İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

AN ONTOLOGICAL APPROACH TO RELEVANT VISUALISATION IN MOBILE GIS

Ph.D. Thesis by
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Department : **Geodesy and Photogrammetry Engineering**

Programme: **Geomatic Engineering**

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

MOBİL CBS'DE İLGİLİ GÖRSELLEŞTİRME İÇİN ONTOLOJİK BİR YAKLAŞIM

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ABBREVIATIONS

LBS	: Location Based Services
GIS	: Geographic Information Systems
HCI	: Human-computer interaction
GPS	: Global Positioning System
IR	: Information Retrieval
KR	: Knowledge Representation
AI	: Artificial Intelligence
DL	: Description Logics
OWL	: Ontology Web Language
CONON	: Context Ontology
COBRA	: Context Broker Architecture
KB	: Knowledge Base
XML	: Extensible Markup Language
XOL	: Ontology Exchange Language
OML	: Ontology Markup Language
HTML	: Hyper Text Markup Language
SHOE	: Simple HTML Ontology Extension
RDF	: Resource Description Framework
OIL	: Ontology Inference Layer
DAML	: DARPA Agent Markup Language
SWRL	: Semantic Web Rule Language
RML	: Rule Markup Language
WS	: Web Service
OGC	: Open Geospatial Consortium
GML	: Geography Markup Language
WMS	: Web Map Server
WFS	: Web Feature Server
SLD	: Styled Layer Descriptor
SQL	: Structured Query Language
ODBC	: Open Database Connectivity
JDBC	: Java Database Connectivity
EE	: Enterprise Edition
SE	: Standard Edition
ME	: Micro Edition
OS	: Operating System
PDA	: Personal Digital Assistant
GPS	: Global Positioning System
ACL	: Agent Communication Language
SPIRIT	: Spatially Aware Information Retrieval on the Internet
GUI	: Graphical User Interface
WSA	: Web Services APIs
API	: Application Programming Interface

nRQL	: new Racer Query Language
IDE	: Integrated Development Environment
JPEG	: Joint Photographic Experts Group
PNG	: Portable Network Graphics
SVG	: Scalable Vector Graphics
KML	: Keyhole Markup Language
KMZ	: Zipped KML
PDF	: Portable Document Format
UMTS	: Universal Mobile Telecommunications System

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C	**:** Conceptualization
D	**:** Domain
I	**:** Interpretation function
L	**:** Logical language
K	**:** Ontological commitment
R	**:** Conceptual relations
V	**:** Vocabulary of a logical language
AL	**:** Attributive Language
A,C,D	**:** Concepts
Δ	**:** Arbitrary non-empty set
R,S	**:** Roles
x,y	**:** Individuals
d	**:** Data type
P	**:** Property
p	**:** Individual of Concept Person
m	**:** Rule
c	**:** Conclusion

MOBİL CBS'DE İLGİLİ GÖRSELLEŞTİRME İÇİN ONTOLOJİK BİR YAKLAŞIM

ÖZET

Son yıllarda ubikutus hesaplama mekânsal verinin görselleştirmesinde önem kazanmaktadır. Dağıtık CBS ve Konum Destekli Hizmetler (KDH) gibi alanları kapsayan Geoinformatik'te, kontekst modeller mobil kullanıcı ile sistem arasında sağlam bir iletişim sağlamak ile yükümlüdür. Durumsal bilginin gerçekleşmesinde "kontekst" ve "kontekst-duyarlı" kavramları önemlidir. Kontekst, bir varlığın durumunu karakterize eden bilgidir ve kontekst tanımındaki en önemli varlıklardan birisi de "kişi"dir. Doğru tanımlanmış kontekst-duyarlı bir sistem kullanıcılarının görevlerini uygun biçimde yönetebilmelidir. Kontekst duyarlı sistemler ubikutus sistemlerde önemli bir konudur ve tasarlanan kontekstin hassas etkisi bu tür sistemlerde görülmektedir. İyi çalışan bir kontekstsel sistem ontolojilere gereksinim duyar. Seçilen ontoloji dillerinin karakteristikleri sadece kontekst temsilindeki kazanımları değil ayrıca kontekstin usavurma (muhakeme) kapasitelerini de belirler. Özellikle DAML+OIL Web Ontoloji Dili (DAML+OIL Web Ontology Language) in gelişmiş bir sürümü olan Ontoloji Web Dili (Ontology Web Language) (OWL) kavram tanımları ve rol yapılandırıcıları ile bilgi temsiline izin veren Tanımsal Mantık (Description Logics) (DL) desteği sağlamaktadır. OWL-DL, OWL'nin en çok tercih edilen bir türevi olarak iyi tanımlanmış bir usavurma imkânı verir. Kullanıcıya uyum sağlayan bir ontolojik model geliştirmek için kullanıcıların çeşitli durumları uygun bir biçimde tanımlanmalıdır. KDH de birçok akıllı system kullanıcının konumu dışındaki kullanıcının durumunun ve rolünün etkisini göz ardı etmektedir. Ancak özelleşmiş görselleştirme tarzı ilgili mekânsal veriyi sağlayabilmek için çeşitli kullanıcı profillerine ihtiyaç duyar. Bilgisayar ve kartoğrafya bilimlerinde mobile cihazlardaki kişisel ve kısa süreli kullanımlar ben merkezli harita terimini ortaya koymuştur. Kullanıcı ben merkezini tatmin eden ben merkezli haritalar; merkezlendirme, azaltılmış kodlama, sürekli değişen ayrıntı seviyesi, çoklu ayrıntı seviyeleri, mekânsal daralma, talebe bağlı detay gösterimi, artırılmış odaklanma, yöneltme işaretleri gibi tasarım örnekleri ile görselleştirme parametrelerini belirler. Bu tezdeki araştırmanın amacı, mobil cihaza sahip herhangi bir kullanıcının ilgili görselleştirme profilini belirleyebilmek için ilgililik teorilerine uygun mobil kontekstsel ontolojileri (sınıfları ve özellikleri) tanımlamaktır. Bu şekilde burada usavurma motoru tarafından OWL dilindeki komple bir anlamsal modelden sonuç çıkarabilen bir çeşit akıllı sistem önerilmektedir. Bir ontoloji editörü ve bilgi elde etme sisteminde ilgililik için kontekstsel ontoloji (OWL DL) hazırlandı. OWL DL için sınıflandırma kararlılığı bir usavurma motorunda test edildi. Sonuçta usavurma motoru bir sunucu olarak ilgili görselleştirmenin profilini usavurma algoritmaları ile veya tanımlanmış Anlamsal Web Kural Dili (Semantic Web Rule Language) ile bir kıstas olarak elde etti. Örneğin, ontolojide iki düşük seviye kavram düşünelim: "Araba", "GPS_Alıcısı" ve iki adet özellik: "konumlanır",

“statü”. Kullanıcı tanımlı kontekst usavurma sonucunda durum şu şekilde tanımlanır: (u? konumlanır Araba) ^ (GPS_alıcısı statü Açık) => (u? durum Navigasyon). Böylece Navigasyon harita görselleştirmede ilgililik kıstasının bir boyutu olarak belirlenir. Örnekte mobil haritanın görselleştirme tarzı navigasyona adapte edilmiştir. Bu kıstas ve diğerleri ilgili haritayı karakterize etmek için Web Harita Sunucusu (Web Map Server) veya Web Özellik Sunucusu (Web Feature Server) için mekânsal sorgulamayı biçimlendirecektir. Mobil kullanıcılar için ilgili görselleştirmeyi sağlayan harita destekli hizmetlerin ben merkezli tasarımı İstanbul Teknik Üniversitesi yerleşke alanında ve İstanbul’un tarihi bölgesi Sultanahmet’te uygulanmıştır. Hizmet uygulamasında önerilen modelin gerçek hayatta kullanımındaki tutarlılığı test etmek amacıyla yapılmıştır. Bilgisayar bilimcilerin bakış açısı ile bu uygulama alanı Akıllı Mekân, Kartoğrafya bilimleri açısından ise Akıllı harita olarak adlandırılabilir.

Cep teflonlarının ve PDA’lerin küçük ekranlarını daha etkin kullanmak için sembol tabanlı basitleştirme anlamsal yaklaşımın tamamlayıcısı olarak önerilmiştir. Önerilen modele göre, ölçekli poligonsal mekânsal gösterim yerine semboller görselleştirmede kullanılmıştır. Teoride bir mekânsal nesne, mobile cihazların kısıtlı ekranlarında algılamayı kolaylaştırabilmek için kare ve daire gibi farklı şekillerdeki semboller ile değiştirilir. O anki görsel seviyedeki uygun sembol boyutunu belirlemek için bulanık mantık çözümü nesnenin orijinal boyutuna ve haritanın ölçeğine bağlı olarak geliştirilmiştir. Bu model masaüstü uygulamalar için önerilen gelişmiş genelleştirme algoritmaları yerine, kısıtlı mobil cihazlar için bir basitleştirme sağlar.

AN ONTOLOGICAL APPROACH TO RELEVANT VISUALISATION IN MOBILE GIS

SUMMARY

Recently, the visualization of spatial data has been gaining importance in 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” and “context awareness” are the key notions in realisation of the situational information. Context is information characterising the situation of an entity and one of the important entities of the context definition itself is “person”. A well-defined context-aware system should fulfil the user’s task appropriately. Context-aware systems are a serious consideration in ubiquitous systems and these systems reflect the delicate effect of the designed context. An efficient contextual system needs ontologies. Characteristics of chosen ontology languages determine not only the achievement of the representation of the context but also the capabilities of its reasoning. Ontology Web Language (OWL), an improved version of the DAML+OIL Web Ontology Language, particularly enables description logic support. Description Logics (DLs) allows knowledge representation with concept descriptions and role constructors. OWL-DL is the preferred subset of the OWL to provide reasoning in a well-defined way. To develop a user-adaptive ontological model, users’ different situations should be defined properly. In Location-Based Services (LBS), a very intelligent system ignores the effect of user’s states and roles except the user’s location. Customised visualisation style, however, needs different user profiles in order to provide relevant spatial data. In the computer and cartographic sciences, individual and short-term usage have brought about egocentric maps for mobile devices. Design patterns of egocentric maps satisfying user’s ego-centre determine visualisation parameters such as centring, redundant encoding, continuous varying of level of details, multiple levels of details, space contraction, single window with details on demand, augmented focusing, orientation gesture and affective emphasis. The aim of this research is to define mobile contextual ontologies (classes and properties) which obey relevance theories so as to define any user’s relevant visualisation profile on the mobile devices. The kind of intelligent system proposed here can therefore 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, the inference engine retrieves criteria for relevant visualisation profiles with its reasoning algorithms or defined SWRL (Semantic Web Rule Language) as a server. For example, consider two low-level concepts in the ontology: “Car” and “GPS_Receiver”; and two properties: “locatedIn” and “status”. As a result of user-defined context reasoning, the situation is defined as follows: (u? locatedIn Car) ^ (GPS_Receiver status ON) => (u? situation Navigating). Thus Navigation becomes a dimension of relevant criteria of map visualisation. The

visualisation style of the mobile map is adapted to the navigation in the example. This criterion and others will form a spatial query for a Web Map Server (WMS) or a Web Feature Server (WFS) in order to characterise a relevant map. Egocentric design of a Map-based service which provides relevant visualisation for mobile users is implemented in the campus area of the Istanbul Technical University and in Sultanahmet, the historic district of Istanbul. Implementation of the service is intended to test consistency of the proposed model for the real user world. From computer scientists' point of view, this application field (campus area) is called Intelligent Space. From a cartographer's perspective, it is called Intelligent Map Space.

To use small screens of mobile phones and PDAs more effectively, symbol-based simplification has been proposed as a complementary algorithm of the semantic approach. According to the proposed model, instead of scaled polygonal spatial representation, symbolisations are used for visualisation. In theory, a spatial object is replaced with a symbol that can be in a different form, such as a square or circle, in order to make the user's perception easier in the restricted screen of the mobile devices. To determine appropriate symbol size for the objects of the current visual level, a fuzzy logic solution has been developed depending on the original area of the object and the scale of the map. The model provides a simplification method for limited mobile devices instead of developed generalisation methods that have been proposed for desktop applications.

1. INTRODUCTION

1.1 Motivation

New technologies such as wireless communication, advanced sensors and high speed processors change application approaches and techniques in various engineering fields. Obviously, mobile cartography is also affected by these new developments. Different visualisation methods that are modelled with the advantages of these technological developments produce enhanced map outputs for mobile users. New technological developments improve features of mobile visualisation and help to improve the service quality of the mobile map service. Despite all developments in mobile devices, however, mobile visualisation still has many obstacles before it can provide a flawless map service.

Location-based services and mobile GIS are major application fields of distributed GIS. Technological developments rapidly increase the degree of usage of these services in daily life. Naturally, many government and private enterprises make significant investments in mobile applications. This rapid expansion of the sector also produces problems in the extraction and representation of the spatial data. Retrieved spatial data should be relevant to the mobile user and represent the environment as realistically as possible. In particular, mobile devices are able to show simple visualisation in two dimensions instead of complex three-dimensional visualisation.

The desktop computer visualisation techniques cannot be applied easily to the mobile systems because of the restricted hardware and software capacity of the mobile devices. The visualisation on mobile devices needs more adaptive and delicate approaches to produce a map that is relevant to the user. Desktop computer visualisation has other advantages, such as its capacity to process a large amount of data or its high resolution display, compared with small mobile devices. To overcome the difficulties of mobile visualisation, new techniques and algorithms should be analysed and applied to provide better map services. Limited display screens should be used in the optimum way in order to represent the real world. The mobile user always seeks a visualisation that is clear and easy to understand in the small display. A mobile map service has many more restrictions and drawbacks during the daily usage. For instance, the information should be updated and served in a short time. Briefly, information that is relevant to the user should be retrieved, designed and presented in an appropriate way in order to provide a mobile service such as location-based services (LBS) and mobile GIS.

The following research questions arise from the problems mentioned above:

- How can the relevant visualisation of the spatial data be defined for the mobile user?
- How can a mobile map service adapt the visualisation to correspond with the ever-changing situations of the mobile users?
- How can a mobile map service evaluate the user's current situation and extract new conclusions?
- How can the cartographic representation of the spatial data be done as simply and comprehensibly as possible on the mobile devices?

1.2 Thesis Objectives

The objectives of the thesis can be enumerated briefly as definition of the relevant visualisation of the spatial data, design of a model for the mobile map service that is able to adapt the visualization to the users and their environments, establishment of a mobile map service which is capable of doing reasoning over the context, and proposal of a method for cartographic representation of the spatial data on mobile devices.

Obtaining relevant visualisation of the spatial data for the mobile user can be explained properly after the principle of relevancy is investigated. The aim of this approach is to define relevancy aspects of the visualisation that is possible for mobile users. Relevant visualisation can be formed by information that is collected from the environment. In this thesis, the author tries to provide operable, ubiquitous computing for a mobile visualisation system so as to produce two-dimensional representations that are relevant to the user.

A context-aware system for ubiquitous computing is essential for mobile visualisation. The users of a mobile system have no fixed or stationary position. A mobile system therefore needs an adaptation process for its environment. The elements of the adaptation process can be achieved by a context model. The context model tries to represent the real world for the computer environment in order to create context-aware applications. The visualisation on the mobile devices is considered in a context model that also includes relevancy notions of the visualisation. The author therefore proposes a system that is able to adapt itself to changing situations in order to create a relevant visual design of the spatial data on tiny mobile devices.

The aim of the thesis is to obtain a conceptualisation depending on the new extracted manifestations of the relevancy, because a well-designed conceptualisation underlies a robust context-aware system. With the semantic languages developed in the last decades by computer scientists a modelled context-aware system can be formed to provide a computer infrastructure that is understandable not only by humans but also by computers. If a visual parameter is accepted as an actuality in the conceptualisation of the context model, relations can be established between the real world and the visualisation of the spatial data. This research attempts to integrate the general agreements of the mobile context and new determined visualisation parameters of the context for mobile devices to obtain a system that is sensitive to the principles of relevancy. In theory, a smart environment that covers a large space is accepted for the relevant visualisation on the mobile device within this research.

Semantic approaches need a meticulous context design procedure. Although a context model is defined precisely, it might not be robust enough to solve all problems in the system. To overcome these obstacles, some additional mathematical algorithms are investigated in the research. With the strength of these algorithms, any insufficiency of the system can be eliminated. This kind of solution can be considered for the cartographic visualisation of the spatial objects. For example, showing a detailed map is too difficult on the limited display of the mobile devices. In order to prevent the confusion that can be inherited from the classical map representation, a kind of simplification method is proposed.

In this thesis, a mobile contextual model is proposed that gives opportunity to perceive situational changes in the environment. The aim of the mobile context model is to provide relevant visualisation characteristics of the spatial data to the mobile users in a distributed GIS. Section 2 presents an expanded review of the theoretical and technological background. In the theoretical background, relevance theories, context, context awareness, ontology and description logics are explained in detail. In the technological background, the recent specifications of knowledge-based systems and the technological aspects of the distributed GIS are elaborated. Section 3 then reviews papers about the related GIS works that have been done so far. The properties of the new ontological context model and its reasoning possibilities are proposed in section 4. The technological architecture of the model and query-based retrieval methods of the information are explained with scenarios in section 5. Concluding remarks are discussed in section 6.

2. SCOPE

2.1 Theoretical Background

Retrieving relevant cartographic visualisation through an ontological approach requires a comprehensive review which is mostly related to computer sciences. To determine the outlines of the relevant visualisation appropriately, the term of ‘relevancy’ should be defined first. Many different disciplines like information science or philosophy have tried to define the meaning of relevance from their perspective. Greisdorf (2000) stressed that interdisciplinary frameworks bring more depth and breadth to an understanding of relevance. Human information behaviour, communication and philosophy have contributed to enhancing a definition of the nature of relevance in information science. Thus section 2.1.1 has many contributions from different disciplines in order to elaborate the subject.

Human-computer interaction (HCI) is a difficult task for an application designer. To overcome the difficulty of HCI, application designers have opted for context-aware systems. Context-aware application is the only way to establish systems which react to changing situations. Naturally, context is the key notion for context-aware application.

People and computers have to communicate with each other to make life easier. The communication matter underlies the main problem of organisations. To provide a more effective process, people and software systems must understand their languages. In this case the key notion is ontology.

Ontologies organise the structure of knowledge. They are necessary to establish any system of knowledge representation. Conceptualisations and vocabulary enable knowledge representation. Thus consistent ontological structure provides robust knowledge representation (Chandrasekaran et al., 1998). On the other hand, planning a coherent ontology is as important as using ontology. Wieringa and de Jonge (1995) expressed the importance of correct analysis of a knowledge representation by means of an example. According to the example of an ontology which includes classes of

Student, Employee, Male and Female as subclass of Person was conceived. If so, each Employee would be identical to a Person. However, there are people who have two or more jobs. In this situation, we would like to able to say that individual e_1 and individual e_2 are two different employees, with different employers, salaries, employee numbers etc., but that they are the same person. But if this is so, Employee can not be a subclass of Person, because this implies that each employee is identical to a Person. And since the identity relationship is transitive, if individual e_1 and individual e_2 are both identical to the same person, they would be identical to each other. Consequently, this kind of incorrect knowledge representation causes difficulties and errors in inferences.

2.1.1 Relevance Theory

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. Following approaches are evolved from intuitive understanding of relevance.

Explosion of information has led scientists to information retrieval (IR); IR has led them to relevance. Schutz's (1970) explanation defined three basic type of relevance, although it was defined many times in the 1960s (O'Neill, 1960; Hillman, 1964; Caudra and Katter, 1967). As regards topical, interpretative and motivational relevance, Schutz (1970) produced a theory that relevance provides all social relations in our world. Topical relevance is about the perception of something being problematic. Interpretational relevance involves the knowledge background, past experience. Motivational relevance is selection from several alternative interpretations.

Nature of relevance and manifestations of relevance are the two important issues of relevance in information science. According to Saracevic (1996), nature of relevance consists of the following five frameworks:

System framework: This is the well-known framework of relevance. Belkin and Croft (1992) described a model showing relations between users and systems. Pragmatic use of relevance is particularly focused on this framework, so most system designers spend their time on developing a system-sided IR. This, however, ignores user conditions and it creates a weak model itself.

Communication framework: Communication is based on the effectiveness of messages between a source and a destination, as Saracevic (1975) stated. Wilson and Sperber (2004) also noted that, in terms of the effect and the effort of an input, an individual who gets the input determines the degree of relevancy and irrelevancy.

Situational framework: Social context, time dependence and dynamics compose the situational nature of relevance and also the subjective nature of relevance. It is the opposite of the system framework. Situational framework is interested in the user and it ignores system concerns.

Psychological framework: It is based on users' cognitive state and processes. Inadequacies of systems or algorithmic relevancies cause the need for a cognitive relevance concept. Harter (1992) stated that the user does not seek information in the same cognitive state. It changes dynamically.

Interaction framework: This framework encompasses the other four frameworks. It establishes a relation among elements of the frameworks in order to produce a system of relevancies. Interactions especially set up a dialogue between user and computer.

"Manifestation" is as important an issue as "nature" to define any notion in science. Manifestation of relevance is based on relation. Different manifestations of relevance can be derived from different relations. The relation is between components of relevance and texts. The information retrieval model includes all interaction among the relevance parameters and resources (Figure 2.1). Text, here, represents all relevant information object types such as documents, images and sounds. Every relevance manifestation therefore includes a relation with an information object.

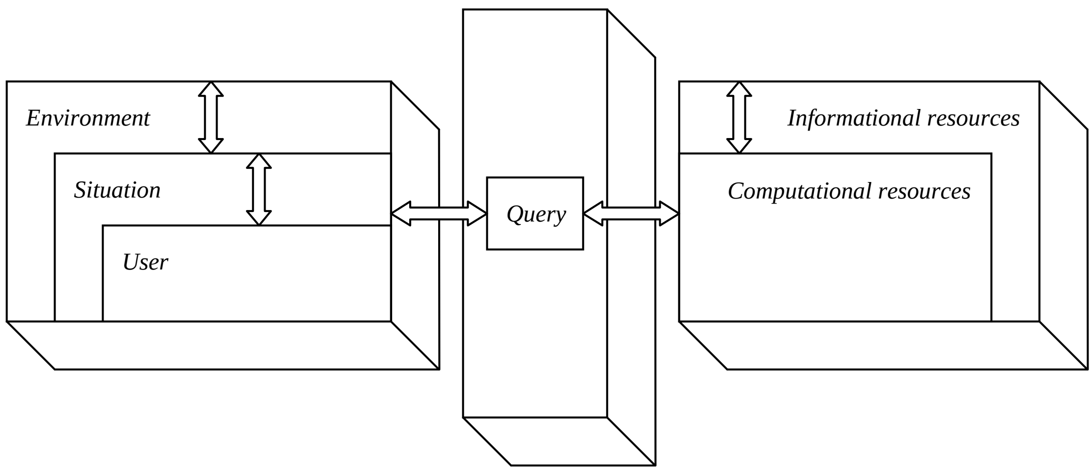

Figure 2.1: Information retrieval interaction (Saracevic 1996)

Saracevic (1996) described five manifestations of relevance:

"System or algorithmic relevance: relation between a query and information objects (texts) in the file of a system as retrieved, or as failed to be retrieved, by a given procedure or algorithm.

Topical or subject relevance: relation between the subject or topic expressed in a query, and topic or subject covered by retrieved texts, or more broadly, by texts in the systems file, or even in existence.

Cognitive relevance or pertinence: relation between the state of knowledge and cognitive information need of a user, and texts retrieved, or in the file of a system, or even in existence.

Situational relevance or utility: relation between the situation, task, or problem at hand and texts retrieved by a system, or in the file of a system, or even in existence.

Motivational or affective relevance: relation between the intents, goals and motivations of a user and texts retrieved by a system, or in the file of a system, or even in existence."

Although Saracevic (1996) explained five manifestations of relevance, Cosjin and Ingwersen (2000) claimed that the fifth manifestation of relevance should have been changed. Motivational relevance should be viewed as an attribute of relevance. Instead, a sociocognitive relevance which is based on sociocultural context meets affective relevance requirements. Sociocognitive relevance is a relation between situation, task or a problem at hand as perceived in sociocultural context and information objects.

Mizarro (1998) stated that the dimension of relevance should be explained so that the nature of relevance can be understood well. Otherwise, definition of the nature of relevance from a relevance concept is not sufficient. Four dimensions of relevance can be described, as follows (Mizarro, 1998):

- Information resources (Document, Information)
- Representation of the user's problem (Real Information Need, Perceived Information Need, Request, Query)
- Time

- Components (Topic, Task, Context)

Time is an important dimension for understanding relevance as expressed above. At a certain point in time some information might not be relevant enough. It depends absolutely on time to determine the relevance degree of information object to any user.

Some theorists chose uncertainty (as in information theory and decision-making theory) 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 rather 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.

2.1.2 Context and Context-Aware

Many scientists have made various context definitions (Brown et al., 1997; Ryan et al., 1997; Dey, 1998; Schilit et al., 1994; Dey et al., 1999; Pascoe, 1998). These researches generally stated that context can be enumerated as user's location, user's environment, identity and time. Dey and Abowd (2000), however, have not thought the definitions sufficient to express context scientifically. They defined context a little differently:

"Context is 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."

They also stressed that context might include not only implicit information but also explicit information, although many researchers maintain the opposite of that. According to this statement a system which is based on context information can get information from the user explicitly. It should not, however, be the preferred way to gather context information.

Chen and Kotz (2000) offered a more general definition for context:

“Context is the set of environmental states and settings that either determines an application’s behavior or in which an application event occurs and is interesting to the user.”

Context has been categorised differently, as has definition of it. Dey and Abowd (2000) claimed that types of context are location, identity, activity and time. These are “primary context” types because they deal with questions of who, what, when and where. Furthermore, they act as indices of other sources of contextual information. The other types of context belong to “secondary context”. They behave as indices of primary context. Chen and Kotz (2000) refer to types of context as active context and passive context. Active context affects behaviour of an application while a passive one just updates itself so as to use it later.

Recently context-aware applications have gained importance in handheld computations. Thus a mobile application definitely needs a context-aware approach in the design stage of the application in order to adapt the dynamic systems. It also facilitates the creation of a reactive system. Dey and Abowd (2000) also defined context-aware as follows:

“A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task.”

The first categorization for context-aware was made by Schilit et al. (1994).

- *Proximate selection* is a user interface technique where the located-objects that are nearby are emphasized or otherwise made easier to choose.
- *Automatic contextual reconfiguration* is the process of adding new components, removing existing components, or altering the connections between components.
- *Contextual information and commands*. People’s actions can often be predicted by their situations. Contextual information and commands aim to exploit this fact.
- *Context-triggered actions* are simple IF-THEN rules used to specify how context-aware systems should adapt.

Dey and Abowd (2000) defined a new categorisation which encompasses Schilit’s (1994) features of context-aware. They summarised categorisation of context-aware again as presentation of information and services to a user, automatic execution of a service, and tagging of context to information for later retrieval.

Chen and Kotz (2000) determined types of context-aware from their definition of context types: active context-awareness and passive context-awareness. Active context-awareness provides for an application automatically to adapt to discovered context by changing the application's behaviour. Passive context-awareness provides for an application to present the new or updated context to an interested user or makes the context persistent for the user to retrieve later.

2.1.3 Ontology

Recently, the term "ontology" has often been used by scientists and thinkers. Though ontology originated in philosophy, researchers in artificial intelligence (AI) have seen the benefits of the ontology theory and have taken to using the word in respect of its meaning in philosophy. The following elaborates ontology from ancient ages to the modern computer age so as to give a sound understanding of it.

The earliest known use of "ontology" is *ontologia* in Latin. According to the Merriam-Webster online dictionary, ontology is "a branch of metaphysics concerned with the nature and relations of being and a particular theory about the nature of being or the kinds of existence".

Aristotle (B.C.350) deals with being as being for first philosophy in his Metaphysics (Ross, 1924). Thus his ideas are accepted as fundamental to modern ontology. "What is being?" and extensions of that question have been considered in philosophy. First, the German philosophers G.W. Leibniz (1646-1716) and C.Wolff (1679-1754) focused on ontology-psychology-logic, which evolved from Aristotle's first philosophy. Leibniz defined ontology as "the science of something and of nothing, of being and not-being, of the thing and the mode of the thing, of substance and accident" (Couturat, 1903).

The well-known philosopher Immanuel Kant (1724-1804) asserted that the entire system of metaphysics consists of four main parts: Ontology, Rational Physiology, Rational Cosmology, Rational Theology (Kant, 1998). E. Husserl (1859-1938) and his pupil Martin Heidegger (1889-1976) also expanded the meaning of "existence" or "being" in line with their own philosophical bent in addition to the other definitions.

The aim of AI is to create a model which almost fits the real world so as to adapt all changes to any application. Thus the problem arising is how to model the world. From this point of view, computer sciences borrow the term Ontology from philosophy. Obviously some conceptual differences occur between the two fields. The first difference which can be expressed in computer sciences is that ontology begins with lower-case “o”. Second, ontology is a countable word in computer science so it can be pluralised as ontologies, while such a word is not possible in philosophy.

One of the most cited definitions is that of Thomas Gruber (1993) in order to elucidate the term ontology: An explicit definition of conceptualisation. Conceptualisation includes the objects, concepts, and other entities that exist in a domain and their relationship (Genesereth and Nilsson, 1987). A more comprehensive definition is as follows: 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). A formal approach to ontology can be expressed by any formal language. The following equations 2.1, 2.2 and 2.3 derive symbolic definition of the conceptualisation C, the interpretation function I and the ontological commitment K (Guarino, 1998). In equation 2.1, D is domain, W is a set of maximal states of affairs of such a domain, and R is conceptual relations. For instance, D may be a set of blocks on a table, W can be a set of all possible spatial arrangements of these blocks and R represents conceptual relations like “above”, “below” or “”near” among the blocks. In equation 2.2, interpretation function is a function assigning elements of D to constant symbols of vocabulary of a logical language L, and elements of R to predicate symbols of V. For example, let us consider red block stands on the blue block, where RedBlock and BlueBlock are the elements of the domain, and isAbove is an element of the relation. An interpretation might be established in a vocabulary of a logical language such as *I: RedBlock(isAbove(BlueBlock))*. In equation 2.3, an ontological commitment can be explained as an agreement to use a vocabulary (i.e. make assertions and queries) in a way that is consistent with respect to the theory specified by an ontology (Thomas Gruber, 1993).

$$C = < D, W, R > \qquad \textbf{(2.1)}$$

$$I : V \rightarrow D \cup R \tag{2.2}$$

$$K = < C, I > \tag{2.3}$$

"Given a language L with ontological commitment K, ontology for L is a set of axioms designed in a way such that the set of its models approximates as best as possible the set of intended models of L according to K" (Guarino, 1998).

Many different kinds of ontologies exist in AI. They vary from subtypes of concepts to task dependency of them. For instance, top-level ontologies or upper ontologies which provide general-level terms can be categorised differently as depicted in Figure 2.2 (Chandrasekaran et al., 1999).

Though differences occur among the ontologies, general agreements exist for ontologies (Chandrasekaran et al., 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.
- Properties and relations can change over time.
- There are events that occur at different time instants.
- There are processes in which objects participate and that occur over time.
- The world and its objects can be in different states.
- Events can cause other events or states as effects.
- Objects can have parts.

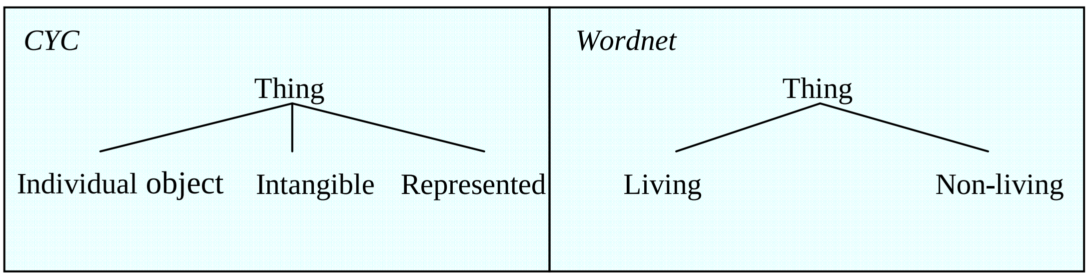

Figure 2.2: Ontologies might differ in general-level (Chandrasekaran et al., 1999)

Ontologies are able to realise knowledge-sharing. A healthy communication between people and software systems requires interoperability and knowledge-sharing. These requirements prevent re-invention of the wheel (Uschold and Gruninger, 1996). Gruber (1995) stated the following requirements as regards design ontology capable of sharing knowledge for a domain:

- Clarity: An ontology should effectively communicate the intended meaning of defined terms. Concept definition should be objective. It should be independent of social and computational context.
- Coherence: Sentences which are inferred from axioms should not contradict any concept definition.
- Extendibility: Ontology should allow definition of new additional terms without revision of existing definitions.
- Minimal encoding bias: Ontology should not depend on any particular symbol-level encoding. It must be conceptualised at the knowledge-level.
- Minimal ontological commitment: An ontology should require the minimal ontological commitment sufficient to support the intended knowledge-sharing activities.

Ontology knowledge needs four fundamental components: concepts, relations (functions), axioms and instances. Let us consider three classes, *Person*, *Pet* and *Country*, in order to facilitate understanding of the components as depicted in Figure 2.3 (Horridge et al., 2004). The individuals (Gemma, Matthew, Italy, England, USA, Fluffy and Fido) of these classes have connected each other with *livesInCountry*, *hasPet* and *hasSibling* relations. In the figure, classes are represented as circles, binary relations are represented as curved arrow connectors and instances (individuals) are represented as diamonds.

Different kinds of ontology languages should support these components in order to implement ontologies successfully. Each component can be examined by different criteria. These criteria, which can be called features or attributes, determine the effectiveness of ontology for applications. Although ontology languages support all fundamental components, features of components might be different for any languages (Gomez-Perez and Corcho, 2002).

- Concepts: Concepts are a set of objects sharing certain characteristics. They are also known as classes, types or categories. Classes are organised in hierarchical relations that are called taxonomies. Taxonomies are based on a subsumption relationship.

- Relations and Functions: Define the relation between concepts. Relations are also called properties or roles. Function determines a special type of relation.
- Axioms: Axioms or assertions define some restrictions for relations.
- Instances: Instances (individuals) are elements of a concept which is specified in a domain. They have different attributes, although they belong to the same concept.

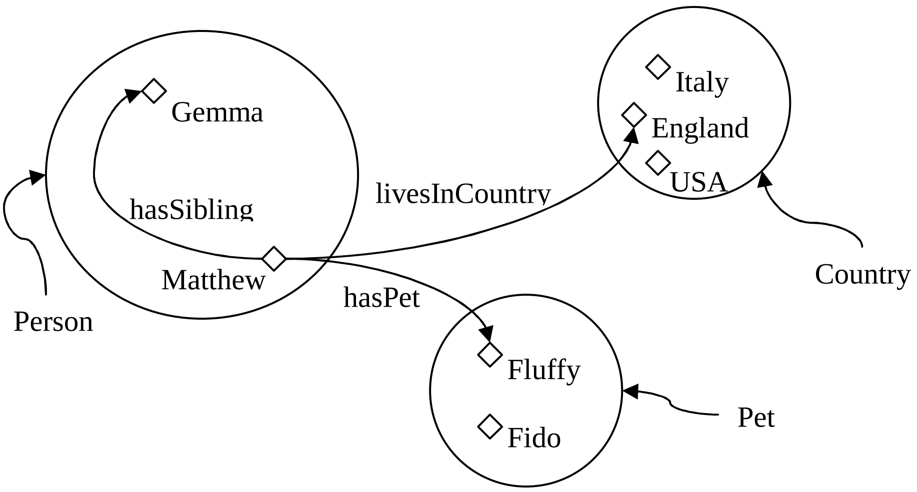

Figure 2.3: Representation of classes, relations and instance (Horridge et al., 2004)

2.1.4 Description Logic

The aim of knowledge representation (KR) and reasoning is to describe the world for intelligent applications. Intelligent systems are able to extract implicit consequences from explicit descriptions. Description logics as the most recent member of the family of the logic-based knowledge representation formalisms is an important field for AI. In description logics, elementary descriptions are atomic concepts and atomic roles (relationships or properties). Schimit-Schauss and Smolke (1991) introduced AL (Attributive Language) which is the fundamental language of description languages. While the letters C and D are an atomic concept and R is an atomic role, Table 2.1 shows syntax rule of the concept description in AL.

To give examples of what can be expressed in *AL*, we suppose that *Person* and *Female* are atomic concepts. Then $Person \cap Female$ and $Person \cap \neg Female$ are *AL* concepts describing, intuitively, those persons that are female and those that are not female. If, in addition, we suppose that *hasChild* is an atomic role, we can form the concepts $Person \cap \exists hasChild.\top$ and $Person \cap \forall hasChild.Female$, denoting those persons that have a child, and those persons all of whose children are female. Using the bottom concept, we can also describe those persons without a child by the concept $Person \cap \forall hasChild.\bot$. (Schimit-Schauss and Smolke, 1991)

Table 2.1: The basic description language in *AL*

Syntax	Statement
A	Atomic concept
$\top$	Universal concept
$\bot$	Bottom concept
$\neg A$	Atomic negation
$C \cap D$	Intersection
$\forall R.C$	Value restriction
$\exists R.\top$	Limited existential quantification

To define formal semantics of AL concepts, interpretations I that consist of a non-empty set Δ^I (the domain of the interpretation) and an interpretation function which assigns to every atomic concept A a set $A^I \subseteq \Delta^I$ and to every atomic role R a binary relation $R^I \subseteq \Delta^I \times \Delta^I$ are considered in equations 2.4, 2.5, 2.6, 2.7, 2.8 and 2.9. (Baader et al., 2003).

$$\top^I = \Delta^I \quad \textbf{(2.4)}$$

$$\bot^I = \emptyset \quad \textbf{(2.5)}$$

$$(\neg A)^I = \Delta^I \setminus A^I \quad \textbf{(2.6)}$$

$$(C \cap D)^I = C^I \cap D^I \quad \textbf{(2.7)}$$

$$(\forall R.C)^I = \left\{ a \in \Delta^I \middle| \forall b.(a,b) \in R^I \rightarrow b \in C^I \right\} \quad \textbf{(2.8)}$$

$$(\exists R.\top)^I = \left\{ a \in \Delta^I \middle| \exists b.(a,b) \in R^I \right\} \quad \textbf{(2.9)}$$

With further constructors, expressiveness of *AL* can be extended as in the following equations 2.10, 2.11, 2.12 and 2.13:

$$(C \cup D)^I = C^I \cup D^I \tag{2.10}$$

$$(\exists R.C)^I = \left\{ a \in \Delta^I \middle| \exists b.(a,b) \in R^I \wedge b \in C^I \right\} \tag{2.11}$$

$$(\geq nR)^I = \left\{ a \in \Delta^I \middle| \left| \left\{ b \middle| (a,b) \in R^I \right\} \right| \geq n \right\} \tag{2.12}$$

$$(\leq nR)^I = \left\{ a \in \Delta^I \middle| \left| \left\{ b \middle| (a,b) \in R^I \right\} \right| \leq n \right\} \tag{2.13}$$

In order to describe classes of objects, complex descriptions of concepts can be formed. Relation between concepts or roles can be defined by some statements. These statements are called Terminological Axioms and they are of two types: inclusions (Equations 2.14 and 2.15) and equalities (Equations 2.16 and 2.17).

Where C, D are concepts and R, S are roles, some sample terminological axioms can be formed as follows:

$$C \subseteq D \tag{2.14}$$

$$R \subseteq S \tag{2.15}$$

$$C \equiv D \tag{2.16}$$

$$R \equiv S \tag{2.17}$$

A definition that is a specific terminological axiom is an equality whose left side is an atomic concept. The following example is about a definition (Equation 2.18).

$$Mother \equiv Woman \cap \exists hasChild.Person \tag{2.18}$$

A finite set of definitions T is called a terminology or *TBox* if no symbolic name is defined more than once, that is, if for every atomic concept A there is at most one axiom in T whose left-hand side is A. (Baader et. al., 2003). The following example indicates a *TBox* with a set of definitions *T*:

$$Woman \equiv Person \cap Female \tag{2.19}$$

$$Man \equiv Person \cap \neg Woman \tag{2.20}$$

$$Mother \equiv Woman \cap \exists hasChild.Person \quad \textbf{(2.21)}$$

Another component of a knowledge base except terminology (*TBox*) is the *world description* or *ABox*. In the *ABox*, a specific state of affairs of an application domain is defined in terms of concepts and roles. Where a, b, c are individual names, C is a concept and R is a role, and in the ABox assertion can be made by two kinds: $C(a)$, $R(b,c)$. The first kind called concept assertion, indicates that *a* belongs to (the interpretation of) C. The second kind called role assertion says that c is a filler of the role for b. For instance *Peter*, *Paul*, and *Mary* are individual names, then *Father(Peter)* means that *Peter* is a father, and *hasChild(Mary,Paul)* means that *Paul* is child of *Mary*. (Baader et al., 2003)

The main advantage of a knowledge representation system based on Description Logics is opportunity of reasoning. The system is therefore able to produce explicit knowledge from implicit knowledge which exists in TBox and ABox. A DL system enables different kind of reasoning called inferences. These inferences might be from TBox or ABox. Architecture of a knowledge representation system based on description logic is depicted in Figure 2.4.

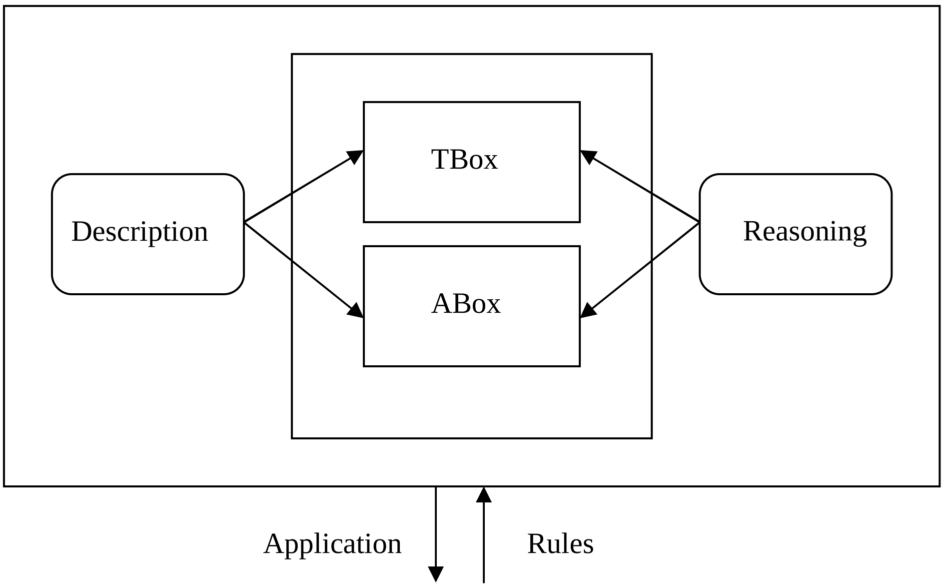

Figure 2.4: Architecture of a knowledge representation system based on Description Logics (Baader et al., 2003)

There are four TBox reasoning types (Baader et al., 2003):

Satisfiability: A concept C is satisfiable with respect to T if there exists a model I of T such that C^I is non-empty. In this case we say also that I is a model of C.

Subsumption: A concept C is subsumed by a concept D with respect to T if $C^I \subseteq D^I$ for every model I of T. In this case we write $C \subseteq_T D$ or $T \models C \subseteq D$.

Equivalence: Two concepts C and D are equivalent with respect to T if $C^I = D^I$ for every model I of T. In this case we write $C \equiv_T D$ or $T \models C \equiv D$.

Disjointness: Two concepts C and D are disjoint with respect to T if $C^I \cap D^I = \varnothing$ for every model I of T.

2.1.5 Knowledge Base of OWL DL

The ontology language OWL DL (Ontology Web Language with Description Logics) is based on the *SHOIQ* DL. With simple form of Datatypes (concrete domains), a variant of *SHOIQ* DL called *SHOIN*(**D**) logic is derived. The following definitions describe the syntax and semantics of *SHOIN*(**D**), ignoring datatypes. In the *SHOIN*(**D**) logic, *S* stands for the basic *ALC* DL extended with transitive roles, *H* stands for role hierarchies (equivalently, inclusion axioms between roles), *O* stands for nominals (classes whose extension is a single individual), *I* stands for inverse roles, *N* stands for number restrictions and **(D)** stands for datatypes (Horrocks, 2005).

Definition 1. Let **R** be a set of role names with both transitive and normal role names $\mathbf{R}_+ \cup \mathbf{R_P} = \mathbf{R}$, where $\mathbf{R_P} \cap \mathbf{R}_+ = \varnothing$. The set of *SHOIN* roles (or roles for short) is $\mathbf{R} \cup \{R^- \mid R \in \mathbf{R}\}$. A role inclusion axiom is of the form $R \sqsubseteq S$, for two roles R and S. A role hierarchy is a finite set of role inclusion axioms.

An interpretation $I = (\Delta^I, \cdot^I)$ consists of a non-empty set Δ^I, called the domain of I, and a function $\cdot^I$ which maps every role to a subset of $\Delta^I \times \Delta^I$ such that, for $P \in \mathbf{R}$ and $R \in \mathbf{R}_+$, $\langle x, y\rangle \in P^I$ *iff* $\langle y, x\rangle \in P^{-I}$ *and if* $\langle x, y\rangle \in R^I$ and $\langle y, z\rangle \in R^I$, then $\langle x, z\rangle \in R^I$.

An interpretation I satisfies a role hierarchy R iff $R^I \subseteq S^I$ for each $R \sqsubseteq S \in$ R; such an interpretation is called a model of R.

Definition 2. Let N_C be a set of concept names with a subset $N_I \subseteq N_C$ of nominals. The set of SHOIN-concepts (or concepts for short) is the smallest set such that

every concept name $C \in N_C$ is a concept,

if C and D are concepts and R is a role, then $(C \cap D)$, $(C \cup D)$, $(\neg C)$, $(\forall R.C)$, and $(\exists R.C)$ are also concepts (the last two are called universal and existential restrictions, respectively), and

if R is a simple form role and $n \in$ ¥ , then $\leq nR$ and $\geq nR$ are also concepts (called atmost and atleast number restrictions).

The interpretation function $\cdot^I$ of an interpretation $I = (\Delta^I, \cdot^I)$ maps, additionally, every concept to a subset of Δ^I such that

$$(C \cap D)^I = C^I \cap D^I \tag{2.22}$$

$$(C \cup D)^I = C^I \cup D^I \tag{2.23}$$

$$\neg C^I = \Delta^I \setminus C^I \tag{2.24}$$

$$(\exists R.C)^I = \{x \in \Delta^I \mid \text{There is a } y \in \Delta^I \text{ with } \langle x, y \rangle \in R^I \text{ and } y \in C^I\} \tag{2.25}$$

$$(\forall R.C)^I = \{x \in \Delta^I \mid \text{For all } y \in \Delta^I \text{, if } \langle x, y \rangle \in R^I \text{, then } y \in C^I\} \tag{2.26}$$

$$\leq nR^I = \{x \in \Delta^I \mid \#\{y \mid \langle x, y \rangle \in R^I\} \leq n\} \tag{2.27}$$

$$\geq nR^I = \{x \in \Delta^I \mid \#\{y \mid \langle x, y \rangle \in R^I\} \geq n\}, \tag{2.28}$$

where, for a set M, we denote the cardinality of M by $\# M$.
For C and D (possibly complex) concepts, C ô D is called a general concept inclusion (GCI), and a finite set of CGIs is called a TBox.

An interpretation I satisfies a GCI C ô D if $C^I \subseteq D^I$, and I satisfies a TBox T if I satisfies each GCI in T; such an interpretation is called a model of T. The syntax and semantics of Description Logic *SHOIN*(**D**) can be summarised as in Table 2.2 (Horrocks and Sattler, 2001).

Table 2.2: The syntax and semantics of description logic SHOIN(D)

Construct Name	Syntax	Semantics
Atomic concept	A	$A^I \subseteq \Delta^I$
abstract role	B	$R^I \subseteq \Delta^I \times \Delta^I$
concrete role	T	$T^I \subseteq \Delta^I \times \Delta^I$
nominals	$\{o\}$	$\{o\}^I \subseteq \Delta^I, \#\{o\}^I = 1$
datatypes	d	$d^D \subseteq \Delta_D$
conjunction	$C \cap D$	$(C \cap D)^I = C^I \cap D^I$
disjunction	$C \cup D$	$(C \cup D)^I = C^I \cup D^I$
Negation	$\neg C$	$(\neg C)^I = \Delta^I \setminus C^I$
exists restriction	$\exists R.C$	$(\exists R.C)^I = \{x \mid \exists y. \langle x, y \rangle \in R^I \text{ and } y \in C^I\}$
value restriction	$\forall R.C$	$(\forall R.C)^I = \{x \mid \forall y. \langle x, y \rangle \in R^I \text{ implies } y \in C^I\}$
atleast restriction	$\geq nS.C$	$\geq nS.C^I = \{x \mid \#(\{\text{y}. \langle x, y \rangle \in S^I\} \cap C^I) \geq n\}$
atmost restriction	$\leq nS.C$	$\leq nS.C^I = \{x \mid \#(\{\text{y}. \langle x, y \rangle \in S^I\} \cap C^I) \leq n\}$
datatype exist	$\exists T.d$	$(\exists T.d)^I = \{x \mid \exists y. \langle x, y \rangle \in T^I \text{ and } y \in d^D\}$
datatype value	$\forall T.d$	$(\forall T.d)^I = \{x \mid \forall y. \langle x, y \rangle \in T^I \text{ implies } y \in d^D\}$

2.1.6 Ontology-Based Context Modelling

Context-aware applications are a very important task for pervasive computing. The main problem arises when researchers think about how to launch a context-aware system. Formal context supports a level of context reasoning. It does not, however, address formal knowledge-sharing for ubiquitous systems. An ontology-based formal context model approach should be defined in order to provide formal context representation, knowledge-sharing and logic-based context reasoning. Wang et al. (2004) conceived the CONtext ONtology (CONON), a detailed design of ontological context model and logic-based context reasoning scheme in pervasive computing environments. CONON divides their context model into upper ontology and specific ontology. Specific ontology defines details of general concepts in any sub-domain such as home-domain ontology and office-domain ontology while upper ontology represents basic contextual entities (Figure 5.5). CONON supports two kinds of context reasoning: Ontology Reasoning (including concept satisfiability, class subsumption, class consistency, and instance checking) and User-Defined Reasoning (deducing higher level context from low-level context).

Becker and Nicklas (2004) proposed an architecture which combines the strengths of both context models and ontologies. The combined approach provides the efficiency of context management through context models with the semantic expressiveness of ontologies. According to Figure 2.5, the first three tiers represent management of scalable context information whereas tier 4 explains the role of ontology in enabling knowledge representation and knowledge reasoning for sophisticated concepts. Thus the combined approached allows the extraction of the information with the context model and the reasoning of the extracted information with ontologies.

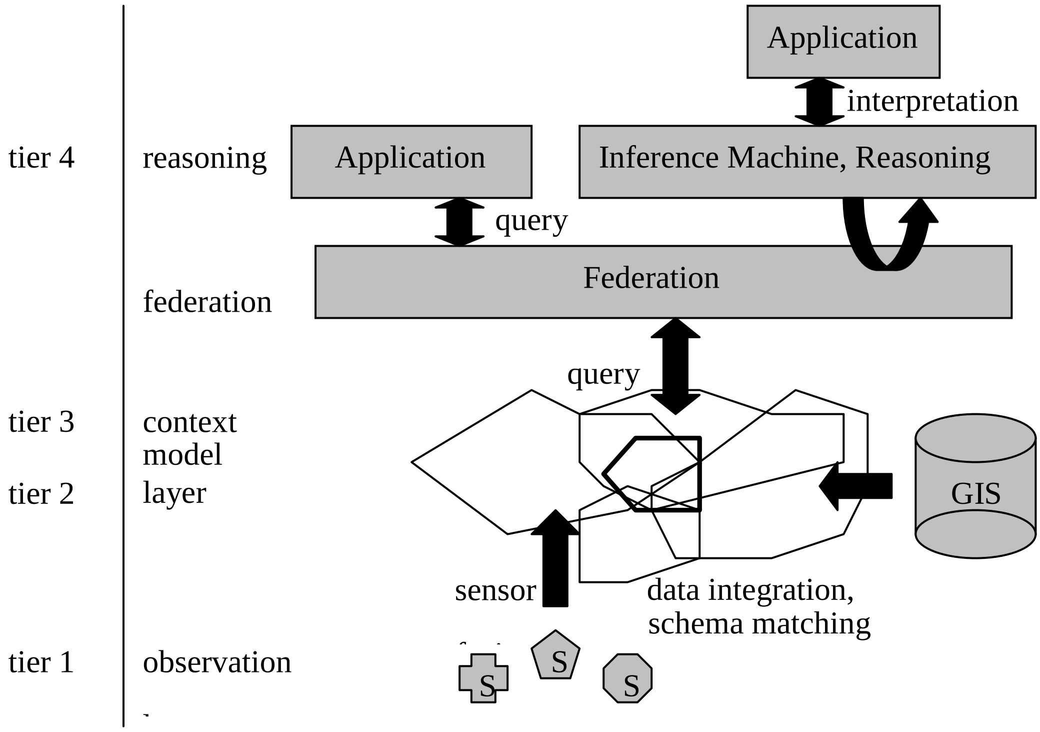

Figure 2.5: The combined approach (Becker and Nicklas 2004)

CoBrA (Context Broker Architecture) is a new context-aware pervasive computing framework (Chen et al., 2004). CoBrA conceives spatial and temporal ontologies which provide context reasoning to detect inconsistency in a knowledge base. The aim of CoBrA is to create intelligent spaces (e.g., living-rooms, vehicles, corporate offices and meeting-rooms). A context broker is responsible for the sharing of context knowledge and acquiring context from heterogeneous information resources. For large-scale intelligent spaces (e.g., a campus or a building), a broker federation is formed by multiple brokers. Chen et al. (2004) emphasise that context-aware pervasive computing systems should be implemented with ontologies. 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 wider field. 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, which are important in determining the performance of the context model, are explained by Christopoulou et al. (2005).

2.2 Technical Background

Knowledge-based (KB) systems reside above a complicated theoretical structure. The theories of knowledge base having an interest with thesis subject are described in sections 2.1.3. and 2.14. To realise a knowledge-based system, computer scientists and engineers have developed some specifications such as languages and rules. These specifications are required to implement a functional KB. On the other hand, web services which have geographic capabilities are introduced in order to understand the technological aspects of a network infrastructure. Because mobile devices are also one of the most important tools in a mobile system, their main features are examined. Thus the next sections on technical background will elucidate required KB specifications, web service specifications and technological structure of mobile devices as the fundamental elements of an intelligent system.

2.2.1 Knowledge-Based Systems

Ontologies enabling knowledge representation are designed with an ontology language in computer applications of artificial intelligence. Ontology languages underlie the knowledge base of a pervasive computing system. Ontology languages which have been developed up to now can be considered as being of two main categories:

- XML-based languages (Schema languages)
- Logic-based languages

Well-known XML-based ontology languages are Ontology Exchange Language (XOL) (Karp et al., 1999), Simple HTML Ontology Extension (SHOE) (Luke and Heflin, 2000) and Ontology Markup Language (OML) (Kent, 1999), RDF Resource

Description Framework (RDF) (Lassila and Swick, 1999) and RDF Schema (Brickley and Guha, 1999). On the other hand, Ontology Inference Layer (OIL) (Horrocks et al., 2000), DARPA Agent Markup Language + OIL (DAML+OIL) (Horrocks and van Harmelen, 2001) and Web Ontology Language (OWL) (Bechhofer et al., 2004) are logic-based ontology languages. Figure 2.6 shows the extension structure of the ontology languages.

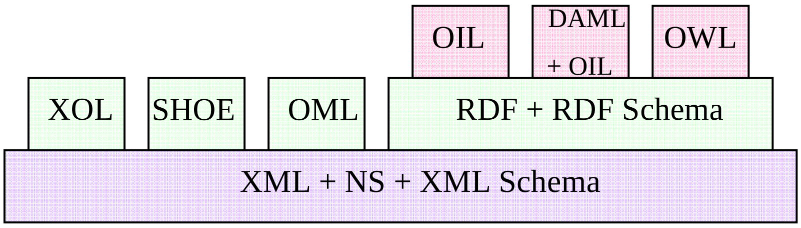

Figure 2.6: Ontology languages and their basis

XML is not an ontology language; it is just a data exchange format. Ontology languages evolve, however, from XML. Although the structure of RDF is close to XML syntax, RDF can be accepted as an ontology language. In addition to XML, RDF includes graphical formalism. It meets the basic requirements of ontology languages and enables meta-data representation, whereas RDFS is an extended form of RDF with ‘schema vocabulary’ such as class, property and domain.

Figure 2.7 shows the example of the RDF model of the sentence “The students in course 6.001 are Amy, Tim, John, Mary, and Sue.” The model is written in RDF/XML, as in Figure 2.8.

Nevertheless, RDFS is not sufficient to describe resources. For instance, it does not support transitive properties. RDFS also has a problem with reasoning. It does not provide full support for reasoning. Corcho and Gomez-Perez (2000) stress the reasoning problems of XML-based ontology languages by comparing them. To satisfy frame-based modelling requirements (concepts, taxonomies, relations, formal semantics and automated reasoning) in description logic OIL, DAML+OIL were developed. Afterwards OWL 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).

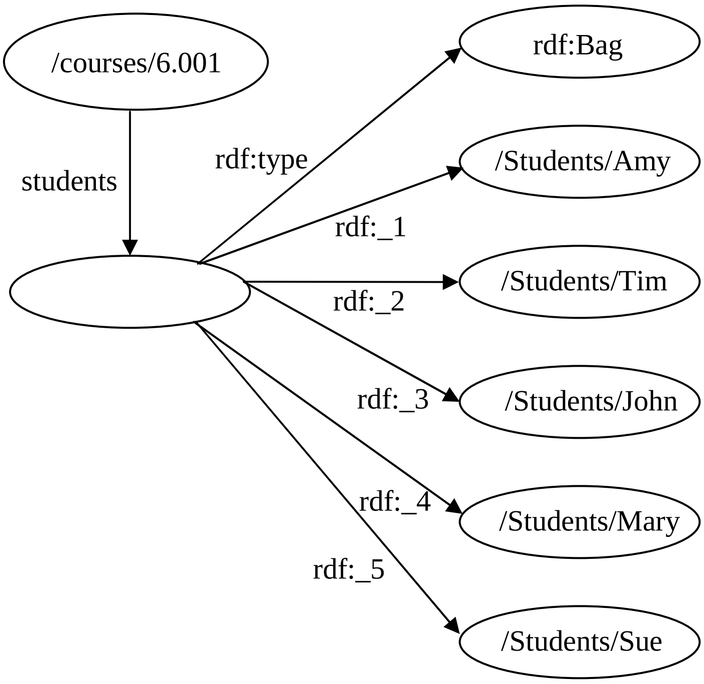

Figure 2.7: An example model of RDF (Lassilla and Swick, 1999)

```
<rdf:RDF>
 <rdf:Description about="http://mycollege.edu/courses/6.001">
  <s:students>
   <rdf:Bag>
      <rdf:li resource="http://mycollege.edu/students/Amy"/>
      <rdf:li resource="http://mycollege.edu/students/Tim"/>
      <rdf:li resource="http://mycollege.edu/students/John"/>
      <rdf:li resource="http://mycollege.edu/students/Mary"/>
      <rdf:li resource="http://mycollege.edu/students/Sue"/>
   </rdf:Bag>
  </s:students>
 </rdf:Description>
</rdf:RDF>
```

Figure 2.8: A screenshot of the RDF syntax (Lassilla and Swick, 1999)

OWL has three subtypes: OWL-Lite, OWL-DL and OWL-Full. OWL-Lite is a subset of OWL-DL while OWL-DL is a subset of OWL-Full. OWL-Lite is able to implement a classification hierarchy and simple constraints. Production of OWL-Lite is a production of OWL-DL at the same time. 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. OWL-Full adds syntactic freedom of RDF but it might be non-computable. OWL-Full is a complete extension of RDF but OWL-Lite and OWL-DL do not meet all RDF specifications. Although all subtypes of OWL are a RDF document, some RDF documents may not be appropriate for OWL-Lite and OWL-DL. The preferable OWL subtype is usually OWL-DL.

Inference engines (e.g., Jena2, Pellet, RacerPro) for description logics enable reasoning in a knowledge base by means of ontologies. These kinds of ontology inference engines are, however, not the only reasoning mechanism in artificial intelligence. The Semantic Web Rule Language (SWRL) is another specification to extract implicit information from explicit ones. SWRL includes acquired knowledge with a rule-based XML syntax language. Therefore it can be perceived as 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, 2004).

2.2.2 Location-Based Services

Recently, new technologies have expanded the scope of GIS. GIS was considered and designed for desktop systems first. Then advancements in the network systems of computers led to new terms such as mobile GIS, web GIS, web-based GIS, internet GIS and distributed GIS. Actually, the meanings of these new terms broadly overlap. Nevertheless, there are some slight but important distinctions in the definition of the terms.

Web is just one of the many services of internet like e-mail, file transfer or chat. From this point of view, internet GIS is totally different from Web GIS or Web-based GIS. One of the main problems with internet GIS is difficulty in integrating GIS components because of their diversity. Chang and Park (2006) explained a new development model for dynamic and interoperable internet GIS application (Figure 2.9).

In Figure 2.9, WS, which stands for the web service, provides connection over SOAP (Simple Object Access Protocol) messages among the technologies. The design of the model was founded on the following structure which includes three components:

- Data repositories.
- Functional components.
- Wrapper clients.

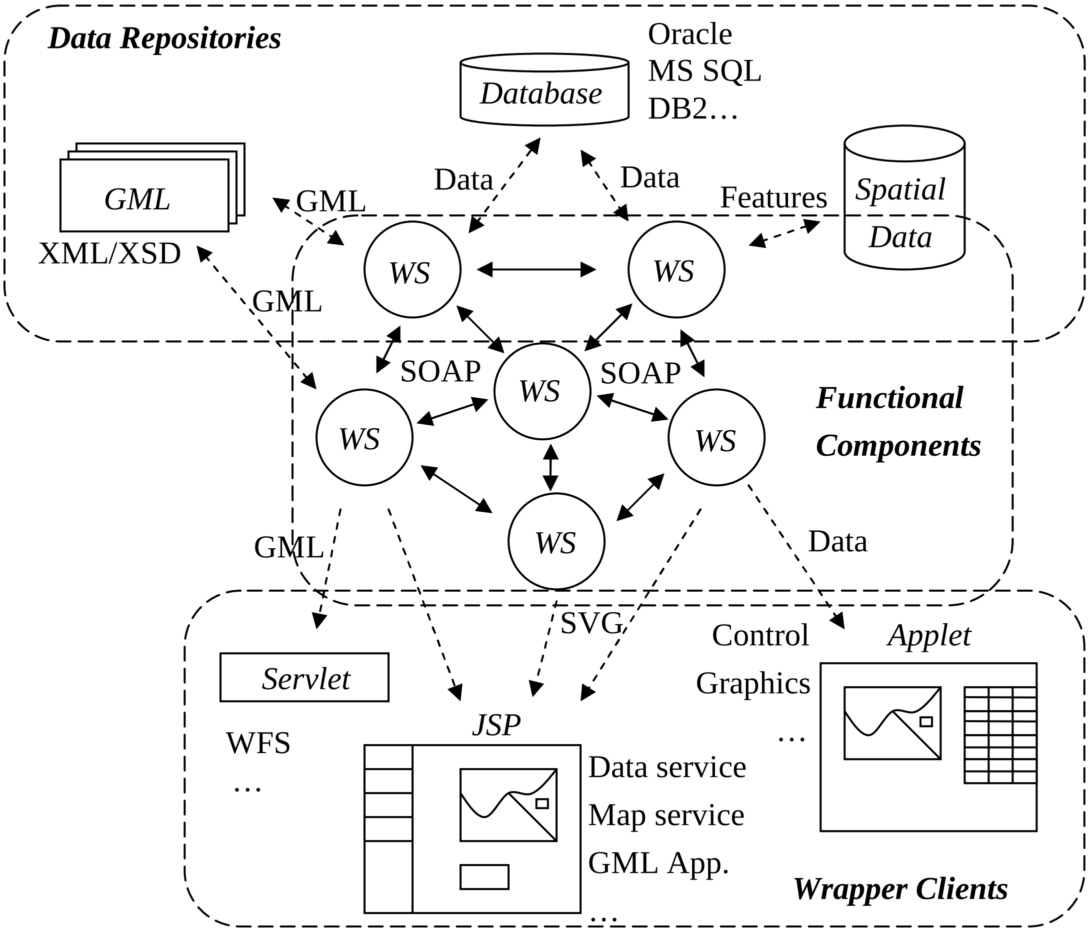

Figure 2.9: Structure of the model for internet GIS (Chang and Park, 2006)

Web GIS has a restricted term to define a GIS which involves an internet connection. A similar phenomenon is valid between the terms of internet GIS and Mobile GIS. The meaning of the internet GIS does not completely include the Mobile GIS, despite mobile GIS being part of the wireless network environment. To overcome this confusion, the distributed GIS concept has been thought up. Distributed GIS combines internet GIS and mobile GIS in a broad sense. A detailed technological platform is developed by Casademont et al. (2004) for the commercialisation of advanced distributed GIS.

Location-based services are an important application of distributed GIS. Peng and Tsou (2003) refer to LBS as a system that offers real-time information about a location and its surrounding area. LBSs can be categorised according to various criteria. Rao and Minakakis (2003) classified LBS according to the type of underlying customer need they seek to serve and also the type of information that can be delivered in a given space-time configuration. They determined typical services and business models for each of these demand categories, such as “Where am I” queries, point of need information delivery, and niche consumer applications. Furthermore, each LBS application has its own unique characteristics. For instance, location-tracking services concerns keeping private user’s location information more than position-aware services do (Barkhuus and Dey, 2003).

Distributed GIS requires some specifications for handling data throughout the system. LBS particularly, or any distributed system, utilises computers, devices which have different hardware configuration, software and operating system capabilities. To unite the components of the system under the same structure, GIS specifications have been developed by the Open Geospatial Consortium (OGC) and ISO/TC 211. Geography Markup Language (GML), Web Map Server (WMS), Web Feature Server (WFS), and Styled Layer Descriptor (SLD) are some specifications for distributed GIS. LBS also require non-geographic standards (e.g., Structured Query Language – SQL, Open Database Connectivity-ODBC and JDBC Java Database Connectivity) to provide full interoperability among system components.

Not only GIS but also other systems involving distributed architecture utilise Java technology. Java technologies comprise three platforms (Figure 2.10):

- Java Platform, Standard Edition (Java 2 Platform) for developing desktop and server applications.
- Java Platform, Enterprise Edition for developing portable, robust, scalable and secure server side applications.
- Java Platform, Micro Edition for developing ubiquitous applications of mobile devices.

Java platforms provide many advantages in developing distributed application. The first advantage of the Java platform is its ability to work on any operation system (e.g. Microsoft Windows, Linux OS, Mobile OS, etc.) because Java-compiled codes run on a Java virtual machine, as shown in Figure 2.10. Thus the installed Java platforms are enough to set up a system that is cross-platform and interoperable. The second main advantage is that the Java platform allows server-side and client-side programming. This feature of the Java platforms enables a portable and secure distributed system.

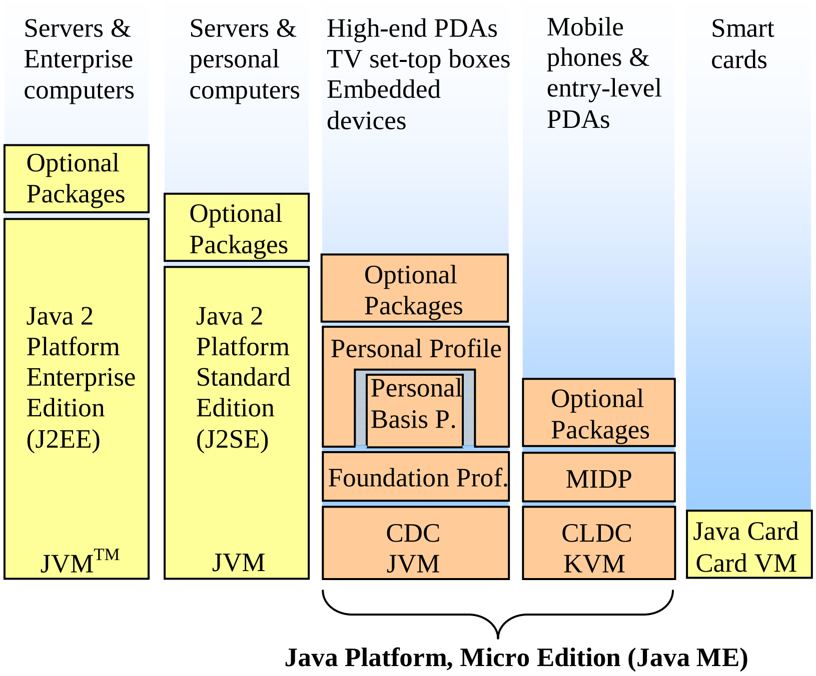

Figure 2.10: The Java platform (Sun Microsystems Inc.)

Scope of the Mobile GIS depends on the technological developments in mobile devices. Mobile devices in LBS are classified in two main categories related to their hardware profiles: PDAs and mobile phones. Mobile phones are more popular and widespread devices than PDAs in the mobile market. Nowadays all mobile phones have Java ME platform although their optional Java package support is different.

3. RELATED WORK

3.1 Retrieving Relevant Geographic Information

GIS involves the management of data which have huge volume and complex structure, which are characteristic features of two- or three-dimensional geographic data. In this context, mining and retrieving relevant data have become one of the main research focuses in GIS. Early researches deal with design of spatial databases and query-processing similar to non-spatial databases. In Samet and Aref (1995), data models, query-processing and query optimisation are discussed to obtain useful information for the user. Different query methods and spatial extensions of the traditional databases are examined so as to provide effective handling of spatial data. The research provides us with some fundamental approaches to spatial data modelling and querying that are important for the retrieval of relevant spatial information. For example, some hints have been included for integrating spatial and non-spatial data such as bidirectional links between the attributes.

Relevance theories cover four or five components, as explained in section 2.1.1, which elucidates details of relevant object properties. The two aims of the relevancy are to find a match between the query terms and the information objects and the relation between the user's situation and the information objects within a system. Beard and Sharma (1997) described multidimensional ranking for two kinds of relevancy in digital spatial libraries. In multidimensional ranking schemes, all targets are specified by users. These targets include spatial, temporal and thematic targets. Each dimension is calculated separately and obtains a score ranging between zero and one, with one being a perfect score. The final result is determined by the combination of three dimensions. Larson and Frontiera (2004) have developed a new algorithm for ranked retrieval of georeferenced objects. They propose a probabilistic spatial ranking instead of the traditional similarity measurement methods. In this method the calculation is based on logistic regression model of IR. Semantic approaches have, however, been preferred to numerical ranking techniques in this research, because numerical techniques might be insufficient to determine relevant data which depend on immeasurable concepts such as user profile, environmental factors and state of the user's knowledge.

Another scheme to measure both thematic and spatial relevance in the case of SPIRIT is developed by Bucher et al. (2005). Thematic relevance decrees:

- A document which contains relevant information about the concept queried and on its own allows you to form a judgement about the document (i.e. requires no external knowledge).
- A document is relevant, since it points to a resource mentioning the concept, but you must consult further pages referenced by the document to perform a judgement.
- A document does not provide information about the concept provided.

Spatial relevance decrees:

- A document refers to a location that is/near the query location and you think that the location in the document has sufficient detail for you to find it on a local map of the area.
- A document refers to a location that is in/near the query location but you think that there is insufficient information for you to find that location on a local map of the area.
- A document does not fall within the query location.

The project combines a conceptual approach with numerical solutions for the search process of the spatial data source via web sites. The approach has, however, only been based on the locations rather than a comprehensive context model such that a model is able to notice the user's interests. It is therefore not appropriate for mobile applications.

Not only GIS experts and GIS users but also any computer users unaware of spatial data features try to extract needed data from a vast information ocean. Some researches have therefore dealt with problem-based spatial and non-spatial information search methods. In the context of spatial and non-spatial information post-processing searches, Li et al. (2005) developed a new methodology in three parts: divide and conquer, integration, dynamic visualisation. The proposed system first formulises the user question, then carries on spatial and non-spatial search in a separate process. In the final step of the methodology, dynamic integration and visualisation are done. Nevertheless, practical results show that the research is inadequate for providing relevance between user expectation and information sources by the visualisation. In the research visualisation highlights the target location with only a bounding box. It might, however, have reflected the features of the obtained non-spatial data, depending on the location.

All researches that the author has cited so far in this section focus on the relevant spatial information search and the ranking of this obtained spatial information. These kinds of IR works are valuable for the projects that include mobile users but they are not sufficient to meet mobile users' dynamically-changing requirements themselves.

Consequently, researchers have looked for methods that provide relevant information to the user apart from Google-style data retrieval. Some of them have tried to determine the state of user knowledge; some of them have tried to adapt the presentation style of the obtained information. For providing user and system relevancy, technological solutions have also considerable contribution potential. In particular, users of location-based services need additional solutions to extract relevant data precisely because mobile services have more specific architecture than desktop GIS. Grossniklaus et al. (2006) designed a LBS capable of using conventional paper maps. To support the provision of location-based services, the system uses three distinct information sources to track positions of the users and objects: a GPS sensor, positions coming from the map and coordinates stored in the application database. The system increases interactivity between the user and the target information object so that the system can evaluate user demand accurately. Hermann et al. (2003) developed a technique using the sun position and sensor information of an electronic compass to obtain a user-oriented map display. The technique is intended for appropriate visualising of pedestrian navigation. The results showed that the egocentric method produced satisfying outputs in navigation efficiency. Even though different aspects of the sensor-supported location-based mobile services are suggested, the relation between the visualisation of the geographic data and obtained data from the sensors are not considered sufficient.

Adaptive systems are systems providing relevancy. Adaptive visualisation methods of geographic information on mobile devices are therefore the important research area in cartography. Zipf (2005) said that a context-adaptive mobile map meets user requirements. A ArcMap2SLD-generator allows designing a map using ESRI ArcMap and automatically converting it into a valid SLD-file. Then the model uses SLD data model and WMS together to generate the adaptive mobile map. In Reichenbacher (2004), adaptive visualisation of mobile maps was examined in more detail. Reichenbacher proposed new adaption dimensions in geographic information visualisation depending on the mobile context. Nevertheless, relevance theories were ignored in the researches in order to provide adaptation.

Relevancy research, in GIS, tends to focus on visualisation relevant to the mobile user. Reichenbacher (2005) stressed the importance of relevancy 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 the mobile environment. Reichenbacher (2005) enumerates relevance types as spatial relevance, temporal relevance, algorithmic relevance, thematic relevance, cognitive relevance and activity relevance. Appearance of the spatial object on the mobile screen represents relevancy degree of the object. Depending on the size, opacity or focus of the object, various figures of similar kinds of objects are obtained differently. This concept is called level of relevancy (LoR). Context and relevance modelling need, however, to be combined with an ontological approach in order to obtain an efficient ubiquitous computing system.

In cartography, relevancy means relation between the user and the visualisation. Visualisation of spatial objects can be handled from different points of view. One of these research efforts is “generalisation”. Generalisation is needed in order to represent relevant information at an appropriate level of detail. Generalisation includes different algorithms such as simplification and displacement to determine an optimal shape of the spatial objects for any scale. Many scientists have developed mathematical models of simplification and displacement for generalisation (Nickerson, 1988; Ruas, 1998; Lamy et al., 1999). Sester (2000) and (2005) explained generalisation models based on least squares adjustment (Figure 3.1). Although the developed generalisation algorithms are efficient enough for desktop systems, mobile systems require simpler visualisation algorithms and approaches to provide maps for mobile devices, because of the limited computation and display capacity of the devices.

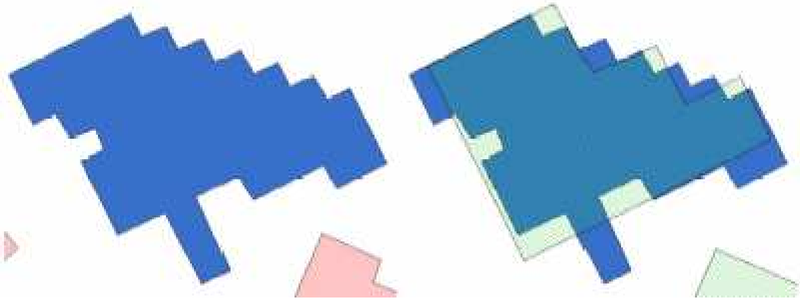

Figure 3.1: Before (left) and after simplification (right) (Sester, 2000)

Edwardes et al. (2005) proposed an approach based on the notion of hierarchical spatial tessellation for generalisation. They used the quadtree to make decisions on the number of objects to display (Figure 3.2).

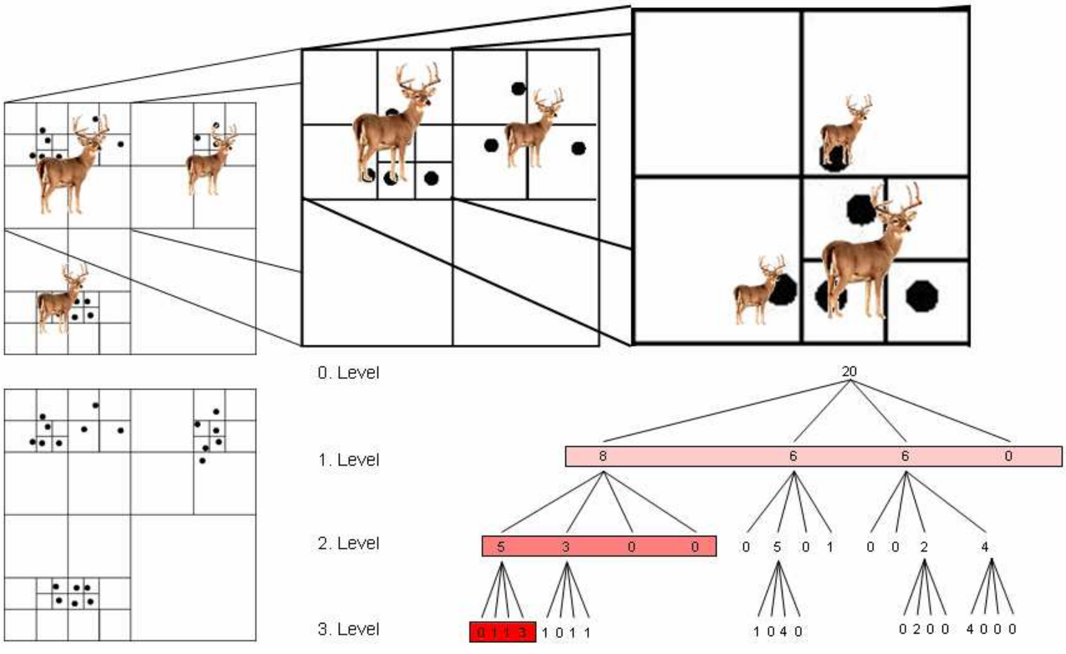

Figure 3.2: Generalisation of deer observations with quadtree (Edwardes et al., 2005)

The quadtree tessellates space until every point is assigned to a separate block. While zooming happens a level is chosen that meets a minimum acceptable symbol size criterion. In particular the solution allows rapid traversal and retrieval of data for LBS. The research stresses the importance of the symbol size in LBS so as to represent data appropriately. In this thesis, visualisation that depends on the object size has been used in a different approach.

Another concept providing relevancy is egocentric design for map-based mobile services. Depending on the mobile usage context, the egocentre is reflected in various aspects (Meng, 2005):

- The current user location in the form of a point, a route or a region of varying size.
- One or many locations that are currently of interest to the user.
- Data items that are currently of interest to the user.
- Actions or operations that are frequently performed by the user.
- Symbolisation styles preferred by the user.
- Interaction modalities preferred by the user.

According to Meng (2005), the design process could lead to many alternative solutions, with each trying to highlight the contents of the ego centre in a distinctive manner. The following design patterns that have been partly practiced in cartography, computer graphics and human-computer interface design are worthy to be considered in the mobile usage context (Meng, 2005). In order to provide the relation between the visualisation and the mobile context, egocentric design and its patterns have been considered in the relevance model of this thesis.

- Centering. If the ego centre is a spatially concentrated location such as a building block, a street segment or a region within the walking distance, it will be placed around the optical or geometrical centre of the vision field.
- Redundant encoding. The contents of ego centre can be visually differentiated from the peripheral information by using a graphic variable such color tone.
- Continuously varying level of details. By applying distortion techniques such as anamorphosis, multi-focal projection, fisheye view, interactive magnifier, a spatially concentrated ego centre can be displayed as a blown-up circular or rectangular area containing fine but legible details while the peripheral area is progressively displaced, compressed and generalized.
- Multiple levels of details. A task-relevant location can be expressed at multiple discrete levels of details.
- Space contraction. In case that the ego centre is composed of spatially widely separated locations, its overall extension will be intentionally contracted to make the associated contents simultaneously visible within the same window.

- Single window with details on demand. The screen space of a mobile device is obviously not able to accommodate the task-relevant mapping contents in multiple windows adjacent to each other.
- Augmented focusing. The one or two most relevant map features for the actual user action will be visually further enhanced with extra design elements such as a bounding box, 3D symbols, blinking, voice, large label and animated magnifier.
- Orientation gesture. Orientation plays a significant role for many navigation related task.
- Affective emphasis. The design pattern affective emphasis has the goal to encode the spatial information with symbols that do not necessarily carry additional information.

Simon et al. (2006) presented an application framework for building spatially-aware mobile applications. Egocentric applications visualise process or exchange geospatial information on mobile phones equipped with such sensors. The core component of the framework is a novel, platform-independent XML data-exchange format that describes the geometric vicinity of the mobile device. The format enables a variety of new mobile interaction styles and user interface types from traditional text-based local search and information interfaces to innovative real-time user interfaces like geo-pointers and smart compasses. The framework is not, however, sufficient to provide all aspects of relevance, although it is a good example that provides user-oriented spatial features.

Some helpful and acceptable conceptions have been given by Gartner (2004) to produce more relevant and adaptive visualisation in location-based navigation services:

- Speech interaction.
- Photo-realistic presentations.
- Change of presentation forms in mixed indoor/outdoor environments.

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 a map product which is more relevant to the user. Caquard et al. (2005) categorised sound maps with sound theory according to their subject, perspective and roles. Brauen (2006) discussed the design of a map of results showing a selection of electoral districts in the vicinity of Ottowa. Particularly, in mapping for mobile devices, some information can be conveyed by sound instead of geometric representation so as to provide more space for drawing in limited display screens. The sound support is an essential part of the relevant visualization, as the last three cited references indicate. The sound particularly can be a complementary tool for the visual design patterns that mobile devices are not able to provide.

3.2 Pervasive Computing for Relevancy in Geoinformatics

Pervasive computing environments gracefully integrate networked computing devices - from tiny sensors to extremely dynamic and powerful devices – with people and their ambient environments. A room, for example, might be saturated with a lot of devices that provide information to people without needing their active attention (Zhu et al., 2005). Since motion is an integral part of everyday life, such a technology must support mobility; otherwise a user will be acutely aware of the technology by its absence when he moves. Hence, the research agenda of pervasive computing subsumes that of mobile computing, but goes much further. Specifically, pervasive computing, also called ubiquitous computing, incorporates four additional research thrusts in its agenda (Satyanarayanan, 2001):

- Effective use of smart spaces. A space may be an enclosed area such as a meeting-room or corridor, or a well-defined open area such as a courtyard or quadrangle. A simple example of this is the automatic adjustment of heating, cooling and lighting levels in a room based on an occupant’s electronic profile. Influence in the other direction is also possible: software on a user’s computer may behave differently depending on where the user is currently located.
- Invisibility. The ideal is complete disappearance of pervasive computing technology from a user’s consciousness. In practice, a reasonable approximation to this ideal is minimal user distraction.
- Localised Scalability. As smart spaces grow in sophistication, the intensity of interactions between a user’s personal computing space and their surroundings increases. This has serious bandwidth, energy and distraction implications for a

wireless mobile user. Good system design has to achieve scalability by drastically reducing interactions between distant entities.

- Masking uneven conditioning. One way to reduce the amount of variation seen by a user is to have his personal computing space compensate for “dumb” environments. As a trivial example, a system that is capable of disconnected operation is able to mask the absence of wireless coverage in its environment. Complete invisibility may be impossible, but reduced variability is well within our reach.

Establishing a pervasive computing application has become one of the major tasks in computer sciences. In particular, pervasive computing demands applications that are capable of operating in highly dynamic environments and of placing fewer demands on user attention. In order to meet these requirements, pervasive computing applications will need to be sensitive to context. Held et al. (2002) developed an appropriate context-modelling concept for pervasive computing, which can form the basis for such a context management infrastructure. The model overcomes problems associated with previous context models, including their lack of formality and generality, and also tackles issues such as wide variations in information quality, the existence of complex relationships amongst context information and temporal aspects of context.

Singh et al. (2005) accepted the user as the most important entity of the context and expressed a semantic user model as shown in Figure 3.3 for pervasive computing to obtain a context-aware system. In the approach each user has a Ubiquitous User Identity and Profile. User profiles will represent user specific information like contact information, schedules, appointments, preferences, financial, and medical information. In addition, the profile will also model user likes/dislikes or interests, so that the system can proactively fetch or disseminate information on behalf of the user. The need for a context model that considers spatial data and its visualisation on mobile devices within a pervasive computing system is, however, one of the main concerns of this thesis. In terms of the visualisation of the spatial data, the context models that have been explained before are not able to meet the requirements of ubiquitous computing appropriately.

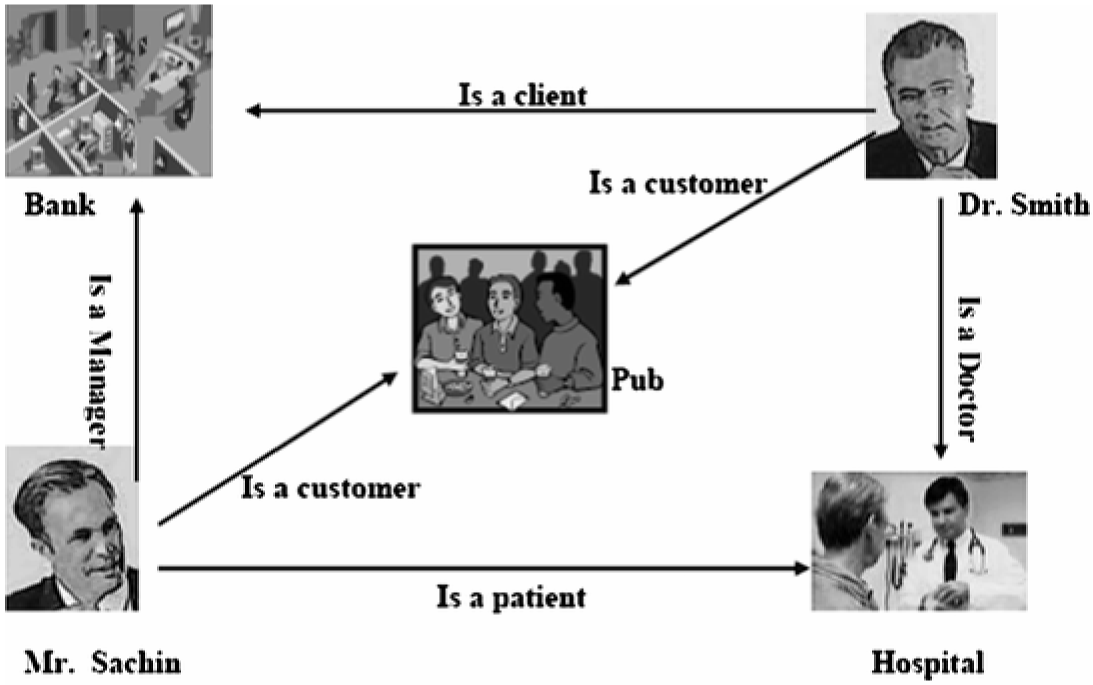

Figure 3.3: User role model for pervasive computing (Singh et al., 2005)

Depending on the advancement of pervasive computing, geoinformation researches have tended to focus on context-aware and semantic modelling. Borriello et al. (2005) stressed that development of ubiquitous location systems is likely to be influenced by market trends in the hardware and software platforms of mobile devices-most particularly cell phones-as much as the technology options within location systems themselves. Hong et al. (2005) proposed an adaptive location data management strategy in order to support adaptivity and scalability of the location-based system using a variety of context which can be accessed in the ubiquitous computing environment. The proposed strategy enables the location-based system to address problems related to heterogeneity and enormity of location sensors or clients, enormity of location data, and multiplicity of location queries based on a variety of context data including location, time and so on. The location-based system can therefore be adapted to any environment, and ubiquitous computing systems can efficiently process location queries. Consequently, the importance of the context modelling of location-based services can be obtained from the research. Hong et al. (2005), however, ignored the need for a semantic projection of the context model in order to obtain a ubiquitous computing system.

In the past few years, a number of papers discussing the importance of the semantic approaches in GIS have appeared in major journals and conferences. Fonseca and Egenhofer (1999) presented a system which uses a container of interoperable geographic objects. The objects were extracted from multiple independent data sources and were derived from a strongly-typed mapping of classes from multiple ontologies. The approach provided a great level of interoperability and allowed partial integration of information when completeness is impossible. Frank (2001) emphasised 5 tiers of ontology integrating different ontological approaches in a unified system. In Frank (2001), the relation of the 5-tier ontology and consistency constraints was explored, and it was shown that different constraints were appropriate to different tiers. Nevertheless, the semantic researches that have been mentioned in this paragraph have not been based on any mobile context in order to handle a ubiquitous geographic information system like LBS. They have tried to propose a semantic approach in general terms of GIS rather than a specific GIS application area.

Agarwal (2005) examined many of the key ontological efforts in Geographic Information Science (GIScience) and in the wider academic community. Certain research issues were summarised in the discussion by Agarwal (2005):

- Focus on semantics and inter-operability within database and data modelling research.
- Methodological and systematic approaches to geographical domain modelling. These methodologies define entities that are needed for the functions to be performed in GIS. Systematic approaches link a large number of methods for ontology specification and development.
- Inclusion of human conceptualisation in the models and development of methods and languages to define and formulise these conceptualisations in a consensual framework.
- Determination of ways that an integrated methodology can be developed as a generic approach to ontology development in the geographical context.

In this thesis a semantic relation has been provided between spatial database and visualisation parameters that have been defined for the mobile context in order to obtain relevant data, as Agarwal (2005) described in the first of his possible research issues.

Ubiquitous computing often uses the terms “agent” and “sensor” in the modelling. Specifically, models trying to realise some spatial behaviours such as making movement predictions, finding available paths, and navigation, should include concepts of agents and sensors. Sensors perceive environmental situations and environmental changes, and then transfer them to the context brokers. Agents represent things which perceive their environment and act depending on the effects. Frank et al (2001) noted multi-agent simulations for three different investigations of spatial and cognitive questions. The simulations, however, were developed too simply and they identified only important parts. Parunak et al. (2006) also discussed a swarming method to reason movement of entities constrained by topological or topological features of environment. They claimed that the methods converge with reasonable speed and can support both robotic control and prediction of natural systems. Winter and Nittel (2006) proposed ad hoc shared-ride trip planning by mobile geosensor networks to cope with spatially and temporally incomplete transportation knowledge. The system integrates the transportation capacities of all types of vehicles in urban traffic in order to identify a trip for persons with an ad hoc travel demand. These kinds of prediction and planning methods can be supportive for relevant visualisation; the systems that have been mentioned above were developed separately, however, and they have difficulties about data interoperability between them without noting pervasive computing basics. If they are considered as part of a semantic system, more relevant spatial data will be provided to the mobile users. The semantic approach provides not only data interoperability but also advantages for building geosensor-based ubiquitous systems that inherit agent-based modelling attributes of the computer sciences like communication language standards.

With the presence of cheaper, miniature, faster, and smart in situ sensors, the increasing availability of abundant ubiquitous computing devices, wireless and mobile network access and autonomous and intelligent geospatial software agents; distributed networked in situ sensing becomes clearly a technological trend. Liang et al. (2004) developed sensor web architecture to perform an extensive monitoring and sensing system that provides timely, comprehensive, continuous and multi-mode observations. They also described the architecture of a distributed geospatial infrastructure for sensor web. The research is important for monitoring environment spatially but it should also be available for mobile devices to provide more interaction.

Nolan et al. (2001) developed an ontology and agent communication language (ACL) for an agent-based Geographic Information System. The ACL uses the ontology as the foundation of communication between agents. The ontology and ACL have been encoded in the RDF by means of the XML. According to Nolan et al. (2001) the ontology includes three parts: Data, algorithms and queries. Galton (2003) claimed that a geo-ontology must provide suitable forms of representation and manipulation to do justice to the rich network of interconnections between field-based and object-based views of the world. Consequently, in this thesis, ontological approaches have been chosen because ontology plays an important role in data exchange standards, as stated in Nolan et al. (2001) and Galton (2003).

Another ontology-based approach is personalised situation-aware mobile service supply (Weissenberg et al., 2006). The ontology was determined to fulfil the notion of characteristic features of contexts that are invariant during certain time intervals. They presented these concepts in the context of a platform development, namely FLAME 2008, which is able to support its mobile users with personalised situation-aware services in push and pull. The research, however, does not include the visualisation styles of any spatial entity that obtained at the context-aware service.

Kim et al. (2005) presented the architecture of tour information services based on semantic web technologies. The Tour Guide Services was implemented by definition of the ontologies of the tour information and generation of RDF contents based on the defined ontologies. The aim of the service is to provide the exact tour information and interoperability between the server systems. Nevertheless, the definition of the ontologies of the tour information explains only a small part of the location-based services. It does not provide a whole semantic system design. The tour ontology should be integrated to user, device and spatial ontology and their relations with each other.

Some GIS researches focused on methods to retrieve relevant spatial data by semantic approaches. Jones et al. (2001) explained ontology of place that combines limited coordinate data with qualitative spatial relationships between places, as shown in Figure 3.4. The ontology has been implemented with a semantic modelling system linking non-spatial conceptual hierarchies with the place ontology. A hierarchical distance measure is combined with Euclidean distance between place centroids to create a hybrid spatial distance measure. The project is a good example of a hybrid approach of a semantic concept and their relationships with algorithmic solution. The system, however, was tested only by limited users.

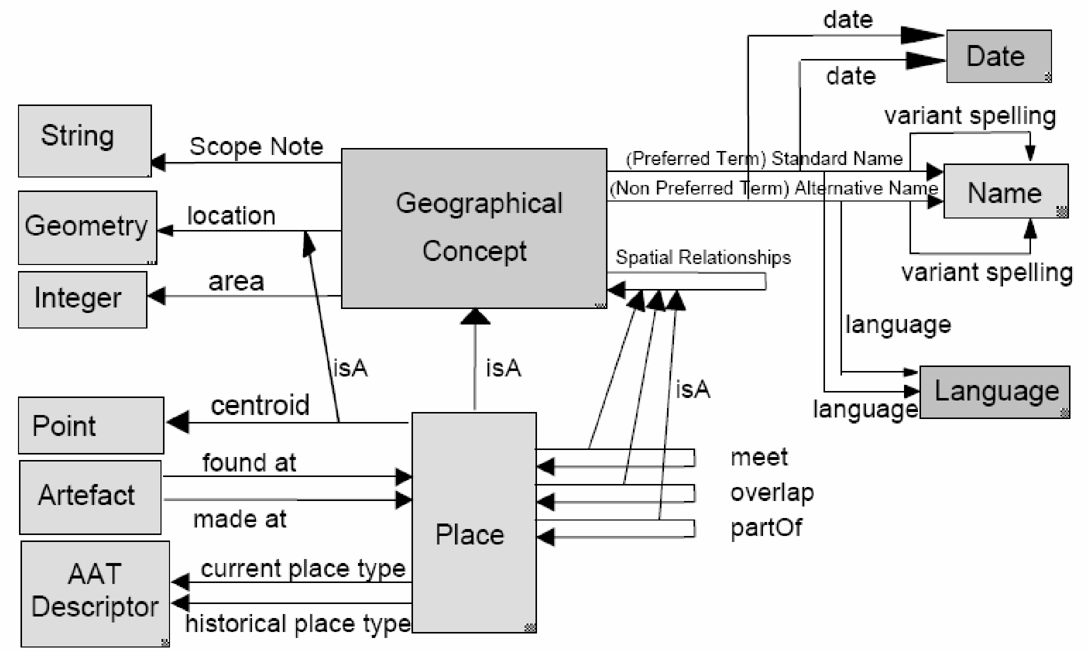

Figure 3.4: Place as a type of geographical concept (Jones et al., 2001)

Jones et al. (2002) claimed that traditional web search engines are not sufficient to retrieve relevant geographical data and determined some techniques by the means of a semantic approach for Spatially Aware Information Retrieval on the Internet (SPIRIT) project:

- Ontologies that model geographical terminology.
- Query expansion and relevance-ranking procedures based on the geographical ontologies.
- Machine-learning techniques for the extraction of geographical context from web documents and for generating metadata providing spatial context.
- A multi-model user interface providing textual input and interactive map feedback of the context of retrieved documents.
- Spatial indices for web collections.

A summary of the necessary and desirable features for a geo-ontology representation language are as follows (Smart et al., 2005):

- Representation of real world geographic concepts.
- Representation of data properties for each geographical concept.
- Representing relationships between concepts.
- Representation specialization/generalization concept hierarchies.
- Representing of simple composition hierarchies, i.e., concepts made up of sets of other concepts.
- Representing constrains on data properties of concepts.
- Representing constraints on relationships.
- Expressing integrity rules over individuals.
- Expressing integrity rules between individuals belonging to different concepts.
- Representation of advanced composition hierarchies that are asserted as a combination of defined sets of concepts and properties, i.e. a class of all houses which are within 10 miles of a motorway.

Jones et al. (2004) explained the details of the structure of the SPIRIT search engine which is described above. The search engine 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. These relationships are determined as "in", "near", "outside", "north-of", "south-of", "east-of", "west-of", and "within a specified distance". Each relationship corresponds to a geometric operation. For example, if relation is "near", then a buffer operation needs to be performed over the selected place to obtain the expanded query footprint.

Hobona et al. (2006) published an approach for retrieving, ranking and visualising geographic metadata according to spatial, temporal and semantic relevance. The method was based on three independent components: geometry, attribute and temporal. The representation of the results of the independent ranking of these three components of spatial data suggests that representation of the results of the ranking process requires an alternative approach to currently-used textual ranked lists: visualisation of relevance in a three-dimensional visualisation environment.

Lutz and Klien (2006) proposed 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.

The ontological concepts have been used mainly in web technologies. The same approach is also valid for web GIS applications. The researches that are mentioned in the last parts of this section have focused on finding new solutions to web-based spatial data search problems. The ontological models of the researches were the representation of the real world in terms of geography. In this thesis, however, a mobile context should be developed in order to visualise the real world in the ubiquitous computing environment. This needs a new mobile context and geo-ontological model. The aim of the ontological model in this thesis is not to create a semantic search engine for a vast data ocean like web environment. A relation should therefore be established between visualisation and the real world in a mobile context.

4. A RELEVANCE MODEL FOR VISUALISATION IN LBS

4.1 Contextual Ontological Model

The basic definitions of the relevance theories have been explained in section 2.1.1. As indicated in section 2.1.1, one of the most important scientific approaches was explained by Schutz (1970). Then Saracevic (1996) elaborated Schutz's (1970) approach and described five manifestations of relevance that are based on the nature of relevance. Furthermore, Borlund (2003) also stressed that relevance is about information need. In this research, five manifestations of relevance have been modified and adapted according to the considerations of the visual design.

Five manifestations have been determined to represent a relevance model for mobile visualizing. Visualization, here, means two-dimensional maps with restricted resolution that almost meet the requirements of poor screen and RAM capability of mobile devices. Manifestations of relevance are based on design patterns of the mobile cartography that have been proposed by Meng (2005) (see section 3.1). Table 4.1 explains manifestations of relevance within their types and descriptions of their relations intends relevancy of spatial visualization.

Table 4.1: Manifestations of relevance

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

Research 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 of this thesis. In particular, this thesis concentrates on the data retrieval, the cognitive, the situational and the motivational types of relevance.

A general approach that is different from an algorithmic relation between keywords of the query and spatial data has been proposed to extract relevant spatial data. Some levels of the spatial data are defined and then all the contents of 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 the user is dealing within the building. Whenever the user leaves the building, the new relevant level changes 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.

Cognitive relevance is the 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, grouping people into the same range of ages or the same range of occupations gives an idea about the users' state of knowledge. Creating a user profile is a well-known way to collect information about the user. The symbolization of the spatial data should be compatible with the user profile to relate user knowledge to the cartographic symbol type.

Situational relevance is the 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 visualization, such as colour of visualization, scale, geocoding and space contraction. It is not only the mobile device but also additional devices and sensors that produce the user's location data revealing 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.

Motivational relevance is the 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 who navigates a place needs visualization with directional arrows. One of the problems about motivational relevance is to determine the user's exact intent. An appropriate graphical user interface (GUI) that is designed to understand the user's real intent can overcome the problem. Figure 4.1 shows detailed relations that represent manifestations of the visual relevance of the spatial data.

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 research. To state the visualization appropriately, we envision a model that includes the visualization parameters as an existence for the spatial data. Conceptualization of the geographical objects and their relations that are explained using a semantic approach are depicted in Figure 4.2. 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 were explained earlier in this section. Figure 4.3 shows the place of the visual parameter in the upper context model.

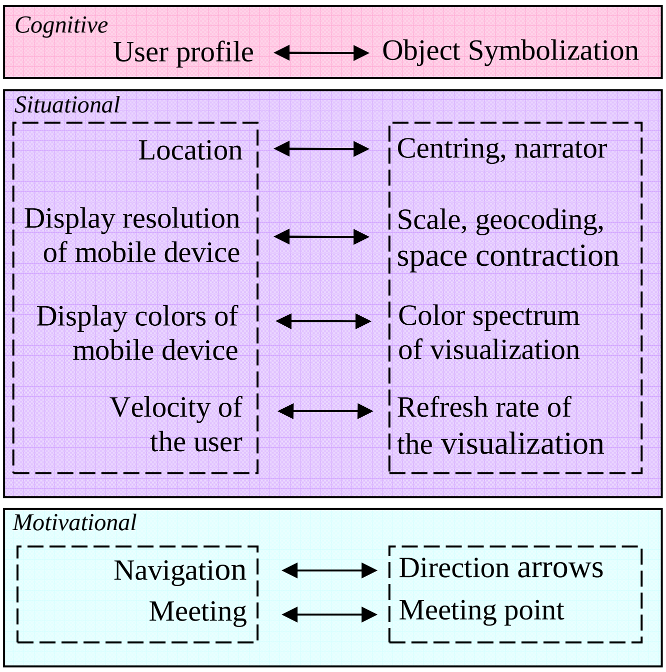

Figure 4.1: The visual relevance of the spatial data

The upper and lower ontological context models that are shown in Figure 4.2 and Figure 4.3 have been determined in a way that provides the definitions of context and context-awareness that are proposed by Dey and Abowd (2000) and Chen and Kotz (2000) (see section 2.1.2). The context models have been formed in the ontological structure that includes concepts (classes) and properties (relations), as indicated in section 2.1.3. In that section, the ontology aspect of the model has been elaborated in theory as cited by many scientists (Gruber, 1993; Guarino, 1998; Chandrasekaran et al. 1999; Gomez-Perez and Corcho, 2002).

The geographical concept that has been defined by Jones et al. (2001), (2002) and (2004) (see section 3.2), enables an efficient place search semantically. It cannot, however, be used as a geographical ontology of a ubiquitous environment. The aim of the ontology is a spatial web search rather than an agent-based decision-maker. A new ontological model that includes some geographical elements has therefore been defined in this thesis in order to prepare the infrastructure of a ubiquitous computing for the mobile environment.

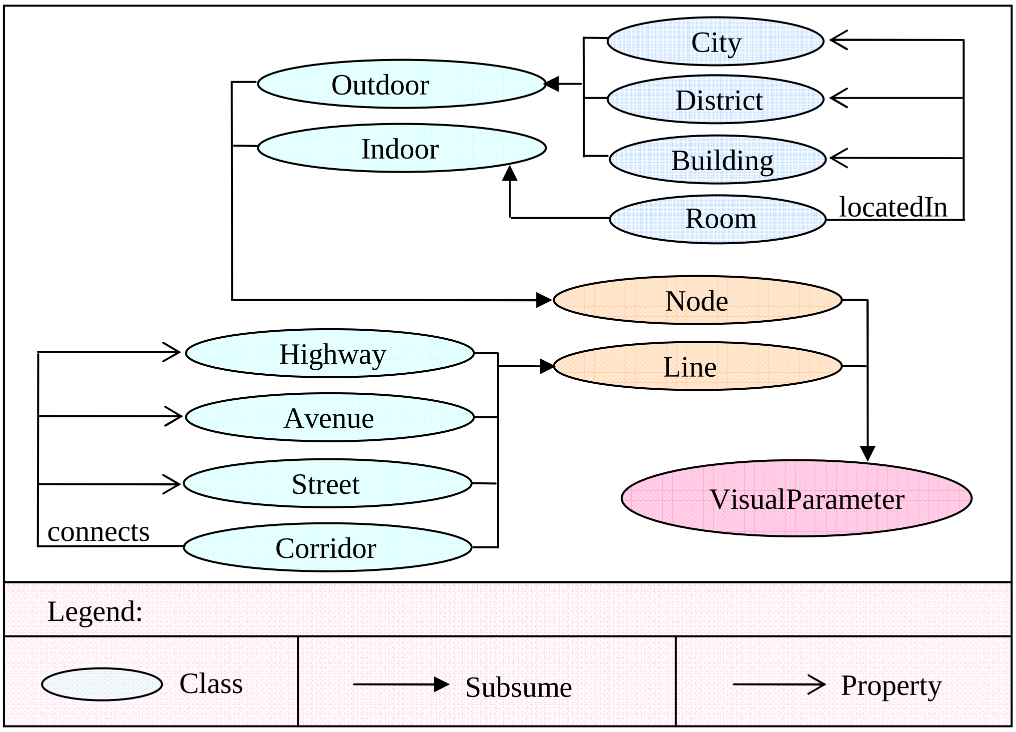

Figure 4.2: Conceptualisation of visualisation and properties

Figure 4.2 has been designed to represent a context model of the lower ontologies. According to the figure, *Node* and *Line* concepts are subsumed under the *VisualParameter* concept. This subsuming means a nodal or a linear geographical feature is a parameter in the visualisation. The *Line* concept subsumes four object types: Highway, Avenue, Street and Corridor. A linguistic is-a relation can therefore be inferred from the model as in the following sentence: “A highway instance *is a* line and a line *is a* parameter of the visualisation.” In the lower model, the *Node* 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 and this outdoor object *is a* node. The figure also reveals that two properties establish 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 provide some statements that explain the model such as *Room locatedIn Building*, *Building locatedIn District*, and *Street connects Avenue*.

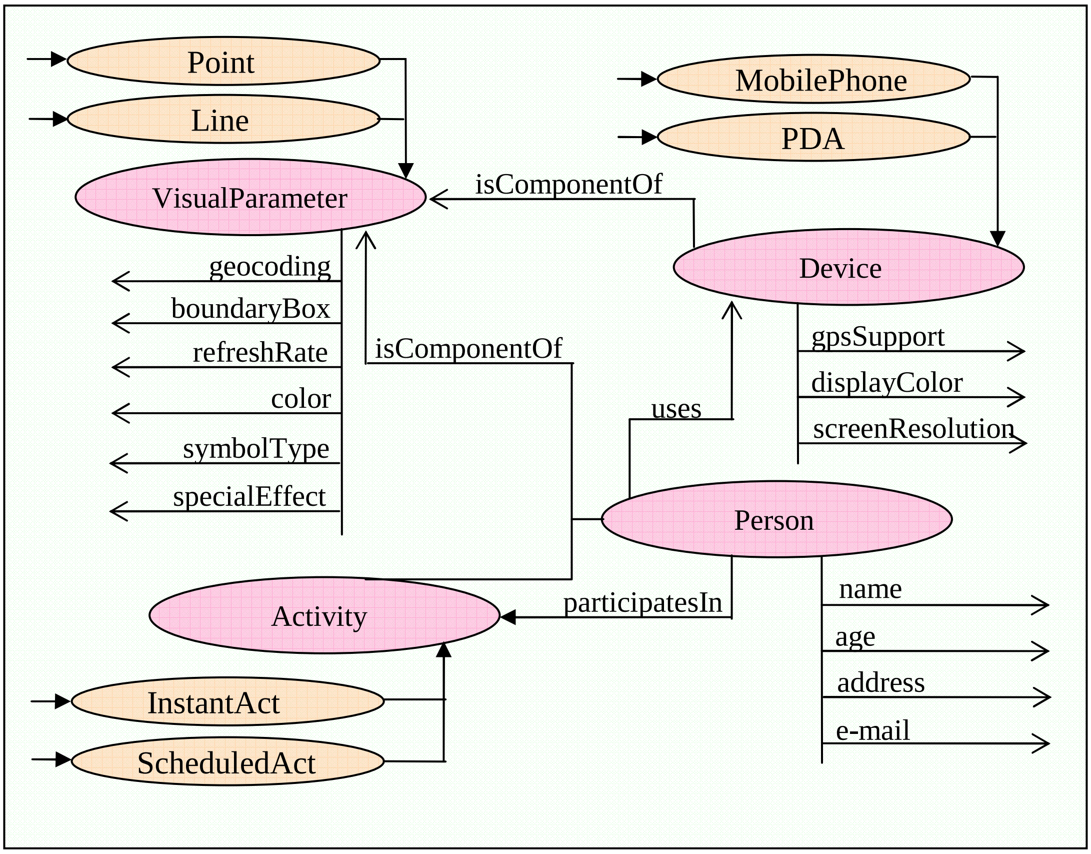

Figure 4.3: Upper ontologies with the visualisation class

Figure 4.3 contains general concepts that are necessary for mobile visualisation. The main concepts are *Device*, *Person*, *Activity* and *VisualParameter*. Device, Person, Activity are the general concepts of the context models of the intelligent applications like smart home. *VisualParameter* concept extends context ontologies that have been explained before (Wang et al., 2004; Chen et al., 2004) (see section 2.1.6). The content of *Device* concept has, however, been rearranged a little in order to represent mobile devices and their features related to visualisation.

The four main concepts are connected to each other by three properties: *isComponentOf*, *uses* and *participatesIn* as shown in Figure 4.3. Properties can be stated as the followings: “*Person participatesIn Activity*.”, “*Person uses Device*.”, “*Device is ComponentOf VisualParameter*.”, “*Activity isComponentOf VisualParameter*.”, and “*Person isComponentOf VisualParameter*.”

The new concept in the upper ontologies is *VisualParameter* that defines necessary parameters of mobile visualisation. These parameters are the individuals of the concepts that are subsumed under *VisualParameter* like *Building*, *Street*, etc. For example, let us assume that Topkapi Museum is an individual of Building Concept. Therefore “Topkapi Museum *is a* VisualParameter” 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 are about the visualisation characteristics of the objects in the scene.

The knowledge base of the whole context model that is depicted in Appendix A (in the appendix, only T-Box of the knowledge base has been shown.),has been composed in OWL-DL language based on *SHOIN*(**D**) description logic (see sections 2.1.4 and 2.1.5). The proposed knowledge base defines some existences and the relations among them with various constructs from semantics of description logic *SHOIN*(**D**). These constructs can be enumerated as concept, role, disjunction, datatypes, exist restriction and value restriction.

Ontological knowledge bases are based on open world assumption (OWA). OWA does not assume something is not true until it is explicitly stated that it is not true. Some properties should therefore provide closure axiom for completeness. Let us assume that the Geomatics Conference will be held in the Faculty of Civil Engineering, and then individual *Geomatics* is created as a member of Activity concept so as to represent Geomatics Conference in the knowledge base. In OWA, the answer is unknown to the following question: “Is the Geomatics conference to be held in the Faculty of Chemistry?” if “*Activity isComponentOf VisualParameter”* is not built with closure axiom in the ontological context. The answer should be “No”, however, because “*Geomatics isComponentOf CivilEngineering”* is told to the knowledge base and an activity, a person or a device cannot exist at two different places at the same time.

In the model, the closure axiom is applied to some relationships and their fillers to prevent this kind of possible completeness error. The closure axiom is the combination of the universal restriction and existential restriction for the same property and the filler in the ontology structure.

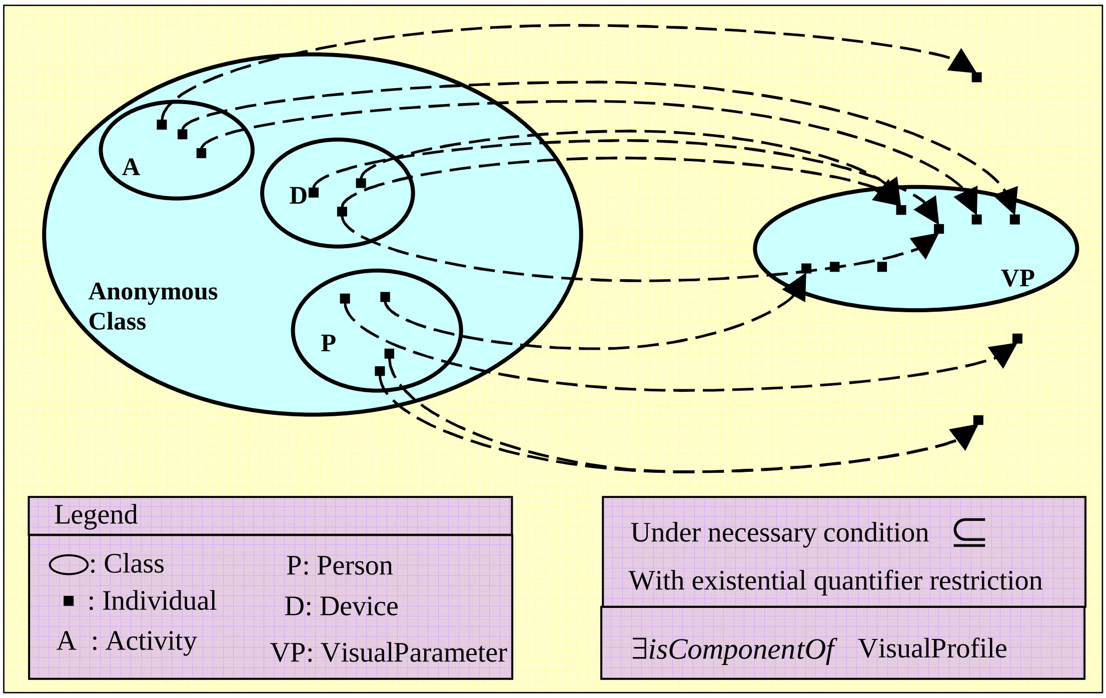

Figure 4.4: Existential restriction for "isComponentOf" property

In the upper and the lower ontologies, 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 conditions in order to establish relations with "*isComponentOf*" property in the upper level of the ontological model. The existential restriction describes sets of individuals that have at least one "*isComponentOf*" relationship to individuals that are members of a class of "*VisualParameter*" (Figure 4.4). The universal restriction makes sure that any filler must be a member of a "*VisualParameter*" with "*isComponentOf*" property (Figure 4.5).

Figure 4.6 shows that all sets of individuals have "isComponentOf" relation with individuals of Class "VisualParameter". The closure axiom also provides that there is no any individual of filler from outside "VisualParameter". The restrictions produce appropriate relations among the classes in the model.

Briefly, in this section, a contextual ontological model has been defined. First, levels of visual classification, cognitive relevance, situational relevance and motivational relevance have been determined. Then these relevance types have been projected onto upper and lower contextual ontological models. The upper ontological model represents general context entities whereas the lower represents entities in more detail. The whole proposed ontological model has been applied to the knowledge base in order to realise the context model in computer environment. The knowledge base that obeys OWA has been produced as concept definitions and their relations.

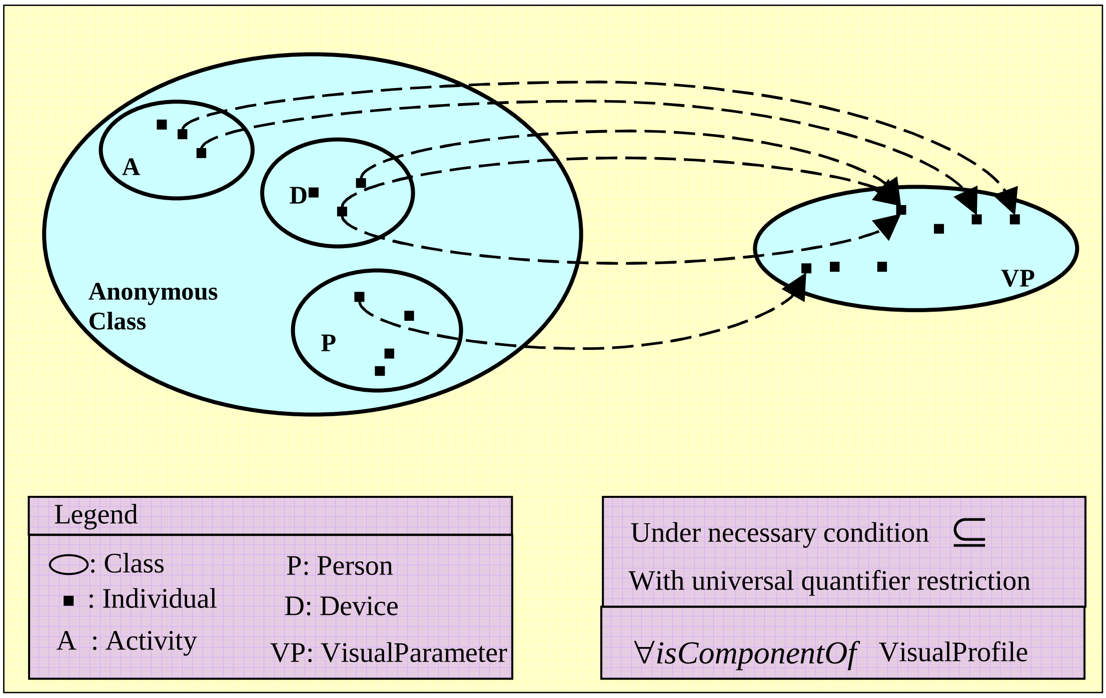

Figure 4.5: Universal restriction for “isComponentOf” property

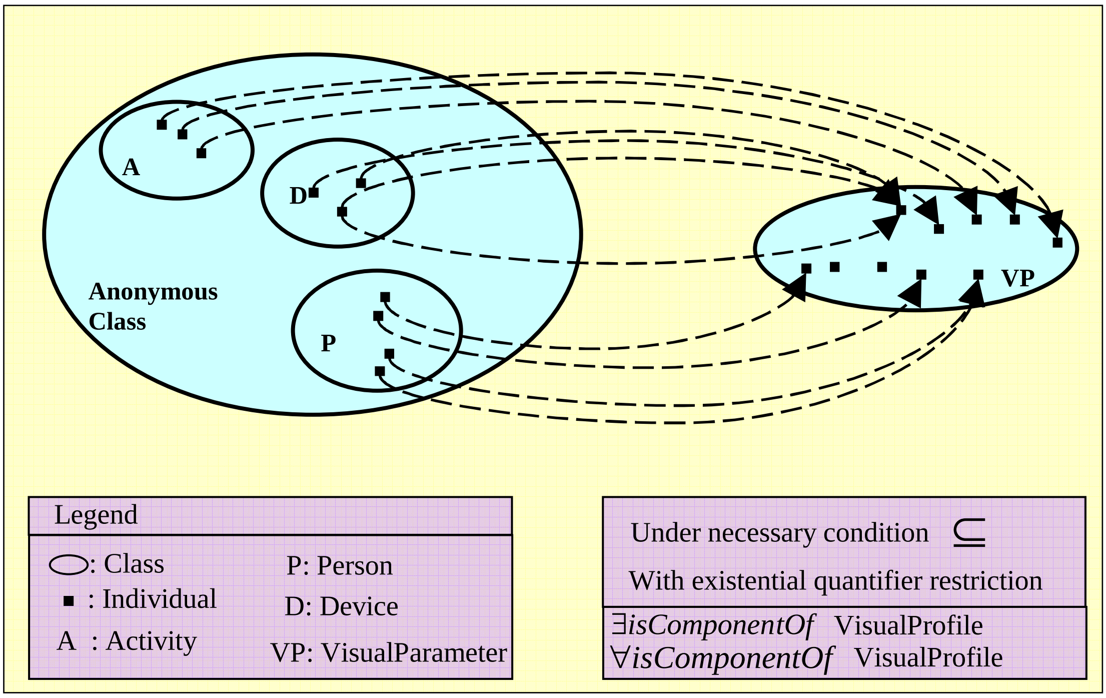

Figure 4.6: Closure axiom for “isComponentOf” property

4.2 Context Reasoning

Context reasoning is implemented as ontological reasoning and 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 as explained in section 3.2. The approach that is proposed in this thesis focuses on mobile visualisation of the spatial data. The query target is not data search in a database. The aim of the knowledge base is to obtain cognitive, situational and motivational aspects of the visualisation components on the mobile device. Although the query method seems quite similar to the method in Lutz and Klien (2006), the aim of the ontological context and its scope is completely different. The context model is designed for mobile user, devices and design patterns of visualisation rather than geographic data retrieval in this thesis. The model tries to reason over new information from the knowledge base with semantic query. Consequently the semantic query can be accepted here as a tool for the reasoning.

The result of the reasoning in the proposed model extracts necessary visual aspects of the spatial data for the mobile users. The reasoning possibilities of the knowledge base have been implemented in two different semantic methods: Ontological reasoning and Rule-based reasoning. Ontology reasoning uses description logic, while Rule-based reasoning uses first-order logic.

4.2.1 Ontological Reasoning

OWL supported with description logic provides ontology reasoning in the context model. Thus, contextual ontology models are composed by OWL-DL specification to fulfil some logical rules. Specifically *TransitiveProperty*, *inverseOf*, *subClassOf*, and *disjointWith* are used as the rules to reason the implicit information from the explicit information (Table 4.2). The success of the extraction of the implied information within an ontology model depends on the appropriate design of the conceptualisation. An improper model that is established by an ontology engineer is not able to produce the new information except the information from that obtained directly by sensors and users.

TransitiveProperty is an OWL-DL property for relations between conceptualizations. In the context model, we determine four visual levels, as shown in Figure 4.2. The classes of *City*, *District*, *Building* and *Room* represent visualization levels of the spatial data. The *locatedIn* relation is a transitive property set-up connection between the levels. *inverseOf* is also an OWL-DL property for the relations and it indicates the relation has an inverse relation for any individual of a class. With *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 an upper visual level of a spatial object is determined, the lower level of the spatial object can be obtained.

Table 4.2: Parts of OWL reasoning rules (Wang et al., 2004)

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)

For example, Table 4.3 explains obtaining implicit topological information from explicit context. There are four visual levels in the model. *RoomA102* is an individual of Class *Room*, *CivilFaculty* is an individual of Class *Building*, and *MaslakCampus* is an individual of Class *District*. In the example, "*RoomA102 locatedIn CivilFaculty*" and "*CivilFaculty locatedIn MaslakCampus*" are stated explicitly. Consequently, statements of "*RoomA102 locatedIn MaslakCampus*" (with TransitiveProperty), "*MaslakCampus contains CivilFaculty*" (with InverseOf), "CivilFaculty contains RoomA102" (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. This 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. In the model, area geometry is replaced by the node representation because of the restricted display capacity of small devices.

Table 4.3: Implicit context (TransitiveProperty and inverseOf)

Explicit Context

```
<owl:TransitiveProperty rdf:about="#locatedIn">
    <rdf:type rdf:resource="http://www...#ObjectProperty"/>
    <owl:inverseOf rdf:resource="#contains"/>
  </owl:TransitiveProperty>
  <Room rdf:ID="RoomA102">
    <locatedIn>
      <Building rdf:ID="CivilFaculty">
    </locatedIn>
  </Room >
  <Building rdf:ID="CivilFaculty">
    <locatedIn>
      <District rdf:ID="ITUCampus">
    </locatedIn>
</Building>
```

Implicit Context

```
  <Room rdf:ID="RoomA102">
    <locatedIn>
      <District rdf:ID="ITUCampus">
    </locatedIn>
  </Room >
  <District rdf:ID="ITUCampus">
    <contains>
      <Building rdf:ID="CivilFaculty">
    </contains>
  </Building>
  <Building rdf:ID="CivilFaculty">
    <contains>
      <Room rdf:ID="RoomA102">
    </contains>
</Building>
```

In Table 4.4, the example shows that the statement '*ElectronicFaculty* is an individual of the Class *District* is not correct, whereas the statement '*ElectronicFaculty* is an individual of Class *Building*' is correct. An input error is determined during the reasoning with the *disjointWith*. The *subClassOf* property extracts that representing type of the individuals of the Class *Room* is a node (point) in the context model. If an individual belongs to *Room* concept, the reasoning tools ask for the upper class of *Room* concept by the means *subClassOf* property. In the example, the result is *Indoor* concept as the upper class. The reasoning tools seek for upper class of *Indoor* concept again so as to define final class that represents spatial existence in the ontology. Consequently, *Node* concept is the upper class of the *Indoor* concept as the visual existence of the spatial feature of the room individual.

Representation of the room instance is therefore determined as a node in the mobile device screen.

Table 4.4: Implicit context (disjointWith and subclassOf)

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>
```

4.2.2 Rule-based Reasoning

Rule-based context reasoning is implemented by SWRL (Semantic Web Rule Language) to obtain new information from explicit context. SWRL provides a high-level abstract syntax that extends the OWL abstract syntax described in the OWL Semantics and Abstract Syntax document. An extension of the OWL model-theoretic semantics is also given to provide a formal meaning for OWL ontologies including rules written in this abstract syntax. The proposed rules are in the form of an implication between an antecedent (body) and 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 (Cover, 2004).

Table 4.5 describes some SWRL rule examples for contextual reasoning to determine relevant visualization profile of the spatial data on mobile devices. Some basic SWRL statements can also be expressed as the concept representation. Therefore these SWRL rules can be exploited by ontology reasoning if they are composed in ontological syntax as explained in section 2.2.1. However, the context model needs a more complex formulation in order to eliminate SWRL statements. Thus, SWRL provides some easiness while editing a knowledge base.

Table 4.5: SWRL rules

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

?p indicates an individual of Class *Person* for all rules in the ontological context. In the first row of Table 4.5, the rule asserts that *isComponentOf Building* property, *uses MobileDevice* property and *participatesIn Activity* property imply *boundryBox* property of the Class *VisualParameter*. For example, John decides to participate in 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 a building plan that is in 50 metres x 50 metres should be sent to the mobile phone until he leaves the faculty. The second rule adds navigational arrows that show the activity place when a person would like to join a scheduled activity. Rule 3, in Table 4.5, adjusts the refresh rate of the map while someone is driving to a scheduled activity like a conference or concert.

4.3 Symbol-based Simplification with Fuzzy Logic

To use small screens of mobile phones and PDAs more effectively, symbol-based simplification is proposed as a complementary algorithm of the semantic approach, a computing algorithm that benefits semantic models by increasing the ability of the model to provide appropriate relevant visualisation for the context in addition to semantic reasoning. According to the proposed model, instead of scaled polygonal spatial representation, symbolisations are used for visualisation. In theory, a spatial object is replaced with a symbol that can be in a different form such as a square or circle in order to make the user's perception easier in the restricted screen of the mobile devices. The model provides a simplification method for the limited mobile devices instead of developed generalisation methods that have been proposed for desktop applications by Lamy et al. (1999), Sester (2000) and Sester (2005).

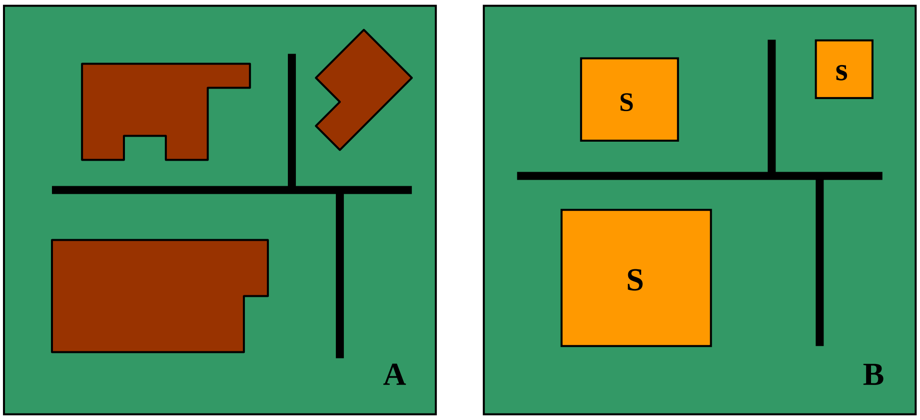

Figure 4.7: Picture A is the original map, picture B is the symbol-based map

The model determines new symbol size depending on area of the object and the pixel size of the screen of the user's mobile device. For instance, Figure 4.7 shows three spatial objects on the left (picture A) and three rectangle symbols replace them on the right (picture B). Different screen sizes and different objects require a unique symbol size to represent spatial objects properly.

To categorise icon size is very complex because of the various parameters of the determination of the symbolisation. There is also a vagueness of the situation in the visualisation. The solution needs a fuzzy logic approach for coherent results. Edwardes et al. (2005) also use adaptive symbols in a different method, as shown in section 3.1, in order to represent data.

4.3.1 Membership Functions

Map scale and the area of a polygonal object are two parameters for determining a new symbol size for the visualisation of any object. Let us suppose that different spatial objects will be represented with a symbol on the map under a certain scale. Symbols that have the same size can cause representation problems because each object has a different size on the map. For example, a symbol size might be too small to represent a large spatial object or might be too large to represent a small spatial object. The aim of the model should be to provide appropriate symbol sizes for different spatial objects according to their original sizes. The second parameter is the map scale to define a convenient symbol size. A symbol size can be too large for a small-scale map or it can be too small for a large-scale map. Map scale is calculated as follows (Equation 4.1):

$$Scale = \frac{PixelDimensionValueOfDisplay \times ActualSizeOfPerPixel(m)}{ActualDimensionOfDisplay(m)} \qquad \mathbf{(4.1)}$$

Actual average pixel size can be accepted as 0.28mm per pixel in equation 4.1. Actual dimensions of the display area are determined as 250m X 250m. Pixel dimension value of the display is therefore only parameter for the scale, since actual pixel size and actual dimension of the display are the constant values in equation 4.2.

$$Scale = \frac{PixelDimensionValueOfDisplay \times 0.00028(m)}{250(m)} \qquad \mathbf{(4.2)}$$

The area of the spatial object and the display resolution of the mobile device (the pixel dimension value of the display) are defined as two subjects of the membership functions. Fuzzy sets in the solution are based on Zadeh (1965). Four IF-THEN rules (two-input, one-output fuzzy reasoning rules) are expressed as

RULE 1: IF area is large AND resolution is high THEN pixel size is 40.

RULE 2: IF area is large AND resolution is low THEN pixel size is 17.

RULE 3: IF area is small AND resolution is low THEN pixel size is 14.

RULE 4: IF area is small AND resolution is high THEN pixel size is 25.

The consequential values of four premises enumerated above have been determined with the trial and error method until the desired results have been obtained for each premise. Memberships function $\mu_{A-Large}(x)$ for large spatial objects in equation 4.3:

$$\mu_{A-Large}(x) = \begin{cases} 0 & x < 360\,m^2 \quad Area\ of\ the\ object \\ \dfrac{x-360}{11000-360} & 360\,m^2 < x < 11000\,m^2 \quad Area\ of\ the\ object \\ 1 & x > 11000\,m^2 \quad Area\ of\ the\ object \end{cases} \qquad \mathbf{(4.3)}$$

Memberships function $\mu_{A-Small}(x)$ for small spatial objects in equation 4.4:

$$\mu_{A-Small}(x) = \begin{cases} 1 & x < 360m^2 \quad \text{Area of the object} \\ \dfrac{11000 - x}{11000 - 360} & 360m^2 < x < 11000m^2 \quad \text{Area of the object} \\ 0 & x > 11000m^2 \quad \text{Area of the object} \end{cases} \tag{4.4}$$

Memberships function $\mu_{B-High}(y)$ for high display resolution in equation 4.5:

$$\mu_{B-High}(y) = \begin{cases} 0 & y < 130 \quad \text{Pixel Dim. Value Of Display} \\ \dfrac{y - 130}{350 - 130} & 130 < y < 350 \quad \text{Pixel Dim. Value Of Display} \\ 1 & y > 350 \quad \text{Pixel Dim. Value Of Display} \end{cases} \tag{4.5}$$

Memberships function $\mu_{B-Low}(y)$ for low display resolution in equation 4.6:

$$\mu_{B-Low}(y) = \begin{cases} 1 & y < 130 \quad \text{Pixel Dim. Value Of Display} \\ \dfrac{350 - y}{350 - 130} & 130 < y < 350 \quad \text{Pixel Dim. Value Of Display} \\ 0 & y > 350 \quad \text{Pixel Dim. Value Of Display} \end{cases} \tag{4.6}$$

Figure 4.8 shows membership functions explained in Equations 4.3 and 4.4, whereas Figure 4.9 shows membership functions given in Equations 4.5 and 4.6.

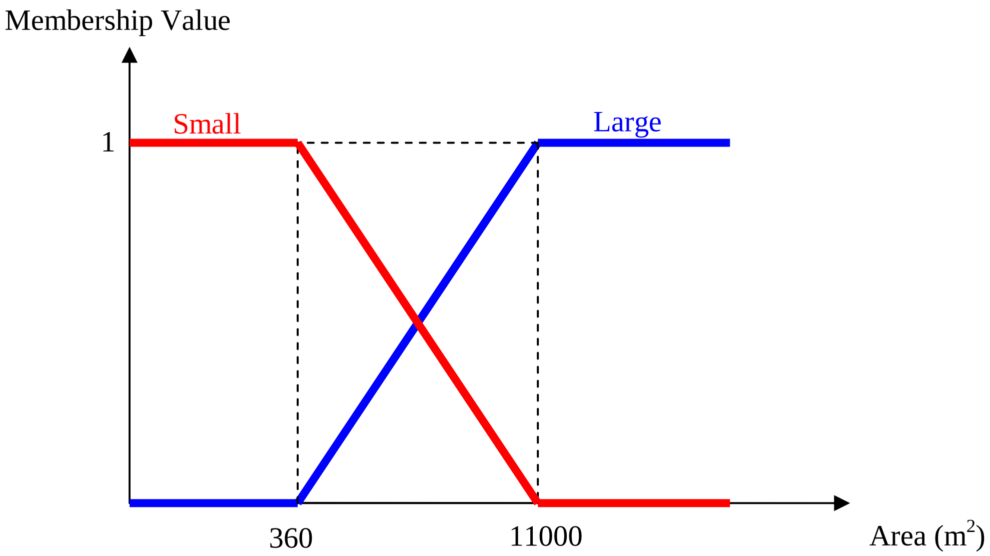

Figure 4.8: Membership functions for large and small spatial objects

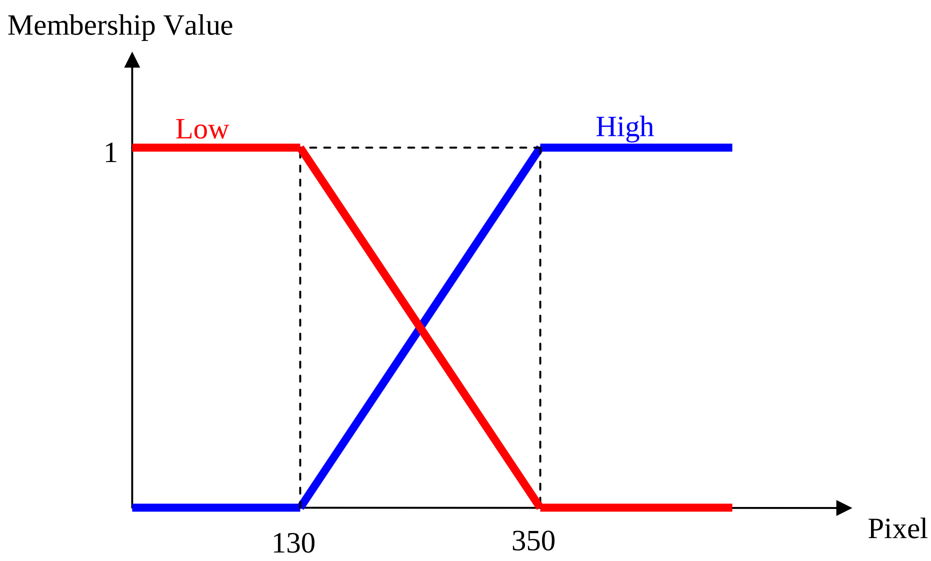

Figure 4.9: Membership functions for high and low display resolutions

4.3.2 Simplified Fuzzy Reasoning

Let us assume that x_0 and y_0 are the input values for the premise variables. Equations 4.7, 4.8, 4.9 and 4.10 apply the input values to the premise variable and compute the minimums of $\mu_{Ai}(x)$ and $\mu_{Bi}(y)$:

$$Rule_1: \quad m_1 = \min(\mu_{A-Large}(x_0), \mu_{B-High}(y_0)) \tag{4.7}$$

$$Rule_2: \quad m_2 = \min(\mu_{A-Large}(x_0), \mu_{B-Low}(y_0)) \tag{4.8}$$

$$Rule_3: \quad m_3 = \min(\mu_{A-Small}(x_0), \mu_{B-Low}(y_0)) \tag{4.9}$$

$$Rule_4: \quad m_4 = \min(\mu_{A-Small}(x_0), \mu_{B-High}(y_0)) \tag{4.10}$$

Equations 4.11, 4.12, 4.13 and 4.14 are conclusion values of all rules:

$$Conclusion_1: \quad c_1' = m_1 c_1 \tag{4.11}$$

$$Conclusion_2: \quad c_2' = m_2 c_2 \tag{4.12}$$

$$Conclusion_3: \quad c_3' = m_3 c_3 \tag{4.13}$$

$$Conclusion_4: \quad c_4' = m_4 c_4 \tag{4.14}$$

Final conclusion is obtained as in equation 4.15:

$$c' = \frac{\sum_{i=1}^{4} c_i'}{\sum_{i=1}^{4} m_i} \tag{4.15}$$

5. TECHNOLOGICAL DESIGN FOR MOBILE DEVICES

5.1 Multi-tier Architecture

A distributed GIS includes many different technological platforms and their interactions. Some obligatory participants of a distributed GIS are a spatial database system, a web map server (WMS), a web feature server (WFS) and some additional technologies that provide transactions between them. The technological design of this research therefore proposes a multi-tier architecture in order to realise the proposed model explained in the early sections.

As depicted in Figure 5.1, the architecture compounding client and server sides is mainly formed by open source technologies. In the server side, PostgreSQL object-relational database system and its spatial database extension PostGIS are used as the database server. In effect, PostGIS spatially enables the PostgreSQL server, allowing it to be used as backend spatial database for GIS, much like ESRI's SDE or Oracle's Spatial extension. PostGIS follows the OpenGIS "Simple Features Specifications for SQL" and has been certified as compliant with the "Types and Functions" profile (Refractions Research, 2005).

In the system, map production is provided by Geoserver, which is an open source map server. Geoserver enables publishing of data and use of open standards. Geoserver supports Web Feature Server (WFS) and Web Map Server (WMS) open protocols from the Open Geospatial Consortium (OGC) to produce JPEG, PNG, SVG, KML/KMZ, GML, PDF, Shape files and more (Holmes, 2007). Because of the limited display capacity of some mobile phones, Geoserver WMS has been chosen as the default server in the system for the visualisation. Styled Layer Descriptor (SLD) has been used as similarly implemented in Zipf (2005) (see section 3.1) in order to provide determined visual features like appropriate colours or symbol size for a certain scale.

The only commercial product in the architecture is RacerPro, which stands for Renamed Abox and Concept Expression Reasoner Professional (Racer System, 2005). As the name indicates, the origins of RacerPro are within the area of description logics. Since description logics provide the foundation of international approaches to standardising ontology languages in the context of the so-called semantic web, RacerPro can also be used as a system for managing semantic web ontologies based on OWL. Furthermore, RacerPro can also be seen as a semantic web information repository with an optimised retrieval engine because it can handle large sets of data descriptions (Racer System, 2005).

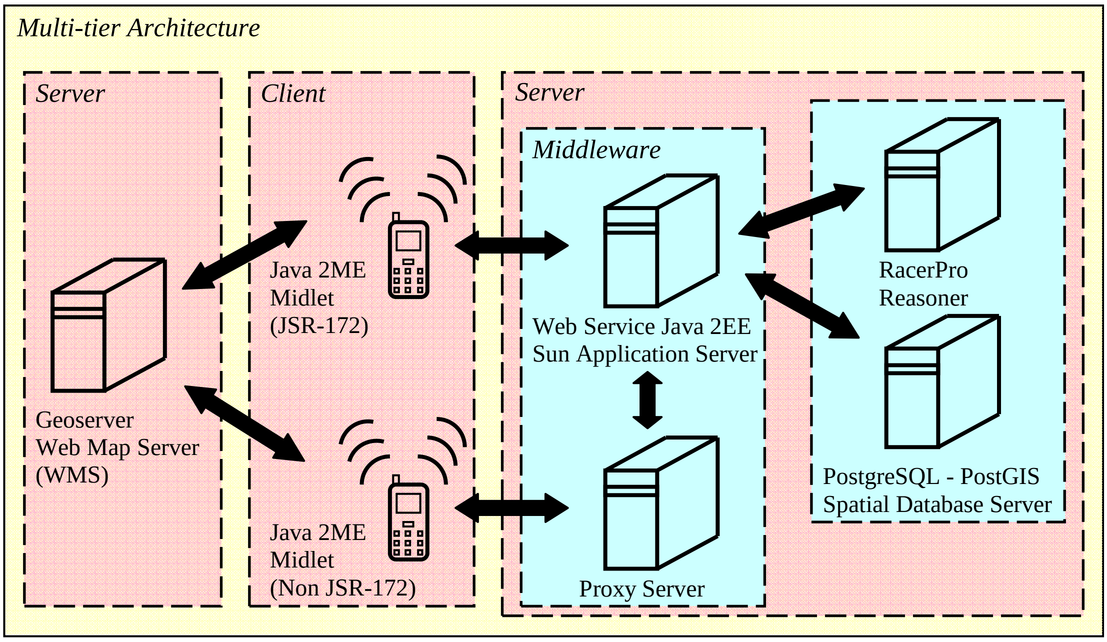

Figure 5.1: Architectural design of the technological services

Two separate connections are established with the ontology server and the database server within Java 2 Enterprise Edition. A web service and a proxy server are implemented as the middleware of the architecture. The web service and proxy server are built in Sun Application Server as a part of Java 2EE programming platform. The web service controls all connection units for RacerPro and PostgreSQL – PostGIS. In Appendix B, Java methods that are able to connect RacerPro and PostgreSQL servers are shown. High capacity mobile smart phones and PDA that have Web Services APIs (WSA) (JSR-172 specification) are able to connect directly to the web service. Mobile phones that do not have JSR-172 specification need the proxy server to connect to the ontology server and the database server via the web service.

Graphical user interface (GUI) for mobile devices is composed within Java 2ME platform. Java Micro Edition provides a robust, flexible environment for applications running on mobile and other embedded devices – mobile phones, personal digital assistant (PDAs), TV set-top boxes and printers. Java ME includes flexible user interfaces, robust security, built-in network protocols, and support for networked and offline applications that can be downloaded dynamically. Applications based on Java ME are portable across many devices, yet leverage each device's native capabilities (Sun Microsystems, 2007). User interface gathers some information from the user manually. First, all gathered information is sent to the servers, then evaluation steps are completed in the server side. Finally, results are sent to the user as a two-dimensional map.

5.2 Test beds

The aim of the ontological models is to represent the real world in the computer environments. All concepts and their individuals are considered as part of the world. In this ontological model two regions of Istanbul are selected as the application area for the sample project. The model enables scalability from a small room to all over the world. The application regions are determined as Ayazaga Campus of Istanbul Technical University and the Sultanahmet district of Eminonu (Figure 5.2).

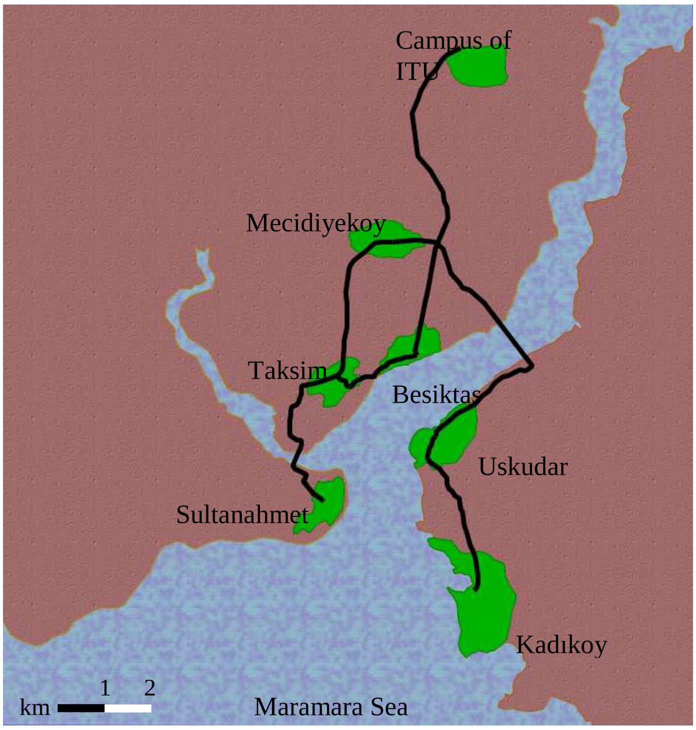

Figure 5.2: Campus of ITU and Sultanahmet district in Istanbul

In the ontological approach to the visualisation, four classes are enumerated as *City*, *District*, *Building* and *Room*. *Istanbul* is an individual of *City* class in the model. Many cities can also be added as an individual. The second concept is the *District*. *District* has *locatedIn* relation with class *City*. The model is populated with seven districts: *Mecidiyekoy*, *Besiktas*, *Taksim*, *Kadikoy Uskudar*, *ITUCampus* and *Sultanahmet*, as shown in figure 5.2. Only two selected districts, *ITUCampus* and *Sultanahmet*, have, however, been populated with individuals of *Building*, so as to create smart environments. The numbers of the individuals are naturally increasing towards the classes that belong to the narrower areas.

The main campus of ITU is located in Maslak to the north of Istanbul. The campus covers an area of approximately 140 hectares. In the ontology model, 49 buildings are determined as the individuals of *Building* class, such as faculties, administration facilities and dormitories (see Figure 5.3).

Figure 5.3: The campus of ITU

Sultanahmet, the historic district of Istanbul, is determined as the second application region. 19 buildings that have *locatedIn* relation with individual *Sultanahmet* of *District* class are defined as individuals of *Building* class (see Figure 5.4). Figure 5.5 shows conceptual design and members of the classes in the graphical manner. Connection among the individuals is established with “locatedIn” relation. Transitive property of the *locatedIn* relation provides additional implicit connections beside explicit ones.

Figure 5.4: The district of Sultanahmet on the ortho-photo image

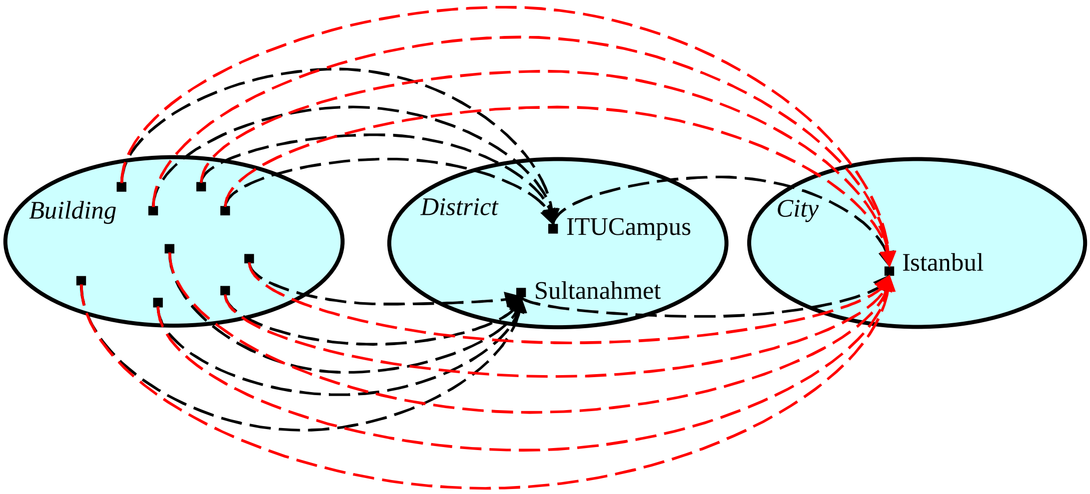

Figure 5.5: *locatedIn* relations among the *City*, *District* and *Building* concepts

The red dashed lines in Figure 5.5 indicate implicit information. The *contains* relation that is the inverse of the explicit *locatedIn* relation also 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* and *ITUCampus* and *Sultanahmet* are the individuals of the concept *District*.

5.3 Information Retrieval with the Semantic Inference Engine

Contextual ontology (OWL-DL) that has been defined for relevancy as upper and lower ontology models in section 4.1 has been edited in an ontology editor and knowledge acquisition system by Protégé software (see Figure 5.6).

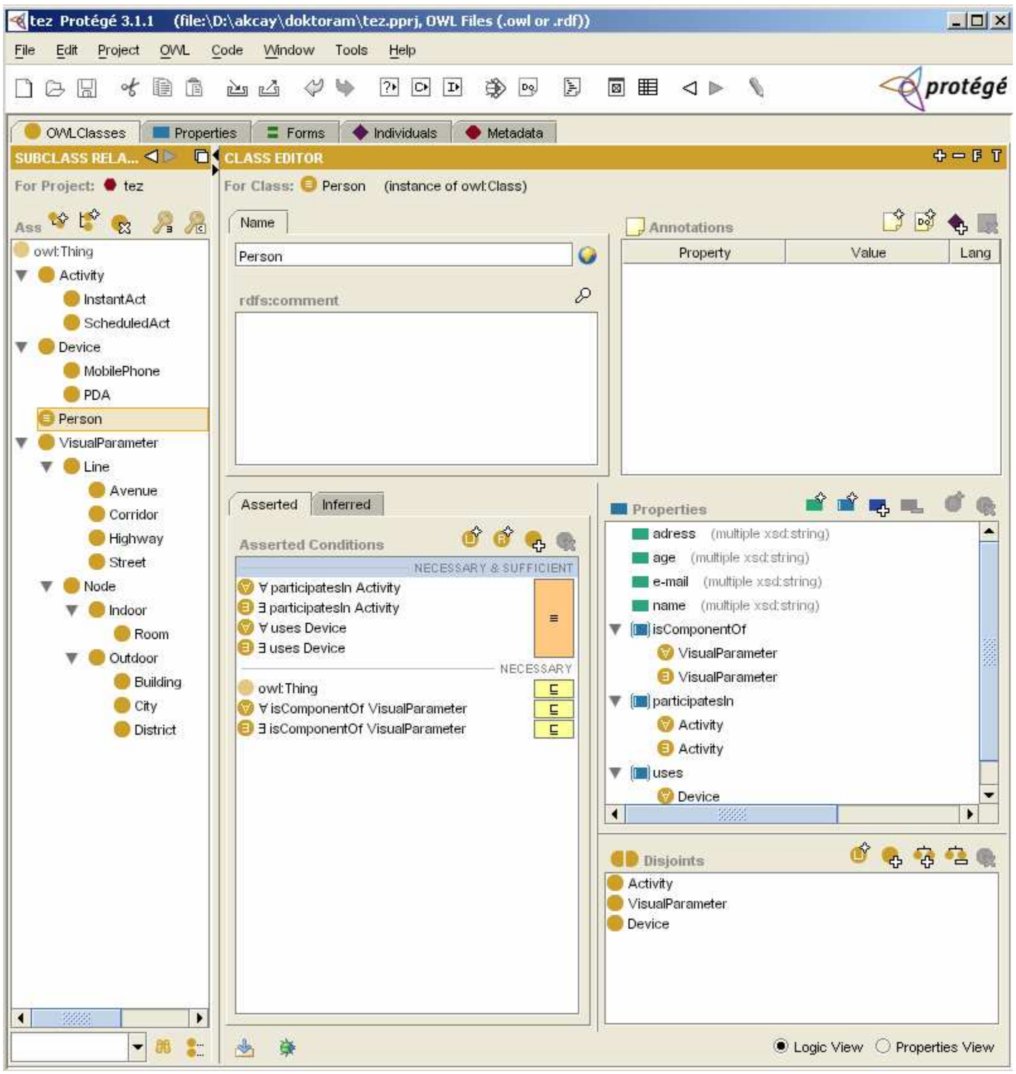

Figure 5.6: Ontology editing in Protégé Software (Protégé, 2007)

In the screenshot, OWL class taxonomy has been illustrated and asserted relations that provide Person class have been explained under necessary condition and necessary & sufficient condition. Some relations have been built under necessary &

sufficient condition because they are only relations that satisfy class Person such as *uses* relation and *participatesIn* relation. Consistency of taxonomies has been checked in RacerPro, a reasoning engine for OWL-DL specification. Then the concepts (T-box) and the individuals (A-box) in the knowledge base system have been stored in RacerPro OWL reasoner. The details of the T-box that is in OWL-DL syntax can be viewed in Appendix A. Concepts and individuals can be viewed in Racer Porter that is a visual interface of the RacerPro server. Figure 5.7 shows the graphical design of the concept which has been edited in the Protégé.

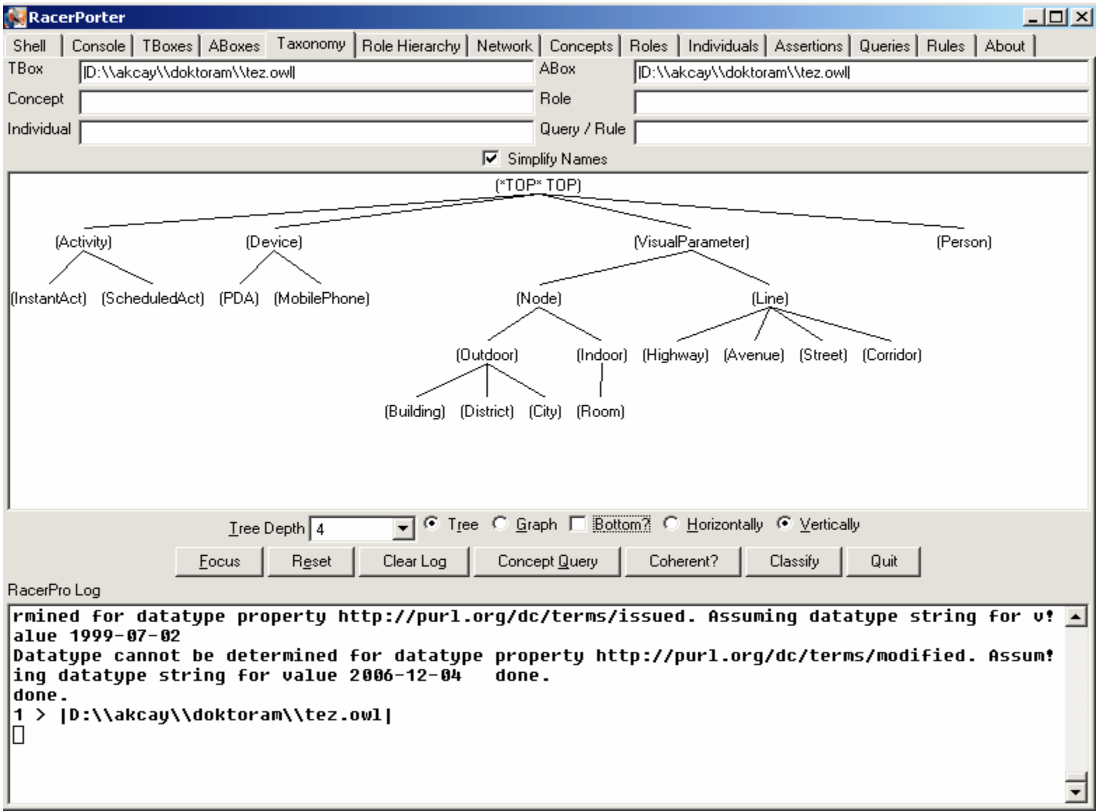

Figure 5.7: Graphical view of the T-Box in Racer Porter (Racer System, 2005)

To retrieve related explicit and implicit information in the context of designed relevancy model a query language called nRQL that is an embedded tool in RacerPro has been used. nRQL is an acronym for new Racer Query Language. The query sentences can be entered manually in the command line of the RacerPro or can be connected with Java API (Application Programming Interface), as has been done in the multi-tier architecture.

In order to define the places where the Hagi Sophia is, in the OWL knowledge base a query statement can be arranged. Let us elaborate the query statement and the answer statement that are built below in nRQL structure in order to explain the meanings clearly. All query statements in nRQL start with *retrieve* word. *Istanbul*, *Sultanahmet* and *HagiSophia* are the individuals of the knowledge base: in other words they are a part of A-Box definition of the knowledge base. The individuals and the property are written as Uniform Resource Locater (URL) because of the OWL-DL syntax that is explained in section 2.2.1. In the query host-of-HagiSophia variable has been constructed so as to represent the places that the individual HagiSophia exists in. As the result of the query, two individuals are obtained. Individual *Istanbul* is extracted as implicit information because of the transitivity feature of the *locatedIn* property. In the answer list, individual *Sultanahmet* is directly obtained from OWL knowledge base.

Query:

[retrieve (?host-of-HagiSophia)
(|http://www.itu.edu.tr/visual.owl#HagiSophia|
?host-of-HagiSophia
|http://www.itu.edu.tr/visual.owl#locatedIn|)]

Answer:

[(?host-of-HagiSophia |http://www.itu.edu.tr/visual.owl#Istanbul|)
(?host-of-HagiSophia |http://www.itu.edu.tr/visual.owl#Sultanahmet|)]

Now, suppose we want to find out building individuals located in a district in the knowledge base. The building individuals can be a faculty, a museum or a hotel. The following nRQL query searches corresponding Abox individuals graphically, as depicted in Figure 5.8:

[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|))]

The query statement has been implemented with sub-queries step by step in Figure 5.8. The query steps have been explained in Table 5.1.

nRQL or Jess engine provides rules for the simple Abox augmentation mechanism. Jess is a rule engine and scripting environment written in Java language. A sample rule statement that is formalised in Protégé SWRL editor can be arranged as follows:

participatesIn (?x, ?y) ^ isComponentOf (?y, ?z) → navigates (?x, ?z)

Table 5.1: Steps of the semantic query

No	Semantic Query Statement	Explanation of the Query
1	(and (?x Building) (?y top))	Variable x indicates individuals that belong to Building concept while variable y indicates all individuals.
2	(and (?x top) (?y District))	Variable y indicates individuals that belong to District concept while variable x indicates all individuals.
3	(and (and (?x Building) (?y top)) (and (?x top) (?y District)))	Intersection of statement 1 and statement 2.
4	(?x ?y locatedIn)	Variable x and variable y indicate that all individual pairs provide "locatedIn" relation.
5	(and (and (?x Building) (?y top)) (and (?x top) (?y District)) (?x ?y locatedIn)	Intersection of statement 3 and statement 4.

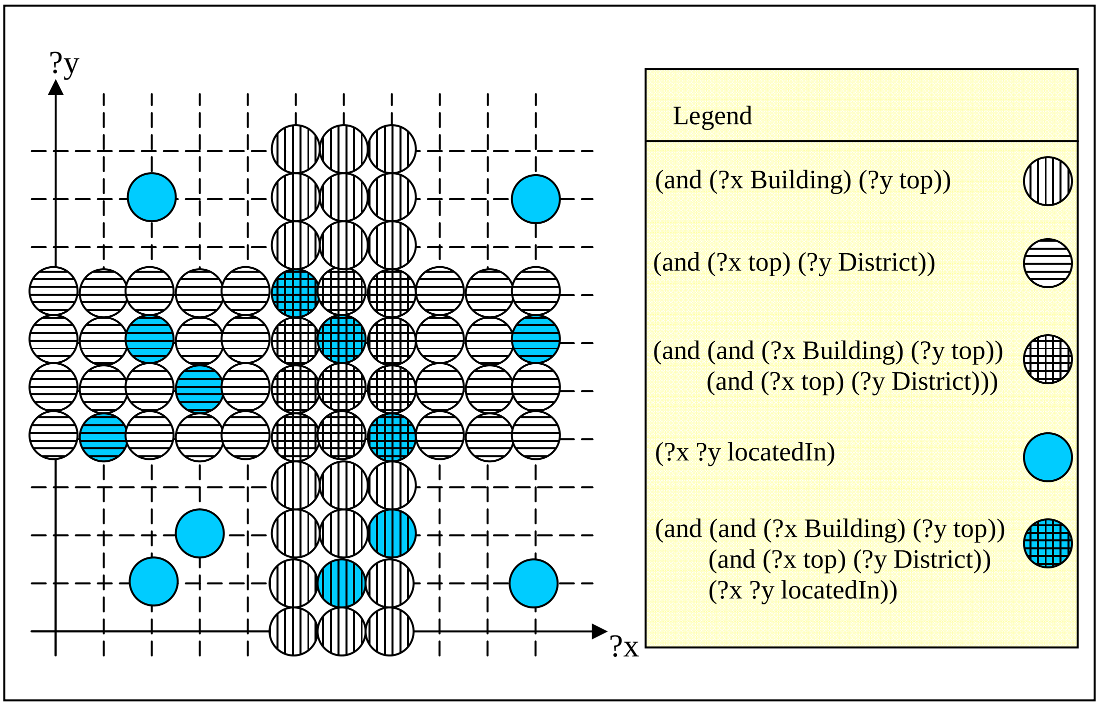

Figure 5.8: Illustration of the data retrieval with a semantic query

In the antecedent of the rule example, there is an intersection of two properties. ?x, ?y and ?z indicate all individuals that provide the relations between the classes. According to the rule, any individual that joins an activity in a place navigates towards the location of the activity. The asserted relation pairs of the individuals that are extracted by the rule definition are added to the OWL knowledge base as additional information.

5.4 Scenarios for Relevant Visualisation in distributed GIS

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 section 4.2. The screenshots of the mobile phone displays have been produced in Java Netbeans Integrated Development Environment (IDE). Netbeans IDE supports the emulators of various mobile phone and PDAs so as to test software that is composed for the mobile applications. An emulator reacts in the same way as the device behaves in the real world.

5.4.1 Scenario I

According to the scenario, John decides to visit Hagi Sophia Museum when he is in room A102 of the Civil Engineering Faculty. He runs the map application on his GPS supported mobile phone. The user interface of the application welcomes the client John. John manually enters the target place that he wants to visit.

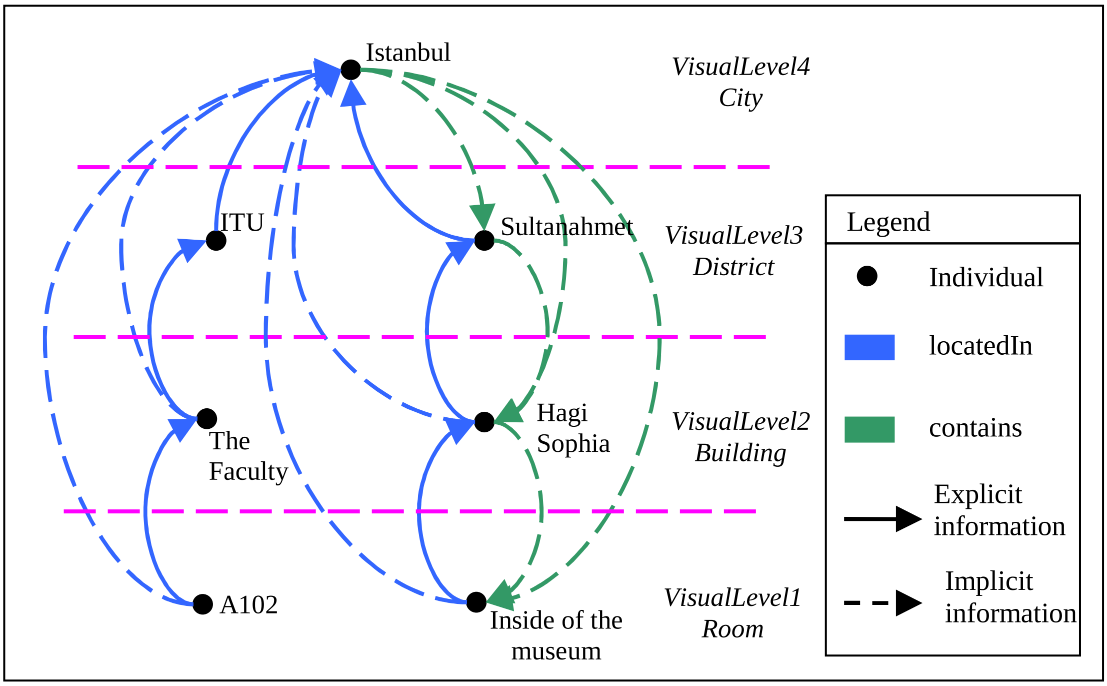

Figure 5.9: Visual levels

The server evaluates John’s location and his request in the context model. John’s visual level and visual levels of Hagi Sophia Museum are determined in the server. The model searches for the covering visual level of the two locations. As shown in Figure 5.9, John and the museum can 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 5.10: Different conceptual visual levels for scenario I

In the upper-left image of Figure 5.10, 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 more simple visualization on the small screen. When John leaves the faculty, the sensor determines that he is outside, and a second visual level appears on the screen, as depicted in the upper-right image of Figure 5.10. The resolution of the emulator mobile phone is 320 x 240 pixels. The second visual level is based on buildings. Buildings are represented by some related symbols instead of their scaled polygons until the user gets out of the campus district.

In the scenario, the district visual level is defined as the covering level by the ontology server (the lower-left image of Figure 5.10). 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 of the Sultanahmet district and the visual level goes back to the building level again for Sultanahmet (the lower-right image of Figure 5.10). The visualization of the scenario is completed in four steps up to the user's current position.

5.4.2 Scenario II

Let us assume that Betty is trying to find Topkapi Palace while she is going around Sultanahmet. Betty runs the mobile visualisation software through GPRS connection to get to Topkapi Palace.

The system detects location of Betty with a GPS sensor. Handheld GPS does not measure coordinates precisely. GPS coordinates therefore point to a building, although she is outside.

The ontology reasoner does not accept the coordinates as correct after a knowledge base query and locates the user a possible location near the building. Because the usage of the GPS sensor must be outside the building and a person cannot be at two different places at the same time according to ontological context, ontology reasoner might inference this correction from the knowledge base. The only visual level is therefore the building level in the scenario in order to navigate to Topkapi Palace (Figure 5.11).

Figure 5.11: The correction for the user's location with knowledge reasoning

5.5 The Definition of the Symbol Size of a Spatial Object

The proposed visualisation model requires symbols instead of scaled polygonal object representation. As explained in section 4.3, symbol-based simplification is applied to the visualisation in order to obtain more uncomplicated map outputs on small screens. The symbol-based simplification can be applied as follows:

Let us suppose there is a spatial object that is 950 m^2 and the mobile device has 320 X 320 pixels capacity to show that spatial object. The spatial object represents a medical unit in the Campus of ITU. In Figures 5.13 and 5.14, the spatial object is symbolised with a capital H letter with black colour in a circle filled with white colour. The membership values for the pixel size of the display of the device and the area of the spatial object are calculated from membership functions in equations 4.3, 4.4, 4.5 and 4.6:

$$\mu_{A-Large}(x) = 0.06 \tag{5.1}$$

$$\mu_{A-Small}(x) = 0.94 \tag{5.2}$$

$$\mu_{B-High}(x) = 0.86 \tag{5.3}$$

$$\mu_{B-Low}(x) = 0.14 \tag{5.4}$$

The minimums of the memberships function values:

$$Rule_1: \quad m_1 = \min(\mu_{A-Large}(x_0), \mu_{B-High}(y_0)) = 0.06 \quad \textbf{(5.5)}$$

$$Rule_2: \quad m_2 = \min(\mu_{A-Large}(x_0), \mu_{B-Low}(y_0)) = 0.06 \quad \textbf{(5.6)}$$

$$Rule_3: \quad m_3 = \min(\mu_{A-Small}(x_0), \mu_{B-Low}(y_0)) = 0.14 \quad \textbf{(5.7)}$$

$$Rule_4: \quad m_4 = \min(\mu_{A-Small}(x_0), \mu_{B-High}(y_0)) = 0.86 \quad \textbf{(5.8)}$$

Equation 5.9, 5.10, 5.11 and 5.12 are conclusion values of rules:

$$Conclusion_1: \quad c_1' = m_1 c_1 = 2.22 \quad \textbf{(5.9)}$$

$$Conclusion_2: \quad c_2' = m_2 c_2 = 1.66 \quad \textbf{(5.10)}$$

$$Conclusion_3: \quad c_3' = m_3 c_3 = 2.73 \quad \textbf{(5.11)}$$

$$Conclusion_4: \quad c_4' = m_4 c_4 = 13.81 \quad \textbf{(5.12)}$$

Final conclusion that indicates one dimension of the symbol in pixel unit is calculated as in equation 5.13. The area that the symbol covered on the map is square of the conclusion value (Equations 5.14 and 5.15). The unit of the area is square pixels in Equation 5.14 and square millimetres in Equation 5.15:

$$c' = \frac{\sum_{i=1}^{4} c_i'}{\sum_{i=1}^{4} m_i} = 18.39 \ pixels \quad \textbf{(5.13)}$$

$$Symbol\ Size = (c')^2 = (18.39)^2 = 338.19 \ square\ pixels \quad \textbf{(5.14)}$$

$$Symbol\ Size = (c')^2 = (18.39 \times 0.28)^2 = 26.51 \ square\ millimetres \quad \textbf{(5.15)}$$

Figures 5.12 and 5.13 show maps that have scaled polygonal representation and symbol-based representation. Figure 5.14 shows a map with a simplification technique (see section 4.3) to produce an adapted map. Adaptation is provided according to the display resolution capacity of the mobile device and the size of the spatial object. The map images in Figures 5.12 and 5.13 are 320X320 pixels.

The 45 buildings that include 12 buildings in the figures (5.12, 5.13 and 5.14) in the Campus of ITU have been calculated separately for three different resolutions (320X320, 240X240 and 140X140). All the values and the results of the fuzzy logic calculation can be found in Appendix C.1, C.2 and C.3.

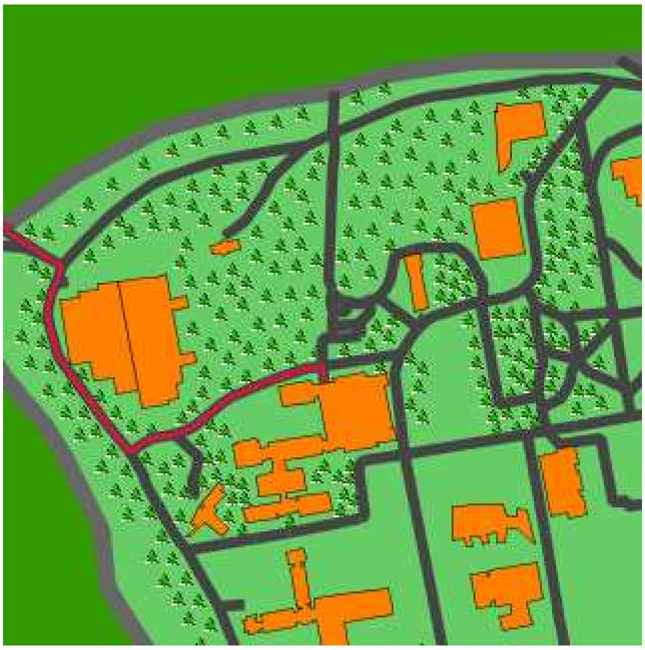

Figure 5.12: Scaled polygonal representation

Figure 5.13: Symbol-based representation

In Figure 5.15, the comparison between polygonal representation and symbol-based representation can be seen graphically. According to the graphic, x axis indicates real area values of the various spatial objects while y axis indicates scaled areas of the spatial objects. The real area value range ranges from 330 square metres to 12191 square metres. As shown in the graphic, the scaled polygonal area has a wider range than the scaled symbol area. Consequently the symbol-based representation reduces big area differences among the spatial objects. The graphic has been drawn to 320X320 resolution. Graphics that have been drawn to 240X240 resolution and 140X140 resolution can be found in Appendix C (Figures C.1 and C.2).

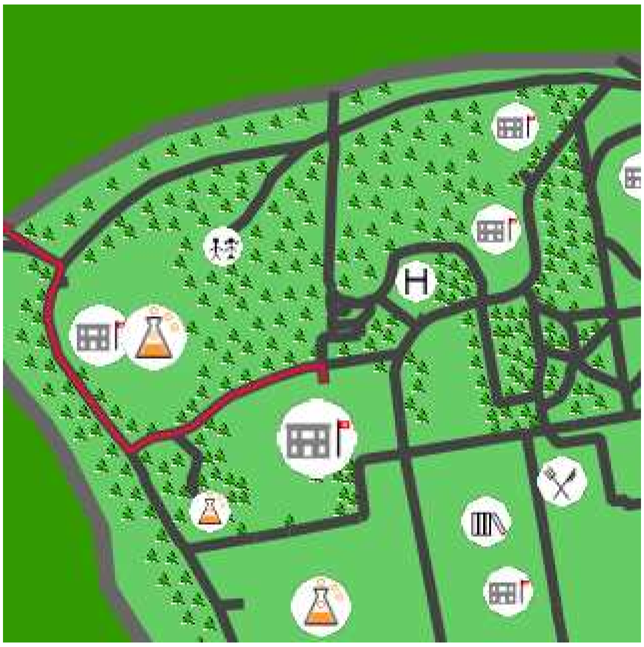

Figure 5.14: Symbol-based representation with simplification technique

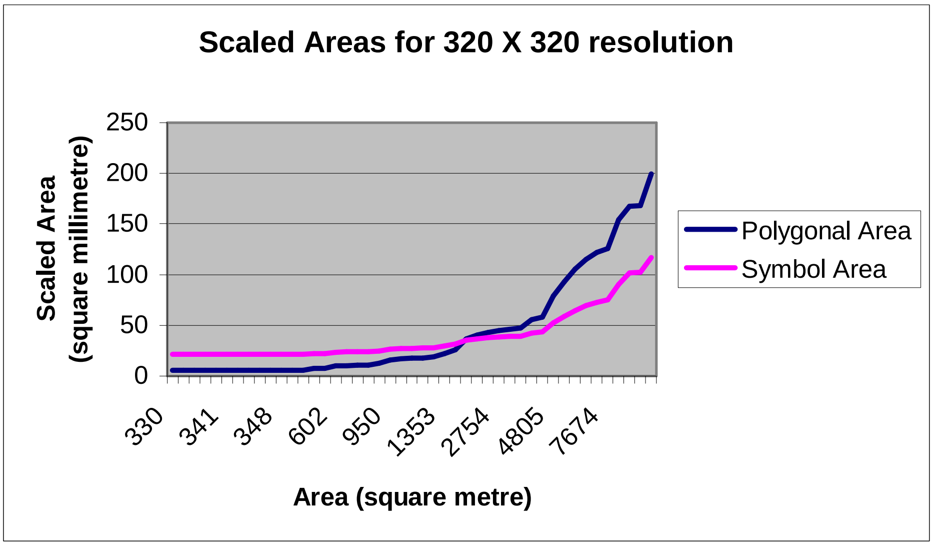

Figure 5.15: The comparison of symbol area with polygonal area

6. CONCLUSION

6.1 Achievements

Relevant visualization of the spatial data on small mobile devices involves many different parameters. To define relevant visualisation for the mobile user, the "relevancy" concept has been reviewed first. According to the relevancy theories, new relations for relevance have been defined. The visualization on the mobile devices requires some specific relations that belong to the mobile context. In the article, proposed relation types have been determined in order to provide manifestations of the relevance. Three manifestations of the relevance that are more difficult to define than others are focused on in the model: cognitive relevance, situational relevance and motivational relevance. Cognitive relevance includes one relation, situational relevance includes four relations and motivational relevance includes two relations. The one side of the proposed relations is about the visual parameters of the mobile device, the opposite side of the relations is about the visual parameters of the spatial data. For example, in the situational relevance display resolution of the mobile device is a component of the mobile device visualization and space contraction is about spatial data visualization. Therefore, relevancy of the visualization has been provided for the mobile context as a result of the proposed relations.

The aim of this research is to obtain a context-aware system that enables relevant visualisation for the mobile user. The context model is defined in the ontological structure that represents a mobile environment within visualisation. Ontology has been chosen to construct the context model because it is one of the most preferred scientific solutions for establishing a context-aware system. Ontology is based on a conceptualisation that represents an entity in the real world. Ontology produces not only conceptualisation but also relationships among the concepts to realise the world in the computer environment. This approach has provided a map service that is able to adapt to the continuously changing situations of daily life.

The ontological model has been achieved in two different levels: upper ontological level and lower ontological level. The upper ontological level has been formed by more general concepts and relations. It realizes the main context entities such as person, device and activity. In the article, the visual parameter concept has been added to the upper context model to state the visual components of the spatial data as an important part of the system. Data type properties of the visual parameter concept have also been placed on the upper ontology. Subconcepts of the visual parameter have been defined as line and node. The relation between a concept and a subconcept is "is a" relation. Therefore, it can be stated that a line is a visual parameter and a node is a visual parameter. Actually, spatial data can be represented in three main geographic features: point, line and polygon. In the research, the polygon feature has been eliminated while representing spatial data. All polygonal data have been converted to the central point of it because of the limited display size of the mobile devices. Consequently, the visualization has been realized as the line and the node.

Lower ontologies are for more specific conceptualization under the upper context, such as smart home application and smart car application. In the lower ontological context, some spatial objects have been determined as the main representation component of the current visual level. For example, the level building focuses on the buildings, like museums. In the building level, polygonal data that belongs to a building has been converted to the central point of the polygon in order to represent the building as a point or a symbol. This approach provides a simpler visualization than the scaled polygonal two-dimensional visualization. Particularly, the limited display of the mobile devices needs map outputs that do not have complex representations. The transitions between the visual levels are up to the sensors that locate the mobile user in the mobile context. The same approach has been proposed for the roads. The polyline data has been categorized, such as streets, avenues and corridors that are parallel to the polygonal visual levels.

In order to obtain a mobile map service which evaluates the user's current situation and extracts new conclusions, some reasoning rules have been applied on the ontological context model with semantic queries. This ontological contextual model is based on a description-logic supported conceptual model that is called a knowledge base. Some restrictions have been applied in the T-box (conceptual structure) so as to create a knowledge base. These restrictions have been composed appropriately to obtain relations (properties) between the concepts. These properties play an important role during reasoning procedure. The more efficiently relations connect the concepts with each other, the more information is retrieved from the context. The structuring of the knowledge base is therefore a time-consuming special procedure. In some literature, the person that creates a knowledge base is called an “ontology engineer”.

In this research, OWL-DL has been preferred as the semantic language to obtain the knowledge base. OWL-DL is a specification that enables reasoning from the context. The context reasoning has provided the implicit information from the explicit information on the model. DL support on the OWL specification increases reasoning capacity. To add new reasoning possibilities, rule-based specification, called SWRL, has also been added to the knowledge base. Therefore, the proposed knowledge base has provided two types of reasoning: ontology reasoning and rule-based reasoning. Both types are able to extract implicit information to obtain more relevant visualization on the mobile devices.

The visualisation model is based on two dimensions instead of three dimensions because of the limited display capacity of the mobile devices. Moreover, low process capacity of the mobile devices cannot run three-dimensional spatial data appropriately. The third reason for preferring two dimensions is the connection speed and connection fee. Although GPRS provides speedy wireless internet connection, it is not as fast as UMTS infrastructure. Furthermore, each data unit that is transmitted between servers and users raises total service costs.

Semantic approaches provide useful solutions for context-aware systems. Nevertheless, semantic approaches might not be a good solution for every problem. The system therefore requires algorithmic solutions to support the knowledge base. In the research, cartographic representation of the spatial data has been done more simply and more comprehensibly with the symbol-based simplification for mobile devices. To determine appropriate symbol size for the objects of the current visual level, a fuzzy logic solution has been proposed which depends on the original area of the object and the scale of the map. The solution has provided reasonable views for the mobile device.

The knowledge base has been integrated in the distributed GIS environment. A multi-tier technological architecture has been designed that includes spatial database, knowledge base and web map server (WMS). To connect the mobile devices to the servers, a web server and a proxy server have also been set up as in the middleware architecture. GPRS connection, that is the only wireless connection provided by the mobile phone operators, has been used in the research. The UMTS has not been provided yet in Turkey. A GUI that collects information from mobile users has been designed. The architecture has been composed with Java 2EE and Java 2ME programming. To implement the inference procedure the semantic query language (nRQL) has been used.

Egocentric design of a map-based service which provides relevant visualization for the mobile user has been implemented at 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 consistency of the proposed model for the real user world. From the computer scientists’ point of view, this application field (campus area) is called Intelligent Space. From a cartographer’s perspective, it can be called Intelligent Map Space.

6.2 Future Work

The proposed knowledge base is based on the crisp ontological approach. According to ontologies, an object is an existence and it is represented in the concept as an individual. Individuals have relationships each other. A new fuzzy approach for the ontology is proposed by some computer scientists. The approach accepts that an existence might be a partial member of a concept. This new idea might bring new expansions to the model. It might lead to new inference possibilities.

Technological advancements always give new opportunities for mobile services. They are also valid for mobile map services. A mobile service has many components such as connection, device and server. The advancement of each component supports a new ability separately for the service. For example, a large connection band is essential for the huge data transmissions among the agents. In the obtaining of three-dimensional spatial data on the mobile device capacities of the mobile devices and internet connection gain particular importance.

In the near feature a mobile user will be able to view complex visualisation of the spatial data. Consequently, the ontological context model will need review for the three dimensions or something else. Connection speed has already been developed with UMTS network in many countries, but it is still not a worldwide service. The band capacity of the UMTS connection provides further application opportunities like live TV broadcast. It will certainly influence mobile web services.

Third dimension and advanced visualisation features require a new contextual model for the implementation of a relevant mobile map service. With relevance manifestations of the visualisation of the spatial data which have been defined in this thesis, visual parameters should be redefined in the light of the features of three-dimensional complex and advanced visualisation. This kind of visualisation will provide more relevant and realistic spatial data presentation for the user.

Developments on geosensor technology will also influence the contextual models and their reasoning capabilities. Different sensor types should therefore be defined, modelled and integrated in the ontological model so as to provide more efficient mobile services. Advantages of the geosensors will direct spatial data providers in order to present better location -ased services to the mobile user.

An agent-based model is also important for wider system implementation. In this thesis, contextual model and ontological projections of this model have been developed. The model has been tested on some scenarios for limited users. An implementation of the model, however, requires agent-based structures such as context brokers, directory facilities and personal agents for large amount of data entry to provide a healthy communication between software and human agents. An agent-based approach might be provided for the proposed model in future work.

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APPENDIX

Appendix A – T-Box of the knowledge base in OWL syntax

```
<?xml version="1.0"?>
<rdf:RDF
    xmlns:p1="http://protege.stanford.edu/plugins/owl/dc/protege-
dc.owl#"
    xmlns:dcterms="http://purl.org/dc/terms/"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:daml="http://www.daml.org/2001/03/daml+oil#"
    xmlns:dc="http://purl.org/dc/elements/1.1/"
    xmlns="http://www.owl-ontologies.com/photo-itu.owl#"
  xml:base="http://www.owl-ontologies.com/photo-itu.owl">
  <owl:Ontology rdf:about="">
    <owl:versionInfo
rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >classified</owl:versionInfo>
    <owl:imports rdf:resource="http://purl.org/dc/elements/1.1/"/>
  </owl:Ontology>
  <owl:Class rdf:ID="Person">
    <rdfs:subClassOf
rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
    <owl:disjointWith>
      <owl:Class rdf:ID="Activity"/>
    </owl:disjointWith>
    <rdfs:subClassOf>
      <owl:Restriction>
        <owl:allValuesFrom>
          <owl:Class rdf:ID="VisualParameter"/>
        </owl:allValuesFrom>
        <owl:onProperty>
          <owl:ObjectProperty rdf:ID="isComponentOf"/>
        </owl:onProperty>
      </owl:Restriction>
    </rdfs:subClassOf>
    <owl:equivalentClass>
      <owl:Class>
        <owl:intersectionOf rdf:parseType="Collection">
          <owl:Restriction>
            <owl:onProperty>
              <owl:ObjectProperty rdf:ID="participatesIn"/>
            </owl:onProperty>
            <owl:allValuesFrom>
              <owl:Class rdf:about="#Activity"/>
```

```
          </owl:allValuesFrom>
        </owl:Restriction>
        <owl:Restriction>
          <owl:someValuesFrom>
            <owl:Class rdf:about="#Activity"/>
          </owl:someValuesFrom>
          <owl:onProperty rdf:resource="#participatesIn"/>
        </owl:Restriction>
        <owl:Restriction>
          <owl:allValuesFrom>
            <owl:Class rdf:ID="Device"/>
          </owl:allValuesFrom>
          <owl:onProperty>
            <owl:ObjectProperty rdf:ID="uses"/>
          </owl:onProperty>
        </owl:Restriction>
        <owl:Restriction>
          <owl:onProperty rdf:resource="#uses"/>
          <owl:someValuesFrom>
            <owl:Class rdf:about="#Device"/>
          </owl:someValuesFrom>
        </owl:Restriction>
      </owl:intersectionOf>
    </owl:Class>
  </owl:equivalentClass>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:someValuesFrom>
        <owl:Class rdf:about="#VisualParameter"/>
      </owl:someValuesFrom>
      <owl:onProperty rdf:resource="#isComponentOf"/>
    </owl:Restriction>
  </rdfs:subClassOf>
  <owl:disjointWith>
    <owl:Class rdf:about="#VisualParameter"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#Device"/>
  </owl:disjointWith>
</owl:Class>
<owl:Class rdf:about="#VisualParameter">
  <owl:disjointWith rdf:resource="#Person"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#Device"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#Activity"/>
  </owl:disjointWith>
</owl:Class>
<owl:Class rdf:ID="MobilePhone">
  <owl:disjointWith>
    <owl:Class rdf:ID="PDA"/>
  </owl:disjointWith>
  <rdfs:subClassOf>
    <owl:Class rdf:about="#Device"/>
  </rdfs:subClassOf>
</owl:Class>
```

```
  <owl:Class rdf:ID="Corridor">
    <owl:disjointWith>
      <owl:Class rdf:ID="Street"/>
    </owl:disjointWith>
    <rdfs:subClassOf>
      <owl:Class rdf:ID="Line"/>
    </rdfs:subClassOf>
    <owl:disjointWith>
      <owl:Class rdf:ID="Avenue"/>
    </owl:disjointWith>
    <owl:disjointWith>
      <owl:Class rdf:ID="Highway"/>
    </owl:disjointWith>
  </owl:Class>
  <owl:Class rdf:about="#Device">
    <rdfs:subClassOf
rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
    <rdfs:subClassOf>
      <owl:Restriction>
        <owl:allValuesFrom rdf:resource="#VisualParameter"/>
        <owl:onProperty rdf:resource="#isComponentOf"/>
      </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf>
      <owl:Restriction>
        <owl:onProperty rdf:resource="#isComponentOf"/>
        <owl:someValuesFrom rdf:resource="#VisualParameter"/>
      </owl:Restriction>
    </rdfs:subClassOf>
    <owl:disjointWith>
      <owl:Class rdf:about="#Activity"/>
    </owl:disjointWith>
    <owl:disjointWith rdf:resource="#VisualParameter"/>
    <owl:disjointWith rdf:resource="#Person"/>
  </owl:Class>
</rdf:RDF>

<!-- Created with Protege (with OWL Plugin 2.1, Build 284)
http://protege.stanford.edu -->
```

Appendix B1 – A web service method that connects the ontology reasoner:

```
  public java.lang.String operation(String concept) throws java.rmi.RemoteException {

      String ip = "localhost";
      int port = 8088;

      RacerServer racer1 = new RacerServer(ip,port);
      try {
         racer1.openConnection();
         String general = (racer1.send("(retrieve (?x) (?x |http://www.owl-
ontologies.com/unnamed.owl#" + concept + "|))"));
         String gecici = general.substring(1);

         String[] words = gecici.split(" ");
         for (int i=1; i < words.length; i+=2)
         words[i] = words[i].substring(43);

         int t = words.length;

         int[] in = new int[t];

         for (int i=0; i < words.length; i++)
         in[i] = words[i].length();

         for (int i=1; i < words.length; i+=2)
         words[i] = words[i].substring(0, in[i] - 3);

         result = words[1];
         for (int i=3; i < words.length; i+=2)
         result = result + "  " + words[i];
         this.result = result.substring(0, result.length() -1 );
         racer1.closeConnection();
      }
      catch (Exception e) {
         e.printStackTrace();
      }

      return this.result;
   }
```

Appendix B2 – A web service method that connects the database server:

```
public java.lang.String getTarget(String nameTarget) throws java.rmi.RemoteException
{

        Statement sql = null;
        Connection db = null;

        try {

            Class.forName("org.postgresql.Driver");
        } catch (ClassNotFoundException ex) {
            ex.printStackTrace();
        }
        try {

            db =
DriverManager.getConnection("jdbc:postgresql://localhost:5432/campusdb", "postgres",
"***"); //connect to the db
        } catch (SQLException ex) {
            ex.printStackTrace();
        }

        try {
            sql = db.createStatement(); //create a statement that we can use later
        } catch (SQLException ex) {
            ex.printStackTrace();
        }

        try {
            //create a statement that we can use later
            //String sqlText = "SELECT name FROM person WHERE gid = 1;";
            String sqlText = "SELECT asewkt(the_geom) FROM buildings WHERE name =
'" + nameTarget + "';";
            ResultSet rs = sql.executeQuery(sqlText);
            rs.next();
            targetcoord = rs.getString("asewkt");
            targetcoord = targetcoord.substring(15,48);
            String x = targetcoord.substring(0,10);
            String y = targetcoord.substring(17,28);
            this.targetcoord = x + " "  + y;

          } catch (SQLException ex) {
            ex.printStackTrace();
        }
    return this.targetcoord;
    }
```

Appendix C

Table C.1: Symbol sizes for 320X320 resolution

No	Area (square meters)	Resol. (pixel)	High Resol.	Low Resol.	Large Area	Small Area	Rule 1	Rule 2	Rule 3	Rule 4	Conc. 1	Conc. 2	Conc. 3	Conc. 4	Final Conc. (pixel)	Symbol Area (square pixels)	Symbol Area (square millimeters)
1	661	320	0.86	0.14	0.03	0.97	0.03	0.03	0.14	0.86	1.13	0.85	2.73	13.82	17.53	307.43	24.10
2	7674	320	0.86	0.14	0.69	0.31	0.69	0.14	0.14	0.31	27.50	4.09	2.73	5.00	30.89	954.26	74.81
3	10246	320	0.86	0.14	0.93	0.07	0.86	0.14	0.07	0.07	34.55	4.09	1.42	1.13	36.07	1301.38	102.03
4	10218	320	0.86	0.14	0.93	0.07	0.86	0.14	0.07	0.07	34.55	4.09	1.47	1.18	35.99	1295.40	101.56
5	7001	320	0.86	0.14	0.62	0.38	0.62	0.14	0.14	0.38	24.97	4.09	2.73	6.01	29.70	881.99	69.15
6	9405	320	0.86	0.14	0.85	0.15	0.85	0.14	0.14	0.15	34.00	4.09	2.73	2.40	33.96	1153.21	90.41
7	7436	320	0.86	0.14	0.67	0.33	0.67	0.14	0.14	0.33	26.60	4.09	2.73	5.36	30.47	928.38	72.78
8	5658	320	0.86	0.14	0.50	0.50	0.50	0.14	0.14	0.50	19.92	4.09	2.73	8.03	27.32	746.28	58.51
9	1353	320	0.86	0.14	0.09	0.91	0.09	0.09	0.14	0.86	3.73	2.80	2.73	13.82	19.45	378.23	29.65
10	755	320	0.86	0.14	0.04	0.96	0.04	0.04	0.14	0.86	1.48	1.11	2.73	13.82	17.82	317.59	24.90
11	454	320	0.86	0.14	0.01	0.99	0.01	0.01	0.14	0.86	0.35	0.27	2.73	13.82	16.87	284.46	22.30
12	1144	320	0.86	0.14	0.07	0.93	0.07	0.07	0.14	0.86	2.95	2.21	2.73	13.82	18.92	357.81	28.05
13	343	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
14	345	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
15	341	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
16	341	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
17	340	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
18	352	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
19	343	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
20	330	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
21	343	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
22	340	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
23	338	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46

Table C.1: Symbol sizes for 320X320 resolution (continuation)

No	Area (square meters)	Resol. (pixel)	High Resol.	Low Resol.	Large Area	Small Area	Rule 1	Rule 2	Rule 3	Rule 4	Conc. 1	Conc. 2	Conc. 3	Conc. 4	Final Conc. (pixel)	Symbol Area (square pixels)	Symbol Area square (millimeters)
24	348	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
25	452	320	0.86	0.14	0.01	0.99	0.01	0.01	0.14	0.86	0.35	0.26	2.73	13.82	16.86	284.23	22.28
26	355	320	0.86	0.14	0.00	1.00	0.00	0.00	0.14	0.86	0.00	0.00	2.73	13.82	16.55	273.75	21.46
27	602	320	0.86	0.14	0.02	0.98	0.02	0.02	0.14	0.86	0.91	0.68	2.73	13.82	17.35	300.97	23.60
28	1095	320	0.86	0.14	0.07	0.93	0.07	0.07	0.14	0.86	2.76	2.07	2.73	13.82	18.79	352.90	27.67
29	1033	320	0.86	0.14	0.06	0.94	0.06	0.06	0.14	0.86	2.53	1.90	2.73	13.82	18.62	346.62	27.18
30	1068	320	0.86	0.14	0.07	0.93	0.07	0.07	0.14	0.86	2.66	2.00	2.73	13.82	18.71	350.18	27.45
31	6444	320	0.86	0.14	0.57	0.43	0.57	0.14	0.14	0.43	22.87	4.09	2.73	6.85	28.71	824.33	64.63
32	634	320	0.86	0.14	0.03	0.97	0.03	0.03	0.14	0.86	1.03	0.77	2.73	13.82	17.45	304.48	23.87
33	642	320	0.86	0.14	0.03	0.97	0.03	0.03	0.14	0.86	1.06	0.80	2.73	13.82	17.47	305.36	23.94
34	1575	320	0.86	0.14	0.11	0.89	0.11	0.11	0.14	0.86	4.57	3.43	2.73	13.82	19.98	399.06	31.29
35	950	320	0.86	0.14	0.06	0.94	0.06	0.06	0.14	0.86	2.22	1.66	2.73	13.82	18.39	338.11	26.51
36	4805	320	0.86	0.14	0.42	0.58	0.42	0.14	0.14	0.58	16.71	4.09	2.73	9.32	25.81	665.97	52.21
37	3387	320	0.86	0.14	0.28	0.72	0.28	0.14	0.14	0.72	11.38	4.09	2.73	11.45	23.29	542.58	42.54
38	2902	320	0.86	0.14	0.24	0.76	0.24	0.14	0.14	0.76	9.56	4.09	2.73	12.18	22.43	503.27	39.46
39	2456	320	0.86	0.14	0.20	0.80	0.20	0.14	0.14	0.80	7.88	4.09	2.73	12.85	21.64	468.43	36.73
40	3531	320	0.86	0.14	0.30	0.70	0.30	0.14	0.14	0.70	11.92	4.09	2.73	11.23	23.55	554.53	43.48
41	2609	320	0.86	0.14	0.21	0.79	0.21	0.14	0.14	0.79	8.45	4.09	2.73	12.62	21.91	480.24	37.65
42	2801	320	0.86	0.14	0.23	0.77	0.23	0.14	0.14	0.77	9.18	4.09	2.73	12.33	22.25	495.27	38.83
43	12191	320	0.86	0.14	1.00	0.00	0.86	0.14	0.00	0.00	34.55	4.09	0.00	0.00	38.64	1492.77	117.03
44	2754	320	0.86	0.14	0.23	0.78	0.23	0.14	0.14	0.78	9.00	4.09	2.73	12.40	22.17	491.57	38.54
45	2218	320	0.86	0.14	0.17	0.83	0.17	0.14	0.14	0.83	6.98	4.09	2.73	13.21	21.22	450.35	35.31

Table C.2: Symbol sizes for 240X240 resolution

No	Area (square meters)	Resol. (pixel)	High Resol.	Low Resol.	Large Area	Small Area	Rule 1	Rule 2	Rule 3	Rule 4	Conc. 1	Conc. 2	Conc. 3	Conc. 4	Final Conc. (pixel)	Symbol Area (square pixels)	Symbol Area (square millimeters)
1	661	240	0.50	0.50	0.03	0.97	0.03	0.03	0.50	0.50	1.13	0.85	10.00	8.00	18.91	357.60	28.04
2	7674	240	0.50	0.50	0.69	0.31	0.50	0.50	0.31	0.31	20.00	15.00	6.25	5.00	28.46	809.99	63.50
3	10246	240	0.50	0.50	0.93	0.07	0.50	0.50	0.07	0.07	20.00	15.00	1.42	1.13	32.89	1081.73	84.81
4	10218	240	0.50	0.50	0.93	0.07	0.50	0.50	0.07	0.07	20.00	15.00	1.47	1.18	32.82	1077.24	84.46
5	7001	240	0.50	0.50	0.62	0.38	0.50	0.50	0.38	0.38	20.00	15.00	7.52	6.01	27.70	767.56	60.18
6	9405	240	0.50	0.50	0.85	0.15	0.50	0.50	0.15	0.15	20.00	15.00	3.00	2.40	31.08	965.89	75.73
7	7436	240	0.50	0.50	0.67	0.33	0.50	0.50	0.33	0.33	20.00	15.00	6.70	5.36	28.18	794.12	62.26
8	5658	240	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	19.92	14.94	10.00	8.00	26.48	701.32	54.98
9	1353	240	0.50	0.50	0.09	0.91	0.09	0.09	0.50	0.50	3.73	2.80	10.00	8.00	20.67	427.41	33.51
10	755	240	0.50	0.50	0.04	0.96	0.04	0.04	0.50	0.50	1.48	1.11	10.00	8.00	19.17	367.68	28.83
11	454	240	0.50	0.50	0.01	0.99	0.01	0.01	0.50	0.50	0.35	0.27	10.00	8.00	18.30	334.71	26.24
12	1144	240	0.50	0.50	0.07	0.93	0.07	0.07	0.50	0.50	2.95	2.21	10.00	8.00	20.18	407.37	31.94
13	343	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
14	345	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
15	341	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
16	341	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
17	340	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
18	352	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
19	343	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
20	330	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
21	343	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
22	340	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
23	338	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
24	348	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40
25	452	240	0.50	0.50	0.01	0.99	0.01	0.01	0.50	0.50	0.35	0.26	10.00	8.00	18.29	334.49	26.22
26	355	240	0.50	0.50	0.00	1.00	0.00	0.00	0.50	0.50	0.00	0.00	10.00	8.00	18.00	324.00	25.40

Table C.2: Symbol sizes for 240X240 resolution (continuation)

No	Area (square meters)	Resol. (pixel)	High Resol.	Low Resol.	Large Area	Small Area	Rule 1	Rule 2	Rule 3	Rule 4	Conc. 1	Conc. 2	Conc. 3	Conc. 4	Final Conc. (pixel)	Symbol Area (square pixels)	Symbol Area (square millimeters)
27	602	240	0.50	0.50	0.02	0.98	0.02	0.02	0.50	0.50	0.91	0.68	10.00	8.00	18.74	351.17	27.53
28	1095	240	0.50	0.50	0.07	0.93	0.07	0.07	0.50	0.50	2.76	2.07	10.00	8.00	20.06	402.55	31.56
29	1033	240	0.50	0.50	0.06	0.94	0.06	0.06	0.50	0.50	2.53	1.90	10.00	8.00	19.91	396.37	31.08
30	1068	240	0.50	0.50	0.07	0.93	0.07	0.07	0.50	0.50	2.66	2.00	10.00	8.00	20.00	399.87	31.35
31	6444	240	0.50	0.50	0.57	0.43	0.50	0.50	0.43	0.43	20.00	15.00	8.56	6.85	27.16	737.53	57.82
32	634	240	0.50	0.50	0.03	0.97	0.03	0.03	0.50	0.50	1.03	0.77	10.00	8.00	18.83	354.67	27.81
33	642	240	0.50	0.50	0.03	0.97	0.03	0.03	0.50	0.50	1.06	0.80	10.00	8.00	18.86	355.54	27.87
34	1575	240	0.50	0.50	0.11	0.89	0.11	0.11	0.50	0.50	4.57	3.43	10.00	8.00	21.16	447.77	35.11
35	950	240	0.50	0.50	0.06	0.94	0.06	0.06	0.50	0.50	2.22	1.66	10.00	8.00	19.70	387.98	30.42
36	4805	240	0.50	0.50	0.42	0.58	0.42	0.42	0.50	0.50	16.71	12.53	10.00	8.00	25.74	662.46	51.94
37	3387	240	0.50	0.50	0.28	0.72	0.28	0.28	0.50	0.50	11.38	8.53	10.00	8.00	24.16	583.95	45.78
38	2902	240	0.50	0.50	0.24	0.76	0.24	0.24	0.50	0.50	9.56	7.17	10.00	8.00	23.50	552.09	43.28
39	2456	240	0.50	0.50	0.20	0.80	0.20	0.20	0.50	0.50	7.88	5.91	10.00	8.00	22.80	520.06	40.77
40	3531	240	0.50	0.50	0.30	0.70	0.30	0.30	0.50	0.50	11.92	8.94	10.00	8.00	24.35	592.86	46.48
41	2609	240	0.50	0.50	0.21	0.79	0.21	0.21	0.50	0.50	8.45	6.34	10.00	8.00	23.05	531.36	41.66
42	2801	240	0.50	0.50	0.23	0.77	0.23	0.23	0.50	0.50	9.18	6.88	10.00	8.00	23.35	545.08	42.73
43	12191	240	0.50	0.50	1.00	0.00	0.50	0.50	0.00	0.00	20.00	15.00	0.00	0.00	35.00	1225.00	96.04
44	2754	240	0.50	0.50	0.23	0.78	0.23	0.23	0.50	0.50	9.00	6.75	10.00	8.00	23.28	541.77	42.47
45	2218	240	0.50	0.50	0.17	0.83	0.17	0.17	0.50	0.50	6.98	5.24	10.00	8.00	22.40	501.78	39.34

Table C.3: Symbol sizes for 140X140 resolution

No	Area (square meters)	Resol. (pixel)	High Resol.	Low Resol.	Large Area	Small Area	Rule 1	Rule 2	Rule 3	Rule 4	Conc. 1	Conc. 2	Conc. 3	Conc. 4	Final Conc. (pixel)	Symbol Area (square pixels)	Symbol Area (square millimeters)
1	661	140	0.05	0.95	0.03	0.97	0.03	0.03	0.95	0.05	1.13	0.85	19.09	0.73	20.63	425.64	33.37
2	7674	140	0.05	0.95	0.69	0.31	0.05	0.69	0.31	0.05	1.82	20.62	6.25	0.73	26.97	727.27	57.02
3	10246	140	0.05	0.95	0.93	0.07	0.05	0.93	0.07	0.05	1.82	27.87	1.42	0.73	29.18	851.69	66.77
4	10218	140	0.05	0.95	0.93	0.07	0.05	0.93	0.07	0.05	1.82	27.80	1.47	0.73	29.16	850.28	66.66
5	7001	140	0.05	0.95	0.62	0.38	0.05	0.62	0.38	0.05	1.82	18.72	7.52	0.73	26.39	696.33	54.59
6	9405	140	0.05	0.95	0.85	0.15	0.05	0.85	0.15	0.05	1.82	25.50	3.00	0.73	28.46	809.93	63.50
7	7436	140	0.05	0.95	0.67	0.33	0.05	0.67	0.33	0.05	1.82	19.95	6.70	0.73	26.76	716.25	56.15
8	5658	140	0.05	0.95	0.50	0.50	0.05	0.50	0.50	0.05	1.82	14.94	10.04	0.73	25.23	636.61	49.91
9	1353	140	0.05	0.95	0.09	0.91	0.05	0.09	0.91	0.05	1.82	2.80	18.13	0.73	21.52	463.20	36.32
10	755	140	0.05	0.95	0.04	0.96	0.04	0.04	0.95	0.05	1.48	1.11	19.09	0.73	20.87	435.45	34.14
11	454	140	0.05	0.95	0.01	0.99	0.01	0.01	0.95	0.05	0.35	0.27	19.09	0.73	20.08	403.28	31.62
12	1144	140	0.05	0.95	0.07	0.93	0.05	0.07	0.93	0.05	1.82	2.21	18.53	0.73	21.34	455.49	35.71
13	343	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
14	345	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
15	341	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
16	341	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
17	340	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
18	352	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
19	343	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
20	330	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
21	343	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
22	340	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
23	338	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
24	348	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79
25	452	140	0.05	0.95	0.01	0.99	0.01	0.01	0.95	0.05	0.35	0.26	19.09	0.73	20.08	403.06	31.60
26	355	140	0.05	0.95	0.00	1.00	0.00	0.00	0.95	0.05	0.00	0.00	19.09	0.73	19.82	392.76	30.79

Table C.3: Symbol sizes for 140X140 resolution (continuation)

No	Area (square meters)	Resol. (pixel)	High Resol.	Low Resol.	Large Area	Small Area	Rule 1	Rule 2	Rule 3	Rule 4	Conc. 1	Conc. 2	Conc. 3	Conc. 4	Final Conc. (pixel)	Symbol Area (square pixels)	Symbol Area (square millimeters)
27	602	140	0.05	0.95	0.02	0.98	0.02	0.02	0.95	0.05	0.91	0.68	19.09	0.73	20.48	419.38	32.88
28	1095	140	0.05	0.95	0.07	0.93	0.05	0.07	0.93	0.05	1.82	2.07	18.62	0.73	21.30	453.69	35.57
29	1033	140	0.05	0.95	0.06	0.94	0.05	0.06	0.94	0.05	1.82	1.90	18.73	0.73	21.25	451.41	35.39
30	1068	140	0.05	0.95	0.07	0.93	0.05	0.07	0.93	0.05	1.82	2.00	18.67	0.73	21.28	452.69	35.49
31	6444	140	0.05	0.95	0.57	0.43	0.05	0.57	0.43	0.05	1.82	17.15	8.56	0.73	25.91	671.24	52.62
32	634	140	0.05	0.95	0.03	0.97	0.03	0.03	0.95	0.05	1.03	0.77	19.09	0.73	20.56	422.79	33.15
33	642	140	0.05	0.95	0.03	0.97	0.03	0.03	0.95	0.05	1.06	0.80	19.09	0.73	20.58	423.64	33.21
34	1575	140	0.05	0.95	0.11	0.89	0.05	0.11	0.89	0.05	1.82	3.43	17.72	0.73	21.71	471.47	36.96
35	950	140	0.05	0.95	0.06	0.94	0.05	0.06	0.94	0.05	1.82	1.66	18.89	0.73	21.17	448.38	35.15
36	4805	140	0.05	0.95	0.42	0.58	0.05	0.42	0.58	0.05	1.82	12.53	11.64	0.73	24.50	600.06	47.04
37	3387	140	0.05	0.95	0.28	0.72	0.05	0.28	0.72	0.05	1.82	8.53	14.31	0.73	23.27	541.70	42.47
38	2902	140	0.05	0.95	0.24	0.76	0.05	0.24	0.76	0.05	1.82	7.17	15.22	0.73	22.86	522.43	40.96
39	2456	140	0.05	0.95	0.20	0.80	0.05	0.20	0.80	0.05	1.82	5.91	16.06	0.73	22.47	505.01	39.59
40	3531	140	0.05	0.95	0.30	0.70	0.05	0.30	0.70	0.05	1.82	8.94	14.04	0.73	23.40	547.49	42.92
41	2609	140	0.05	0.95	0.21	0.79	0.05	0.21	0.79	0.05	1.82	6.34	15.77	0.73	22.60	510.95	40.06
42	2801	140	0.05	0.95	0.23	0.77	0.05	0.23	0.77	0.05	1.82	6.88	15.41	0.73	22.77	518.46	40.65
43	12191	140	0.05	0.95	1.00	0.00	0.05	0.95	0.00	0.00	1.82	28.64	0.00	0.00	30.45	927.48	72.71
44	2754	140	0.05	0.95	0.23	0.78	0.05	0.23	0.78	0.05	1.82	6.75	15.50	0.73	22.73	516.62	40.50
45	2218	140	0.05	0.95	0.17	0.83	0.05	0.17	0.83	0.05	1.82	5.24	16.51	0.73	22.27	495.84	38.87

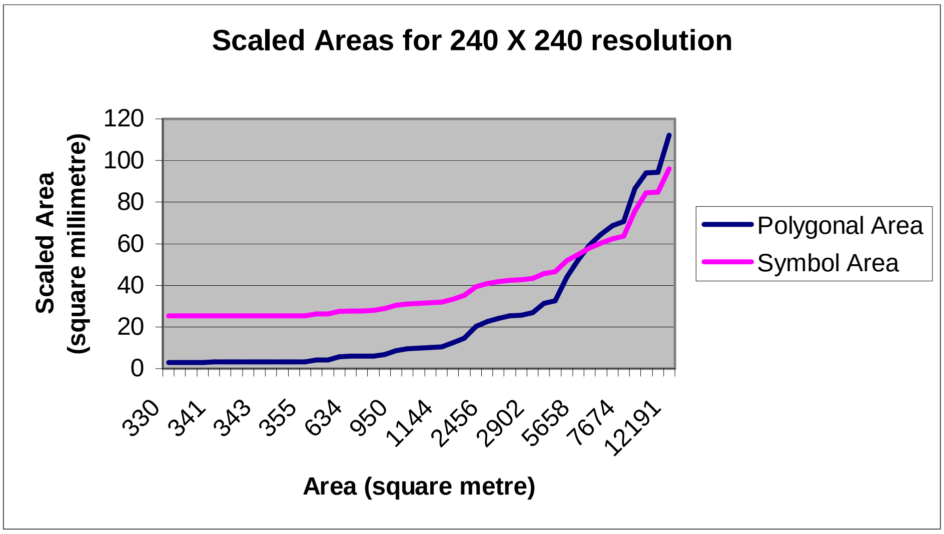

Figure C.1: The comparison of symbol area with polygonal area for 240X240 pixels

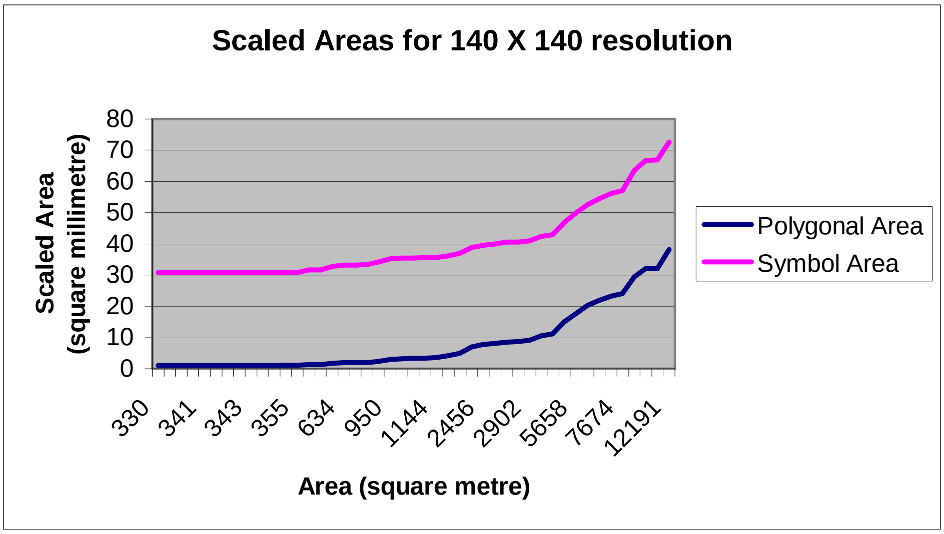

Figure C.2: The comparison of symbol area with polygonal area for 140X140 pixels

AUTOBIOGRAPHY

Ozgun AKCAY was born on 2nd July 1976 in Samsun, Turkey. He studied at primary school between 1982 and 1987, secondary school between 1987 and 1990 and high school between 1990 and 1993 in Samsun. He graduated from the Department of Geodesy and Photogrammetry Engineering at Istanbul Technical University (ITU) in 1999. He studied for a master's thesis at the Geodesy and Photogrammetry Engineering Department of ITU between 1999 and 2002. He has been working as a research assistant at the Photogrammetry Division of the Civil Engineering Faculty of ITU since 2001. During his PhD research he studied at the University of Vienna for three months and the University of Hannover for three months. He is married and has one child.