Using Semantic Web Technology for Ubiquitous Location and Situation Modeling

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Abstract
We use semantic web technology to utilize the world wide web for a large-scale ubiquitous (qualitative and geometric) location model, in order to achieve shareability and extensibility at low operational cost. Our intention is to model location and user characteristics, in order to realize location aware applications with a focus on pedestrian navigation in buildings and situated user interaction. We present the ubiquitous symbolic location and situational context model *UbisWorld* and the tool *Yamamoto* for the modeling of hierarchical geometrical maps.

Keywords: Semantic Web, Hybrid Location Model, Ubiquitous Computing, Pedestrian Navigation, Situated Interaction.

1. INTRODUCTION

Imagine yourself being a traveler in the near future, and a breakpoint in your journey brings you to Frankfurt airport, where you have to find your way from the arrivals to the departures terminal. You feel uneasy because you are in an unfamiliar envi-ronment and decide to use your smartphone to guide you directly. In this situation, any interaction with the device aside from listening to navigational aid is difficult and distracting. Once you have checked in, you are in a completely different situation and have some time to spend before boarding and are likely to adopt location based services like a shopping assistant (Stahl, et al., 2004).This introductory scenario outlines a ubiquitous pedestrian navigation system that works in buildings as well as outdoors, and in which the user interface adapts the presentation of audio and visual media output to situational parameters, to better suit a user (Wasinger, et al., 2003). The situation relates to the users' personal characteristics, the available resources of the device being used for interaction, and the environmental context. Since our main research interest is in the design of intelligent user interfaces within ubiquitous computing environments, we have implemented several experimental pedestrian navigation systems in order to explore the opportunities of novel user interfaces, such as 3D animations on stationary information kiosks or multi-modal interaction on mobile devices (see section 2 for details). The used location models however have been proprietary and limited to a specific domain. In this paper, we wish to present a ubiquitous location model that allows for positioning, generating navigational aid and map visualization as well as for describing spatial situational context. It inherits the World Wide Web's shareability, extensibility and low operational cost by means of Semantic Web technology. The idea behind the *Semantic Web* (Fensel, et al., 2003) is to annotate documents in the World Wide Web (WWW) with semantic information by the use of ontologies, a standardized vocabulary referring to real-world semantics enabling automatic and human agents to share information and knowledge. Current search engines are limited to a syntactical analysis of the content of their indexed pages. Since it is hard for a machine to understand the meaning of graphical and textual information found on a website, languages like RDF[1] have been designed to allow the author to declare the page contents as resources. Statements can be included in order to describe the semantics and relationships between resources using an ontology. By doing so, the Web may be used in the form of a very large distributed knowledge base. In the next sections we present related work, motivate a hybrid symbolic and geometric location model, and present our design approach for such a model. In the last sections we present the components that we have developed in more detail, that is the symbolic world model *UbisWorld* and finally the geometric map modeling tool *Yamamoto*.

[1] Resource Description Framework (http://www.w3c.org/RDF/)

2. PEDESTRIAN NAVIGATION IN BUILDINGS

Today you might associate pedestrian navigation with a PDA and GPS receiver together with some routing software, which may even include additional POI information. However, these products are intended to be used as a reasonably priced car navigation solution, and their user interface and geographical database closely resembles the built-in navigation systems. On the other hand, there are GPS receivers with built-in map visualization designed for navigation on sea or hiking, some allowing for customized maps and routes. For indoor pedestrian navigation, there are commercial positioning infrastructures like *Ubisense*[2] and *Ekahau*[3] available, that allow the tracking and visualization of tags and PDAs. They also provide interfaces for the design of location based services, but do not serve navigational aid to the user.

2.1 Recent Work

There has already been significant work done on navigational guides and pedestrian navigation systems in recent years (Cheverst, et al., 2000; Long, et al., 1995; Not, et al., 1998), and also on the use of automatically generated maps in navigation tasks (Berendt, et al., 1998; Klippel, et al., 2004). Systems like *Cyberguide* (Abowd, et al., 1997) or *GUIDE* (Cheverst, et al., 2000) provide visitors with up-to-date and context-aware information whilst exploring a city. A more recent project *LoL@* (Popischil, et al., 2002) was designed for UMTS (Universal Mobile Telecommunications Systems) technology and implements a tourist guide for users in the city of Vienna. In the project *REAL* (Baus, et al., 2002), we have focused on developing hybrid indoor-outdoor pedestrian navigation systems. A stationary information kiosk has been implemented to provide the user with resource adaptive navigational aid in buildings, presented as an animation through a virtual 3D model of the building. Besides the kiosk, the *BMW Personal Navigator* (Krüger, et al., 2004) is a handheld system based on the Pocket PC hardware platform. Its *M3I* (mobile multi-modal user-interface) architecture allows the user to interact through the combined use of speech and stylus gesture (Wasinger, et al., 2003) to overcome the limitations of the small screen size of the PDA. The mobile system locates itself outside buildings using a GPS receiver, while indoors the environment has been instrumented with infrared and RFID beacons. We have chosen commercially available street data (*Navtech Navstreets Street Data Preminum Germany*). For the graphical visualization and route finding, we have used the open source GIS (*GRASS version 5.0*) with some custom shell scripts and components. In addition to the street segments, indoor path networks have been acquired by scanning architectural plans, importing them as bitmap layers, and drawing the path network over the bitmap backgrounds.

Fig. 1: The BMW Personal Navigator.

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[2] http://www.ubisense.net

[3] http://www.ekahau.com

2.2 Positioning, Routing and Navigational Aid

Pedestrian navigation requires positioning of the mobile device by some tracking technology, route finding within the environment and finally the generation and presentation of situated navigational aid for the user.

For indoor positioning, there exists a range of solutions. Specialized GPS receivers may be able to pick up a weak satellite signal even inside of buildings. Radio-based positioning technologies evaluate the received signal strength of an existing communication infrastructure like IEEE801.11 WiFi access points or GSM/UMTS antennas. The position of the device is estimated either by looking up a map of point samples (see *RADAR* by Microsoft Research (Bahl and Padmanabhan, 2000) or *Ekahau*) or by triangulation between the locations of the base stations (mobile phones). For increased resolution, the environment may be instrumented with infrared or RFID technology in two opposing approaches. Either beacons emit a position code (e.g. *Cool-town* (Kindberg, et al., 2002) or *RADAR*), or multiple receivers are used to pick up an identification signal emitted from the user (e.g. *Active Badge* (Want, et al., 1992) or *Ubisense*).

Routing also poses new challenges, since pedestrians are not bound to follow paths or streets. Instead they usually walk directly towards their goal, crossing places and lawns where it is possible. The route planning component should reflect this and provide shortest paths within arbitrary spaces. This requires new algorithms and modeling the actual shapes of streets and sidewalks rather than abstracted centerlines.

The systems' overall purpose is to convey navigational aid to its user. Current mobile computing devices offer a large design space for user interfaces by providing various interaction modalities, such as vision, speech and gesture. Research conducted by (Baus, et al., 2002; Höllerer, et al., 1999; Kray, et al., 2003) has explicitly stressed the importance of landmarks, 3D-graphics, and multimodal interaction. However, considering the highly situated nature of interactive devices, there is no single user interface design to best fit all situations. Besides personal preferences, the interaction with a mobile system depends on the context of the surrounding space, see (Dix, et al., 2000). For example, technical resources like network bandwidth or display resolution play an important role, but also the presence of other devices and users. Hence we wish to design intelligent user interfaces that adapt to their context through a notion of location.

2.3 From Ubiquitous Navigation to Location Based Services

The notion of location is not only of interest for navigational assistance, but for any mobile application. In comparison to location, date and time are already deeply integrated in all kinds of computing devices, and we take simple alarm functionality or even complex organizers for granted. Any information, from voice messages in answering machines to the files in our computer, are indexed by date. The location model of a pedestrian navigation system has the potential to provide a schema to geo-reference any information, and significantly ease the development of location based services. For example, the *Geonotes* (Persson, et al., 2001) project allows the virtual annotation of physical locations, so called 'digital graffiti'. The *Stick-e Notes* (Brown, et al., 1997) and *CybreMinder* (Dey and Abowd, 2000) support context-aware reminders that are triggered at certain locations. The *DealFinder* (Chan, 2001) is an application that presents location-specific shopping assistance.

3. MOTIVATION FOR A UBIQUITOUS HYBRID LOCATION MODEL

We desire a location model that supports the generation of visual and verbose navigational aid within indoor environments and the representation of situational context. In this section, we discuss requirements, previous work and motivate our own modeling languages and tools.

3.1 Requirements for a Location Model Space

Outdoors, geographical features are best modeled using the *WGS-84* spatial ellipsoidal coordinate system, since GPS is used for positioning. Indoors, local metric Cartesian coordinate systems are more convenient to model buildings and locations according to ground plans or own measurements. Sometimes it is also practical to use pixel coordinates of a digital image. At least every local system can be transformed into another by the specification of three reference points. Abstracting from the earths' curvature, this also holds for the *WGS-84* system.

In order to provide navigational aid, Cartesian coordinates are simple to visualize in maps. However, often verbose directions are preferred. In this case we have to use a symbolic vocabulary instead of coordinates in order to denote locations. Distances and angles have to be described in adequate natural language by spatial relations of distance and direction. In a multi-level building environment, symbolic vocabulary is also better suited to describe a location than geographical coordinates given in longitude and latitude, even with precise height in meters. So it is not only for verbalization, but for a meaningful expression of location in general that we propose terminological knowledge to refer to physical or logical entities like rooms, wings of a building and places. Such a symbolic (or qualitative) location model is further useful as an index from which we can infer the overall context influencing the mobile application (Dix, et al., 2000). We wish to express the state of the infrastructure, other devices and users in one coherent database. In particular, qualitative spatial relations of containment and neighborhood are useful for querying situational statements about the surrounding space. In conclusion we need both, a geometrical and a symbolical (or qualitative) location model, with strong interrelationship.

3.2 Related Work on Hybrid Location Models

Symbolic and geometric location models are discussed in (Leonhard, 1998), and a hybrid model is proposed in his work. The aura location indentifier *ALI* (Jiang and Steenkiste, 2002) is based on hierarchical subspaces and is used to realize a space service to handle spatial queries based on a relational database. In order to express complex containment relationships between rooms to wings and floors of a building, (Dürr and Rothermel, 2003) suggest a lattice instead of a tree structure to model hierarchical symbolic locations.

The *Geography Markup Language 2.0* (GML, 2001) by *Open-GIS* is an XML encoding for the transport and storage of geographic information, including both the spatial and non-spatial properties of geographic features. It is open and vendor neutral and supports specialized domains and enables the creation and maintenance of linked geographic application schemas and data-sets. However the geometric modeling is limited to so called “simple features” in two dimensions, it only provides vector data, and is not sufficiently expressive to explicitly model topology.

In the geographic information sciences, there is also work related to symbolic location models and the Semantic Web. The concepts of relation-based systems concerned with the qualitative representation of spatial knowledge are discussed by (Papadias and Sellis, 1994), as well as symbolic spatial indexes. Egenhofer envisions a semantic geospatial Web (Egenhofer, 2002), where multiple spatial and terminological ontologies, each with a formal semantics, allow for the processing and evaluation of geospatial queries based on the match between the semantics of the expressed information need and the available semantics of the information resources and search systems.

3.3 Ubiquitous Modeling

We wish to design a location model, that aside from its core functionality for navigation also provides a common notion of location to mobile applications. This requires a standardized and structured vocabulary referring to real-world locations that allows for spatially indexed information and the exchange of positions between a variety of applications.

Such knowledge has already been compiled and published, like the *Getty Thesaurus of Geographic Names On Line* [4]. It contains more than one million names and other information about places. The TGN includes all continents and nations of the modern political world, as well as historical places. It includes physical features and administrative entities, such as cities and nations. However the emphasis in TGN is on places that are important for art and architecture, and the model is limited to the level of inhabited places.

For a commercial provider, the collection and maintenance of a extensively detailed location model is an expensive and risky investment. But this task could also be carried out by a voluntary user community, as the *Wikipedia*[5] project has successfully demonstrated in the domain of encyclopedic knowledge. The required information on states, towns and streets is public and any submitted information can easily be reviewed by local residents; there is no expert knowledge required. This also holds for the geometric modeling of building environments, since architectural drawings are mandatory and accessible at least to the owner of the building. There is already similar work in progress. The *Project OneMap* (Misund, et al., 2004) at Østfold

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[4] http://www.getty.edu/research/conducting_research/ vocabularies/tgn/index.html

[5] http://www.wikipedia.org

University College aims to create an open world map based on submissions of free geodata in a peer review process. The geographical features are represented in layers of global extend. They are stored in GML files on a distributed repository as sheets at different scale and level of detail. The world map can be browsed and edited by a graphical Web interface based on *Scalable Vector Graphics* (SVG). This is a good example on how the World Wide Web can provide for shareability and extensibility at low operational cost. Once an organizational framework provides modeling languages and tools, the location model is ready to grow and provides a basis for a pedestrian navigation system.

3.4 UbisWorld and YAMAMOTO

We have outlined the requirements for a ubiquitous location model and presented an idea on how it could be realized, even at the desired high level of detail. Yet fundamental questions remain to be solved. Besides the organizational issues, we have to define the details of a modeling language and supporting tools. In the remainder of this paper, we will present our current experimental work, which aims towards a working prototype of a ubiquitous situation-aware pedestrian navigation system, based on an indoor positioning infrastructure.

The *UbisWorld*[6] database has been designed to model and query the characteristics of a user, including their activity, as well as environmental context. It also provides a symbolic spatial model to express location. *UbisWorld* is presented in section 4. In order to associate the spatial vocabulary of *UbisWorld* with real-world coordinates (as supplied by a GPS receiver), we develop the *YAMAMOTO* tool, which is presented section 5, for the creation of a hierarchical geometrical spatial model. This model represents real-world places at different granularities as resources in the World Wide Web. The geometrical model is joined with *UbisWorld* by uniform resource identifiers (URIs) (RFC2396, 1998) as location identifiers.

4. UBIS WORLD

UbisWorld can be used to represent some parts of the real world like an office, a shop, a museum or an airport. It represents persons, things and locations as well as times, events and their properties and features. *Situational Statements* (Heckmann, 2003) describe the state of the world in sentences made of a subject, predicate and object. The vocabulary is provided by concepts, instantiated individuals and relations. An underlying ontology defines classes and predicates, such as a taxonomy of physical things, user characteristics and activities, and places at different levels of granularity, like city, building or room. It is also possible to express spatial topological relations like inclusion, see figure 2.

The concept of situational statements provides for the flexibility that is needed to model any situational context that might be relevant to a specific ubiquitous computing application. In particular it is possible to model various properties of spatial elements, such as room-temperature, noise-level or humidity. The default ontology can easily be extended to specific domains. Additionally, the presence of persons and physical objects can also be expressed and visualized. Figure 3 shows the current situational context of room 124 in the computer science building 36 at our university.

The goal of *UbisWorld* is to provide a flexible Web-based model, that can be inspected by the user through a convenient user interface, as shown in figures 2 and 3, and accessed by applications using Semantic Web technologies. The current implementation stores the situational statements in a relational database for performance reasons. Several export modules allow to represent query results in various Semantic Web languages.

4.1 Representing Situational Statements in RDF

In this section we will show by a simple example how *UbisWorld*, particularly the part of the symbolic location model, can be made available on the Web by representing it in the Semantic Web language RDF. *Situational Statements* represent partial descriptions of situation within the ubiquitous world model, like user model entries and context information, but also spatial knowledge. The information is expressed by a sentence made of subject, auxiliary, predicate and object. It is enriched with a predefined hierarchy of meta level information as shown in figure 4 to express "who is responsible for this piece of information", or "what is the confidence value for it". Furthermore the basic information content is enriched with temporal and spatial constraints like "this property holds between now and tomorrow".

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[6] The Web Site for UbisWorld is www.u2m.org/ubisworld.htm

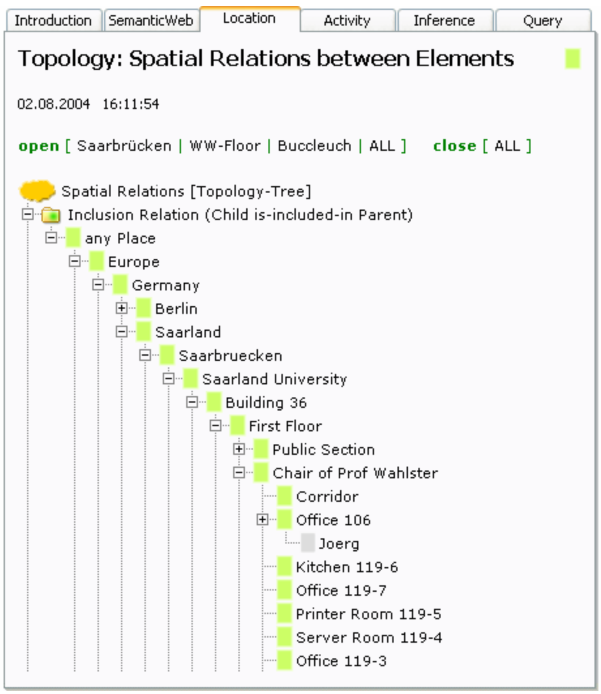

Fig. 2: Browsing nested instances of location categories.

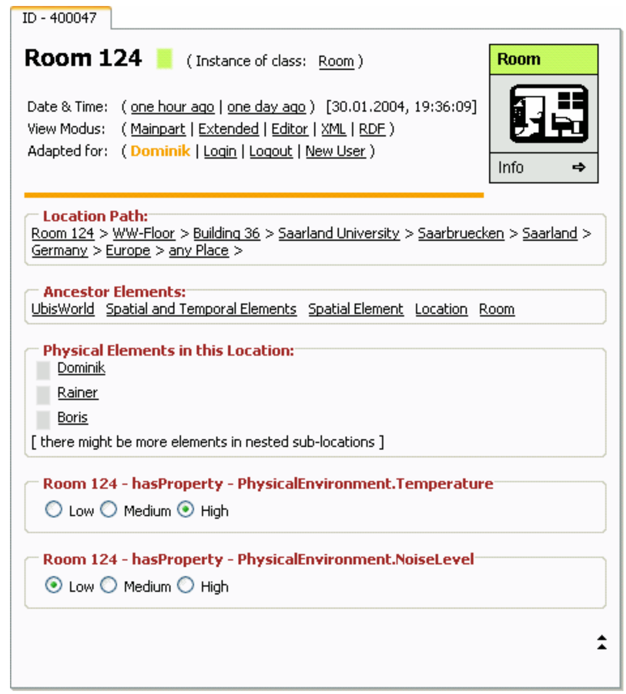

Fig. 3: Properties of a room, as represented in *UbisWorld*.

The Resource Description Framework (RDF) (Manola and Miller, 2004) is based on the idea of identifying things using Web identifiers (called *Uniform Resource Identifiers*, or *URIs*), and describing resources in terms of simple properties and property values. RDF is intended for situations in which information on the Web needs to be processed by applications, rather than being only displayed to people. RDF provides a common framework for expressing this information so it can be exchanged between applications without loss of meaning.

In our example, we use RDF to express that the city of Berlin is located in Germany. First we have to create Web resources to represent the spatial vocabulary of our ontology, then we can use them to represent *Situational Statements* by RDF statements.

Now lets have a look on the code listed in figure 5. To represent RDF statements in a machine-processable way, RDF uses the eXtensible Markup Language (XML), so we enclose our code in an XML tag. Next, we create a RDF element and declare namespaces as abbreviations for the full URIs of predefined elements, such as RDF-Schema and UbisWorld. In the next code section, we create Web resources for the two spatial concepts of a country and a city and classify them as subconcepts of a general location. RDF is based on the idea of expressing simple statements about resources, where each statement consists of a subject, a predicate, and an object. In our example, the subject is the new resource *Country*, the predicate is the *subClassOf* predicate defined by the RDF-Schema (RDFS) language extension, and the object refers to a previous definition of *Location*. We also add a label and an encyclopedic description to our new resources. Now we create Web resources to represent Germany and Berlin, and state that they are instances of the *Country* and *City* classes by RDF triplets like "*Germany* has a *type* whose value is *Country*".

Figure 6 shows the RDF representation of the situational statement "Berlin is located in Germany". We use the *Inclusion* relation given by UbisWorld and define some meta information for this statement, such as the creator is Christoph Stahl, and since the statement represents a well known fact, we set the confidence level to the maximum value.

In practice, we do not have to create the ontology from scratch. The *IEEE Standard Upper Ontology Working Group*[7] has already defined terms for countries, regions and geography.

[7] http://suo.ieee.org/

```
<?xml version="1.0" encoding="UTF-8" ?>
<!-- Namespaces -->
<rdf:RDF
xmlns:rdf = "http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:rdfs = "http://www.w3.org/2000/01/rdf-schema#"
xmlns:dc = "http://purl.org/dc/elements/1.1/"
xmlns:s = "http://u2m.org/2003/rdf-situation#"
xmlns:u2m = "http://u2m.org/2003/rdf-ontology#" >

<!-- Ontology: Classes -->
<rdfs:Class rdf:ID="Country.300003">
<rdfs:label>Country</rdfs:label>
<rdfs:subClassOf rdf:resource="#Location.300040" />
<u2m:identifier>300003</u2m:identifier>
<dc:description>politically organized body of people under a single
government </dc:description>
</rdfs:Class>

<rdfs:Class rdf:ID="City.300005">
<rdfs:label>City</rdfs:label>
<rdfs:subClassOf rdf:resource="#Location.300040" />
<u2m:identifier>300005</u2m:identifier>
<dc:description>a large and densely populated urban area; may include
several independent administrative districts </dc:description>
</rdfs:Class>

<!-- Instances -->
<rdf:Description rdf:ID="germany.400002">
<rdf:type rdf:resource="#Country.300003" />
<rdfs:label>Germany</rdfs:label>
<u2m:identifier>400002</u2m:identifier>
</rdf:Description>

<rdf:Description rdf:ID="berlin.400006">
<rdf:type rdf:resource="#City.300005" />
<rdfs:label>Berlin</rdfs:label>
<u2m:identifier>400006</u2m:identifier>
<dc:description>Berlin is the capital of the federal republic of Germany
</dc:description>
</rdf:Description>
</rdf:RDF>
```

Fig. 5: RDF code example for spatial concepts and instances.

```
<!-- Situational Statement -->
<rdf:Description rdf:ID="statement1026">
  <s:subject>berlin.400006 </s:subject>
  <s:auxiliary>hasProperty.600100 </s:auxiliary>
  <s:predicate>inclusion.800200 </s:predicate>
  <s:range>SpatialObject.400000 </s:range>
  <s:object>germany.400002 </s:object>
  <s:creator>christoph_stahl.210113 </s:creator>
  <s:evidence>general knowledge </s:evidence>
  <s:confidence>1.00 </s:confidence>
</rdf:Description>
```

Fig. 6: Situational Statement "Berlin is located in Germany."

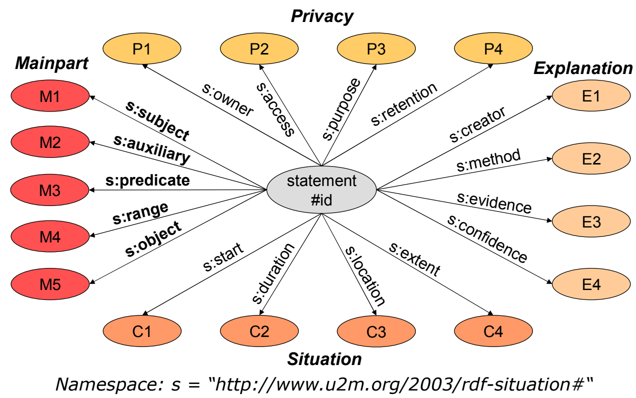

Fig. 4: The structure of Situational Statements in *UbisWorld*.

4.2 Integrating the Symbolic Model and Physical Dimensions

In order to represent not only the logical structure, but also the physical dimension of the environment, the symbolic model has to be supplemented by geometric information on the spatial entities. This knowledge is essential to associate locations with coordinates, e.g. for pedestrian navigation systems. We identify the symbolic locations and also the geometrical models as Web resources, and represent their relationships using RDF statements, as shown in figure 7. The geometry is represented in various granularities, higher-level entities are refined by more detailed models, using local coordinate systems. The next section describes the hierarchical structure in more detail.

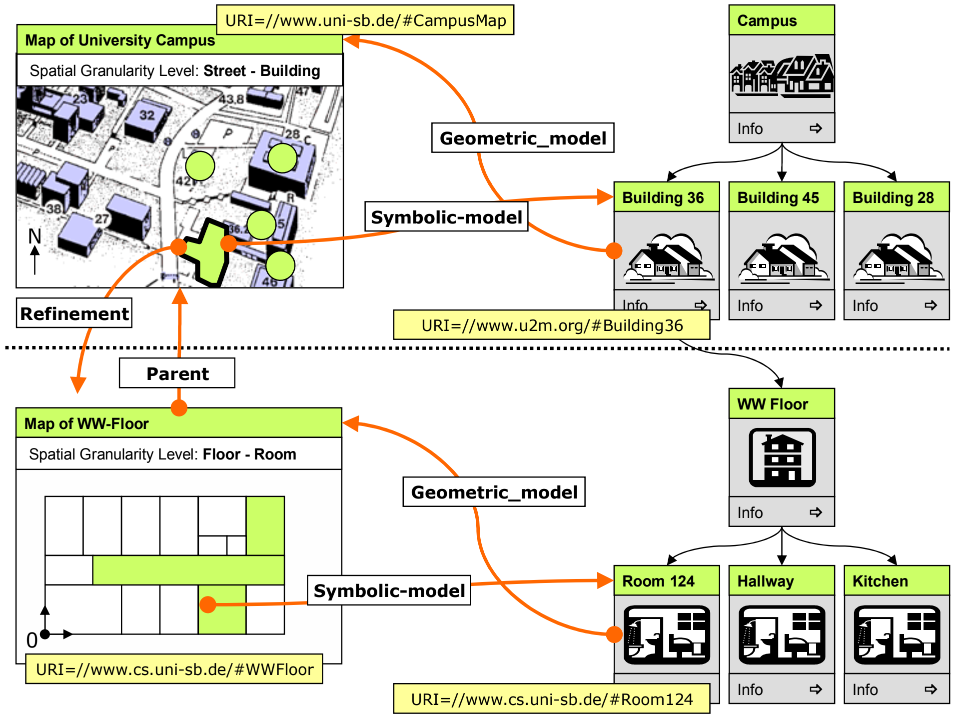

Fig. 7: Integration of geometric and symbolic models by URIs into a hybrid location model.

5. YAMAMOTO MAP MODELING TOOL

YAMAMOTO[8] is designed to create a hybrid symbolic and geometric location model for pedestrian navigation systems, with strong a emphasis on positioning and route finding. It addresses scalability and operational overhead of such a model by the use of Semantic Web technology, such as XML and RDF, instead of a dedicated server infrastructure. In the first section, we outline the concept of distributed hierarchical refinements and the resulting benefits. The next section describes the geometrical modeling process, and the final section discusses the symbolic annotation in more detail.

5.1 Distributed Hierarchical Refinements

Our physical environment is evolving constantly, even though at a slow pace. Therefore it is not only for memory considerations, but for maintenance efforts, to adopt a 'divide-and-conquer' strategy for the creation and operation of a large-scale environment model for pedestrian navigation. We divide the world into a hierarchical tree structure, where each node refines one object of its parent node and represents one or more levels of granularity. Each refinement-node may specify its geometry using an own coordinate system, as described by (Jiang and Steenkiste, 2002). The nodes contain both, geometric information and references to the symbolic spatial model of *UbisWorld.* They are encoded using XML and are made accessible on the World Wide Web. We use the Semantic Web language RDF to integrate the nodes to form a coherent model. This approach supports the growth of multiple models on different levels of granularity, and their refinement as well as their union. Everyone is invited to use the editor and to add new nodes representing their own environment, and to integrate it into a larger scale model (and be responsible to update the content as required).

[8] **Y**et **a**nother **Ma**p **Mo**deling **To**ol.

5.2 The Geometric Modeling Process

The basic idea of the modeling process is to use graphical representations of the environment like architectural plans or aerial photographs as a source for the modeling. The geometric location model is drawn over the background of a bitmap image. A mesh of polygons is used to represent the logical and physical entities of the environment, like streets, places, buildings and rooms. An example is shown in figure 8. Since flexibility is more relevant than precision, especially in the indoor environment (due to the lack of precise positioning technologies), existing AutoCAD-drawings may be imported as bitmap images to start the re-modeling with the *YAMAMOTO* editor.

The polygons are used to represent physical boundaries in the environment by their edges, outdoors those are mostly discontinuities in the surface, and indoors walls or doors. Polygons may also be used to define the boundaries of logical entities, like buildings or floors, which may be refined in separate nodes. The refinement of a polygon is specified by its URI.

Modeling in the third dimension is supported by multiple layers, to represent the levels of a building. Export plug-ins will allow to create 3D models for advanced visualization from the 2.5D location model by the help of 3rd party „off-the-shelf" 3D editors.

5.3 Modeling Navigational Fixpoints for Positioning

In order to use the model for navigational purposes outdoors, it has to be related to geographical coordinates given by a GPS receiver. Three reference points have to be specified to map model coordinates to longitude and latitude in the WGS84 notation and vice versa. Alternatively, for a refinement model, the reference points may refer to the coordinate system of the parent model within the hierarchy. This might be more convenient for models of buildings or rooms, since indoors geo-coordinates are difficult to measure. Instead of three reference points, a single base point in conjunction with a meter scale and north orientation can be defined as shown in figure 8.

For the indoor positioning of the mobile device, we have to model some navigational fixpoints within the environment. For best results, heterogeneous sensor information should be used. In our current positioning infrastructure, we use a combination of RFID and infrared beacons. The editor provides various basic geometries to model the beam angle of the sender, such as point, disc and section. Whereas the RFID beacons radiate their position-identifier signal (tag-id) almost equally in all directions (disc model), the LEDs of the infrared beacons emit an directed id-signal with a range of 5 meters and a cone angle of 30 degrees (section model). Besides their position, the name and position-identifier of the beacon can be specified. In our scenario, the mobile device sends its IR- and RF-sensor readings to the positioning service, which uses the XML encoded geometrical location model to compute the devices' position by triangulation between the beacon positions. It returns numerical coordinates for map visualization and a symbolic location identifier, which allows to query *UbisWorld* for the situational context of the surrounding area.

5.4 Symbolic Annotation

Besides the geometrical model, the editor allows the symbolical annotation of the polygons and their edges. URIs are used to refer to location instances in *UbisWorld*, where spatial relations like a lattice may be represented, which can not be expressed by the tree-structure of the geometrical refinements.

In order to support route finding for pedestrian navigation, the model has to represent the connections between entities and their pass-ability. In comparison to cars, a pedestrian is not bound to a path network, but able to shortcut and cross large places. Therefore the system has to consider all routes across areas. The editor allows for naming and annotation of the edges which are shared by adjacent polygons. For example, a small path may be accessible for pedestrians, but not for cars, and some floors may require a key card outside working hours.

By naming edges, multiple representations of the same edge in other layers or even different nodes may be easily identified. This allows for route planning beyond the boundaries of the current granularity level. Using names instead of coordinates offers the freedom to abstract details from subsumed polygons on a higher level of granularity.

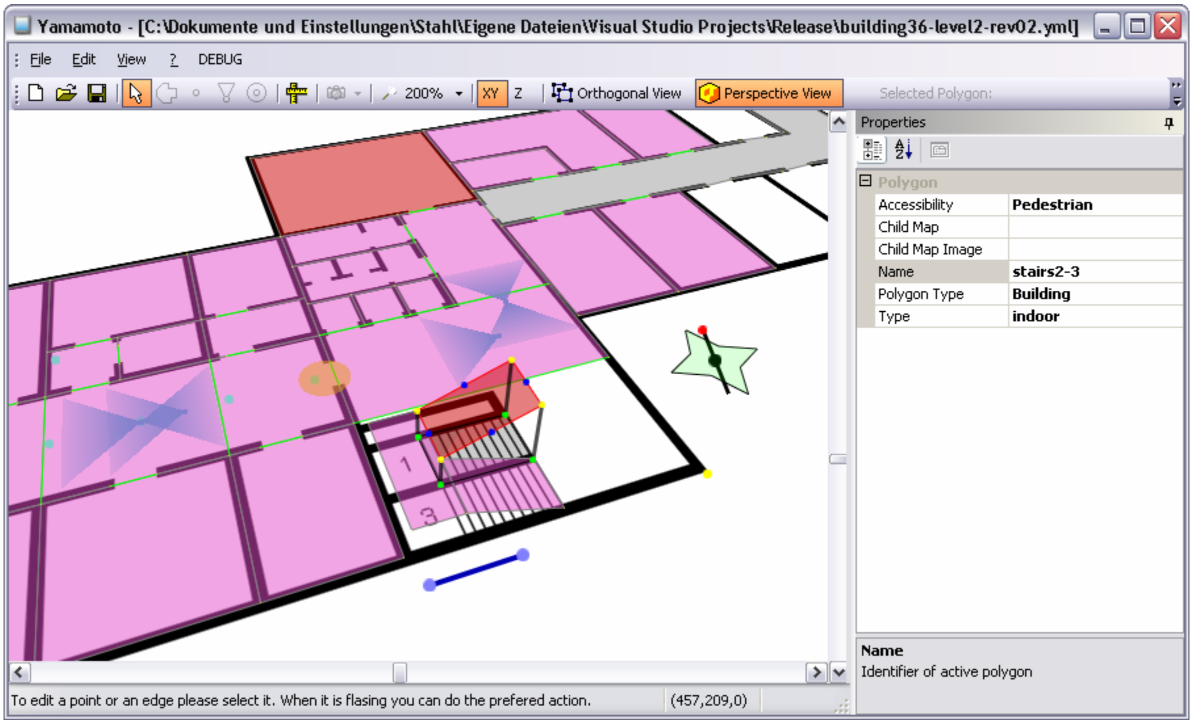

Fig. 8: Yamamoto screenshot showing the GUI, modeled rooms, beacon positions and symbolic annotation.

6. CONCLUSIONS

We envisage a ubiquitous pedestrian navigation system on a mobile computing device such as a PDA or smartphone. It should provide the user with a detailed map of the surrounding outdoor or indoor environment, such as a shopping mall or air-port terminal, and direct the user towards their goal. What are the reasons that there is no such product on the market today?

In the beginning of this article we have presented the available positioning techniques. Currently the precision desired for pedestrian navigation can not be achieved without instrumenting the environment, which is expensive. We have also discussed the routing requirements for pedestrians and have come to the conclusion that we need a detailed polygonal model instead of a rather abstract path network of street segments, as used for car navigation. Whereas the positioning problem might be over-come in the near future by technical advances, such as dead reckoning sensors or predictive algorithms like bayesian net-works, the modeling effort remains the most important issue.

We have analyzed the requirements of a location model and have come to the conclusion that we need both, a geometric and a symbolic (or qualitative) location model, with strong interrelationship. The geometric model represents map knowledge, that is needed for localization and visualization. The symbolic location model provides the vocabulary for a meaningful expression of location in general. Current research prototypes in the area of location-based services are limited in their interoperability by their proprietary domain-specific location models. By separating symbolic location identifiers from the geometric map knowledge, they can be used for the spatial indexing and retrieval of information. If the same symbolic names are shared by different mobile applications, they can easily exchange localized information between them.

This approach implies that the symbolic location model grows with every application and individual user. We have argued that Semantic Web technology provides for the required shareability and extensibility at low operational cost, and we have demonstrated by example that it is feasible to use a language like RDF to identify locations as Web resources and to represent additional ontological knowledge about them. We have also shown how to model maps for the Web in XML using the Yamamoto tool and how to integrate them into a hybrid location model.

The detailed specifications of a ubiquitous hybrid location model are beyond the scope of our project. We have written this article with the intention to inspire joint research activities by the communities of ubiquitous computing and geoinformatics.

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