ONTOLOGY FOR CONTEXT-AWARE VISUALIZATION OF SPATIAL DATA IN MOBILE DEVICES

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ABSTRACT:

Recently, the visualization of the spatial data is gaining importance in the ubiquitous computing. In geoinformatics such as distributed GIS or Location Based Services, context models are responsible for the robust communication between the mobile user and the system. Context-aware systems are considerable issue in ubiquitous systems, reflecting delicate effect of the designed context leads us to ontologies. To develop a user-adaptive ontological model, users' different situations should be defined properly. In Location Based Services (LBS), much intelligent system ignores affect of user's states and roles except user's location. However different user profiles need customized visualization style in order to provide a relevant spatial data. In this paper, the aim of the research is to define new mobile contextual ontologies (classes and properties) which obey relevance theories so as to define any user's relevant visualization profile on the mobile devices. Therefore a kind of intelligent system proposed here can reason over the complete semantic model of the OWL language by an inference engine. A contextual ontology (OWL-DL) for relevancy has been edited in an ontology editor and knowledge acquisition system. Consistency of taxonomies has been checked in a reasoning engine for OWL-DL. Consequently inference engine retrieves criteria for relevant visualization profile with its reasoning algorithms or defined SWRL (Semantic Web Rule Language) as a server.

1. INTRODUCTION

Location Based Services (LBS) is an important application field of distributed GIS that originally evolves from the advancements in computer sciences such as distributed systems and mobile computing. This new technological subjects are discussed under pervasive computing and ubiquitous computing concepts. Pervasive computing is about acquiring context from the environment and dynamically building computing models dependent on context whereas ubiquitous computing aims to provide pervasive computing environments to a human user as she or he move from one location to another (Singh *et al.* 2005). Satyanarayanan 2001 enumerates characteristics of pervasive computing as smart spaces, invisibility, localized scalability, uneven conditioning. In the context of ubiquitous computing, Borriello *et al.* 2005 claimed that location systems are not yet ubiquitous, but a number of applications are candidate for ubiquitous location systems.

In LBS, different sensor types are used to gather location data of the system participants. Grossniklaus *et al.* 2006 proposed a method that combines a GPS sensor and a Bluetooth digital pen to provide LBS in mobile environments based on interaction with printed maps. Simon *et al.* 2006 developed a spatially aware mobile phone for LBS. The module includes differential GPS, a compass, and 2 axis tilt sensor in a self-contained Bluetooth unit. Winter and Nittel 2006 designed a model for shared ride trip planning in ad-hoc mobile geosensor networks. The system searches for available shared ride opportunities with geosensor and derives optimal shared ride travelling.

In this point of view, any research that deals with ubiquitous computing should concern context and context awareness. Dey and Abowd 2000 defined context as any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. Brown *et al.* 1997 explained that context-aware applications can be divided into continuous and discrete. Continuous context-aware applications are more challenging than the discrete however most applications can be described as discrete. Continuous context aware applications provide associated information in the overlapped contexts. Burrell *et al.* 2002 designed a context-aware application for a collage campus area to inform visitors about activities going on in the environment. The campus application is location sensitive and enables user feedback for the content. Prekop and Burnett 2003 claimed that simply defining context is not enough to be able to use the concept of context to develop context-aware applications. They described a conceptual model of activity-centric context capable of supporting complex, cognitive activities. According to the activity-centric theory, the context that is based on activity is specialized from a higher level, more generic context. Dey and Makoff 2005 described an architecture that supports the building of context–aware services that assume context is ambiguous and allows for mediation of ambiguity by mobile users in aware environments. The design guidelines arise from supporting mediation over space and time, issues not present in the graphical interface domain.

The ontology-based modelling is key requirement to build an effective context-aware application. This concept leads us to understanding meaning of ontologies and its applications in computer sciences. The aim of the Artificial Intelligence (AI) is to create a model which almost fits the real world so as to adopt

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all changes to any application. Thus the arising problem is how to model the world. In this point of view, computer sciences borrow term Ontology from philosophy. One of the most cited definition is done by Thomas Gruber (1993) in order to elucidate term ontology: An explicit definition of conceptualization. This definition refers to another term conceptualization that includes the objects, concepts, and other entities that exist in a domain and their relationship (Genesereth and Nilsson 1987). More comprehensive definition is as follow: the theory of distinction which obeys different states of the world. Distinctions are physical objects, events, regions, concept, property, quality, state etc. (Guarino and Giaretta 1995).

Enabling knowledge sharing is one of the some tasks of ontologies. A healthy communication between people and software systems require interoperability and knowledge sharing. These requirements prevent re-inventing the wheel (Uschold and Gruninger 1996).

Though differences occur among the ontologies, some general agreements exist for ontologies (Chandrasekaran and Josephon 1999):

- There are objects in the world.
- Objects have properties or attributes that can take values.
- Objects can exist in various relations with each other.

Necib and Freygat 2005 presented an approach for query processing within single relational databases using ontology knowledge in addition many efforts have put into developing ontology based techniques for improving the query answering process in database and information systems.

Ontologies enabling knowledge representation are designed with an ontology language in computer applications of artificial intelligence. Ontology languages underlie a pervasive computing system in a knowledge base. To satisfy frame-based modelling requirements (concepts, taxonomies, relations, formal semantics and automated reasoning) in description logic, OIL and DAML+OIL were developed. Afterwards OWL is derived from DAML+OIL incorporating experiences obtained from design and application of DAML+OIL. OWL includes more vocabulary for describing properties and classes such as disjointness, cardinality and equality (McGuinness and van Harmelen 2004). OWL-DL enables computable conclusions (complexity) which can be completed in a certain time (decidability). DL refers to Description Logics as it provides formal properties. The Semantic Web Rule Language (SWRL) is another specification to extract implicit information from explicit ones. SWRL concludes acquired knowledge with a rule based XML syntax language. Therefore it can be perceived a different kind of OWL DL specification. In any case, SWRL is based on a combination of the OWL DL and OLW-Lite sublanguages of OWL with the Unary/Binary Datalog RuleML sublanguages of the Rule Markup Language (RML) (Horrocks *et al.* 2004).

Recently, a number of papers discussing the semantic representation of the geographic data in order to provide interoperability have appeared in major GIS researches. In Frank 2001, 5-tiers of ontology integrating different ontological approaches are explained in a unified system. The relation of the 5 tier ontology and consistency constraints was explored, and it was shown that different constraints were appropriate to different tiers. Jones et al 2004 claimed that traditional web search engines are not sufficient to retrieve relevant geographic data. Jones et al 2004 developed SPIRIT search engine which includes user interface, geographical and domain-specific ontologies, web document collection, core search engine, textual and spatial indexes of document collection, relevance ranking, and metadata extraction. To support retrieval of documents that are considered to be spatially relevant to users' queries, the query expansion techniques are expressed by Fu et al 2005. The proposed method expands a spatial query by trying to derive its geographical query footprint, and it is spatially designed to resolve a query that involves a fuzzy spatial relationship.

Agarwal 2005 examined many of the key ontological efforts in Geographic Information Science (GIScience) and in the wider academic community. Some research issues were briefly determined from the discussion in the Agarwal 2005:

- Semantics and inter-operability within database and data modelling research.
- Methodological and systematic approaches to domain modelling.
- Representation of human conceptualization in the models and developments of methods and languages to define and formulize these conceptualizations.
- An integrated methodology can be developed as a generic approach to ontology development in the geographic context.

In this paper, a mobile contextual model is proposed that is capable of perceiving situational changes in the environment. The aim of the mobile context model is to provide relevant visualization characteristics of the spatial data to the mobile users in a distributed GIS. Section 2 presents relations between relevancy theories and visualization of spatial data for the new contextual ontological model. Section 3 then describes two reasoning possibilities for the defined context. Concluding remarks are given in section 4.

2. CONTEXTUAL ONTOLOGICAL MODEL

The relevancy theories propose different point of views to support new context models that able to create relevant data to the user. The theories should be reviewed to obtain appropriate model though context-aware applications already provide a relevancy by themselves. It is difficult to define and measure degrees of relevance because understanding of relevance is based in cognition. In this way, it is clear that relevance should be understood intuitively. According to Saracevic 1996, manifestation of relevance is based on relation. The relation is between components of relevance and texts. Text, here, represents all relevant information object types such as documents, images and sounds. Therefore every relevance manifestation includes a relation with an information object. Saracevic 1996 described five manifestations of relevance:

- System or algorithmic relevance.
- Topical or subject relevance.
- Cognitive relevance or pertinence.
- Situational relevance or utility.
- Motivational or affective relevance.

Although Saracevic 1996 explained five manifestations of relevance, Cosjin and Ingwersen 2000 claimed that fifth manifestation of relevance should have been changed.

Motivational relevance should be viewed as an attribute of relevance. Instead, a socio-cognitive relevance which is based on socio-cultural context meets affective relevance requirements. Socio-cognitive relevance is a relation between situation, task or a problem at hand as perceived in socio-cultural context and information objects. Some theorists chose the uncertainty as the base for information retrieval (IR) instead of relevance. However Saracevic 1999 claimed that IR can not be successful with the uncertainty approach. The result of the relevance revolution is an increasing acceptance that relevance should be judged in relation to the information need than the request (Borlund 2003). Xu and Chen 2006 suggested that topicality and novelty are the two major underlying dimensions of relevance. If they are, then the concept of relevance can be depicted with different combinations of topicality and novelty levels.

Relevancy also becomes a key notion in GIS researches to retrieve spatial information appropriately from different point of views such as database and visualization. Specifically, we focus on visualization issues in this paper. Edwardes *et al.* 2005 proposed an approach based on the notion of hierarchical spatial tessellation for generalization. They used the quad tree to make decisions on the number of objects to display. The quad tree tessellates space until every point is assigned to a separate block. While zooming a level is chosen that meets a minimum acceptable symbol size criterion. Particularly the solution allows rapid traversal and retrieval of data for LBS. Reichenbacher 2005 stressed the importance of being relevant for LBS. The paper claimed that further relevance types beyond positional relevance used in LBS should be considered. Relation between mobile context and relevance determines relevance types for mobile environment. Reichenbacher 2005 enumerates relevance types as spatial relevance, temporal relevance, algorithmic relevance, thematic relevance, cognitive relevance and activity relevance. Meng 2005 enumerates design pattern as the centring, redundant encoding, continuously varying level of details, multiple levels of details, space contraction, single window with details on demand, augmented focusing, orientation gesture and affective emphasis.

We determined five manifestations to represent relevance model for mobile visualizing. Visualization, here, means two dimensional maps with restricted resolution that almost meet requirements of poor screen and RAM capability of mobile devices. Recently, some papers (Caquard *et al* 2005, Brauen 2006) claimed that sound design in cyber cartography is necessary for better understanding of the geospatial information. Efficient and well defined sound design can support map product which is more relevant to the user. The accuracy of the location data of the mobile user determines the accuracy of the narrator support of the visualization at the same time. Table 1 that explains manifestations of relevance within their types and descriptions of their relations intends relevancy of spatial visualization.

Relevance	Describes a relation between
Data retrieval	query and spatial data
Object ranking	topic of query and spatial data
Cognitive	user profile and symbolization
Situational	device or location and visual features
Motivational	intent and supportive symbolization

Table 1. Manifestations of relevance

Researches about algorithms of data retrieval and object ranking are mostly related to IR. The algorithmic relevance that is described by the second manifestation of relevance for the visualization is out of the scope in this paper. In particular, this paper concentrates on the data retrieval, the cognitive, the situational and the motivational types of the relevance.

We proposed a general approach that is different from algorithmic relation between key words of the query and spatial data to extract relevant spatial data. Some levels of the spatial data are defined and then the all contents of the each level are accepted as the relevant spatial data. For instance, outside of a building and inside of a building are different levels. Therefore inside of the building should be visualized separately from outside while user is dealing within the building. Whenever user is leaving from the building, new relevant level changes in to the district representation level that includes the buildings and the streets connecting them. Inside of the building and outside of the current district are irrelevant spatial data for the mobile user according to the theory.

The cognitive relevance is relation between the user's knowledge and the symbolization of the spatial objects. Users perceive the real world differently depending on their own experiences and knowledge. Perception capability changes from user to user. Therefore the users should be categorized to guess their state of knowledge and the information need of the user. Categorization provides a system that is able to react to a certain group of people. For example people that are grouped into the some ranges of age or the some range of occupations give an idea about the users' state of the knowledge. Creating a user profile is a well-known way to collect the information about user. The symbolization of the spatial data should be compatible with user profile to relate user knowledge with the cartographic symbol type.

The situational relevance is relation between the device properties or location data and the digital visual features of the screen. The capability of the mobile device is a part of the current situation that represents the user. Thus the mobile device should determine some characteristics of the visualization such as colour of visualization, scale, geocoding, space contraction. Not only mobile device but also additional device and sensors that produce the user's location data reveal the current situation. There is an explicit relation between the user's location information and the centring of the visualization. Another relation can be established between average velocity of the location change and the refresh rate of the visualization.

The motivational relevance is relation between the intent of the user and the supportive symbolization. The intent of the user can be navigation, meeting, shopping etc. For example, a user that navigates a place needs visualization with direction arrows. One of the problems about the motivational relevance is to determine exact the user's intent. An appropriate graphic user interface (GUI) that is designed to understand the user's real intent can overcome the problem. Figure 1 shows detailed relations that represent manifestations of the visual relevance of the spatial data.

Many scientists developed methods to create context and contextual ontological model for pervasive computing environments. Chen *et al.* 2004 presented context broker architecture to create intelligent spaces with ontologies for pervasive computing. Though Chen *et al.* 2004 developed a detailed context ontological model. Gu *et al.* 2004 proposed a service oriented context aware middleware architecture in order to implement an ontological model. However the model is developed only for smart home application instead of a wide field. Becker and Nicklas 2004 explained an architecture which combines the strengths of both context models and ontologies. They claimed that the combined approach provides the efficiency of context management through context models with the semantic expressiveness of ontologies. Christopoulou *et al.* 2005 developed an ontology based context modelling, management and reasoning process for composing context aware applications. However neither ontology reasoning nor SWRL reasoning that are important to determine the performance of the context model are explained by Christopoulou et al. 2005. Weissenberg *et al.* 2006 described larger ontology architecture to realize mobile system retrieving relevant information during 2008 Olympic Games in Beijing.

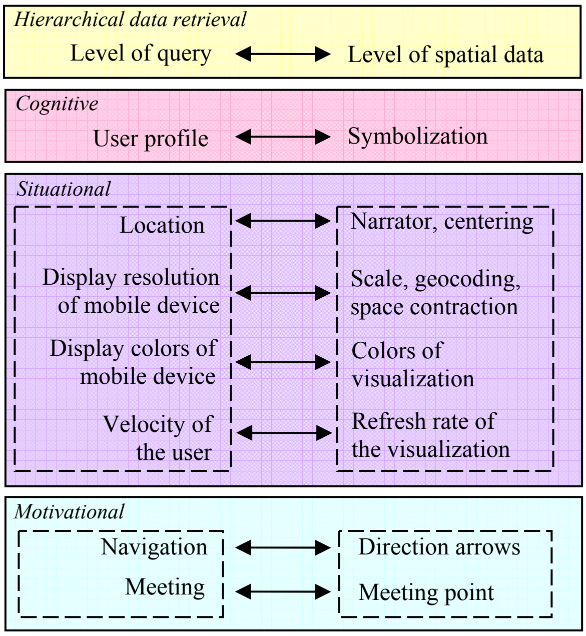

Figure 1. The visual relevance of the spatial data

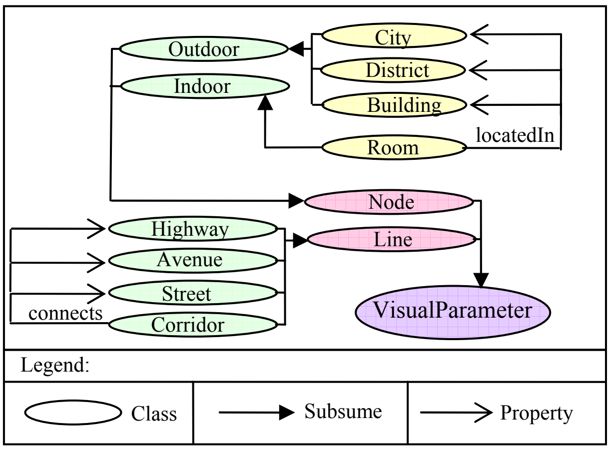

Figure 2. Conceptualization of the visualization and properties

The manifestations of the visual relevance and mobile context form the base of the contextual ontological model. The model specifically focuses on the visualization of the spatial data for mobile devices that are ignored by preceding researches. To state the visualization appropriately, we envision a model that includes the visualization parameters as an existence for the spatial data. Conceptualization of the visualization and their relations that explained in semantic approach are depicted in figure 2. The aim of the model is to reason the visual relevancy of the spatial data depending on the adapted manifestations of the visual relevance that are explained before in this section. Figure 3 shows the place of the visual parameter in the upper context model.

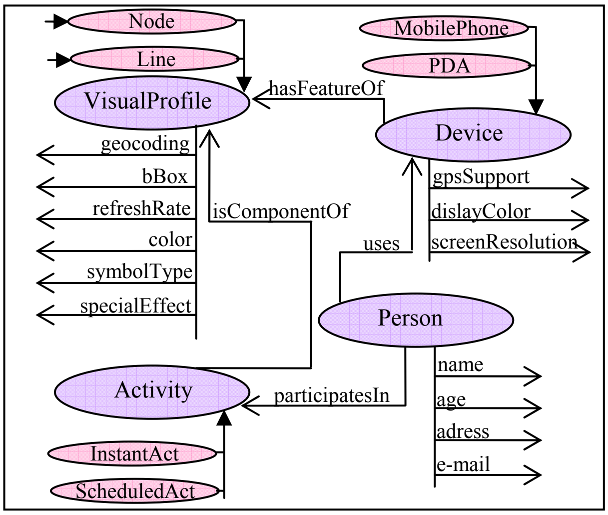

Figure 3. Upper ontologies with the visualization class

3. CONTEXT REASONING

Context reasoning is implemented as the ontological reasoning and the rule based reasoning. To launch reasoning, the semantic query language is used in this research. A similar query method is used by Lutz and Klien 2006 for a different approach. They presented an approach to ontology-based GI retrieval that contributes to solving existing problems of semantic heterogeneity and hides most of the complexity of the required procedure from the requester. A query language and graphical user interface allow a requester to intuitively formulate a query using a well-known domain vocabulary. From this query, an ontology concept is derived, which is then used to search a catalogue for a data source that provides all the information required to answer requester's query. If a suitable data source is discovered, the relevant data are accessed through a standardized interface.

3.1 Ontological Reasoning

OWL supported with description logic provides ontology reasoning in the context model. Thus contextual ontology model are composed by OWL-DL specification to fulfil some logical rules. Specifically TransitiveProperty, inverseOf, subClassOf, disjointWith are used as the rules to reason the implicit information from the explicit information (Table 2).

TransitiveProperty is an OWL-DL property for relations between conceptualizations. In the context model we determine four visual levels as shown in Figure 2. The classes of City, District, Building and Room represent visualization levels of the spatial data. *locatedIn* relation that is a transitive property setup connection between the levels. *inverseOf* is also an OWL-

DL property for the relations and it indicates the relation has an inverse a relation for any individual of a class. With the *TransitiveProperty*, the ontology reasoning provides that at least one covering level of the visualization of any two spatial objects can be obtained in the contextual model. With the *inverseOf* property, the ontology reasoning provides that if a upper visual level of a spatial object is determined, the lower level of the spatial object can be obtained.

Transitive-Property	(?P rdf:type owl:TransitiveProperty) ^ (?A ?P ?B) ^ (?B ?P ?C) => (?A ?P ?C)
subClassOf	(?a rdfs:subClassOf ?b) ^ (?b rdfs:subClassOf ?c) => (?a rdfs:subClassOf ?c)
inverseOf	(?P owl:inverseOf ?Q) ^ (?X ?P ?Y) => (?Y ?Q ?X)
disjointWith	(?C owl:disjointWith ?D) ^ (?X rdf:type ?C) ^ (?Y rdf:type ?D) => (?X owl:differentFrom ?Y)

Table 2. Parts of OWL reasoning rules (Wang et al 2004)

Explicit Context

```
<owl:TransitiveProperty rdf:about="#locatedIn">
  <rdf:type rdf:resource="http://www... #ObjectProperty"/>
  <owl:inverseOf rdf:resource="#contains"/>
 </owl:TransitiveProperty>
 <Building rdf:ID="Room201">
  <locatedIn>
   <Room rdf:ID="CivilFaculty">
  </locatedIn>
 </Building>
 <Building rdf:ID="CivilFaculty">
  <locatedIn>
   <Room rdf:ID="MaslakCampus">
  </locatedIn>
 </Building>
```

Implicit Context

```
 <Building rdf:ID="Room201">
  <locatedIn>
   <Room rdf:ID="MaslakCampus">
  </locatedIn>
 </Building>
 <Building rdf:ID="MaslakCampus">
  <contains>
   <Room rdf:ID="CivilFaculty">
  </contains>
 </Building>
 <Building rdf:ID="CivilFaculty">
  <contains>
   <Room rdf:ID="Room201">
  </contains>
 </Building>
```

Table 3. Implicit context (TransitiveProperty and inverseOf)

For example, table 3 explains obtaining implicit information from explicit context. There are four visual levels in the model. *Room201* is an individual of Class *Room*, *CivilFaculty* is an individual of Class *Building*, and MaslakCampus is an individual of Class *District*. In the example, *Room201 locatedIn CivilFaculty* and *CivilFaculty locatedIn MaslakCampus* are stated explicitly. Consequently, statements of *Room201 locatedIn MaslakCampus* (with *TransitiveProperty*), *MaslakCampus contains CivilFaculty* (with *InverseOf*), *CivilFaculty contains Room201* (with *InverseOf*) are obtained with ontology reasoning.

According to the context model, *disjointWith* property confirms that a spatial object can not be at the two different visual levels. It prevents input errors during the pervasive computing. On the other hand, *subClassOf* property extracts drawing types of the spatial objects such as line or node.

Explicit Context

```
<owl:Class rdf:about="#Building">
  <owl:disjointWith>
   <owl:Class rdf:about="#City"/>
   <owl:Class rdf:about="#District"/>
   <owl:Class rdf:about="#Room"/>
  </owl:disjointWith>
</owl:Class>
…
<owl:Class rdf:about="#Room">
  <rdfs:subClassOf>
   <owl:Class rdf:about="#Indoor"/>
  </rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="#Indoor">
  <rdfs:subClassOf>
   <owl:Class rdf:about="#Node"/>
  </rdfs:subClassOf>
</owl:Class>
```

Implicit Context

```
<Building rdf:ID="ElectronicFaculty">
<District rdf:ID="ElectronicFaculty">---Error---
…
<owl:Class rdf:about="#Room">
  <rdfs:subClassOf>
   <owl:Class rdf:about="#Node"/>
  </rdfs:subClassOf>
</owl:Class>
```

Table 4. Implicit context (disjointWith and subClassOf)

In table 4, the example shows that the statement of *ElectronicFaculty* is an individual of the Class *District* is not correct whereas the statement of *ElectronicFaculty* is an individual of Class *Building* is correct. The ontological model determines that an error is occurred as a result of the reasoning with the *disjointWith*. The *subClassOf* property extracts that drawing type of the individuals of the Class *Room* is a node in the context model.

3.2 Rule-based Reasoning

Rule-based context reasoning is implemented by SWRL (Semantic Web Rule Language) to obtain new information from explicit context. Table 5 describes some SWRL rule examples for contextual reasoning to determine relevant visualization profile of the spatial data on mobile devices. Some SWRL rules can be exploited by ontology reasoning as explained in section 3.1. However context model needs a more complex formulizing in order to eliminate SWRL statements. Thus, SWRL provides some advantages while creating context model.

p? indicates an individual of Class *Person* for all rules in the ontological context. In the first row of the table 5, the rule asserts that *isComponentOf* Building property, *uses* property and *participatesIn* property imply *bBox* property of the Class *VisualParameter*. For example, John decides to participate the Spring Sport Fest of the ITU when he is at the Civil Engineering Faculty and he connects to the server with his mobile phone. The rule implies that an building plan that is in 50 meters X 50 meters should sent to the mobile phone until he leaves from the faculty. Second rule adds navigation arrows that show the activity place when a person would like to join a scheduled activity. Rule 3, in the table 5, adjust refresh rate of the map while someone driving to a scheduled activity like a conference or concert.

bBox: 50meters	(p? isComponentOf Building) ^ (p? uses MobileDevice) ^ (p? participetesIn Activity) => (VisualParameter bBox 50meters)
Special-Effect:	(?p participatesIn ScheduledAct) ^ (?p isComponentOf District) => (VisualParameter specialEffect NavigationArrow)
Refresh-Rate	(?p participatesIn ScheduledAct) ^ (p isGettingOn Car) => (VisualParameter refreshRate 10 seconds)

Table 5. SWRL rules

4. CONCLUSION

The application is implemented as a multi-tier architecture. The architecture of the technological model includes a map server, an ontology server, an application server, a proxy server and mobile graphical user interface for mobile phones. Server side and client side programming are composed in Java2EE and Java2ME. Client send queries to the server via a user interface and server evaluates user's current situation with sensors. Consequently server determines a relevant visualization profile based on the contextual ontology. 30 class and subclasses are used to represent the environment that is focused on mobile user. 22 properties are defined to show relations among class definitions.

In this paper, the visualization of the spatial data that are relevant to the mobile user is examined. To provide relevancy, relevance theories is reviewed and the manifestations of the relevance are adapted to the visualization of he spatial data. In the ubiquitous computing, sensor and computer that are invisible to the user are able to determine the current environmental situation. With the advantages of the ubiquitous computing, a context model that is composed in a semantic language can be implemented to provide relevancy. We developed a new context model that includes dimensions of the relevance for the visualization. Specifically, OWL-DL specifications have the capability of the reasoning for the description logic. Thus OWL-DL is chosen to represent context model explicitly so as to exploit implicit context in this research. The aim of the contextual ontological model is to design a context aware system for mobile user in the distributed GIS. Not only ontological reasoning but also rule based reasoning is provided in order to obtain implied information.

In this paper we mainly focused on theoretical issues. For the future work, the detailed practical results will be presented for the implemented prototypes.

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