Relation-based Spatial Adaptation in Pervasive Computing

Report of a Research Visit Funded by PerAda

Clemens Holzmann

Johannes Kepler University Linz
Institute for Pervasive Computing
Altenberger Straße 69, 4040 Linz, Austria
clemens.holzmann@jku.at

Abstract. This article reports on my research visit at the University of Modena and Reggio Emilia, Italy, in June/July 2009. The purpose of the visit was the elaboration of principles and methods of pervasive adaptation to spatial contexts. More precisely, it addressed the autonomous adaptation of pervasive information and communication systems to their position, direction and spatial extension with respect to the surrounding space as well as with respect to co-located systems. This is an upcoming research topic, especially with regard to taking into account spatial relations between spontaneously networked computers that are embedded in everyday artifacts, as they usually operate without a centralized control and thus have to autonomously adapt to their current spatial situation or context. As spatial context information – i.e. spatial properties like position and extension as well as relations between them – can be highly dynamic due to the mobility of computers and other computationally augmented artifacts, not only their static spatial situations but also context-changes over time play a key role in pervasive adaptation. With this research visit, a first step towards a long-term collaboration between the involved institutions concerning the relation-based spatial adaptation of mobile devices has been made.

1 Introduction

Thanks to technological advances within the past few decades, it has become possible to shrink sensors as well as processing and wireless communication technologies to a size that enables their integration into virtually everything. This development leads to a huge and ever-growing number of computational devices in the environment, and there is strong evidence that this trend will continue. Common examples for the ubiquity of computation and communication are mobile phones which are connected to the Internet, car keys using radio-frequency identification, computer-augmented meeting rooms, and recently also GPS-enabled wrist watches or shoes with integrated motion sensors. As they are distributed throughout physical space and more and more interconnected with each other, their *spatial situation* as well as its *changes over time* – e.g. due

to movements or manipulations by humans – are a significant context for the services they provide. With an awareness about their spatial situation, mobile devices would be able to adapt their behavior to spatial changes accordingly, and hence provide a basis for new forms of human-computer interaction.

In pervasive computing research, spatial information has always played an important role. Especially the location of devices and their proximity to each other turned out to be of utmost value for building context-aware applications [1], but also their orientation in space as well as information about their acceleration in two or three dimensions have received much attention. Many technologies for sensing the spatial information of individual devices are readily available (e.g. real-time location systems and micro-electro-mechanical inertial or magnetic sensors), but it is a little investigated issue how spontaneously networked computational devices can be made aware of their spatial contexts with respect to each other. Such *relative* spatial contexts like distance, orientation or containment relations between devices are often more relevant for the development of spatially adaptive applications than *absolute* contexts like their position and direction in space, in particular with regard to the interaction among co-located devices [2–5]. To the latter we refer to as *spatial properties* in the following, and to the former we refer to as *spatial relations*.

The focus of the research visit was on the acquisition of spatial relations between wireless mobile devices and their use for building spatially adaptive applications. In pervasive computing, the acquisition and use of information which describes the current situation of a device is referred to as *context-awareness*, which has been defined as *any information that can be used to characterize the situation of an entity* in [6]. It is considered important especially for applications where the environment changes frequently [7], which is commonly the case in mobile and pervasive computing. The techniques and technologies for location awareness – which refers to the concept of adapting services to the locations of devices – have already been investigated in depth, and there exists a plethora of location-aware services and sensing technologies. In contrast to location-awareness, which relates to the concept of adapting services to the locations of devices, the spatial situation of devices in the presented research work is described solely by their *spatial relations* among each other. This means that the application behavior is modeled depending on the recognized spatial relations, which is suitable for applications which are adaptive to their spatial situation with respect to *surrounding* computational devices.

In Section 2, I will first give an overview about the goals and outcomes of the research visit. Afterwards, Section 3 will discuss in more detail ongoing work which has been started during the visiting period. It is about a survey and taxonomy on the acquisition and use of spatial relations between mobile devices, both from a conceptual as well as from a technological and programmatic perspective.

2 Goals and Outcome of the Research Visit

The research visit was scheduled from 29th June to 3rd July 2009 at the *Agents and Pervasive Computing Group* (http://www.agentgroup.unimore.it) at the University of Modena and Reggio Emilia in Italy. My supervisor at the host institution was Prof. Franco Zambonelli. The general goal of the research visit was a confluence of adaptation work conducted by the two participating institutions: (i) Institute for Pervasive Computing, Johannes Kepler University Linz (Prof. Alois Ferscha) and (ii) the Agents and Pervasive Computing Group, University of Modena and Reggio Emilia (Prof. Franco Zambonelli). One line of research conducted by the group of Prof. Alois Ferscha, and on which I am working on, concentrates on abstractions of space for the development of spatially adaptive systems and applications (e.g. Zones of Influence [8, 9] and Vibro-Tactile Space-Awareness [10, 11]). Research conducted by Prof. Franco Zambonelli investigates self-organization in distributed and autonomic computing systems as well as coordination models and middleware for distributed systems, also with a focus on spatial aspects (e.g. Spray Computers [12] and the TOTA approach [13]). A combined consideration of these two areas, namely abstractions of spatial contexts on the one hand and distributed coordination models on the other hand, would be beneficial for developing a conceptual framework and new software engineering methods for the design and implementation of adaptive systems in the context of spatially dynamic environments.

At the first day of the visit, I gave a presentation about my past and current research activities to Prof. Franco Zambonelli, Marco Mamei, Gabriella Castelli and Cynthia Villalba from the Agents and Pervasive Computing Group, as well as to Prof. Roberto Montanari from the Human-Machine Interaction Group (http://www.hmi.unimore.it). At the end of my presentation, I went over several research questions regarding the *pervasive adaptation to spatial relations*, which I consider both challenging and highly relevant to investigate. They concern the issue of how to make spontaneously networked devices aware of their spatial contexts with respect to each other, and which spatial context information can be acquired exclusively from spatial relations among devices in range – both concerning *individual devices* and *groups of devices*. In particular, the *research questions* included the following:

- Which spatial relations can be recognized with currently available sensors?
- How to cope with different types, accuracies and sample rates of spatial sensors in this regard?
- What are methods for acquiring relations between devices out of range?
- Which spatial properties of a whole group of devices – such as its shape, size, direction, position or velocity – can be acquired from relations between the group members?
- Which spatial relations can be acquired between groups of devices or between individual devices and groups, just from binary spatial relations between the group members?
- What are programming models and software architectures for the development of spatially adaptive applications based on spatial relations?

– What are suitable spatial abstractions in pervasive computing (i.e. which spatial aspects should be represented in which situation, and how)?

After that, Cynthia Villalba held a presentation about her research on a nature-inspired approach for large-scale pervasive service ecosystems (see [14]), and Gabriella Castelli and Marco Mamei presented their ongoing work on the Whereabouts Diary (see [15]). During the visiting period, we had many discussions about our research activities, which improved the mutual knowledge between the two participating institutions at the JKU Linz and the University of Modena and Reggio Emilia. I shared most of my time with Marco Mamei, and we had several meetings together with Prof. Franco Zambonelli; I would like to thank both of them for the many fruitful talks and their friendliness. From the discussions, it turned out that a good starting point for a long-term collaboration concerning the pervasive adaptation to spatial relations would be the joint writing of a respective *survey paper*. It should give a comprehensive overview of the state-of-the-art and open issues on the one hand, which has not been done yet, and provide the fundament for future collaborative projects in this field on the other hand. Together with Marco Mamei and Prof. Franco Zambonelli, I have developed a first structure of the paper during my research visit, which is explained in more detail in the next section.

3 Relation-Based Spatial Adaptation

Relation-based spatial adaptation is an *interdisciplinary topic*, which comprises several computer science disciplines such as computer networks and human-computer-interaction, and it is an emerging field in pervasive computing which is driven by the technological advances that make it possible to detect the spatial relations between physical things of everyday use. Until now, mostly absolute spatial information has been used in context-aware applications, but recently a stronger focus on spatial relations can be observed. Our intention is to write a paper which provides a reference for researchers and practitioners who are concerned with the computational use of spatial relations between mobile devices, whereas our focus is on the field of pervasive computing. It should show the possibilities and limitations in this domain, provide a useful guide for the development of relation-based spatially adaptive applications, and help researchers to identify opportunities for future work.

The first part of the paper will be the identification of *application scenarios* from the literature, as well as the detailed description of a scenario which should serve as a running example throughout the paper. It comprises different services for individual people or groups of people in a particular environment, who carry mobile devices which are equipped with spatial sensors and wireless communication facilities. Afterwards, we plan to give a comprehensive survey and a *taxonomy of spatial relations* within the scope of pervasive computing, which comprises an overview of the different types of spatial relations and the criteria – such as the related entities and the frames of reference for the representation of the relations – according to which they can be classified. An important issue

is the *acquisition and abstraction* of the surveyed spatial relations. This will be a further part of the paper, which deals with their recognition from sensor data and their representation in a way such that they can be processed by a computer. In order to be able to use spatial relations in applications without having to deal with all the low-level details concerning their acquisition and programmatic use, a *middleware* is necessary. A huge body of middleware approaches is available, and it appears that they are usually designed for specific domains or are suitable under specific conditions only. Therefore, we plan to survey existing middleware approaches as well as their provided relation-based concepts for spatial programming in the paper, and come up with guidelines which should help programmers to select the most suitable tools for building their applications. Finally, we will present *directions for future research* on the issue of relation-based pervasive adaptation, which should provide a starting point for other researchers to make a contribution in this new field.

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