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Smart Spaces: A Metacognitive Approach

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Abstract. Smart spaces provide services that support users in their daily lives. This requires the smart spaces to recognize the situations and adapt to them. Identifying the situation and adjustment to it in the physical environment has attracted lots of research, but recognition and adaptation at the meta-level has not been studied much. We refer with meta-level recognition and adaptation, that is, with metacognitive functionality, to evaluating the decisions made by the smart space and to adapting the decision making to maximize user experience. The main objective of this PhD work is to equip smart spaces with metacognitive functionality and the expected main contribution is a general framework for Metacognitive Smart Spaces (MSS).

Keywords: smart space, ubiquitous computing, metacognition, metareasoning, reasoning

1 Introduction

Smart spaces are physical environments enriched with technology sensing the environment and changing its state. They interact with people in the environment, in order to provide them the right services at the right time, the right place, and the right situation. Smart spaces act as containers for different ubiquitous services and supply unobtrusive support for the user based on contextual information.

A lot of research has been carried out on different aspects of the development of ubiquitous systems. Context acquisition and data fusion techniques provide context data for users and applications. Research on context modeling has produced many formal representations of context, like ontologies. Context reasoning studies, in turn, have produced different approaches for deducing relevant information from context, such as case-based and rule-based reasoning. Many solutions to facilitate the development of ubiquitous systems by reusable middleware have been suggested. Also, human aspects of interaction with ubiquitous systems have attracted a lot of attention, such as how to address privacy and personalization, how to balance the ubiquitous systems autonomy and control, and how users can correct wrong system behavior.

However, not much research has been conducted on interaction at the smart space level. Instead, ubiquitous services and applications are mostly considered in isolation from each other. Smart spaces are full of services interacting with users. Some services collaborate directly with each other, others influence each other without any intentional collaboration. Hence, good user experience requires considering the overall interaction provided by all these services together. As a consequence, the overall interaction cannot be tailored beforehand but must be considered at runtime.

Our research aims to improve the user experience of smart spaces. We propose to equip smart spaces with metacognitive functionality, which by means of self-analysis and self-regulation provide better user support. This is realized by monitoring of the execution of tasks and the overall interaction and adapting service functionality as required. The expected main contribution of this PhD work is a general framework for Metacognitive Smart Spaces (MSS). The results on metacognition research provide the theoretical framework [2]. We apply the metareasoning model presented in [3] to smart spaces.

The rest of the paper is organized as follows. Section 2 explores aspects of interaction in smart space. Section 3 introduces our metacognition approach. Research questions are formulated in section 4. We present related work with section 5. General discussion is provided in section 6.

2 Interaction in smart spaces

2.1 User-smart space interaction

There are several aspects to consider about user-smart space interaction. First, ubiquitous computing spreads computing resources and functionality everywhere in the environment. Generally, there is no direct Human-System interaction. Interaction is always mediated through environment (Human-Environment-System). That is, human actions are perceived by the system through sensing the environment or explicit input, the system notifies users via environment as well, for instance by showing information on the displays. Hence, the environment itself becomes the user interface [4].

Second, as soon as the user is in the smart space, the personal borders of the services as the independent units are getting blurred. The interaction of the user with all services and devices of smart space are perceived by him as interaction with a single system [5].

Third, a lot of challenges arise when a user enters an unknown smart space, such as: How to advertise available services and their added value, achieved via services' interactions with the user? How to address personalization of these services, according to user preferences? A smart space should constantly learn user preferences from his actions and gradually target itself to match user interests better.

Fourth, several user and smart space contextual parameters affect the user-smart space interaction. Inexperienced user might need more guidance to use the smart space. When the user becomes more familiar, less explicit support from the smart space is needed. Moreover, user behavior can change in presence of other users, according to their familiarity, status, etc. User behavior is also strongly affected by the system performance, accuracy and relevancy of support. Hence, user-smart space interaction is always dynamic and volatile, evolving with experience.

2.2 Service interactions in smart space

Smart spaces consist of many services and devices. Services directly or unintentionally (via a user or via changes in environment state) interact with each other to support users. Generally, from smart space's perspective, user support can be achieved both in decentralized and in a more centralized manner. In the first approach, each ubiquitous service of smart space adapts itself based on user and environmental context. That is, services are considered as autonomous agents acting in the environment. This approach introduces the following challenges: 1) Sophisticated techniques are required to achieve service collaboration, 2) Context acquisition can easily become overlapping and overwhelming, because many services can acquire user information to adapt their behavior, 3) Handling of conflicts, arising because of (un)intentional service interactions, and failures is difficult. In second, more centralized approach, smart spaces monitor the users and their interactions with environment (i.e. acquire context information) to tailor services composition to achieve better users support. This approach solves above issues, however it also introduces deployment challenges, issues of scalability, privacy and reliability.

2.3 Improving interaction in smart space

Improvement of user-smart space interaction aims at providing better, more pleasant, trustworthy and reliable solutions for users' tasks, considering dynamic situations and user preferences. Serious challenge in this course is to measure the user satisfaction in unobtrusive fashion, e.g. perceived usefulness.

From another hand, we cannot improve user-smart space interaction if interaction between the services is poor. This issue leads towards autonomic computing systems design. Such systems are able to function by their own, without human intervention and posses self-* features, such as self-configuring, self-healing, self-protecting, and self-optimization.

In our opinion, to provide good user experience, smart space must be able to monitor, evaluate, and alter the decisions it makes, both from these decisions performance and user satisfaction perspective. That is, smart spaces should be able to do analysis of its own decisions based on the acquired information, evaluate whether user is satisfied with them, and modify its own decision making when necessary. In other words, smart spaces should possess metacognitive facilities, in similar way as humans do. We call such smart spaces Metacognitive Smart Spaces (MSS).

3 Metacognitive approach

Metacognition research covers studies about reasoning about one's own thinking, memory and the executive process, controlling selection of the strategies and their processing allocation [2]. Figure 1 illustrates the general framework for the metacognitive facilities of smart space, applying the basic metareasoning model [3]. The physical space consists of users and devices that sense and act in the space, which includes different sensors, actuators and input/output devices(Ground level). This interaction can be explicit for the user, that is, he manually inputs commands to the input devices. Alternatively, this interaction can be implicit: the user's context is perceived with different sensors and other monitoring devices (perception inside the environment in Fig. 1). Services make decisions on what actions to perform to present information to the user or to change the state of the environment (i.e. what commands to send to devices) based on perceived context from sensor data and other available information. That is, the services perform reasoning (Object level). The commands executed by the devices and the actions of users change the state of the physical space (Ground level). Users act based on their own reasoning and also react to the devices' actions. This in turn, is perceived and triggers more reasoning and the cycle continues. Metareasoning, or more generally metacognition, builds a higher abstraction level to this model (Meta-level). That is, metareasoning is reasoning about this perception-reasoning-action cycle.

Metareasoning is analysis of how well the actions progress the tasks the services are performing and how well these tasks support users. It allows estimating and understanding what was happened, why it happened, and when it happened, why something went wrong, or why something achieved better results than expected, for example. Alternative strategies can be applied or even solutions can be created and evaluated to achieve the goals in dynamic settings. Metareasoning consists of both the meta-level control of computational activities and the introspective monitoring of reasoning [3]. Both these activities facilitate smart spaces to achieve better user support. Figure 1 makes it clear that Meta-level does not correct the actions themselves, but the reasoning process of the services. Moreover, Meta-level changes Object level, but not vice versa.

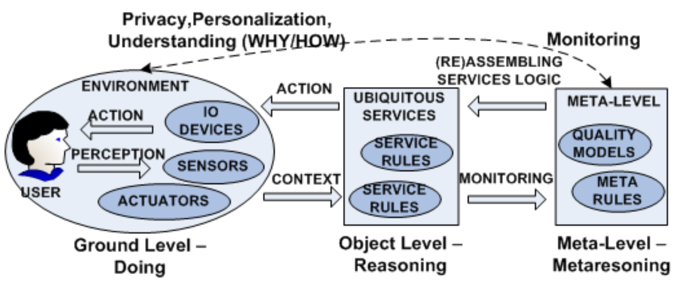

Fig. 1. The metacognitive approach

Meta-level of smart space is responsible for the following tasks: *Monitoring* of the system performance, state, possible conflict situations, and user satisfaction. Based on monitring, Meta-level evaluates how well the system (which in case of smart space would be the composite logic of services) supports the users, and creates an alternative solution for the problem if the system performs poorly. Monitoring also allows informing the user about execution, for example, justifying decisions and explaining failures.

Control. In our approach, control is building and modifying the services' reasoning processes, based on changing environmental context, user's goals and satisfaction and system performance. Control functionality is responsible for interpreting the collected data, evaluating it, and changing decision making when necessary. There are many challenges in building such functionality. First, models of good and bad performance in different circumstances are required (Quality models in Fig. 1). These models have volatile nature and they change with the system usage. Evaluation mechanism should be developed to judge the system performance and user satisfaction as poor or good based on these Quality models. Second, control mechanism, which actually changes the Object Level by constructing new or applying different decision making strategy, is needed.

We add the tasks of managing the *user privacy and preferences information*, which are not directly related to metacognition of the smart space itself and can be considered as a separate module of Meta-level. When a user acts in a smart space, a user profile is modified by a learning mechanism. This profile is used by the service logic assembling and execution mechanisms. Sensitivity of user-related information should be considered as well.

Metacognitive Smart Spaces are expected to support users in their tasks by monitoring task execution and planning, allocating, and tailoring the execution as necessary; according to user preferences, context information, and system performance. Metacognitive Smart Spaces define conflicts and failures and trigger decomposition of decision process in order to avoid them. Metacognitive Smart Spaces trigger learning when system performance or user satisfaction needs to be improved. Also, metacognitive facilities allow explaining the system behavior to end users. Generally, Metacognitive Smart Space resembles an adaptive system: It adapts its decision making process based on the contextual information, user satisfaction and overall system performance. Ideally, Metacognitive Smart Spaces should posses self-* properties of adaptive systems, such as self-awareness, self-monitoring, self-healing [6]. We emphasize the importance of estimating the quality and tailoring the decision-making process, that is why we call Metacognitive, rather than Adaptive.

4 Research hypothesis

The purpose of this research work is to enrich smart spaces with metacognitive facilities. By doing so, we would like to evaluate whether interactions within smart space become more trustworthy and reliable.

General research hypothesis is the following: *Metacognitive Smart Space provides better user-system interaction support, by monitoring and tailoring itself according to its performance, context and user experience.* Better can mean faster, more pleasant, or reliable. We will address two sub-hypothesis: 1) Metacognitive Smart Space provides cause-and-effect relations details, hence users can improve understanding and control of the system. 2) We believe that the Meta-level of smart space can be realized using the same functional structures as the Object level. Our aim is to apply the rule-based approach in developing the Meta-level. We are planning to represent the Object level as a pool of rules. Rules will be applied also to make the evaluations and adaptations of the Object level of smart space (so called Meta-rules). The expected main contribution of this research work is a general framework for Metacognitive Smart Spaces.

Conducted research will be directed to prove outlined hypothesis and can be divided into three main phases: First, studying the theoretical issues, related to state of the art in smart spaces middleware development, adapting and autonomic systems development, and metareasoning aspects in context of smart spaces. Second, designing the general framework of Metacognitive Smart Space and building the prototype verifying the theoretical concepts. Third, development and implementation of the scenarios or conducting the simulation experiments to verify feasibility and usefulness of the approach, and incremental improvement of the framework based on the experience gained from the prototypes.

We expect that our research will help to improve the User - Smart Space interaction experience, user awareness and understanding of system facilities and, finally, overall user acceptance of the system, by providing metacognitive facilities for Smart Spaces.

5 Related work

There is not much attention from the research community to metacognitive site of smart spaces. Mostly, existing research addresses separate aspects of smart spaces. McBurney et al. [1] explore personalization aspects of pervasive environments. Authors fairly note that instead of users, learning mechanism should be utilized to collect a user profile. Roman et al.[7] address meta-level issues at the application level in their Gaia metaoperating system. Their coordinator component manages the application composition and fault tolerance.

A lot of research has been done in monitoring of different aspects of information technologies, such as networks, software; however, not much studies were conducted regarding monitoring collaborating services for the smart spaces. Kang et al.[8] suggest USS (Ubiquitous Smart Space) Monitor, a monitoring system for a collaborative ubiquitous computing environment, providing monitoring and visualization of the collaborative applications. Lee et. al. [9] go further with their UMONS (Ubiquitous Monitoring System in Smart Space). It includes Analyzing module, which creates high-level, complex information via inference and recognizes system or application errors. Thus, this information constitutes initial levels of self-introspection.

Control of ubiquitous services is mainly focused with the logic adaptation or adjusting services compositions. White et al. [10] use context information to reconfigure services and resources to adapt the user access rights and protect user privacy. Xiang and Shi [11] propose to utilize personal service aggregation (PSA) that maintains tasks, services, user's role, and underlying resources for each user. So the system reschedules the underlying resources, based on PSAs in case of resource collisions.

Nowadays the field of Autonomic Pervasive Computing emerges, which studies how key-main properties of autonomic computing, such as self-configuration, self-optimization, self-healing and self-protection can be achieved in pervasive computing [13],[14]. There are middleware proposals as well, e.g. [15]. Some of these considerations may help us in development of the Metacognitive Smart Spaces framework.

A lot of research were conducted about metacognition and metareasoning in computational Artificial Intelligence research [2],[3],[12]. Metareasoning approach has got a lot of interest for agent design [16], [17]. Cazenave [18] provides example of the meta-rules usage.

6 Discussion

Smart spaces provide unobtrusive ubiquitous user support. However, to achieve better user experience, smart spaces should possess metacognitive facilities, the same way as humans do, like "Is this algorithm sufficient to solve the task ? Or should I select another one?" Smart spaces definitely should include introspective monitoring and system execution control. That means, that smart space should be able to monitor all aspects of it: what is currently happening, are users satisfied with the decisions, etc. and alter the decision making process accordingly. Moreover, understanding of system execution quality is necessary, in order to achieve correct evaluation for tailoring. For instance, if a user is not satisfied with the efficiency of the service, a system should find out another algorithm or migrate execution on more powerful devices.

We are assured that some sorts of metacognitive facilities are necessary to achieve better user experience in smart spaces, hence this work is important. This research is at the early stage and our main interests are on the required control mechanisms of Metacognitive Smart Space.

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