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Using Ontologies for Integrity Constraint Definition

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Abstract

To assure the quality of acquired data quite a number of quality checks have to be carried out before the data is inserted into the database. For these checks quality requirements and integrity rules defined by the application play an important role (for example constraints between object classes). To-date there is no standardized formalism for the definition of constraints or rules within the existing data model. In particular for mobile data acquisition such formalization technique would be of great benefit, since it could support an automatic or semiautomatic process of quality consistency checking already during the acquisition workflow. Standard interfaces like OGCs (Open Geospatial Consortium) WFS (Web Feature Service) allow for an access and also for an update of heterogeneous databases through the Internet (transactional mode of WFS)[Plan et al. 2004]. But the important aspect of providing information about rules and/or constraints is unfortunately not supported by the WFS-interface, because there are no possibilities to encode integrity constraints within the feature class description of the WFS provided.

In this paper ontologies as a description of integrity constraints in a formal way are discussed. It is described how such constraints can be defined in SWRL (Semantic Web Rule Language), which is a combination of OWL (Web Ontology Language) and RuleML (Rule Markup Language). It is shown how these rules can be used as an extension to the data schema information, available for example through the WFS interface.

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Keywords: ontology, OWL, SWRL, axiom, quality constraints, quality assurance, mobile data acquisition

1 Introduction

The project "Advancement of Geoservices" aims at the conception and the prototype implementation of a sophisticated open standards based mobile geodata acquisition system. The architecture of the developed system allows for applications in different spatial domains and enables the fieldworker to access any information source that might be of interest for the current use. This flexibility is possible due to the fact, that with OGCs (Open Geospatial Consortium) standard interfaces like WFS (Web Feature Service, [OGC 2002a]) the application schema of the specific domain can be downloaded during fieldwork. These interfaces allow for an access and also for an update of heterogeneous databases through the Internet (transactional mode of WFS)[Plan et al. 2004]. Within the project "Advancement of Geoservices" such client / server interfaces are applied for mobile online data acquisition. Information about the object classes, i.e. feature types, and some other basic information is available through the WFS capabilities document. The particular data schema (i.e. schema information of the particular object type) is specified in XML-schema documents. The developed prototype application for mobile data acquisition is able to download schema information and to adjust the acquisition process to this information at runtime. In particular, this means that the measuring process including the selection of geometry types and templates for the input of attribute values must be flexible and adaptable. A more detailed description of this generic acquisition concept can be found in [Mäs et al. 2005].

To assure the quality of acquired data quite a number of quality checks have to be carried out before the data is inserted into the database. The direct transfer of newly acquired or updated data to the database makes investigations on the quality assurance during mobile data acquisition essential. For the necessary quality checks requirements and restrictions defined within the data model (for example constraints between object classes) play an important role. Such integrity rules, which describe specific user requirements in the data model, are therefore necessary extensions of the application schema and enable quality checks for each object i.e. instance during data acquisition.

There are a number of ways to describe an application schema. Today schema information is often provided through GML application schemas. Such application schemas describe what kind of data has to be collected and how this data has to be organized, but they leave out information about specific integrity rules and constraints contained in the data model. The XML-schema (XML = eXtensible Markup Language), which is available through the WFS interface, only contains information like object types, their properties and interrelations, but no constraints like e.g. a forbidden intersection of objects or semantic conflicts between certain attribute values. For the definition and transfer of such information other formalization methods are required.

In the paper ontologies as a description of integrity constraints in a formal way are discussed. It is described how such constraints can be defined in SWRL (Semantic Web Rule Language, [W3C 2004b]), which is a combination of OWL (Web Ontology Language, [W3C 2004a]) and RuleML (Rule Markup Language). It is shown how these rules can be used as an extension to the data schema information, available for example through WFS interface.

In the following chapter we briefly survey related work and based on that we outline issues where further research is needed. Chapter 3 gives an overview on how quality constraints can be defined in an ontology and which requirements an ontology formalization language therefore has to fulfill. After that it is shown how spatial operators can be defined in OWL. Chapter 5 presents a framework for the definition of integrity constraints in SWRL, making use of the operators defined earlier. Finally the application of the integrity rules to extend existing application schemas is described.

2 Related Work

A generic structure for the definition of topological integrity constraints, which refer to the semantic of the object classes, has been given by [Ubdea & Egenhofer 1997]. They defined a topological constraint as an association of two geographical object classes, a relation, which is in this particular case a topological relation like touch or intersect, and a specification (see figure 1), which can have one of the following values:

1. Forbidden (i.e. zero times allowed)
2. At least n times
3. At most n times
4. Exactly n times.

Constraint = (Entity class1 , Relation , Entity class2 , Specification)

Figure 1: Definition of integrity constraints [Ubdea & Egenhofer 1997]

In literature, there are many examples of the application of these or similar topological constraints for consistency assessment of databases. E.g. [Servigne et al. 2000] and [Ubdea & Egenhofer, 1997] worked on an automatic procedure to identify and correct topological errors within an existing database. [Cockcroft 2004] focused on the definition of constraints and consistency checks applied during the data entry. She extended the former constraint definition by adding further attribute constrictions to address only particular objects, like for example “a pipe > 14 cm in diameter”. In [Pundt 2002] it is illustrated, how semantic rules can be used for the simultaneously control of the data collection procedure during fieldwork, e.g. for resolving conflicts of attribute values of an object. With such plausibility checks it is possible to warn the field worker immediately, if any semantic conflicts occur. Pundt suggested to include the description of integrity constraints within the classes (in our case this means in the application schemas), e.g. through class paradigm like RDF (Resource Description Framework) or ontology languages like OIL (Ontology Inference Layer). The relation between consistency constraints in the different levels of ontology has been pointed out by [Frank 2001]. As shown in [Mostafavi et al. 2004] an ontology in principle can be used for quality assessment of spatial databases.

But up to now there is no generic formalism for the description of spatial data integrity constraints known. Such formalism should not be restricted to constraints concerning only two object classes without further differentiation, like it is shown in figure 1. It should allow for the definition of restrictions affecting multiple object classes in combination with their attributes and geometry in a single constraint. A formalized description of integrity rules would make quality information transferable and available also for the users. It would allow for quality checks against the defined rules already during mobile data acquisition.

3 Use of ontologies for integrity constraint definition

Ontologies allow for a formal description and specification of different conceptualizations of the real world. They encode the concepts of a domain and the relationships between these concepts. Indirectly, an ontology provides a formal description of the required model concepts and does so independently from the internal or application specific data structures [Greenwood et al. 2003]. Thus ontologies enable a better understanding of shared data, can support users to comprehend the intended meaning of the concepts and so prevent the incorrect use of data. Beside these issues ontologies also can be applied to support quality assurance during mobile data acquisition.

Compared to a conceptual schema, ontologies are representing concepts in the real world, while a schema only refers to those parts of the concepts, which are stored in a database. These differences between an ontology and a conceptual schema are extensively described in [Fonseca et al. 2003]. They pointed out that a conceptual schema leaves out some of the concepts and ideas the data modeler and the user have agreed upon. This background knowledge of the user is very important for quality assurance, since it implies rules and restrictions on the object classes, which have to be added to the schema information. This limitation of conceptual schemas is also valid for the schema available through the WFS interface. To assure data quality it would be of great benefit to extend the data model as described to be able to check data during acquisition against rules etc.

Within an ontology integrity constraints should be presented through axioms. Axioms of ontologies are prescriptions to complement semantic knowledge. They constrain the defined concepts and relations and express further relations between concepts [Guarino 1998]. In [Staab et al. 2000] a list of 7 major axiom categories is introduced and cited without further discussion in table 1.

1. Axioms for a relational algebra (reflexivity, irreflexivity, symmetry of relations, asymmetry, antisymmetry and transitivity of relations and inverse relations)
2. Composition of relations
3. (Exhaustive) Partitions
4. Axioms for subrelation relationships
5. Axioms for part-whole reasoning
6. Nonmonotonicity
7. Axioms for temporal and modal contexts

Table 1: Major axiom categories [Staab et al. 2000]

Ontology formalization languages have their origin from the Semantic Web aiming at the facilitation of machine interpretability of Web content. In the Semantic Web society it is still under hard discussion what kind of axioms are necessary and should be supported by a standardized ontology formalization language [Staab 2003]. Some would like to remain with a basic set of “simple” axioms, others argue for more powerful languages especially containing rules on numerous object classes or their attributes. The selection of a certain ontology formalization language for the definition of quality constraints depends primarily on the supported kinds of axioms.

The latest standard for the description of ontologies is OWL [W3C 2004a]. Unfortunately, OWL doesn't provide the possibilities for a more extensive definition of object properties through axioms. This fact has been exposed in more detail by [Horrocks et al. 2004]. They pointed out the limitations of OWL in terms of the axioms and proposed an OWL Rules Language (OWLR) as a syntactic and semantic extension to OWL. OWLR introduces rules with a

$$\text{Antecedent} \Rightarrow \text{Consequent}$$

structure (Horn clause rues) as a new kind of axiom (which is not included in the categorisation in table 1). Recently these ideas have been taken into consideration for SWRL, a W3C (World Wide Web Consortium) member submission. SWRL is extending OWL with parts of RuleML (Rule Markup Language), a markup language for rule description, to provide the possibility to include Horn-like rules as axioms in the OWL knowledge base. Such rules define an implication between an antecedent (body) and consequent (head) part. These two components consist out of a number of (possibly zero) atoms. Atoms contain conditions like data literals or variable assignments (among others). Multiple atoms in the antecedent or consequent are treated as a conjunction of their attributes. Informally a rule may be understood by the meaning that if the antecedent holds (is "true"), then the consequent must also hold [W3C 2004b]. Such rules can be used for the definition of integrity constraints of geospatial data allowing one property value or object to be derived from a composition of others. Through the definition of the formal meaning of the SWRL rules the constraints also allow for reasoning.

4 Spatial relations in OWL

For the definition of constraints within a spatial data ontology relations specifically considering location, extent, shape and neighborhood / topology are needed. Such relations have also been used in the constraint definition by [Ubdea & Egenhofer 1997], which is given in an extended form in figure 1. In our approach we don't restrict them to topological relations; spatial relations like "beyond" or "dWithin" are also included. For rules concerning the semantic of attribute values SWRL already provides a set of comparison and other operators (in the member submission called builtin atoms). In OWL spatial relations have to be treated as object properties of the relevant object classes. For the semantic description of these properties, OWL provides axioms like "subPropertyOf", "symmetric", "transitive" or "inverseOf" (correspond to point 1 in the categorization in table 1). Through these complemented axioms it is possible to design a hierarchy of spatial relations (see figure 2), which later on can also allow for reasoning [Mäs et al. 2005].

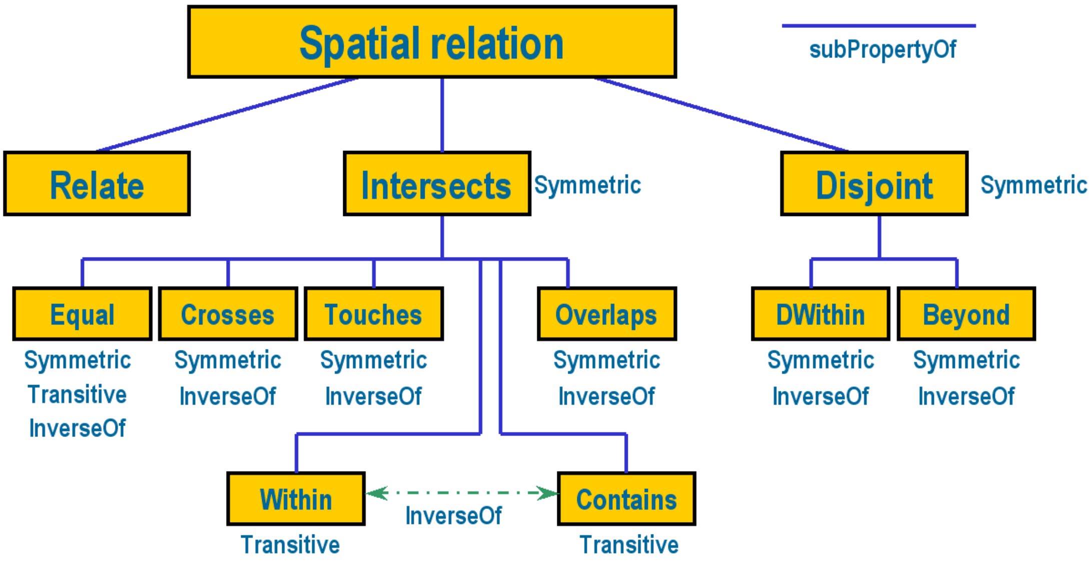
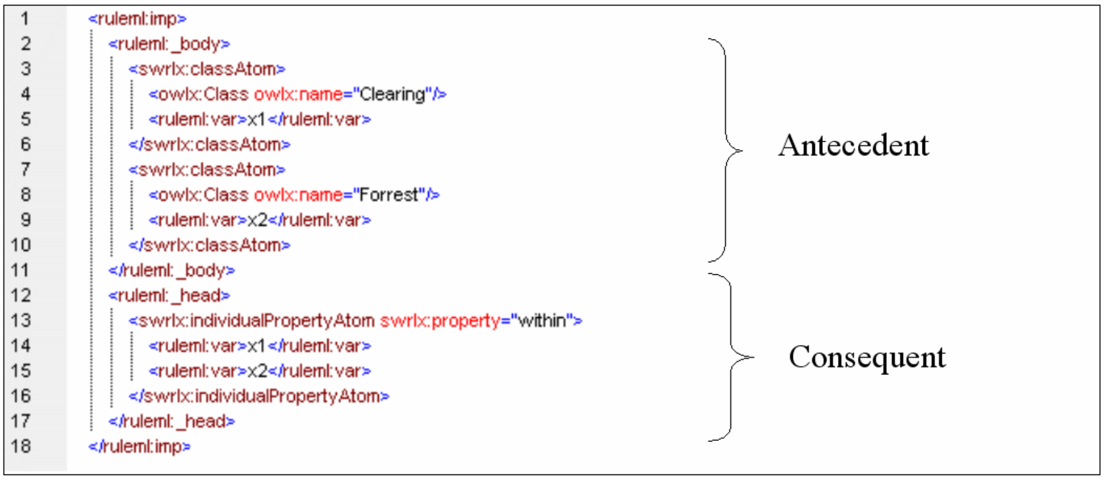


Figure 2: Hierarchy of spatial relations [Mäs et al. 2005]

In this hierarchy, for example, the property “Equal” is defined as a symmetric, transitive, sub-property of “Intersects” and the inverse property of itself. “subPropertyOf “ means in this case: if two objects are equal they are also intersected. The generic “Spatial Relation” on top of the hierarchy is abstract. The denotation and the definition of the spatial relations refer to the spatial operators defined in OGCs Filter Encoding Implementation Specification [OGC 2001]. Further explanations on the employed axioms and examples for corresponding XML formalizations are given in [W3C 2004a]. An example for logical reasoning based on that hierarchy is the conclusion from the fact “a clearing is within a certain forest” to the inverse “the forest is containing the clearing”. This is possible because “Within” and “Contains” are defined as inverse properties of each other. Such hierarchical structures can play an important role for the management of quality constraints, since it helps to find conflicts or constraints that include - or are included by - others.

5 Quality constraints in SWRL

A simple example of a quality constraint for geospatial data is given in figure 3. In natural language the meaning of this rule is: “a clearing is always within a forest”. The two atoms in the antecedent define variables for each one of the object classes. In the consequent these variables are used to set the object classes in relation. Therefore the “Within” relation of the hierarchy explained in the previous chapter is employed. SWRL limits the scope of variables to the rule in which they are declared.



```
<ruleml:imp>
  <ruleml:_body>
    <swrlx:classAtom>
      <owlx:Class owlx:name="Clearing"/>
      <ruleml:var>x1</ruleml:var>
    </swrlx:classAtom>
    <swrlx:classAtom>
      <owlx:Class owlx:name="Forrest"/>
      <ruleml:var>x2</ruleml:var>
    </swrlx:classAtom>
  </ruleml:_body>
  <ruleml:_head>
    <swrlx:individualPropertyAtom swrlx:property="within">
      <ruleml:var>x1</ruleml:var>
      <ruleml:var>x2</ruleml:var>
    </swrlx:individualPropertyAtom>
  </ruleml:_head>
</ruleml:imp>
```

Figure 3: Simple topological constraint encoded in SWRL

Because this rather simple example only relates two object classes, it could be also defined in OWL. But as soon as there would be a certain attribute value for one of the classes or a third class included, the expressive power of OWL would not be sufficient any more.

Compared to the constraint definition shown in figure 1 the example above still lacks in the possibility to express a specification i.e. a cardinality for the relation. The definition of a relation “forbidden” between two object classes would require a separate operator. A flexible cardinality variable n is not feasible since this requires the definition of complex relation descriptions (i.e. property descriptions in OWL), which is not supported by OWL and therefore also not possible in SWRL. For spatial relations like “Beyond” a distance value has to be defined, which is also not possible in this structure. SWRL provides such complementing arguments of relations for some of the earlier mentioned builtin atoms. In our approach we decided to define additional builtin atoms to satisfy the requirements of spatial data constraints.

Figure 4 shows an example of a constraint from a geological application. The constraints of this application define relations in particular for object classes that represent landslide phenomena like ditches or edges. The meaning of the example is “Ways are not allowed to be intersected by a ditch”. The consequent (head) contains the builtin atom for the “Intersect” operator. The complementing argument specification is defined as forbidden (definition refers to [Ubdea & Egenhofer 1997]). The lines 2 to 5 of the example contain annotations for further description of the constraint. Therewith it is possible to encode

- an unique ID,
- a severity,
- correction instructions
- and explanation comments (in this case the constraint in natural language)

for each constraint. The definition of a severity value allows for distinction of the treatment of constraints. Possible values in our application are:

1. strict
2. avoid violation
3. apply with caution, users reaction necessary.

The severity value “strict” means that a violation of the constraint is illegal and the violating data has to be changed. The two others leave it up to the users decision what has to be done in case of a violation. Therewith it is possible to use constraints as a description of (maybe unusual) relations of objects, which are not strictly forbidden but nevertheless have to be checked. The third value additionally requires some reaction by the user. This could be some reaction in the field or at least the input of comments on the specific situation as an explanation for possible other users.

```xml
<ruleml:imp>
    <swrlagis:constraintID rdf:datatype="http://www.w3.org/2001/XMLSchema#positiveInteger">1</swrlagis:constraintID>
    <swrlagis:severity rdf:datatype="http://www.w3.org/2001/XMLSchema#string">strict</swrlagis:severity>
    <swrlagis:correctionInstruction>Split the way into two Objects</swrlagis:correctionInstruction>
    <rdfs:comment>Ways are not allowed to be intersected with a Ditch</rdfs:comment>
    <ruleml:_body>
        <swrlx:classAtom>
            <owlx:Class owlx:name="Way"/>
            <ruleml:var>way</ruleml:var>
        </swrlx:classAtom>
        <swrlx:classAtom>
            <owlx:Class owlx:name="Ditch"/>
            <ruleml:var>ditch</ruleml:var>
        </swrlx:classAtom>
    </ruleml:_body>
    <ruleml:_head>
        <swrlagis:builtinAtom swrlagis:builtin="intersect">
            <ruleml:var>way</ruleml:var>
            <ruleml:var>ditch</ruleml:var>
            <swrlagis:specification>Forbidden</swrlagis:specification>
        </swrlagis:builtinAtom>
    </ruleml:_head>
</ruleml:imp>
```

Figure 4: Forbidden intersection with a strict severity encoded in SWRL

An example of a constraint with a minor severity is given in figure 5. Transformed into natural language it means: “Ways that are publicly accessible should not be closer to ditches than 10m.” The severity value “to apply with caution, users reaction necessary” states, that in case of an offending against the constraint, the violating data not necessarily has to be changed.

To illustrate the usage of such a rule during mobile data acquisition in a landslide monitoring application [Plan et al. 2004] we explain a possible scenario of a violation against this constraint in more detail. In this scenario a geologist comes to the landslide area, detects a new ditch in the field and measures its geometry. The prototype system we developed in the project mentioned in the introduction allows for the consideration of such rules during data acquisition. That means, if the geologist measures the new ditch the system automatically detects that a way is within a distance of 10m of the ditch and the “publiclyAccessible” attribute of this way is true and pops up a corresponding warning window. In our data model the Boolean data type attribute “publiclyAccessible” points out if the way is closed (i.e. marked as dangerous to walk on) or open for public access. After the violation has been indicated it is up to the responsibility of geologist how to react, because the minor severity of the constraint doesn’t force a change of the data. In case there is a fence in between the ditch and the way he might rate the situation as harmless.

```
<ruleml:imp>
    <swrlagis:constraintID rdf:datatype="http://www.w3.org/2001/XMLSchema#positiveInteger">2</swrlagis:constraintID>
    <swrlagis:severity>to apply with caution, users reaction necessary</swrlagis:severity>
    <rdfs:comment>Ways that are publicly accessible should not be closer to ditches than 10 Meters</rdfs:comment>
    <swrlagis:correctionInstruction>Set way attribute "publicly accessible" to false, close the way for public access </
swrlagis:correctionInstruction>
    <ruleml:_body>
      <swrlx:classAtom>
        <owlx:Class owlx:name="Way"/>
        <ruleml:var>way</ruleml:var>
      </swrlx:classAtom>
      <swrlx:classAtom>
        <owlx:Class owlx:name="Ditch"/>
        <ruleml:var>ditch</ruleml:var>
      </swrlx:classAtom>
      <swrlx:individualPropertyAtom  swrlx:property="publiclyAccessible">
        <ruleml:var>way</ruleml:var>
        <ruleml:var>x</ruleml:var>
      </swrlx:individualPropertyAtom>
      <swrlx:builtinAtom  swrlx:builtin="swrlb:equal">
       <ruleml:var>x</ruleml:var>
       <owlx:DataValue owlx:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</owlx:DataValue>
      </swrlx:builtinAtom>
    </ruleml:_body>
    <ruleml:_head>
      <swrlagis:builtinAtom swrlagis:builtin="dWithin">
        <ruleml:var>way</ruleml:var>
        <ruleml:var>ditch</ruleml:var>
        <swrlagis:specification>Forbidden</swrlagis:specification>
        <swrlagis:distance>10m</swrlagis:distance>
      </swrlagis:builtinAtom>
    </ruleml:_head>
</ruleml:imp>
```

Figure 5: Forbidden object distance with a minor severity encoded in SWRL

So the geologist only has to document this decision for future checks. In case there is no fence he might decide to set the “publiclyAccessible” attribute to false and marks the way in the reality with “danger” signs. In general constraints with a minor severity do not force a certain reaction. The decision what to do is up to the users evaluation of the situation. In case the user decides against an adjustment of the data he has to document this decision. Therewith the reaction is comprehensible, also for future quality checks.

The constraints defined can be applied, for example,

- on spatial relations between objects of the same or of different object classes,
- on a single or numerous attribute values,
- a defined relation between two attribute values of one object
- or a combination of spatial relations and attribute values of different objects.

The rules are not restricted to relate only two object classes or attributes. Even complex spatial and topological relations between numerous spatial objects together with their attribute values can be described.

6 Integration with application schema

A quality assurance process using the described rules can be integrated into the data acquisition workflow and thereby assist the user to acquire data in coincidence with the data model and the quality requirements of the application. First tests of the proposed quality assurance concepts have been made with a WFS based mobile acquisition and monitoring system within a landslide area, as mentioned above. The defined constraints and integrity rules have been used as an extension to the existing data schema (in this case based on GML, [OGC 2002b]). Figure 4 schematizes the information separation between the XML-schema and the application ontology. Further details have been presented in [Mäs 2005].

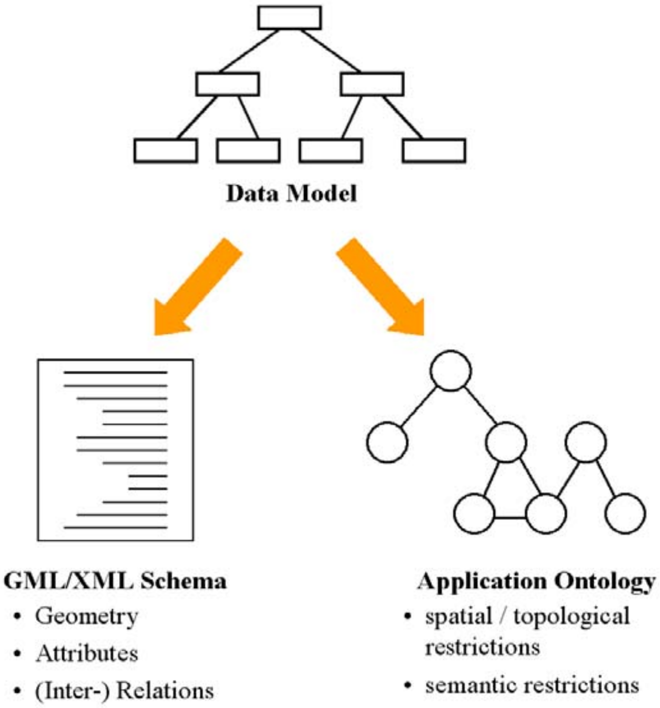


Figure 6: Separation of information between schema and ontology

During practical tests it has been proven, that the possibility to include such rules and check them automatically minimizes the time for data acquisition and checking and assures the quality of the data. For landslide monitoring the accurate collection of data in the field and efficient inspection are very important. For such an application the definition of integrity rules can help to minimize the reaction time and therewith the possible damage that slope movements might cause. Beside the plausibility check against integrity constraints of the data model it is also possible to prove the captured data against rules that reflect the conditions of universal laws or instructions. Therewith the application can advert the fieldworker to illegal or dangerous situations that are identified in the data but eventually not directly visible in the field and so help him to react to hazardous or risky situations.

7 Conclusion and Outlook

The paper introduces a framework for the to definition of spatial and other constraints of geospatial objects in an ontology. For this purpose available ontology description languages have been investigated with regard to their possibilities to formulate constraints and their provided axioms in particular. The definition of complex integrity rules that are constraining numerous objects together with their attributes makes rules with an antecedent / consequent structure (Horn clause rules) necessary. Such axioms are provided by SWRL, a relatively new member submission of the W3C. For the definition of comparison and other relations in such an axiom SWRL features so called buildin atoms. To satisfy the requirements of constraints of spatial data we decided to define additional builtin atoms for spatial and topological relations. With this extension SWRL enables for the definition of quality constraints for geospatial data. The definition of rules is not restricted to relate only two object classes or attributes. Even complex spatial and topological relations between numerous spatial objects together with their attribute values can be described. The application of such description of integrity rules makes quality information transferable and available also for the users. During mobile data acquisition the acquired data can be checked already in the field and errors are recognized early. With such an automatic checking procedure the costs of quality assurance can be reduced. Beside that the training costs of the field staff can be decreased, since they are relieved of having to understand detailed relationships and rules.

In the paper we focused on the application of axioms of an ontology for the definition of integrity constraints. In general such constraints should be part of an ontology that is formalizing the full domain knowledge and not treated separately. Therefore, as shown in [Frank 2001], it might be

necessary to define a context with its temporal, spatial and thematic limits for each constraint. In particular if an ontology is used for data integration this might become a need.
Moreover the management of integrity rules is of great significance. Flexible interfaces for the definition but also the deactivation and change of existing constraints have to be developed. A management system should also take advantage of the ontology based constraints since it allows to expose possible conflicts or constraints that include - or are included by - others. Further work in this field should take future developments of ontology modeling and rule description languages (e.g. RuleML, currently under version 0.9) into consideration.

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