Semantic annotation of geodata – a step towards interoperability and harmonization

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Abstract. Widespread of user-friendly technology contribute largely to rapid increase of geoinformation users. Both need and offer of geodata rise. But users of geoinformation differ in their information needs and also their conceptualization of the real world may vary accordingly. As the technological interoperability seems to be highly accented and almost solved (thanks to activities of OGC), elimination of semantic interoperability is still a challenge. Data sharing by different geoinformation communities faces problem of the lack of semantic description which would be understandable across all disciplines. Solution seems to be using ontologies. Describing data by using ontologies and ontology sharing may profit both to users and producers of data. But geographic data is a very specific kind of data. Building ontology on geospatial domain and defining bridging concepts for different conceptualization is a crucial task for geographers. Presented paper describes theoretical principles of semantic data integration and annotation. Special attention is paid to domain of emergency management. Semantic heterogeneity issues are demonstrated on practical examples - the case study of topography base definition - on data commonly used in Czech Republic (topographic - “ZABAGED”, “DMÚ” and thematic datasets).

Keywords: semantic heterogeneity, semantic integration, semantic annotation, geo-ontology.

1 Introduction

Emergency management (EM) is an example of cross-border domain - due to high diversity of emergency situation it embodies a great number of disciplines. There is a huge demand on data - most of them have a spatial aspect, these are called geodata. Huge number of geodata sources that are available for the use in EM emphasizes the importance of spatial data integration and fusion. Issue of data integration in the field of EM is very important due to fact that successful decision making depends on fast and effective processing of available data.

Only a few information that are used in EM are geodata originally produced for the needs of EM - more likely, due to complexity of EM domain data sharing and reuse is of primary importance. Some geodata that are used (or have potential of use) in EM are distributed via GI web services. Discovery and access of such geodata are possible thanks to catalogues. Other geodata are not distributed via web - there are just used within the organization of data producer for their purposes. Both of these geodata might be used in EM - but they have one feature in common - their semantics is fully understandable only by the organization that it produces or by their “typical” users. For users outside it, the meaning of data might be hidden even despite of being described by using standard metadata.

When transferring a set of geodata from an external source into an information system, user has to cope with several technical issues like data formats, coding systems and spatial referencing, otherwise the data remains unusable [1]. These kinds of technical issues dominate in present metadata standards. However, the semantics of data is the most important issue in the evaluation of the suitability of data to an intended use. The metadata standards provide means for describing data contents, or the semantics of data, but currently they are poorly developed. Semantic issues are even tackled by currently ongoing INSPIRE directive, but solutions are only blueprinted.

Interoperability aims at the development of mechanisms to resolve any incompatibility and heterogeneity and to ensure access to data from multiple sources [14]. The dynamic interaction of different applications requires not only the technical support for the exchange of data, but the preservation of the underlying semantics as well. However, although, the technical aspect of data exchange is developed successfully due to advances in information technology, issues related to the semantic aspect need further examination.

Paper addresses two main issues - semantic annotation and semantic integration of geodata. The aim is to present semantic heterogeneity issues that users must deal with when searching, integrating or simply interpreting data from different sources to fit their intend of use. This issues are illustrated on most commonly used data in Czech Republic. Two use cases are presented that deals with solution of the partial task “Transport of dangerous goods” within research project “Dynamic Geovisualization in Risk Management”. Paper is structured as follows: First part (chapter 2) deals with theoretical approaches to semantic heterogeneity and ontology principle. Chapter 3 deals with describing content of database by data source ontology. Chapter 4 illustrates semantic heterogeneity on two use cases that deal with data integration and interpretation.

There will be three databases in focus of this paper: **Fundamental Base of Geographic Data** (in Czech - widely used abbreviation **ZABAGED**) - it is product of Czech Office for Surveying, Mapping and Cadastre (COSMC). It is digital geographic model of Czech Republic with accuracy and level of detail equivalent to Base Map of Czech Republic in scale 1:10 000.

Digital Landscape Model (in Czech - widely used abbreviation **DMÚ**) - it is product of Military Topographic Institute. It is vector database of information about topographic features and phenomena. Its accuracy and level of generalization is equivalent to Topographic Map in scale 1:25 000.

StreetNet - it is product of Central European Data Agency, a.s. (CEDA). The map set contains a complete road network of the Czech Republic to the level of streets and local roads. It is designed for car navigation, vehicle routing, traffic analysis and other application. Data model is appropriate to specification GDF 4.0 (Geographic Data Files). Its accuracy is 5-10 m.

2 Semantic issues and ontology

2.1 Heterogeneity of spatial databases

Sharing geodata is difficult due to diverse conceptual schemata and semantics [14]. Indeed, different interpretations of geospatial data encoded in different databases cause heterogeneities between them. Heterogeneities between different databases can be classified to three major categories [3]:

Syntactic Heterogeneity is caused by different logical data models (e.g., relational vs. object-oriented) or due to different geometric representation (raster vs. vector).

Schematic Heterogeneity occurs because of different conceptual data models (e.g., objects in one database considered as properties in another, different generalization hierarchies).

Semantic Heterogeneity raises most information integration problems. It occurs because of differences in meaning, interpretation or usage of the same or related data.

Semantic heterogeneity is divided to: naming (homonyms and synonyms), and cognitive (different conceptualizations, e.g. class definitions or geometric descriptions).

According to Klien 15], semantic heterogeneity problems can occur at different levels.

At the *metadata* level, semantic heterogeneity impedes the *discovery of geographic information***.** Missing or insufficient documentation makes it difficult or even impossible for users to discover data sets and to assess whether a given data set is useful for their tasks. Catalogues allow client to search for spatial resources available on servers, but keyword-based search can have low recall if different terminology is used and/or low precision if terms are homonymous or because of their limited possibilities to express complex queries.

At the *schema* level, semantic heterogeneity impedes the *retrieval of geographic information*. While the service can be queried for the schema of a data source, a requester might still run into trouble when formulating a query filter if the property names are not intuitively interpretable.

At the data *content* level, semantic heterogeneity impedes the interpretation and integration of geographic information**.** When interpreting the content of data, problems can occur due to using different units of measure or classification system. Classification systems differ between information communities (e.g. between geology and soil science), but also within *one* information community when the vocabulary used by the information community changes over time.

2.2 Ontology

Different user groups have different abstractions and descriptions of the real world, depending on their application field. This specific world view is also termed *The Universe of Discourse (UoD).* UoD determines the conceptualizations used to describe specific information units. This includes not only the domain specific vocabulary, but also the relationships and rules that hold between these concepts, constituting a conceptual model. User groups that share, at least part of the time, common abstractions, metadata, and spatial feature definitions are termed Geographic Information Communities (GIC)15]. The set of features in the real world, which are of interest to a particular GIC, forms its Universe of Discourse [3].

There is definition of GIC provided by OGC [18]: “Geospatial information community (GIC) is a collection of people (a government agency or group of agencies, a profession, a group of researchers in the same discipline, corporate partners cooperating on a project etc.) who, at least part of the time, share a common digital geographic information language and share common spatial feature definitions."

It is required to have a higher-level language, i.e. above the conceptual model, which formally defines the UoD of the underlying GIC without restricting its way of representation. Bisher at al. [4] propose ontology as a higher level language. From that point of view the following definition of GIC is suggested: "A geospatial information community is a group of spatial data producers and users who share an ontology of real-world phenomena."

There exists many definitions of ontology. Most common definition is from Gruber [11]: An ontology is "an explicit specification of a conceptualization". An ontology is a formally described, machine-readable collection of terms and their relationships expressed in an ontology language. A formal ontology, uses concrete classes, properties, relationships, and axioms to describe a domain. It is based on the conceptualisation of the domain and its specification using adequate languages. It is aimed at the implementation of the domain's description in a computer readable manner [20].

Ontologies represent many different kinds of things in a given subject area (domain) (e.g. medicine, physical object, wire)[21]. These things are represented in the ontology as *classes* (or *concepts*) and are typically arranged in a lattice or taxonomy of classes and subclasses. Each class is typically associated with various *properties* (also called *slots or roles*) describing its features and attributes as well as various *restrictions* on them (sometimes called *facets or role restrictions*). An ontology together with a set of concrete *instances* (also called *individuals*) of the class constitutes a *knowledge base*.

Ontology is mainly concerned with *intension.* The intension of a concept is the set of characteristics (formalized with axioms in the ontology) which are shared by everything to which it applies. This set of objects that the concept refers to is its *extension* [15].

Between two or more concepts, different semantic *relationships* can be distinguished [16]:

- *Hyponymy or the superconcept/subconcept relation* (or hierarchical order) is the order proceeding top-down from more generalized concepts with larger extent and smaller intent to more specialized concepts with smaller extent and larger intent. The subconcept inherits all the properties of the superconcept and adds at least one property that distinguishes it from the other subconcepts of that superconcept. For instance: a 'river' is a kind of 'watercourse'.
- *Synonymy* refers to similarity in meaning. Both the extension and the intension of the concepts are exactly the same. For instance: the concepts 'stream' and 'watercourse' are synonyms.
- *Meronymy/holonymy* is the part-whole relation, e.g. 'midstream', 'ford' and 'meander' are parts of 'stream'.

Formal ontologies can be used to describe specific domains comprehensively [20]. Using languages that are readable by computers, such as the XML-based RDF and OWL, those information communities that collect data can provide formal ontologies and make them accessible via the Internet. Ontologies can be seen as a tool that could support effectively data identification-, access-, and sharing processes. By using ontology users can easily guess about relevancy of data within a specific context.

Ontologies are classified in a few groups, according to their dependence on a specific task or point of view [11, 7]:

Top-level ontologies describe very general concepts like space, time, matter, object, event, action, etc., which are independent of a particular problem or domain: it seems therefore reasonable, at least in theory, to have unified top-level ontologies for large communities of users.

Domain ontologies is a formalization of the knowledge in a subject area (domain) such as topography, ecology, biology, flooding, etc.

Task ontologies is a formalization of the knowledge necessary to solve a specific problem or task but abstracted above the level of a specific situation or organizational context, for example performing the task of monitoring fresh water quality. Domain and task ontologies specialize terms introduced in the top-level ontology.

Application ontologies contains knowledge for a specific application designed to complete a task in a specific situation and organization setting, such as the task of monitoring water quality as performed by the Environment Agency. Such ontologies will contain little knowledge that is directly reusable by other organizations and serve to provide a semantic interface between the domain and task ontologies and the application.

Data ontology. A data ontology models the structure of a particular database and is typically used to interface between legacy data in a relational database and higher level (domain or task) ontologies.

3 Data source ontology vs. database schema

An ontology represents concepts in the world. Although ontologies and database schemas can be related, ontologies are richer than database schemas in their semantics [8].

Here we assume that by creation of data source ontology we get simplifying view on UoD of given GIC. We considered hierarchies adapted in database schemas as simple ontology that can semantically describe content of geodatabase.

In an example below we focus on domain of topography. Since there are two topographic databases in Czech Republic that exist in parallel, we suppose existence of two GIC on that domain - one conceptualizing real world by ZABAGED and other by DMÚ. In despite of having very similar UoD, their conceptualization differ. Defining both - data ontology of ZABAGED and DMÚ is illustrated. Different approaches must be adapted due to schematic heterogeneity of both datasets.

In focus there are so-called topographic concepts. According to Aerts [2], topographic concept can be defined as abstract specifications of real world objects as they exist in a specific community or national mapping agency. Concepts can have properties, which are the attributes or characteristics that can be assigned to a specific concept. Properties distinguish the concepts they characterize. “Classifying” and “non-classifying” properties can be differentiated. Classifying properties are those properties that distinguish one topographic feature from another. The distinction between classifying and non-classifying properties is not always clear and depends on character of topographic concept (for example: *the width* is nonclassifying property for roads, but watercourses can be further categorized by their *width,* making *width* a classifying property). So-called *weak concepts* can play important role in defining data source ontology - these concepts are not present in data schema but improve significantly its hierarchy.

Data source ontology were created manually by analysis of data catalogues [5, 6]. Principle of its creation is shown on figure 2. Category is the highest level on data hierarchy. Type of object (in catalogues given by its code) is a core concept (CONCEPT I). In case of some concepts on level CONCEPT I, it is possible to specify another concept level (CONCEPT II) based on classifying property of core concept. Within data schema of DMÚ, it is possible to specify another hierarchical level between CATEGORY and CONCEPT I - level BASIC FORM, that specify generic form of topographic object (for DMÚ data in shapefile format - it is equal to table name). Data of ZABAGED miss such a level (it that case, CONCEPT I is equal to table name). With respect to other use of ontology, it is reasonable to add weak concept that would specify this generic form - it is set by its geometry in data catalogue and its logic interpretation (e.g. buildings and areas are both features with polygon geometry in catalogue, in ontology there is different BASIC FORM concept defined for buildings and areas).

It is obvious, that there is great heterogeneity between both topographic databases. Similarity and heterogeneity of concepts in data source ontologies DMÚ and ZABAGED is analyzed in [17].

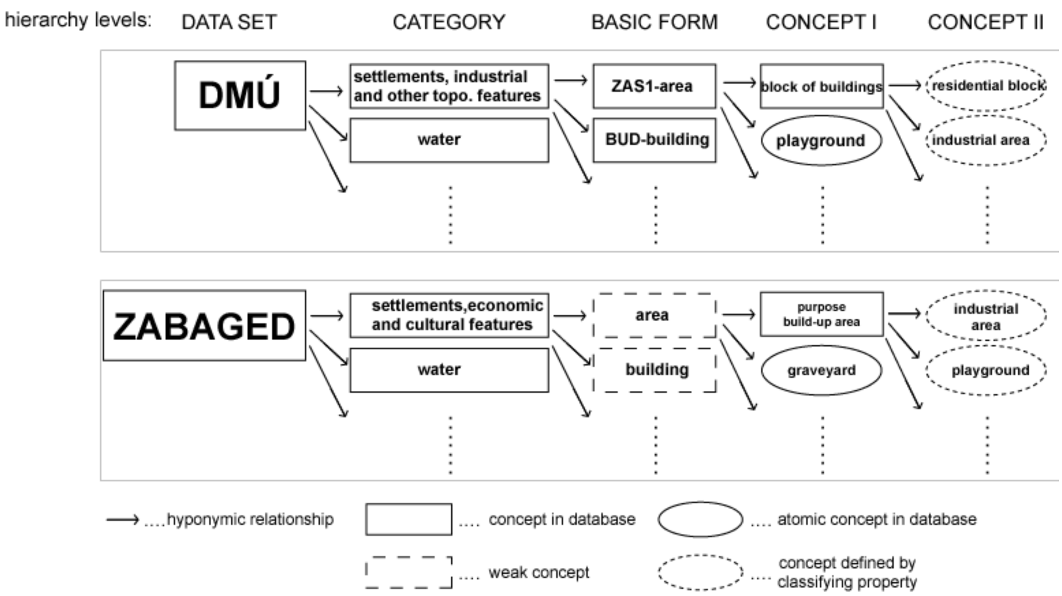

Figure 2: Principle of building data source ontology for topographic databases DMÚ and ZABAGED.

4 Case studies

Semantic heterogeneity causes problems when integrating data from different sources or even during data interpretation. Semantic heterogeneity issues are demonstrated on practical examples that deals with research project “Dynamic visualization in crisis management”. A few case studies dealing with topography base (TOPOBASE) definition for emergency scenarios “transport of dangerous goods” are presented.

Topographic maps have a wide variety of applications. In following use cases, it will support emergency services in case of a crisis - the purpose is to build TOPOBASE, e.g. to supply basic topographic situation that would serve as a background for visualization of context-specific (thematic) information. There are two main requirement that must be fulfilled - simplicity and scaleability. Simplicity means that there must be shown only as much information as necessary - information redundancy would cause in lower readability and drown of context specific information. Scaleability point out that data content should change with scale - detailed topographic information (in sense of granularity) is expected in lager scale and in opposite. These needs determine design of concepts and taxonomies in application ontology.

4.1 Use case I - data integration - an example of communication network

Communication network is a substantial part of TOPOBASE. Besides “topographic GIC´s”, there is concept *road* also in focus of “traffic GIC” (e.g. GIC that uses GDF standards - here case of StreetNet database). The way, how they conceptualize road may differ. Topographic GIC conceptualize features of real world as artifacts that are part of landscapes. UoD of “traffic GIC” is transportation networks - it conceptualize road as a section of the earth, which is designed for, or the result of any vehicular movement 12]. Semantics of data and purpose of the application must by analyzed to chose right representation of road concept for given case. For this use case - ZABAGED and STREETNET databases were considered.

Data of both databases are relevant. But if we expect that traffic analysis will also play an important role within application in EM, StreetNet seems to be a better solution. As for requirement of scaleability - we expect to have more detailed information in higher scale levels. Because Universe of Discourse of Traffic GIC is “what is designed for, or the result of any vehicular movement”, in high detail we will probably miss communications “that are not designed for vehicular movement”. For monitoring phase of our scenario “transport of dangerous goods”, it is an adequate solution to represent only roads for vehicle movement, but in response phase of incident, any kind of communication can be essential to access the place of accident.

Solution is the integration of both datasets - to use road network of SteetNet and trails from ZABAGED. The trail is defined as “local or specific purpose road, that originates by vehicle-drive on part of the land, possibly improved by local ground works or with surface adjustment in all its with” [5]. Apparently, definition of trail overlap with definition of communication network of StreetNet as it was verified spatially (Fig. 3A).

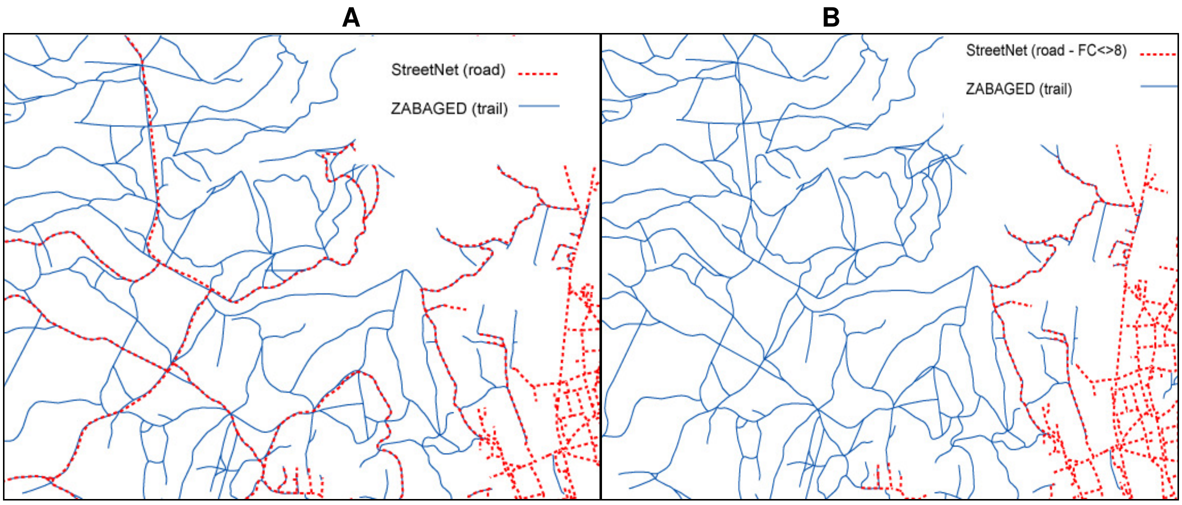

Figure 3: Duplication of object, A - as a result of simply integration, B - after applying semantic filter

To enhance visualization and fulfill requirements on TOPOBASE, an application ontology was built. In order to present road network in different levels of detail, the application ontology contains concepts that reflect different levels of regional importance of roads. Four level of regional importance were set: regional, microregional, local, sublocal (Fig. 4).

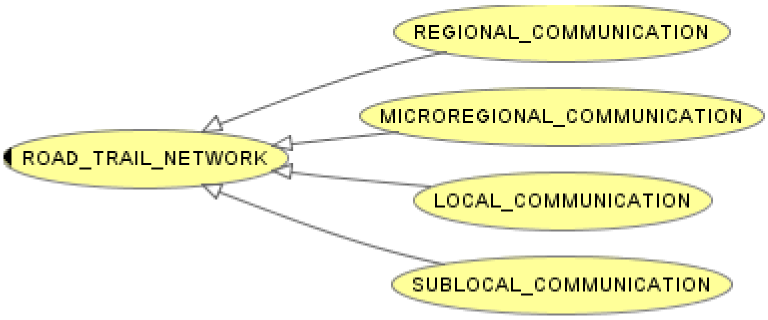

Figure 4: Visualization of application ontology TOPOBASE - concept road and trail network.

To be able to establish mappings between our application ontology and concepts of data source ontologies it was necessary to analyze data model and to find classifying property that would suite our application. There are two attributes that have values in ordinal scale and could allow meaningful categorization of regional importance - besides class of road, that is captured in both datasets, it is a functional class (road category in StreetNet). The functional class (FC) is a subjective indicator of the importance of the road. Typically, navigation systems use this attribute as one of the indicators whether to construct longer-distance routes over specific roads [13]. Attribute FC was chosen as classifying property of road network in StreetNet.

Figure 5 shows mapping that were established manually to populate concepts of application ontology. Concept *rural_forest_road* remains unmapped since it was analyzed as semantically similar with concept trail but with extent that do not fit the application and thus was eliminated. Instead, concept *sublocal_communication* was instantiated by concept *trail* (ZABAGED). Figure 3B shows integration of ZABAGED and StreetNet when concept *rural_forest_road* is eliminated. It is obvious, that due to cognitive heterogeneity, semantic integration can never eliminate all collision.

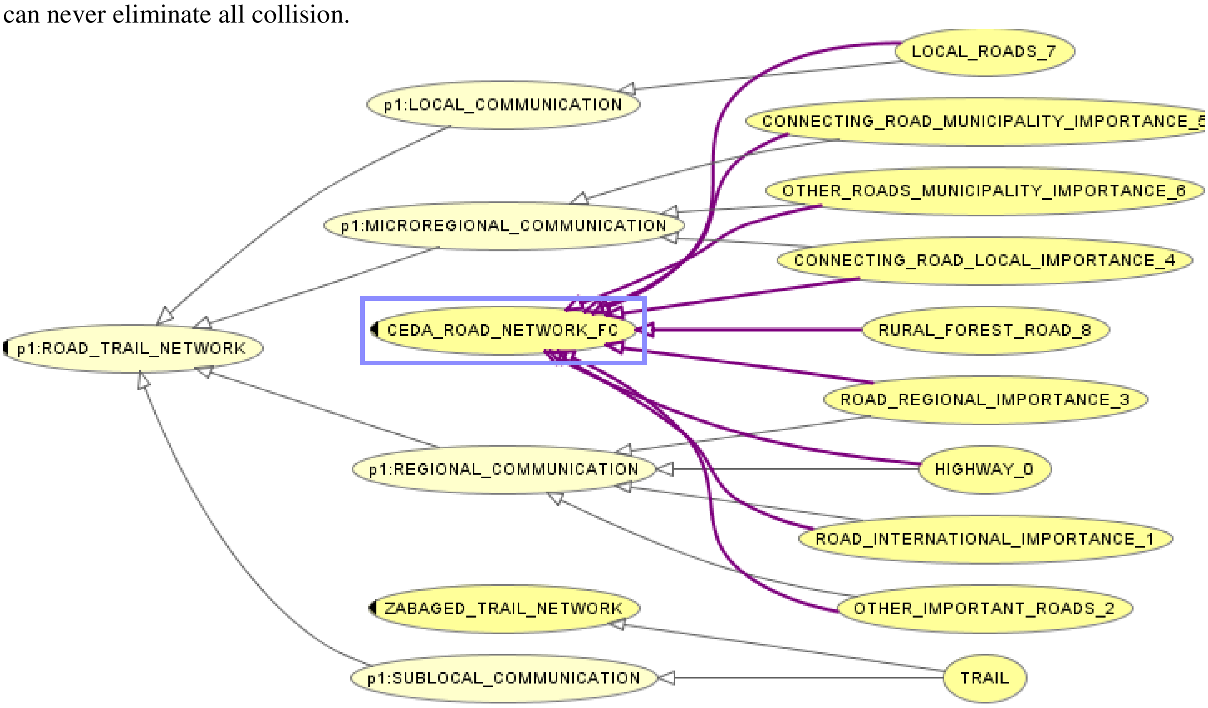

Figure 5: Population of concepts in application ontology (p1) by Streetnet (CEDA) and ZABAGED.

4.2 Use case II - data interpretation - an example of area features

Urban settlement is scale-dependent phenomena. If it is perceived in a small scale, the level of detail is usually small, it can be represented as a point or as a simple polygon. If perceived at larger scale, it becomes necessary to represent its internal structure with more detail. Ontologies offer a possibility to specify exactly how higher-level abstraction relate to concepts of a lower level. Concepts on higher level of hierarchy have lower intend and higher extend than concepts lower in hierarchy and so could represent thematic features in lower level of detail.

Following use case deals with simplifying topographic database for representation urban settlement and other build-up areas. Both topographic databases used in Czech Republic are rich in specification build-up areas but their database model does not support scaleability. Application ontology was defined with concepts on different levels of granularity which reflects different levels of detail. In this use case data source ontology of ZABAGED was chosen for integration with the application ontology.

Data source ontology ZABAGED was defined as specified in section 4 of this paper. Only concepts that were categorized as basic form *area* were selected and ad-hoc data source ontology was created. Figure 6 shows the hierarchy. Schematic heterogeneity of the database is evident - concepts of the same granularity are on different level of hierarchy (subconcepts of purpose_build_up_area vs. subconcepts of settlement_area). This heterogeneity causes problems in data interpretation.

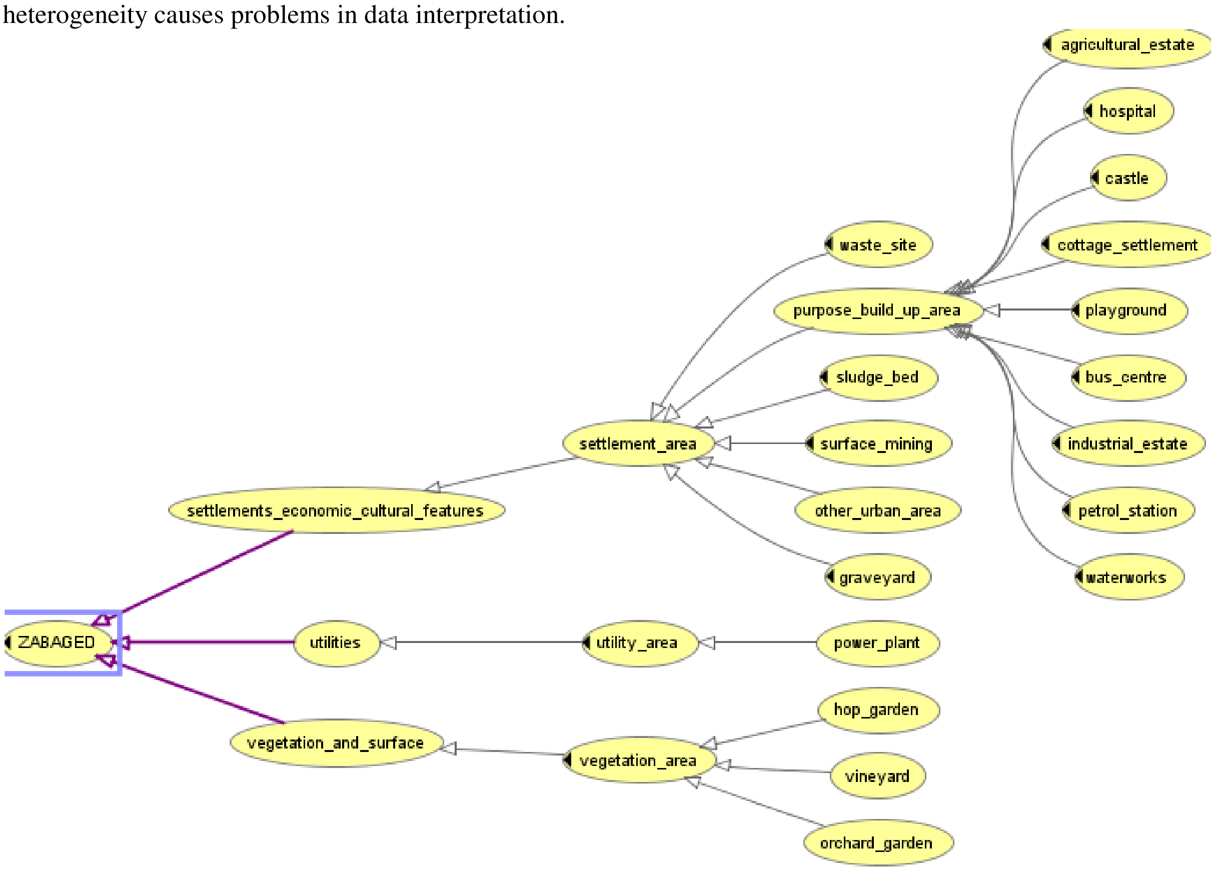

Figure 6: Hierarchy of concepts in data source ontology of ZABAGED (selected concepts)

Simple application ontology was designed - hierarchy of two levels of concept that correspond with two levels of detail. For the purpose of TOPOBASE it is sufficient to generalize urban settlement and other build-up areas in lower scale into one concept *BUILD-UP AREA*. In higher level of detail, there are 3 concepts that are specification of it - *CIVIL ESTATE* that represents all residential areas, sport, cultural, commercial areas and other where people are concentrated, *INDUSTRY-AGRAR ESTATE* that represents areas connected with economic activities, and *GREEN AREAS* that represents areas with grower activities and graveyards (Fig. 7). Each concept represents group of different kinds of buid-up areas - each group differ in a sense of outer form (that influence orientation in terrain), concentration of people (their potential presence and amount), influence on environment (dangerous objects). There is no need to specify more concepts on this level of detail since other specification can be achieved intuitively thanks to depiction of buildings on this level of detail.

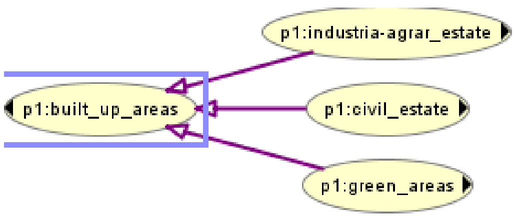

Figure 7: Hierarchy of urban settlement for purpose of TOPOBASE.

Mappings between data source ontology and application ontology were established. Figure 8 shows the way how subconcepts of *purpose_build_up_area* populate concepts in application ontology. It is evident, that property "kind" of *purpose build up area* must essentially serve as classifying property otherwise data could not fit the intend of application.

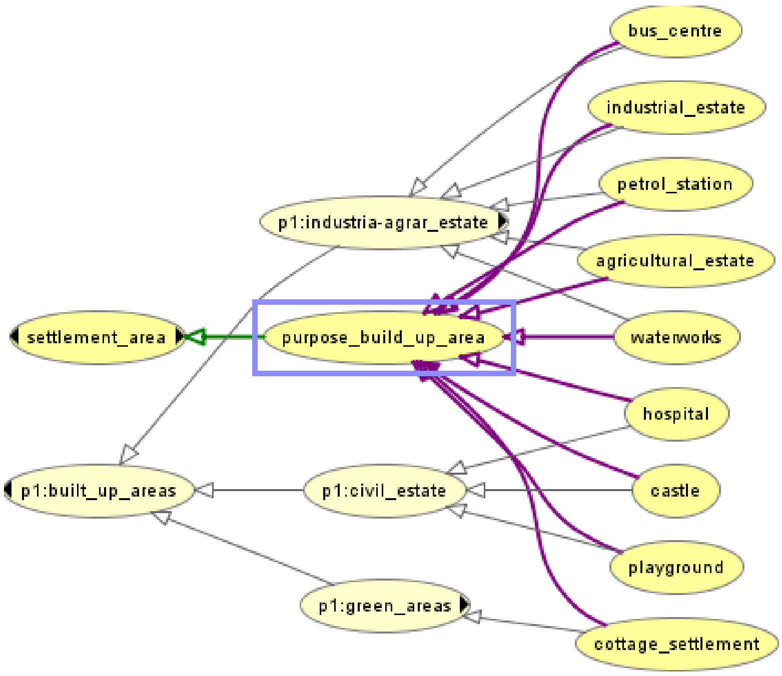

Figure 8: Mapping between selected subconcepts of purpose_build_up_area and concepts of application ontology (p1)

5 Conclusion

Paper addresses main issues concerning semantic interoperability constrains in spatial databases. Theoretical background is set and heterogeneity causes and impacts are outlined. Ontology is regarded as a tool for representation of semantic knowledge that is given by Universe of Discourse of specific geoinformation community.

Data source ontology is seen as a simple kind of ontology. Hierarchy adapted in database reflects conceptualization of given GIC. On example of two topographic databases, defining concepts and its relations of data source ontology based on data catalogue is shown. To define concepts on the highest level of granularity (e.g., concepts on the lowest level of hierarchy) it is necessary to chose attributes that serve as "classifying properties", e.g. property that can distinguish one topographic feature from another.

Semantic issues are illustrated on practical examples of datasets used in the Czech Republic. Two kinds of semantic heterogeneity is introduced: heterogeneity within one dataset and between two data sets. On the conceptual level, mappings between data source ontology and application ontology are shown.

Data source ontology is used to describe data content of the database. In this case, terminology of particular GIC was used (here it means: exact translation to English). In order to achieve semantic understanding even outside community of data producer, dataset should be semantically annotated by mapping to concepts of ontology that is developed to describe knowledge of given domain in more general (and widely excepted) terms.

Due to complexity of geoinformation, building ontology on geospatial domain that could serve as annotation base for geodata providers is a great challenge. First step is to build or reuse top-level ontology of concepts to formulate general knowledge that is acceptable for all geoinformation communities. By specification of concepts from top-level ontology, domain ontology can be build. Granularity of concepts in domain ontology should be on proper level - general enough to be understandable for all users but also specific enough to be able to secure description of specific knowledge. Instead of extensive geospatial ontology, there should exist number of sub-domain ontologies that would describe some part of geospatial domain - e.g. topography, water management. Combining domain specific ontologies with data source ontology offers a new approach to the generation of semantic metadata for datasets. Once ontology for specific sub-domain is developed, the data provider could select concepts from domain ontologies that best describe the content within the dataset.

Explicit expression of geospatial semantics is very important - it would not only enhance discovery and retrieval of geographic information, but it would also enable information sharing and its reuse in other contexts than the original one. It is very important in case of emergency management where the potential of reuse of existing data is great. Also issue of data relevancy is significant for area of EM. Semantic annotation of data would support the identification of relevant data sources. Only information that fits specific context of the user is relevant. If data sources are described via ontologies, the processes of identification, access and information sharing can be supported significantly [20].

Parekh at al. [19] summarized a few motivating factors for using ontology based approach for generating semantic metadata schemas:

• Ontologies can be constructed to provide *a shared, common vocabulary* involved in describing the dataset, thereby defining a standard of metadata which can be used by all.
• Ontologies can provide *a conceptual schema* for any dataset regardless of its format, structure or size.
• Ontologies can be designed to semantically *understand the content and structure of data present in the dataset.*
• Ontologies can be used to help the data providers to enter the *metadata in a semantically valid form*.
• Interoperability among heterogeneous datasets can be achieved by using *shared ontologies.*
• Ontologies are viewed as the most advanced *knowledge representation model.*
• Ontology can be used as a basis for *content based discovery and retrieval of datasets.*

Building ontology on geospatial domain will be a crucial task for geographical research. Also the way how to realize semantic annotation to establish reference between geodata and the ontology is still a research topic. But it is obvious that semantic heterogeneity is a great barrier on the way to interoperability and adapting ontology principles may help to overcome it.

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