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# An ontology-based visualization for mobile geoinformation services

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**In mobile geoinformation services, most intelligent systems ignore the users' states and roles and only include the user's location. However, different user profiles need customized visualization styles in order to provide relevant spatial data. With the availability of a variety of data sources and the ability for continuous data updates, the service is able to perceive and react to instant changes. The aim of this research is to describe contextual ontological model which provides visualization on mobile devices. Therefore, intelligent visualization explained in this study is defined by a complete semantic model of the Ontology Web Language – Description Logic (OWL-DL) and Semantic Web Rule Language (SWRL). Consequently, a mobile visualization service sensitive to the instant changes of the user's situation has been proposed. Egocentric design of a map-based service has been tested on a scenario-based application of a mobile emulator.**

**Key words:** Context, ontology, knowledge-base, mobile, reasoning, visualization.

## INTRODUCTION

New technologies such as wireless communications, advanced sensors and high speed processors have changed approaches to many applications and techniques in various engineering fields. Clearly, distributed GIS has also been affected by these new developments. Technological developments have significantly increased the usage of these services in daily life. Mobile GIS systems therefore need to be adapted to its environment, the elements of which can be defined by context modelling. Context modelling is a simplified representation of the real world to enable management of the information in the computer environment.

Visualization on mobile devices is considered in a context model that also includes notions of relevance. The proposed system is able to adapt to the changing situations in order to create a relevant visual design of the spatial data on small mobile devices. If a visual parameter is accepted as an actuality in the conceptualization of the context model, relations can be established between the real world and the visualization of the spatial data. This research attempts to integrate general principles for the mobile context and the newly determined visualization parameters for the context of mobile devices, to obtain a system that is sensitive to principles of relevance.

Researchers have presented different points of views on relevance theories in support of new context models that are able to provide relevant data to the user. The theories need to be reviewed, though context-aware applications inherently provide relevance by themselves. According to Saracevic (1996), manifestations of relevance are based on relations between components of relevance and texts. Text in this context represents all relevant information about object types such as documents, images and sounds.

Therefore, every manifestation of relevance includes relations with objects. Saracevic (1996) described five manifestations of relevance: Algorithmic, topical, cognitive, situational and motivational relevance.

Relevance also becomes a key notion in GIS research when retrieving appropriate spatial information for different applications, such as from databases and for visualization. Specifically, visualization issues have been focused on in this study. Edwardes et al. (2005) proposed

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**Table 1.** DL notation.

| | |
|---|---|
| $C$ | Concept term |
| $R$ | Role term |
| $C_1 \doteq C_n$ | Equivalent |
| $C_1 \sqcap \ldots \sqcap C_n$ | Conjunction |
| $C_1 \sqcup \ldots \sqcup C_n$ | Disjunction |
| $\exists R.C$ | Exists restriction |
| $\forall R.C$ | Value restriction |

an approach based on the notion of hierarchical spatial tessellation for generalization. They used quad trees to determine the number and size of objects to be displayed. Quad trees tessellate space and every observation is assigned to a separate block. In particular, the solution allows rapid traversal and retrieval of data for LBS. Reichenbacher (2004) examined adaptive visualize-tion of mobile maps in detail and proposed new adaption dimensions in geographic information visualization depending on the mobile context. Reichenbacher (2004) stressed its relevance for LBS. This study rearranges the relevance types proposed by Saracevic (1996), the main difference being physical relevance. According to Reichenbacher (2005), physical relevance, including spatial and temporal relevance should be considered in LBS. Spatial relevance is about a user's position, whereas temporal relevance is the time reference of an object or event. Meng (2005) enumerated the components of a design pattern for relevant visualization including centring, redundant encoding, continuous variation and multiple levels of detail, space contraction, single window with details on demand, augmented focusing, orientation and effective emphasis.

Ontology-based modelling is a key requirement to build an effective context-aware application. This concept leads us to understand the meaning of ontologies and their applications in computer sciences. In artificial intelligence (AI), knowledge engineering (KE) focuses on tasks and methods for representing knowledge with symbolic descriptions of entities and relations between these entities (Mira, 2008). From this point of view, computer sciences have borrowed the term 'ontology' from philosophy. One of the most cited definitions is by Gruber (1993), who has elucidated the term 'ontology' as: 'an explicit definition of conceptualization'.

Ontology enabling knowledge representation is designed using an ontology language in computer applications of artificial intelligence. OWL-DL was developed to satisfy frame-based modelling requirements (concepts, taxonomies, relations, formal semantics and automated reasoning) in description logic (McGuinness and van Harmelen, 2004). Table 1 explains some formal notation for description logics.

Many scientists have developed methods to create context and a contextual ontological model for pervasive computing environments. 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 users and applications themselves. Wang et al. (2004) conceived the CONtext ONtology (CONON), as a detailed design of ontological context model and logic-based context reasoning scheme in pervasive computing environments. Chen et al. (2004) presented a 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 for smart home applications. Context ontologies are divided into upper and domain-specific (lower) ontologies. The upper ontology represents more general context knowledge about the physical world. It describes the basic concepts such as Person, Device and Activity. Details of these basic concepts and their descendants can be described depending on the application. The lower ontology defines details of the general concepts and their properties about a domain.

Becker and Nicklas (2004) discussed the relation between spatial context and ontologies in context management and claimed that context models are large, while knowledge bases of contextual ontologies are rather small. Their work, however, ignores relevance modelling. Weissenberg et al. (2006) described a larger ontology architecture to realize a mobile system for retrieving relevant information during the 2008 Olympic Games in Beijing. Lutz and Klien (2006) 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. Although their semantic query method is similar to this study, the aims of their ontological context and its scope are completely different. Akcay and Altan (2007) presented some theoretical basis of the ontological context model for mobile visualization. However, the work did not include the methods and results of the ontological reasoning as Bettini et al. (2009) emphasized the importance of context modelling and reasoning techniques.

In this study, a mobile context model that is capable of perceiving situational changes in the environment is proposed. The aim of the model is to provide relevant visualization characteristics of spatial data to the mobile users in a distributed GIS. The study describes subsequently, relationships between relevance theories and visualization of spatial data for a new contextual ontological model. Context reasoning then describes some reasoning possibilities within this context. The technological architecture of the model and query-based retrieval methods of the information are explained with scenarios afterwards. Finally, concluding remarks are given in "conclusion".

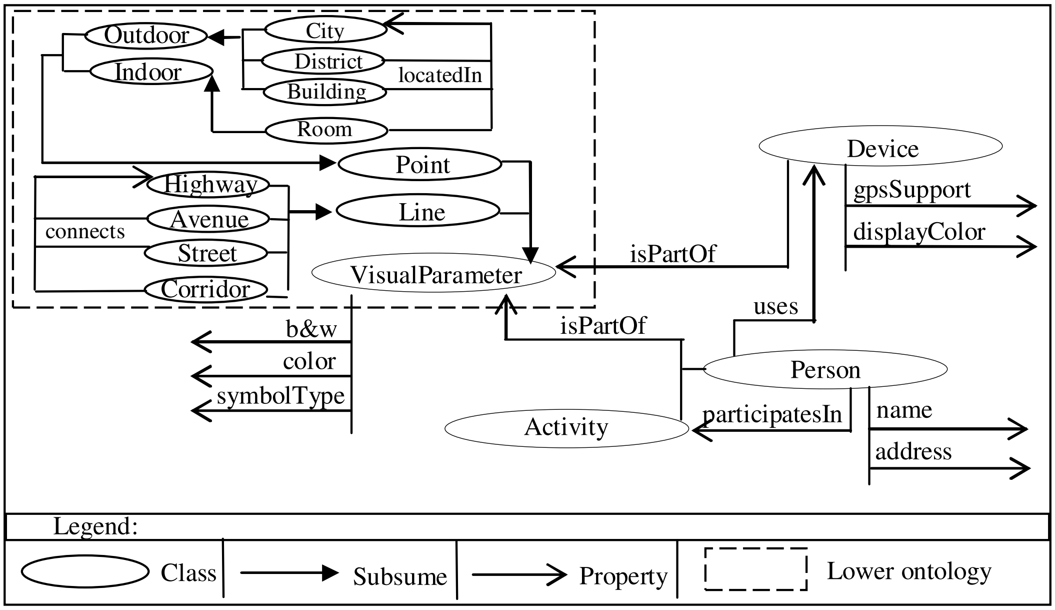


**Figure 1.** Conceptualization of visualization and properties.

## CONTEXTUAL ONTOLOGICAL MODEL

Algorithmic relevance, as well as cognitive and motivational types of relevance for the visualization are outside the scope of this study. Therefore, this study concentrates only on situational relevance. Visualization, in this study refers to two-dimensional maps with restricted resolution that are suitable for the limited screen and RAM capabilities of mobile devices.

An approach has been proposed that is different from an algorithmic relationship between keywords in the query and spatial data for extracting relevant spatial data. Some levels of the spatial data are defined and then all the contents of these levels are accepted as the relevant spatial data. For instance, outside (building, district and city concepts) and inside a building (room concept) are different levels. Therefore, inside the building should be visualized separately from the outside. Whenever the user leaves the building, the relevant level changes to the district representation level that includes the buildings (building concept) and the streets (street concept) connecting them. According to this approach, inside and outside the current district are irrelevant spatial data for the mobile user.

Situational relevance is the relationship between the device properties and visualization. Digital visual features on the mobile device screen are part of the current situation that represents the user. Thus, the mobile device should determine some characteristics of visualization, such as colour and symbolization. GPS support for mobile devices also contributes to visualization because of the relationship between the user's location information and the visualization. Another relation can be established between average velocity of location change and the refresh rate of the visualization on the screen.

In Figure 1, the model by Akcay and Altan (2007) which provides the appropriate visualization parameters for semantic visualization has been revised. The aim of the model is to define the relevance of spatial data depending on the adapted manifestations that were explained earlier in the contextual ontological model. According to the figure, 'point and line' concepts are subsumed under the VisualParameter concept. This subsuming means that a nodal or linear geographical feature is a parameter in the visualization. The line concept subsumes four disjoint object types: Highway, avenue, street and corridor. A linguistic relation can therefore be inferred from the model as in the following: "A highway instance is a line and a line is a parameter of the visualization."

Visual parameter and its subconcepts (point and line) are considered in the lower ontology as they specifically belong to the visualization domain. In the lower model, the point concept subsumes the outdoor and indoor concepts. Outdoor represents spatial objects on the terrain, while indoor represents places in the buildings. For example, a building instance is an outdoor object which is defined at a point. The figure also reveals that two properties establish the relation between instances of the concepts. The locatedIn property has been proposed for nodal spatial objects and the 'connects' property has been proposed for linear spatial objects. These relations explain the relations such as Room locatedIn Building, Building locatedIn District, and Street connects Avenue. Figure 1 also contains general concepts that are necessary for mobile visualization. The main concepts that are disjoint from each other are Device, Person, Activity and VisualParameter. These four main concepts are connected to each other by three properties: isPartOf, uses and participatesIn as shown in Figure 1. Properties can be stated as follows: "Person participatesIn Activity", "Person uses Device", "Device isPartOf VisualParameter", "Activity isPartOf VisualParameter", and "Person isPartOf VisualParameter". Three properties, isPartOf, uses and participatesIn, are necessary to integrate the low-level ontology into basic concepts such as Activity and Person. They also contribute some rule-based inferences in the knowledge base inferences. Some rule-based assertions have also been described in "context reasoning".

The new concept in ontologies is VisualParameter that defines necessary parameters for mobile visualization. These parameters are the individuals of the concepts that are subsumed under VisualParameter such as Building, Street, etc. For example, it should be assumed that TopkapiMuseum is an individual of Building concept. Therefore, "TopkapiMuseum is a VisualParameter" that can be inferred from the ontological context. Each member of the VisualParameter has some properties such as geocoding, colour and symbol type. These properties are called data type properties of the concept and they describe the visualization characteristics of the objects in the scene.

Ontological knowledge bases are based on open world assumptions (OWA). OWA do not assume anything that is not true until it is explicitly stated as such. Some properties should therefore provide a closure axiom for completeness. It should be assumed that the Geomatics Conference will be held in the Faculty of Civil Engineering, and then the individual Geomatics Conference is created as a member of the activity concept so as to represent Geomatics Conference in the knowledge base. Civil Engineering and Chemistry are instances of building. VisualParameter subsumes building as shown in Figure 1; therefore, CivilEngineering and Chemistry are also instances of VisualParameter. In OWA, the answer to the following question is unknown: "Is the Geomatics Conference to be held in the Faculty of Chemistry?" if "Activity isPartOf VisualParameter", it is not built with a closure axiom in the ontological context. The answer should be "No"; however, because "GeomaticsConference isPartOf CivilEngineering", it is represented in the knowledge base, and an activity, person or device cannot exist at two different places at the same time. In the model, the closure axiom is applied to some relationships to prevent this kind of possible completeness error. The closure axiom is the combination of the universal and existential restrictions for the same property and the filler in the ontology structure.

In the ontologies, some properties have been produced with both quantifier existential restriction and quantifier universal restriction. For instance, existential and universal quantifier restrictions have been built together under necessary and sufficient conditions, in order to establish relations with "isPartOf" property in the ontological model. The existential restriction describes sets of individuals that have at least one "isPartOf" relationship to individuals that are members of a class of "VisualParameter". The universal restriction makes sure that any filler must be a member of a "VisualParameter" with "isPartOf" property. Necessary and sufficient conditions ensure that there is no individual from outside Device, Person and Activity concepts for isPartOf property.

The closure axiom provides that all sets of individuals have "isPartOf" relations with only individuals of Class "VisualParameter". There is no isPartOf relation with an individual from outside the "VisualParameter". The restrictions produce appropriate relations among the classes in the model. The closure axiom that is composed of both quantifier existential and quantifier universal restrictions is represented as follows:

$$\text{Person} \sqcup \text{Device} \sqcup \text{Activity} \sqsubseteq \ni \text{isPartOf Visual Parameter} \quad (1)$$

$$\text{Person} \sqcup \text{Device} \sqcup \text{Activity} \sqsubseteq \forall \text{isPartOf.Visual Parameter} \quad (2)$$

When a necessary and sufficient condition is applied to the closure axiom, two equations will also be added

$$\exists \text{ isPartOf Visual Parameter} \sqsubseteq \text{Person} \sqcup \text{Device} \sqcup \text{Activity} \quad (3)$$

$$\forall \text{ isPartOf Visual Parameter} \sqsubseteq \text{Person} \sqcup \text{Device} \sqcup \text{Activity} \quad (4)$$

While $C_1 \sqsubseteq C_2 \, and \, C_1 \sqsubseteq C_2 \Rightarrow C_1 \doteq C_2$ , the following equations can also be written:

$$\exists \text{ isPartOf Visual Parameter} \doteq \text{Person} \sqcup \text{Device} \sqcup \text{Activity} \quad (5)$$

$$\forall \text{ isPartOf Visual Parameter} \doteq \text{Person} \sqcup \text{Device} \sqcup \text{Activity} \quad (6)$$

isPartOf property has been examined in detail in the foregoing. All the other properties (uses, participatesIn locatedIn, contains and connects) have been built in the same way that isPartOf has been built.

The OWL file of the contextual ontological model can be reached at: http://web.itu.edu.tr/akcayoz/itu.owl. Some individuals and their properties which are not related to the study have been removed from the OWL file. Therefore, the file is a shortened version of the ontologies. The file has been produced using Protégé ontology editor (http://protege.stanford.edu).

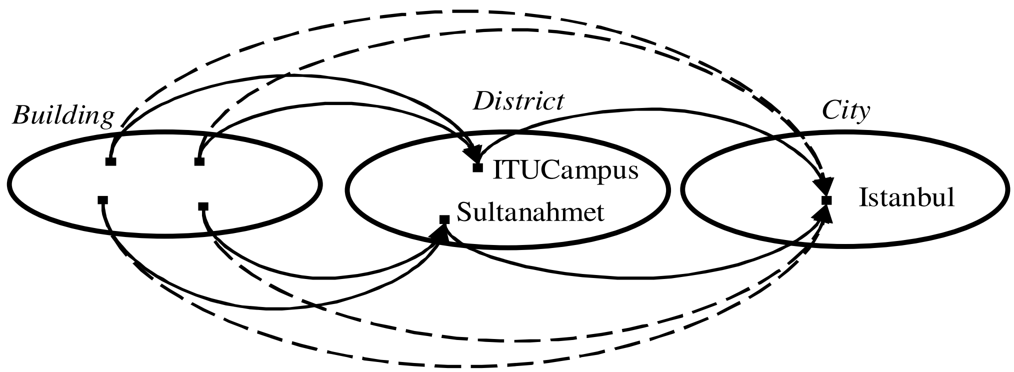


**Figure 2.** Implicit and explicit locatedIn relations among the City, District and Building concepts.

**Table 2.** Rules in human readable form.

| No | Rule |
|---|---|
| 1 | Uses (?person, ?device) ^ gpsSupport (?device, available) => isPartOf (?person, Outdoor) |
| 2 | Participatesin (?person, ?activity) ^ isPartOf (?activity, ?building) => symbolType (?building, highlighted) |
| 3 | Uses (?person, ?device)^ displayColor (?device, b&w)=> color (VisualParameter, b&w) |

## CONTEXT REASONING

Context reasoning is implemented as an ontological reasoning. Specifically, TransitiveProperty, inverseOf, subClassOf and disjointWith are used as rules to reason the implicit information from the explicit information.

Figure 2 shows a part of the conceptual design and some members of the classes in a graphical manner. Connection among the individuals is established with the locatedIn relation. Transitive property of the locatedIn relation provides additional implicit connections beside explicit ones. The dashed lines in Figure 2 indicate implicit information. This contains a relation that is the inverse of the explicit locatedIn relation. Also, it provides more implicit information from the context. For example, Istanbul contains ITUCampus and Istanbul contains Sultanahmet statements can be inferred from the context. While Istanbul is an individual of the concept ‘City’, ITUCampus and Sultanahmet are the individuals of the concept ‘District’.

DisjointWith property assures that individuals of different concepts are placed only with their own concepts. For example, HagiSophia is an individual of Building and Sultanahmet is an individual of District. So, it implies that HagiSophia can neither be the individual of District nor Sultanahmet the individual of Building. Subclass of property is also a fundamental ontological property that supports reasoning capability of the knowledge base.

Ontology reasoning can be extended with semantic web rule language (SWRL). The proposed rules are of the form of an implication between an antecedent (body) and a consequent (head). The intended meaning can be read as: whenever the conditions specified in the antecedent hold, then the conditions specified in the consequent must also hold (Horrocks et al., 2004). In Table 2, three rules have been described with SWRL. The first rule indicates that if a mobile device receives a GPS signal, the person who uses the device is outside. According to the second rule, if a person joins an activity in a building then the building will be highlighted to attract the user’s attention in the visualization. The third rule shows visualizations in black and white, if the user’s device has a black and white screen.

## SCENARIOS FOR RELEVANT VISUALIZATION ON MOBILE DEVICE

Two scenarios have been described to show the visualization features of the model. The scenarios that have been implemented in Sultanahmet and the Campus of ITU define relevant visualization with the context reasoning explained in “context reasoning”. The technological design of this research therefore proposes a multi-tier architecture in order to realize the proposed model. The architecture of the technological model includes a map server, an ontology server, an application server, a proxy server and a mobile graphical user interface for mobile phones. In the server side, PostgreSQL object-relational database system and its spatial database extension PostGIS are used as the database server. In the system, map production is provided by Geoserver, which is an open source map server. Due to the limited display capacity of some mobile phones, Geoserver WMS has been chosen as the default server in the system for the visualization. Styled Layer Descriptor (SLD) has been used similarly as implemented in Zipf (2005) in order to provide determined visual features such as appropriate colours or symbol size for a certain scale. In the architecture, RacerPro has been used as the ontology server. Server-side and client-side programming have been composed in Java2EE and Java2ME. A web service and a proxy server are implemented as the middleware of the architecture. The screenshots of the mobile phone displays have been produced in Java Netbeans Integrated Development Environment (IDE), which supports the emulators of various mobile phones and PDAs, so as to test the software that is composed for the mobile applications. An emulator reacts in the same way as the device behaves in the real world.

Contextual ontology (OWL-DL) that has been defined for relevance, as the upper and lower ontology models in the “contextual ontological model”, has been edited in an ontology editor and knowledge acquisition system by Protégé software. Then the concepts (T-box) and the individuals (A-box) in the knowledge base system have been stored in RacerPro OWL reasoner. To retrieve related explicit and implicit information in the context of designed relevance model, a query language called nRQL (new Racer Query Language), that is an embedded tool in RacerPro, has been used (Wessel, 2005).

A query statement can be arranged to define the location of the Hagi Sophia, in the OWL knowledge base. The query and answer statements are built underneath the nRQL structure in order to explain the meanings clearly. All query statements in nRQL start with the word ‘retrieve’. The individuals and property are written as a uniform resource locater (URL) because of the OWL-DL syntax (Wessel and Möller, 2005). Now, suppose we want to find building individuals located in a district in the knowledge base (Equation 7).

```
[retrieve (?x) (and (?x |http://www.itu.edu.tr/visual.owl#Building|)
                    (?y |http://www.itu.edu.tr/visual.owl#District|)
                    (?x ?y |http://www.itu.edu.tr/visual.owl#locatedIn|))]
```
(7)

According to the scenario, a person decides to visit Hagi Sophia Museum when he is in room A102 of the Civil Engineering Faculty. User runs the map application on their GPS supported mobile phone. The user interface of the application welcomes the client. The user manually enters the target place that he or she wants to visit. At the campus, each building has an entrance registration that is controlled by the visitor’s electronic card. As an indoor smart environment, the server perceives the entrance whenever someone steps into the building. The server therefore evaluates the user’s location and their request in the context model. The user’s visual level and the visual levels of Hagi Sophia Museum are determined in the server. The model searches for the upper visual levels of the two locations. The user and the museum can both be represented in the “building visual level”. However, they do not belong to the same district.

As a result of the upper visual level of the different districts, a common level, city Istanbul, is obtained. Figure 3 depicts the scenario and the process steps as a flow chart, while Figure 4 shows the screenshots of the results. In the upper-left image of Figure 4, the screenshot shows class A102 as the first visual level. At this visual level, room polygons are converted to the classroom symbolization in order to make a simpler visualization on the small screen.

When the user leaves the Faculty, the sensor determines that it is outside, and a second visual level appears on the screen, as depicted in the upper-right image of Figure 4. The second visual level is based on buildings. Buildings are represented by some related symbols instead of their scaled polygons until the user exits the campus district. In this scenario, the district visual level is defined as the covering level by the ontology server (the lower-left image of Figure 4). The district level emphasizes the main regions of the city and the avenues that connect each region. According to the scenario, the system pops up a map including ITU and Sultanahmet until John arrives at Sultanahmet. The system detects John’s entrance into the Sultanahmet district and the visual level goes back to the building level again for Sultanahmet (the lower right image of Figure 4). However, the visualization of the scenario is completed in four steps for the user’s current position.

## CONCLUSION

Egocentric design of a map-based service which provides relevant visualization for the mobile user has been implemented for the campus area of the Technical University of Istanbul and Sultanahmet (the historic district of Istanbul). The implementation of the service has been intended to test the consistency of the proposed model
for the real-world user. From the computer scientists’ point of view, this application field (campus area) is called intelligent space, while from a geomatics scientists’ perspective, it can be called intelligent map space.

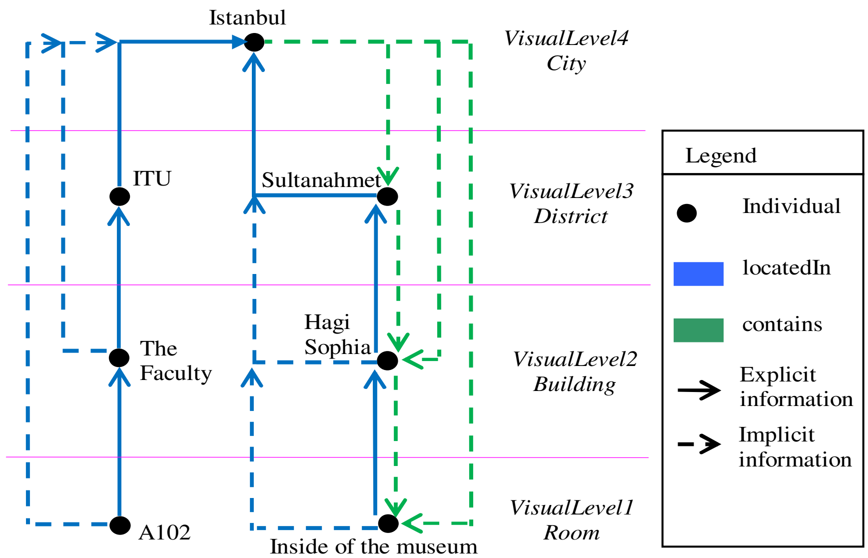


**Figure 3.** Illustration of the data retrieval with a semantic query.

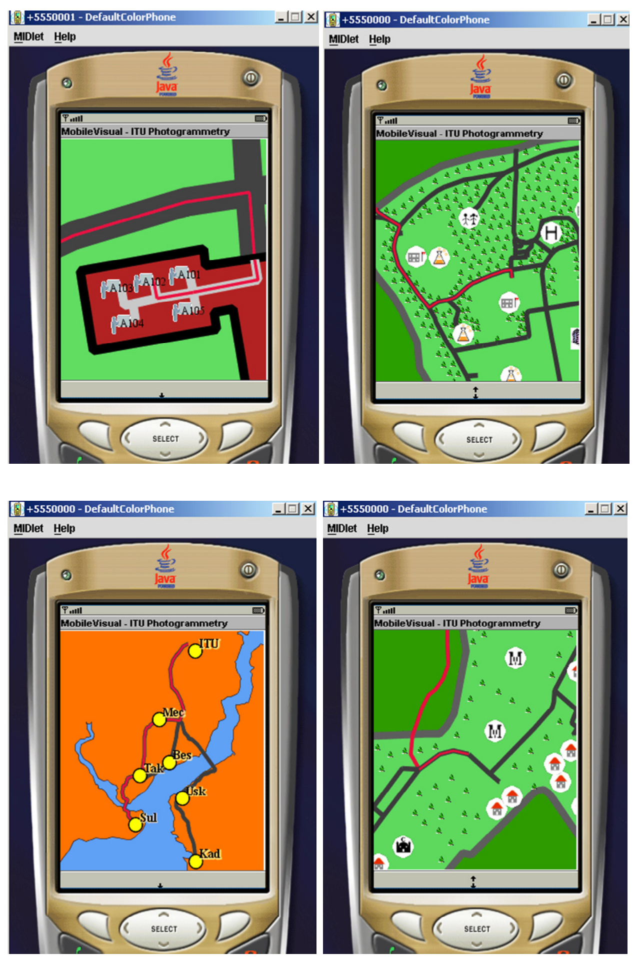


**Figure 4.** Different conceptual visual levels for scenario I. Upper-left image is visual level 1 (rooms), upper-right image is visual level 2 (buildings), lower-left image is visual level 3 (districts), and lower-right image is visual level 3 (buildings).

Semantic web language (OWL) has been used in order to represent knowledge. Databases are not appropriate for knowledge representation because they are built on a closed world assumption (CWA). CWA that may derive false conclusions about statements have not been made explicitly. PostgreSQL – Postgis database was used only as a data repository because loading spatial data to the knowledge base as a data property causes some practical problems.

In the model, a complex three-dimensional visualization has been ignored. In future work, visualization and its context should be elaborated as a parallel rapid development of mobile technologies. A semantic query method is used in order to obtain the situational aspect of the visualization components from the knowledge base. Cognitive and motivational relevances will be considered so as to provide a more comprehensive ontological context.

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