Modeling Location for Pervasive Environments

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***Abstract*—The representation of spaces, locations and the entities they contain is of great importance to location aware systems and pervasive computing scenarios. There has been an active research community in developing many diverse models of location, resulting in significant progress in the area. Various types of location model have evolved through experiment and experience however there still remains many challenges to be met by the research community. This paper aims to highlight previous trends in location modeling, discuss the research challenges ahead and to outline the initial design of a location model for the Strathclyde Context Infrastructure [1].**

I. Introduction

Location information is a fundamental aspect of pervasive computing. The ability to discover an entity's location within a space and be able to reason about relationships with other entities sharing this space is very useful. Location modeling refers to the capture, organization and reasoning of location information. The earliest efforts to develop ubiquitous computing environments [2] introduced abstract models of location for the environment. Since then the models of location have developed in terms of representation and complexity. Previous work [3], [4] has identified four types of location model.

- *Geometric* - allows points, areas and volumes to be modelled, 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.
- *Semantic* - rather than focusing purely on position, this model type is concerned with relationships of entities in space and between the spaces themselves.

Despite the progress made so far with respect to modeling location many challenges have been identified that must be overcome. The next section highlights some of the pertinent challenges.

II. Challenges

The following list briefly discusses a collection of challenges that have to be overcome in order to progress the utility of 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.
- *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. Aggregation of this multiple sensor data would depend on an abstract location model not directly connected to or reliant upon a particular 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 including both physical and conceptual 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. We propose a location model for pervasive environments that will overcome shortcomings of previous models and meet the challenges highlighted.

III. Design

A. Outline of Strathclyde Context Infrastructure

The Strathclyde Context Infrastructure (SCI) is organized into two distinct layers. The upper layer of the infrastructure is a network overlay of partially connected nodes. The lower layer of the infrastructure concerns the contents of each node, which consists of entities (People, Software, Places, Devices and Artifacts) responsible for producing, managing and using contextual information, and is referred to as a Range [1]. The purpose of the Range is the logical partitioning of space. Our context infrastructure requires a location model for Ranges that captures the geometric, topological and logical spatial relations that will allow fine grained control over the interaction of entities with the real world and the user.

B. Location Model Design

In order to make the model of location as flexible as the notion of a SCI Range, multiple environment types must be considered from the initial design onwards. It is deemed too restrictive to design a model with a bias towards a single environment type. It is believed that modeling transitive environments, whilst difficult, brings us closer to a more realistic model that would be useful across the many diverse environments encountered in everyday scenarios.

Extending from the above point is the need to make use of multiple sensor technologies (passive IR, RFID tags, GPS and wireless signal strength [5]) found within environments and deal with uncertainty when faced with imperfect information. This points to the need for the model to employ simple abstractions that enable an interface between sensor and model to be developed that hides the complexity.

Previous location models have largely relied upon a static hierarchical tree structure as a natural means of how humans reason about space and how buildings are constructed. This approach however limits aspects of reasoning beyond physical connectedness and provision of navigation using path cost metrics. Whilst at the basic level location can be viewed as hierarchical it is perhaps more accurate to model location with multiple parents, eventually representing a graph structure. This flexibility allows for basic navigation tasks like a route from A to B, to more logical concepts of navigating administrative group structures instead of just architectural structure. A graph approach is suitable for modeling more than physical relationships between entities. For instance a group of rooms may be physically connected by doors and corridors, but they also form a research area within a department which does not have physical form. This notion could also support rooms that are physically separated by floors or buildings, but which are logically related. A hierarchical model would struggle to represent this form of concept. Modeling conceptual arrangements of location and entities beyond their physical location is a goal of this model.

C. Location Queries

Having described the need for interaction with multiple low level sensors, consideration must be given to providing high level access to the information contained within the model. The form of the query and the resultant reply will be of great importance to the variety of contextual services and location aware applications that may demand location information. The design of the query will be such that it is both open and flexible with due consideration to returning sensible replies. The query should benefit from the graph model, remembering both physical and logical connectivity attributes, so that a query asking, "which members of the research group X are presently in their offices?" would pose no problem.

D. Management of Model Information

In terms of managing the location information modelled, it's accessibility, integrity and security, a distributed model will be used instead of a centralized solution. This decision is partly influenced by the nature of Ranges within SCI, distributed across and connected by an overlay network. Whilst a centralized solution may favour performance, it will not be suitable to deal with the scalability issues inherent in pervasive computing environments. The management of the model will include features of openness and extensibility. It is envisaged that as more location information becomes available that it can be integrated easily in order to evolve the model. The ability to extend the model should encourage the process where the content can evolve without the need to develop new models to cope with new information. These features however raise the question of whether an ontology for space needs to be developed and how new information can be mediated for inclusion.

IV. Summary and Future work

This paper has sought to provide an brief overview of how location models are currently being developed and the future research challenges. The list of challenges is by no means exhaustive but it does highlight the types of issues location modeling must overcome.

The next step will be to formalize the design goals of the location model for Strathclyde Context Infrastructure into a specification. Prototypes of this model can then be implemented and tested in order to determine their usability and areas of improvement. The evaluation of the model will be initially the simulation of environments and typical usage, with a view to modeling real world environments and scenarios.

References

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