Ontologies for Disaster Management Response

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Abstract

Increasing numbers of natural disasters and man-made disasters, such as earthquakes, tsunamis, floods, air crashes, etc., have posed a challenge to the public and demonstrated the importance of disaster management. The success of disaster management, amongst all, largely depends on finding and successfully integrating related information to make decisions during the response phase. This information ranges from existing data to operational data. Most of this information is geographically related and therefore when discussing integration of information for disaster management response, we often refer to the integration of geo-information. Current efforts to integrate geo-information have been restricted to keyword-based-matching Spatial Information Infrastructure (SII, may also known as Spatial Data Infrastructure). However, the semantic interoperability challenge is still underestimated. One possible way to deal with the problem is the use of ontology to reveal the implicit and hidden knowledge. This paper presents an approach for ontology development and ontology architecture, which can be used for emergency response.

1. Introduction

The five phases of disaster management, namely mitigation, prevention, preparedness, response and recovery (GRIP Animation 2006), have urged a good collaboration among various users such as the fire brigade, the police, the medical service, the municipality, Red Cross, urban planners, and other organisations or even amongst different countries. They all have to

be able to work together and understand each other. These requirements are especially valid for the emergency response phase (Zlatanova et al. 2007). During this phase, we need to ensure interoperability of emergency services, and to provide appropriate information at the right place and in the right moment (van Borkulo et al. 2006).

The information ranges from existing data to operational data, of which most is geographically related. However, successfully discovering and combining geo-information in a time-critical manner for decision making is not an easy job, because the required geo-information is distributed among different organisations. Exchanging geo-information (and knowledge) by interacting on a personal/phone/fax basis is slow and might even be prone to errors. We need to allow machine automation so that we can integrate geo-information in a time-critical manner to help decision making during disaster management.

Current efforts to integrate geographic information data have been restricted to keyword-based-matching Spatial Information Infrastructure (SII, others use Spatial Data Infrastructure) (Groot and McLaughin 2000, SDI cookbook 2004). SIIs are being set up within regions, countries or even across national borders (Bernard 2002, Riecken et al. 2003), to facilitate the access to geographic information. SII supports the discovery and retrieval of distributed geospatial data sources and geographic information services by providing catalogue services and syntactic interoperability standards (Lutz and Klien 2006).

The integration of geo-information has been greatly advanced by SII. However, the semantic interoperability problem, which presents challenges for the integration of geo-information in the open and distributed environments, still exists. One possible way to deal with the problem is the use of ontology to reveal the implicit and hidden knowledge (Wache et al. 2001). Ontology is an explicit formal specification of a shared conceptualisation (Gruber 1995). Much research has been carried out on the use of ontologies for information discovery and retrieval Klien et al. 2004, Lutz and Klien 2006, Wache et al. 2001). In this paper, we suggest an approach of ontology development and ontology system architecture of geo-information to support disaster management.

The rest of the paper is divided into the following sections: Section 2 introduces the current management of a disaster in the Netherlands and explains briefly the complexity of the emergency response. By comparing different ontology perceptions and architectures in Section 3, we illustrate the potential use of ontologies to facilitate the management work for a disaster. Section 4 introduces new ontology architecture to facilitate emergency response. The last two sections discuss implementation aspects and future work.

2. Example: Discovery and Integration of Geo-Information

Let's consider the following scenario. In Fig. 1, an accident is reported to a fire station. An explosion happened at a chemical plant and toxic gas is leaking from destroyed pipes. In order to evacuate the inhabitants of the affected districts, the gas plume has to be created to plan evacuation and guide rescue teams. The forecast of the gas plume's dispersion is an essential part of this task.

For the management of such a disaster, information from different sources needs to be obtained and combined immediately. Fig. 2 gives an indication of such information: the plant's ID, the location of the plant (the exact location of the emission), real-time measured data from the field (type of released gasses and concentration), the nearest airport information (the airport code), the measurement of the wind from the weather station (the wind speed and wind direction near the place of the accident). For evacuation, we will also need other specific data (like the population of the potential area, road network).

Fig. 1 Fire at a chemical plant

One possible way to obtain the exact location of the plant is by querying databases (for example, a cadastral database or a risk map) with the name of the plant. The output, a pair of coordinates, is used to find the nearest airport and weather station from which current wind speed and direction can be obtained. The weather information and the emission rate of the gas leak are used to calculate the gas plume. A map is created, showing the plume on top of the road network and land use data of the region (Fig. 2).
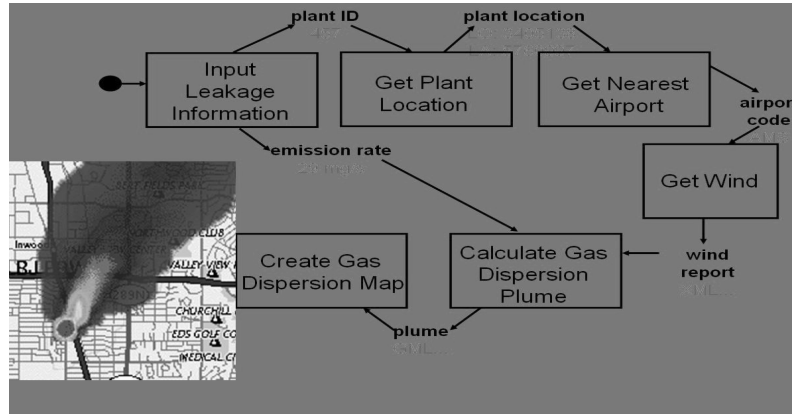
Fig. 2 Integration from various data sources

Referring to Fig. 1, if we want to find the information about the wind ('Get Wind' in Fig. 2), we will type and search the keyword 'wind' or 'prevailing wind direction' in the Disaster Management Service. We will get a large amount of results related to the keyword, among which we need to choose one (or several that are combined) that answers our question (the direction, the speed and etc.). We have to be careful about the content (semantic) of this information. Fig. 3 illustrates challenges in using the word 'prevailing direction' for wind:
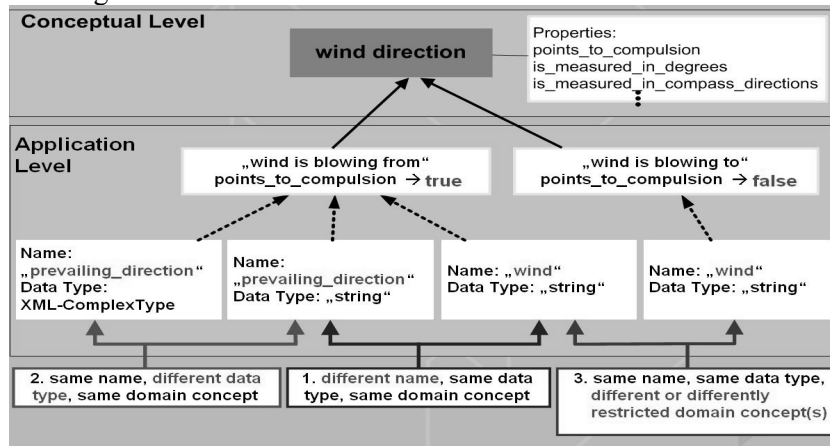

Fig. 3 Semantic heterogeneity

- 'prevailing direction' in different geo-services (or datasets) may mean the same thing, but the storage approach differs (e.g., one with XML-Complex Type and the other with String Type). This is actually the same name with the same domain concept but with different data-type.

- 'prevailing_direction' may also refer to different things — one refers to the direction which the wind is blowing from and the other refers to the one which the wind is blowing to. (Same name with same data-type but with different domain concept.)
- 'prevailing_direction' does not exist; the direction is included in the word 'wind'.

During the whole process of disaster management, we have been continuously facing such challenges. For instance, with different levels for disaster emergency, different hierarchical levels of organisation are required and therefore different combinations of datasets are needed. The content of each information source must be fully understood by and described for machines so that they can be discovered and combined automatically. It is impossible for humans to examine the information and understand content, and then discover and combine this in a short time under time pressure in disaster management.

If machines could be employed to help humans discover and combine related information, it will be possible to efficiently deal with disasters. We believe that with the help of ontologies, the content (semantic) of the information can be made explicit and thus machine process-able.

3. Disaster Management in the Netherlands

This paper is based on the research work undertaken by GDI4DM (Geospatial Data Infrastructure for Disaster Management). In the rest of this section, an overview is given of some disaster management issues in the Netherlands. The Netherlands is used as an example for better understanding the complexity of disaster management and also summarise some insights from the work being done (see also Diehl et al. 2007, van Borculo et al. 2005, Diehl and van der Heide 2005).

3.1 Organisational structure

The fire brigade, the police, the medical service and the municipality are the main actors in emergency response. Each of these organisations maintains their own data and carries out their own daily work. They have-well defined protocols how to cooperate with each other in case of a disaster. Other institutions and organisations such as Red Cross, Military forces, Ministry of Internal Affairs, etc., and more specialized organisations may also be involved in managing the disaster when needed but usually they follow direct orders from operational centres..

To specify the cooperation, and communication between the first responders, six GRIP (Common Regional Incident management Procedures) levels have been defined (GRIP 2006). On GRIP 0, the fire brigade, the police, the medical service and the municipality are doing their daily work. There is simple cooperation among them. However, with increasing the importance of incident, the need of coordination increases. For example, during GRIP 1, the mayor of the Municipality will be informed; within GRIP 2 a Regional Operational Team is formed. Depending on the magnitude and type of disaster, different organizations may become involved. For instance, emergency officers at provincial or national level are informed if the disaster affects a large section of the community; the Ministry of Internal Affairs will take the administrative lead if the disaster extends beyond the provincial; the Office of the Queen will be informed if the disaster crosses the national border (e.g. a nuclear leak). So with different levels of GRIP, different types of cooperation are established and different policies are used to form the structure to deal with disasters.

Besides the GRIP levels, each of the first responders have well-defined task described in 25-29 (depending on the province) processes. Which processes are going to be initiated depends on the type of disaster. There are processes which are related to each other (if one starts it triggers another one) and also processes, which are always active (e.g. press conferences). Examples of such processes are: performing measurements needed to compute a gas plume (completed by the fire brigade), traffic control (performed by the police), contacts with the press (a task of the municipality), etc. An initial study on the processes has revealed the following important characteristics:

- Processes exist independent of disaster types. Processes emphasise that 'core functions and the important characteristics of the disaster management are described in consistency with the other activities'.
- Processes are strictly defined and therefore very convenient to be formally described and used by system developers.
- Processes could be organised in sector clusters, i.e. the fire brigade, the police, the medical service and the municipality, which may give further indication on the information needed by a particular cluster (operating daily as one independent organisation).
  A particular incident is therefore managed by combining processes with respect to the type of disaster and the GRIP levels. Since GRIP and the processes intend to outline the way working, they specify the roles of the actors and can be used as an indication for the kind of information needed for the different actors.

3.2 Data needed for emergency response

During disaster management, large amounts of data are created, maintained and integrated to deal with the disaster. These data ranges from existing data, like topographical data, to operational data, like the measurements from the field.

- Existing data are those that are created and maintained by organisations before the disaster happens. For instance, TOP10 (which is 1:10,000 topographic maps), GBKN (which is large scale basic map of Netherland 1:1,000), utility data, hydrological data, transportation data, topographic maps along rivers and roads (maintained by RWS, which is the Ministry of Transport, Public Works and Water Management), risk maps (maintained by municipalities), information about dangerous goods, statistics about population, etc. These data could help answer questions like 'which roads are available', 'what are the dangerous goods stored', 'people in the area in this moment' and so on.
- Operational data are those received from the field during disaster management. They are not available prior to a disaster. Dynamic data could be a report (description) of an incident, camera images, video clips, measurements, etc. Maintenance of operational data is usually carried out in the Commando centre but could be also by various organisations, for example, the fire brigade, the police, the medical service, the municipality, and some other specialised organisations.

Commonly the data (existing and operational) are heterogeneous in creation, maintenance and presentation:

- Data are used for multiple purposes. Users create their unique data to meet their own needs. Even when they are referring to the same problem, they might have their own interpretations. For instance, people forecasting floods might only be concerned with the height of the water, while people measuring the pollution might only have interests in the chemicals in the water.
- Data are stored in various formats. Various technologies are used to collect and create the data, and different storage systems are employed to update and maintain the data. For example, the data could be files in a relational database, an attribute in an object model, a picture or a video clip and so on.
- Users are used to their own representations. The presentations are sometimes combined in data models. For instance, the fire brigade will expect a red colour to mean danger while other people refer to red colour as any other colour, e.g., only a distinguish between green pipelines and

red pipelines (pipelines marked in green represent water pipelines and those marked in red represent fibre-lines).

3.3 Problems with disaster management — interoperability

In the management of a disaster, different people from various organisations are involved, and large amounts of heterogeneous data are required to be created, collected and integrated. So the success of disaster management could be interpreted as 'getting the right resources to the right place at the right time; to provide the right information to the right people to make the right decisions at the right level at the right time.' As we can see from previous sections, these data sources are created, and maintained individually. Interoperability problems will arise when we try to integrate these individual data sources.

With the word 'interoperability', we mean the ability of systems to provide services to and accept services from other systems and make them to operate effectively. Usually three types of interoperability are identified namely system interoperability, syntax and structure interoperability and semantic interoperability (Sheth, 1999). System interoperability refers to the ability to deal with hardware, operating systems, and communications heterogeneity, such as the instruction sets, communication protocols, different file systems, naming, file types, operation and so on. Syntax and structure (schematic) interoperability is relevant to data representation, formatting, data models, different DBMS (Data Base Management System). Semantic interoperability has more to do with the meaning of the data. Semantics refers to the aspects of meanings that are expressed in a language, code, message or any other form of representation. Sheth argues that 'semantic interoperability requires that the information system understands the semantics of the users' information request and those of information sources, and uses mediation or information brokering to satisfy the information request as well as it can' (Sheth 1999).

During disaster management, we also have problems with interoperability at system, syntax and semantic level. Sheth (1999) made a summary of the previous efforts and achievements with respect to the system and syntax interoperability. OGC (Open Geospatial Consortium) and ISO (International Standards Organisations) are current efforts to provide standards to solve syntax heterogeneity. SIIs, which are being built by different regions, countries and even across national borders (Bernard 2002, Groot and McLaughin 2000, Riecken et al. 2003), can be seen a typical example of attempts toward resolving syntax heterogeneity. SIIs support the discovery and retrieval of distributed geospatial data sources and geographic infor-

mation. SIIs provide syntax interoperability only to certain extends (Lutz 2006).

Sheth (1999) concluded that a standard terminology is not prevalent within the GIScience domain and is dependent on the context of use and the user. The use of different terms and approaches causes confusion in the specification of universally accepted entities, concepts, rules, relations, and semantics as the basis of a consensual ontology. In disaster management, we also lack such a terminology. Apart from that, the semantics of the creation, maintenance and representation are not clear to the people outside the organisation. It urges that the semantics of these data understood by all the users involved in disaster management, so that they could exchange their information under high time pressure. Neches, who is one of the earliest to talk about the use of ontologies to better allow information interoperability, has pointed out we could use ontologies to represent domains and make it sharable (Neches et al. 1991).

4. Ontologies

The word, ontology, originates from philosophy, and stands for 'the study of being existence' (Ontology 2006). Computer science borrows this word from philosophy, which 'defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary' (Neches et al. 1991).

There are two key points of ontology — (1) ontology is a kind of conceptualisation and (2) ontologies should be shared. According to Studer et al. (1998), conceptualisation is an abstract model of the real world phenomenon, by which the real world is identified as a set of concepts. Shared means the notions are accepted by a certain group as consensual knowledge (Studer et al. 1998, Uschold and Gruninger 1996). There are two important aspects in defining ontologies:

- Explicit: Explicit stands for the meanings of the types of concepts that are used in the conceptualisation and the constraints of their usage are defined (Studer et al. 1998, Uschold and Gruninger 1996).
- Formal: Formal refers to the fact that the ontology is defined in an artificial and well-defined language so that it is machine-readable (Uschold and Gruninger 1996).

Ontology could be defined explicit or non-explicit (implicit), with different degrees of being formal and being shared. We adopt the definition from Audi, defining ontology as 'the study of explaining reality by breaking it down into concepts, relations and rules' and share it with others

(Audi 1995). In order to solve the semantic interoperability and allow machine-automation of data integration, it is desired that the semantics of the data are defined explicitly and represented in a machine process-able way. Explicit and formal ontolgies can help us define the semantics of the data, make them sharable by different users and allow machine process-able. So when we talk about ontologies, we are referring to explicit, formal and shared ontologies.

4.1 Ontologies approaches

General speaking, there are two approaches to build ontologies, namely top-down approach and bottom-up approach. They have their own pros and cons. We will examine the two approaches and compare them in order to find our approach of building the ontologies for disaster management.

- Top-down ontologies development indicates ontology is constructed by first examining the domain of interest in general at a very abstract level and then constructing it based on top levels concepts. This is accomplished by building an abstract model of the domain of interest first (or by starting from a top level ontology) and then extending the model further to map more specific concepts from low levels. The result ontology from top-down approach is a complete model over the domain of interest. It contains all the relations between concepts within the domain of interest. When building such ontology, there are some challenging issues we need to remember. First it remains a problem for domain experts to reach an agreement over a domain, because we cannot force people to look at the problem in one single way— they might have different views over one problem. Second, it is difficult to extend the top level concepts with lower level data sources at the same time maintaining the model integrity.

- Bottom-up approach begins by looking at existing data sources from low levels (data schema, data structure labels and etc.), developing ontologies for specific individuals, and then combining them as a whole. The process starts from the low level data sources and moves towards a higher level of abstraction. The resulting ontologies from a bottom-up approach focus on the specifications of the data sources. It captures the relationship between the data sources well, like the inconsistencies, overlapping, disjoint-ness, equivalence and so on. It works well for data exchange. When building such an ontology, too many concerns are being paid to the details of the data, such as the document structure of the data sources, the implementation details of the data and so on.

In order to take the advantages of both approaches and minimise their disadvantages, we decide to use a 'hybrid approach' to build the ontologies for disaster management. We will start by examining the underlying data and at the same time will refer to more abstract concepts. So we approach from both sides: by abstracting the low level data to higher level concepts and generalising high level concepts to lower levels. The resulting ontologies will be not only general enough to exchange domain information but will also have enough information for mapping among different data.

4.2 Ontologies architecture

Visser and Stuckenshmidt (2002) and Wache et al. (2001) identified and explained three different architectures for using ontologies. A division has been made into a global (single) ontology, peer-to-peer (multiple) ontologies and hybrid ontologies.

- In a global ontology architecture, one global ontology is used to provide a shared vocabulary for specifying the semantics. All information resources have to use this shared vocabulary or a subset of it. We can have such an ontology, only when all the different parties involved in the domain of interest have a common agreement over the domain and no conflicts within the parties in a domain.
- Peer-to-peer Ontologies are characterised by demanding a distinct ontology for each service. All transformation rules from one ontology to another need to be defined manually. As a result, the relationships between two services can be identified by considering the transformation rules between their related ontologies. Peer-to-peer ontologies make sure this is a mapping between any pair of parties, but the drawback is it results in large amount of mappings.
- Hybrid Ontologies are developed to overcome the drawbacks of the other two approaches. Each service is referenced to a local ontology. In order to make them comparable, a shared vocabulary is used to build the local ontologies. The shared vocabulary contains basic terms (primitives) of a domain. The advantage of hybrid ontology is that new sources can easily be added without the need of modification.

5. Ontologies for Disaster Management

We propose to use the hybrid ontology architecture for disaster management (Fig. 4). Due to the complexity of disaster management, we believe the use of only one global ontology is unable to model the domain well.

Peer-to-peer ontologies will definitely describe the domain, but will result in relatively man ontologies since large amounts of datasets are needed to be combined and many organisations will participate. Therefore the ontologies for disaster management have to consist of data ontologies and organisational ontologies.
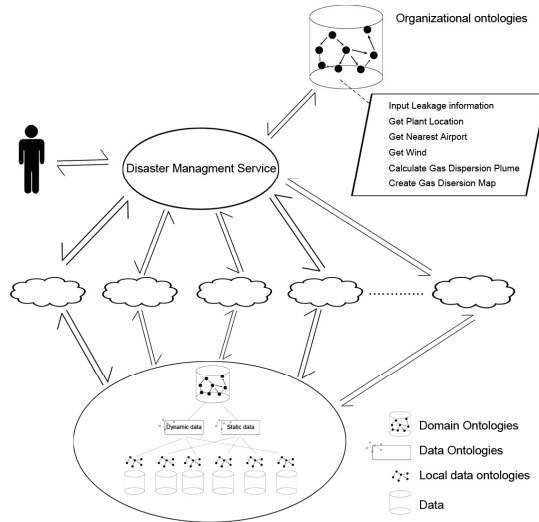

Fig. 4 Hybrid ontology architecture

Data ontologies are those that describe the datasets (e.g., topological datasets, utility datasets, cadastre datasets and so on) that are needed for disaster management. They are independent from the domain of disaster management, because all these datasets could be used for other domains, like, cadastral domain, environmental domain and so on. With data ontologies, one data set can be mapped with another (e.g., from cadastre data to utility data) or several datasets can be combined (e.g., the combination of cadastre data, utility data and topological data). In disaster management, we have plenty of data not only from the existing databases (e.g., the plant information in Fig. 3) but also from the field (e.g., the measurement of the wind in Fig. 3) that need to be processed and combined (e.g., the gasmal in Fig. 3). For each of these data, we will build a local data ontology describing the content of the data. The local data ontologies are defined together with corresponding vocabularies. In order to have grounding for all the data that are needed for disaster management, a controlled vocabulary will be made and a (possible) relation will be put on the controlled vocabulary. We give the controlled vocabulary plus the relation on it a name: upper

level data ontologies. We will also build data mapping ontologies between each of the local data ontologies to the upper level data ontology. With the data mapping ontologies, each of the local data ontologies will be mapped into the upper data ontology, so that there is grounding for all the different datasets.

Organisational ontologies are those that describe the structure of organisation—how the organisation is structured, what are the responsibilities of each user within this organisation, how the users communicate with each other, how the work is carried out within the organisation, which user needs what data and so on. Organisational ontologies are dependent on the domain. For instance, the medical service will get involved in disaster management. Besides that, the medical service has its own daily task, such as sending an ambulance to do first aid rescue. As another example, let's consider the fire brigade. Apart from taking part in disaster management, the fire brigade will also do their daily work, e.g., giving advice on the storage of dangerous goods. During disaster management, people from these two organisations together with others have to cooperate with each other and work as a whole organisation (organisation of disaster management). We will examine through the process (there 25 to 29 processes in the Netherlands) and GRIP (GRIP 0 to GRIP 5) levels to work out the relations among different people in disaster management. In order to make it easier for people with different backgrounds to cooperate for disaster management, a controlled vocabulary will be worked out to help ease semantic interoperability. For instance, a vehicle might mean an ambulance to the medical service but might indicate a wagon to the fire brigade.

Generally speaking, data ontologies serve as the glue integrating different datasets. It helps disaster management to discover and combine datasets. Organisation ontologies consist of the domain knowledge of disaster management — who participates in disaster management (e.g., the fire brigade, the police, the medical service, the municipality, the Ministry, the Office of the Queen and etc.), what their task and roles are (e.g., a user in case of GRIP level 1 with process 9 needs to do measurement), what information they need (e.g., a user in case of GRIP level 1 and process 9 needs measurements of the gas from the field), how they communicate with each other (e.g., user A should send the measurement to user B after the process 9), how to cooperate to achieve disaster management (e.g., in case of a disaster at GRIP level 1, process 3 and process 4 needs to be activated and so on), and so on. The ontologies for disaster management consist of the two types of ontologies. It hides the integration of data and parts of knowledge of disaster management from the user. Any application that uses the ontologies for disaster management will maximally allow machine automation for disaster management.

As shown by the example in Fig. 2, a fire at a chemical plant has been reported to the emergency centre. The responder decides the scale of the incident according to the report and input the request in to the system. The system will make use of organisational ontologies in the database and a series of actions will be activated. The corresponding services will be invoked. With the help of data ontologies, Heterogeneous data sources will be integrated and serve as a whole database to the service. Fig. 4 illustrates the idea of the system.

6. Outlook

We have already perceived ontology architecture. Keeping this in mind, the next step will be looking at the real datasets (could be many) and building the local ontologies. We will try to analyse the relationships between the data, like super or sub relationship, equivalent, complement, disjoint and etc. The direct result of this work will be a kind a core model. At the same time, we will investigate different users and their 'language' and try to find a common vocabulary, in such a way that different terms used by different users could be mapped into the common vocabulary, i.e. we will build the domain ontology Using the definition of processes (and thus knowing the user's roles), the needs for data can be identified. Last step will be relating the users' needs and the existing data (that could be static and dynamic). Using this approach we believe we could help in automating the procedures of finding data and integrating them to answer a specific question.

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