Ontological exploration of geospatial objects in context

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Structured study of spatial objects and their relationships leads to a better cognition of the geospatial information and creates the concept of context at a higher level of abstraction. This study is aimed at providing a comprehensive definition of the context for geospatial objects. A combination of binary qualitative spatial relationships (i.e., direction, distance, and topological relations) among the members of a set of spatial objects will be used accordingly. In addition, by incorporating the general concept of context, obtained from either static data (attributes in a database) or dynamic data (sensors), the compact context of spatial objects will be introduced. Our framework for presentation of the involved knowledge and conception about the objects in context is also explored using ontology and description logic because of powerful conceptualization of relationships, either spatial or non-spatial, integrally. For this purpose, the hierarchies of main structure and object properties are formed at first. The constraint and characteristics of classes, such as subclasses, equivalent classes, cardinality etc., and object properties, such as being functional, transitive, symmetric, asymmetric, inverse functional, disjoint etc., are discovered and presented in more detail using web ontology language in description logic mode. The implementation is then performed in the framework of semantic web and extensible markup language syntaxes. The method ultimately facilitates, spatial reasoning by effective querying in a semantic framework taking pellet reasoner and SPARQL (a recursive acronym for SPARQL Protocol and RDF Query Language).

Keywords: spatial objects’ context; geographic information system; qualitative spatial relation; ontology; description logic; OWL

1. Introduction

In ubiquitous computing, context is referred to any information used for describing the state of an entity (1). Therefore, contexts might include location of an entity, time, activity, intentions, features, and environmental conditions. In geographic information system (GIS), many attempts were made to define spatial context based on dual of graph (2) or spatial relations of an entity (3). In the recent years, progress in technologies has contributed to considerable development in the field of location-aware systems (4) or mobile GIS (5); following that, the necessity to investigate spatial relations has been exceedingly increased. Numerous methods have been also devised for distinguishing mobile object behavior, and obtaining motional and situational context, and as a result, providing services commensurate with the situation in location-based services, and context aware systems (6). Since the notion of context mainly makes sense in pervasive computing with the intention of providing services according to a distinct situation, its principle is founded on one entity. However, many spatial applications and consequently, the activities based on GIS would require considering the collective circumstances of a group of objects or their relationships. For example, in the case of disaster management, the collective nature of relationships will enforce the requirement for a new definition of the context which is achieved from a group of objects and regions (7). Here, the objective no longer is providing services to a single entity according to its specific circumstances. That is, the context is indicative of the whole existing circumstances. In addition, although spatial properties have been widely used in such context-aware systems, this usage is often limited to properties such as location quantitatively and merely important spatial relations have been considered. This is while, in order to classify and detect similar contexts that the objects lie in, the quantitative usage of geospatial properties appears ineffectual. Quantitative paradigms about spatial data might not be sufficiently efficient in the case of data deficiency about the location of respective objects or when the expressiveness of relationships is of interest to us. Consequently, the idea of qualitative presentation of the information and relations can be used (8). In this perspective, a qualitative spatial reasoner would be efficient to compensate the data deficiency concerning the objects, and to infer and discover new qualitative information (9). Now it is evident that qualitative methods play essential role in ideal

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presentation of human perception, cognition, and reasoning. For instance, instead of merely stating the locations of two objects in terms of latitude and longitude, describing their qualitative and relative situations, such as their closeness or orientation with respect to each other, lead to better cognition commensurate with human perception. Another issue is related to integrating spatial and non-spatial knowledge involved in a context. For example, we may need to recognize a topological relation as much as we need to the value of a thermal sensor in describing a context. Perhaps, such integrity has not been presented and discussed yet. Consequently, as far as geospatial related stuff, it is required to present a more comprehensive framework so as to represent and recognize knowledge about geospatial objects in context as well as to incorporate the conventional notion of context.

As the main contribution of this study, the context will be placed, through a new definition, in an abstract level beyond the qualitative spatial relations and situational information. Herein, spatial context will be defined as a set of qualitative binary relationships, such as distance, direction, and topology. Spatial relations and non-spatial context (e.g. sensors data) will be put together to constitute the compact context of spatial objects. The proposed framework to organize context information is ontology driven due to its privilege in formal representation of concepts and knowledge. We believe that ontology and description logic, in general, are appropriate disciplines as they allow for integrated reasoning about concepts either spatial or non-spatial. The method also provides high expressiveness. Note that the current qualitative methods suffer from discrepancies like the lack of generality and suitable comprehensiveness besides difficulty of knowledge retrieval and representation. The recent developments in the field of knowledge engineering, including ontology, provide the possibility to resolve many of these issues. Another concern is to involve the extent of objects as regions (not points), which is in contrast to the generally prevailing practices in pervasive computing. In fact, the problem is considered in a larger scale and the relations of regions are considered in more detail.

In the rest of the paper, we present our definition of context for geospatial entities in Section 2. Next, in Section 3, we concentrate on knowledge representation and reasoning about geospatial objects in context relying on ontology and description logic. Finally, we conclude in Section 4.

2. Spatial objects in context

2.1. Description of context based on a combination of spatial relations

In some geospatial problems, one might need to investigate the behaviors of a group of objects as time elapses. For example, someone may want to know which relations exist in the set of regional entities in a certain time interval (Figure 1). In other words, there is a need to understand to which context or behavior these entities and objects tend. As an example, it can be detected that if in a certain moment, “b” is located inside “a”, very close to “c” and in the south-western side of “c”, then how this situation will change in the next moment. Now, suppose that the position and geometry of “b” be equivalent to “d” in the next snapshot while the other objects remain unchanged. Clearly, a number of situations become distinct as “b” will be located disjoint in the north-eastern side of “a” while overlapping with “c”. In the new snapshot, the relationships between “a” and “c” will remain unchanged. This sample shows the way that spatial objects are compared to each other in different contexts and using qualitative relationships is the way to discretely classify such difference. Therefore, by investigating the variation in contexts, one can determine how spatial relations have changed at different time periods; so as to derive whether the initial relations have been maintained.

From a theoretical point of view, numerous paradigms have been established based on spatial relations until now which can be used in our framework as well. Many primary methods comprised extension of Allen interval algebra for reasoning about the spatial events at different times (10). Kettani and Moulin benefited from the idea of spatial conceptual maps for generation and description of routes in a qualitative manner (11). Their spatial model was founded on the concept of objects influencing an area, which determines how people reason about the objects, evaluate the metric dimensions, and express the qualitative distance between objects. Moreover, the qualitative reasoning was supported with stronger theoretical fundamentals through using topological relations in the models such as 9-intersection (12), region connection calculus (RCC) (13), and egg yolk topology (14). Assuming a set of spatial objects, context is referred to the set of binary qualitative relations, either metric or topologic, between the members of that set. As observed in Figure 2, approximate and qualitative distance relations including very close (VC), close (C), commensurate (CO), far (F), and very far (VF) have been used in this study. As indicated in the figure,
qualitative direction relations are north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), and northwest (NW). Moreover, the qualitative binary topological relations signify eight basic relations used in 9-intersection and RCC models. These relations comprise disconnected (DC), externally connected (EC), partially overlapping (PO), equal (EQ), tangential proper part (TPP), non-tangential proper part (NTPP), inverse of tangential proper part (TPPi), and inverse of non-tangential proper part. The readability of a relation is from first object towards the second one; for example, if for two objects "a" and "b", the relations VC(a, b), NTPP(a, b), and E(a, b) are established, they would imply that object a is very close to b, object a is NTPP of object b and object a is located in the south side of b. Some relations, like distance relations, are symmetric or a relation like TPP have an inverse relation (TPPi), while some others do not. Such characteristics of qualitative spatial relations will be further discussed in Section 3.1. For the sake of computation, there are various techniques, which can be used depending on the data model and application. In a vector data model, for instance, computational geometry techniques are efficient to determine topological relations (15). One of the simplest ways to specify the metric relations, like distance and direction, is using centroid of objects and taking given intervals to convert distance and direction into qualitative ranges. Being invariant with respect to the variation of scale and rotation is regarded as an important property of topological relations compared to metric relations. Such variations must be certainly taken into account in the transformation of coordinate system where the qualitative metric relations may need to be re-examined.

2.2. Description of compact context of spatial objects
So far, all discussions concerning context have been focused on its description based on the situation of spatial relations among objects. On the other hand, in the field of computer sciences, context provides choices for offering intelligent services on the basis of sensors related to individuals or entities. In a more advanced level, that analysis of information obtained from sensors, which are interpreted as behaviors and characteristics are determinant criteria for invoking a service (16). It must be taken into account that any spatial object or entity may contain a collection of non-spatial information as well. For example, each object may consist of a number of ambient sensors describing some environmental features of the object. In addition, the attribute information tailored to an object can be stored in a database, which may also provide more elaborate information to create a context. To conclude this section, as seen in Figure 3, a compact context of spatial objects is structured as a collection of spatial objects (either fixed, mobile or content, whose qualitative binary spatial relations have been discovered), the determinant information describing each object (including the data obtained from portable devices and sensors, as dynamic circumstances) and non-spatial data stored in databases, as static circumstances.

3. Modeling with ontology and description logic
From philosophical point of view, ontology is nothing but the studying of entities and their relationships. In artificial intelligence, the ontology is known as the explicit specification of concepts and representation of a conceptual system via a logical theory (17). For a given domain, ontology consists of statements that define
concepts, relationships, and constraints that form the information of the domain model. For knowledge representation in the realm of geospatial relations, Delafontaine et al. already presented a qualitative assessment for analyzing mobile points in which a number of class-diagrams, in the form of unified modeling language, were developed to execute an information system (18). In the area of image interpretation aimed at representation of knowledge for human brain tissue, Hudelot et al. practically benefited from ontology and fuzzy spatio-temporal relationships (19). Haav et al. used ontology for merging GIS information resources, users’ profile information, and context in order to provide smarter location-based services, in which some spatial relations were considered slightly improved (20).

The ontology is, to some extent, analogous to a database schema or an object-oriented class diagram (21). We already know that an object-oriented model has many advantages with respect to relational models (22). But, we must have compelling reasons to select ontology rather than object-oriented approaches in this study. In contrast to object-oriented solutions, relationships in ontology exist distinct from the concept that they join. This allows relationships to have inheritance and

![Figure 3. Sample of a compact context of spatial objects.](image3)

![Figure 4. OWL DL descriptions, data ranges, properties, individuals, data values, axioms and facts.](image4)
restriction rules of their own which gives great flexibility to the model. For example, the spatial objects’ context could offer a “hasSpatialRelation” as a relationship that contains a sub-relationship “hasMetricRelation” and another sub-relationship “hasTopologicRelation”. In an object-oriented solution, an object is bound for its lifetime to its class. While the ontology offers flexibility with instances, an instance is not permanently bound to any class or set of classes. It is possible to assign multiple classes to a given instance. This allows the flexibility to form and capture information independent from class definitions. The other important characteristics that make ontology more suitable than other knowledge representation methods are logical reasoning (23). Ontology offers logical reasoning capabilities to infer new relationships, once information has been properly described.

Different ontological languages have their own specifications and facilities. Recent development in standardizing these languages has led to Web Ontology Language (OWL) from World Wide Web Consortium (W3C). The OWL can be employed at different levels of: OWL Lite, web ontology language in description logic mode (OWL DL), and OWL Full. OWL Full has some more abilities compared to OWL DL; however, the possibility of having a complete logical framework with reasoning is reduced in OWL Full compared to OWL DL (24). Hence, in order to have a better representation of ontology for spatial objects in context, the OWL DL will be used in this study which is fully based on description logic. Figure 4 represents the symbols and definitions related to the components of OWL DL, its facts, and axioms. It contains the abstract syntaxes in the left side and the corresponding OWL DL syntaxes in the right side. The tautology $\top$ is interpreted as always possible interpretation (“Thing”), and the contradiction $\bot$, is interpreted as unsatisfiable statements (“Nothing”). The main components that make up this ontology are classes, properties, and individuals. Classes are sets of individuals and each individual is considered as an instance of a class. Properties are binary relationships either between individuals, which is called object property, or between an individual and the value of an attribute, which is called data-type property. All values of data-type properties have their own range. Classes can have subclass (“SubClassOf”), disjoint class (“DisjointClasses”), or equivalent class (“EquivalentClasses”). Furthermore, the union (“unionOf”), intersection (“intersectionOf”), and complement (“complementOf”) of classes can be defined. Another ability of OWL DL is restricting classes by defining object or data-type properties in the form of: universal quantifier (“allValuesFrom”), existential quantifier (“someValueFrom”), having a specific value (“hasValue”), minimum cardinality (“minCardinality”), and maximum cardinality (“maxCardinality”). On the other hand, the object properties can be defined through domain and range and can get the properties such as being symmetric, anti-symmetric, functional, inverse functional, transitive, reflexive, or irreflexive. The object properties can be restricted to the specific domain and range of classes. As will be seen in Section 3.1, OWL DL syntaxes are useful tools to tackle complicated aspects of domain knowledge. The implementation of ontology consists of two main steps namely structuring the main components, concepts, and relationships, $\text{Tox}$, and then introducing instances to the ontology, $\text{Abox}$ (For more details about the ontology and description logic, see (25)).

3.1. Structuring the concepts and relations

For implementing ontology in this research, the main classes in the domain of spatial objects in context were primarily determined. One of the main classes is spatial object class which can in turn have two sub-classes, namely; mobile objects and content or immobile objects. Each class of immobile or content objects contains sub-classes which specify whether the objects are equipped with information device or they are simple. Another main class is sensor device which can comprise sub-classes for various types of sensors including ambient and smart-tag sensors. Another main class is the context class which includes two subclasses; spatial context and situation context. Figure 5 illustrates these main classes of ontology. In addition, the hierarchy of classes and object properties can be seen in Figure 6. The binary spatial relations are divided into two main types of metric and topologic. The metric relation in turn includes two sub-properties of direction and distance. A context can be in relationship with a set of objects (“hasSpatialObject”) and mutually, a spatial object can be regarded as a member of a context (“isSpatialObjectOf”). In addition, spatial objects can be equipped with some information device (“hasInformationDevice”) and mutually an information device belongs to a spatial object (“isInformationDeviceOf”). By now, the classes and properties were introduced in general. There are many semantic lookup and constraints which can be expressed in terms of axioms in the description logic. Regarding such relations, the ontology may find stronger reasoning ability and the domain knowledge would be modeled comprehensively and aggregates as well.

Some constraints in classes, such as being a subclass of another class, were presented in the figures; however, many of other ones cannot be demonstrated. For example, it should be determined that the union of two classes namely “ContentObject” and “MobileObject” are equivalent to “SpatialObject” or that “EquippedContentObject” in real is the intersection of content objects and those objects that have at least an information device. In addition, using description logic, “SituationContext” class is defined as a class including only those spatial objects which are either equipped content objects or equipped mobile objects. Moreover, “SpatialContext” is composed of spatial objects which participate in a certain spatial relationship. “CompactSpatialContext” is another class that is equivalent to the intersection of two classes, namely “SpatialContext” and “SituationContext”. These
concepts have been defined based on required facts and axioms; however, we cannot explain here the entire set due to space limitation. Some of them are represented with OWL DL syntaxes as follows:

- Spatial Object \equiv Mobile Object \sqcup Content Object
- Mobile Object \sqcap Content Object \sqsubseteq \bot
- SmartTagSensor \sqsubseteq Sensing Device
- Equipped Content Object \equiv Content Object \sqcap (\geq 1 \text{hasInformationDevice}.SensingDevice)
- Equipped Mobile Object \equiv Mobile Object \sqcap (\geq 1 \text{hasInformationDevice}.SensingDevice)
- Situation Context \equiv \forall \text{has Spatial Object. (Equipped Content Object \sqcup Equipped Mobile Object)}

Figure 5. A preliminary representation of classes in the compact context of spatial objects.

Figure 6. Hierarchy of classes and object properties in the compact context of spatial objects.
• Spatial Context $\equiv \forall$ has Spatial Object ($\exists$ has Spatial Relation. Spatial Object)
• Compact Spatial Context $\equiv$ Spatial Context $\cap$ Situation Context
• Spatial Object $\cap$ Sensing Device $\cap$ Context $\in \perp$

Deeper meanings of properties in the ontology could be gotten through description logic. For example, the property “isInformationDeviceOf” is defined as a functional relation in such a way that a sensor device may not belong to more than one spatial object. There are similar properties like this in our ontology. “NonTangentialProperPart” is a transitive relation as if object “$a$” be inside the object “$b$” and object “$b$” be inside the object “$c$”, as non-tangentially proper part (NTPP) form, then “$a$” will participate in a “NTPP” relationship with “$c$” too. Another characteristic is that the property “PartiallyOverlaps” is symmetric. It means that if object “$a$” is partially overlapped with object “$b$”, then “$b$” will also be partially overlapped with “$a$”. Some other properties such as directional relations (e.g. West) have inverse properties (East). It should be pointed out that all relations in the sub-properties namely distance, direction, and topological relations must be disjoint regarding the relations of the same type. For example, only one of the topological relations can exist between two objects. A semantic reasoner can take into consideration all of such situations and infer new statements for the ontology. Some of these characteristics are given below and more sophisticated investigation on object properties has been presented in Table 1:

- $\top \subseteq \subseteq \subseteq \subseteq 1$ isInformationDeviceOf
- $Tr$ (NonTangentialProperPart)
- PartiallyOverlaps $\equiv$ PartiallyOverlaps
- West $\equiv$ East
- Commensurate $\subseteq$ hasDistanceRelation

### 3.2. Implementation of the main structure

For implementation purposes, OWL can be presented in the form of extensible markup language (XML) tags. Some prefixes such as “owl”, “xsd”, “rdf”, and “rdfs” help to access to existing structures and primary concepts of ontology and making new classes, properties, and statements. For example, using the prefix owl, we can apply common concepts such as “unionOf”, “intersectionOf” etc.

The tags and their hierarchical structure in the OWL, like other ontologies under the web, follow the XML framework. The following tags show how two classes of “CompactSpatialContext” and “MobileObject” are created:

```xml
<Declaration>
  <Class IRI="#CompactSpatialContext"/>
</Declaration>
<Declaration>
  <Class IRI="#MobileObject"/>
</Declaration>
```

The following tags are samples of creating constraint and axiom for the class of “SituationContext”. In addition, it shows that the “ContentObject” is a subclass of “SpatialObject” and two classes of “EquippedMobileObject” and “SimpleMobileObject” are disjoint.

```xml
<EquivalentClass>
  <Class IRI="#SituationContext"/>
</EquivalentClass>
<ObjectAllValuesFrom>
  <ObjectProperty IRI="#HasSpatialObject"/>
  <ObjectProperty IRI="#HasContentObject"/>
</ObjectAllValuesFrom>
<DisjointClasses>
  <Class IRI="#EquippedMobileObject"/>
  <Class IRI="#SimpleMobileObject"/>
</DisjointClasses>
```

Some examples from sub-properties, inverse and functional object properties have been represented in following tags:

```xml
<SubObjectProperty>
  <ObjectProperty IRI="#ExternallyConnectedFrom"/>
</SubObjectProperty>
<InverseObjectProperty>
  <ObjectProperty IRI="#HasTopologicalRelation"/>
</InverseObjectProperty>
<FunctionalObjectProperty>
  <ObjectProperty IRI="#IsInformationDeviceOf"/>
</FunctionalObjectProperty>
```

### 3.3. Data entry

After configuring the main ontological structure, the procedure proceeds by introducing the samples and allocating the classes and the relations among them. For example, some spatial objects of variety of content and mobile could be created in either equipped or simple types. Subsequently, varieties of the relations between them could be introduced. In our case, the context containing a given set of spatial objects was introduced. A number of such items have been illustrated in the following tags. You can see how the simple mobile object SMO1 has been introduced, and how some object properties and data properties have been asserted.

```xml
<Declaration>
  <NameIndividual IRI="#SMO1"/>
</Declaration>
<ClassAssertion>
  <Class IRI="#SimpleMobileObject"/>
  <NameIndividual IRI="#SMO1"/>
</ClassAssertion>
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#Commensurate"/>
  <NameIndividual IRI="#SMO1"/>
  <NameIndividual IRI="#SMO1"/>
</ObjectPropertyAssertion>
<DataPropertyAssertion>
  <DataProperty IRI="#ID"/>
  <NameIndividual IRI="#SMO1"/>
  <Literal datatype="xsd:plainLiteral">smo1</Literal>
</DataPropertyAssertion>
```
Table 1. Object properties in the ontology of compact context of spatial objects and their characteristics.

| Object properties                  | Functional | Inverse functional | Transitive | Symmetric | Asymmetric | Reflexive | Irreflexive | Disjoint properties | Inverse properties | Super properties |
|------------------------------------|------------|--------------------|------------|-----------|------------|-----------|-------------|----------------------|-------------------|------------------|
| 1 hasInformationDevice             | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 2 hasSpatialObject                 | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 3 IsInformationDeviceOf            | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 4 IsSpatialObjectOf                | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 5 hasSpatialRelation               | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 6 hasMetricRelation                | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 7 hasDirectionRelation             | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 8 East                             | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 9 North                            | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 10 NorthEast                       | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 11 NorthWest                       | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 12 South                           | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 13 SouthEast                       | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 14 SouthWest                       | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 15 West                            | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 16 hasDistanceRelation             | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 17 Close                           | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 18 Commensurate                    | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 19 Far                             | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 20 VeryClose                       | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 21 VeryFar                         | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 22 hasTopologicalRelation          | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 23 Disconnected                    | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 24 Equals                          | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 25 ExternallyConnected             | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 26 NonTangentialProperPart         | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 27 NonTangentialProperPartI        | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 28 PartiallyOverlaps               | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 29 TangentialProperPart            | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
| 30 TangentialProperPartI           | ✗          | ✗                  | ✗          | ✗         | ✗          | ✗         | ✗           | ✗                   | ✗                 | ✗                |
3.4. Reasoning and querying

If a model follows the logical framework, the logical reasoning is accordingly possible for that. A reasoner could determine whether all logical terms and the de
finitions exist among the individuals of the classes. The constraint of classes, such as subclasses, equivalent classes, cardinality etc., along with the characteristics of object properties, such as being functional, transitive, symmetric, asymmetric, inverse functional, disjoint, were then presented in more detail using OWL DL. The implementation was performed in the framework of semantic web and XML syntaxes. By employing the Pellet reasoner, the complementary statements were made and added to the ontology, and finally sample SPARQL queries such as “which members of a spatial context overlaps with a given object?” were addressed.

The major difference between the spatial context introduced in this study and the related activities, such as pervasive computing, is regarding the entire set of objects where spatial context relies on qualitative description of relations in a collective manner. Such comprehensive consideration will be effective in applications dealt with management of geospatial objects in which the behavior of objects in the collection and the comparison of situations in different contexts is of importance to us. The results were suggestive of effective capability of ontology for modeling the classes and relations flexibly and logically, performing integrated reasoning in the semantic framework, and executing useful queries. The future studies can benefit from spatial and semantic reasoners to represent and identify the situational and spatial context simultaneously, which will bring about new capacities in geospatial information sciences.

Notes on contributor

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