Controlling multiple devices

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ABSTRACT
Two major differences between ubiquitous computing and a traditional desktop scenario consist of the number of users interacting simultaneously with a system, and the number of devices that they use. This paper focuses on the physical user interfaces problem of how device control is allocated, shared, and released by services and users. Based on a classification of different types of devices, we analyze in which ways a device can be controlled. We then identify several influencing factors in allocating devices, and conclude by sketching out a high-level strategy for the (semi) automatic handling of device allocation.

Categories and Subject Descriptors
H.5.2 [**User Interfaces**]: Input devices and strategies, interaction styles.

General Terms
Management, design, human factors.

Keywords
Human computer interaction, ubiquitous computing, device control.

1. INTRODUCTION
Until recently, interfaces for single users in a stationary setting were the focus for much of the research in human-computer interaction. This usually took the form of a single person using a single desktop computer. Although research is now being conducted on interaction with multiple devices [3], interfaces for mobile applications [4], and computer-supported collaborative work (support for multiple users in a distributed setting) [1,2], the research community is only slowly advancing on the combination of these features in an intelligent environments setting that supports multiple collocated users.

A common feature of intelligent environments today is that they consist of multiple devices, and that multiple users can simultaneously request services from the environment. In comparison to typical desktop scenarios, devices are now distributed throughout the environment, and like the user, some of them are now highly mobile. Devices and users may enter or leave an environment without warning, and individual users may bring along their own devices. In comparison to interfaces for typical desktop scenarios, the interfaces for ubiquitous computing are increasingly transparent, and as dynamic as the devices they contain. In the right light, the effect of such environment characteristics can result in a much more natural and flexible means of interaction for users with the environment around them, and an enriched range of available services. However, for this to be true, there are different concerns that first need to be addressed regarding multiple users and multiple devices. This is independent of the type of environment that exists, be it at work, at home, in a museum, while shopping, or even outdoors.

To illustrate such concerns, let us assume that all members of a household wish to retire to the living room. One person wishes to watch TV, while another wishes to have a book read out to them. Yet another would like to play chess, and a final person wants to surf the Internet. One concern with this scenario is who controls what device at which time, and what this control might look like? Can devices be shared, and if so which ones, and by how many users? Will different services offered by the environment require the same devices? Will the delivery of multiple services affect the quality of other services currently being requested? This paper outlines the underlying concepts and relationships that will help to address these issues in the future.

In section 2, we define the interacting components of a physical user interface. In section 3, we discuss how an intelligent environment may incorporate device allocation, device sharing and device release for multiple users. Sections 4 and 5 discuss factors concerning the allocation of devices to users and services, and how such an allocation strategy might conceptually look like.

2. INTERACTING ELEMENTS OF A PHYSICAL USER INTERFACE
An intelligent environment can be seen to encompass three essential interacting elements – devices, services, and users. In comparison to traditional desktop environments, these components are largely decoupled from traditional graphical interfaces, and interactions primarily take place through (partially) transparent interfaces. We can distinguish between several classes of *interface devices*, depending on their type and their individual profile properties. When a device is primarily concerned with the handling of input and output, as in the case of cameras, microphones and displays, their *type* can be classified as

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dedicated. However, when the primary role of a device is to fulfill other functions in everyday life, they may be classified as *non-dedicated*. Non-dedicated devices can be further classified based on whether they have been augmented or *enhanced*. Enhanced devices can be grouped as either *active* when they pursue interaction with their environment (e.g. a smart bookshelf, or touch-sensitive table), or *passive* when the environment must pursue interaction with them (e.g. an RFID tagged book). A *non-enhanced* device in comparison would simply be a non-tagged ordinary coffee mug. This device taxonomy is shown in Figure 1 below.

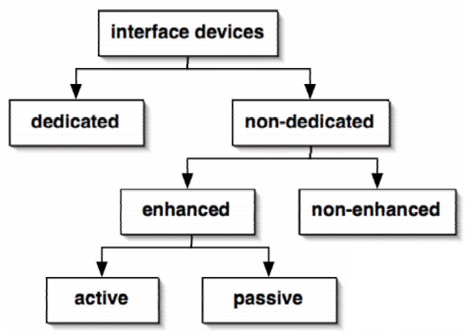

Figure 1. Device taxonomy

An extended categorization of devices would see the incorporation of *device profiling*. This would cover individual properties of the device such as whether the device is suitable for *private* or *public* use, or whether or not it is *shareable*. Other properties in a device profile may include the devices ability to *cater for different human senses* (e.g. sight, sound, touch, smell, taste), and information regarding device *ownership*. Device ownership is particularly important for devices such as PDAs and bluetooth headsets, which may be owned by single users, and only be brought into an environment as additional infrastructure. This is in comparison to devices such as large displays and speakers that belong to an environment's own infrastructure.

Services represent the functionality of an intelligent environment, and rely on the availability of underlying devices to form a channel of communication with its users. For example, watching television requires both audio and visual output devices to function. In contrast to typical single-user desktop scenarios, the spatial location of both the user and the required devices is more dynamic, and this also gives rise to a range of external factors that need to be considered when allocating services to users, such as whether one service will interfere with another service, or how many services a device can physically support.

In comparison to single-user desktop scenarios where a sole user controls all devices, scenarios catering for the simultaneous support of several users must share devices among *multiple users*, all of whom may be moving around in the environment. Users may be *collaborating* with one another, or interacting *independently*. They may be *distributed* (in different environments), or *collocated* (in the same environment). Users may have a preference for using particular devices (e.g. a large screen over a small screen). Some users will have a preference for the set of input modalities they wish to use (e.g. a disabled person with poor vision), and other users will place a different emphasis on the type of services available (e.g. users that prefer reading books compared to watching TV).

An important aspect that arises in intelligent environments is which user or service controls what device, and how devices are shared among users and services. *Control* refers to the allocation of a device to a particular user and/or service so that the user or service can use it for interaction. Some devices may support multiple users, so the notion of device sharing is also of relevance. *Sharing* may be either user independent, cooperative, or parallel. These concepts are discussed in more detail below.

3. CONTROL AND SHARING

The entities and concepts we defined in the previous sections (e.g. users, devices, and control) form a complex and interacting system that is strongly influenced by situational factors. In this section, we propose a preliminary analysis of these interactions.

In an intelligent environment, both users and services (the system) may request control of a device, and in different ways. One such form of request is *user-initiated*, in which a user asks for a specific service, and directly specifies which device(s) should be used. However, there are several ways to specify a device, ranging from spoken commands ("Show my email on the big plasma display.") to multi-modal references ("Show my email on that [pointing gesture] screen.") and physical acts such as picking up a pointing device. The set of possible (physical or non-physical) actions for obtaining device control depend on the type of device (see Figure 1) and its profile properties. For example, while a user can pick up small devices such as remote controls, larger devices like touch-sensitive tables cannot be picked up.

Another form of request is *system-initiated*, in that the system (or a service) automatically allocates a set of devices for a given task. The resulting assignment may however displease the user – even if multiple situational factors are taken into account – and the user may feel controlled by the system. In addition, a combined *user-system initiated* approach is possible, where the user directly specifies some devices while others are selected by the system. While this may combine the problems inherent to both approaches, it may also remedy some. For example, if a user can specify at least some devices, they may less likely feel that they are not in control. In addition, the mixed allocation of devices would free the user from specifying *all* devices that s/he wants to use for a task, which could be tedious (e.g. "I want to browse the web using this screen, this loudspeaker, this keyboard…").

As shown in Figure 2, the control of a device can be either *exclusive* or *shared*. In the first case, a single person uses the device, while in the later case several users may access the device either *cooperatively* (e.g. playing a game together) or in *parallel* (e.g. two users browsing the web in two separate windows on a single large screen). In principle, the methods for allocating device control also apply to device sharing, with the exception that not all devices are shareable (e.g. a headphone), and purely system-driven decisions on device sharing would most likely alienate users. As an example, consider a user reading their email on a desktop monitor, as the layout of the screen is suddenly changed so that only part of it still displays the email while the rest is used for a video game that two other users want to play.

The final step in the handling of device control consists of releasing the control of a device. Again, the considerations we presented for allocating control also apply to the release process in that either the user or the system may explicitly or implicitly release control of a device. In addition, there may be a strong spatial-temporal component in the process, such as when a user simply walks away from a set of devices or does not use the device(s) for a longer period of time. In this case, control of the devices should also be implicitly released.

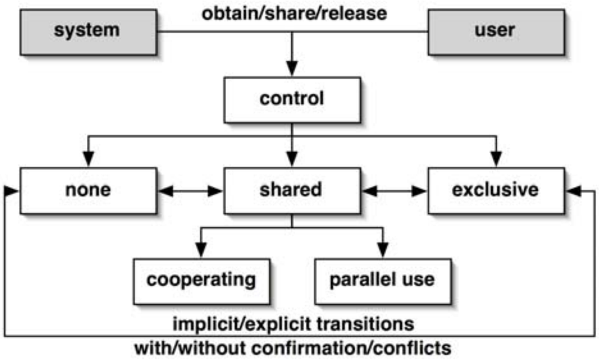

Figure 2. Assignment of device control

An orthogonal dimension to the processes of obtaining, sharing, and releasing control is the way in which changes in control are *confirmed* and *authorized*, as well as how conflicting requests are handled. Furthermore, we can distinguish between two different ways in which users are informed about a change in control. The change is either communicated *explicitly* (e.g. the system generates speech output such as "the plasma screen is now in use by Brian."), or *implicitly*, i.e. the device is simply allocated to another user without notification. The most appropriate way to communicate change in control also depends on who initiated the change, for example if the change was initiated by the system, an explicit explanation may be beneficial to avoid alienating users.

4. FACTORS INFLUENCING THE CONTROL OF MULTIPLE DEVICES

The control of multiple devices by users and services in an intelligent environment can (as shown above) be divided into the areas of device allocation, sharing and release. These forms of control are however influenced by a multitude of factors characteristic of a dynamically changing environment. There is for example a need for constant re-evaluation and adaptation of the allocation of resources, due to fluctuations in users and devices as they move in and out of an intelligent environment. In this section, we describe service and user implications on device control as required for physical user interfaces, and also consider social issues and spatial/temporal constraints relating to multiple users.

Both services and users may have preferences for different types of devices. One way to accommodate for this is through *device modeling*, by listing the properties of each device (e.g. shareable/non-shareable, private/public, modalities being catered for), and making the model accessible by each service and user. An added level of complexity arises when a device is only partly shareable. Some devices such as touchscreen displays although being shareable on the presentation side (screen can be split in two halves), are currently still difficult to share in parallel on the input side, due to the touch sensors only identifying a single user's interactions at a time. Another factor is that of *resource limitation*. If the devices that a service requires are no longer available, the system will have to either consider redistributing the already allocated devices, or inform the user of an expected waiting time. Such a redistribution of devices may be classified as *resource adaptation*.

Similar to devices, users must also be modeled if the system is to best understand their needs, and this information must be merged with any prerequisites the user may currently have. An important issue is that users need to be provided with system resources in a fair manner, and must also "feel" that this is the case, especially in times of device conflict. The system must be able to make distinctions between the desired needs of a user, i.e. *soft prerequisites*, and the required needs of a user, i.e. *hard prerequisites*. For example, a distinction may be made between a user who desires a large screen to read their email simply because the screen is large, compared to a visually impaired user who requires a large screen in order to see anything at all. Distinctions may also be required to classify the *value of a user's work* (e.g. an intern playing solitaire, compared to the CEO's secretary updating business spreadsheets), and the *access rights* a user or service may have to devices (e.g. should a service be allowed to assign the personal PDA of a user to another user's use?)

In contrast to single-user scenarios, multiple users also require certain *social aspects* to be considered when allocating the control of devices, such as *privacy*, *background noise* to other users, and *urgency*. Social implications can affect either the user themself / *1st party* (e.g. introverted users, and users desiring privacy while reading emails), or cooperating users / *2nd parties* (e.g. does one input device such as a microphone dominate over another input device such as a keyboard), or other users / *3rd parties* (e.g. one user watching television while another is trying to read). Social aspects may also apply to the type of service such as bank transfers or the editing of finance spreadsheets, and to the type of task within a service such as entering a PIN number or password.

Spatial influences can also have a large effect on allocating device control to multiple users. While a system must try and distribute users to areas that best support the service, it must also consider any desires of the user, and try not to force a user to move "too" far away from their current position. Spatial concerns become more complex when devices are already in use by other users, as the system must then try and predict for optimal allocation of resources for the present time, and also for the future. Decisions must also be made as to when a person wishes to move their service to another part of the environment, or has stopped using a set of services altogether (e.g. a user going to the toilet compared to a user who no longer wants to watch television). It must also weigh up the need for some users to relocate to other areas in order to accommodate for additional users in the environment.

Temporal influences include for example the urgency in which a user requires a service or set of devices. Temporal conflicts may arise when there are too few devices for a required service, and may require decisions to be made by the system as to how long a user must wait before either an alternative user's service is disrupted, or other users are relocated. The importance of the new user's task is also relevant in such a situation, as user disruptions are only rarely appropriate. For example, a conflict may arise if one user wants to watch the news (which is only broadcast at specific times) while another is already playing a computer game. Providing user feedback on expected waiting times and feedback regarding the information that the system is grounding its decisions on, along with the ability for the user to schedule events in the future, will all help a user feel more in control in such a situation.

5. CONCEPTUALIZING AN ALLOCATION STRATEGY

Strategies allowing for multiple users and services to obtain, share and release control of multiple devices must be flexible and fair. This section illustrates a basic conceptual strategy to help the understanding on how important factors such as those described in section 4 may fit together in a practical implementation. As shown in Figure 3, the strategy is flexible in that the user can select either a service (e.g. “I want to watch TV”), a service and a set of devices (e.g. ”I want to watch TV on that display and those speakers”), or just a set of devices (e.g. ”I want to use that display and those speakers”). This is achieved through the notion of a service/device request, in which the system tries to fill in the “UNKNOWN” fields, based on implicit and explicit user input. In this strategy, devices are generally associated to a service. This means that if a user only selects a set of devices and the system cannot implicitly or explicitly determine what the user wants the device(s) for, the device(s) will be reallocated when required by another service. As described in section 4, the prerequisites for devices and users need to be considered, as too the social implications that may arise to any 1st, 2nd or 3rd parties involved. Spatial and temporal constraints are also considered, and only then are the devices allocated to a user. Conflicts will undoubtedly also exist in a system that allows for multiple users interacting with multiple devices, and solutions to these (if at all adequately resolvable) may take the form of removing soft prerequisites in the search for appropriate devices, calculating new optimal device allocations, or simply informing the user of expected waiting times. Transforming this conceptual strategy into a concrete solution will form a major part of our future work.

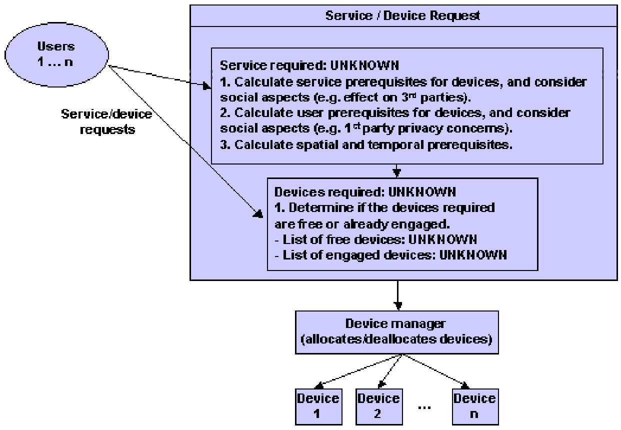

Figure 3. Outline of a device allocation strategy

6. CONCLUSIONS

Physical user interfaces are an important aspect to modern intelligent environments, and have been shown to be very dynamic and difficult to model. The main components of such interfaces are the devices themselves. This paper addresses the concerns on allocating, sharing and releasing multiple devices to multiple users and services in such a physical user interface setting. We illustrate the factors affecting this process, and also sketch out how they may conceptually fit together in a practical solution.

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