A Hybrid Model for Indoor Spatial Reasoning

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1. Introduction

As applications continue to evolve from stand-alone applications in static scenarios to distributed mobile applications which extensively interact with each other and human users in an increasingly dynamic and mobile environment, the context of use becomes ever more important (e.g. time and location, device and user profiles, and other factors).

Applications need to have an understanding of the context in form of a comprehensive world model. At the same time as requirements grow, applications have to cope with all kinds of technical restrictions, especially regarding computing power, memory, input/output capabilities, and bandwidth. Powerful infrastructure often cannot be directly accessed and/or made use of in a mobile context in the same way as is possible on a desktop system.

Therefore, a suitable world model must be as simple as possible while still offering enough structural depth to carry out geospatial and geotemporal tasks, such as path planning or scheduling appointments. In geospatial modelling two paradigms exist predominantly: *qualitative* and *quantitative*. Qualitative methods are closely related to the way humans reason, quantitative methods are more akin to machine reasoning.

In this paper we propose a hybrid model which integrates quantitative and qualitative methods in order to facilitate multi-paradigm reasoning, to some extend on incomplete and/or imprecise data. The model is intended for indoor scenarios, such as described in the next section, and is based on a graph structure enriched by meta data. The key idea is to support quantitative information by a qualitative base structure. This paper is a short version of a forthcoming technical report (Lorenz, Ohlbach and Stoffel, 2006).

2. Sample Scenarios

Automated guidance of people in medium/large scale indoor environments is an increasingly important field of research. Increased numbers of plane movements in connection with ever larger aircraft result in an increased load on airport infrastructure which cannot always be met by structural expansion. Dynamic and efficient guidance of passengers can counteract these developments to some extend. A similar situation can be found at large clinics or hospitals. Patients and visitors are normally not familiar with the often large complexes, and factors such as pressure of time or exceptional stress aggravate problems with the underlying infrastructure. The following two sections shortly sketch typical situations in the two scenarios.

2.1. Air travel

Passengers are often under pressure of time, since delays and short connections are common. Increased and longer security checks as well as fewer available ground staff make all aspects of air travel more demanding. Automated assistance via mobile devices could substantially help in a number of aspects. Finding facilities such as information booths, departure gates, baggage claims or parking lots could be assisted by routing applications. Changes and updates of all kinds could be communicated via Personal Digital Assistants (PDAs) or mobile phones. Indoor positioning and dynamic event handling could aid the ground staff in locating passengers late for departure. Paper tickets can be replaced by electronic counterparts, and check-in can be done using 2D-matrix-code sent via MMS to mobile phones[1] to reduce queues.

2.2. Healthcare

Modern hospitals often consist of complex infrastructures integrating all kinds of special units, employing a wide range of experts and implementing complex processes in order to cater for the needs of patients. Visitors are generally neither familiar with these environments nor with individual procedures. Especially today, where human resources are scarce and must be deployed with optimal efficiency, people can benefit from automated assistance. Locating not only certain premises but also employees, which are often moving around in the building, is a task that occurs regularly for both patients and staff. Active badge systems have been devised to eventually replace beepers. Patients' vital signs could be monitored and their movements tracked for safety reasons. People would not be confined to areas with constant audiovisual supervision, staff could concentrate on more important matters.

3. A Hybrid Model

The model described in the following was developed for geospatial reasoning, although similar applicability can be expected in other areas as well. As indicated in the introduction, both qualitative and quantitative models have been incorporated with their inherent advantages and disadvantages regarding certain tasks in geospatial reasoning.

3.1. Quantitative vs. Qualitative Methods

Quantitative spatial reasoning deals with exact numerical values, such as pairs of coordinates, distal or angular values. Information is presented as *54,964° N, 12,342° E* instead of *Museum of Modern Art*. Directions are expressed as *268,5°* instead of *west* and distances as *64,23m* as opposed to *near*, *far*, or *at the end of the street*. The former of these examples are quantitative in nature, while the latter are qualitative. The reader can easily spot the important difference and the meaning for software interacting with human users becomes apparent. The way humans reason about space is arguably efficient and delivers consistently good results (Dutta, 1988). It can also deal to some extend with imprecision, uncertainty, and incompleteness, which quantitative reasoning cannot. Using RCC-8 relations (Gerevini and Nebel, 2002) to symbolically represent cities and states for example, it is very easy to define that Munich is located in Bavaria, Frankfurt in Hesse, that they both share a border and both are a part of Germany (see Figure 1).

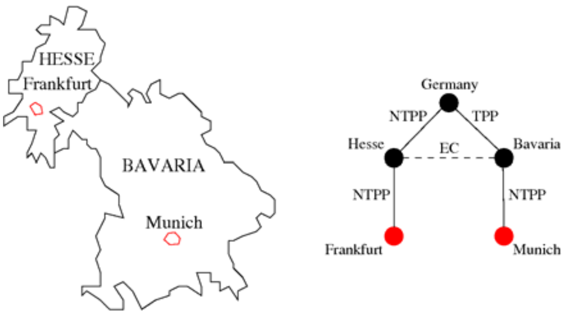


Figure 1. Symbolic Data Representation

Similar information could theoretically be derived from quantitative representations (e.g. polygons), although computation would be complex and error prone. However, some other tasks are better dealt

[1] http://www.heise.de/newsticker/meldung/70240

with in a quantitative manner. Classical applications are routing and navigation, the main focus being shortest or quickest routes. These, in turn, are more easily determined by quantitative means.

The necessity for representing both qualitative *and* quantitative data in an integrated model for geospatial reasoning in any context involving human interaction is apparent. One of the major problems with qualitative data is their availability. Qualitative data can be collected and input manually, deduced from existing qualitative data or computed from quantitative data – the former usually being more, the latter being less expensive.

3.2. The Basis: A Graph Structure

Due to its suitability for routing tasks and its qualitative nature, a graph structure represents the basis for the hybrid data model. A building complex can be modelled in a graph structure by representing rooms as nodes and doors as edges. By transformation of blueprints (see Figure 2), the building's structure can be acquired in an (at least semi-) automatic way. This facilitates a number of graph related operations, such as *shortest path* or *travelling salesman* algorithms.

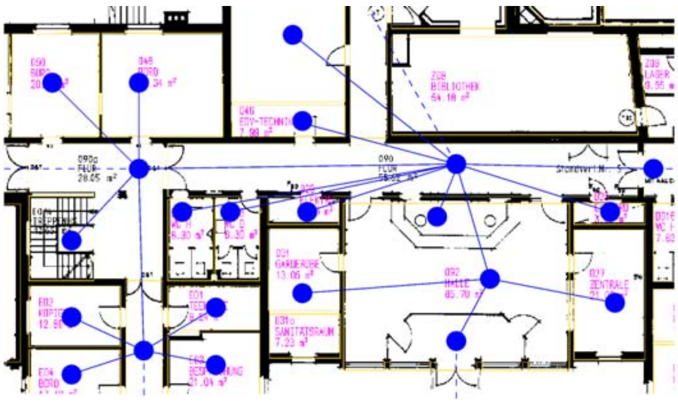


Figure 2. Blueprint with Network Overlay

The semantics of a building, e.g. restricted areas or one-way corridors, can easily be integrated in this model using suitable attributes and directed edges. Furthermore, since graphs are also suitable for representing networks (e.g. streets, public transportation), they facilitate seamless and straightforward integration of indoor and outdoor environments. This is often necessary for dealing with premises consisting of a number of independent buildings, and can be extended to networks of basically arbitrary size.

3.3. Metadata in Nodes and Edges

Intelligent labelling of nodes and edges as well as comprehensive metadata, for example the name of the owner of an office, availability of telephone and network connections, furniture, room dimensions, or any other data necessary, complete the pool of information available for reasoning. Generally, any information needed for a certain application can be coded this way.

3.4. Ontologies

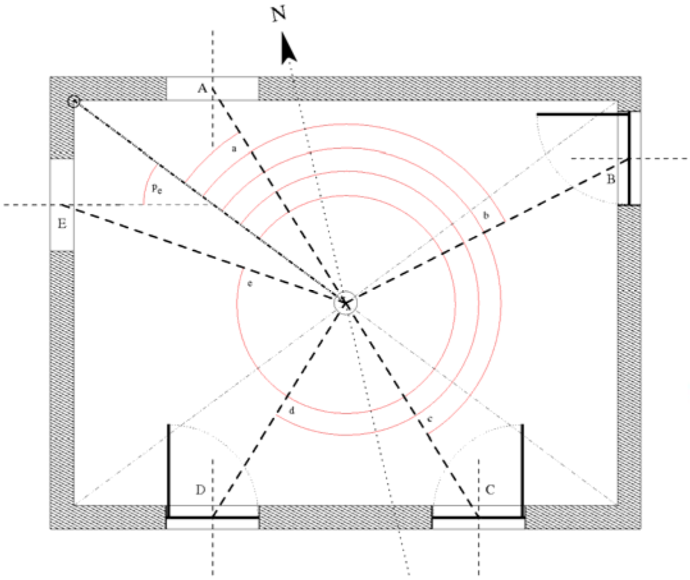
The use of ontologies in this model is particularly appealing in two respects. On the one hand, structural information can be semantically enhanced (e.g. *halls*, *corridors*, and *chambers* belong to the class *room* and have special properties). On the other hand, user and device profiles can be handled in this way. Especially user modelling in connection with multimodal networks can benefit from such a modelling, since there is complex interaction (e.g. using stairs while travelling with a pram).

Our approach makes similar use of ontologies as for example (Tsetsos, Agnanostopoulos and Kikiras, 2005), however, we minimise the data to be processed *beforehand* instead of matching results against different constraints *afterwards*.

3.5. Quantitative Data

Quantitative information needs to be incorporated at some point. Without concrete data it would not be possible to generate precise guiding instructions, such as *"Use the third door to your left, go directly across the hallway through the double-doors and turn right…"*. Apart from guidance there are other queries which would normally require precise cadastral data: *"How many exits does room 1.42 have?"*, *"What rooms are adjacent to the central staircase?"*, *"Does room 2.13 have windows which point southward?"*. In order to be able to reason about these issues without requiring comprehensive cadastral information, we tried to reduce quantitative data to the minimum amount possible. Essentially, the following data is stored: spatial coordinates of the centre, shape and orientation, and angles to doors, windows, etc., as well as their perpendiculars (see Figure 3). Angular expressions are given in relation to the room's orientation, which in turn is given in relation to an external reference system, e.g. magnetic north. The anchor is always the northernmost corner of the room, the westernmost one, if more than one qualify.

Anchoring the room in space using coordinates of its centre (or another reference point) and its orientation corresponds neatly to a number of indoor positioning techniques, such as WLAN fingerprinting (Bahl and Padmanabhan 2000) or active/passive methods using RFID or IR.



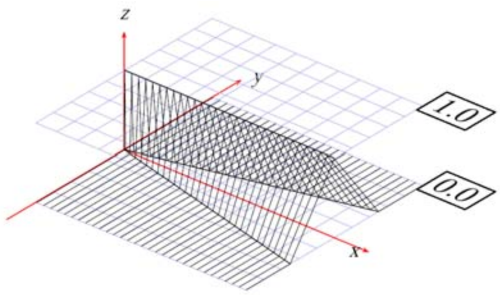


Figure 3. Quantitative Properties of a Room

Figure 4. Fuzzy Angle

Considering the example shown in Figure 3, several statements can be computed. We suppose a routing algorithm has produced a route leading through the room, entering at door *B* and leaving through door *D*. The desired output consists of the instruction *"take the second door on your left"* and optional clarification *"[the door] directly opposite the window to your right"*. For example the trajectory from *B* to the centre can divide the room into *"left"* and *"right"*, the order being derived from the angles to doors and windows respectively. Likewise, the orientation of *A*, i.e. its perpendicular p_a, faces the position of the door in question. A fuzzy treatment of the orientation angle (see Figure 4) ensures that slight deviations can be handled. Technical detail can be found in (Lorenz

Ohlbach and Stoffel, 2006). Additionally, the distance from *B* to *D* can be computed, albeit distances and travel durations play a minor role in indoor routing scenarios. This collection of quantitative values can be arbitrarily adjusted for different applications.

Some premises have to be decomposed into smaller cells by exact cell decomposition. This must be done in order to be able to handle larger rooms, rooms with irregular (i.e. not rectangular) shape, and areas with different semantic features. For example airport or railway terminals with waiting areas in front of counters or buildings with rather continuous features (i.e. rounded or non-perpendicular walls) fall into this category. Figure 5 shows an airport hall with a sample segmentation of different areas in front of counters *C* and passport control *P*. Boundaries can take on any form from hard (walls) to soft (barriers, lines on the floor), sometimes they even need not be visible. A segmentation like this is arbitrary and can be adapted to any specific purpose. In contrast to approximate cell decomposition, this approach results in clearly defined cells which have distinct properties and don't suffer from problems with partial membership or overlap (see Latombe, 1991).

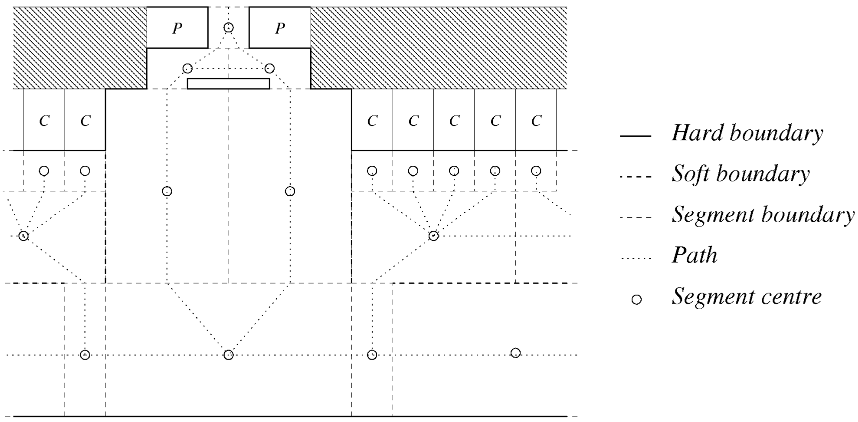


Figure 5. Segmentation

4. Conclusion

The hybrid model presented above combines both qualitative and quantitative techniques to facilitate the application of different spatial reasoning paradigms. Qualitative techniques enable elegant solutions in symbolic reasoning and graph related applications, without the need for heavy computation on huge data sets. This is a clear advantage for mobile applications. The semantic integration of quantitative data facilitates more complex reasoning, such as composite queries (see 3.4) or the use of complex cost functions (as used in routing). Future work includes fully automated graph generation (and segmentation), comprehensive integration in prototypes dealing with outdoor scenarios (see Stoffel, 2005), and deeper integration of ontologies and ontology reasoning.

5. Acknowledgements

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Biography

Prof. Dr. Ohlbach studied Mathematics and Physics. After his first degree in Physics he moved into Artificial Intelligence, in particular Automated Reasoning. He got his Ph.D. for a translation approach from Modal Logics to Predicate Logic and a corresponding resolution calculus. From 1990 until 1996 he worked at the Max-Planck institute for Computer Science in Saarbrücken. From 1996 until 2000 he had research positions at the Imperial College and the King's college in London. Since 2000 he is Professor for Computer Science in Munich. His current area of work is geotemporal and geospatial information processing. He is a member and WG coordinator of REWERSE – http://rewerse.net.

Bernhard Lorenz is a third year Ph.D. student at the Institute for Informatics, University of Munich. He wrote his diploma thesis in computer science about motion planning for non-holonomic vehicles. His main research interests include qualitative and quantitative geospatial reasoning techniques, geospatial modelling and robot motion planning. He is a member and WG assistant of REWERSE – http://rewerse.net.