DYNAMIC SPATIAL INFORMATION MODEL FOR LARGE URBAN COMPUTING ENVIRONMENT

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Abstract. A new urban space information model for urban computing environment is proposed to achieve dynamic state of context-awareness in urban computing environment. For this, an abstract space model served as an integrating layer for disparate indoor and outdoor spatial information models based on potential design scenarios. At the end of the project, a prototype and a test-bed are implemented.

Keywords. Urban computing environment; dynamic spatial information model; sub-spacing; SAFA ontology.

1. Introduction

Urban computing is the integration of computing, sensing, and actuation technologies into everyday urban settings and lifestyles (Kindberg et al., 2007). To date, this has been realized by means of advances in microelectronics, battery and wireless sensor networking technologies. Urban computing middleware between control program and application program has been simultaneously developed in order (1) to utilize spatial information of place and manifold context, (2) to activate collaborations between human beings in urban context, and (3) to support the development of urban IT applications.

The purpose of urban computing middleware is to deliver optimized service to users based on space, society, and time context in a dynamic manner. This service is achieved when interoperation among users, tools, and intelligent objects has reached digital ecosystem by ubiquitous network installed in public-large urban space.

To accomplish this goal, (1) support for semantic communication among diversified smart objects distributed in digital ecosystem using contextual information acquired by ontological analysis of space, and (2) support for real-time searching and re-structuring of objects, and their interoperation using this context information are two main tasks. A smart environment must support context-aware services for participants. In an urban computing environment, when carrying mobile personal devices, each person will be able to navigate smartly and efficiently while accessing smart services. This will be realized by means of the traverse communication that will silently occur between embedded place devices and mobile personal devices.

2. Problems

Current studies on spatial data model for smart environments can be found in ubiquitous computing research which demonstrates how smart services can be autonomously configured and performed according to the context. However, the boundary of typical research is generally limited to small areas with a set of predefined interaction between the users and the environment. Examples of those projects are *UbiHome* (Jung and Woo, 2006), and *NICT's Ubiquitous Home* (Minoh and Yamazaki, 2006). Moreover, not many studies have included spatial information in their computation model.

Although some spatial data models for ubiquitous computing environment were proposed such as *V-Placesims* (Lertlakkhanakul et al., 2008), and *U-PlaceLab* (Lee et al., 2006), none of them can describe the dynamic state of public urban environment. At the moment, new and emergent social lifestyles as supported by urban computing technology have been demonstrated by such projects as *UnderSound* (Bassoli et al., 2007), *Familiar Stranger* (Paulos and Goodman, 2004), and *Social Serendipity* (Paulos and Goodman, 2004; Eagle and Pentland, 2005; Bassoli et al., 2007). 'Peer to peer' , 'centralized mobile computation' and 'familiarity, interest and encounter based interaction' are common research themes.

However, the spatial information used in such studies was limited to only simple location data. Information on the Info-sphere of urban computing environments is different from that of previous ubiquitous computing environments because it contains important context information about social relationships such as the sense of place and its related associations.

Commonly, participants are unpredictable in terms of quantity, age, culture, demand and personality, etc. Further, activities that occur in the urban computing space may be various and dynamic according to the particular time and space. In such environments, participants and relevant resources are "far more dynamic and dense" in terms of what and who would participate in an application or system (Kindberg et al., 2007). To serve suitable functions and to give rise to activities depending on spatio-temporal user context, it is necessary to subdivide the large space into more detailed ontological levels. Furthermore, for the seamless service without discontinuation between indoor space and outdoor space, it is indispensable to contrive the unified spatial information model for urban computing environment. However information models such as Building Information Model (IFCs), CityGML have been developed separately and seldom cover this issue. A context for urban computing environment cannot be fully describable based on existing spatial data model.

As a result, direct application of those technologies to urban computing is not recommended. Space of urban environment is quite different from that of indoor buildings as discussed before. It is a prerequisite for a barrier-free urban environment to be described by a spatial model which combines outdoor and indoor space. Thus we require a new framework to connect outdoor and indoor models as well as to solve the problem of sub-space issue.

3. Our Approach

Our research has been initiated by investigating related studies on urban computing and defining the main characteristics of an urban computing environment. By doing so, we have found that scenarios proposed on several papers mentioned before had shown promising frameworks that could be used to generate main research issues. Consequently, two scenarios have been defined to extract the information required to construct a new spatial data model for the urban environment. Based on scenarios, we introduce *'Abstract Space*

Model' and *'Dynamic Functional Area'* with the aim to handle dynamic spatial contexts. We setup a physical test-bed and create a prototype to validate our proposed model.

4. Scenario

To predict the potential services provided in urban computing environment as well as to anticipate problems for the implementation, two scenarios are created and described as following; (1) *'Performance-driven Zones Scenario'*, (2) *'Emergent Vote (Music Together) Scenario'*.

In the first scenario, both music and television can make typical temporal functional zone in public space. Held on every Wednesday evening, certain area of an underground passage is crowded by people who want to watch great music performance called *'Rail Art Concert'* in one of subway stations in Seoul. This zone doesn't have commuters' physically dynamic movement, but static standing mixed with music and dance. At the same time, the main function of small areas around TV-set near the music zone is changed from normal circulation to TV-watching. Thus, the number of people going through both zones is gradually decreased.

For the second scenario, using users' profile and current behavior in urban computing environment, people can enjoy context-based ubiquitous service. By knowing where, who, and what they are doing, it is possible to share their favorite music and to provoke common activities among people. Each person has an influential area and installed sensors can detect familiar strangers whom he/she may share their interesting contents in a dynamic manner. As a result, temporal subspace in large space arises and it also influence people in the same mode and induce someone's behavior entering into this zone.

5. Abstract Space Model

Indoor space can be regarded as a room bound by building components as defined by '*ifcSpace*' entity in IFC specification (Kim et al., 2008). On the contrary, this outdoor model is not based on space but defined as different type of areas, such as *'LandUse'*, *'_TransportationObject'*, *'_VegetationObject'*, *'_WaterObject'*, and *'_Site'* (CityGML specification). Thus it is necessary to make a general data model to unify the spatial information between both domains. However, instead of creating a new data model, a new abstract layer spatial model is created which allows flexible referencing to existing standards of both indoor and outdoor models.

In the center of this model is the most essential class, named *'Abstract Space'*. It is defined to serve as a generic entity to represent the fundamental spatial unit. To avoid any incompatibility between outdoor and indoor spatial structure, only the minimum set of common attributes required for specifying context are defined.

To maintain flexible connectivity, each instance of abstract space contains reference information to its concrete counterpart in the existing models. Registration of an abstract space for each space is handled by a class called *'Space Manager'*. Considering the scenarios mentioned before, information binding in Abstract Space can be considered into two states; static information and dynamic information. Static information refers to those characteristics of space unchanged over time.

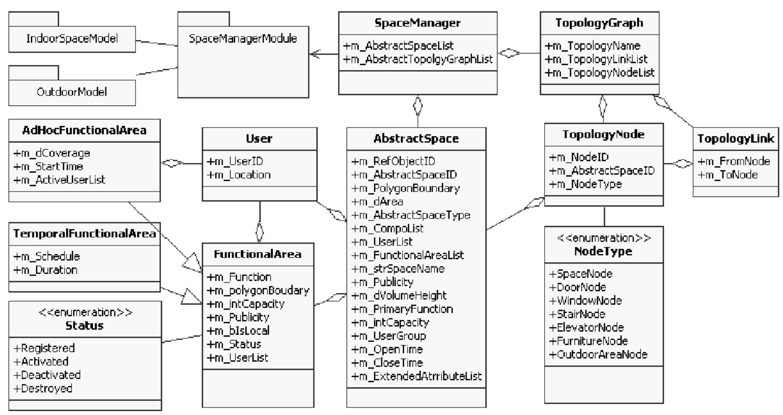

Figure 1. Abstract Space Model

5.1. SUBDIVIDING SPACE WITH SAFA ONTOLOGY

One of the important roles for ubiquitous computing is the ability to determine where people are, what objects and software services can be used at those locations, and how people can move from place to place (Weiser, 1993). That is to say, location provides information about activity and intention, and supplies information about the devices available to the user, which allows determination of what will be effective means of communicating with him/her (Weiser, 1993). The same principle also applies in urban computing environment except that location always refers to a large urban area. In such an environment, knowing only numerical location cannot yield enough meaningful information.

Unlike ubiquitous computing environments, context in public space can be dynamic and altered by the changes in users and activities overtime. Thus, the definition of 'sub-space' can be ephemeral and dynamic as suggested in our scenarios. These issues lead to the question of how to subdivide a large place to accommodate dynamic change in urban computing space. In order to answer these questions, an investigation on how designers and architects design building and urban environment at the level of space design ontology was conducted.

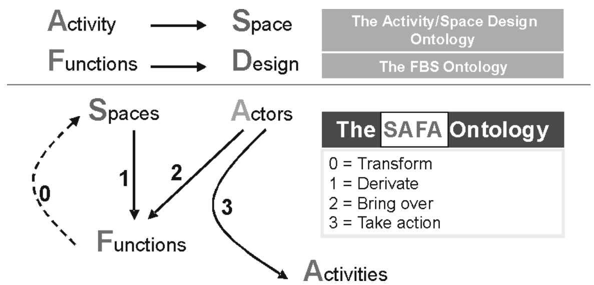

Figure 2. Space-Actor-Function-Activity (SAFA) Ontology.

Activity-Space Ontology (Simoff and Maher, 1998) defines building design in architectural terms of spaces and activities performed in spaces. It was proposed as a dynamic approximation of design domain knowledge. Based on this ontology, it is possible to accommodate changes in meaning during the evolution of a design idea and to maintain these changes at the levels of the data model and data structures.

Another formal ontology in design is *the Function-Behavior-Structure* (FBS) ontology (Kannergiesser and Gero, 2008). It represents designing by a set of processes linking function, behavior and structure together, which can be seen as different states of the developing design. It uses a perspective that is oriented to the object being designed. Thus, design can be considered as a set of transformations between the function, behavior and structure of the artifact (Kannergiesser and Gero, 2008).

Applying this ontology to architectural design, we can see a coincident perspective between Activity-Space Ontology and the FBS Ontology in that

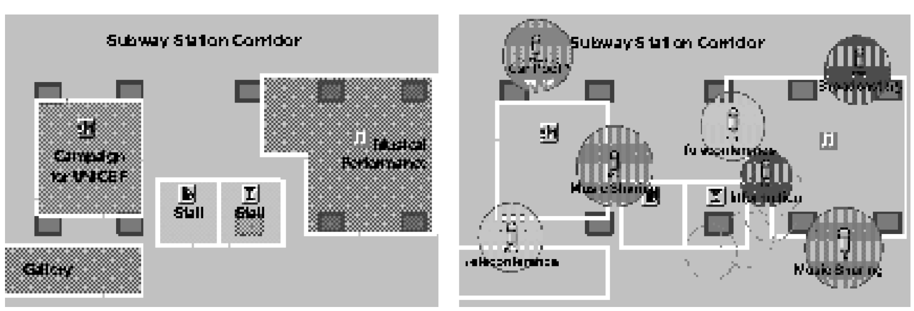

Figure 3. Temporal Functional Areas (left) and Ad-hoc Functional Areas (right)

'Function' of the later can be regarded as 'Activity' of the former. In other words, function of a space is defined beforehand according to potential activity during the design process.

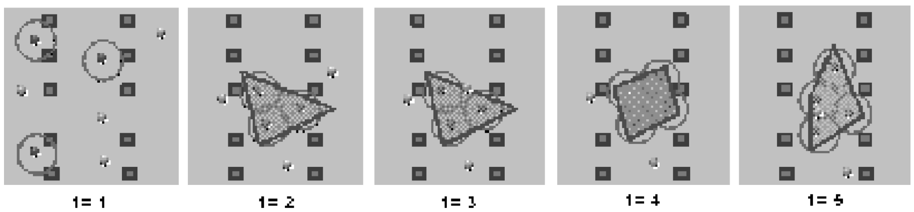

Figure 4. Configuration of Ad-hoc Functional Area

In an urban computing environment where activities are not limited to predefined functions but ever-change due to the uncertainty of the users, a new ontology so called *Space-Actor-Function-Activity* (SAFA) is proposed to handle sub-spacing problem as shown in Figure 2. First, based on the FBS ontology and Activity-Space ontology, spaces are designed according to their original functions (potential activities) during the design process. Second, as for common built environment, people normally inhabit and perceive functions of spaces in their mind through spatial settings and configuration designed by the space designer. Functions in this manner are directly derived from the spatial setting. However, functions available in space are not limited to original usages defined during the design state but can be appended by emergent users.

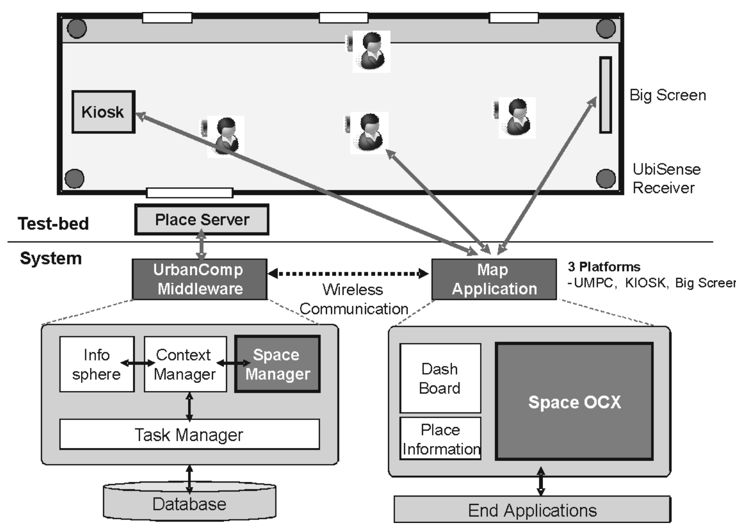

Figure 5. Test-bed and Middleware Framework.

In addition, as the key technology of urban computing relies on the network of smart mobile devices to enable interaction among individual, public and environment, people can initiate new functions shared among people in the same place by their personal mobile devices. Finally, activities in each space are performed according to functions generated by spatial configuration of both users and environment.

5.2. SUBSPACE DATA MODEL

Based on SAFA Ontology, it is possible to deduce the importance of 'available functions' in each space which can be used as criteria to subdivide a large space into sub-spaces so called 'functional area'. Considering urban environment where functions are changing overtime, two types of dynamic functional areas can be emerged as described in the scenarios; 'temporal functional area' and 'ad-hoc functional area'.

Temporal Functional Areas (see Figure 3, left) are defined as temporary small settings, where their functions differ from the predefined one in terms of its location (space). They could either emerge with or without an explicit schedule but they are usually active for a certain period. Typical information on TFA includes abstract space ID, boundary, function, schedule, duration, status, and the owner. Examples of temporal functional areas found in urban settings are stalls, on-street art exhibitions and performances, and temporary kiosks for campaign or demonstration. Automatic registration of TFA can be achieved on an assumption that each TFA is linked to its temporal setting such as a booth with RFID tags. This can be detected by RFID readers embedded in the space. Combining this with image processing of streamed video captured by CCTVs may improve the accuracy for TFA registration.

Ad-hoc Functional Areas (see Figure 3, right) are defined as ephemeral small areas unintentionally emerging in urban settings as people utilize the urban space and suddenly create ad-hoc functions or services shared among the others nearby through their personal mobile devices. This kind of functional area s perpetually changing, it migrates and re-groups to form new spatial networks according to the place context.

General information of AFA includes abstract space ID, boundary, function, start time, status, and the active users. An example of this functional area can be an ad-hoc network of users who share music using mobile devices while waiting for trains on the same subway platform, which temporarily defines a music sharing area (AFA). Automatic AFA registration on the space could be realized on the assumption that each user carries on themselves a personal device storing available AFA service information which can be registered and transferred to the place server only when allowed by the user. One critical characteristic which differentiate TFA from AFA is that each single AFA can be grouped and merged with the others when their functions are matched. The more users in one AFA the stronger impact of AFA on the location will be. Figure 4 illustrates a potential scenario.

6. Implementation

In order to demonstrate how the dynamic model proposed in this paper can work along with other modules to realize a new urban computing environment, we are setting up a physical test-bed based on the scenarios. This section explains the method to apply our new model to enable u-services in urban computing environment focusing on hardware, middleware and application levels.

Due to time and cost limitation, a multi-purposed room was configured to be the project test-bed. The room is being decorated to imitate a part of subway platform. Tracking user location is enabled using *Ubisense System* (www.ubisense.net) installed on the ceiling and small tags are carried by users. Each user has his/her ultra-mobile PC (UMPC) which can be used to retrieve the subway station information from a place server installed in the space. This place server contains urban computing middleware, an intermediate infrastructure between end users and sensing devices to accommodate context-aware services on the space.

The middleware keeps tracking the place and user information over time and converts them into high-level place context to be utilized by user applications. The abstract space model with dynamic subspace introduced in this paper is now being implemented in Space Manager Module as a part of the urban computing middleware. Space Manager stores the space information and abstract space model. Based on the place context, it updates sub-space information in a real-time manner and offers spatial reasoning services to the other modules running on the middleware. A BIM based modeler namely *GongTown* (www.vbuilders.co.kr) was developed to create the subway model and abstract spaces. As users enter and play out their activities in the urban space, they can retrieve on-going subspaces and other place information from Space Manager on the map application running on their UMPCs.

7. Conclusion and Future Work

This research is a part of a long-term project called *'Development of Urban Computing Middleware'*. It addresses our role on how spatial information model must be modified to enable context-aware services in large urban environment. As functions and activities can be changed overtime, an abstract space model with dynamic subspaces are firstly introduced. Scenarios are created to demonstrate the abstract space information model. At the moment, we are developing the test-bed, the middleware and the map application. We expect this demonstration will guide us as to how smart context-aware services could be realized. As dynamic functional areas are adaptive depending on time, user and other situations, the spatial information can be re-configured based on the dynamic information in a real-time manner. This issue on topology of subspaces as well as its effects will be investigated in the future work.

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