Location Modeling for Intentional Behavior in Spatial Partonomies

Christoph Schlieder, Thomas Vögele, Anke Werner

Technologie-Zentrum Informatik, Universität Bremen, Postfach 330440
28334 Bremen, Germany
{cs, vogele, anke}@tzi.de
http://www.tzi.de/

Abstract. Due to technical and design-based constraints, mobile devices need special capabilities of proactive information presentation. In the simplest case, these can be the intelligent arrangement of menu items based on their relevance for a specific situation. Typically, the decision about what is relevant to the user is taken on ground of information about the user's spatial location. We show that if the regions of the geographic space in which the user moves are structured hierarchically by partonomies a disambiguation problem arises. To resolve the problem, not only the user's location but also his motion must be taken into account. We propose a location model that supports inferring intentional behavior in spatial partonomies from motion patterns.

1 Intentional behavior in geographic space

Location-aware services pioneered by researchers at the Xerox Parc Laboratory under the vision of ubiquitous computing (see e.g. Schilit & al., 1993) exploit the idea that the intentions of a human agent can be inferred from information about his current location. This is a valid assumption in certain cases. However, intentional behavior often correlates with complex motion patterns rather than with location. A further challenge for location modeling comes into play when the user's mental representation of space is considered. From psychological research it is known that region-based representations of geographic space tend to be organized hierarchically by part-of relations (Hirtle, 1995). Thus, intentional spatial behavior seems intrinsically bound to what AI research has called spatial partonomies (e.g. Davis, 1990). For ubiquitous computing, this raises the problem of finding a suitable location model for identifying the intentions of a user who is moving in an environment structured by partonomies.

This paper reports on a particular instance of this problem which we encountered in the TourServ project[1]. Within the scope of this project, a service platform is build that provides regional information and navigation support to tourists. A pilot system is under development for the Italian ski resort of Scopello near Milan. The tourists use mobile devices, such as PDA or smart phones, to get optimal support during their

[1] Funded by the European Union IST-1999-20414

skiing, mountaineering, or hiking activities. The tourist's actual position is gained by GPS and this information is used to guide proactive information presentation and navigation support. In the simplest case, this amounts to finding an arrangement of menu items based on their relevance for a given situation.

Positioning technologies like GPS are able to provide sufficiently exact information for navigation purposes but they do not resolve the problem of identifying which spatial context is relevant for the user. A position on a digital map typically corresponds not to a single region but to a hierarchy of regions. The tourist located at the ski lift in the resort of Scopello is also located in the commune of Scopello, in the valley of Varese, and in Italy. Depending on the tourist's intentions, any of these regions can become the focus of relevance for services such as formation presentation or navigation.

2 The problem of ambiguous location

We would like to illustrate the problem of ambiguous location, and to present our solutions for that problem, using a simplified application scenario. In this scenario, a tourist explores an art museum. He is assisted by a mobile device connected to the museum's tourist information system. The basic problem lies in the fact that the tourist's location is part of multiple, hierarchically stacked "spatio-thematic regions". A typical museum consists of a number of buildings or wings, each of which is subdivided into several exhibition rooms (Fig. 1). Each room holds a number of exhibits. The museum itself is located in a specific district of a city, and the city is part of a country.

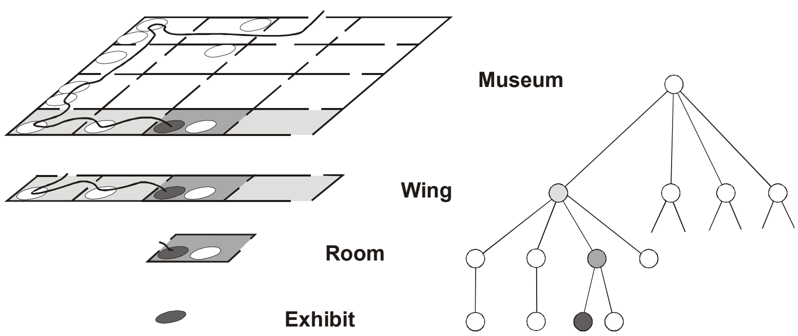

Fig. 1. Ambiguous location in the museum partonomy

Depending on the spatio-thematic region we look at, different types of services are relevant: On the museum level, we are interested in global navigation services which guide the user from one wing to another whereas on the exhibit level specific information services are needed which inform about a painting and its painter (Tab. 1). A proactive mobile information system has to decide which of the spatio-thematic regions is the most relevant.

Tab. 1. From motion patterns to service layers

Motion pattern	Intentional behavior	Level in partonomy	Service layer
any type of motion	touring_museum	museum	global navigation
moving fast	traversing_wing	wing	local navigation
moving slowly or looking_at_exhibit	visiting_room	room	general information
resting and oriented towards exhibit	looking_at_exhibit	exhibit	specific information

The naïve approach of simply using the region that is closest by would yield erroneous results in the case of a user who moves through the exhibition rooms to get from one wing of the museum to another. He would be prompted with (unwanted) information about all the exhibits on his way while actually needing help on how to navigate through the building.

To solve the problem of disambiguation, i.e. to decide, which one of the spatio-thematic regions is relevant, we propose to analyze the tourist's motions. The detected motion patterns can be used to make assumptions about the tourist's intentional behavior, which in turn can define the relevant focus region and the services to be offered by the tourist guidance system. To be able to solve this task we need a.) to encode typical motion patterns, b.) to represent a partonomy of the regions, and c.) to encode the 2-dimensional, spatial relations of the spatio-thematic regions. In this paper, we will focus on a.) and b.). For c.) we adopt the solution described in Schlieder et al. (2001).

3 Location modeling with partitioned motion patterns

The encoding scheme for motion patterns has to meet several requirements. Firstly, there is the need for an adequate representation of the temporal dimension. Secondly, the encoding should be domain-independent, which implies that it should abstract from specific sensors. Thirdly, it should be sufficiently expressive to deal with spatial partonomies. In the following, we propose such an encoding scheme.

Encoding motion patterns

Formally, a *motion pattern* is defined as a non-empty sequence of *elementary motions* each of which is a 5-tuple of spatio-temporal parameters:

(*position, heading, direction, distance, duration*).

Position and heading describe the outcome of the motion, that is, the current location of the agent and the direction it heads towards. The other parameters give some information about the motion itself. Direction, distance, and duration of the motion are measured with respect to the previous elementary motion (see Fig. 2). Note that the parameters convey redundant information only if they are computed from complete and correct sensor data – an assumption which is rarely given in practice.

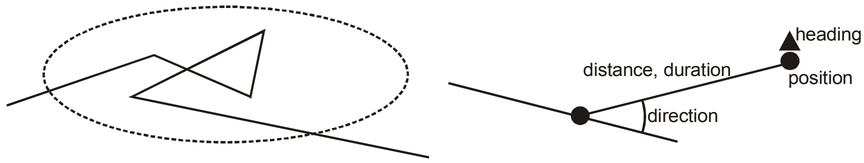

Fig. 2. Motion pattern and parameters of an elementary motion

Each parameter is specified by a magnitude and a measuring system, e.g. 15,3 m or 3 s. This way, not just the results of quantitative measurements but also those of qualitative measurements can be stated. Different systems of qualitative spatial and temporal measures have been studied in the field of Qualitative Spatial Reasoning (see Cohn, 1997 for an overview). Typically, magnitudes of qualitative measurements are elements of relational algebras that axiomatize simple computational operations such as relational composition (Ladkin & Maddux, 1994). For instance, a relational algebra defined over {north, west, south, east} allows to express qualitative directions, whereas a relational algebra defined over {near, medium, far} describes qualitative distances.

The 5-tuple of measurement systems of an elementary motion is called the motion's *signature*. Below are the signatures of a quantitative and a qualitative description of a motion.

position: [Gauss-Krüger]	position: {inside, outside}
heading: [radian]	heading: {any}
distance: [meter]	distance: {any}
direction: [radian]	direction: {any}
duration: [second]	duration: [second]

The quantitative description is typical for GPS-based localization as it is used, for instance, in the TourServ project. The qualitative description abstracts from all distance, direction, and heading information. It only indicates whether the agent's position after the motion falls inside or outside the region considered. This matches with region-based sensors that can only detect that the agents enters or leaves a region. Obviously, the encoding scheme is sufficiently flexible to handle both, quantitative and quantitative description. Therefore, it fulfils the requirement of sensor-independence.

Encoding spatial partonomies

Motion patterns easily combine with hierarchical data structures that describe spatial partonomies. Such partonomies are the result of recursively applying the spatial part-of relation to describe the decomposition of wholes into parts, i.e. regions into subregions. In our approach we make use of the representation for spatial partonomies described by Schlieder & al. (2001) in a GIS context. Different types of spatial part-of relations can be distinguished. To define these types, we assume that the regions are encoded as polygons, and that each polygon is a closed sets of points, i.e. edges and vertices belong to the polygon. If we consider polygons $P_1, \ldots ,P_n$ that are contained in a part of the plane bounded by a polygon P, three types of arrangements of the polygons within the containing polygon P can be distinguished.

(1) *polygonal covering*, where $P_1 \cup \ldots \cup P_n = P$. The polygons cover the containing polygon. In general, they will overlap. (2) *polygonal patchwork*, where for all $i \neq j$ from $\{1, \ldots, n\}$ interior $(Pi \cap Pj) = \varnothing$. The polygons are either disjoint or intersect only in edges and/or vertices. (3) *polygonal tessellation*, which is a polygonal covering that also forms a polygonal patchwork.

We introduce the *decomposition tree* which is defined recursively as hierarchical data structure for encoding the spatial part-of relation together with the type of arrangement of the parts. The nodes of the decomposition tree denote regions and are labelled with one of the following arrangement types: patchwork, covering, tessellation, undecomposed, other. By abstraction from the type of spatial arrangement one obtains the *partonomy* that underlies a decomposition. This partonomy is obtained by omitting the labels from the decomposition tree.

The type of spatial arrangement determines which spatial relations may be modeled. For polygonal tessellations, it is possible to formalize both metric (denoting distance), ordinal (denoting directions), and topological (denoting neighborhoods) spatial relations (Schlieder, 1996). These can be represented using graph-theoretical constructs like neighborhood- and connection graphs (Schlieder et al., 2001). Given the existence of valid quantitative GIS or CAD data, the automatic or semi-automatic creation of such qualitative models is straight-forward. Where tessellations are not available, it is possible to map other polygonal arrangements onto standard tessellations.

For the purpose of describing motion patterns, we need to represent the way in which a partonomy (or a decomposition) divides the motion pattern into subpatterns. Each spatial region determines a subpattern: the sequence of elementary motions that occur within the region. The organization of the regions in the partonomy is inherited by the subsequences. We call this hierarchical structure a *partitioned motion pattern* (see. Fig. 3).

Analyzing partitioned motion patterns

The primary interest of partitioned motion patterns is that they provide information about the agent's intentional behavior with respect to the spatial partonomy. To extract this information, an analysis is run on the fly. Each new elementary motion triggers an evaluation cycle. The evaluation tries to associate an intentional behavior to each *open region*, that is, to each region in the partonomy which contains the agent's current location. First, the open region with lowest position in the partonomy is considered. Then, the analysis proceeds to the superregions in the order they appear in the partonomy (see. Fig. 3)

Finding an intentional behavior for some part of the motion pattern amounts to solving a classification problem. Different algorithmic solutions for classification are available such as neural networks or decision rules. We chose a rule-based approach because it enables the software developer to explicitly state which motion patterns are associated with a specific intentional behavior in the application domain he is modeling. During an evaluation cycle, the decision rules are applied to the parts of the motion pattern proceeding from the most specific to the most general open region. As soon as a rule fires, a region has been found for which the motion pattern can be associated with an intentional behavior. This most specific region with an intentional behavior is then identified as the focus region and the menu for the service associated with the focus region is presented to the user on his mobile device.

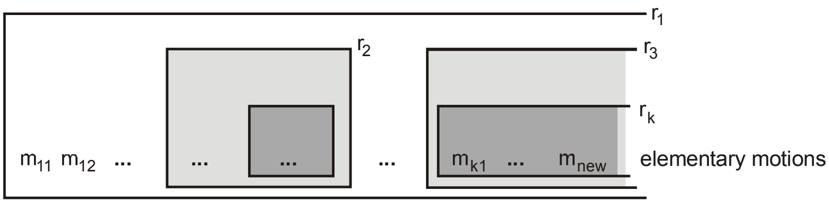

Fig. 3. Identifying intentional behavior from partitioned motion patterns

4 Related approaches and discussion

In a wide range of published work, location is the dominant context parameter to tailor information presentation. Several guide systems have been built (e.g. Abowd & al., 1997, Davies & al., 1998, Oppermann & al., 2000.) which use the user's current location and his travel history to predict objects of interest to visit. But most of these simply use spatial regions that are closest by, or represent the smallest region for a specific location and do not consider that this location belongs to several spatial regions of a partonomy. If the user is located within the region of a specific object as defined for example by an Active Badge (Want & al., 1992) sensor, the system would decide that this region is the most relevant one and prompt the user with detailed information about this object. We are not aware of any work dealing with the disambiguation problem connected with intentional behavior in spatial partonomies.

Mental representations of motions have been studied by researchers on spatial cognition, especially Musto & al. (2000). Based on data from psychological experiments, they propose a qualitative motion representation which uses sequences of qualitative motion vectors. These can easily be expressed in our more general framework as they encode only the direction and distance parameters of the elementary motion we defined. The central concern of Musto & al. (2000) is with a cognitively plausible segmentation of a motion pattern into subpatterns. In our case, however, segmentation is not internal but external, that is, induced by the regions of the partonomy. In our paper, we have shown that a disambiguation problem arise in connection with the interpretation of the user's intentional behavior in a spatial partonomy. We have argued that the observation of the user's motion can provide valuable information for inferring his intentions and proposed the idea of partitioned motion patterns.

References

1. Abowd, G.D., Atkeson, G.C., Hong, J., Long, S., Kooper, R., and Pinkerton, M. (1997). Cyberguide: A Mobile Context-Aware Tour Guide. ACM Wireless Networks, Vol. 3, pp. 421-433.
2. Cohn, A. (1997). Qualitative spatial representation and reasoning techniques. In Proc. KI-97: Advances in Artificial Intelligence, (pp. 1-30). Springer: Berlin.
3. Davis, E. (1990). Representations of commonsense knowledge. Morgan Kaufman: San Mateo, CA.
4. Davies, N., Mitchell, K., Cheverst, K., and Blair, G. (1998). Developing a Context Sensitive Tourist Guide. Proceedings of the First Workshop on Human Computer Interaction with Mobile Devices, pp. 64-68, University of Glasgow, UK.
5. Hirtle, S. (1995). Representational structures for cognitive space: Trees, ordered trees and semi-lattices. In: Spatial Information Theory (COSIT-95), (pp.327-340), Springer: Berlin.
6. Ladkin, P. & Maddux, R. (1994). On binary constraint problems, Journal of the ACM, 41, pp.435-469.
7. Musto, A., Stein, K., Eisenkolb, A., Röfer, T., Brauer, W., & Schill, K. (2000). From motion observation to qualitative motion representation. In: C. Freksa & al. (eds.) Spatial Cognition II (pp. 115-126). Springer: Berlin.
8. Opermann, R., and Specht, M. (2000). A Context-sensitive Nomadic Information System as an Exhibition Guide. Proceedings of the Second International Symposium on Handheld and Ubiquitous Computing, Bristol.
9. Schilit, B.N., Theimer, M.M., Welch, B.B. (1993). Proceedings of the USENIX Mobile and Location-independent Computing Symposium, pp. 129-138, Cambridge, MA.
10. Schlieder, C., Vögele, T., & Visser, U. (2001). Qualitative spatial representation for information retrieval by spatial gazetteers. In: Spatial Information Theory (COSIT-01), Springer: Berlin.
11. Schlieder (1996). Qualitative shape representation. In A. Frank (ed.), Spatial conceptual models for geographic objects with undetermined boundaries. London: Taylor & Francis.
12. Want, R., Hopper, A., Falco, V., and Gibbons, J. (1992). The Active Badge Location System. ACM Transaction on Information Systems, Vol. 10, No. 1, pp. 91-102.