture must also consider the accuracy of the sensor [32] that was used by the mobile device of the rapporteur to avoid him from an erroneous evaluation.

Another approach to use as a validation method is to check the matching reports originated from the same local at the same time. If a user passes on a particular road, certain time of day, reporting a traffic jam, probably another citizen should post same claim when crossing this same road. A high concentration of the same type of information can confirm the validity of this information.

The proposed architecture components are comprise of six layers. Four of them are already present in a typical information system: data, integration, application and user layer, and two others were specially created to support the recommendations of Linked Data: Raw to Linked Data Processing Layer and Semantic Layer.

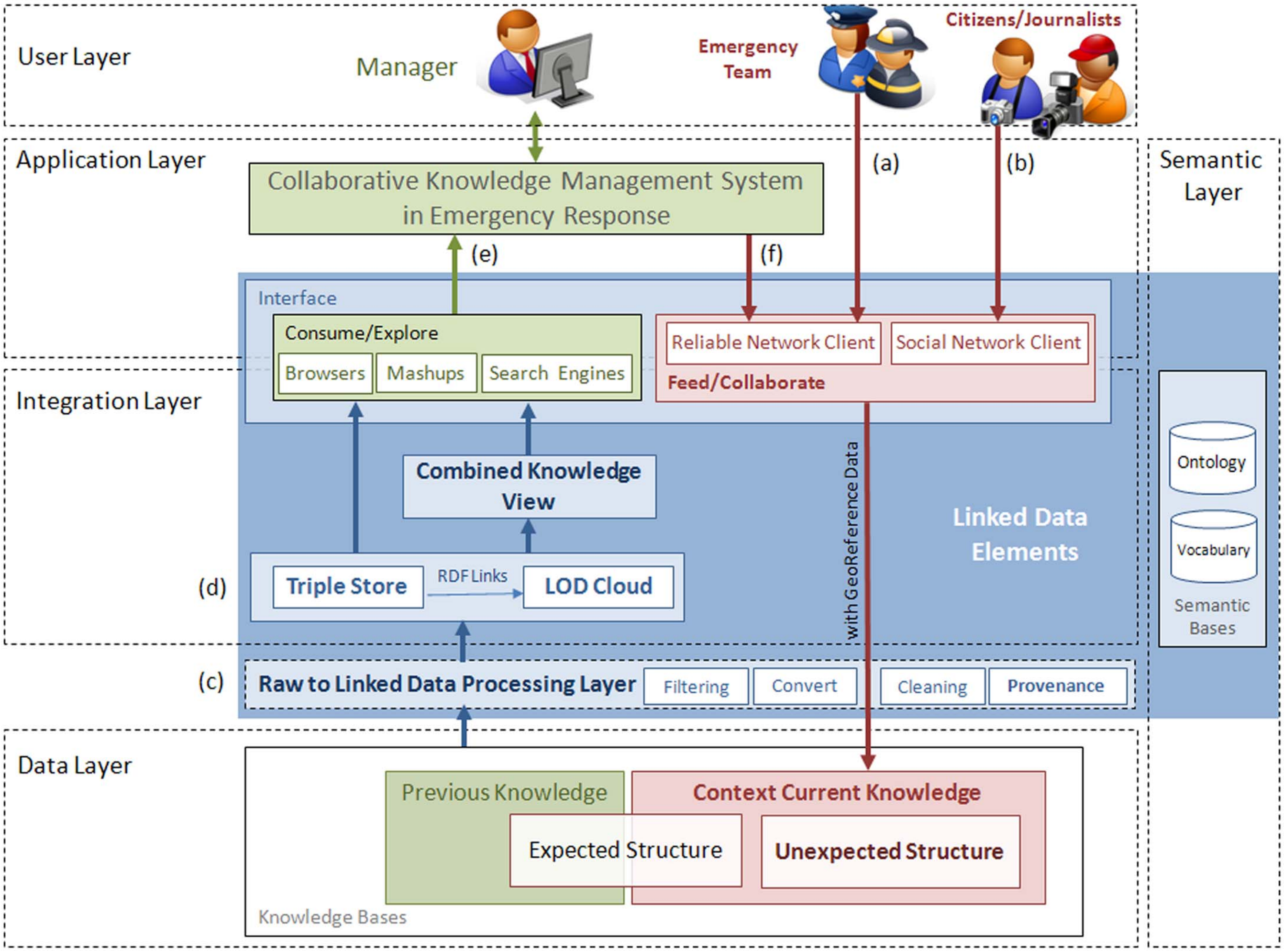

Figure 2. Linked Data for Collaborative Knowledge Management Architecture

C. *Consuming and Exploring Combined Knowledge as Linked Data*

Linked data can be consumed and explored by the management system using appropriate interface applications, directly or through a combined knowledge view (e). By analyzing the data, the managers can feed the system with new information (f), which will be linked to the data already stored.

D. *Semantic Support*

The implementation of the Linked Data Cycle´s steps are support by a set of ontologies and vocabularies of the Emergency Domain, which can be re-used or developed, and are available on a layer that interacts with all others layers. These terminology resources are used to semantically enrich the triplification, interlink and consume process, caring about the meaning of the information that flows thought the environment.

V. Example Case

The example case of an emergency situation takes place on a flood and landslide scenario caused by a long period of heavy rain. Facing this chaotic situation, different teams work in emergency management and rescue operation, dealing with safety, health, firefight, media, army and non-governmental organizations providing different kinds of support. Acting directly and officially in the field is the "Emergency Team", agents of the organizations cited before, each one playing a specific role. All sorts of information gathered by these teams should be available to all others involved. The media, for example, trying to get information about the number of victims, (coming from civil defense and rescue teams), roads blocked (originated from roads department), weather forecast, and many other types of information, provided by these Emergency Teams.

Citizens and "Emergency Teams" compose the field agents, who transmit their perceptions in real time directly through a communication channel in order to feed the Team Manager´s "Knowledge Base". They also consume information, logically organized and certified, from all other teams. The "Team Manager" is composed by highly experienced professionals, commanders and public administrators, working in emergency management offices. They direct the Emergency Teams and support them with useful information in order to reduce the response emergence time, making their work more effective.

These three groups compose the "User Layer". At the level of the "Application Layer", we have the system interfaces for data feeding via safe and easy front-ends. This layer also interface with social networks as a channel for information input from ordinary citizens.

At the "Integration Layer", field collected information is treated according to its provenance. In the field, time available for non emergency related tasks is very scarce. Thus they need very direct and user-friendly interfaces to send and receive information, so to ensure that teams spend as little time as possible in this task. In our scheme this interface is named "Reliable Network Client". Common citizens feed the system through social networks, 'illustrated as "Social Network Client", uploading text and multimedia information. This is a channel with low complexity and very familiar to the community.

The main difference between the official and the "non-official" interfaces is the information reliability. Information uploaded from Emergency Team does not need to pass by the filtering and testing process. This is not always the case with information coming from social networks. All this information is classified as "Context Current Knowledge", because it´s related to information collected on the fly, nearly in real time. Joining the current with the previous contextual information, from government agencies, we structure the "Data Layer". We should remember that information provided by the collaborative environment comes embedded with geotagging information. Today, social networks already offer methods of providing the geographic location of users, by capturing it directly and transparently from GPS receivers embedded devices. As shown by Hickson [32] even mobile devices that do not have a GPS receiver are capable of capturing their location using routing and antennas triangulation methods.

In the next step, data goes back from the "Data Layer" to the "Integration Layer" passing through standardization, cleansing, conversion and testing processes, rewarding providers of reliable information and penalizing providers of false information. Unreliable data do not go to the next step because they have been discarded in the filtering step (c). After this filtering, the standard RDF *triplifying* process occurs, by making data available through a Linked Data unified standard. In the next step, the *triplified* data pass through the "Application Layer". At this point, all available collected data is standardized and able to be classified by precedence and theme, presented in simple mashup front-end.

Finally, the "User Layer", now represented by the Manager, is ready to consume data that will support the decision-making process. The decisions and any other knowledge and information acquired directly by managers may also be inserted through the same interface as the "Emergency Team" in order to enrich the "Knowledge Base" for next decisions and missions.

VI. Conclusions and Next Steps

In this article we described an architecture based on the knowledge framework proposed by Diniz et al. [2, 34] that makes use of the Linked Data approach for data integration. We described a scheme built to deal with emergency response scenarios, particularly the knowledge provided to decision-making and operational teams. We showed how a collaborative supply of information can be integrated into a comprehensive scheme aimed to support the decision-making process.

Although the solution has been applied to emergency response scenarios, it can be customized to other scenarios. Actually, the scheme can be applied to any scenario that needs a collaborative interface and an integration layer to support dynamic information with unexpected structure. At the current stage we are applying and gathering feedback from emergency scenarios, but in the future we will investigate the design of a domain independent architecture, that can handle other issues of linked data, such as dynamic datasets [33]. In this context, an issue that has not yet been properly addressed is the linking on the schema level or on the instance level, taking into account the high probability of changes at the instance layer. Also, for the semantic interoperability, we are working on a core ontology for emergencies and on a specialization process to extend this ontology to particular emergency types.

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