An ontology for shared personalizable ubiquitous smart spaces

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***Abstract*— We identify mediation between three types of spatial context as a key component for realizing shared personalizable ubiquitous smart spaces, and argue for an ontology of spatial contexts to provide a common language for these mediation processes. Basic prerequisites for such an ontology are identified, so that requirements of all three types of spatial context can be reflected in a unifying way that allows for seamless integration. The representation of sensing areas and personal interaction spheres is presented as an example for a relevant application from the domain of location-based AR for which the proposed ontology would be advantageous. Main technical requirements are outlined, and suggestions are given on how to ensure that such a spatial representation enhances users' awareness of services and sensors without requiring their active attention. The sketched technology, as a calming interface enabling users to be aware of invisible computing facilities and other user's interaction spheres would address important issues of usability of ubiquitous computing environments and could become a powerful tool to chart and control such environments.**

I. Introduction

The notion of ubiquitous smart spaces [20] that assist and support users in an unobtrusive and calm way [25] is enriched by a new dimension if combined with the idea of mobile augmented reality. The resulting technology not only supports users in everyday tasks but opens completely new ways for users to control their environment, generate and transform information, and cooperate with others. Mobile device based augmented reality technology, such as [11], allows each user to interact with a virtual, augmented, or mediated reality on a personal device that can be configured to exactly fit its owner's preferences. Moreover, since these preferences are kept on a trusted personal device, control over information disclosure can remain with the user even in spaces with a multitude of sensing devices. An appropriate representation of the spatial context of a user is key to realizing this technology.

Three types of spatial context have to be distinguished: first, users and their personal equipment are located in a certain spatial environment that has certain physical restrictions, provides locally meaningful services, and is equipped with certain locally operating sensing technology; second, the personal equipment of a user provides a personal virtual environment that is configured to serve the user's needs; third, a user may at any time be part of one or more groups, which in turn share a common virtual environment.

In order to allow for seamless integration of these three types of spatial context a spatial ontology is needed that provides a common language in which to formulate, reason about, and mediate between requirements.

This work was supported by Seondo project of MIC, Korea, by the UCN Project, the MIC 21st Century Frontier R&D Program in Korea, and by the Brain Korea 21 Project in 2006.

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II. An Application Scenario: Establishing Awareness of Ubiquitous Smart Space

Location-based AR applications [14], [23] provide georeferenced information to mobile users. Specific applications, such as navigation systems [1] or cultural heritage guides [5] combine information about geographical or large-scale space with navigation support and historical information, with technical information on facilities in industrial environments [26], or with information necessary for environmental management [19].

A scientific challenge for location-based AR applications is how to link the local visual perception as provided by the AR-interface with global and often more abstract information as provided by, e.g., geographic information systems (GIS) [23]. Besides traditional map-based information, AR-technology is used to provide visual access to otherwise invisible parts of a place, such as events in its historical past, or pipes and cables inside a wall or below a road: AR, like VR, provides a three-dimensional view on a local environment, whereas map-based information, as stored in GIS, is mostly twodimensional.

This section suggests representation and audio-visual presentation of services in ubiquitous computing environments as a relevant application for location-based mobile AR. We show that information about locally available computing services and sensor techniques is a further category of invisible yet localized information; and we will motivate that an ontology-based spatial context-model can help in maintaining, monitoring, and controling ubiquitous computing environments. Moreover, the way in which Ubiquitous and Mobile Computing can change an environment will be outlined as relevant geographical information.

For the following sketch of possible applications, the notion of *augmented space* is used to denote a portion of real space that temporarily or permanently receive a special relevance through locally available services, installed sensor technology, or the relevance it has with respect to other users. This additional notion is introduced, in order to separate the 'outside' perspective a user or a geographer might have on spatially distributed sensing and computing technology from the more technically motivated 'inside' perspective of a computer scientist, which is assumed in the research term of ubiquitous smart space.

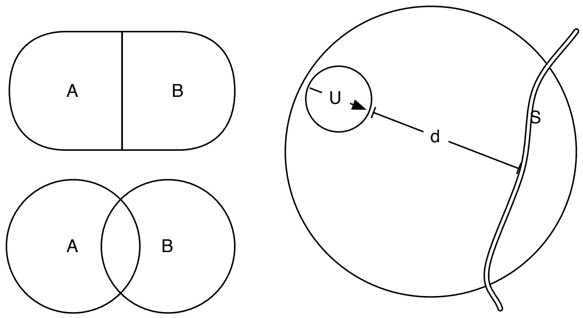

Fig. 1. Examples for improving awareness of augmented space: a) in narrow spaces, awareness of other user's personal interaction spaces is required to—automatically or by agreement—avoid conflicts; b) approaching the boundary of an augmented region that is relevant to a user, they should be made aware of the extent of the region, so that they can directly approach or avoid it.

A. Information about Availability of Services and Other User's Interaction Spheres

Currently, users can only guess what they can do to improve reception of a signal, or where they can get access to a certain service. Additionally, installation and maintenance of ubiquitous computing environments is a time consuming and complex task [2] that confines today's ubiquitous computing technology to research institutes. AR-technology could be employed to establish awareness of spatial sensor ranges and installed services to facilitate access and maintenance. Likewise, the virtual interaction spheres of other users and groups of users might be relevant spatial information for a mobile user. Even if I cannot see the personalized virtual spaces of a user or a group of users, it might neverless be relevant to be aware of where the virtual boundaries of their interaction spaces are, e.g., in order to avoid disturbing them (Fig. 1a).

Above, we assumed a user seeking access to an information service or sensor technology. However, ubiquitous computing technology raises questions of how rights of privacy of a user can be ensured. Acceptance of new technologies depends on the potential users' being in control instead of being controlled. Location information about availability of services is an important factor in this respect [16]. Use of invisible sensing technology, which can be a threat to a user's personal rights, could thus be restricted to legal authorities [18]. Currently, signs, e.g., at the entrances of video monitored spaces are the only type of information provided to monitored persons. For highly augmented spaces with a high density of services and a broad range of sensor technologies, this method is not sufficient as users would not have enough time to study all the relevant information. However, a map of used sensing technology could be used to ensure privacy in a convenient and usable manner: a PDA or mobile phone could be configured to warn users before they enter a zone that provides lower privacy than they prefer, or send a demand to the service provider to blind out the person (Fig. 1b).

B. Administration of Augmented Space and the Geography of Augmented Space

Another group of relevant questions is how augmented spaces could be controlled and administered. Who is allowed to augment and monitor a certain portion of space? May a vendor broadcast an advertisement in front of a competitor's shop? Maps and GIS for augmented space can be used, in order to control, monitor, and regulate use of spaces with high density of services. Especially, since advances in GIScience [13], [8], [10] have addressed the representation of spatio-temporal phenomena, which has been identified, e.g. in [17], [3], as an important first requirement if GIS are to be useful for monitoring dynamic Ubiquitous Computing environments.

Augmented space is a part of real space in so far, as human beings will react to it. Equipped with a privacy sensitive mobile phone, as outlined above, one user might choose to avoid a certain route; another user wanting to schedule a video conference during a journey might want to take a route on which full availability of the service is ensured. Sensor technology and availability of services will thus influence spatial behaviour. Maps of augmented space can serve this purpose, and ensure that the changes this new technology enacts on the real world can be monitored by geographers. Conventional GIS and GIS-based information on augmented space could be overlayed to assess consequences of the use of specific augmentation technologies.

III. A Spatial Ontology for Relative, Local Space

One main scientific challenge is to find a representation of the local spatial availability of services and the spatial range of sensors that is general enough to cover all possible types of spatial entities mentioned above. Furthermore, appropriate interfaces for this information have to be designed. For spaces with a high density of services and sensing technologies, an adequate structuring of the provided spatial information has to be ensured.

A. Representing Availability of Services

Two models of location are employed in ubiquitous and mobile computing [3]: *geometric* and *symbolic* location models. This distinction has technical as well as semantic aspects. Geometric location models use coordinate-based information, which can directly be interpreted spatially, if the used reference system and resolution are known. Symbolic location models, in contrast, are used in location systems employing sensors that only determine whether or not objects are in a certain stationary or mobile area. How different sensor areas are spatially related is stored in the form of relations, such as containment and overlap.

A main scientific challenge is to specify an ontology for augmented space that is general enough to relate between a wide range of spatial representations, such as the location models of ubiquitous computing and the data models used in GIS. This ontology would have to comprise concepts for representing

- *point-like coordinate-based locations* as well as *region-based symbolic locations* [21] to reflect the distinction in location models;
- not only *absolute* but also *relative locations* [6], e.g., to represent sensors installed in walkable vehicles, such as trains, but also to represent a user's personal virtual space, which moves with the user;
- multiple levels of *granularity* [12], [22] to handle sensors of different resolution and to deal with the complexity of ubiquitous smart spaces with a high density of sensors and services.
- *spatial vagueness* [15] to appropriately represent vague locations and locations with vague boundaries e.g., to allow for a user's personal virtual space to move only if the user moves by a relevant amount, but to remain aligned with the surrounding space, as long as the user stays in approximately the same location;
- the location of *dynamic collectives* [9], such as the locations occupied by spontaneously formed groups.

B. Designing a Usable Interface

A further challenge is the design of an interface that displays the different types of local spatial information mentioned above in a way that furthers awareness but does not require attention. A qualitative region-based approach to the representation of spatial information [4] would facilitate the design of such an interface: qualitative descriptions derived from natural language expressions were, for instance, successfully used to improve querying of GIS [7]. A representation using extended regions [21] could help to reduce cognitive load: a signal and navigational information can be given to users, when are about to they enter or exit the area of a service that is relevant to them, i.e., when they are near the boundaries of a region of availability. However, when a user is completely within or outside of the region, information about a service needs only be delivered as the result of an explicit request. The notion of granularity in a context could be crucial to implementing this mechanism: a user moving at high speed, e.g. in a train, needs a representation of services available outside at a coarser granularity. Local services that might be interesting to pedestrian users, but do not provide a certain minimal area of availability, are not useable while the train moves, and could therefore be excluded from being displayed.

IV. Conclusion

We identified mediation between three types of spatial context as a key component for realizing shared personalizable ubiquitous smart spaces, and argued for an ontology of spatial contexts to provide a common language for these mediation processes. Basic prerequisites for such an ontology were identified, so that requirements of all three types of spatial context can be reflected in a unifying way that allows for seamless integration.

We presented the representation of augmented space as an examplary location-based AR application with growing relevance. Main technical requirements were outlined, and suggestions were given on how to ensure that a representation of augmented space enhances users' awareness of services and sensors without requiring their active attention. The sketched technology would address important issues of usability of ubiquitous computing environments: we argued for a calming interface [25] enabling users to be aware of invisible computing facilities [24] and for a powerful tool to chart and control augmented space.

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