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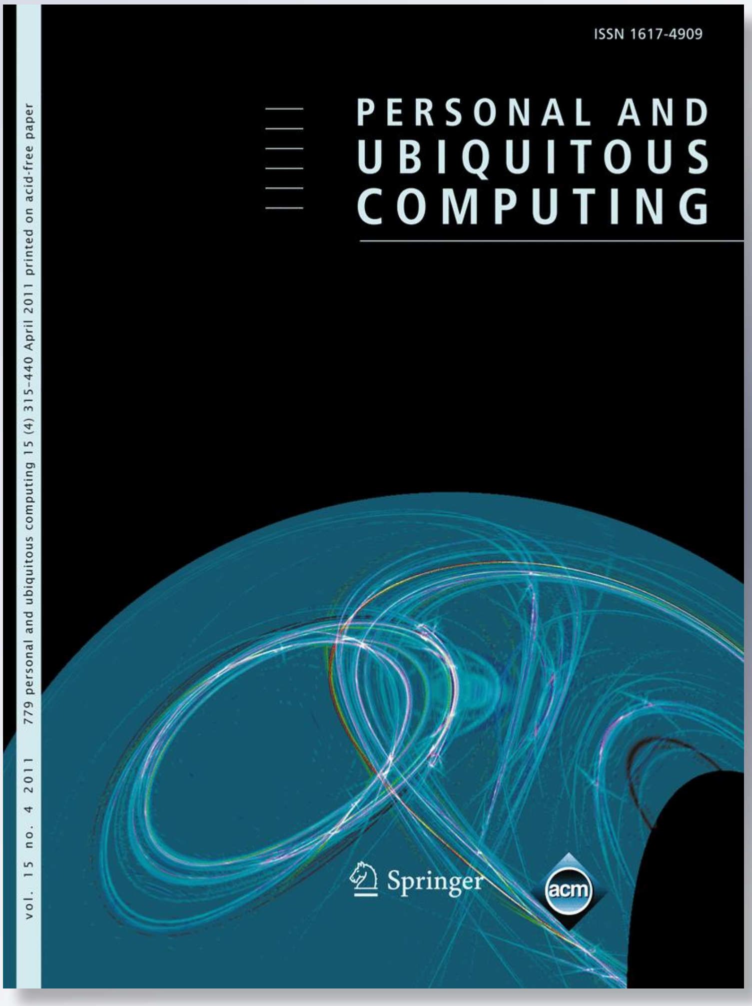

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ORIGINAL ARTICLE

Awareness marks: adaptive services through user interactions with augmented objects

Ramón Hervás · José Bravo · Jesús Fontecha

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Abstract The ambient intelligence paradigm involves one important challenge: to be adaptive to users and context through simple and natural interactions. To meet this goal, it is important to associate data with relevant everyday objects in the environment, including users themselves, and to enable interaction mechanisms between these objects. Following this premise, in this paper, we present a conceptual model to link contextual information with augmented elements acquired from user interactions in an implicit and transparent way. In this way, it is possible to personalize and enhance offered services in order to facilitate daily user activities. We call this contextual data "awareness marks", and these awareness marks make it possible to offer novel services adapted from past events that were captured as they happened. Moreover, we have developed and evaluated a set of prototypes using Near Field Communication technology, which follows the presented model.

Keywords Context awareness · Ontology · Ambient intelligence · Human–computer interaction · Augmented objects

R. Hervás (✉) · J. Bravo · J. Fontecha
Technologies & Information Systems Department,
Castilla-La Mancha University, Paseo de la Universidad s/n,
13071 Ciudad Real, Spain
e-mail: ramon.hlucas@uclm.es

J. Bravo
e-mail: jose.bravo@uclm.es

J. Fontecha
e-mail: jesus.fontecha@uclm.es

1 Introduction

Context-aware environments can be implemented by linking data and enabling interaction mechanisms to relevant elements such as users, devices, objects and areas. This is one of the challenges to develop smart environments where devices work to support people carrying out their everyday life activities in a natural way. Therefore, it is necessary to know the entities in the environment and to consider new interaction schemas and styles with them.

Traditional human–computer interaction requires frequent user interventions to indicate every action to the computer. This vision is opposite to the idea of invisible computing. Consequently, it is important to reach a more natural interaction, making it more implicit versus the traditional explicit dialog with the computer. A decrease in user interactions will also reduce the user's attention. In this way, we are going to think about human–ambient intelligence interaction instead of human–computer interaction as a new perspective closer to human–human interaction.

We have developed the concept of "Tagging-Context" in order to distribute information embedded in the environment and provide automatic services to the user. For that, it is necessary to augment the relevant environmental entities and enable their embodiment in user–ambient intelligence interaction. Typically, whenever users interact with an augmented object, they receive explicit and expected services; however, as a consequence, these user interactions bring changes in the environmental situation that should be captured. Our proposal manages this information through well-formed marks that are used later to enhance system awareness and offer implicit services to the user based on previously stored marks.

This paper is organized into six sections. Section 2 analyzes related works with a focus on identifying objects in the environment, representing their behavior, enabling user interaction with them, and a comparison with our proposal. Section 3 presents a general model linking awareness marks to augmented objects in the environment and techniques to define the adaptive behavior of the services offered to users by means of decision trees. This model is independent of the technology to augment objects and communication mechanisms. Section 4 describes a particular implementation based on this model utilizing Near Field Communication (NFC) technology. In Sect. 5, we evaluate our infrastructure and, finally, Sect. 6 analyzes the conclusions and contributions of this paper.

2 Related work and approach

Some proposals regarding interaction styles in smart environments have to be considered. Spontaneous interaction is introduced in the Digital Aura project [1]. This system enables interaction between objects within physical proximity. We can also emphasize embedded interaction in which sensors and actuators are embedded into devices, tools, and everyday objects in addition to interaction embedded within user tasks [2]. Multiperson–display interfaces have also been studied. For example, Terrengui et al. considered physical constraints, the focal point of attention, social context, and type of body movement/interaction [3]. Most related works tackle the challenge of providing intelligence to digital objects and interaction mechanisms between entities in the environment. We present a proposal for achieving a more natural interaction with the intelligent environment using digital and non-digital objects (for example, a door, table, etc.).

There are also several proposals to bear in mind when focusing on awareness in intelligent environments. For example, Loke visualized intelligent environments based on multiple context-aware artifacts [4]. A context-aware artifact uses sensors to perceive human or other artifact contexts and sensibly respond to them. By adding context awareness to artifacts, we can increase their usability and enable new user interactions and experiences. Focusing on smart homes as a particular intelligent environment, Taylor et al. [5] suggest the use of surfaces such as refrigerator doors, wall displays, and bowl-shaped surfaces, drawing intelligence from our interactions with these surfaces and from the corresponding response from them. Lopez de Ipiña proposed a procedure of storing, reading, and sharing care-related data thanks to the use of radio frequency identification (RFID) tags that serve as mini databases that are associated with relevant elements of elder care [6]. Fuentes et al. approached the problem of introducing embedded software into a wide variety of everyday smart objects by associating a features model and runtime contextual aspects; in this way, they achieve the automatic derivation of different configurations for those objects by means of proposed middleware [7]. Garcia-Herranz et al. presented an approach and prototype to semi-automatic adaptation of perceptive environments through a system of rule-based, configurable and modular agents, which are able to explain their behaviors and adapt to changing user habits [8]. Specifically, they implemented their prototype over a living room equipped with sensors and actuators. This is precisely the main difference from our proposals. We propose a non-sensor-based infrastructure that provides an autonomous and dynamic mechanism to update contextual information in an implicit way while users perform everyday tasks. Additionally, and possibly the principal contribution of this paper, we present mechanism to enhance the awareness by means of ontological-based decision trees to determine environmental behavior and the possible consequences of user interactions.

3 Awareness marks model

We define awareness marks as data traces stored whenever users interact with any relevant elements in the environment, including users themselves. These traces are used to enable a better understanding of the user activities and to offer adaptive services later. The elements that have linked awareness marks are called augmented elements. Specifically, we can differentiate four kinds of elements: devices such as printers, displays, notebooks, and mobile phones; inanimate objects such as doors, chairs, desktops, and panels; areas such as rooms, buildings, corridors, and parks; and users. This taxonomy was inspired by previous work from Hervás et al. that analyzed the context from a user-centered perspective thought formal ontological languages [9].

3.1 Interaction taxonomy

In terms of adaptive services, awareness marks support the activities of individual users (individual and cross-object interaction) as well as groups of users (cross-user and cross-element interaction). Individual interaction occurs when a user interacts with an augmented element (big white circle) putting an awareness mark (small blue circles) implicitly (Time 1: T1). Later, when he/she interacts again (Time 2: T2), the user receives an adaptive service based on that previously stored mark. Figure 1 demonstrates this process graphically.

Cross-user interaction takes place when one (T1) or several (T2) users put awareness marks in an augmented element and a third user (T3) later receives adaptive services empowered by the marks stored by the others (Fig. 2).

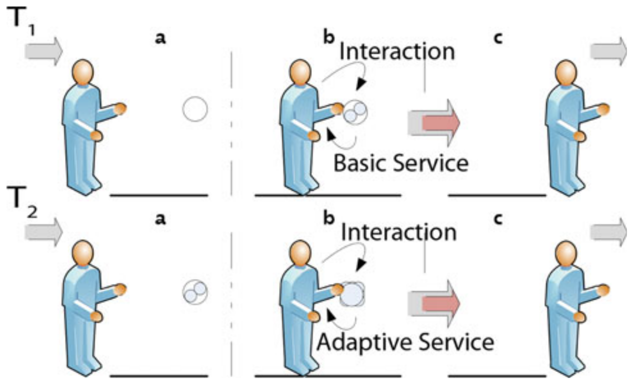

Fig. 1 Individual user interaction

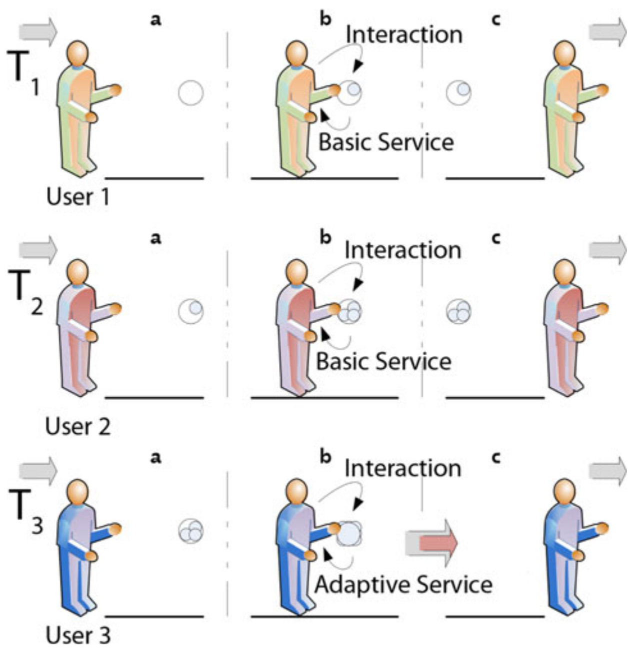

Fig. 2 Cross-user interaction

Cross-object interaction consists of adapting user services (T2) related to a specific augmented element (white square) in the environment through awareness marks generated in previous interactions (T1) with another augmented element (white circle). This kind of interaction requires distribution or communication of marks among different objects (Fig. 3).

Finally, cross-element interaction is the combination of cross-user and cross-object interaction. Awareness marks generated from the interaction of a user with an augmented object enhance the services offered to another user in another object (Fig. 4).

3.2 Model requirements

The proposed model tries to be general and technology independent; however, the use of awareness marks entails several system requirements:

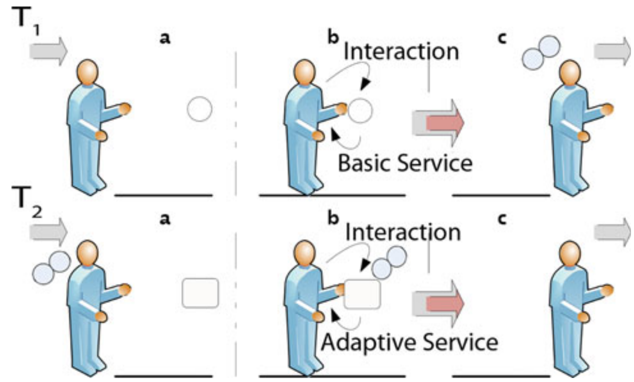

Fig. 3 Cross-object interaction

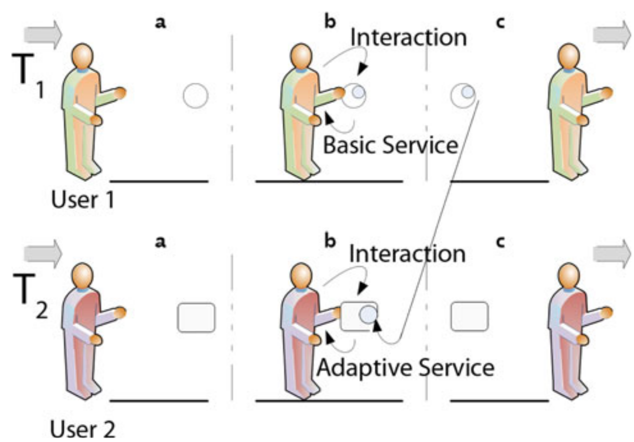

Fig. 4 Cross-element interaction

- To implement mechanisms for linking information to relevant elements in the environment. It is also desirable but not indispensable to decentralize the storage of marks, they should be directly associated with augmented elements.
- To enable interaction between users and augmented elements. At a minimum, this interaction has to allow for the writing and reading of awareness marks. This interaction should also be natural and easy for users following the ambient intelligence principles.
- To support the communication of awareness marks across relevant elements in the environment. This requirement is essential to enable cross-user, cross-object, and cross-element interactions. The commutation could be direct such as facilitating communication capabilities to augmented elements, or indirect, where the user carries awareness marks along the environment transparently.
- To provide the environment with processing points to analyze awareness marks, launch the behavioral mechanisms (that is, decision trees), and adapt services offered to users. Again, it is desirable but not indispensable to decentralize the processing points.

3.3 Mark metaphors

We have to this point described a model in which users leave marks whenever they interact with augmented elements. We can detail in a high-level abstraction the kinds of marks users leave implicitly. In an initial analysis, there are five main aspects to consider: who, where, when, what, and why. Based on these aspects, we have identified four kinds of marks described as metaphors to make their understanding easier:

- *I was here* (where): A user interacting with an element leaves a mark indicating her/his identification and the date/time of the moment when the interaction occurred.
- *I did this* (what): The awareness mark store information about the activity or task performed.
- *I am thus* (who): Information about the current status or profile of the user is linked to an augmented element.
- *I need this* (why): A known need is stored to be taken into account in the future.

Basic and adapted services are launched whenever a user interacts with augmented objects, as we have described earlier. As a consequence, the "when" issue is trivial, and it is not necessary to define it as a metaphor; however, any awareness mark has associated with it a timestamp to manage updating policies and enhancing associated knowledge.

All of these metaphors are useful when designing the information to put into awareness marks and developing adaptive services to users.

3.4 Ontology-based mark model

The use of ontology in ambient intelligence brings forth several benefits and additional functionalities. The ontology formalization is the first step to exploit the benefits of this kind of formal conceptualization. In general, this formalization is a powerful mechanism for structuring, organizing, and reusing knowledge. The Semantic Web provides a common framework that enables people and machines to share information, describing the semantics of concepts and services on the Web and in ambient intelligence.

Based on these premises, the awareness marks model has been described through the OWL language. This general model does not define the specific information that contains the awareness marks and should be defined according to the services to be implemented and environmental characteristics; however, the formal definition of this model makes the model specialization easier.

The proposed model defines four taxonomical elements to be specialized: user, device, object, and area. These elements have associated contextual information that can be static (defined in the context model) or dynamic (awareness marks). In Fig. 5, we show the general model including the taxonomical organization based on principal elements and the kind of data stored in augmented objects. This includes static data containing general contextual information of the object (e.g. identifier, owner, profile, and characteristics, among others) and dynamic data representing awareness marks.

3.5 Grammar and decision trees

So far, we have described how users interact with augmented objects and put marks implicitly. This fact helps us to understand what is happening in the environment. This information enables proactive services whose behavior is defined by the following grammar.

The dynamic behavior of the systems is based on a rule-based mechanism; specifically, Event–Condition–Action (ECA) rules. The grammar has been specified following the Backus Naur Form (BNF) notation. In Listing 1, we describe this grammar.

Rules are compounded by an assessment element that evaluates awareness marks stored in an augmented element. The assessment element contains a condition, two alternative execution ways, and a set of services to be launched. The condition checks the value that contains each mark or static contextual data. Following the ontology-based perspective, any mark or contextual data has to correspond to a valid class or property in the context model (members of rdfs:class or rdf:property). It is also necessary that classes and properties take values in valid ranges (rdfs:range).

Depending on the conditions, true way or false way will be executed. Each way can implicate the direct execution of services or the evaluation of additional conditions.

4 Implementation and prototype

The awareness marks model has been tested in a real scenario and several prototypes and services have been developed. This section describes this scenario and the implementation of the prototypes through Near Field Communication (NFC) technology and Java_ME-based services. These technologies enable the development of context-aware services powered by awareness marks.

4.1 Collaborative group scenario

This scenario involves groups of users that share interests and agendas working collaboratively with a dynamic information flow. The prototype supports the daily activities of research groups by means of NFC services and

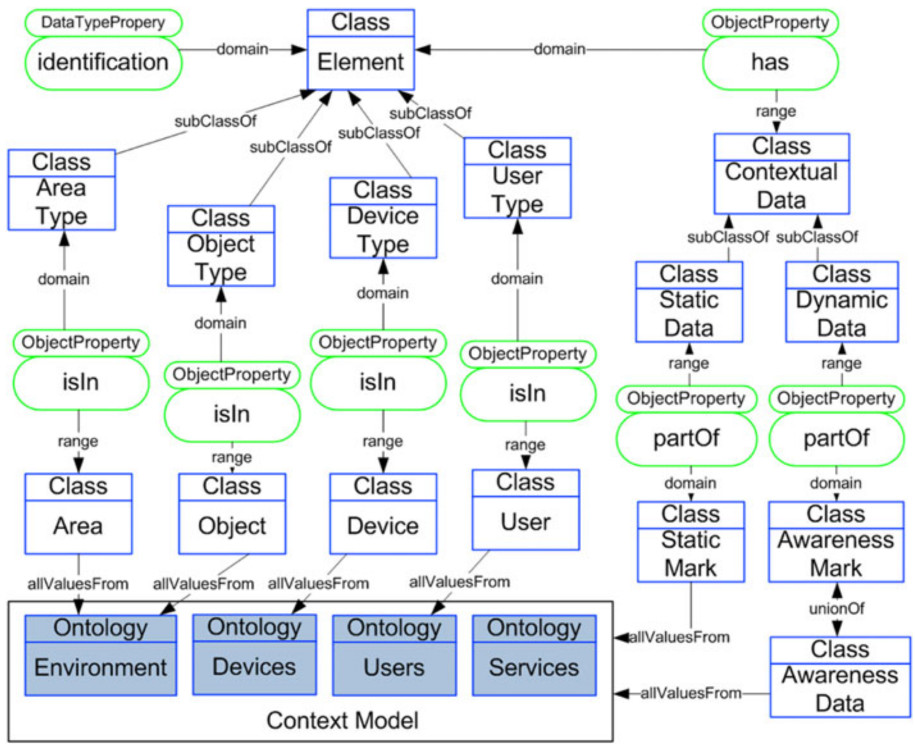

Fig. 5 Simplified awareness marks model

Listing 1 Awareness mark processing grammar

Assessments : = Assessment {'#@#' Assessment}
Assessment : = tree_levels condition true_way false_way
condition : = ('ce' | 'cg' | 'cl') tree_level '{'type, mark_class, mark_value '}'
true_way : = way
false_way : = way
way : = '{'((condition true_way false_way) | services) '}'
services : = service {',' service}
service : = 's_' idservice
type : = utf-8
mark_class : = utf-8
mark_value : = utf-8
tree_levels : = {1-9} + {0-9} | 0
tree_level : = [{1-9} + {0-9}]
idservice : = utf-8

awareness marks, using augmented objects in the environment. This specific prototype can be applied to similar scenarios that involve people working together, for example, in an office. The principal objective is to provide quick and easy access for the users to share information and coordinate collaborative activities.

4.2 Interaction through NFC

Natural interfaces allow people to interact more easily with computational devices. This type of interaction could be achieved by using technology and adapting it so that it passes unnoticed at the time of use. For this, we need a user-friendly technology that makes it a part of daily activities and through a very simple interaction. The mobile phone is an excellent device that has found widespread use over the world. On the other hand, the sensory technology to identify short range as NFC allows interaction with a simple touch or contact with environmental elements.

We need to identify relevant entities in the environment and distribute contextual information throughout the building. Every relevant entity wears an NFC tag storing contextual information e.g. identification, location profile, etc. When users touch a tag, three types of events can be thrown: (a) the calling of applications on the mobile phone; (b) the activation of services in the tagged object or in a nearby one; and (c) the redefinition of the tag information.

4.3 Specific context model

The managed context model is compounded by four related types of ontology: (a) user ontology, describing the user profile, their situation (including location, activities, roles, and goals, among others) and their social relationships; (b) device ontology, that is the formal description of the relevant devices and their characteristics, associations and dependencies; (c) physical environment ontology, defining the space distribution; and (d) service ontology to describe the adaptive services offered to users. The context model and context management mechanisms have been described in a previous document [9] and are not our focus here. In this article, we discuss the mechanism to generate adaptive services based on awareness marks; however it can be interesting to consult context model details because information stored in awareness marks is always a valid element in the context model.

4.4 MiAwa: implementation and process

MiAwa is the name of the mobile application to manage adaptive behavior based on awareness marks. This application was developed in Java ME language and is in charge of analyzing information stored in NFC tags (static data and awareness marks) and launching services for users. The runtime process consists of several steps:

1. Touching interaction: The user touches a tagged element with the mobile phone. This operation is managed by the interaction layer and communication is enabled by NFC.
2. Data retrieval: Static data describing the augmented element, serialized decision trees, and previously stored awareness marks are read and sent to the analysis layer.
3. Decision trees acquisition: The analysis layer deserializes the decision tree information, obtaining conditions, execution ways and services to launch.
4. Context model retrieval: The context sub-model related to decision tree conditions is obtained through Bluetooth (if available) or via HTTP connection from a dedicated server.
5. Behavior analysis: Decision trees are executed and services are selected depending on conditions and awareness marks.
6. Service reconfiguration: Awareness marks, in addition to determine the services to offer, contribute to adapt services to user needs.
7. Adaptive services: Services are launched in the mobile phone or in the augmented object.

Figure 6 shows this process graphically and includes some pictures.

4.5 Deployed services

Focusing on the current scenario, we have developed a set of services. The principal goal was to simplify daily user activities, reducing the number of interactions to realize common tasks, and offer additional functionalities. A wide spectrum of services have been identified for the described scenario, including services for authentication, customization, status recovery, activities tracking, and dynamic service discovery. However, to make our proposal clear, we

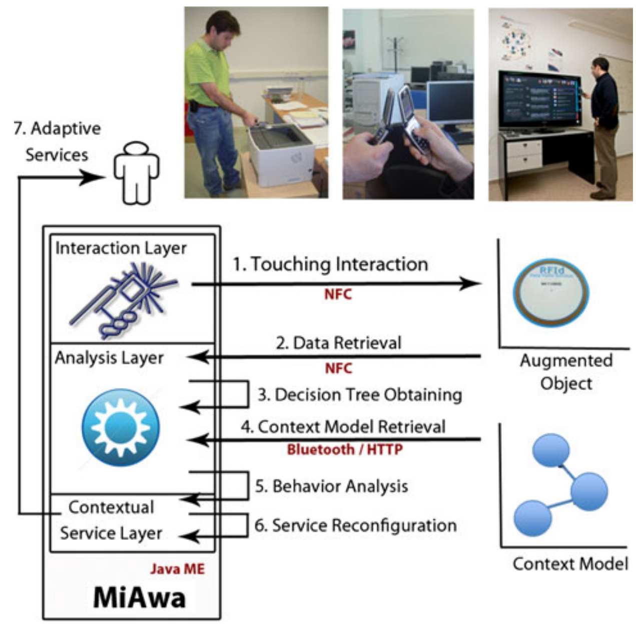

Fig. 6 MiAwa layers and execution process steps

have centered the prototype development and evaluation on a simple and characteristic service; we have focused the developed prototypes on offering relevant documents to users based on their interactions with augmented elements and on matching their profiles and particular interests. The runtime-generated user interfaces to visualize the relevant documents is described in [10], and the framework for contextual information management is explained in [11].

The key idea of the developed services is to supervise, in an implicit way, which documents a user is consulting, distribute this information across the augmented objects, and use it for enhancing future document retrieval to this user or to another using the same or another augmented object.

Under this premise, we next describe a particular situation in which several users obtain personalized documents based on previous interactions in the environment (Fig. 7). User A interacts with a poster about a significant event—for example, a speech—and when he/she touches the poster tag, he/she receives several references to documents related to the poster topics. This is an example of a basic service provided through NFC technology that does not imply the use of awareness marks; the device simply reads a set of static data stored in the tag. However, the acquired references to documents are transformed into awareness marks to conceptualize the interactions with augmented objects and the information that the user is interested in. The awareness marks are stored in the augmented object, the poster in this case, and in the NFC device.

Whenever user A interacts with an augmented object with capabilities that are related to documents, such as

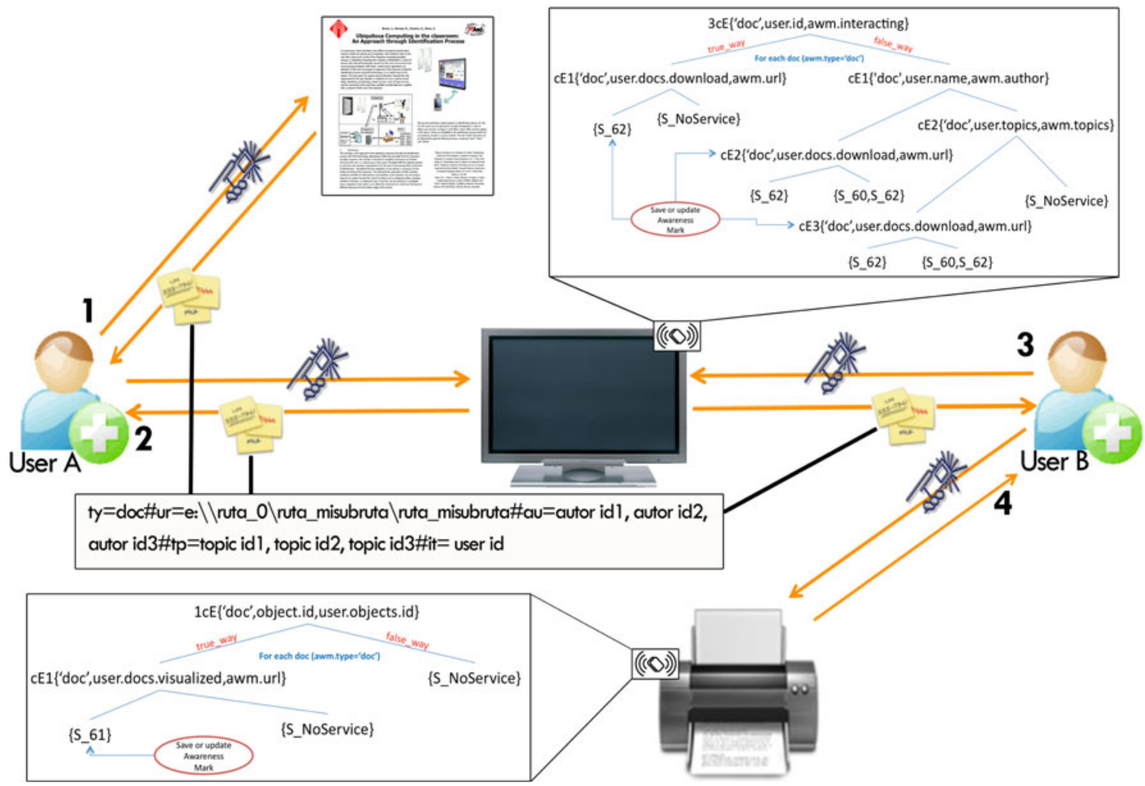

Fig. 7 Interaction scenario, involved decision trees, and generated awareness marks

displays that can visualize the documents, printers that are able to print a copy, and desks that can store a reference copy of the document for later recovery by the user of that workstation, the stored awareness marks are used.

In our example situation, user A is using a public display to visualize his/her related information: the documents determined by stored awareness marks, among others. This is an example of cross-object interaction; the service offered in the display is personalized through marks generated in previous interactions with another object, in this case, the poster. This kind of interaction requires the distribution of marks among objects; this distribution is performed through mobile phone mediation, in a manner transparent to the user. Additionally, awareness marks representing which documents the user has explicitly interacted with within the display are generated and stored into the display tag to adapt the visualization for that user in the future (individual user interaction).

At a later time, when another user (B) is interacting with the same display, his/her NFC device reads the awareness marks from the previous user's interaction and checks the document's relevance based on a matching algorithm between the current user's profile and the document information. In this case, the matching algorithm usually needs to recover information about the user profile from the centralized context model via Bluetooth, WiFi, or GPRS. This adapted service is an example of cross-user interaction. Finally, the relevant document references are transformed into awareness marks and stored in the NFC device of user B to personalize future interactions. In our example situation, user B goes to an augmented printer and the NFC device offers to print relevant documents. In this case, a cross-element interaction has been produced because awareness marks generated when user A interacted with the augmented display have been propagated to another device, the printer, to enhance services to User B.

Figure 7 shows the user actions described earlier and includes the decision trees that represent the behavior of the augmented printer and display objects. Moreover, this figure shows the specific awareness marks that are distributed across different elements as a consequence of user interactions during the described scenario. The awareness marks and serialized trees are compressed before being stored in the NFC devices and tags. Moreover, in Table 1, we have described some of these developed services, including the kind of interaction involved in each service following the taxonomy presented in Sect. 3.1. Moreover, we describe which marks are written or read and finally, and the serialized decision trees taking part in each service.

Table 1 Example service description including kind of interaction, marks, and decision trees

Services	Description	Interaction	Marks	Serialized decision tree
Location {S_0}	The location service is updated whenever an interaction occurs	Individual	Location	0cE{object.loc,user.loc}{S_0}{S_NoService}
DownloadDoc (Poster) {S_60}	Poster offers download of the related documents	Individual	interact ing url author topics	0cE{object.loc,user.loc}{S_0}#@#2cE{'doc',user.id, awm.interacting}{cE1{'doc',user.docs.download, awm.url}{S_NoService}{S_60}}{{cE1{'doc',user.name, awm.author}{S_60}{{cE2{'doc',user.topics,awm.topics}{S_60}{S_NoService}}}
ViewDoc (Display {S_62}	Display offers relevant documents depending on context	Cross-user Cross-obj. Cross-elem.	interact ing url author topics	0cE{object.loc,user.loc}{S_0}#@#3cE{'doc',user.id, awm.interacting}{cE1{'doc', user.docs.download,awm.url}{S_62}{S_NoService}}{{cE1{'doc',user.name,awm.author}}{{cE2{'doc',user.docs.download,awm.url}}{S_62}{S_60,S_62}}{{cE2{'doc', user.topics,awm.topics}}{{cE3{'doc', user.docs.download,awm.url}}{S_62}{S_60,S_62}}{S_NoService}}}
PrintDoc (Printer) {S_61}	Printer offers relevant documents	Cross-user Cross-obj. Cross-elem.	url	0cE{object.loc,user.loc}{S_0}#@#1cE{'doc', object.id,user.objects.id}{cE1{'doc',user.docs.visualized,awm.url}{S_61}{S_NoService}}{S_NoService}

5 Evaluation

We evaluated the prototypes both through interviews and user studies and through a quantitative system analysis. Ten users (six men, four women) participated in the experiment over a period of 12 days. The experiments were incorporated into their daily activities to simulate actual situations. The amount of time that each user tested our prototypes was 45 min per day on average. The population included three engineering undergraduates, one Ph.D. candidate, two professors, and four users that are not linked with the university community, all between the ages of 20 and 55. The users associated with our university were familiar with the technology and the tasks, whereas the other users were not familiar with this kind of system and 50% of them had no familiarity with the task being performed.

The objective was to validate the system from three perspectives: (a) by determining the user agreement about the usefulness of the interaction with augmented objects and the personalization of services based on previous actions in the environment, (b) by validation of the implementation through NFC according to the current technology capabilities, and (c) by analysis of the differences between the proposed distributed mechanism and a more centralized one.

The first evaluation focused on user experience. These items are defined in the MoBiS-Q questionnaire [12]. The users evaluated the use of augmented objects to share and obtain relevant documents in daily collaborative tasks. The questionnaire is constructed of three blocks addressing issues related to productivity, aspects of ease of use and general satisfaction, and questions about user interfaces. The users gave high ratings to the control, the gathering, and the sharing of information; to coordinating; and to satisfaction with personalization; these are the main aspects of the experience that we wanted to achieve in this work. They gave lower ratings to ease of task performance and to the reduction of time required for additional traveling in the environment. Moreover, issues related to mobile user interfaces could be improved (Fig. 8).

The second evaluation tried to validate the storage capabilities of NFC tags in a continued-use study of our prototype. The proposed implemented prototype needs 70 bytes per awareness mark, on average. Taking into account the approximately 264 bytes needed for static information and serialized decision trees and the storage capability of each NFC tag (type Mifare 1 K with 700 bytes of actual capability), the maximum number of awareness marks a tag can hold is seven. Focusing on the usage pattern analyzed in our experiments, the capacity of the tags is reached around the second or third day of use. From this moment on, the awareness marks storage policy is to delete older marks to add new ones. We consider this behavior to be satisfactory because actions performed several days ago are usually not relevant to current activities. This storage policy should be reconsidered for others usage scenarios. If necessary, awareness marks could be compressed using a

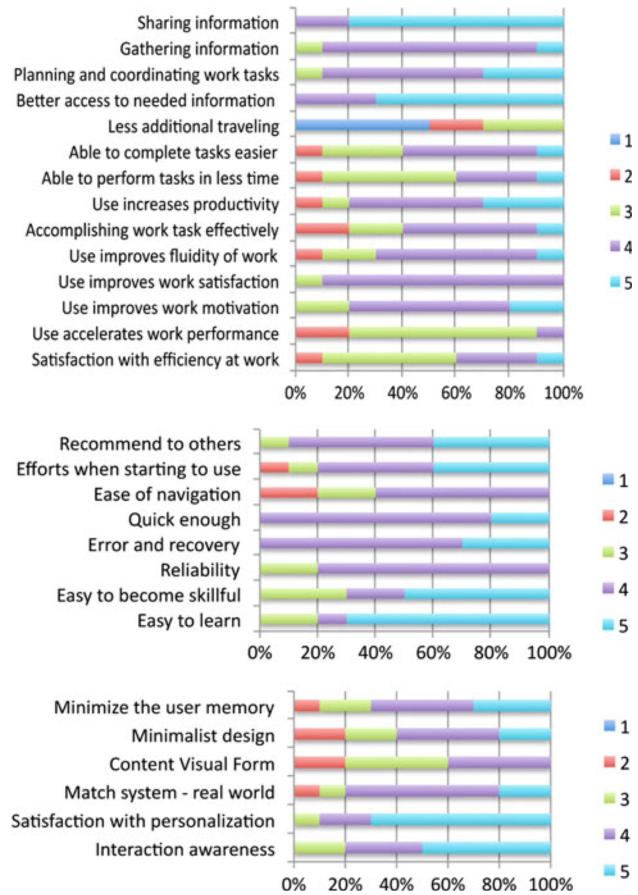

Fig. 8 User experience questionnaire

more complex technique or higher capacity NFC tags (e.g. Mifare 4 K) could be used.

We have applied a decentralized strategy in the development of this prototype. The awareness marks tends to store a larger amount of information to reduce the level of communication between the NFC device and the central server of contextual information. We also tested our prototype by following a centralized perspective reducing the amount of information stored in awareness marks to a minimum and consequently increasing the level of communications to the centralized context model to obtain data relevant to the adapted services. As a result, the maximum number of awareness marks in a tag is around 14, and the communication traffic increased by up to 60%.

6 Conclusions

In the last few years, proposals for context awareness have contributed to a better understanding of the field, and it is widely recognized as a crucial component in ambient intelligence; however, real and usable applications that achieve market and user acceptance have not yet been developed. One of the key problems is the lack of models and technologies to interact with augmented object in the environment and obtain proactive services depending on context information. In this way, we present an effective model to link contextual information to augmented elements and, in consequence, enhance the offered services to ease user's activities. Moreover, the model includes an autonomous and dynamic mechanism to implicitly update the context information while users carry out their daily activities. This information, called awareness marks, allows us to offer novel services adapted from past events, in a non-intrusive way.

Focusing on technological issues, we have presented an NFC approach for providing storage and communication capabilities to digital and non-digital objects and to attain an effortless interaction. In this way, we have implemented an intelligent and adaptive environment based on the previously described model.

Altogether, this approach endows a higher intelligence to the user environment, enhancing and simplifying the interaction with augmented objects and services related to them through contextual and adaptive distributed information called awareness marks.

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