Ubiquitous Computing in Physico-Spatial Environments - Activity Theoretical Considerations

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ABSTRACT
Interaction design of pervasive and ubiquitous computing (UC) systems must take into account physico-spatial issues as technology is implemented into our physical surroundings. In this paper we discuss how one conceptual framework for understanding interaction in context, Activity Theory (AT), frames the role of space. We point to the fact that AT treats space primarily in terms of analyzing the role of space before designing IT-systems and evaluating spatial effects of IT-systems in use contexts after the design phase. We consequently identify a gap in that role of space is not recognized in the design process.

We address this gap by discussing the role of physical space in relation to key concepts of AT in terms of how an increased awareness of physico-spatial aspects influences the understanding and design of IT systems.

Author Keywords
Activity, Space, Interaction Design, Activity Theory.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
With ubiquitous computing, the traditional computer forms change and become part of our physical space. Information technology can be construed as primarily temporal as it is essentially constituted by the dynamics of executing program code. Consequently, IT has traditionally been considered non-spatial and non material. But as computation manifests its expressions in the spatial, physical realm, we have increasingly come to work with spatial IT-artefacts. Though, physical space has not been a major topic in traditional human-computer interaction (HCI). The embedding of information systems into our physical surroundings makes an understanding of space in relation to computer mediated activities pertinent for interaction designers. While HCI has traditionally been oriented towards task completion [13], interaction design can be understood as an activity oriented discipline: in interaction design there is a focus on ongoing activities and the experience of interacting with the system [11]. In line with this, an important distinction can be made between HCI as empirical science and interaction design as design practice [7]. In HCI there is a strong focus on empirical usability studies where design is seen as the mere derivative of analysis. However, the problem of turning analysis into design remains in HCI.

As practitioners within a Nordic information systems design tradition, we are inspired by activity theoretical perspectives [4, 10], and we consider ourselves interaction designers in that we design what Winograd [13] dubbed interspaces, assemblages of interfaces, actors and environments. We thus regard the challenge of ubiquitous computing interaction design as the design of spaces for human communication and interaction. In this paper, we address the issue of space and physical surroundings and discuss how an activity-centered approach to interaction design frame the role of space.

We discuss the role of space in an activity-centered approach to interaction design, namely Activity Theory [4, 10]. AT emphasizes the importance of space in interaction, but address spatial issues only in domain studies prior to the design of information systems, or after the systems have been introduced into the domain.

What is seemingly left open and unexplored is the issue of how to understand and work with spatial issues and the gap between these two phases, namely in the design process itself. This is obviously problematic for interaction designers: these spatial issues do not resolve themselves, and it must at least in part be the responsibility of conscientious designers to contribute to the configuration of the environment of interspaces as well as that of interfaces. Based in Schön's [12] notion of the design process as a dialogue between the design situation and the reflective

designer drawing upon a repertoire of knowledge, we will argue that design experiments are key to gaining insights into physico-spatial design issues, and propose that insights from the realm of architecture may inspire interspace designers. This may lead not only to a better understanding of spatial issues in the design phase, but also inform the analytical phases before and after the design phase.

The rest of the paper is organized as follows: Next some background to AT and space, and to pysico-spatial issues in the design process, followed by a discussion on conceptual understandings and design considerations for physico-spatial surroundings. Finally, some concluding remarks.

BACKGROUND: ACTIVITY AND SPACE

For two decades, the Activity Theory framework has gained increasing popularity within IT-design [4, 10]. In the perspective of Activity Theory, activities are construed as the total of subjects, objects, mediators, physical surroundings and socio-cultural circumstances. The spatial and physical environment is thus an implicit part of any activity. In this perspective, subjects use mediating tools to manipulate objects to achieve intended outcomes. The mediating tools, objects and outcomes may be immaterial (such as mental calculations based on algebraic rules-of-thumb in order to guesstimate the sum of a grocery bill), however activities are generally carried out in order to effectuate a material reconfiguration in the acting subject's environment. Material surroundings also play an important role in regard to perception and cognition, in that subjects externalize mental conceptions and intentions through activities, and furthermore internalize knowledge acquired through the perception and understanding of physical surroundings and artefacts. Spatial configurations and physical artefacts can thus be understood as the crystallization of activities through historical processes, mediation, externalization and internalization.

Physico-spatial issues in the design process

The activity-oriented approach described above stress the importance of understanding the role of space in activity. However, the approach primarily offers a framework for analyzing and understanding these relations rather than action-oriented guiding principles for practitioners engaged in the design process.

A number of activity theoretical studies of information systems have been carried out to present analyses of information systems in particular physio-spatial settings, such as [3]. In [2] Bertelsen however points out that Activity Theory has mostly been applied as a conceptual framework for researchers, and that there is a gap between academic activity theorizing and practical design. Therefore Activity Theory has not quite succeeded in being a genuine resource for practical design. Design practitioners thus have few, if any activity theoretical resources to draw upon when wrestling with physico-spatial issues in the design process.

PHYSICO-SPATIAL CONSIDERATIONS FOR IT DESIGN

Based on the six basic AT concepts presented in [8], namely *consciousness & activity*, *object-orientedness*, *structure of activity*, *internalization-externalization*, *mediation*, and *development*, we initiate a discussion of conceptual understandings of physico-spatial surroundings and some considerations for design of ubiquitous computing systems. The discussion of these concepts is summarized in Table 1. Due to the scope of this paper, we do not offer an introduction to the six basic concepts – for this, we refer to [10]. Rather, we discuss them specifically in the light of ubiquitous computing systems in physico-spatial surroundings.

Unity of consciousness and activity

Physical space frames most ubiquitous computing *activities*, and by implication also the *consciousness* of the users partaking in such activities.

It is vital to incorporate all aspects of the domain space into the design process. Means of doing this, except for traditional studies, interviews and so on, is to bring spatial representations into the design process. Design representations that embody physico-spatial aspects of the interspaces being designed can take various shapes throughout the design process and may encompass aesthetic and affective aspects of interspaces as well as instrumental and functional aspects. There is a need in interaction design for understandings of how both the augmented and the physical spatial layout effects the users' experience and the users' behavior and social relations. Adapting understandings of physical space into ubiquitous computing interaction design, both in the design process as well as in the designed artifact, may yield new ways of understanding activities and use. Architectural models, both in the shape of physical foam-core models and virtual 3D models, are one example of this kind of spatial representations. Such physical and digital models are an embodiment of the design process, where alternative designs and design decisions are represented in different forms. Prototypes in interaction design traditionally demonstrate and explore interaction with a focus on functionality, whereas models in architecture often serve to provide visual overviews and understandings of the entire space in which spatial forms and users will co-exist in the performance of activities. Physico-spatial design representations may expand the functional focus of traditional prototypes and serve as vehicles for communication, exploration, and understanding. As such, these representations supplement not only prototypes, but also design representations such as mock-ups [5], storyboards, scenarios etc. Another approach to incorporate all aspects of the domain space into the design process is to carry it out in situ. The advantages with performing design sessions or even the entire design process in the right domain space is further described in [6].

	Conceptual understanding of ubiquitous computing systems in physico-spatial surroundings	Some considerations for design of ubiquitous computing systems in physico-spatial surroundings
Unity of consciousness & activity	Physical space frames most ubiquitous computing activities and thereby also frames the consciousness of users.	Incorporate perspectives and understandings of domain space into the design process. Bring spatial representations into the design process. Carry out design sessions in situ.
Object-orientedness	Activity is directed towards objects that may be physico-spatial and activity often concerns the ongoing engagement towards adapting to or transforming physico-spatial configurations	Consider how the users may decipher the activity space of applications, devices and other users/actors, how they may anticipate effects manipulating the object of their activity, and how this may change the activity itself.
Structure of activity	Physico-spatial surroundings influence activities on multiple levels – activities, actions and operations - as well as the motives, goals and circumstances for acting.	Consider motives for using UC devices and applications. Consider goals to achieve with devices and applications. Consider affordances and constraints as circumstances for using devices and applications.
Internalization-externalization	Space frames internalization and is in itself internalized in terms of spatial literacy. Externalizations take place in and may be directed towards physical space.	Consider how users make sense of UC devices and applications as part of a physico-spatial surroundings. Consider possible ways of using devices and applications to reconfigure physico-spatial surroundings.
Mediation	Spatial surroundings can mediate activity as well as tools and concepts.	Consider how space may serve as mediator for activity in combination or convergence (or possibly in opposition to) mediating devices and applications.
Development	Physico-spatial surroundings evolve over time as crystallizations of and frames for certain types of activities.	Consider existing tools, habits and physical constraints as sources of inspiration and the base for new UC systems and interaction Consider how devices and applications may adapt to and/or co-evolve with changing physico-spatial configurations.

Table 1: Activity-theoretical concepts and physico-spatial surroundings

Object-orientedness

Activity is directed towards achieving an outcome by transforming the object of the activity. Due to their nature of being spatially distributed and often mobile, ubiquitous computing devices and applications are frequently employed to achieve outcomes related to physico-spatial configurations, such as bring together the right people at the right time as in [1]. Practical design implications thus include explorations of how users may decipher the activity space of applications, devices and other users/actors, and how they may anticipate effects manipulating the object of their activity. During the process of the activity, the activity itself may change due to changes in the subjects' conception of the activity, changes in the mediating tools, or possibly in the object of activity. Design considerations also entail how to respond to such transformations of activities.

Structure of activity

The configuration of physico-spatial surroundings frame and influence activities on a number of levels. On the level of activities, aspects of this configuration may constitute the motive for carrying out activities; on the level of actions, goals may concern navigating in and/or reconfiguring parts of the physical environment; on the level of operations, the physico-spatial circumstances of operations may afford or constrain operations. For designers of ubiquitous computing systems, this multi-levelled perspective on activities means that design considerations not only regard the concrete constraints and affordances of interfaces, but also the goals for interacting with devices, and indeed the very motivations for using them in certain spaces.

Internalization-externalization

The process of internalization is often influenced by the physico-spatial environment in which it takes place. In some cases the internalization process may even be directly

concerned with spatial surroundings, forming so-called *spatial literacy*, ie. concepts and understandings of human beings' relation to their physico-spatial surroundings [9]. Reciprocally, externalization of intra-mental processes are often directed towards affecting - and in most cases are visible as reconfigurations of - the subject's physical surroundings. For designers, this on the one hand calls for exploring how users make sense of devices as part their physico-spatial surroundings, and on the other hand calls for explorations of how devices and applications may allow for reconceptualizations and reconfigurations of users' surroundings.

Mediation

Spatial configurations can mediate activities just as can tools. Such configurations may even be considered tools, eg. hotel lobbies mediate transitional activities of arrival and departure, auditoriums mediate lecture activities etc. For designers, this on the one hand requires insight into the types of mediation that is always already taking place in the domain for which one designs. On the other hand, it prompts considerations regarding how reconfigurations of space may affect existing mediating processes and initiate new ones.

Development

Considering the activity theoretical concept of *development*, physico-spatial surroundings evolve over time as crystallizations of and frames for certain types of activities. Returning to the concept of spatial literacy, cultures over time develop physical spaces for certain activities, as well as narratives and literacies that complement them. As means for design, it is important to consider what is already out there in the physico-spatial surrounding, and to consider these tools, habits and physical constraints as inspiration and the base for ubiquitous computing systems and interactions. One aspect of this implies consideration of how devices and applications may adapt to and/or co-evolve with changing physico-spatial configurations.The nature of a design material is its ability to take up new forms or relate to other materials in new ways shifting its initial function. The primary interaction design material, IT, has been construed as non-physical, however, when designing spatial interfaces, physical materials come into play and designers must understand how the properties of IT relate to spatial properties and boundaries as design materials.

CONCLUSION AND FUTURE WORK

In this paper, we have argued that there is a growing need for understanding the physico-spatial surroundings for ubiquitous computing interaction design. We have therefore presented a discussion of physico-spatial concepts and considerations for design using basic activity theoretical concepts. Our discussion is cursory and initial, and it prompts future expansion and experiments to elaborate and further develop both the conceptual perspectives and the design-oriented considerations.

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