Towards semantic interpretations of spatial information in adaptive smart homes[1]

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Abstract: In this paper we address two major application areas of IFC building models in smart home environments. In the first case the model deals as the basis for 3D spatial search queries, i.e. to resolve qualitative spatial relationships between objects in order to fulfil a spatial search (e.g. "Where is my purse?"). In the second application area the building model is employed for semantic enrichment of spatial information for activity pattern recognition. We discuss how to combine low level semantic interpretation of basic activities like movement trajectories with spatial knowledge based on an IFC model and an ontology based reasoning. The recognition of activities enables us to adapt the environment according to the actual situation, e.g. create a stimulating lighting scenario and adjust the behaviour of software agents.

1 Introduction

In Karstaedt et al. 2010 the IFC-based *Indoor Spatial Information Service*[2] (ISIS) has been introduced as a spatial service for the smart home *Living Place Hamburg*[3] (see Figure 1). Here the focus was on the development and integration of existing interfaces for communication, persistency and location information in an architecture that allows building models to be used as a resource for a variety of scenarios in dynamic, sensor-rich environments.

Figure 1: Rendered Living Place model (Luck et al. 2010)

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[2] At that time it was called *BIM as a Service.*

[3] The *Living Place* is an on campus apartment suitable for experiments under real life conditions

In this paper we will further discuss *ISIS*' major application areas in our smart home:

1. Providing a spatial service for requests by use of 3D spatial relations
2. Semantic enrichment of location information for activity pattern recognition

At first we will give an overview of comparable work. Secondly, we will discuss the application areas in detail and show how ISIS contributes to semantic interpretation of spatial information. For each area future enhancements for use of IFC-based spatial information in adaptive smart homes is outlined. We conclude with a summary of our state of work.

2 Applications of semantic building models in smart home environments

Besides traditional application areas of semantic building models in construction informatics several other research areas have evolved in the last decade – there are basically three fields where these models are employed: *visualisation* (Mao 2010), *simulation (*Siltanen et al. 2008; Kühner et al. 2003) and *navigation* (Rüppel et al. 2010).

In smart home environments 3D building models are typically used for *visualisation* purposes in order to support furnishing and installation planning. Others, like Lertlakkhanakul et al. 2008 and Borodulkin et al. 2002, employ 3D building models in order to create a virtual reality as a *simulation* platform for smart home configurations.

Recently Borrmann et al. 2010 has proposed to use 3D *queries* and qualitative spatial constraints in order to facilitate the overall design and construction process of buildings. They have developed a spatial 3D query language for IFC building models which includes metrical, topological and directional operators.

In addition to the above mentioned approaches we propose spatial services for dynamic smart home environments (chap. 3) and show how continuous spatial information contributes to activity pattern recognition (chap. 4).

3 1st application area: spatial 3D service requests

In this case ISIS operates as a service for 3D spatial queries, i.e. to resolve qualitative spatial relationships between objects. In conjunction with a camera based object recognition system this can support a resident in finding objects. The 3D spatial relations are discovered applying the approach proposed in Borrmann et al. 2009, where a spatial 3D query module resolves metrical, topological and directional relations within the digital building model.

E.g., when our resident "Sal" asks her smart home: "Where is my purse?", the object recognition system will search the object by help of several PTZ-dome-cameras[4] – if it finds the object a spatial service request will be submitted to ISIS, which will then resolve the spatial relations of the given requested object's 3D-coordinates with regard to nearby located entities in the building model. The outcome might look as follows:

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contains(room4,req)

above(id7,req)

northOf(id3,id7)

distance(id1,req)= "very_close"
```

This might then be verbalized by: "Your purse is next to the coffee machine in the kitchen on top of the kitchen unit".

In order to come up with these spatial relations describing the nearby objects, those are first retrieved by help of the metrical operator (e.g. "get all objects within 2m"). Then the spatial relations (metrical, topological and directional) of the given point to these objects and the relations among them are computed and finally sent back.

3.1 Future work for spatial 3D service requests

From the cognitive point of view the final outcome of a service request should be a "cognitively adequate description of the relationships" (Güsgen et al. 1989), where it is not necessary to be as mathematically precise and complete as possible. For our application areas this means that "non prominent" objects should be filtered out the spatial search results. The question which objects and relationships in a scene are most prominent and what might be a suitable formal representation is subject to future research.

4 2nd application area: semantic enrichment of spatial information for activity pattern recognition

Activity pattern recognition plays a key role towards adaptive smart environments. Here we focus on the combination of positioning information with model-based approaches to recognize residents activity patterns (e.g. a "morning routine"), in order to adjust the environment accordingly. According to Chen et al. 2000 our approach can therefore be classified as an *active context aware service* as the content is autonomously changed.

[4] PTZ: Pen Ten Zoom

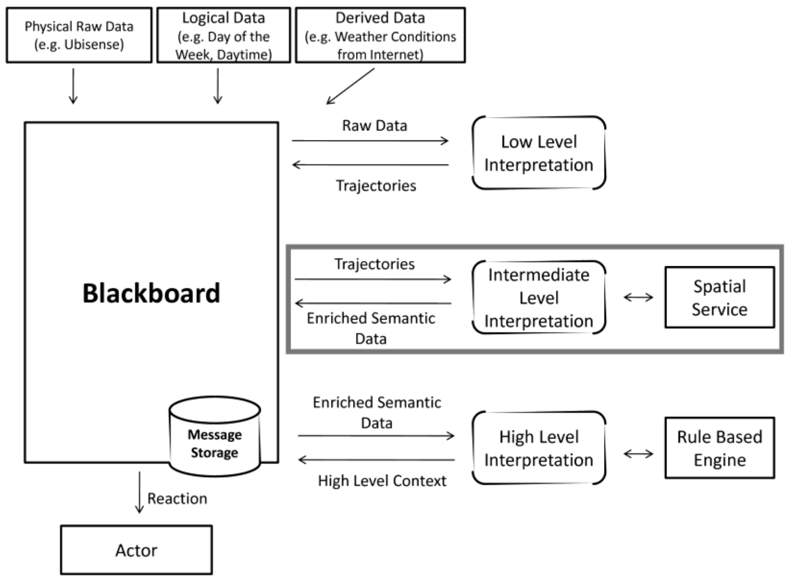

Figure 2: Living Place architecture for activity recognition

Based on the following scenario, we will further elaborate our approach presenting the models and procedures involved in order to come up with a reasonable guess about situations and a control setting for a reactive environment in turn:

"*Sal is getting up early in the morning. She is moving towards the bathroom in order to take a shower. Afterwards she is dressing in the bedroom and has breakfast in the kitchen area. Finally she leaves her home and is going to work.*"

4.1 Interpretation Layers

We have chosen a layered architecture (Ellenberg et al. 2011) where we combine low level semantic interpretation of basic activities like trajectories of movements at a specific day of the week, daytime and weather conditions (e.g. moving from A to B at a weekday in the morning at a cold winter day) with spatial knowledge based on an IFC model (e.g. the movement observed started at the bedroom area, ended in the kitchen area), and ontology based reasoning (e.g. this movement belongs to a weekday morning ritual).

The architecture is divided into three different interpretation layers. ISIS takes place at the intermediate layer (see Figure 2) where it yields knowledge about spatial entities, their relations and the residents' whereabouts. This knowledge is used on a higher level where a model of typical domain tasks and situations supported by an activity ontology will detect (and react to) behavioural patterns of residents. In the following the two layers are described in detail.

4.1.1 Intermediate Level Interpretation with ISIS

On this level ISIS combines topological information derived from the IFC building model with external location information[5] in order to create intermediate level semantic interpretations.

Here ISIS deals with the questions: where *was*, *is* and *will* the resident be? On the one hand the IFC-model already contains geometrical information about rooms, so that we can say in which room a person currently is. To answer more detailed topological questions the IFC model was enriched with so called *spatial artefacts* introduced in Bhatt et al. 2009. Spatial artefacts include several types of spaces: range space, operational space, functional space, visibility space and movement space (see Bhatt et al. 2011) among others. In ISIS we use *visibility spaces* to determine visible screens, in order to switch them on or off according to the resident's perspective. *Range spaces* of cameras allow us to select the one that is best for e.g. a video conference.

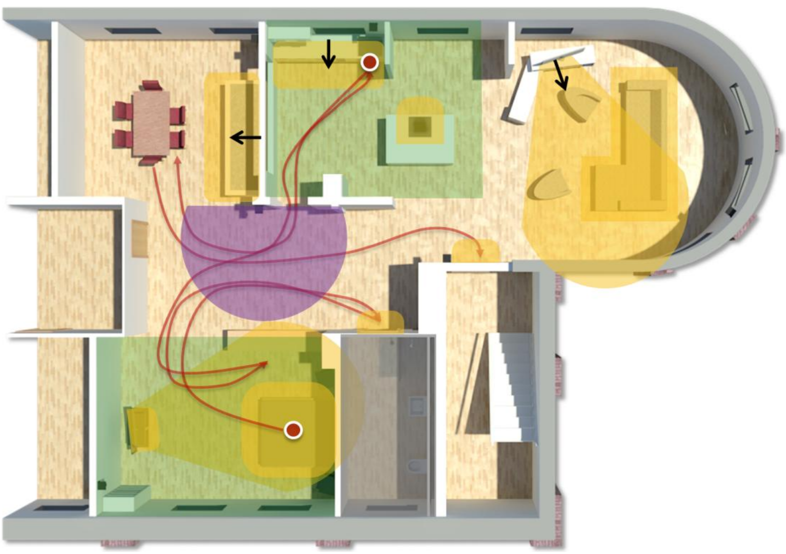

Figure 3: Spatial artefacts in the Living Place

Functional spaces are another important concept for activity recognition. We describe functional spaces as an area, where an agent can interact (not only physically) with an entity. A person situated inside a functional space of an object is likely to interact with this object (e.g. Sal is inside the functional space of the oven for a while she might be cooking).

Based on the spatial information in the IFC model ISIS constantly informs the higher interpretation level about changes in the spatial context. ISIS hereby offers higher level spatial information like path descriptions as trajectories between rooms and the resident's abidance with respect to visibility and functional spaces.

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[5] For positioning information we have the UWB system *Ubisense* with a precision of approx. 15cm.

4.1.2 High Level Interpretation: The Living Place Ontology

For the high level interpretation we have chosen the activity theory from Greenberg (Greenberg et al. 2001), which uses activities to describe a situation. On this interpretation layer the model of the environment is mapped onto an ontology which combines location and spatial information with activity, time and further context information. Within this model we are able to describe behaviour patterns in detail. E.g. "having breakfast" is part of the ontology. Here Sal's breakfast takes place in the morning, with her standing in a close range to the table in the kitchen.

In order to detect sequences and dependencies between patterns we are currently investigating the approach proposed in Bohlken et al. 2011. There entity recognition is based on video data with poor accuracy. With a Bayesian network they get good results out of poor raw data.

As far as entity recognition in our environment is concerned, the building model delivers the position of the resident and the relation to any known entity in the living place. With this knowledge we have a small uncertainty in matching the entities in the living place with the individuals of the ontology.

The difficulties in activity pattern recognition lie in the range of possible actions and behaviours within daily life. Also some activities can only be recognized when they are finished. E.g. "going into bed" starts with the trajectory towards the bed and ends in the bed. The trajectory with the direction towards the bed gives a hint to the activity "going to bed" but it is uncertain if it really ends in the bed. In Ellenberg et al. 2011 has been proposed to use a Bayesian Network to express the level of correctness.

4.2 Future Work

Regarding the functional spaces we are currently investigating which shapes for functional spaces suit best. Mostly an enlarged convex hull is sufficient. Sometimes a semicircle or conical section seems more appropriate. Another topic is the dynamic mapping of functions to spaces according to time aspects and the situated agent (e.g. a person or thing). E.g. the functional space of an oven for an infant should be zero, so that the oven refuses to heat the stoves.

The building model also gives us the opportunity to predict a resident's next target based on the movement trajectory. E.g., when Sal is moving towards the bathroom we can prepare the suitable lighting for the time of day. This approach has to be evaluated within real testing scenarios.

5 State of work

By now most of the main components of ISIS are implemented. We have integrated a message broker for communication, a product model server for persistency and the

Open IFC Tools (Tulke et al. 2010) for visualisation of the model and modification of IFC entities.

Currently the spatial 3D query module from TU Munich (Borrmann et al. 2009) is integrated as well as the JTS[6] in order to enable spatial service request to the IFC building model.

A prerequisite for correct results from spatial service request is to ensure consistency between the building model and the real world – i.e. if objects are moved around, the building model has to be adopted accordingly. This has been accomplished by integrating the Ubisense positioning system into ISIS. For this purpose furniture is assembled with positioning tags so that the position and direction can be derived.

6 Summary

Two different application areas of ISIS in smart home environments are presented in this paper. The first area of ISIS is to provide a spatial service for requests by use of 3D spatial relations. The general spatial search query process was outlined including the involved software components as well as the discovery of qualitative spatial relationships.

Secondly, this work has discussed ISIS' integration in our open multilayered architecture for activity pattern recognition. Here ISIS is employed for semantic enrichment of location information by means of topological queries to the semantic building model. Activity pattern recognition allows us to adapt the environment according to the current situation. Amongst others we are working on situation adaptive lighting with changing atmospheres and will compare to a flexible and controllable lighting system which is currently installed at the living place in cooperation with designers.

For us it is vital to test hypotheses in early prototypes. Whereas our current prototypes are short-cuts, where small applications directly interpret location data bypassing the three levels of interpretation, the next prototype will go a step further towards an adaptive smart home. In our future work we will evaluate our approach for activity pattern recognition in detail and aim at further improvements.

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[6] Formerly known as „Java Topology Suit"

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