

# SpaceSemantics: An Architecture for Modeling Environments

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## ABSTRACT

The notion of modeling location is fundamental to location awareness in ubiquitous computing environments. The investigation of models and the integration with the myriad of location sensing technologies makes for a challenging discipline. Despite notable development of location models, we believe that many challenges remain unresolved. Complexity and scalability, diverse environments coupled with various sensors and managing the privacy and security of sensitive information are open issues. In this paper we discuss our previous experience combining location sensing with mobile agents and how the lessons learnt have led to the conception of *SpaceSemantics*, an open architecture for modeling environments.

## Keywords

Location modeling, semantic model, typed object/relationship graph, distributed persistent object model.

## INTRODUCTION

The discipline of ubiquitous computing is well established. A sub-domain of this study is location-aware computing in which a device will behave differently depending on its location and perhaps pro-actively supplying information to a user appropriate for a particular location or situation. Whilst location-sensing technologies can answer the standard question, “*Where am I?*” to varying degrees of accuracy, there exists a need to frame ‘*where*’ in the context of a modeled environment in order to move beyond simple inferences of position to a better understanding of what ‘*where*’ relates to semantically.

Previous research has produced various types of location models that provide an abstraction between users/devices and the raw data provided by various location sensing technologies. The earliest investigations into ubiquitous computing environments [6] introduced abstract models of location for the environment. Since then the models of location have developed in terms of representation and complexity. Previous work [4,5] has identified three types of location model:

- *Geometric* - allows points, areas and volumes to be modeled; however a point in geometric space has no relationship to what it points to. The resolution of this model is as fine as the units of measurement used.
- *Symbolic* - describes location and space in terms of names and abstractions. Unlike the previous model type, humans and computational devices can understand this model, however they lack the precision of geometric models.
- *Hybrid* - represents a logical step forward in combining the advantages of the previous model types in order to overcome their respective disadvantages. As a consequence the hybrid model is more complex, requiring greater amounts of data.

Despite these advances challenges still exist within the field of location modeling. This paper aims to highlight some of the current areas of research interest in location models for location aware computing and ubiquitous computing, discuss our early experience with location sensing technologies and present our vision of a novel approach for modeling environments.

## CHALLENGES

There are several complex aspects inherent in ubiquitous computing environments that make location modeling difficult. The earlier challenges of location modeling, representing position accurately and ensuring this representation was understandable to both humans and computers, have been superseded by greater challenges. The following list summarizes a selection of pertinent challenges facing future location models:

- *Managing complexity and scalability*: As models increase in complexity the management and integrity of the information becomes a critical design issue. In addition the design of a model should not only take into account the potentially large number of entities in a single environment, but also factor for multiple environments linked together.
- *Transient environments and aggregation of sensor data*: Designing a model that successfully bridges the

difference between administrative, social and home environments is challenging. Focusing the design on a single environment may obscure difficulties when applying it to another environment type. Many environments will support one or more differing location sensing technologies [3]. Aggregation of this multiple sensor data would rely on an abstract location model not directly connected to or dependent upon a particular location sensing technology.

- *Inference beyond position:* Whilst determination of position remains important there is potential for greater contextual inferences to be made from a model in terms representing conceptual, logical and physical connectivity.
- *Privacy and security:* Although previously acknowledged there are still many issues surrounding the access control and management of potentially sensitive location information.
- *Ontology for location:* The decision of how to describe space is not a trivial matter, however a common means to represent location across various different models may be useful.
- *Open and extensible model:* The task of providing location information for the model should not rely solely on a single source. The ability for other providers to supply additional information is desirable. In order for a model to evolve along with changes in the environment it and the sensing technologies employed it must be easily extensible and adaptive.

This list is not exhaustive, but it does reflect the effort still required in designing models. The following section discusses our previous experience in investigating location aware computing through combining location sensing with mobile agents.

#### **PREVIOUS EXPERIENCE**

The idea behind Boarders is very simple: Imagine a handheld device (such as the IPAQ) with a radio networking capability. When the device is carried into range of a radio base station, a mobile agent jumps onto (boards) the device and carries out whatever computation is deemed necessary. When the device goes out of range (and by implication the user leaves the location), the boarder agent is deleted from the device (after a suitable delay). In this manner software and data can be associated with a location. This technique is eminently suitable for the limited capability devices that are currently available for mobile computing: Software is installed on demand only where and when needed.

The real surprise with Boarders was how easy it was to implement on top of the mobile agent framework, AgentSpace2 [2]. It required the creation of an agent (which became known as a range-server agent) that listened for devices entering the range of the base-station and then

created instances of appropriate application agents and launched them onto the newly discovered devices. This experience convinced the author that mobile agents are an interesting approach to the problems of supporting location aware computing.

Several applications have been built using the boarders framework. One, Whiteboarders, is a communal whiteboarding application for use with students in lecture theatres. As students with suitably equipped and set-up devices enter a lecture theatre, they come within range of a base station that causes a whiteboard agent to be installed. The agents communicate with a coordinating agent allowing any drawings or marks made on the mobile devices to be displayed upon the projected display in front of the class. The ability to freely share impromptu diagrams and emphasizing marks is (usually) constructive.

A second example system was based on the idea of being able to associate information with both a location and a person (or group). In it's simplest form it allows users to leave virtual post-it notes in given locations for particular people or groups to pick up ("Since you're passing the store dear, can you pick up some potatoes please?") but the same design framework is now being evaluated as the basis for a larger scale (city-wide) tourist guide.

There are problems with the approach and reasons why it might not scale well: As yet there has been no serious consideration of security aspects, thus the system has prior knowledge (via configuration files) of devices that are allowed to participate. Introduction of a new device requires manual intervention. In the restricted context of a single department it has, however, proved successful.

The limitations of the Boarders approach soon became apparent - equating a radio base station with a room is a course-grained approach and ignores all manner of issues of signal propagation. The obvious solution, allowing a single base station/range server combination to control whatever physical rooms/regions are within its range, leads to the need for a second, finer grained stage of location service to be employed once a device enters a range. Several technologies could provide this level of service but for experimental purposes an audio-based solution was used. Basic operation remains the same - once a device's location is determined via the two-stage process, boarder agents appropriate to the location are launched onto the device.

Providing such a service requires that a range server maintain a description of the physical environment it is responsible for and have the ability to cross-reference that with any location services. The desirability of a general technique for describing ranges, locations, services and information rapidly became apparent and has lead to a project to provide such a technique for the development of a distributed (potentially global-scale) world-model. The project utilizes several other features of the mobile-agent paradigm - globally unique identifiers, persistence, inter-

agent communication - to facilitate the construction of a globally available distributed persistent object database and various languages including X3D and XML. Admittedly in this scenario, mobility is relegated to a minor role of supporting load balancing.

In the following section we propose an open architecture for modeling location in ubiquitous environments that will progress beyond previous models, address the challenges highlighted earlier and build upon the experience gained.

## VISION

We envisage a novel architecture, *SpaceSemantics*, which provides descriptions of arbitrary aspects (conceptual, logical and physical) of the real world and the relationships between entities existing therein, implemented across an open, distributed computing environment. *SpaceSemantics* will provide a universal model on top of which applications and devices can query over location knowledge and data from various location sensors can be aggregated under a common model.

Our proposed solution takes the form of a graph consisting of typed nodes connected by typed relationships. The nodes are implemented as distributed persistent objects and the relationships as references between the objects.

Unlike previous models that largely relied upon hierarchical arrangements we believe that a graph permits intuitive traversal whilst still allowing hierarchies to be modeled. The relationships between nodes will form various typed networks ranging from simple containment and connectedness to ownership, all of which can be linked and traversed.

*SpaceSemantics* will possess properties of openness and extensibility such that the model is not maintained nor provided by one authoritative source. If for example a department provides a basic floor map with little detail other than room nodes with names, then an occupant can overlay their own model of their room to create a more detailed model. Inspiration for an open model is drawn from the same distributed and participatory approach, to constructing a world-model, as demonstrated by the World Wide Web and Peer-to-Peer networks.

The overview of features that this architecture will possess place great demands on the technology employed to implement it. The network of nodes is not static; instead it is expected to grow and evolve (as information becomes available or is refined) and requires a flexible solution. A

distributed network database of persistent objects is adaptive and flexible to change making it a suitable approach. The objects, descriptions and relationships are collapsible to XML, X3D and Xlink in order to maintain parts of the model as they become unavailable through disconnection from the network.

## SUMMARY AND FUTURE WORK

The modeling of location information is of great importance to location-aware computing. The results of previous research have increased our understanding of the issues inherent in the field. Challenges however are still present and require effort to overcome. This paper has highlighted a few of the interesting challenges facing location modeling and we have introduced our approach with *SpaceSemantics*.

Work on *SpaceSemantics* is currently at the design/first prototype stage. The desire is to integrate *SpaceSemantics* with the Strathclyde Context Infrastructure [1], a project investigating the composition of contextual components to support context-aware applications.

## REFERENCES

1. R. Glassey, G. Stevenson, M. Richmond, P. Nixon, S. Terzis, F. Weng and R.I. Ferguson. Towards a Middleware for Generalized Context Management. *In Proc. 1<sup>st</sup> International Workshop for Middleware for Pervasive and Ad-hoc Computing*, pp. 45-52, Middleware 2003 companion.
2. D. Grey, P. Dunne and R.I. Ferguson. A Mobile Agent Architecture for Searching the WWW. *In Proc. Workshop on Agents in Industry, 4<sup>th</sup> International Conference of Autonomous Agents*, Barcelona, 2000.
3. J. Hightower and G. Borriello. Location Systems for Ubiquitous Computing. *IEEE Computer*, 34(8), pp. 57-66, 2001.
4. C. Jiang and P. Steenkiste. A Hybrid Location Model with a Computable Location Identifier for Ubiquitous Computing. *Lecture Notes in Computer Science*, v. 2498, pp. 246-263, 2002.
5. U. Leonhardt. Supporting Location-Awareness in Open Distributed Systems. PhD Thesis, University of London, UK, 1998.
6. B. Schilit and M. Theimer. Disseminating Active Map Information to Mobile Hosts. *IEEE Network*, 8(5), pp. 22-32, 1994.