Indoor Semantic Location Models for Location-Based Services

Xin Wang, Jianga Shang, Fangwen Yu and Jinjin Yan

Faculty of Information Engineering, China University of Geosciences,
Wuhan 430074 China
lisa.xin.wei@163.com, jgshang@cug.edu.cn

Abstract

With advances in Location-Based Services(LBSs), the motivation for indoor LBSs is becoming stronger since the complexity of indoor spaces. Semantic location model is becoming a pervasive data model to face with this challenge. The hybrid semantic methods and theories are used into this model to define and manage semantic information and location information. In this paper, we analyze some semantic location models based on math and ontology methods including brief description and comparison. We also extract the characteristics of semantic information in the multilayered location model and depict their significances for indoor space LBSs. Finally, we discuss the possible directions of semantic location models for indoor space LBSs.

Keywords: *semantic location model, mathematic-based, ontology-based, multilayered, ubiquitous computing*

1. Introduction

Location model plays an important role in LBSs and provides a range of meaningful representations about topological, geometric, direction and location information which are relevant to landmarks and objects [1, 2]. It is used to capture location knowledge (like locations, distance, spatial relationship) as well as to represent and manage these information. However, in indoor space, positioning technologies provide various data related to location information, not only GNSS data for outdoor environment. How to organize and manage these data should be taken into account. And indoor LBSs, included position queries, navigation, nearest neighbor queries, range queries, depend on some semantic locations and spatial relationships [2], like POIs (Points of Interest). For these challenges, location model could act as a data model to organize this information. However, the simple location models, like geometric and symbolic location models, couldn't satisfy these changes. Consequently, researchers have investigated different modeling methods to design novel location models by some formalized descriptions or programmatic frameworks to adapt to these changes. A reasonable location model could provide valuable location information and reduce complexity of location information management. The existing well-designed location models ease the development and deployment about location applications.

Indoor space, like home, office, is becoming the main scenes for indoor LBS in ubiquitous computing. Investigations show that a person may spend around 90% of their time in indoor space on average [3]. Location information about indoor surroundings is different from common professional geo-information. Indoor LBSs need not only fundamental geo-information, but also special location information interacted with users and surroundings to understand physical world. Hence, location models for indoor space should pay more attention to acquire this special location information and excavate high level information from them. Adding semantic information into location models makes information no longer isolated, which combines different aspects of location information for LBSs [4, 5]. Therefore, researchers have been proposing semantic location model to offer suitable representations and applications for indoor LBSs.

Existing methods to build semantic location models consider many special aspects of concrete applications which need various context information. They are fused into location models as some semantic information. By reasoning techniques, this semantic could provide appropriate and intelligent LBS applications [5, 6]. Constructing semantic location model is a perfect way to combine kinds of semantic information. The goal of this paper is to show the state-of-the-art in modeling indoor semantic location models and analyzing the semantics in them. We discuss modeling methods, show lessons learned from current semantic location models and summarize the types of semantic information in the multilayered location model.

The remainder of the paper is organized as follows: Section 2 introduces semantic information of location models. Section 3 shows the semantic location models based on mathematic methods, which interpret some special spatial concepts and relationships. Section 4 shows the semantic location models based on ontology and their functions. We also explain some projects/systems and frameworks which employ these semantic location model. Section 5 describes what main semantic information contains in the layers/subspace layers of the existing multilayered location model and show. It also analyzes appropriate semantic information that takes the requirements of indoor LBSs into account. The paper ends with the future development of the multilayered semantic location model in Section 6.

2. Semantic Information of Location Models

Semantic information could enrich location models from different aspects. Considering the characteristics of spatio-temporal, there are two kinds of semantic information, named static information and dynamic information (in Section 5). They could be expressed and employed by hybrid methods, such as mathematic-based methods, ontology-based methods.

Semantic information includes spatial and non-spatial in location models. The semantic of spatial information mainly contains some physical, geometric and geographic information, such like coordinates, Euclidean distances, topology relationships. Associated mathematic-based methods could provide these semantic concepts. They strengthen the meaning of general geo-information and are applied into algorithms to realize LBS applications, like selecting paths, computing lengths, finding shortest paths. These ways could solve the semantic deficiency of fundamental geo-information. The semantic of non-spatial information mainly concentrates on context information about the real applications. It contains some additional information (like users' preference) and combines semantic web technologies. The semantic context is organized into different ontologies. Combining reasoners and defined rules, the context information could infer into high level information affiliated with location information. In duality spaces, semantic location model is also the bridge of physical space and cyber space [7]. So, in the following, we analyze functions of this semantic information in semantic location models for indoor LBSs.

3. Semantic Location Models based on Mathematic Methods

In indoor LBSs, the location models based on mathematic methods could cope with complex spatial problems, like indoor space decomposition, indoor positioning and navigation. The mathematic theories, such as algebra, set theory and graph theory, could be used to solve these challenges and improve modeling efficiency for indoor LBSs. These theories could be integrated into a programmatic framework by algorithms. No other than, the semantic location models based on mathematic methods finally combine both these theories and the programmatic framework.

3.1. Related Mathematic Methods for Semantic Location Model

Mathematic theories mostly interpret complex topological relationships (like connectivity, adjacency and inclusion). The main mathematic theories of semantic location models include Poincare Duality [8, 9], graph theory [8], hierarchy data structure [10], algebraic topology [11].

Poincare Duality, graph theory, hierarchy data structure are three main elements of NRS(Node-Relation Structure)[8]. Poincare Duality interprets topological terms by drawing a dual graph, which simplifies complex spatial relationships between 3D entities. Duality has been used in constructing DIME(Dual Incidence Matrix Encoding) or a voronoi diagram[8, 9]. The advantage of topological duality is to preserve the duality transformation. Graph theory is a branch of combinational mathematics, which can be used to define special relationships and regions, such as doors, corridors, floors, walls and stairs [8, 11, 12]. Hierarchy data structure corresponds closely to hierarchy spatial relationships reasoning and provides effective ways for representing geographic space and entities [10, 13].

Algebraic topology [11], its core element is simplex. The simplex is attached to each column of related incidence matrix and each simplex has a dimension [11]. In Euclidean space, a 0-dimensional simplex is a point, a 1-dimensional simplex is a line segment and a 2-dimensional is a triangle [11]. Consequently, a simplicial family is a finite collection $\sum$ of these simplexes [11]. Based on these, various topology relationships could be defined and applied into semantic location models.

3.2. Evaluation of Mathematic-based Semantic Location Model

Those mathematic theories are successfully applied into semantic location models for indoor LBSs. There are three typical models, that is, graph-based semantic spatial model [13], topology-based semantic location model [11] and location-exit semantic location model [14]. Understanding semantics in them is helpful to capture more rich location knowledge.

In graph-based semantic spatial model [13], it uses graph theory to decompose indoor space. The decomposed indoor space considers two important aspects of pedestrian indoor navigation. One is visibility within spatial areas and the other one is generating route description, which shows functions of semantic information [13]. Meanwhile, spatial regions partition algorithm describes navigation paths based on some semantic concepts defined in this model, such as spatial region, concave corner, boundary node. And the applications could understand various distances depending on these semantic concepts. The major difference between indoor and outdoor space is that the indoor space include many special constraints [12]. These semantic concepts also describe these constraints, like hard constraints and soft constraints [11].

In location-exit semantic location model [14], it uses graph theory and hierarchy structure to improve some navigation algorithms. The concepts of location and exit are the so-called semantic locations [14]. The exit is a boundary like doors and stairs, however, the location is an area which contains one or more exits [14]. These so-called semantic locations maintain topology relationships and distances between entities. From location--exit hierarchy, the location hierarchy defines some special semantic topological relations, like reachable semantic relation, distance semantic relation [14]. The exit hierarchy applies semantic distances in location model. The semantic distances act as weight attached to edges and also provide the other relevant information, such as Euclidean distance and the shortest distance

[14]. Combining locations and exits into hierarchy could define lemmas based on concrete situations.

On the base of location--exit semantic location model, the topology-based semantic location model uses algebraic topology to describe potential semantic relationships [11]. These relationships are based on the locations and exits. However, these locations and exits are stored in incidence matrixes [11]. And, n-ary relationships show difference between graph-based model and topology-based model, because the topology-based method could represents more than two entities, the graph-based method could only represents relationships between two entities [11]. Two fundamental kinds of semantic are semantic relationship and semantic distance. The semantic relationships express n-ary relationships and it could use connective strength and connective length information to reflect the semantic topology relations between n-entities [11]. Related algorithms could compute connective strength and length [11]. The semantic distances capture both indoor structure information and real distance information for the nearest neighbor queries between entities. This enhances semantic information of relationships between different entities for indoor space applications.

The three typical semantic location models based on mathematic methods are used into navigation applications for indoor space. These semantic location models need mathematic theories and mainly concentrate on topological spatial relationships to indoor location applications by algorithms. The majority of these methods solve semantic extension through algorithms, but the semantic ignores interaction with real users. At last, we made a comparison according to the three semantic location models from semantic characters, concrete applications, algorithms (see Table1).

Table1. Comparison of the Three Semantic Location Models based on Mathematic Methods

name of model	semantic characters	application	typical algorithms
graph-based semantic spatial model [11]	semantic distances	visibility within spatial navigation route description for navigation	spatial regions partition
location-exit semantic location model [13]	semantic topological semantic distances	shortest path query nearest neighbor search	find the shortest path in graph extract CEH from exit hierarchy
topology-based semantic location model[12]	semantic relationship semantic distance	position query nearest neighbor query range query navigation	computing connective strength computing connective length computing the importance of exits

4. Semantic Location Model based on Ontology

General speaking, in ubiquitous computing, context expresses a state of entities, like users and interactive objects with users[15], which could reflect some spatial/location information associated with entities around our daily life. The semantic of these spatial/location information aims at developing indoor LBSs with enhanced functionality. The ontology-oriented modeling approach is also a semantic way of organizing context, which shares context knowledge and improves advanced reasoning capabilities. Ontology could represent and process contexts, the related knowledge and adaption rules [16]. Developers could not only define some domain, application, task ontologies but also reuse some shared ontologies. Meanwhile, by reasoning engines, the spatial rules based on corresponding ontologies could acquire higher context knowledge [17], such as some latent location information, the relationships between entities. At last, the whole infrastructure could be combined into the ontology-based semantic location models by the hybrid semantic technologies.

4.1. Ontology Function Analysis in Semantic Location Model

In indoor LBSs, there are two essential purposes about ontology-based location models. The first is about consistency check for relationships in ontologies. These relationships are about classes and instances. The consistency check could automatically detect availability about ontologies [18]. Hence, it is easier to check consistency of location and spatial relations between different objects. The second is to recognize instances of basic context data and relationships which reveal some more abstract context characteristics (*e.g.*, recognize the potential spatial relationship of the users) [18]. The instances are mapping into the classes/properties in ontologies. The interactions between instances reflect users' activities to improve indoor LBSs.

With actual location models, traditional 3-D visualization and modeling tools, like Sketch Up, AutoCAD, Skyline, are using a pile of polygons to render location models, but little meaning in semantic knowledge [19]. However, applying some algorithms and reasoning analysis need some special geo-information with some semantic knowledge, like route knowledge, distance knowledge. Combining with the software engineering, like Object-Oriented Analysis methods and Object-Oriented Programming paradigm [18], ontologies define classes and instances to model the relations of part-of and is-a through rules [16], which could reuse these conceptions in software engineering to make analysis and reasoning. Therefore, researchers have been concentrating on the ontology-based semantic location models for several years.

4.2. Evaluation of Ontology-based Semantic Location Model

In ontology-based semantic location models, context information takes into account most semantic meanings (*e.g.*, positioning techniques, users and surroundings) into the models. We would show some typical location models used ontology engineering methods.

In LOC8 framework [20, 21], context information is fused into the location model. The whole framework contains three models, named context model, sensing model and space model. They are expressed by ontologies, which provide API to describe and apply context information into the location-based services [21]. Space model has three classes named SymbolicRepresentation, GeometricRegion and RelativeLocation. Context model attaches additional information to enrich location data for intelligent LBSs. And then, sensing model maps location information about entities (*e.g.*, persons, positioning tags and wireless devices) into space model by relative points and regions. OWL serves as an expressive language to describe the three ontologies. Ontology attributes could build up relationships between entities and surroundings. With the help of ontology modeling tools, protégé could efficiently build the three ontology models. In particularly, these ontology models could combine rules based on points and regions to infer location information from abstract context level, and OWL API based on Java develops programs to optimize this context knowledge. At last, the framework provides programmatic interfaces for LBSs.

In some smart/intelligent and navigation systems, researchers also discover that location is the most valuable information to promote smart services, and location models could efficiently organize these location information. They use semantic web methods to build corresponding location models in the following state:

(I)OntoNav is a semantic indoor navigation system and an ontological framework of handling routing requests [22, 23]. User Navigation Ontology (UNO) and Indoor Navigation Ontology (INO) are Knowledge Models in OntoNav [22, 23]. UNO reuses and extends some concepts of exiting ontologies [23], like GUMO [24]. INO develops based on description of path elements, like corridors, junctions, stairways [23]. Based on UNO and INO, path-selection rules described by SWRL (Semantic Web Rule Language) could discard some paths which are not physical accessible for users, and identify paths which match users preferences[23].

(II)Smart hospital project presents a semantic model, mechanisms and a service to locate mobile entities [25]. There are physical location, semantic location and atomic location in its semantic location model [25]. Physical locations specify positions of mobile entities and are characterized by different granularities and scopes, depending on the particular positioning system. Semantic locations are identifiers of some locations like floor, door, meeting room. One semantic location is grouped by a set of physical locations. Atomic locations are the link between physical locations and semantic locations. Atomic location dimension is based on the best granularity from the positioning techniques in the current area. When introduce a new positioning system, this location model could adapt to these changes easily by the three special locations. In this project, the ontologies and the defined SWRL rules are used to infer knowledge from the sensing conditions and insure the consistency of the whole system [25].

Aforementioned semantic location model both use ontology engineering methods and show advantages for expressive representation and reasoning. However, ontology maintenance is a difficult problem. Dynamic environments are typical characteristics in ubiquitous computing. Researchers should pay more attention to strategies that maintain ontology consistency. Sharing knowledge also generates some information security problems. So, researchers should consider it from both developers and users. We also show the comparison between the three models from usage of ontology and the rules for location applications in Table2.

Table 2. Comparison of the Three Semantic Location Models based on Ontology

name of model	usage of ontology	the rules for location applications
LOC8 framework[16,17]	space model ontology context model ontology sensing model ontology	spatial relationships rules
OntoNav[18,19]	user navigation ontology indoor navigation ontology	path-selection rules
Smart hospital project[21]	entities ontology semantic locations ontology physical locations ontology	sensing areas rules

5. The Multilayered Semantic Location Model

Recently development in the field of location models have given a rise to an interest in the multilayered location model [25, 26]. This model implicitly embodies some physical space and cyber space fusion theories, which represents the development of location models. We focus on semantic information in the multilayered location model and analyze the semantics from static information and dynamic information in this location model. These could improve the visualization ability and analysis ability for indoor space location-based applications.

5.1. Structure of the Multilayered Location Model

According to the types of context, the multilayered location model could be divided into layers, which decreases modeling complexity. T. Becker [25, 26] studies joint state, N-partite graph, NRS [8, 9] to decompose space and construct the multilayered location model. Based on NRS, whole space is divided into different layers. Every layer transforms primal space into dual space by Poincare Duality [8, 9]. Besides, joint edges which are from joint state conception combine separate layers together. Finally, total parties form N-partite graph and realize the model from conception perspective.

Based on these theories, the multilayered location model for indoor space LBSs is constituted by three main layers named physical space layer, logical space layer and additional space layer [26, 27]. The physical space layer could deeply be divided into some subspaces according to physical surroundings and space relationships, like topographic space layer, topographic subspace layer, sensor space layer. The logical space layer is based on logical conditions or semantic conditions, like accessibility condition, safe condition. The additional space layer has a fine scalability for model expansion, which is added by different concepts and semantics.

5.2. Semantic Information in the Multilayered Location Model

In the multilayered location model, semantic information could commendably improve its visualization ability and analysis ability to realize links between different layers/subspace layers. According to the characteristics of spatio-temporal, semantic information in the multilayered location model is divided into static information and dynamic information. The static information commonly describes the inherent features and functionalities about entities, which would not change with spatio-temporal changes. On the contrary, the dynamic information represents actions, states, roles, processes and strategies about entities, which would cope with spatio-temporal change. These two kinds of semantic information are conducive to expand location information, and then, real time information could be flexibly analyzed by this enriched multilayered location model. The Figure 1 shows some clear meanings of this semantic information. In Figure 1, A contains some relative static topographic information since the whole structure of rooms would not change. The sensing areas in B may change with condition of the Aps (Access Points). The route of C is formulated by the characteristics of the pedestrians. The D is constructed according to the special additional conditions, like happening fire.

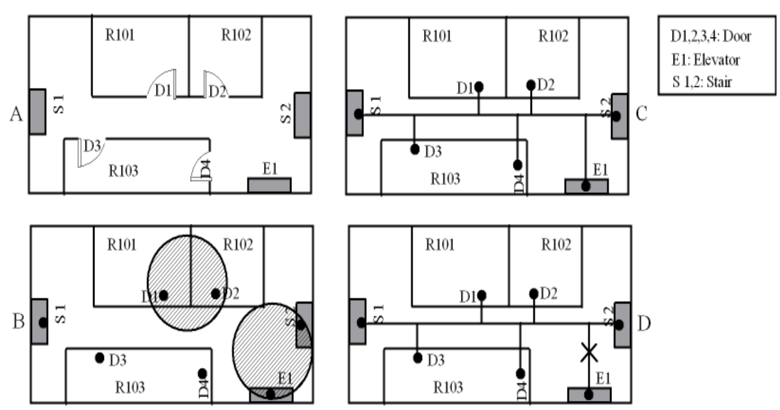

Figure 1. Subspace Layers of the Multilayer Semantic Location Model. A is the Topographic Space Layer. B is the WiFi Sensing Layer, the Shadow Areas are the AP Sensing Areas. C is the Pedestrian Navigation Layer, the Doors and Exits could be connected in the Navigation Network. D is the Fire Protection Layer, the E1 in D is an Unavailable Exit under the Condition of happening Fire. A and B is belong to *Physical Space Layer*. C is belong to *Logical Space Layer*. D is belong to *Additional Space Layer*

Links between subspace layers which is shown in the Figure 1 would be perfected by static and dynamic semantic characteristics. With the multilayered semantic location model framework, sensor coverage is one type of semantic information and could act as a standard of dividing sensing space layer in the main physical space. Therefore, links between topographic space layer and sensor space layer could realize by mapping sensor covering range into topographic space. In logical space, pedestrian space layer could be compartmentalized logical areas for walkers by pedestrian semantic characteristics. In this pedestrian logical subspace layer, navigation topology relationship could link with topographic space layer to acquire most adaptive topology information for walkers in this environment. In a manner, these space layers and semantic mechanism could realize the fusion of different space layers.

5.3. Evaluation of the Multilayered Semantic Location Model

The multilayered semantic location model has special advantages that each layer could maintain independency. When sensor coverage has changed, sensor layer should response to this change, however other layers may not immediately react to this change. This could reduce mutual influence and couple with each other layers to keep stable structure for multilayer location model.

The main purpose is to design a unique multilayered semantic location model and provide a programmatic framework for indoor space LBSs. The multilayered semantic location model could satisfy these requirements. However, this location model needs synthetical techniques and theories. The mathematic-based, ontology-based and other methods could combine in this model to realize our novel multilayer semantic location model for indoor LBS applications. In this process, there are many problems and contradictions between conceptual mode and real model. Maybe, some thoughts of conceptual model are inappropriate for real model, so we need find some tradeoff methods to eliminate these.

6. Conclusion

This paper presents different semantic location models or relevant projects. Existing location models for indoor space differ in theories, design, structure and techniques. Analyzing each semantic location model could find different semantic requirements and capture high location knowledge about LBSs. The multilayered semantic location model contains semantic information integrated various context information around ubiquitous computing environment, which is about location, topology relationships and distances. Those information are acquired from some positioning sensors and reasoning rules to express the states of entities and provide services for indoor LBSs.

In this study, semantic location models concentrate on locations, users and entities interacted with concrete environment. Divided structure of the multilayered semantic location model could be expanded easily by adopting some mathematic algorithms and ontology expression to display semantic functions. Meanwhile, fusing semantic information into location model is an essential requirement for context-awareness and location-awareness applications in ubiquitous computing.

Semantic location model is a data model for indoor space LBS applications. In the future, our purpose of this research is to build perfect multilayered semantic location model that employ these semantic methods for indoor LBSs. What this study needs are in the following:

- Analyses of mathematic methods, semantic techniques, semantic information of indoor space are the key elements for building semantic location model.

- Under the background of indoor space for ubiquitous computing, how to formulate the layers and analyze the characteristics of different layers are worth of exploring.
- Mining semantic information and considering methods of fusing this information into indoor location model could solve the combination between physical space and cyber space.
- Based on the multilayered location model for indoor space, designing and developing context model engine could provide interfaces for LBSs applications.

The discussion of these shows that semantic information enriches location knowledge for LBSs. Finally, this information could be formalized and organized by semantic location models. The development of semantic location models also simplify location/spatial knowledge and combine physical world and cyber world to realize smart location services for life.

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Authors

Xin Wang is current a postgraduate at Faculty of Information Engineering, in China University of Geosciences(Wuhan). She received her Bs. from the University of the Three Gorges in 2011. Her research interests are about context-awareness and location-awareness computing. She concentrated on semantic web and ontology engineering. She is also an IEEE Graduate Student Member and China Computer Federation member.

Jianga Shang is an associated professor in China University of Geosciences. He got his B.S. and MS. in China University of Geosciences(Wuhan). And now, he is studying in Huazhong University of Science and Technology for PhD. His research is about ubiquitous computing which relates context-awareness, location-awareness, location techniques, and location-based services.