Semantic World Models for Ubiquitous Augmented Reality

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Abstract

Augmented reality (AR) applications use geometric models as a central component of their operation. Both rendering and interaction require a detailed knowledge of the environment and the objects to be visualized. Usually such models are created especially for a single application and provide exactly the required information. With the combination of AR and ubiquitous computing more complex requirements for such models are appearing. In this paper we describe our experimental prototypes of semantic data models for ubiquitous augmented reality applications and discuss some further research directions and approaches to such world models.

Keywords: augmented reality, semantic data models, location based services, ubiquitous computing

1 Introduction

Augmented Reality (AR) is a new user interface technology that uses see-through displays to superimpose context-sensitive computer generated information onto real scenes, for example to provide a surgeon with X-ray vision into the patient's body, or to instruct a repair person on location how to perform a complex maintenance procedure.

One crucial aspect of many augmented reality applications is an accurate and detailed model of the real world and its relations with the application's content. Because the interaction in AR plays out in the real world and not in a completely controlled environment, the machine has to make up for lack of control over every aspect of the presented impressions by exerting even more control over the artificial parts of it. A simple example are occlusions between real and virtual objects. Here the virtual objects are clipped against 'invisible' twins of real objects to achieve the desired effect.

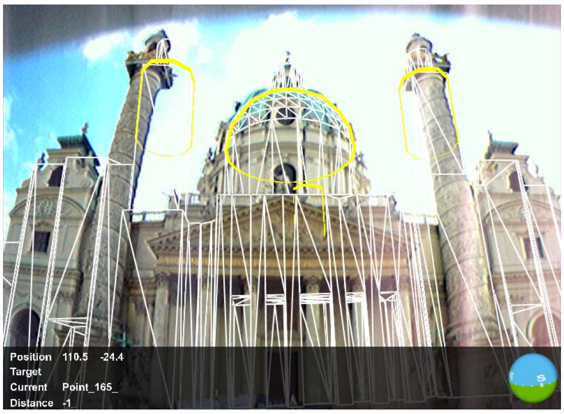

Figure 1: A view from an augmented reality tourist guide application: A historic building where annotated locations on the facade are highlighted.

An emerging area of AR applications overlaps with the domain of mobile and ubiquitous computing. Here the geometric models behind the application will certainly grow in size and complexity as they will have to cover a larger area and diverse structures from city scape building blocks to individual rooms and interiors. For such models a number of new requirements appear concerning cost, ease of reuse, inter-operability between providers of data, and finally use in the individual application.

In our research experience with mobile AR systems we created models of city environments and encountered a set of problems that led to a first attempt at building a reusable and extensible world model. Several applications are based on the model and store mutually independent, application specific information associated with reusable geometrical data (see Figure 1). The existing prototype helped us to identify a number of shortcomings and we will present our ideas towards a semantic data model for ubiquitous applications that integrates high-fidelity 3D information.

2 Requirements for semantic world models

A generic world model for ubiquitous augmented reality applications needs to scale the traditional aspects of models for standard AR applications to large environments.

Content for stationary, location-bound applications usually has a fixed structure and clearly specified variations. For example, a car maintenance application deals with a defined workflow description and individual models of car parts. A location-based, ubiquitous application will work in a very different software environment. While its purpose might be well defined, such as navigation, the data provided will not likely come from a single source. Rather federated information providers will exist that each are responsible for a certain part of the overall environment such as a single building. An application will therefore have to content with different formats, model resolutions and properties.

2.1 What to model

3D models for augmented reality differ from pure visualization applications in that not every object is actually rendered. Nevertheless, the 3D boundaries are required to provide an engaging and immersive experience by creating visual effects such as correct occlusions and artificial shadows or providing complex interactions with real or artificial objects. Therefore, in addition to detailed geometric information, extensive annotation is required to describe the properties of objects such as being part of the real world or not, being tracked, translucent or light emitting.

Moreover, applications require information on various relations between objects. Some examples are: relative transformations to be able to render objects at correct positions once the user's location is established; connectivity information for rooms to be able to derive routes for navigation; association between facade features such as windows to rooms to reuse the windows for information display that concerns the rooms. The modeling aspect of such different topological relations was typically neglected in traditional computer graphics which was mostly concerned with realistic images.

2.2 Reuse and efficiency

Creating such models is expensive, thus an important objective is to be able to reuse them across different applications. Indeed we expect that the models are provided by application independent services and that individual applications will on the fly query the models to retrieve geometric information. The annotation information can then be used to integrate the object models as required into the presentation.

2.3 Meta-data and annotations

Inter-operability between models and applications should be dealt with in the most flexible way. By describing the relations and types in a model with explicit meta-data an application can adapt to a given model by mapping the model's relations to the application's. Having such translation mappings will allow to expand the scope of an application while keeping the effort low, because instead of transforming the whole model or rewriting the application, all that is required is a new mapping.

Therefore meta-data on the model's structure and content is necessary. This data should follow industry-wide standards which are currently developed by the semantic web community and are already being adapted to pervasive computing environments [1].

Another requirement is to relate the model's objects with other abstract data, such as business, administrative or engineering databases. Without such connections, no real world applications would be possible. However, in the interest of maximizing reuse of the model itself, such relations should be again stored and described independently of the model.

2.4 *User interface challenges*

The number of degrees of freedom in an AR user interface is larger then in other user interfaces because not only the user's own movements are required to be tracked but also state of the world such as object locations need to be taken into account correctly. Therefore, a successful presentation of information in an AR setting has to take a large number of cases of spatial and visual relationships between the application entities into account. The number of combinations overwhelms the possibility of designing solutions for all of them by hand.

Thus, automated methods of creating appropriate presentations from an appropriate model and rule set will be required to make intelligent and good presentations possible. The KARMA [2] system was an early example of this approach. Future AR applications will be better informed of the goals of the user and be able to derive appropriate presentations from the known goals automatically. Information-rich models are required as a basis for knowledge-based algorithms to perform well. Therefore it is worthwhile to investigate such models.

3 First experiences

We created an outdoor augmented reality system to gather requirements for modeling large environments. On this system we implemented a tourist guide application which requires extensive 3D models and information which is presented to the user. Accurate and complete models of the buildings and other obstacles in the environment are required for rendering occlusions and highlights of buildings. Additional models mark the active regions of objects which trigger information displays. The navigation mode requires a network of paths and address information related to the buildings. Finally, semantic data links historical information, address points

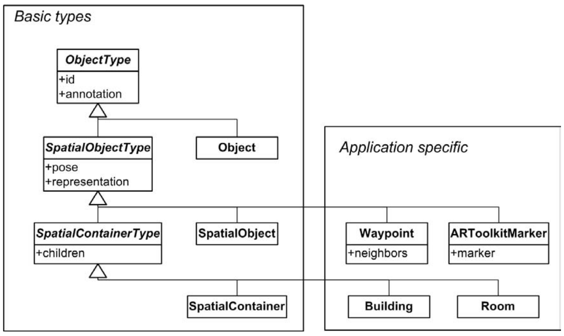

Figure 2: Overview of the type hierarchy in the model schema. A set of basic types can be used for general modeling. Applications may derive additional types for specific requirements.

and building models together.

3.1 *Modeling*

At the heart of our architecture lies a data model that encompasses all application requirements. Care was taken in keeping the model extensible so that new data could be integrated during the development. This data model is described by an XML schema.

A number of key requirements were established from the outset. Geometric representations and hierarchies need to be stored in the model. Interaction with other data schemas should be possible to maximize reuse of already established knowledge presented in the form of these schemas. Extensibility for new applications and data types with fall-back options for generic processing is important.

The model is based on an object-oriented approach using a type hierarchy to define a taxonomy of objects. The root type is called *ObjectType* and contains an id and a generic annotation subelement that can be used to store any XML tree. All data types defined in the model are derived from this type. The *SpatialObjectType* adds pose information and a geometrical representation to the super class. We further derive the *SpatialContainerType* that adds a child subelement to aggregate entities of type *ObjectType* for hierarchical composition.

From the three base types, we derive a number of application specific types that are used in the actual data files. The *Object, SpatialObject* and *SpatialContainer* elements are used for general purpose data and correspond directly to the base types (see Figure 2). Applications can define additional types derived from the base types to provide more specific information. For example, we define a special *Waypoint* element used by an outdoor navigation application which has a specific subelement to define neighboring waypoints connected by a path. Because elements refer back to their base type, an application can always provide a reasonable fall back behavior if it encounters an unknown derived application element. The Nexus project [3] uses a similar structure to model their data types.

The XML tree is interpreted in the standard geometrical way, by defining a child's pose relative to its parent. We chose this mapping to support conventional modeling of visual data as trees. However, the open XML based format is not bound to any particular visualization tool or platform, and affords the definition of other than spatial relations by using relational techniques such as referring to object ids. The annotation subelement of the abstract root type can be used to model free form data or to augment preexisting types with extra information. Hence, more flexible technologies can annotate the objects in our model.

For example, icons representing historical information are modeled as simple *SpatialObjects* that are annotated with keywords and content. Different representations are generated for the tourist guide application based on a mime type stored in the content. Similarly we could use any meta-data standard to annotate content.

3.2 Implementation

We implemented the model building upon XML technology, thus leveraging recent developments in the web application community. The proposed architecture is very common in this area and directly supported in a number of products, either open-source or proprietary. The use of XML has a number of advantages:

- A hierarchical data model fits well to our general spatial model. Rather than using a flat enumeration of building representations, a hierarchical model can represent several levels of a spatial hierarchy, from districts and streets down to rooms within buildings and other detailed geometrical data.
- XML tools such as XSLT [4] allow rapid prototyping and development of import, transformation and export tools to and from the data model. Such tools focus on the functional aspect of the transformations and reduce the overhead in implementing parsers and generating data structures.
- Standards for semantic descriptions of data such as the Web Ontology Language [5] or the Dublin Core [6] allow the use of ontologies to support semantically rich queries and interactions.

3.3 Example instance

An instance of the general model was built to serve as the basis for a prototypical tourist guide application. A 3D model of part of Vienna was kindly provided by the city administration of Vienna. The department of Geoinformatics at Vienna University of Technology supplied a network of accessible routes for pedestrians which was derived from the general map of Vienna and is represented as an undirected graph. Each node in this graph is geo-referenced and represented by an object of type Waypoint in the model. For each building a waypoint was defined as well and incorporated into the path network to construct a path to this address (see Figure 3). Furthermore, annotation information such as businesses located at certain addresses was associated with the buildings. Finally, we placed virtual icons as spatial representations of interesting information into our model. Cultural information taken from a guide book was included at various places to provide the detailed data for the information browsing component.

The inside of our institute building was also partially modeled and included. The interior is modeled as a set of rooms with connectivity information between doors that connect individual rooms to provide navigation information. The model also contains information on optical fiducials for a wide-area tracking solution [7].

The model instance contains a collection of information items that usually have geometric representations but are not tied to a single purpose or application. Different applications will

Figure 3: Overview of an extensive model covering a part of Vienna for a tourist guide application.

query the model for all items of interest which are determined by meta-data or relations to other items in the model. The resulting set of items is then visualized using the geometric representations. Moreover, the geometric models are also important for user interaction such as selecting an item or determining visibility.

3.4 Application prototypes

Several application prototypes were developed that build upon the described model instance. These include a tourist guide application for outdoor environments which allows a user to roam a city, navigate to reach interesting locations and browse the location for additional information. Such information is selected by looking at an object which is visually highlighted to signify that further information is available (see Figure 4, left). When an object is selected, the historical information is presented in the view of the user. The information itself is stored in an application independent manner within the attribute subelement of objects. The browsing component searches for and only uses such objects that are annotated in this way.

Another application is a generic navigation application for indoor environments. Because the topology of rooms in buildings is very different from open spaces outdoors, navigation hints may be presented very differently. Here the application directs the user from room to room by pointing him to the next door which is again visually accentuated (see Figure 4, right).

3.5 Mobile augmented reality system

The described applications used a mobile AR system consisting of a notebook computer with a 2GHz processor and an NVidia Quadro4Go graphics accelerator operating under Windows XP. It includes a wireless LAN network adapter to enable communication with a second mobile unit and a GPRS card for more robust network access. A Trimble Pathfinder Pocket differential GPS receiver is used to determine the position of the system in outdoor applications. All the equipment is mounted on a backpack worn by the user. We use a Sony Glasstron optical-see-through stereoscopic color HMD fixed to a helmet as an output device. An InterSense InertiaCube2 orientation sensor provides information on the direction the user is looking in, and a PointGrey Research Firefly camera mounted above the HMD is used for fiducial tracking indoors and video see-through configurations. Both devices are mounted on a helmet worn by the user.

3.6 Discussion

The presented world model provides integration of geometric data with semantic information. Geometric data serves as an application independent basis for the visualizations and is associated varying meta-data. However, the emphasis on the geometric aspect is still too strong as the model's structure is solely oriented towards the relative geometric locations of objects.

The direct mapping of geometric structure to XML is not flexible enough. Therefore, an explicit representation of the geometric and other relations is necessary to provide the required flexibility. Also we want to use a more general approach to define other relationships besides relative geometric locations within the model itself to provide a basis for application specific extensions of relations in the model. A general

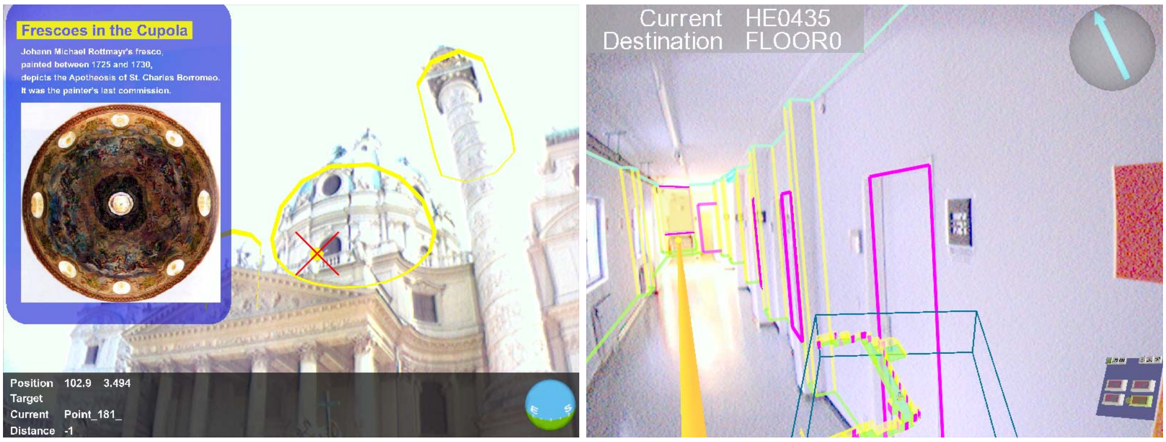

Figure 4: (Left) Tourist guide: different parts of a building are highlighted to show possible additional information. (Right) Indoor navigation application directing the user to the next door.

conclusion is that both attributes of objects and relations between them need to be extensible by applications.

Another aspect that was not touched by the work described above is the automated generation of user interfaces. Here static transformations from the generic models were implemented for each application component in turn. While this approach fostered reuse of the model data in different components, it does not have enough knowledge to change the visualization substantially. As the transformation did not happen at runtime, it could only provide static data on which a dedicated application could operate.

4 Research directions

As future research direction, we want to focus on creating a flexible semantic world model for ubiquitous augmented reality applications. We propose to view such a model as a semantic network and implement it with current semantic web technology. The idea is to explicitly and dynamically model all required relations between models in a such a web. These will consist of:

- Topological relations
- Attributes of objects
- Type information on objects
- Association with abstract and structured data

The proposed approach promises to bring the following advantages to our undertaking:

Explicit representation Various spatial relationships can be represented explicitly and independently of each other in a general network model. Thus we reduce the implicit assumptions present in application code on the provided model and explicitly state them in query operations on the model. Furthermore we abstract the required relationships from the application by representing them in the intermediary query and result transformation steps.

Schema-independent representation A semantic web representation is independent of any schema used to create and describe the model. A dedicated ontology description language is used to create one or more interrelated schemas to annotate the model data and support query mechanisms.

Adaptable to any schema Because of the last point the model will be adaptable to any schema by formulating translation ontologies between two different schemata. Data can therefore naturally be fused and only a well defined maintenance step is required to make it possible.

Deduction-based query algorithms Based on the additional schema descriptions query algorithms have been developed that allow complex and 'meaningful' queries on a semantic web of information. We can deploy such tools to integrate queries based on spatial relations and such based on traditional assertions stored in the web.

4.1 Assumptions

A number of explicit assumptions and restrictions are made to arrive at a feasible approach.

Geometric vs. Topological Topological relations are stored explicitly. It is possible and, to some extent, feasible to compute topological relations from geometric properties of the stored objects.

Future implementations of ubiquitous AR applications will require the creation of relevant topological information from the underlying geometric data because of the sheer size of the required data sets. Deriving topological relations will probably involve good definition of the relations, heuristics in the implementation and a lot of infrastructure development in the area of GIS and spatio-temporal databases. As such it certainly is beyond the scope of a first prototype.

Federation of distributed databases A real-world implementation of a semantic model for ubiquitous AR applications will not come from a single source of data. Therefore the federation of several databases into a single front-end for the application is an important topic. Another successful research project Nexus [3] is already addressing this issue.

Design of scalable model server Similarly to the problem of distributed databases we will also not concern ourselves with achieving true scalability in our model server infrastructure. While we certainly want to operate in real-time within networked environment using a dedicated model server, we do not expect to go beyond a handfull of clients and into complete city-scale databases. Therefore we do not plan to immediately address the design and implementation implications of hundreds of users, queries or large-scale data sets.

4.2 Adaptive visualization

One direction we are particular interested in is using the extensive knowledge on the objects' relations and attributes to create visualizations in an algorithmic manner. To achieve this goal we will need to model the following aspects of an AR application.

Tasks A set of common tasks that such applications should provide. Examples are to point out or accentuate an object in the environment; To show a certain spatial orientation that an operation requires; to show a direction or target in an environment. These tasks are reused across different application domains and make up a large part of an AR interface. Applications need to specify what objects should be presented to achieve which of these tasks.

Modalities A set of possible visualization modalities and the knowledge which tasks they can support. Research is already defining adequate visual styles for presenting objects in AR that have special relations with their environment, e.g. occluded objects.

Constraints should describe the applicability of different modalities with respect to the context of the visualization. For example, the user's view direction dictates if the object that should be accentuated is within the current view volume or not. A corresponding constraint could then describe whether an arrow pointing in the general direction of the object is sufficient or a more detailed visual highlight should be used.

Rules will tie task, modalities and constraints together. They are the basis on which an inference engine will work to determine from the specified tasks and objects the appropriate modalities which are to apply to the individual entities of the final visualization. Such an inference would be dynamic to take the interactive nature of AR into account and react to any changes in the user's pose or environment.

5 Related work

Navigation and information browsing are two common themes used in demonstrating wearable computing and mobile augmented reality. The Touring Machine [8], the work described by Thomas et al. [9], and the Context Compass [10] show how pedestrian navigation can benefit from heads-up displays and AR interfaces. Information browsing was first demonstrated in the Navicam project [11] and has since become a popular topic of AR applications. Later work on the ARCHEOGUIDE [12, 13] and LIFEPLUS [14, 15] projects demonstrates the use of mobile augmented reality for tourist guide applications. Both support complex models for story-telling purposes which are again tailored towards the application's requirements. Some work on information filtering [16] and label placement [17] addresses the issue of managing user interfaces for large numbers of data items, but from a user's point of view rather than that of the application.

Typical AR demonstrations work with small data sets that have been created manually and do not require extensible semantic models. Consequently, there has been little work on semantic data models for large AR models. Höllerer et al. [18] describe the use of a database and description logic based meta-data to store a model of a building floor which is annotated with meta-data for navigation target selection. The sentient computing project [19] uses a CORBA run-time infrastructure to model a live environment as distributed software objects where locations and attributes of objects are updated permanently. Newman et al. [20] describe a set of AR applications based on this infrastructure.

The Nexus project [3] is unique in that it specifically deals with the software architecture required for ubiquitous location-based applications and provides abstract interfaces for location data to such applications. Although the project does describe some preliminary augmented reality applications [21], it does not focus on AR applications interacting with complex information structures. Glonass [22] also describes a software architecture to distribute context information but does not provide the extensive models that advanced AR applications require.

The geographic information systems (GIS) community has a lot of experience with storing and manipulating large scale geometric data [23]. However, the current data sets are still mostly dealing with 2D features without complex interrelations. A current trend towards 3D models for communities such as the City of Vienna [24] will hopefully provide a better basis for mobile AR applications. Another direction of research is the conceptual modeling required for complex 3D GIS systems that also capture temporal development of the data sets [25].

Recent research already focuses on visualization techniques specialized for augmented reality. Furmanski et al. [26] and Livingston et al. [27] presented studies on what visual attributes help users discern distance to occluded but visualized objects, while Leykin and Tuceryan [28] investigated the readability of text in overlays. Bell et al. [17] describe automated layout of presentation items in the user's view. And Coelho et al. [29] describe the use of knowledge about tracking uncertainties for adaptive visualizations. All these techniques could be combined and made available to AR applications in general by an automated approach.

6 Conclusion

We are only at the beginning of this research direction. However, we feel that the issues discussed here are vital for the vision of mobile and ubiquitous applications of augmented reality. Also semantically rich models are applicable to more traditional application domains such as GIS systems or location based services.

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