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TOWARD A VISUAL FORMALISM FOR MODELING LOCATION AND TOKEN-BASED INTERACTION IN CONTEXT-AWARE ENVIRONMENTS

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ABSTRACT
This paper introduces a visual formalism for modeling location and token-based user interaction in context-aware environments. As computer technology is embedded into our surrounding environments and interaction is moved into the physicality of the real world, we argue that there is a need for effective methods that allow designers to model systems as they appear from the outside, i.e. the users' perspective. The current formalism can in many ways be considered a compromise between storyboards and UML case diagrams. To assess the applicability of the formalism we conducted a preliminary evaluation with a usability expert group. The evaluation indicated that key features that make the formalism useful from a designer perspective is its relative simplicity, that it allows designers to build explicit models of interaction for various scenarios, and that it encourages discussion and reflection on design solutions.

KEY WORDS
Interaction modeling, Interaction techniques, Pervasive computing, and Ubiquitous computing.

1. Introduction

Interaction with computer technology is no longer limited to the desktop. Mobile computing devices and wireless communication technology make digital information accessible in diverse environments. This can be seen as a major motivation for enabling computer devices and systems to sense and respond to changing contexts of use - a principle often associated with pervasive and ubiquitous computing (UbiComp). As computer information systems are influenced by activities and events taking place in the physical world, human-computer interaction is no longer limited to conventional input and output devices such as mice, keyboards, and stationary displays. In context-aware environments persons, places, and objects in the world also become potential elements of computer interaction [1]. Effectively, the design space of interactive computer systems is expanded.

Despite the interaction possibilities the new design space opens up for, we find that there are few tools available that allow designers to denote aspects of what could be described as the physical interface of context-aware systems. De facto modeling formalisms, such as UML, tend to abstract away physical features of the real-world system that is modeled. For example, how a user provides computer input, properties of the devices and tools, and co-location between interaction elements is not easily described through conventional formalisms. With regard to traditional desktop computer systems such simplifications can be considered purposeful because these systems are left unaware of their physical surroundings. However, as computer and sensor technology merge with our physical environment, there is arguably a need for tools that supports modeling of user interaction with the physical interfaces of these systems.

Motivated by the need for a well-defined, yet flexible, tool that allows designers to conceptualize user interaction with context-aware systems, this paper presents a simple modeling formalism. It has been specifically developed to support modeling of location and token-based interaction.

To assess the applicability of the formalism and the comprehensibility of the associated notation we conducted a preliminary focus group evaluation with three usability experts.

Section 2 describes relevant background material and the motivation behind the current work. In section 3 we point out the most characteristic aspects of the formalism. The modeling components, their formal notation, and interrelationships are presented in section 4, along with sample models. Section 5 gives an overview of the evaluation with the expert group, and section 6 describes the response from the participants. Some reflections on the formalism and the evaluation are given in section 7, while conclusions are drawn in section 8.

2. Background and Motivation

The modeling formalism that we will present and discuss in the current paper is based on previous work that has focused on context-aware technology from a user's perspective. An early version of the applied notation was introduced by Svanæs [2] as a means to explain how users 'make sense' of augmented space. A further specification of the notational building blocks can be found in a more recent study [3]. The latter work also provides more extensive modeling examples, and makes use of a clinical drug administration scenario to show how various models can be implemented.

As part of an ongoing research project on electronic patient records[1], we have focused on various forms of mobile and pervasive computer support for clinical hospital workers. In this connection, we have made use of the formalism internally in discussions concerning potential design solutions. The current work presents a first attempt on an external evaluation of the modeling formalism. The motivation behind the formalism is to provide a tool that allows designers to describe the mental model that they want users to adopt.

The value of considering context-aware technology from a user's perspective has been acknowledged in a number of relevant studies (e.g. [4-7]). In recent times, different approaches that put focus on how mobile and context-aware technologies present themselves to users have been investigated. Scenario-based design [8] and role-playing [9] are examples of methods that are intended to help designers capture and understand how contemporary technologies are or can be used in-situ. There are also examples of techniques that allow designers to represent and model the *situatedness* that characterizes interaction with such systems. Storyboards have been used to model conventional graphical user interfaces, and has more recently been proposed as a useful technique for describing physical and situational aspects of interaction [10, 11]. The modeling formalism discussed in this paper is in many ways similar to storyboards in the sense that it allows for sequential visualization of interaction. This principle is also reflected in earlier prototyping tools for location-aware applications such as *Topiary* [12].

3. Characterizing the Formalism

We consider the current formalism to be an alternative that falls between storyboards on one side, and UML use case diagrams on the other, and that it can be complementary to both. To describe its characteristics we have found it useful to classify it along three dimensions: Formal versus informal representation, granularity, and perspective.

[1] The Norwegian EHR Research Centre (http://www.nsep.no)

3.1 Formal vs. Informal Representation

In contrast to conventional computer system modeling formalisms, storyboards typically do not imply the use of a formal notation, and consequently has a lower level of abstraction. Landay and Myers [13] identify the roughness and lack of detail to be essential features of informal representations. This flexibility means that storyboards can be read and understood not only by system designers, but also by other stakeholders (e.g. users). However, by not conforming to a standard notation, storyboards and other informal representations potentially loose many of the advantages associated with modeling formalisms, such as unambiguousness (each notational shape represents the same category of things), seeing immediate similarities between different designs, and re-use of former solutions on new problems. In addition, models constructed by means of standardized modeling formalisms can be used with computerized modeling tools to automatically generate source code.

By adopting a formal visual notation (see section 4) that can be used to create storyboard-like views (frames) of interaction, the current formalism aims to achieve some of the advantages associated with both of the approaches described above.

3.2 Granularity

Granularity refers to the level of detail at which a system can be described. In principle, the formalism allows interaction to be described in terms of physical *presence*, *proximity*, and *touch* (immediate proximity). In its current form the formalism does not handle modeling of more fine-grained forms of interaction, such as twisting and turning of tokens and directional sensing.

3.2 Perspective - Taking a User's Point of View

Rather than modeling an interactive system from a system perspective, or the way software objects interact, the current formalism focuses on how a system ideally should appear from an external view, i.e. the user's perspective. The resulting models can therefore be regarded as metaphors for the physical interface of location and token-based systems.

4. Formalism Description

4.1 Modeling Components, Notation, and Relationships

To describe location and token-based user interaction in context-aware environments we have developed a set of abstract building blocks. The respective notation is shown in Fig. 1. A short description of the various building blocks and how they interrelate is provided below.

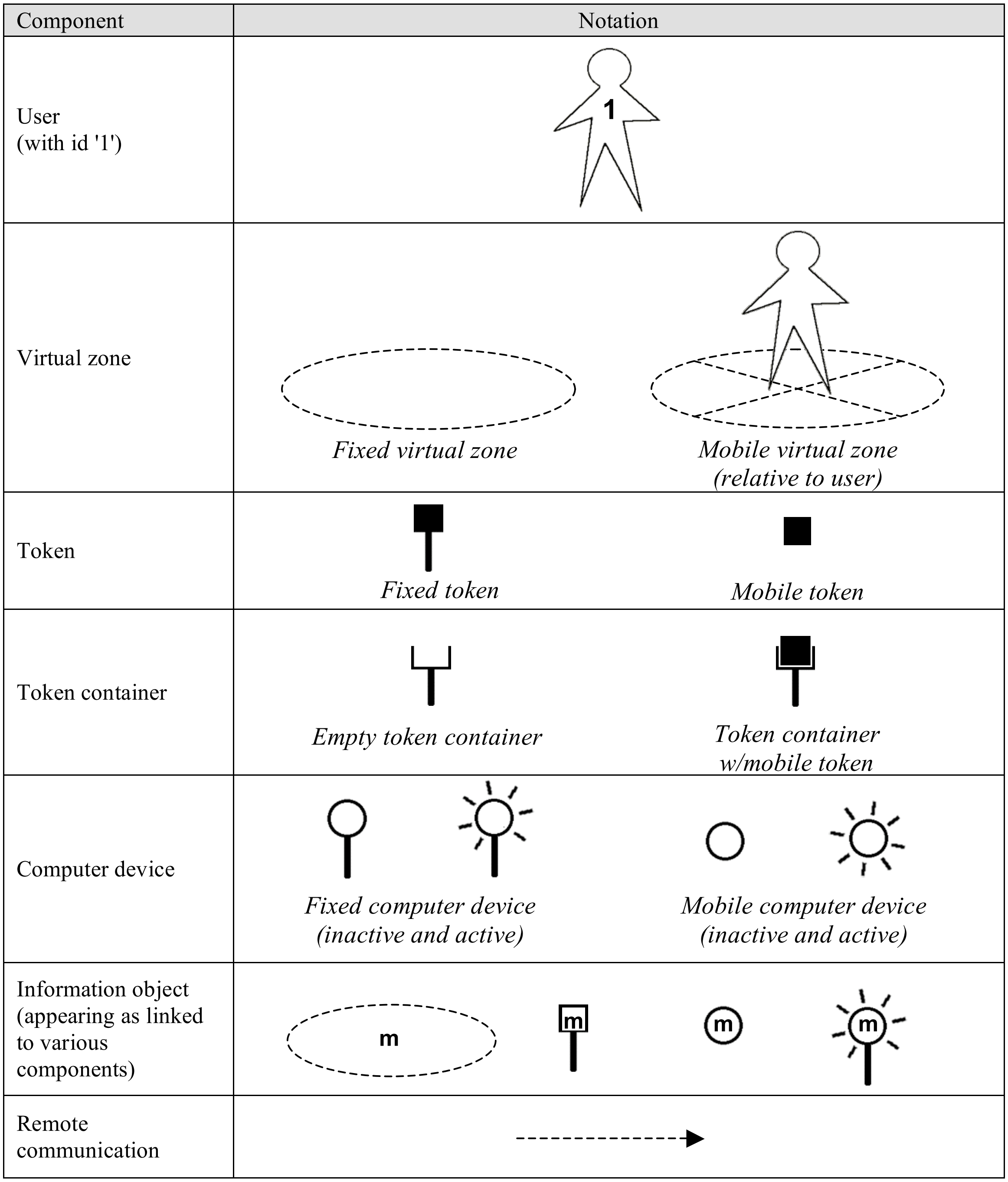

Fig. 1: Notation.

User: Each user is marked with a unique identity (e.g. a number). A user can interact with a computer device by entering or leaving a virtual zone, by scanning a token, or via another computer device. Users can carry one or more mobile tokens or mobile computer devices.

Information object: An information object corresponds to a particular unit of electronic information, such as a web page, an e-mail, an electronic voice message, etc. Users, tokens, virtual zones, and computer devices can contain information objects. To denote information objects we have used bold letters (e.g. '**m**') that are placed inside the symbol of the modeling components they are associated with.

Virtual zone: A virtual zone is a predefined physical area in which presence of users can be detected via sensor technology (e.g. GPS, WLAN positioning, IR, face recognition, etc.) operating in the background. A user entering or leaving a virtual zone can trigger a specific computer device response, i.e. cause an associated information object to be presented (or stop being presented). Location-based interaction is typically considered to be what Buxton [14] refers to as a *background* activity. That is, the triggering of the computer response is consequential, and to a lesser degree the objective of the user.

Virtual zones may be fixed to a particular physical space, or may be relative to the physical position of a user[2]. The physical shape of a virtual zone is implementation specific. To make virtual elements (i.e. virtual zones and remote communication channels) of the system that is modeled easily distinguishable from elements that are physical, the former are drawn with a dashed line while the latter are drawn with a solid line.

Token: Holmquist et al. [15] define a token as a representation of digital information by association or resemblance. We have adopted a similar definition. Accordingly, a token is a physical object that can contain a reference to an information object. In addition we use the term on physical objects that can exclusively identify a user (e.g. a credit card or an access card). A token is considered to be a passive medium. The user has to explicitly provide the contained reference to a computer device (i.e. scan the token with a token reader) in order to get access to the information object. Hence, token-based interaction, as apposed to location-based interaction, typically corresponds to a *foreground* (intentional) activity.

Tokens can be mobile (carried by users) or fixed to a particular location. They can either be digital or non-digital. iButtons[3] are examples of digital tokens, while barcode tags are examples of non-digital tokens. Depending on the actual implementation, the reference that a token contain may be static, or modifiable.

Token container: A token container is a fixed physical object that can receive and hold one or more mobile tokens temporarily or permanent depending on the actual implementation. In the *WebStickers* sytem [16] and *CybSticker* sytem [17] any physical object to which a sticker can be attached can form a token container. For modeling purposes, we consider it sufficient to represent only token containers that are meaningful with regard to the particular scenario that is outlined. While CybStickers remains stuck to the physical objects on which they are placed, WebStickers can be attached to and removed from an object, and potentially reattached to other objects.

Computer device: This building block represents any displays, token readers, wireless network cards, speakers, etc., that are connected, and that users are likely to experience as one unit. Such a unit can be either mobile or fixed to a particular location. A computer device can respond as tokens are scanned, as a user enters or leaves a particular virtual zone, or as other computer devices are physically proximate. This can change the current state of a computer device (1) from inactive (default) to active, (2) from active to inactive, or (3) from one active state to another. A computer device in an active state presents a given information object to a user. Computer devices can distribute information object to other interaction elements.

Remote communication: This component is used to represent conventional network communication (e.g. WLAN). It is a supplement for describing remote distribution of information objects (e.g. from a remote computer device to a virtual zone or token).

As shown in Fig. 2, all physical interaction elements (users, computer devices, tokens, and virtual zones) can contain information objects. These information objects may be associated with a particular interaction element from a remote location. Fig. 3 illustrates the interrelationship between the interaction elements, as described above.

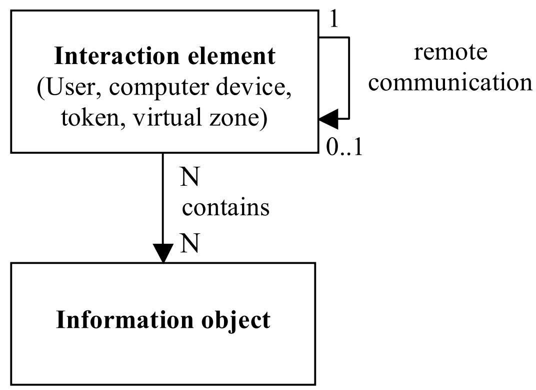

Fig. 2: The semantic relationship between interaction elements and information objects. Each interaction element supports remote communication, and may be associated with an information object from a remote location.

4.2 Examples of Use

The modeling components described above allow us to model a wide variety of interaction techniques. Figs. 4-7 show some simple examples of solution that have been frequently applied within ubiquitous and pervasive computing. These examples can in many ways be considered general UbiComp design patterns that have emerged over the past 10-15 years.

4.3 UbiComp Design Patterns

In Fig. 4 the user's mobile device responds as he or she enters a fixed virtual zone. This is the underlying interaction model of numerous UbiComp prototypes described in relevant literature. Examples include *GUIDE* [18], *HIPS* [19], *Stick-e notes* [20], *Place-its* [21], and the *context-aware pill container* described in [22].

In Fig. 5 the computer response occurs in a fixed device as the user enters a fixed virtual zone. Designs that have made use of this technique include various ambient displays such as *Hello.Wall* [23] and *Mo@i* [24].

Fig. 6 shows the token-based counterpart of the model illustrated in Fig. 4. A fixed token, which has to be explicitly scanned by the user's mobile device, replaces the fixed virtual zone shown in Fig. 4. The WebStickers

[2] Location-aware systems often treat the physical position of a traceable computer device as an indication of the physical position of a user. While such an assumption is practical with respect to modeling purposes, we are aware that this simplification may not hold in many use settings.
[3] http://www.maxim-ic.com/products/ibutton/

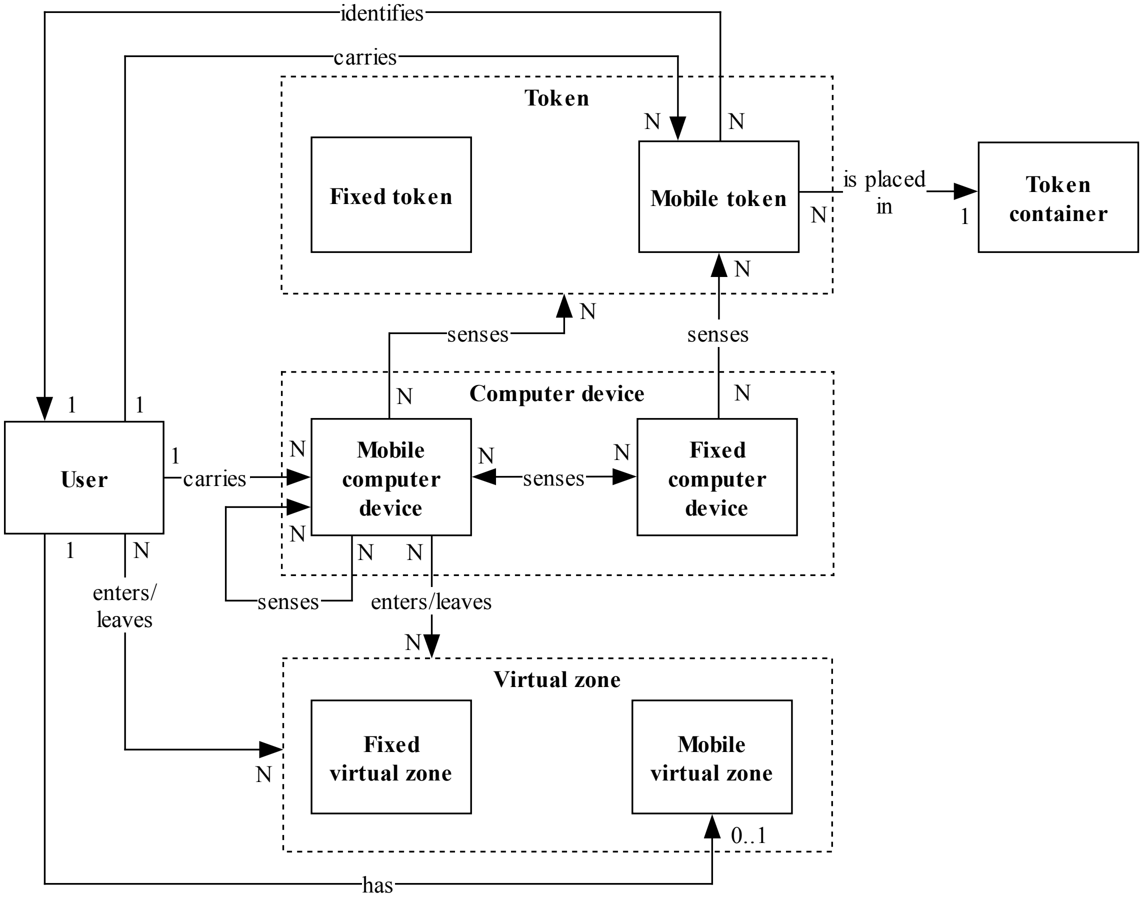

Fig. 3: The semantic relationship between interaction elements.

system mediate (output) information to its users by means of this interaction model. This is also one of the interaction techniques *Cooltown* [25] supports.

In Fig. 7 the token-based counterpart of the model shown in Fig. 5 is illustrated. Here, the user carries a token that must be read by a fixed computer device in order to produce a computer response. A well-known example that implements this interaction model is Durrel Bishop's Marble Answering Machine [26] - The computer device represents the telephone answering machine, and each marble that is associated with an incoming voice message corresponds to a token that is carried by the user. Other examples of UbiComp designs that implement the interaction model shown in Fig. 7 include AmbientROOM - Ishii and Ullmer [27] describe how moving a physical icon or *phicon* (token) into the proximity of an information *sink* (token reader) triggers an ambient display.

An alternative version, involving the same interaction elements, is shown in Fig. 8. Here, the token does not carry an information object, but exclusively identifies the user. Thus, the token can be regarded as an access tool to a specific service provided by the computer device.

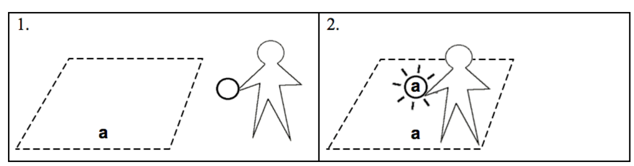

Fig. 4: The user's mobile computer device responds as he or she enters a fixed virtual zone.

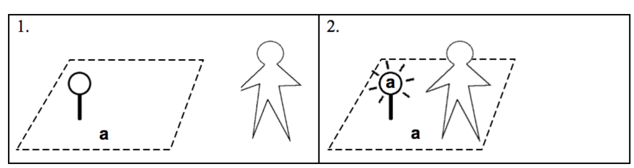

Fig. 5: A fixed computer device responds as a user enters a fixed virtual zone.

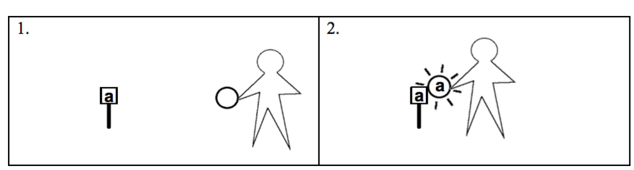

Fig. 6: The users' mobile computer device responds as it reads a fixed token.

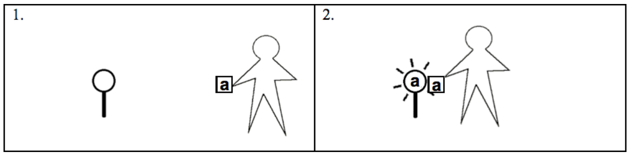

Fig. 7: A fixed computer device responds as it senses the mobile token carried by the user.

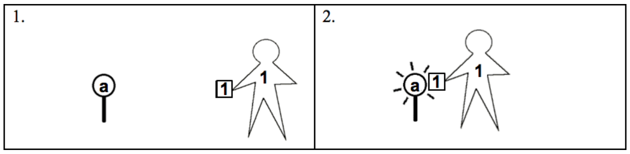

Fig. 8: A fixed computer device responds with a particular service as it senses the token that identifies the user.

To further illustrate interaction techniques that can be expressed using the current formalism, we have included three additional figures (Figs. 9-11). Fig. 9 shows a simplified model of the Hello.Wall system [23]. Fig. 10 and 11 show interaction techniques where various degrees of physical proximity between mobile computer devices trigger response. Fig. 10 shows interaction as it occurs e.g. with *Hummingbirds* [28]. In Fig. 11 an alternative solution where, in contrast to Hummingbirds, it is the immediate physical proximity (i.e. touch) between computer devices that trigger response. This is the underlying interaction model of UbiComp designs such as *iBands* [29].

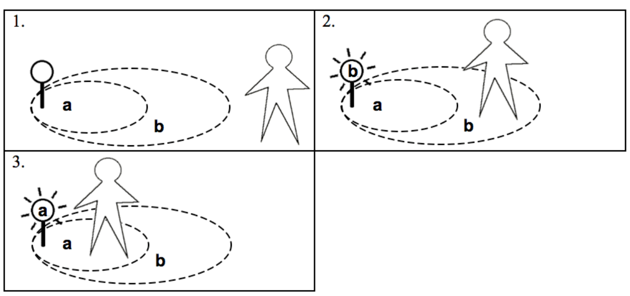

Fig. 9: A fixed computer device responds as the user approaches it.

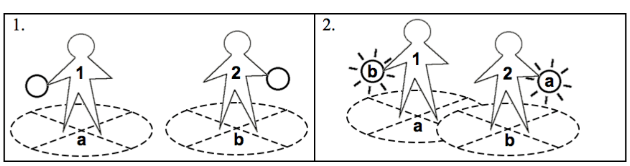

Fig. 10: The users carry mobile computer devices that respond to other proximate users.

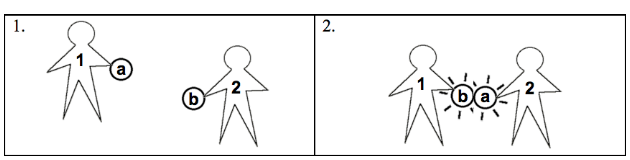

Fig. 11: The users carry mobile computer devices that respond to other computer devices that are immediately proximate.

4.4 Example Scenarios

The current formalism can also be used to build models of particular scenarios. Fig. 12 shows a simplified model of the previously mentioned CybSticker system in a supposed use scenario: (1) A user carrying a CybSticker (token) and his mobile phone approaches e.g. a bench. (2) The user glues the CybSticker to the bench. (3) He then creates an MMS on his mobile phone. (4) The MMS is associated with the Cybsticker by taking a photo of the sticker's unique ID, and sending an MMS to a CybSticker reception number[4]. (5) The user then leaves. (6) Next, a second user walks past the bench, and sees the attached CybSticker. (7) He approaches it, and uses his mobile phone to take a picture of the token. When the picture is sent to the reception number he receives the MMS that was previously associated with the sticker (frame 4).

Fig. 13 illustrates a location-based variant of a similar scenario. In this scenario, however, the information object is distributed from a remote location. We have previously implemented and tested the latter variant in related work [30].

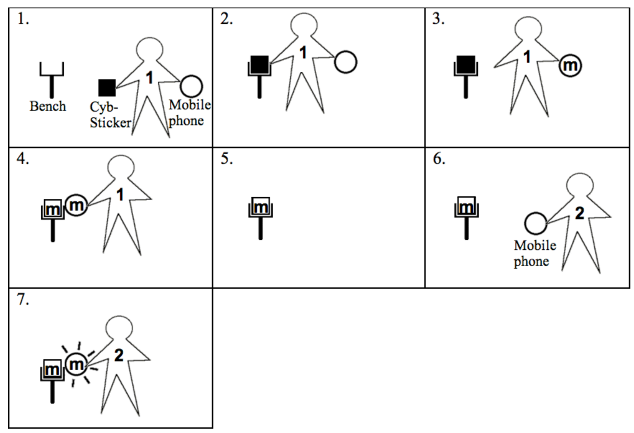

Fig. 12: Interaction with CybStickers in a supposed scenario.

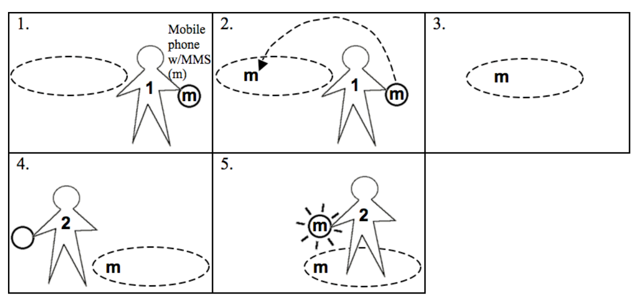

Fig. 13: Location-based variant of scenario shown in Fig. 12.

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[4] For simplicity, the process of linking or retrieving an MMS to and from a Cybsticker (Fig. 12, frame 4 and 7) has been represented as one operation. Technically, this consists of two distinct operations. Assuming that a photo of its unique ID has been taken, a CybSticker can be associated with, or checked for information content from a remote location.

5. Expert Group Evaluation

The current section describes the objectives and the structure of the evaluation, and the feedback from the expert group.

5.1 Objectives

As previously pointed out, the overall objective of the expert group evaluation was to assess the current modeling formalism with regard to its applicability to model location and token-based interaction in context-aware environments. More particularly, we wanted to address the following issues:

- The intuitivism and the ease of use of the notational building blocks.
- The extent to which the perspective offered by the formalism can provide valuable insights.
- Potential user groups.

5.2 Structure

Participants

The focus group consisted of three researchers with extensive experience in usability design and testing. Two of the participants had prior experience in modeling ubiquitous or pervasive computing systems, or systems that supported mobile users. For this both participants had used UML.

Data Gathering

The evaluation session was video and audio recorded. Transcriptions from the recordings, the resulting models of three practical modeling exercises, and a questionnaire were used in the subsequent analysis.

Procedure

The overall procedure of the evaluation involved the following steps:

1) *Introduction*: The focus group was informed about the objective of the evaluation, as well as the background of the modeling formalism and the motivation behind it.
2) *Presentation of modeling components, notation and relationships*: The participants were introduced to the various modeling components and their notation. They were also given a short explanation on how the various modeling components interrelate.
3) *Presentation of simple examples*: To give the expert group participants a concrete idea of the modeling semantic, they were presented with the five general modeling examples shown in Figs. 4-8, and the supposed scenario built around the CybSticker concept (Fig. 12).
4) *Modeling exercises*: The participants were given three practical modeling exercises to be solved in collaboration. In the first exercise the users were asked to model a location-based variant of the CybSticker system based on the scenario shown in Fig. 12. In the two subsequent exercises the participants were given the opportunity to model interaction as it occurs in the HummingBird system and with iBands (see Fig. 10 and 11).
5) *Discussion*: This step occurred partly during, and partly after step 4. The intention was to discuss the suggested solutions to the modeling exercises openly with respect to perspective, the appropriateness of the notation, and alternative solutions.
6) *Concluding questionnaire*: To conclude the evaluation session, each participant was given the opportunity to express his first-impression of the applicability and usefulness of the modeling formalism in a short questionnaire (see Fig. 14).

Questionnaire

- *Prior experience*
  Have you previously used formalisms to model ubiquitous/pervasive computing systems or systems that support mobile users? If yes, please list the formalisms you used.
- *Intuitiveness*
  Do you find the modeling components (the notation) intuitive? Are they easy to combine into meaningful models?
- *Usefulness*
  Do you find the formalism useful? Are there aspects that you find particularly positive or negative? Would you consider using the formalism in the future?
- *User groups*
  What do you think the formalism is most appropriate for - To create a common understanding between designers, or between designers and non-professionals (e.g. users, customers, etc.), or both?
- *Suggestions*
  Do you have any suggestions concerning how the current formalism can be modified or expanded to become more appropriate for modeling interaction in context-aware environments? Feel free to sketch your ideas.

Fig. 14: Questionnaire.

6. Results

Many of the aspects and issues that were brought up and discussed during the preliminary evaluation can be considered partly related. To structuralize the feedback from the focus group, however, we have grouped it into the following categories: Intuitiveness and ease of use, utility, user groups, and modifications and extensions.

6.1 Intuitiveness and Ease of Use

At an overall level, the focus group gave a positive response concerning the intuitiveness of the notation and the extent to which it allowed for construction of meaningful models. The practical modeling exercises also indicated that the participants quickly understood how to describe interaction with the respective notation (see Fig. 15).

With some minor exceptions (see section 6.4) the expert group expressed that the icons for the notation were both simple enough for rapid (paper-based) sketching, and expressive enough to allow the distinctive characteristics of the various interaction elements they symbolized to be reflected.

Regarding the extent to which the formalism is suited for practical use, particularly three issues were brought up and discussed during the evaluation. To a certain extent all issues relate to the purpose of the model that is created and its level of abstraction.

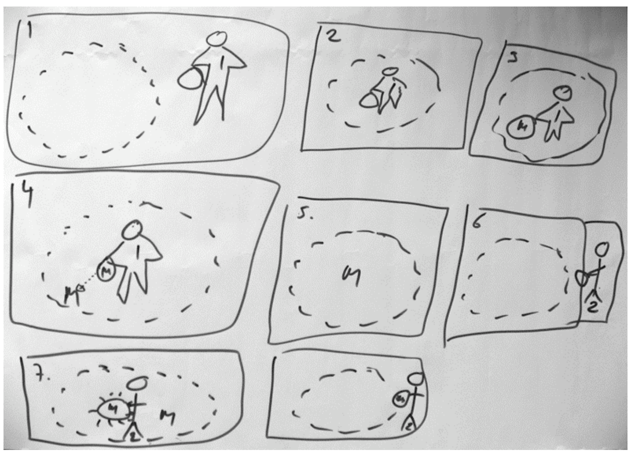

Fig. 15: The expert group's model of the location-based variant of the CybSticker system.

Shorthand Annotations

The first issue had to do with the need for a formal way of referring to the various interaction elements in a model, i.e. a shorthand annotation for users, computer devices, tokens, and virtual zones that are represented. However, it was remarked that such a convention would be helpful primarily from a designer perspective (e.g. such as when translating from one modeling language to another), and that more descriptive labeling probably would make the diagrams more comprehensible for non-professionals.

Frame Detail and Scaling

The second issue that is related to the expert group's perceived practical use of the modeling formalism concerns the level of detail that can or should be represented in one frame. During the presentation of the CybSticker example and during the subsequent exercises this was frequently discussed among the participants. One participant expressed that deciding on the granularity of action in each frame was perhaps the greatest weakness of the formalism, and was uncertain about how well the formalism would scale for complex cases. On the other hand, we also received feedback indicating that idea of outlining particular aspects or subsets of interaction over a series of frames is a practical way to provide detailed system descriptions.

Representation of Implementation Specific Aspects

The last issue concerns the possibility to represent or denote more implementation specific aspects of the model. For example, it was suggested that it would be practical to represent how (i.e. by which technological means) the physical position of a user is detected, quality of service, and possible servers for network communication. Since these aspects were largely considered irrelevant from a user's perspective, it was suggested that they could be described in a supplementary representation (e.g. a sublevel) that could partly present the scenario from designer or system perspective.

6.2 Utility

All participants stated that they found the modeling formalism useful, and that they might possibly use it in future work. The evaluation and the concluding questionnaires indicated various factors that contributed the formalism's usefulness. One such factor was that the formalism allows one to create explicit representations of patterns of interaction as they occur in various scenarios. In addition, it was pointed out that it is well suited for describing combinations of interaction techniques.

We also received feedback indicating that the relative simplicity of the notation added to its usefulness.

Lastly, the practical modeling exercises and statements from the participants indicate that the formalism promotes reflection and encourages discussion on design solutions.

6.3 User Groups

The entire expert group agreed that the formalism, in its current form, is primarily suited for creating a common understanding between interaction designers or between people with experience from ubiquitous and pervasive computing. Depending on the level of abstraction and the complexity of the system that is to be modeled, however, they also saw the possibility that non-professionals (e.g. users) can read and understand models created with the formalism. A precondition for this, as expressed by one of the participant during the evaluation, is that the various interaction elements (users, devices, tokens and virtual zones) that are part of a scenario must be made concrete to the users. As such, the exact physical manifestation of the interaction elements (e.g. the mobile phone, the PDA, the CybSticker, etc.) must be explicitly denoted.

6.4 Modifications and Extensions to the Notation

During the evaluation three modifications and extensions were suggested. Firstly, it was suggested that the icon representing the user could be more similar to the "stickman" icon symbolizing the *actor* in UML. This would make it simpler to draw the user icon by hand.

Secondly, the intuitiveness of the *mobile virtual zone* icon was questioned, but no concrete suggestions on how to improve it were proposed.

Thirdly, a concrete suggestion for formal annotation of interaction elements was given: (1) users: u1..un, (2) tokens: t1..tn, (3) virtual zones: v1..vn (4) computer devices: d1..dn.

7. Discussion

In this section we will briefly discuss the extent to which design models created with the formalism map onto users' mental model of the system. We will also reflect on the approach for the current study.

7.1 Do Users Experience It This Way?

Johnson and Henderson [31] argue that the users' mental model is not accessible to designers in any objective sense, and further point out that different users are likely to have different mental models of a particular interactive system. Our experience from prior usability testing of location and token-based interaction is that implementation specific aspects of a design (e.g. sensor accuracy, visibility of interaction elements, product design, etc.) have a great impact on how end-users perceive such systems [3]. As such, any design model will only represent an ideal and simplified view of an interactive system. However, because interaction with context-aware systems tends to be physical in nature, we consider it likely that aspects such as presence, proximity, and touch are central to how users will understand and describe such systems.

7.2 Reflections on Approach and Results

As with any evaluation, the background of the participants will influence the response. We are aware that a usability expert group is likely to be familiar with concepts that are central to the current formalism (e.g. tokens, zones that can detect user presence, foreground, background, etc.). It is therefore to be expected that that a focus group with a different background may respond differently.

We are also aware that learning how to use any modeling language efficiently requires practice. Thus, issues such as deciding on the appropriate granularity in each frame, might be considered less of a problem given time and training.

8. Conclusion and Future Work

Given the limited scope of the evaluation we consider the current work to represent only the first iteration of a more extensive evaluation process. Nevertheless, it has provided valuable feedback. The key findings can be summarized:

- The formalism appeared to be reasonably intuitive and the expert group quickly managed to combine the notational building blocks into meaningful interaction models. However, deciding on the appropriate granularity of actions to be represented in each frame might be challenging.
- There might be useful to have sublevels or supplementary representations for implementation specific aspects of the designs. Designers also need a formal way to denote the different interaction elements.
- It is primarily a formalism for designers. In order to be comprehensible for user and non-professionals the annotations for interaction elements (users, computer devices, tokens and virtual zones) must be concretized for each particular design.
- The formalism's implicit user-perspective promotes discussion and reflection on design solutions.

The fact that the expert group found the modeling formalism useful suggests that the perspective it provides can be a valuable asset in the design process of interactive systems that support location and token-based interaction.

We view the results from the current work as an incentive for further refinement, development and evaluation of the modeling formalism.

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