Location Modeling: State of the Art and Challenges

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Abstract. Modeling of location information is an interesting and important topic, which influences essentially the quality of developed location-aware computer systems. In this paper the author takes a look at the means of representing spatial information. Different model types and some of their extensions are presented and compared. Then following onto the discussion on some special features of location-aware systems design in ubiquitous computing environments, a set of open questions is offered for all enthusiasts to work on.

1. Introduction

Location modeling became recently an essential topic in the field of ubiquitous computing (UC) systems. A wide selection of different sensing technologies is available for the system developers who want to use spatial information, whether to offer better service or just to provide the users their current position. Location is an essential part of context, which turns out to be useful in many UC applications, in particular for such purposes as position determination, navigation, routing, tracking, logistics, monitoring of ubiquitous computing devices and many others.

Success of every system depends for the most part on good system design. That's why it is also important for all systems providing location-awareness to ensure that the underlying location model is really suitable for the aimed functions. For example, it may be difficult for a child who just wanted to know where his house is to be given its destination position as 47°24′ N, 8°18′ E. And it may be difficult for the system to calculate the remaining distance between "the car" and "the petrol station" if it is operating with them just as symbolic names.

That is one of the differences of ubiquitous computing concepts in contrast to common computer systems and also an additional challenge – computer systems become unobtrusively a part of everyday appliances and should possibly be able to perform some computation as well as communicating with people in a *human understandable* way. Another point demands the *exactness* of given information, which may vary in accordance with the usage scenario. The third issue to take into consideration is that position information is often obtained by different sensor types. In this case computer systems should be able to deal with various data formats. At last there is the general importance of distance definition. All this cannot be obtained without an appropriate location model.

In the next sections, an introduction into the field of location modeling will be followed by a brief overview of existing models. Then the enumeration of demands made on the location-aware applications should clarify the challenges of location representation in UC environments.

2. Location Modeling

The idea of location representation is not really new. Perhaps, a landscape map was the very first representative of a place model. An ancient genre in cartography was the cadastral map, which used a very unsystematic space subdivision by metes and bounds [11]. Later the notions of latitude and longitude were applied to provide more precise position description. Usually most objects on the map were connected with historical events and, in a while, with some qualitative features of the place such as sights, climate, resources, population etc., so the position image was used as a reference to find out contextual information.

Modern means of location representation are more flexible than maps since they allow not just visualization and reference, but also complex hierarchies of places and objects, querying mechanisms and behavioral analysis. Most of them make use of Euclidean and analytic geometry, as well as elements of set, probability, and graph theories.

2.1 Basic Models

There is a tendency to distinguish between two groups of location models, which are related to each other.

Models of the first group were used by humans very early and are therefore historically accepted and well known. This group contains so-called physical and geographical models [12]. Both of them are absolute specifications, since they deal with a universally valid coordinate system, geographical names, and reference systems.

Physical location is related to a global geographic coordinate system and provides absolute, accurate, grid based position in form of <latitude, longitude> pair. (A third <altitude>-coordinate can be added if necessary.)

Geographical location is used to deal with natural geographic objects, such as countries, cities, and also zip codes, postal addresses and so on. The remarkable property of such objects is their clear hierarchical organization. Such a position description is suitable for delivery of spatial information to a human.

Models of the second group are more abstract, and therefore easier to adapt to automatic processing. This group consists of geometric, symbolic, and combined models [1].

In a *geometric model* both, locations and located objects, are represented by sets of coordinate n-tuples, better understood by a human as points, areas, and volumes. This model type is based on one (simple model) or more (unified model) reference coordinate systems (RCS).

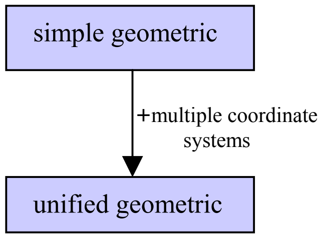

Fig. 1. Geometric models [1]

Such descriptions mostly carry with them the advantages of preserved position accuracy and simple predefined communication interface, since both, sensors and applications, only need to know about the used RCS to exchange the information. In addition, the RCS can be typically reused without customization [1]. However, a separate location directory and appropriate mapping service are needed as soon as the system delivers to the user some meaningful information about his or her current location.

The biggest disadvantage of these model types are the superfluous data and computations, which can overload small devices which often have strong restrictions on memory and computation power. *Symbolic models* refer to a location by some abstract symbols. Descriptions of location and located object are in that case different since locations are represented by sets, and located objects are referred as members of these sets[1]. Mentioned above geographical location seams to be an instance of this model type.

Such a representation allows a reference to a place simply by abstract symbol or name, which makes it very convenient for human interaction. Place names can easily be organized hierarchically. It is possible to define additional secondary models as an overlay to achieve further semantic flexibility.

Some weaknesses of such a model should be mentioned: the unavoidable manual construction and management of the names, their dependence on the application domain and a restricted spatial resolution of the model.

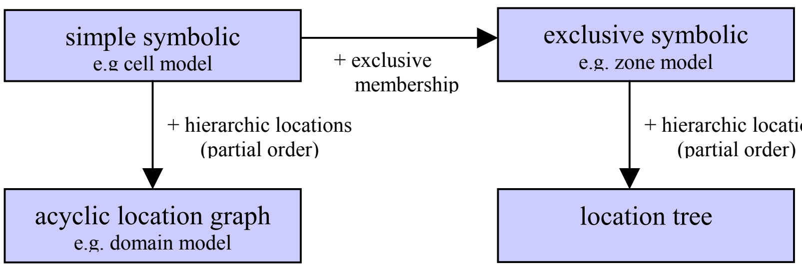

Fig. 2. Symbolic models [1]

The combination of two mentioned model types is a so-called *semi-symbolic model* (also referred to as *combined* or *hybrid* model). A located object is represented here by both: area coordinates (like in geometric model) and a name with membership in

[1] For further information about subclasses of symbolic model – cell, zone, and location domain models see [1]

one or more location domains for instance (compare with symbolic model). On the other hand the location can be a well-defined fixed area or a large mobile object with changeable absolute coordinates in the space (and eventually its own relative coordinate system).

This model does not include time as a parameter and does not allow changes of located-objects composition. This means that once an association between two objects is defined (for example me and the mobile phone in my pocket, or me and the room I am currently in), it cannot be changed for the single model instance any more.

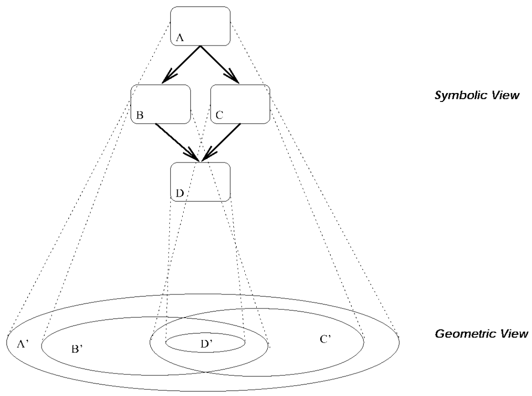

Fig. 3. Semi-symbolic model [1]

All three model types are not dependent on any special coordinate system, they often consider the specification of position accuracy, can deal with vague space shapes and be easily applied and furthermore reused by different systems.

2.2 Object Arrangement and Measurement Resolution

There are two different ways to associate any located object with a location:

- *Containment* – determine positions of objects by identifying spatial regions which contain those objects.

  

  In other words, location encloses subordinate objects (model entities - places, people, devices etc…) like a container. The subordinate objects can be but are not necessarily hierarchically related to each other. In this case the size of a container governs the resolution. Examples are geographical location, symbolic location, geometric model with location defined as n-tuples, n>2.

- *Positioning* – track objects by reporting their coordinates in a frame of reference.

  

  Each object is represented only by its current position. Relations between single locations can be defined by distance between them. The resolution is specified by a given grid spacing. Examples are physical location, geometric model with locations represented by one-dimensional coordinate tuples (points), also symbolic location in case any location contains only one located object at a time.

2.3 Distance

Distance is one of the most important notions in location modeling. It determines relations that can be established between any two objects independent on their hierarchic affiliation and allows processing of inquiries like “Where is the nearest book shop?”

The above mentioned model types use disparate definitions of distance: Physical models use common Euclidean distance; in geometric models it is not predefined, but restricted by demands of partially order of distance values and by dependence of a distance on the path covered by the mobile object on its way from A to B. (In accordance to this the distance between two points has no single value but will vary by every measurement as long as it is made by other devices with dissimilar movement behavior.)

The notion of distance is also closely connected with the notions of proximity, which becomes very important in privacy aspects in UC systems and co-location that imply the same notion of closeness/proximity. (Two located-objects are co-located if they are spatially close to one another [1]). All these spatial relations need to be clarified by the further works.

2.4 Further Model Developments

Recently, some extensions of basic models were proposed due to the desire to improve as well as to the necessity of their adaptation to the conditions of upcoming UC environments. In general, following common threads in the development of recent location models are recognizable by now:

Merging of different location representations with various accuracy levels within a single model. For example in the NEXUS [9] system, use of different variously detailed location descriptions is proposed, since not every application that is applying to the system needs data of height resolution. NEXUS uses also a complex truthful 2- and 3D World model with the assistance of knowledge based systems and machine learning techniques. That also addresses the next issue:

Search for concrete suitable representations of fundamental elements forming the basic models. For example, an approach of semantic location [12] revises the common notion of location as only a point or area in space and suggests virtual locations those may not have any physical presence at all.

Embedding more complex semantic content and logical structure into the model. An interesting extension of the symbolic (resp. semi-symbolic) model type suggested in [7] distinguishes between raw location (lower description level; compared to a geometrical view) and more abstract “logical location context” or “realms of interest”. The elements of upper layers in symbolic model build units of semantically connected entities (e.g., “all rooms owned by the computer science department”, “conference rooms with installed beamers”), so that the 3D-space can be viewed by applications logically. Also cross-references and double memberships are allowed. Further an alternate notion of “r-distance” that has to be flexible for representing pseudometrics other than Euclidean distance (e.g., cost, time, accessibility, work etc.) is proposed.

And finally, since located objects became mobile, the need to *identify localized objects, to describe their movements and to estimate their future positions* comes up. For this purpose the elements of probability theory, statistics and machine learning are used [15, 16].

3. Challenges

What are the aims desired by developers of location-aware systems? What do we expect from the location-aware systems of tomorrow?

One of the eternal qualities, *scalability*, will become very important, since location applications should be able to cope with countless sensors deriving their data and probably with many ubiquitous devices making use of a system. In this situation it is important for every device to obtain as much useful information as it needs, but not more since this may waste its limited resources. This means that *different description levels* with diverse amounts of information, data accuracy, and formalization grade may be very useful. At least to represent the location information to a user, *human-friendly* location representation should be ensured if necessary.

If some users are not willing to keep their location data open, the *privacy* problem has to be solved, especially when the sensing technology allows to perform only remote-positioning (recognize location of an object *by* its environment). Then it must be decided if privacy constraints should be included by modifying the underlying representation model or if this is a task of system design. If a location-aware application deals with distance and co-location for the purpose of giving information as well as by spatial-dependent [13] event generation, then the notions of a *distance* and *proximity* should be clearly specified. The representation of locations as *vague shapes* may have certain advantages, e.g. by location intersection [10], also the models dealing with uncertain location information may be of interest.

By the applications that require knowledge of object *orientation* in addition to the *position*, a model extension providing *spatial awareness* instead of plain location awareness should be developed. In the future *more than one sensor technology* (e.g. GSM and WAP [14], or one for position, another for orientation etc.) is likely to be used, so data formats of different structure and characteristics such as accuracy, regularity etc. should be integrated into a system. It is possibly meaningful to look for ways to use the achievements gained in the fields of *knowledge representation* and *context modeling*. But that is not all in the upcoming to-do list of location modeling supported by new UC-applications.

4. Conclusion

Among the basic location models described systematically in 1997-98 [1,3], many of their extensions and also new paradigms are being developed due to a new application field opened by the spread of small, mobile, ubiquitous devices. The present location models contain representations of space and located objects as well as suggestions for modeling relations between the model entities. The modeling of vague space shapes and relationships have to be detailed. That means a great field of research activity. Among the basics there is a vide variety of open questions concerning further development of suitable representation models as well as their integration into the location-aware systems.

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