The EPISECC Ontology model: spatio-temporal ontology for disaster management

Editor(s): Name Surname, University, Country
Solicited review(s): Name Surname, University, Country
Open review(s): Name Surname, University, Country

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Abstract. The EPISECC project's investigation revealed that 70% of tools used by first responders during disaster management reach physical and syntactical interoperability and only 30% are covering semantic interoperability. To improve information sharing, the EPISECC project developed a concept of Common Information Space (CIS) including three semantic structures: taxonomy, semantic repository and ontology model. As there is no reference ontology for disaster or emergency management, the EPISECC project team developed a spatio-temporal ontology for disaster management, modelling common operational picture for the first responders. A two steps approach is applied: the first step models the application knowledge and the second step links concepts with reference ontologies. The ontology backbone is a subset of the EPISECC Taxonomy representing the application knowledge. GeoSPARQL, W3C Time and DOLCE-Lite ontologies are referenced. Representing dynamic features ask for a new concept with properties varying in both space and time. Thus, the concept of "spatio-temporal part" is introduced in the ontology. The conceptual model is formalised in the Ontology Web Language (OWL) schema and validated by the competency questions based on the EPISECC scenario. Future research should tackle a new paradigm in disaster management: including ad-hoc participants and trustworthiness of their data.

Keywords: disaster management, semantic interoperability, spatio-temporal data, 4D data, ontology

1. Introduction

Disaster management, particularly in case of disasters such as a big flood or an earthquake, should facilitate collaboration of rescue teams from different countries having different perspectives (e.g. medical services, fire brigades, civil protection, humanitarian organisation, etc.). A response to a critical event, is a complex human domain described as "*a complex dynamic system composed of actions taken in a certain spatial, technical, organisational, and legal environment during a disaster, including one or more situations which straightforwardly lead to a disaster, as well as handing over to a recovery phase*" [7]. Access to information and communication among first responders is a key factor for effective emergency operations. Different technologies are used for communication and data sharing, from voice communication devices and mobile radios to smartphones/radio hybrid devices. Mostly, communication and data sharing are realised between team members of the same organisation but not between different organisations, and thus shared situation awareness is difficult to achieve. The current status of information sharing between the first responders is not satisfactory, as reported by the FP7 projects ACRIMAS [1] and CRISYS [4]. The undertaken research within the FP7 EPISECC project revealed that more than 70% of the investigated tools used by first responders reach physical and syntactical interopera-

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bility, but only 30% (12 of 41 investigated tools) are covering semantic interoperability [6]. Also, there is growing volume of various data used in multiagency and multinational emergency operations, including social media data and data coming from ad-hoc participants. To provide a common operational picture to the first responders, new tools based on new technological and organisational paradigms should be investigated and proposed. Such an effort is undertaken by the EU Commission funded FP7 project EPISECC.

To improve information sharing among the first responders, the EPISECC project follows several objectives including the following one: to develop a concept of a Common Information Space (CIS) including appropriate semantic definitions by taxonomies and ontologies. The CIS's architecture encompasses protocol & network interoperability, information interoperability and operational interoperability. The EPISECC project team has designed and prototyped the CIS adaptor that is standardised interface enabling first responder's tool to communicate with other tools via CIS. Moreover, the CIS is not regarded as a static space but as a dynamic one, where additional participants can be added as required. Information sharing is managed by the The Cooperation Group Online Room (CGOR) allowing subgroups of participants to share different type of data. Adding additional participants to such a group can be done ad-hoc.

To facilitate semantic interoperability within the CIS, the EPISECC project elaborates three semantic structures: taxonomy, semantic repository and ontology model.

The EPISECC Taxonomy provides a common classification system for concepts describing disaster response: 399 concepts are defined and described with labels and definitions, and organized in hierarchies and as facets [10]. Semantic interoperability in the emergency management, as seen from the perspective of the European Interoperability Framework for European public services [13], ensures that the precise meaning of exchanged information is understood and preserved throughout exchanges between organisations. As stated in [13], achieving semantic interoperability in the EU context is a new undertaking and a starting point is to create sector-specific sets of data structures and data elements that can be referred to as semantic interoperability assets. In the context of the EPISECC project, the EPISECC Taxonomy represents such an interoperability asset.

To make the EPISECC Taxonomy operable, the EPISECC Semantic Repository is introduced in the CIS serving as storage of the semantic descriptions: the EPISECC Taxonomy, the first responders concepts and the semantic mappings of responders concepts to the EPISECC Taxonomy. The Resource Description Framework (RDF) data model and Simple Knowledge Organisation System extension for thesauri (SKOS – thes) design pattern [19] are selected for the Semantic Repository as state-of-the-art for the semantic interoperability. Implementation is done in the open source Apache Jena database management system. The CIS's service 'Semantic box' performs semantic matching over the concepts stored in the EPISECC Semantic Repository and delivers semantically annotated messages to the first responders [8].

While semantic descriptions have to be entered into the Semantic Repository prior to a disaster, the ontology model enables that semantic descriptions are exchanged together with data. The objective is to merge spatio-temporal data coming from various first responders. The EPISECC Ontology model is application ontology serving disaster response tasks for the EPISECC use case. Sharing both situational and operational data among the first responders is a focus of the EPISECC use case. Thus, the EPISECC Ontology models a common operational picture: spatio-temporal data showing locations of the most urgent resources requested by the first responders.

There is still no reference ontology intended for the disaster or emergency management. The reason could be that the domain is complex and composed of several domains such as: organisations, events, workflows, resources, etc. The FP7 project DRIVER elaborated existing ontologies for disaster and emergency management in [20] and eleven subject areas are identified including critical infrastructures, resource management, decision support, situation awareness, response coordination, command and control, etc. Another overview is given in [16] and it shows that several attempts are made but they are limited either to one disaster type, or to one infrastructure system, or to the method of development etc. The FP7 project DISASTER developed the EMERGEL ontology [5], interpreting a disaster as a kind of events and using SKOS model. The World Wide Web Consortium (W3C) elaborated a framework for emergency information interoperability including several approaches such as building the conceptual mind map, using Wordle for generating the most used terms on the Web, studying the existing systems and research projects, etc [29]. Yet, the report describes only candidate components for the emergency management ontology based on the common use cases.

None of the above mentioned ontologies fit the scope and tasks of the envisaged EPISECC Ontology model and therefore could not be reused. Consequently, the EPISECC project team decided to develop a spatio-temporal ontology for disaster management serving the EPISECC use case.

This paper describes the EPISECC Ontology model. The following section 2 delivers the methodological approach for the development of the model. Section 3 describes model's content and references to upper level and domain ontologies. A description of the model by OWL constructs applicable to be used by software is given in the section 4, followed by implementation and validation in the section 5. The section 6 concludes the paper with future perspectives of the model and follow-up research.

2. Ontology development approach

There are several ontology development methodologies such as Methontology [15], On-To-Knowledge [14], Diligent [28], and NeOn Methodology [25]. Two-steps approach developed by Kun et al. [18] is selected for the development of the EPISECC Ontology model because the approach suits the ontology scope and the application level. The first step (or bottom-to-top) models the application knowledge. Experts define basic concepts and relations among them, and define axioms and rules for data interpretation and reasoning. The second step (or top-to-bottom) links the application concepts with concepts in the reference upper and domain ontologies.

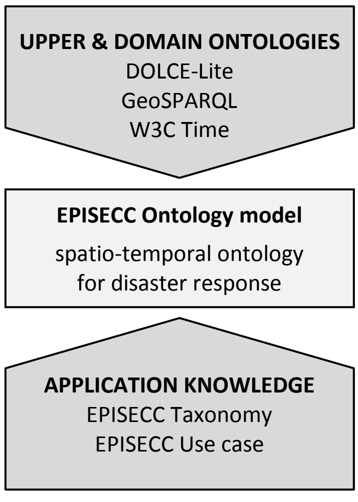

Fig. 1. Two-steps approach for building ontology.

The sources of application knowledge used for the EPISECC Ontology are the EPISECC Taxonomy [7] and description of the EPISECC use case [11]. The selected upper and domain ontologies are: Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE)-Lite (upper ontology) [21], A Geographic Query Language for RDF data (GeoSPARQL) (domain ontology for spatial data) [23], and W3C Time (domain ontology for temporal data) [31] (see Figure 1).

The selected approach consists of the following seven tasks:

– Defining the scope of ontology;
– Listing the key concepts in the selected domain/application;
– Establishing the conceptual model for ontology;
– Reusing the existing ontologies and/or make references to domain and upper ontologies;
– Formalizing ontology and populate it with individuals;
– Validating ontology;
– Revising and refining ontology.

The EPISECC Ontology model is formalised by Resource Description Framework Schema (RDFS) and Ontology Web Language (OWL), the W3C standard languages. The Protégé Desktop tool [24] is selected for ontology schema development because it supports RDFS and OWL languages and includes reasoning algorithms used for the consistency checking of the ontology schema.

Following the selected approach, the EPISECC Ontology model is developed. A brief description of the result is given in the following sections. The detailed description of the model is given in [9].

3. Ontology model

3.1. Ontology scope: the EPISECC use case

The EPISECC project has a focus on the disasters' response period, namely the first 72 hours after the disaster, and that represents a domain of the EPISECC Ontology model.

To define a scope of ontology, one should define its purpose and tasks the ontology should serve. The EPISECC use case narrows down the domain of disaster response to the scenario designed for the CIS's Proof of Concept, elaborated in [11,12]. The scenario describes the earthquake in Italy, having impact in the border regions of Slovenia and Austria. Three use cases are elaborated to reflect major stages in the response to a disaster with international first responders. Information that needs to be exchanged among the responders compiles the common operational picture.

Zlatanova et al. [33] classify the data of the common operational picture into static and dynamic data. Static data exists prior the disaster occurred and it includes maps, critical infrastructure, vulnerable objects, population etc. Dynamic data is further classified into operational and situational data and is collected during the disaster response. Operational data describes the disaster response operations such as locations of rescue teams and other resources that can be commanded. Situational data describes the situation in the affected area such as disaster location, affected people and properties, meteorological data etc. The EPISECC use case focuses on the dynamic data and the static data is omitted from further analysis. All EPISECC use case data is spatio-temporal data or 4D data which means that includes geolocation and reference to time.

To conclude, the scope of the EPISECC Ontology model encompasses the situational and operational data exchanged among the first responders in the EPISECC use case. The EPISECC Ontology models the common operational picture with dynamic spatial information (or spatio-temporal/4D data) showing the situation in the affected area and locations of the resources.

3.2. Main concepts and their relations

The EPISECC Ontology model's backbone is the EPISECC Taxonomy [10]. A subset of the concepts and facets included in the EPISECC Taxonomy is selected and modelled as ontology classes, suiting the needs of modelling common operational picture. Besides the concepts and their hierarchy already included in the taxonomy, the relationships or properties between classes are derived. Directed graph in Figure 2 shows the five main concepts modelled as ontology classes (shown as ovals) and four main properties (shown as links with arrows).

The five main classes are as follows:

- Disaster: Any situation which has or may have a severe impact on people, the environment, or property, including cultural heritage [10].
- Process: A process is a set of actions aiming for a certain result, executed by an organisation during a response to a critical event [10].
- Resource: Assets an organisation has available for the response to a critical event [10].
- Organisation: An organisation is a unit established to meet goals related to disaster management. It is structured along its management, which defines the relationships between responsibilities, tasks and its structure [10].
- Common operational picture: A single identical display of relevant information shared by more than one command [27].

The four main properties are: 'invokes', 'uses', 'executed by' and 'has available'.

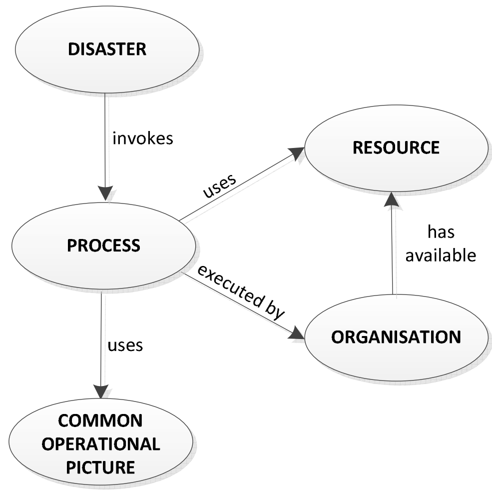

Fig. 2. Directed graph of the main classes and properties [9].

The main classes are further elaborated following the EPISECC Taxonomy classification. Concepts describing the ontology classes are defined and described in the EPISECC Taxonomy [10].

The class 'Disaster' has 18 subclasses on the first level of the classification (e.g. 'Avalanche', 'Earthquake', etc.) and 26 subclasses on the second level of the classification (e.g. 'Flash flood', 'Urban flood', etc.).

The class 'Resource' has 5 subclasses on the first level of the classification (e.g. 'Animal', 'Physical', etc.), 11 subclasses on the second level of the classification (e.g. 'Decontamination', 'Search for people', etc.), 31 subclasses on the third level and additional classes on the fourth and fifth levels of the classification.

The class 'Organisation' has 3 subclasses: 'Governmental', 'Non-governmental' and 'Private'. By facet 'Specialisation', 'Organisation' has 5 subclasses (e.g. 'Civil protection', 'Emergency medical assistance', etc.).

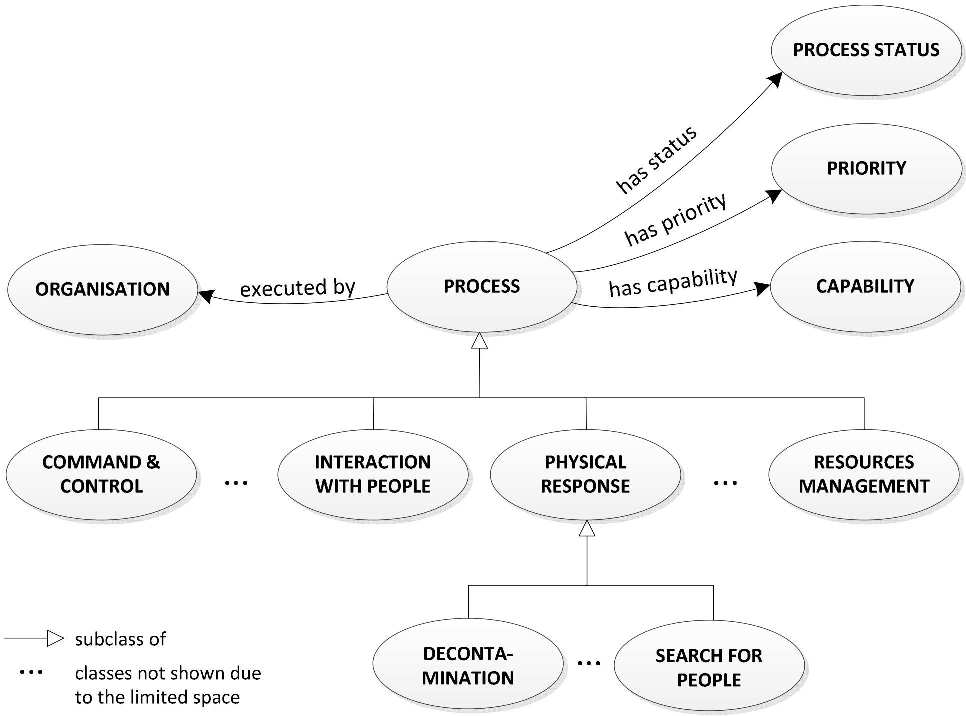

Fig. 3. Directed graph of the class Process [9].

The directed graph in Figure 3 visualises the class ‘Process’ having 5 subclasses on the first level of the classification (e.g. ‘Command & control’, ‘Physical response’, etc.), 22 subclasses on the second level of the classification (e.g. ‘Decontamination’, ‘Search for people’, etc.), and 2 subclasses on the third level of the classification. The classes ‘Process status’, ‘Priority’ and ‘Capability’ are not further classified and they could contain individuals (or data items) such as ‘planned’ or ‘high priority’ or ‘partially capable’, respectively.

The class ‘Common operational picture’ is elaborated in the Figure 4. ‘Common operational picture’ consists of ‘Static data’ and ‘Dynamic data’. ‘Situational data’ is further classified according to the concepts of the ‘Data set content’ facet of the EPISECC Taxonomy having 17 subclasses on the first level of the classification and 7 subclasses on the second and third level (e.g. ‘Casualties’, Weather forecast’ etc.). Figure 4 shows the main classes ‘Process’ and ‘Resource’ as subclasses of the ‘Operational data’ which means that data describing processes and resources are considered as operational data. The main class ‘Disaster’ is a subclass of ‘Situational data’ meaning that data describing a disaster is considered as situational data.

Additional to the classes and object properties shown in Figure 4, the following data type properties of situational and operational data are used for detailed description of a situation: ‘has size’ (e.g. for ‘Affected area’), ‘has number’ (e.g. for ‘Casualties’), and ‘has value’ (e.g. for ‘Damages data’).

Concepts describing observations and measurements such as ‘Epicenter’ or ‘Magnitude’ could be further elaborated by use of domain ontologies such as Semantic Web for Earth and Environmental Terminology (SWEET) [22] or Semantic Sensor Network (SSN) [30]. Classes such as ‘Quantity’ are also not further classified and they could contain data items such as numbers representing quantities. The concept of quantity is a complex concept including measuring units etc. and it could be further elaborated by use of domain ontologies such as Quantities, Units, Dimensions and Data Types Ontologies (QUDT) [26].

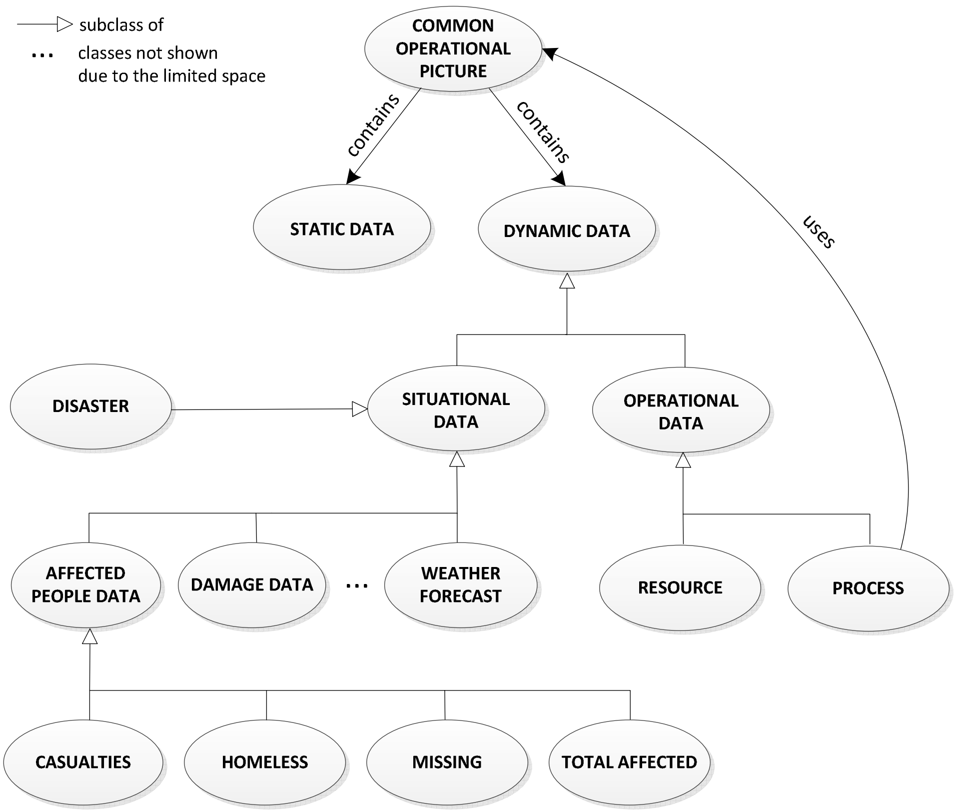

Fig. 4. Directed graph of the Common operational picture [9].

3.3. References to the domain and upper ontologies

References to the domain and upper level ontologies enable the EPISECC Ontology model to be merged with other semantic structures using the same reference ontologies. As reference domain ontologies, two ontologies are selected: GeoSPARQL for spatial data [23], and W3C Time for temporal data [31]. As a reference upper level ontology, the DOLCE-Lite ontology is selected [21].

The EPISECC Ontology models spatio-temporal or 4D data showing situational and operational data. Spatio-temporal data includes geolocation and reference to time. The geolocation can be represented by different geometry entities such as points or areas, and different geolocating systems such as WGS 84, the national coordinate system or addresses.

Time reference could include the time interval or the instant in time described by any time unit such as day-hours-minutes. As an example, the medical triage could be geolocated by the area. As the process evolves in time, the area representing the operation's scene changes its shape and position. Another example is the location of the rescue team which could be represented by a moving point.

Representation of 4D or dynamic features asks for the properties varying in space and time. Although the reference domain ontologies exist for the spatial and temporal data, putting these two concepts together requires a solution for a new concept: the evolution of concepts in time and space. An overview of approaches for the 4D data ontology modelling is given in [2]. Welty and Fikes in [32] have demonstrated that 4D Fluent model is the most appropriate one for ontology modelling of 4D data using the OWL language. The 4D Fluent model asserts that all entities are perdurants. *"Perdurants (also called occurrents) are entities that 'happen in time', they extend in time by accumulating different 'temporal parts', so that, at any time 't' at which they exist, only their temporal parts at 't' are present."*, is the definition of the perdurants in the DOLCE ontology [21]. Thus, the perdurants have temporal parts and can be thought as 'space-time worms' whose temporal parts are slices of the worm. Baučić in [3] has extended 4D Fluent model to represent entities varying also in space. The spatio-temporal part represents 4D entity in the certain moment in time with its location and geometry.

For example, a flood can have its spatio-temporal part consisting of a flooded area and a time record when the flood had that extent, as well as stating other flood's characteristic valid for the same instant of time.

To model 4D data, the class 'Spatio-temporal part' is introduced in the model and related with the property 'is spatio-temporal part of' to the class 'Dynamic data'.

The EPISECC Ontology model with main classes and their references to the domain and upper ontologies is shown in Figure 5. The model corresponds to the one described in [3] and is accommodated to the main classes of the EPISECC Ontology model.

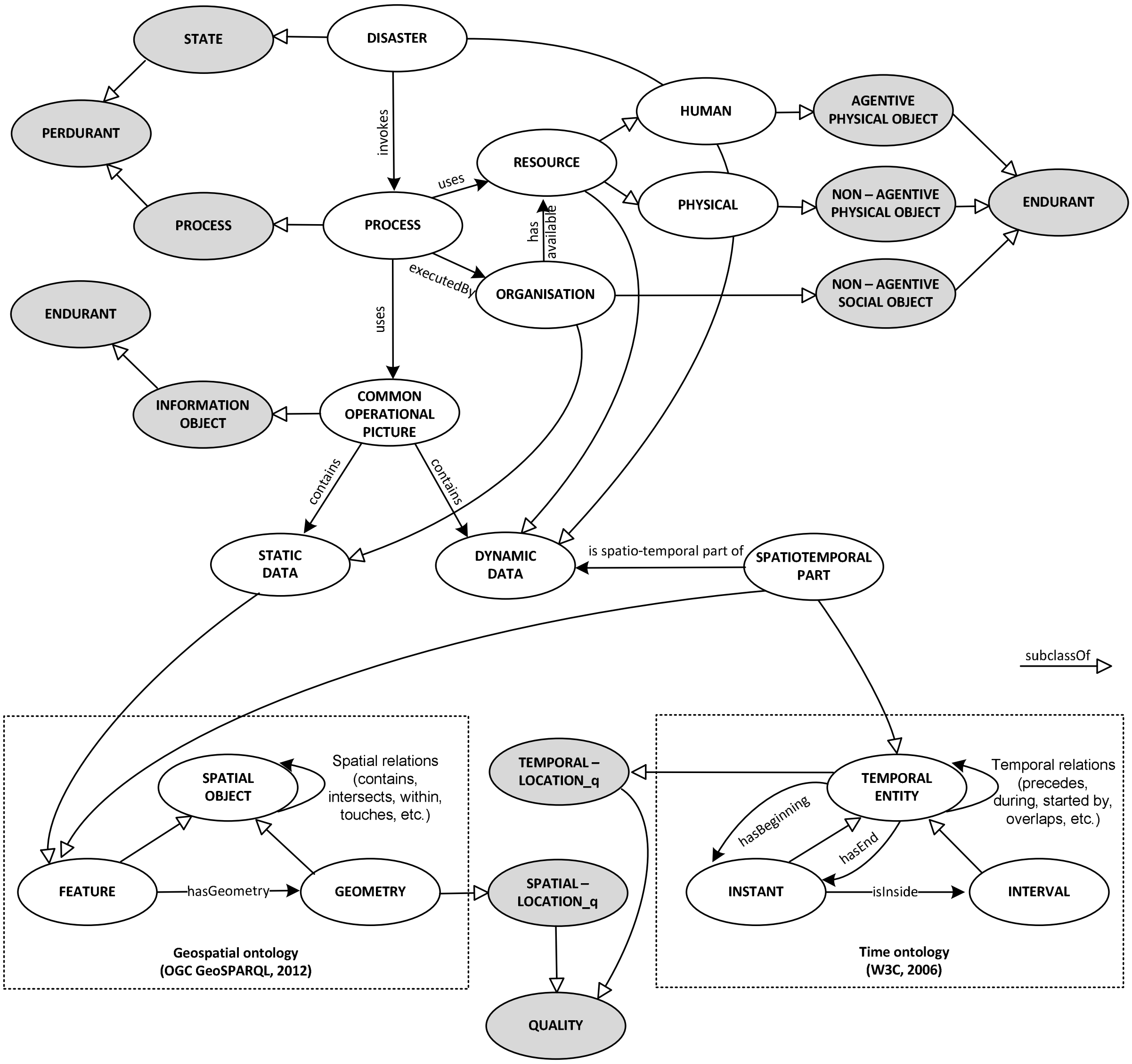

Fig. 5. Directed graph of main EPISECC classes and with references to DOLCE-Lite (grey ovals), GeoSPARQL and W3C Time ontology classes (adopted from [3], [9]).

Domain ontologies further explain the spatial and temporal concepts. 'Spatio-temporal part' is referenced as a sublass of the class 'Feature' of the GeoSPARQL ontology and also of the class 'Temporal entity' of the W3C Time ontology. The class 'Static data' is referenced only to the class 'Feature' because it does not contain temporal properties. Grey ovals, shown in Figure 5, represent DOLCE-Lite classes referenced to the EPISECC Ontology classes.

There are other domain ontologies which could be referenced such as SWEET [22], SSN [30] and QUDT [26]. As the focus of the EPISECC Ontology model was on 4D data, they are omitted from the further study.

4. Ontology schema

The conceptual ontology model is formalised in OWL schema to enable deployment and validation. The EPISECC Ontology model's classes and properties are inserted to the OWL schema by Protégé Desktop software. Domain ontologies GeoSPARQL and W3C Time are imported into the OWL schema. Figure 6 shows two class hierarchies. The left hierarchy shows the first level of classes of the EPISECC Ontology schema. Classes written in bold letters are defined by the EPISECC Ontology conceptual model and classes written in regular letters are defined by GeoSPARQL and W3C Time ontologies e.g. class 'Spatiotemporal part' is the EPISECC Ontology conceptual model class, 'Spatial object' is the GeoSPARQL class and 'Temporal entity' is the W3C Time class. On the right side of the Figure 6, the class 'Common operational picture' and some of the subclasses are shown.

5. Implementation and validation

The EPISECC Ontology model was implemented with the Protégé Desktop software and ontology schema is stored in an OWL file locally on the computer in RDF/XML syntax. For the validation of the EPISECC Ontology schema a two stage approach is applied: checking of logical consistency and application of competency questions defined by the use cases.

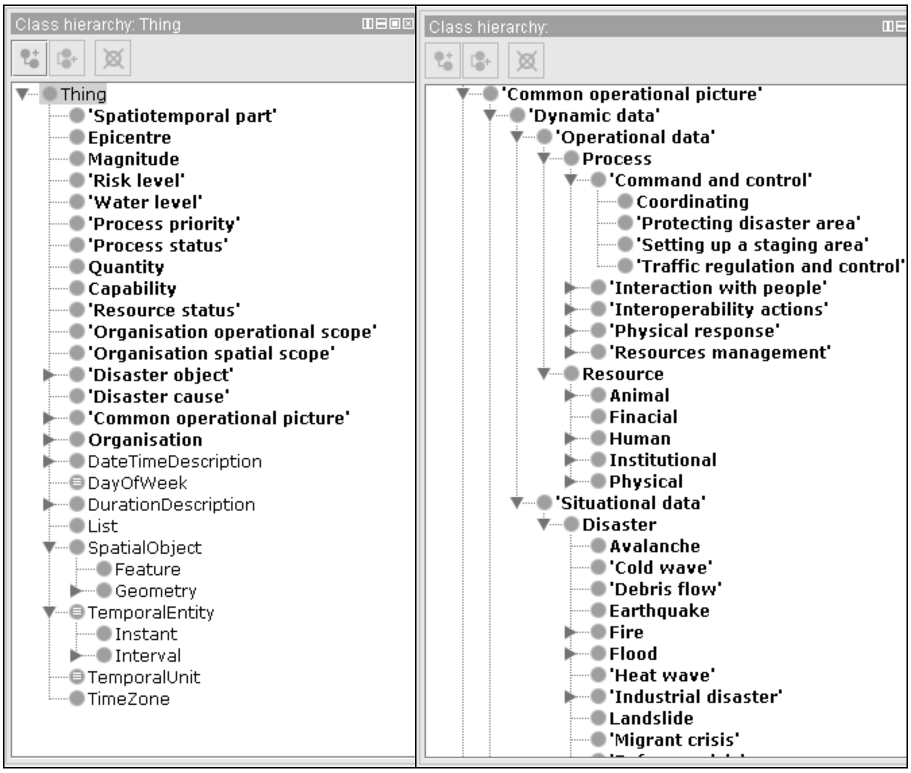

Fig. 6. Protégé Desktop interface showing the class hierarchies [9].

The logical consistency of the model is checked by applying reasoning algorithms and the results show the EPISECC Ontology schema is logically consistent (having no individuals belong to two disjoint classes).

Based on the CIS's Proof of Concept (PoC) elaborated in [11,12], the first version of the EPISECC Ontology model is validated and revised. The competency questions are created, the model should be able to answer to [17]. The EPISECC scenario and accompanying use cases were the basis for the creation of the competency questions, encompassing the data exchanged among the first responders during the PoC. By omitting the overlapping questions, the final list of eight competency questions is obtained. The analysis has identified the EPISECC Ontology model's elements (classes and properties) available for getting answers to the competency questions and proposed the improvements. The questions and improvements are given in Table 1. The class 'Dynamic data' provides data on a location and time for all the subclasses and thus answers the questions: 'Where?' and 'When?'. The location and time are provided by an object property 'has spatio-temporal part' and a related individual, a member of class 'Spatio-temporal part'.

The improvements from Table 1 together with the improvements propagated from the EPISECC Taxonomy were incorporated in the final EPISECC Ontology model and given as OWL file in the [10]. Beyond the EPISECC project lifetime, the changes of the EPISECC Ontology model are foreseen in the further development of the EPISECC Taxonomy and in the extension of the EPISECC Ontology scope, which is now limited to the EPISECC use case.

Table 1

Competency questions and ontology model's improvements

No.	Competency question	Ontology model's improvements
1	Where and when did the disaster happen, what is the type and intensity of the disaster?	None
2	Where are the damages, when did they happen, and what are the types of the damages?	Class 'Disaster object' needs properties describing location and time and it should be placed as subclass of 'Dynamic data'/'Situational data'. Add properties 'has size', 'has number' and 'has value' for describing damages.
3	Where are injured people, when were they injured, and how many people are injured or dead?	Add property 'has number' for describing casualties.
4	Where and when are operations executed, who executed operations, what are the types of operations?	Add object property 'executes', the inverse property of 'executed by' (property relating 'Organisation' and 'Process').
5	Where are the resources, when are they needed, what are the types and capacities of resources which have been urgently needed?	Add individuals 'high priority', 'medium priority' and 'low priority' and redefine 'Process Priority' class to be equivalent to the list including these individuals.
6	Where are available resources, when are they needed, what are the types and capacities of the available resources and what response units do resources belong to?	Add individuals 'available', 'needed' and 'in use' and redefine 'Status' class to be equivalent to the list including these individuals.
7	Where and when do operations happen, what are the types of operations and what response units are operations assigned to?	Add object property 'executes', the inverse property of 'executed by' (property relating 'Organisation' and 'Process').
8	Where are the resources, when are they needed, who needs the resources, what are the types and capacities of needed resources?	Add object property 'executes', the inverse property of 'executed by' (property relating 'Organisation' and 'Process').

6. Conclusions and further research

The role of the EPISECC Ontology within the CIS is to merge spatio-temporal data coming from different first responders into one operational picture. Using the Semantic Repository, only a priori end users who have already entered their concepts and semantic mappings can get semantically annotated messages. The ontology model enables that semantic descriptions are exchanged together with data and that opens possibilities of including ad-hoc users with their data in the common operational picture. Including ad-hoc participants asks for a development of new concepts able to manage unverified data, thus CIS's functionalities could be extended towards ad-hoc participants.

Further developments of the Ontology model could follow several directions. One is expanding the ontology model's scope, now limited to the EPISECC scenario and use cases. Further development, as an example, could include workflow of undertaken actions during the response or making references to other domains' ontologies such as sensors data. Another direction is prototyping and testing with ad-hoc users, e.g. merging data from social media into a common operational picture.

Use of ontology models and semantic web technologies for the disaster management has many open issues among which is trustworthiness of data. The new paradigm of including ad-hoc participants and their data during disaster management asks for solution able to tackle with unverified data.

Acknowledgment EPISECC is co-financed from the EU funds under grant agreement no. 607078 within the Seventh Framework Programme.

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