Location Models from the Perspective of Context-Aware Applications and Mobile Ad Hoc Networks

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Abstract. Location models are crucial to location-aware applications. In this paper we present two approaches for modeling location information in an infrastructure-based and an ad hoc network based application scenario. From these approaches we deduce requirements for a general location modeling language for ubiquitous computing.

1. Introduction

Ubiquitous computing applications depend on information about their environment. Modeling the environment, and especially location, can be done either implicitly, meaning the application contains the model information, or explicitly via a service that stores model information and allows applications to query the model data. In this paper we focus on explicit models. The development of detailed location models is a costly task and we therefore believe that different applications should be able to share the same model information. Having such a common model may increase interoperability between applications and make new classes of applications possible. The basic requirement for such an approach is a common language for describing and querying location information.

Before being able to define such a language, it is important to look at different classes of applications. We consider the network environment, e.g. the availability of a connection to an infrastructure or the ad hoc information exchange between devices, to be an important factor for distinguishing between application classes.

In this paper we want to sketch two different approaches of our group that tackle location information. One is situated in the domain of context-aware computing, relying on an available infrastructure, and the goal is to provide a common platform for location-aware applications. The other aims at location management in mobile ad hoc networks (MANETs). In the infrastructure-based approach we refer to world models containing objects of the real world augmented with virtual objects, such as virtual Post-its. An important part of such a world model is related to spatial information, modeling the environment. In the ad hoc case we rely on a spatial model as the foundation for other models as they are required by applications.

Based on these two approaches we will try to derive some important requirements for a general location modeling language in ubiquitous computing.

This paper is structured as follows: first we want to present a classification of model based architectures depending on the infrastructure support and cooperation of mobile nodes. After that the aforementioned approaches are discussed. Finally, based on our experiences with these approaches, we derive some requirements for a location modeling language.

2. Classification of Model-Based Application Environments

In the following we will describe three classes of model-based application environments that we have identified. They can be distinguished based on the storage of the model data and the cooperation and distribution of the application.

2.1 Infrastructure-based

Storing model data in a globally accessible repository enables distributed applications to interact with their environment according to the model and their location. Mobile nodes in such systems require access to the infrastructure in order to access stored model data. Location information of the nodes has to be provided to the infrastructure thus they can retrieve location-dependent information. As a result, mobile nodes have to obtain their geographic position via GPS or other means. This implies mobile nodes with certain capabilities with respect to their communication as well as computing power and sensor inputs, e.g. GPS or RFID-reader for location determination.

This class of applications is characterized by the centralized model information. Distributed applications are based on the consistent model information. Locally stored data is mainly used for performance reasons or to allow for tolerating network partitions. An example of such an approach is the NEXUS system discussed in Section 3.

2.2 Ad hoc

MANETs are constituted through mobile nodes without any a priori known topology, which is highly dynamic. Nodes are small computing devices, such as smart things or cell phones, PDAs to name a few. The interaction of these devices is dependent on the environment. First, long range communication is too costly in either monetary terms or energy consumption. Relying on locally accessible data helps to optimize the power consumption. Second, applications on such devices are typically related to the user and his desires respectively. Hence, the discovery of services in the proximity of the user can guide him through a smart environment and provide a multitude of information. Storing model information about the world in a MANET is different from an infrastructure based approach. MANETs do not allow the access of services from every position in the network due to partitioning of the network. As a result, applications relying on model data have to store them locally. Different applications on different nodes can rely on potentially inconsistent states of the same model. In Section 4 we will discuss the CANU approach to update location information using a diffusion-based approach.

2.3 Isolated

So far we have discussed applications sharing the same model in either a centralized or distributed data storage. A different kind of application does not share the model but relies solely on its local model. Inconsistencies do not occur – at least from the point of view of an application – since decisions based on the model are based on the locally stored data. Examples are applications from the domain of robotics where nodes are mainly autonomous. The model contains data about the environment, e.g. a factory map, and allowed transitions within the environment.

2.4 Common Ground

The aforementioned approaches describe different application models relying on model data. Location information is crucial for most of the application scenarios ubiquitous computing aims at. The infrastructure and ad hoc approach will coexist in many scenarios. The MANET could be used to propagate information that is too short-lived for a centralized storage or only interesting in a small area. The infrastructure could provide the ad hoc network nodes with model data in distinct areas, thus giving mobile nodes accurate model data for the surrounding area. Therefore, it is feasible to aim at an integration.

3. Location Models for Location-Aware Applications: The NEXUS Case

The goal of the NEXUS project is to develop an open platform for location-aware applications. The objective of such a common platform is to provide a foundation that makes the development of location-aware applications much easier and allows for a better integration of and interaction between different applications. In this section we will focus on the parts that are relevant regarding the modeling of location, a more detailed description of the NEXUS project can be found in [1].

3.1 Augmented World Model

The core of the NEXUS platform is a common augmented world model that provides the whole location context for context aware applications. This includes the representations of static real-world objects such as houses, streets and offices, mobile objects such as human users, cars and trains, but also virtual objects with which the real world is augmented. Examples for such virtual objects are virtual billboards, virtual Post-its or virtual kiosks.

Since the objects we want to model have very different levels of detail, the world model will be distributed and offered by different providers, e.g. the city of Stuttgart might provide a model of the whole of Stuttgart with the granularity of houses and streets, the University of Stuttgart might provide a more detailed model with some information about the buildings on campus and, finally, the Faculty of Computer Science might provide a detailed plan of the interior of its building with lecture halls and offices.

3.2 Location Information in NEXUS

The augmented world model is described using the Augmented World Modeling Language (AWML) and the model can be queried using the Augmented World

Querying Language (AWQL). Both languages are defined using XML schemas. A detailed description of the languages can be found in [2].

Objects in AWML have attributes that give their geometry relative to some coordinate system. For this geometry description we use the Geographic Markup Language (GML) [3], an XML-based language that has been specified by the OpenGIS Consortium. The GML geometry schemas support points, lines and polygons as its basic geometric elements, but also geometric collections such as multipoints, multilines and multipolygons.

GML does not define a fixed coordinate system to be used. Instead, a spatial reference system (SRS) has to be given, relative to which the coordinates are defined. In NEXUS we will use several different coordinate systems, e.g. WGS84 coordinates that are used by the GPS system, but also Gauss-Krüger and UTM coordinates, that are commonly used for maps and therefore are often found in geographical information systems. In some cases, it may also be necessary to use a local coordinate system, e.g. when defining locations on an object such as a ship that is moving relative to a global coordinate system.

However, AWML not only models geographic location and the geometry of objects, but also symbolic descriptors of the objects such as room numbers and explicit relationships between objects, such as the *part-of* relation. This is especially important when linking together different parts of the model that may be supplied from different providers.

The query language AWQL allows the querying of the world model for objects adhering to certain restrictions. These restrictions include spatial relationships to other objects, such as *inside*, *overlaps*, *includes*, *excludes* and *closest*. With boolean expressions, restrictions can be combined. In addition, the language supports generalization and aggregation rules which allow smaller details to be removed and small objects to be merged into larger objects, e.g. for a large map, drawing every single house is too detailed, instead the houses are combined to one large block.

Information about the current location of mobile objects may be provided by a number of different sensor systems, ranging from GPS/DGPS outdoors to infrared- and radio-based systems indoors. Because of the different characteristics of these sensor systems and the update rate, the Nexus platform has to deal with different levels of accuracy and has to provide parameters that allow the user to specify what should and what should not be included as the result of queries to the platform.

4. Location Models in MANETs: The CANU Case

The CANU project aims at supporting applications in MANETs. Similar to NEXUS the applications in the CANU project depend on model data about their environment. Due to the ad hoc network characteristics mobile nodes do not have access to a centrally stored world model as it is provided by NEXUS. As a result, relevant parts of the model have to be stored on every node. Space constraints as well as inconsistencies between the model data require distinct precautions. This section briefly sketches the model data and its usage for message delivery as well as the exchange of model data via diffusion.

4.1 CANU Environment

CANU nodes are situated in a mobile ad hoc network. We assume such networks to be formed by mobile devices users carry, e.g. cell phones or PDAs. These devices are equipped with short range wireless communication such as Bluetooth or IEEE 802.11 in peer to peer mode and can obtain their location.

A major assumption of our work is that human beings do not follow the random walk pattern. Humans typically move with either a distinct purpose or at least with a pattern constrained by their environment, e.g. people have distinct schedules – commuting the same route at more or less the same time each day. As a result, this information can be used for choosing a relay for message transport in MANETs.

4.2 Models in CANU

CANU nodes obtain model data about their environment either through some infrastructure if available, e.g. when entering a building, or from other mobile nodes. The fundamental model for CANU applications describes the spatial environment, e.g. a road map or building chart. We want to refer to this data as *spatial world model*. This model is internally represented as a graph with nodes referring to rooms, places, or buildings in the real world and edges denoting the interconnections between places. This spatial model is the foundation for all other information provided to CANU applications. Information is considered to be affiliated with a location, hence linked to a node in the spatial model. The spatial model acts as a world model to the CANU applications allowing queries about objects.

As mentioned before, we consider nodes following distinct movement patterns. These patterns describe the likelihood a user – and therefore the mobile device – moves to a distinct location. A *user profile* is another model in CANU representing the movement pattern of a user.

Application specific models can be realized with respect to the spatial model as well. For a simple example consider a location service for a building or a floor. Objects of interest are stored with a link to the spatial model indicating their position. Whenever two nodes meet, they update their information taking the latest of both. We have shown through simulations that such a simple diffusion algorithm propagates data in typical indoor scenarios with tolerable delays, e.g. 39 seconds average delay with 100 nodes in a typical 3 story building. Based on such information, messages can be routed to locations. This can be used to route a query to a location obtaining current data available at that location. Such query routing can rely on the user profile as well as normal message routing. Choosing a relaying node can incorporate information about the most likely direction, hence choosing better relays than only based on bearing and speed.

To sum up, the spatial model in CANU provides a framework for location-dependent information. This can be used as a foundation for application specific models as well as for user profiles allowing different routing protocols in MANETs.

5. Requirements for Modeling Location in Ubiquitous Computing

So far we have discussed two approaches of location-aware platforms. Common to both is that they explicitly model the world independent of a particular application. The model can be queried, using a querying language that provides a useful abstraction, decoupling the application from the internal representation of the world model. We see this as the first requirement for modeling location in ubiquitous computing.

The primary representation of model data in NEXUS is the geometry of *objects* using geographic coordinates. What CANU needs is a model represented as a graph with *nodes* referring to *places* and *edges* denoting the *interconnections between places*. With a geometric model, the relevant *objects* that are *places* for CANU have to be identified, which requires symbolic information that NEXUS already provides in form of attributes. This information is used to restrict a query to return only relevant objects such as rooms or buildings. At the same time, the appropriate level of detail has to be selected, e.g. if the application is used outdoors, it is sufficient to return *places* at the granularity of buildings, whereas indoors, the rooms of the building the user is currently in are appropriate. In order to get the *interconnections between places*, it is necessary to have relations between the objects involved. Some relations are modelled implicitly when the geometry is modelled, e.g. which rooms are next to each other. However, this may not be sufficient, if the geometric model lacks information about doors between rooms. In this case, this relation has to be explicitly modelled. Since all this information can be modelled in NEXUS, the spatial model needed for CANU can be downloaded at special locations with connection to the infrastructure and from then on, it can be used in its ad hoc environment.

From this example, we derive the following requirements for a general location modeling language for ubiquitous computing applications that should be able to:

- describe the geometry of objects relative to different coordinate systems.
- express symbolic information, i.e. names and descriptions of objects.
- express certain relations between objects.
- support the description of objects in different levels of detail and provide the means to express connections between sub-models in different levels of detail.

Overall, we believe that location models are crucial to the development of location-aware applications and most applications in the area of ubiquitous computing are, at least to some degree, location-aware. We argue for explicit location models. The development of location models, especially when extending them to detailed world models, is a costly task. Therefore, different applications should be able to share the model. This also leads to a better interoperability between applications and new classes of applications may only become possible with the existence of such models. Decoupling the application through a query language from the internal model representation allows to hide the different levels of detail of models as well as the necessary model representations.

References

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