User Interfaces and HCI for Ambient Intelligence and Smart Environments

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Abstract The chapter on User Interfaces and HCI will attempt to systematically structure the field of User Interfaces, as it applies to Ambient Intelligence and Smart Environments. It will start with the machine side (i.e., the hardware in use) and the human side (i.e., conceptual models, human issues in interaction), then proceed to sections about designing and evaluating UIs, and end with some case studies.

1 Input/Output devices

As this book clearly demonstrates, there are many ways to create smart environments and to realize the vision of ambient intelligence. But whatever constitutes this smartness or intelligence, has to manifest itself to the human user through the human senses. Interaction with the environment can only take place through phenomena which can be perceived through these senses and through physical actions executed by the human. Therefore, the devices which create these phenomena (e.g., light, sound, force, ...) or sense these actions are the user's contact point with the underlying smartness or intelligence.

In the PC paradigm, there is a fixed set of established input/output devices and their use is largely standardized. In the novel field of Ambient Intelligence and Smart Environments, there is a much wider variety of devices and the interaction vocabulary they enable is far less standardized or even explored. In order to structure the following discussion we will look at input and output devices separately, even if they sometimes coincide and mix.

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1.1 Displays

As the visual sense is the most widely used for traditional human-computer interaction, this situation persists in smart environments. Displays hence constitute the vast majority of output devices. They can be categorized along several dimensions, among which are their size and form factor, their position and orientation in space and their degree of mobility.

1.1.1 Form Factor of Displays

in fact, the size and form factor of display devices has been recognized in the pioneering projects of the field, such as the ParcTab project (Want, Schilit, Adams, Gold, Petersen, Goldberg, Ellis, and Weiser, 1995). In this project, the notion of *tabs*, *pads* and *boards* has been established in analogy to classical form factors and usage scenarios of information artifacts. The tabs correspond to small hand-sized notepads and provide a very personal access to information. Figure 1 shows such a device. The pads correspond to larger note pads or books and enable sharing of information between individual users, as well as collaboration. The boards correspond to classical chalk boards or white boards and enable presentation and sharing of information with a group of people.

Fig. 1 The Xerox ParcTab device as presented in (Want, Schilit, Adams, Gold, Petersen, Goldberg, Ellis, and Weiser, 1995)

This distinction has survived until today and is reflected in the device classes of PDA or smart phone, laptop or tablet PC, and commercially available interactive whiteboards ore tables. It hence seems to provide a useful classification along the size dimension.

1.1.2 Position and Orientation of Displays

The next important property of any stationary display is its position and orientation in space. Board-sized displays, for example, exist in a vertical form as proper boards, or in a horizontal form as interactive tables. The usage scenarios and interaction techniques afforded by these two variants differ strongly.

Because standing in front of a board for a longer time quickly becomes tiring, vertical large displays are often used as pure output channels or interaction only happens from a distance, where users can be conveniently seated. An interactive table, on the other hand, provides an invitation to users to gather around it and interact on its surface for almost arbitrary amounts of time.

This immediately brings about another important distinction between vertical and horizontal displays: On a vertical display, all users share the same viewing direction, and since there is a well defined *up*-direction, the orientation of text and UI elements is clearly defined. If multiple users gather around an interactive table, there is no clearly defined *up* direction and hence it is highly questionable, which is the right orientation for text or UI elements. Some projects evade this problem by using interactive tables in a writing desk manner, i.e., for a single user and with a clear orientation, but if taken seriously, the orientation problem on horizontal interactive surfaces is a quite substantial design problem. To date, there are basically three ways of dealing with it: researchers have tried to a) remove any orientation-specific content, such as text, b) keep orientation-specific content moving, so that it can be recognized from any position for part of the time, or c) orient such content in the (sometimes assumed) reference frame of the user, resulting, for example, in text which is always readable from the closest edge of the table. For a good discussion of spatiality issues in collaboration see (Dourish and Bellotti, 1992).

1.1.3 Mobility of Displays

For non-stationary displays, their degree of mobility is an important factor for their usage. The smaller a display is, the more likely it is to be used in unknown contexts or even in motion. Smart phones, for example, enable a quick look while walking, whereas tablet PCs require some unpacking and laptops even require a flat surface for interaction. The smartness of the environment has to account for these different usage scenarios and for the changing positions and physical and social contexts of mobile displays.

On the other hand, display mobility can even be actively used as an input modality, as described in (Buxton and Fitzmaurice, 1998). The cameleon is a (within limits) mobile display, which shows a 3D model as if seen from the devices current position and orientation. The device thereby creates a kind of porthole through which the user can look into a virtual world which is otherwise hidden to the user. This is a very compelling and rather early example of using device mobility for the inspection of an information space which is overlaid to the physical space.

Fig. 2 The Boom Chameleon, whose base concept is described in (Buxton and Fitzmaurice, 1998)

1.2 Interactive Display Surfaces

Over the last two years, interactive surfaces have become a research focus of many HCI groups around the world. They combine visual output of sorts with immediate input on the same surface. Simple examples are the commercially available interactive whiteboards, or any touchscreen of sufficiently large size. The majority of interactive surfaces currently under investigation are either interactive tabletops or interactive walls. The rapidly growing number of submissions to the IEEE Tabletops and Interactive Surfaces Workshop documents this trend. One can claim that the field started with projects such as the MetaDesk (Ullmer and Ishii, 1997) or the InteracTable (Streitz, Geißler, Holmer, Konomi, Müller-Tomfelde, Reischl, Rexroth, Seitz, and Steinmetz, 1999), which is shown in Figure 3.

Fig. 3 The InteracTable, an early commercial interactive tabletop (Streitz, Geißler, Holmer, Konomi, Müller-Tomfelde, Reischl, Rexroth, Seitz, and Steinmetz, 1999)

For a long time, input was restricted to a single contact point, as in early touch screen technologies, or rather flaky and unreliable camera-based input. Recently, a number of input technologies for interactive surfaces have appeared, which enable so-called multi tpouch input, i.e., the recognition of many contact points. The FTIR technology (Han, 2005) is one of the most widely used and is readily available to researchers as an open source implementation. Commercially, interactive multi touch tables are starting to appear on the market, such as the Microsoft Surface table. Interactive tabletops enable a number of collaborative scenarios, since they lend themselves very naturally to multi user interaction. Since these multiple users will often approach the table from different directions (and thereby benefit frm true face to face collaboration), the interface design need sto account for different usage directions, and hence directionality becomes an important design problem and research topic here. Interactive walls don't raise this directionality issue, but because of their inherently big scale, they raise other challenges related to large display, such as the positioning of interactive elements, focus and context of human perception (Boring, Hilliges, and Butz, 2007), and fatigue of their users.

It can be expected that interactive surfaces will become much more widespread as the technologies above mature and novel, even more robust technologies will appear.

1.3 Tangible/Physical interfaces

Another concept which is sometimes used together with interactive display surfaces, is the concept of Tangible User Interfaces or TUIs as described in (Fitzmaurice, Ishii, and Buxton, 1995). A TUI provides physical objects for the user to grasp. Early projects in this field used physical objecs either as placeholders for information (Ullmer, Ishii, and Glas, 1998) (see also Fig. 4), as handles to digital objects (Underkoffler and Ishii, 1999), or as actual tools, which act upon digital data (Ullmer and Ishii, 1997).

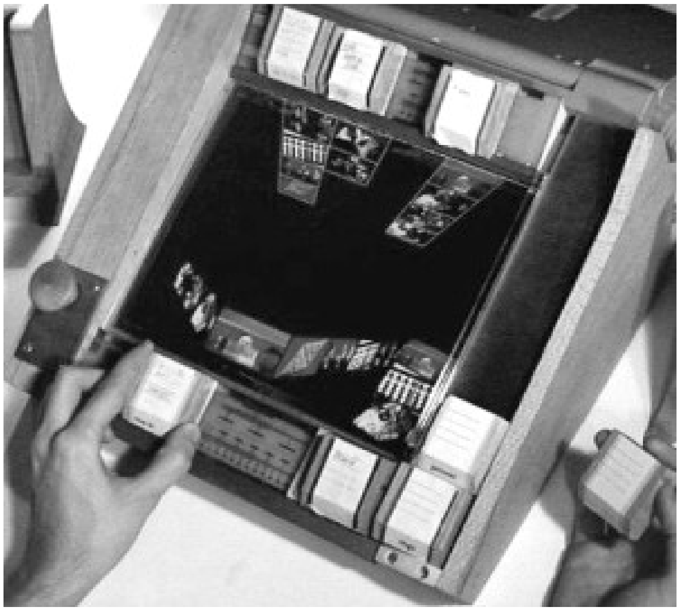

Fig. 4 The MediaBlocks Tangible User Interface described in (Ullmer, Ishii, and Glas, 1998)

Feedback is mostly provided on separate screens or on the interactive surface, on which the TUI is used. The main advantage of a TUI is its physicality and the fact, that humans have learned to manipulate physical objects all their life. Manipulating a physical placeholder, handle or tool hence borrows from human life experience and provides haptic feedback in addition to visual or acoustic feedback. it hence uses an additional sensory channel for the interaction between human and machine.

1.4 Adapting traditional input devices

One popular route to interaction in Smart Environments leads through existing interaction devices from other computing paradigms, such as mice, keyboards, data gloves, or Tracking systems normally used for Virtual or Augmented reality.

1.4.1 Hardware Hacking

Since many of these devices are rarely suitable for interaction in their original form, but many of them are easily accessible for programming, there is a high incentive for modifying or ”hacking” devices, such as mice or even consumer hardware, such as remote controls. The rope interface described in (Burleson and Selker, 2003) or the Photohelix (Hilliges, Baur, and Butz, 2007a) both use the hardware of a commercially avbailable, cheap, and easily programmable mouse to achieve entirely different forms of input. Remote controls have been used as simple infrared beacons or have been hacked to control the consumer applications they were built for through a very different physical interface (Butz, Schmitz, Krüger, and Hullmann, 2005) (see also Fig. 5).

Fig. 5 A TUI for media control, using a hacked remote control to actually control a hi-fi unit, described in (Butz, Schmitz, Krüger, and Hullmann, 2005)

1.4.2 Mobile Phones

The mobile phone has assumed a special role in the context of HCI for Ambient intelligence and Smart Environments. The fact that it is so widespread and well-known, as well as its increasing technical capabilities, enable a wide range of usage scenarios for mobile phones beyond making phone calls. The fact that mobile phones nowadays provide a rather powerful computing platform with built-in networking capabilities makes them an ideal platform for prototyping ultra-mobile interaction devices.

If the phone is just used as a mobile display with a keyboard, its small screen and limited input capabilities have to be be accounted for by a suitable interface design. If the phone includes additional sensors, such as acceleration sensors, NFC readers or simply a camera, this enables other and more physical types of interaction. For a detailed discussion, see (Rukzio, 2007).

1.5 Multi-Device User Interfaces

Many interactions in Smart Environments involve multiple devices. In fact, in many cases, the actual user interface is distributed over different devices, taking input from one device and feeding output through another. Examples were already given in the ParcTab project (Want, Schilit, Adams, Gold, Petersen, Goldberg, Ellis, and Weiser, 1995) where the ParcTab device could be used for remote control of the pointer on a board device. More generally, one can speak of device ensembles (Schilit and Sengupta, 2004), which aggregate single devices into a coherent combination. It is a major challenge to structure, develop and run such multi device user interfaces in a consistent and stable way, and the coordination of multiple devices in such a way is often managed in a middleware layer.

2 Humans interacting with the Smart Environment

In Ambient Intelligence and Smart Environments, the computing power of the environment pervades the physical space, in which the user actually lives. It hence becomes extremely important, to investigate the user's perspective of these interactive environments. Today, it is state of the art to use human-centered engineering methods for classical PC-style graphical interfaces, and in this domain, the strategies and methods are reasonably well understood. A survey of current practices is given in (Vredenburg, Mao, Smith, and Carey, 2002). The methods of user-centered design have been extended to other interaction paradigms as well, as described in (Gabbard, Hix, and Swan, 1999). While in PC-style interfaces, the interaction bandwidth between the human and the computer is relatively low (limited by the use of mouse, keyboard and screen), this bandwidth is much higher for interaction with smart environments. The human user can interact using her or his entire body and multiple senses. Units of information can occupy the same space the user actually lives in. This situation makes the transfer of classical user-centered design and development methods, but also evaluation much more difficult, since interaction becomes very rich and highly context-dependent.

2.1 Metaphors and Conceptual Models

When Computers first appeared, their operators had to write their own programs to solve a problem. When computers became more widespread, also non-programmers wanted to use them and the *user* was not necessarily the same person as the *programmer* anymore. Users had to understand how to operate a computer, and with increasing complexity of computing systems came the need to provide an understandable *user interface*.

One promising strategy, to keep operation of a novel device understandable, is to employ a metaphor to a known device or part of the world. In the mainframe world, human-computer interaction was structured along the metaphor of a typewriter. Text was typed on a typewriter keyboard, and results came out of a printer or later on were scrolled on a CRT monitor. In the PC world with its graphical user interfaces, the dominant metaphor for operating a computer, has become the desktop metaphor, which employs the analogies of files, folders, documents and a trash can, for example. It forms the basis for our conceptual understanding of the computer, for our conceptual model. In Ambient Intelligence and Smart Environments, there is no widely accepted common metaphor or other conceptual model (yet).

2.2 Physicality as a particularly strong conceptual model

One conceptual model, that seems very natural for ambient intelligence, is physicality. Since computing moves into the real world, and everything else in this world follows the laws of physics, it seems to make sense, that also digital objects or at least their (visual, haptic, acoustic, ...) manifestations should follow these laws. Just as the desktop metaphor breaks down in places, (the most prominent example being the trash can *on* the desk instead of *under* it,), also physicality cannot be take too literally. Otherwise, digital objects would slide down vertical displays, and other absurd things would happen. It therefore makes sense, to deviate from perfect physicality where needed, but keep the general direction nevertheless.

2.2.1 Types and degrees of physicality

In (Hilliges, Terrenghi, Boring, Kim, Richter, and Butz, 2007b), three variations on the physicality theme are discussed, as they appear in the user interface of a brainstorming application for a Smart Environment. Figure 6 shows the user interface of this application, which doesn't contain any conventional graphical widgets and incorporates physical behavior of the displayed artifacts in various forms.

Fig. 6 A multi device multi user UI using various forms of physicality as a guiding principle (Hilliges, Terrenghi, Boring, Kim, Richter, and Butz, 2007b)

Pseudo-physicality describes an apparently physical behavior, which in fact is far from physical reality, but still close enough to be recognized as physical and thereby enables assumed benefits of physicality, such as understandability. Sticky notes, for example, could be grouped together on the wall display in order to form clusters of related ideas. The actual lines people drew around the notes would then be beautified into smooth shapes, as if a rubber band was put around them. This was a relatively abstract use of a physical analog.

Hyper-physicality describes a situation, in which a physical behavior is simulated quite accurately, but then applied to an object which doesn't actually exhibit this behavior in the real world. Sticky notes on the table could be flicked across the table to other users in order to simulate the act of handing over a physical note to somebody else. In order to do this, users had to touch the note with the pen or finger, accelerate it in the intended direction, and let go of it while in motion. The note would then continue to slide across the table with the physical behavior of a billiard ball and eventually stop due to simulated friction. This was a realistic simulation of physics, but this type of physics can never be seen with physical sticky notes, since they are much too light to skid across a table.

Meta-physicality describes the situation, in which a physical analogy is only the starting point for a design, but then functionality is added, which goes substantially beyond this analogy. One corner of the digital sticky notes seemed to be bent upwards, which - when found on a physical sticky note - makes it very easy to lift the note at this corner and flip it over. This was a very direct analogy to the physical world and was used both as a visual clue to turn the note and as the actual sensitive area for turning it. On the back side users would find a an icon, which, when touched, would copy the note. This can't be done with physical sticky notes at all.

There are, of course, many other examples where physicality is employed as the guiding principle of a user interface. One of the most prominent systems in this field is the bumptop interface as described in (Agarawala and Balakrishnan, 2006).

Fig. 7 The Bumptop interface, using a physical simulation (Agarawala and Balakrishnan, 2006)

It relies on a physical simulation and makes all graphical objects in the interaction behave in a very physical way, but then it adds stylus gestures and menus on top of this, in order to handle complex interactions. An even more consequent application of physicality in the interfaces can be found in (Wilson, Izadi, Hilliges, Garcia-Mendoza, and Kirk, 2008), where the physical simulation is the only application logic involved. This creates an interface, that can be appropriated by the user: users can try out the interface and develop their own strategies for solving tasks in it.

2.3 Another Example: the Peephole Metaphor

Another example for a conceptual model borrowing from known things in the real world, is the *Peephole Metaphor* described in (Butz and Krüger, 2006). The peephole metaphors core idea is a virtual layer superimposed on a physical environment.

While normally imperceptible, this layer can become visible, audible, or otherwise sensible when we open a peephole from our physical world into the virtual layer. Such a peephole might open as a display (visual peephole), a loudspeaker (acoustic peephole), or some other device. In a living room, for example, a display on a coffee tables surface might show users a collection of personal photographs.

The virtual layer has three basic properties: spatial continuity, temporal persistence, and consistency across peepholes. If two different portable displays are moved to the same position in the environment, they display the same information (though not necessarily using the same graphical representation). Peepholes can be implemented through a tracked, head-mounted display (HMD), making the virtual layer a virtual world that is superimposed on the real world wherever we look, producing the general paradigm of spatial augmented reality (AR). Another option is to implement the peephole using a position-tracked handheld computer. This adequately describes the Chamaeleon (see Fig. 2), which implements a spatially continuous virtual layer that is visible only through the peephole opened by the tracked display. Peepholes in a Smart Environment work much like magic lenses on a 2D screen. When interactivity is added, they behave like toolglasses.

Although the peepholes are not as general and immediate as physicality, they allow a number of other analogies to be used (filters, wormholes, ...) on top of them, and thus provide a basis for understanding the behavior of the smart environment by using analogies to known objects.

2.4 Human-centric UIs

The fact, that the user inhabits the same physical space, which is now entered by computing power in various forms, makes this novel form of computing much more accessible, but also potentially much more threatening or tedious for the user. It is absolutely indispensable that these technologies are designed after the human and her or his physical and mental capabilities.

2.4.1 Bimanuality

While interaction in the PC world is reduced to the keyboard and mouse, interaction with a smart environment can be much richer. If we only look at the hands, they can already do much more on an interactive surface than on a keyboard. UI design for interactive surfaces needs to account for known mechanisms, such as bimanuality, for example. In (Guiard, 1987), the kinematic chain provides a model for asymmetric bimanual interaction, which is the standard case when humans interact in the real world. This suggests that interfaces, which distribute functionality according to this model to both hands, will be more convenient or natural than symmetrically bimanual interfaces.

2.4.2 Body-centric Interaction

Another effect of computing being spread throughout the environment, is the fact, that a UI can assume much larger scales than in the PC world. If the user interacts with a wall-sized display, for example, an interactive element in a fixed position, such as the start menu on a windows desktop, becomes unfeasible. The user would have to walk back and forth to this interaction element, because it is fixed in the reference frame of the environment. If we put the user in the center of the UI design, interaction elements should rather live in the reference frame of the user, i.e., move along with the user. Finally, the entire body can become part of the interaction, leading to entirely novel interface concepts, such as the *exertion interfaces* described in (Mueller, Agamanolis, and Picard, 2003).

3 Designing User Interfaces for Ambient Intelligence and Smart Environments

The design process for user interfaces in Ambient Intelligence and Smart Environments is subject to ongoing research and speculation. While there is a rather established set of tools for user-centered design of interactive systems in the PC world, there is no established development policy for ambient intelligence yet. Research currently tries to transfer human-centered engineering practices to this new computing paradigm, to clarify the differences, and account for them.

3.1 The User-centered Process

Many elements of current user-centered development practice can be used in the design of Ambient intelligence interfaces. (Preece, Rogers, and Sharp, 2001) give a good overview of the various stages of user involvement in the design process, in the concept and requirements phase, as well as in the evaluation phase. They discuss prototyping at different levels and recommend a looped process which continues to involve users to evaluate intermediate design or prototype stages. Additional insights about the nature of physical design of interactive everyday objects are provided in (Norman and Collyer, 2002).

3.2 Novel challenges

The fact, that interactive systems in a smart environment invade the user's actual living environment much more, makes their use much less predictable. There is no well-defined interaction situation or context anymore, and interaction can happen serendipitously or casually. As the physical user interface devices may move out of the direct focus of the user, so will the interaction process itself. Users can interact with their environment implicitly or on the side, during other activities. Interaction thus needs to be interruptible and in many cases, the entire interface needs to remain rather unobtrusive in order not to overload the space which also serves as a living environment for the human.

Another challenge in the development of user interfaces for Ambient Intelligence and Smart Environments is the fact, that they might employ novel input devices, or even consist of a mixture of physical and digital elements. The computer scientist, which is experienced in developing software and hence purely digital user interfaces, must also learn the skill set of, or be supported by, an industrial designer. This latter knows about the design of physical objects and interface elements. If a user interface therefore involves physical and digital parts, the interface design requires a much wider skill set.

To make things worse, there is even a clash of cultures between software design and physical design. Most classical approaches to software design assume a relatively clear idea of the intended result after an initial concept phase and then work iteratively towards this goal. This process is mainly convergent, once the initial concept is done. Product designers, on the other hand, work in a much more divergent way. In the beginning, they create a very wide range of possible designs, which are only sketched. After selecting a few of these designs and discarding others, the selected designs are taken to the next level of detail, for example by carving them from styrofoam to get an impression of their spatiality. Eventually, also this process converges on one final design, which is then built in the form of a functional prototype, but the entire process is much broader than that of a software designer.

4 Evaluating User Interfaces for Ambient Intelligence and Smart Environments

Evaluating user interfaces for Ambient Intelligence and Smart Environments faces the same challenges as designing and developing them. Since the usage context is mostly unknown beforehand, it is hard to make predictions and an evaluation assuming one certain context might become entirely worthless for other situations.

4.1 Adaptation of existing evaluation techniques

Just as for the design methods, a first step is the transfer of known techniques from the PC world. These include early evaluation techniques, such as expert evaluation or cognitive walkthrough, but also detailed qualtiative and quantitative user studies. Again, (Preece, Rogers, and Sharp, 2001) gives a good overview of the respective processes.

When trying to transfer predictive models of human-computer interaction, these have to be adapted to the increased expressivity and interaction bandwidth in Smart Environments. (Holleis, Otto, Hussmann, and Schmidt, 2007), for example, extend the keystroke level model from the desktop PC world to the use of advanced mobile phone interactions. Other studies have shown, that the well-known Fitt's law, which predicts selection speed with a pen or mouse on PC screens, doesn't hold in its original form on large displays.

While PC interfaces can be evaluated in the very controlled and convenient setting of a usability lab, mobile or ubiquitous user interfaces can hardly be evaluated there regarding the full spectrum of their potential usage contexts. In exchange for this, the concept of a living lab has emerged, in which users actually inhabit a Smart Environment, and their interactions with it can be studied and to some extent also evaluated (Intille, Larson, Tapia, Beaudin, Kaushik, Nawyn, and Rockinson, 2006).

4.2 Novel evaluation criteria

Finally, as this novel type of interactive applications pervades the life of their users much more, effectiveness and efficiency, which are by far the dominant criteria for evaluating PC interfaces, become less important. Issues of unobtrusiveness, integration in the environment and processes, playfulness and enjoyability are increasingly important for these interfaces. What exactly the criteria are, is the topic of ongoing research.

Many aspects of interaction in Smart Environments are also more social in nature, rather than technical. They might have to do with social acceptance, social protocols, etiquette, but also with stability and fault-tolerance as a basis for user acceptance. Systems to support everyday life are difficult to evaluate in the lab. Their evaluation will therefore only become possible, once they are integrated into the actual everyday environment. This somewhat invalidates the classical approach of evaluating prototypes of an interactive system in the lab, before fully implementing and commercializing it.

5 Case Studies

The following is a collection of examples for different interaction concepts in smart environments. This collection neither claims to be complete nor to represent every group which has worked in this area. In order to gain a historical perspective, the chosen examples are presented roughly in chronological order and while the beginning is relatively general, the list of examples will become more and more specific towards the end, focusing on physical interaction as a basis for HCI in smart environments, which is, of course, only one of several possible directions.

5.1 Applications in the ParcTab project

Since the Parctab Project ((Want, Schilit, Adams, Gold, Petersen, Goldberg, Ellis, and Weiser, 1995)) is one of the fundamental projects in ubiquitous computing, it is well worth having a closer look at the applications that were written for the ParcTab device (see Figure 1) and the other displays in that environment, which were discussed in section 1. On the input side, the ParcTab project used (from today's perspective) rather conventional technologies and techniques, such as pushbuttons, lists, pen input, and a predecessor of the Graffiti handwriting recognition called Unistroke. At the time, though, these were novel technologies and the novelty consisted in the mobility and context sensitivity of the devices, as well as in the coordination across multiple devices.

The Applications on the Tab included (nowadays familiar) PIM applications, such as a calendar, notepad and address book, but also a number of applications that made use of the networking and location infrastructure, such as a file and a web browser, an email application, and a location-dependent pager. Finally, a number of applications worked across devices: With a remote pointing and annotation tool, multiple people in the audience could control their own cursor on a large presentation display. A voting tool allowed taking quick polls in a meeting, and a remote control application was built to control light and heat in the room. In terms of the underlying concepts, proximal selection and ordering was a novel feature. It preselected, for example, in a printer list, always the nearest printer, depending on the mobile device's location.

Many of these applications seem commonplace today, but we have to realize that they were a novelty at the time of their publication and hence the ParcTab deserves credit for many elements later found in electronic organizers and for some basic multi device interaction techniques.

5.2 The MIT Intelligent Room

The Computer Science and Artificial Intelligence lab (CSAIL)[1] presented the concept of ”intelligent spaces” and set up an intelligent room in the early 1990ies. The room (see Figure 8) contained mostly conventional PCs of that time in different form factors (projection display on the wall and table, PDAs as mobile devices and laptops on the table) and a sensing infrastructure consisting of cameras and microphones. This allowed to use speech input and computer vision in addition to the conventional PC interface devices. Applications in this room include an intelligent meeting recorder which would follow meetings and record their content, as well as a multimodal sketching application. For a number of informative videos, please refer to the lab's web page at www.csail.mit.edu.

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[1] http://www.csail.mit.edu/

Fig. 8 The Intelligent Room at MIT (Picture taken from www.csail.mit.edu)

5.3 *Implicit interaction: the MediaCup*

In 1999, a group at TECO in Karlsruhe, Germany presented the MediaCup (Beigl, Gellersen, and Schmidt, 2001)[2]. This was an instrumented everyday artifact which was able top sense a number of physical properties and communicate them to the environment. While this can be described as context sensing, it is also one of the early examples of a concept called ”embedded interaction”. This term has actually two different interpretations, both of which are correct: On one hand, it describes human interaction with devices, into which digital technology is embedded, and on the other hand, it describes the fact, that interaction with the computer is embedded into everyday actions. The user does not explicitly interact with acomputer by pushing buttons or controlling a pointer, but instead, interaction is sensed from activities with mundane objects.

The MediaCup was able to sense, for example, the temperature of its contents and communicate this value to computers in the environment. Its presence in a room was simply detected by its connection to an RF access point with limited reach, which was in every room. This simple technical setup allows interesting inferences and applications, for example the following: If several cups are detected in the same room and their contents are all hot, this hints at the situation that a (potentially informal) meeting is taking place. In order to protect this assumed meeting, an electronic door sign could then be change status and keep other people from entering the room.

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[2] http://www.mediacup.de/

Fig. 9 The MediaCup, a device for implicit interaction (Beigl, Gellersen, and Schmidt, 2001)

5.4 Tangible Interaction: The MediaBlocks

Arguably one of the first Tangible user Interface prototypes was the MediaBlocks system (Ullmer, Ishii, and Glas, 1998), in which simple wooden blocks act as placeholders for information bins. The information is not physically stored in these blocks, of course, but it is conceptually associated with them by simple relatively physical operations: A MediaBlock can be inserted into a slot on a screen and then the screen's content is (conceptually) transferred to the block. In the other direction, when a block is inserted to a printer slot, the contents of that block are printed. On a block browser device, the block can be put onto trays of different forms and all of its contents can be browsed by scrolling a dial and seeing the contents on the screen (see also Fig. 4 on page 6). These operations make good use of our sense of physical interaction, and they appear very intuitive, once the concept of the block as a placeholder for information is understood by the user.

5.5 Multi Device interaction: Sony CSL Interactive Workspaces

One of the earlier projects to integrate multiple input and output devices into one coherent workspace are Sony CSL's Augmented Surfaces (Rekimoto and Saitoh, 1999). The setup basically consists of a large top projection table with two cameras watching its surface. On the table, physical objects can be used, as well as more computing devices, for example, Laptops. This immediately raises the question how information is transferred between the laptop and the surrounding table area.

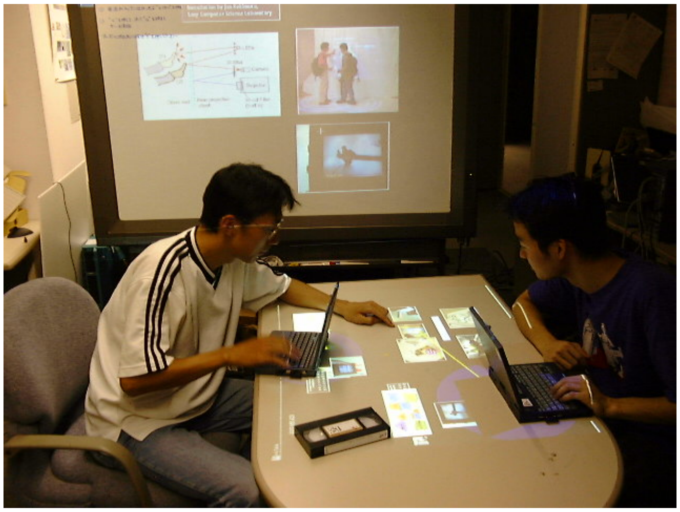

Fig. 10 The augmented surfaces project at Sony CSL (Rekimoto and Saitoh, 1999)

The authors propose several interaction techniques for this, which bridge the gap between the digital and the physical world in relatively direct ways: The Hyperdragging technique allows the mobile device's mouse curser to leave the display and move on in the surrounding table area. In this way, digital objects can be picked up on the screen and dropped onto the table and vice versa without switching interaction devices. The desk surface appears as a shared extension of the workspaces of all mobile device screens, and it therefore also provides a place for exchanging data between them. The Cameras overhead can detect optical markers on physical objects and thereby associate digital data with them (e.g., a trailer clip with a physical video tape). The cameras can also be used to digitize actual physical objects, e.g., scanning a business card, and then share its digital copy with the mobile devices. This latter, on the other hand, conceptually dates back to Wellner's digital desk as described in (Wellner, 1993).

Another interesting interaction technique from the same group, which also borrows from our understanding of interaction with the physical world, and also can be seen as a straightforward extension from single screen interaction, is ”pick and

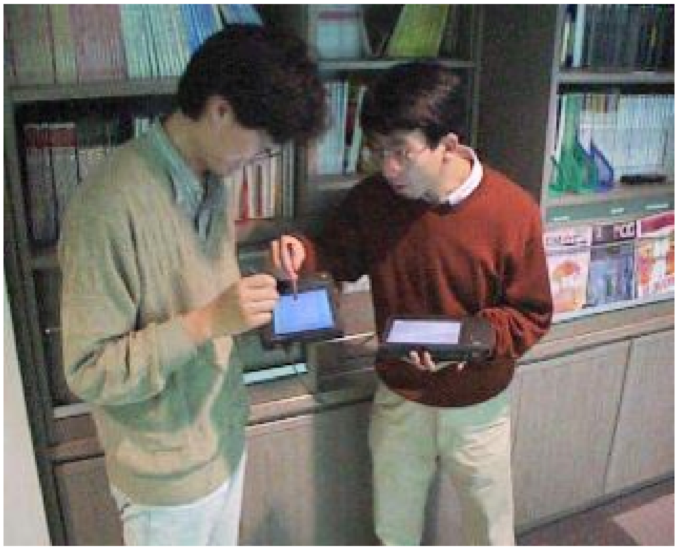

Fig. 11 The pick and drop interaction for moving information between displays (Rekimoto, 1997)

drop" (Rekimoto, 1997). A digital piece of information is picked up from one screen with a pen and the dropped onto another screen with the same pen. This clearly corresponds to the way we would move a physical object from one container to another, or how a painter would dip a brush into the paint in order to paint on the canvas.

5.6 Hybrid Interfaces: The PhotoHelix

Finally, the PhotoHelix (Hilliges, Baur, and Butz, 2007a) is an example of a category of interfaces which lies between Tangible UIs and purely graphical UIs on an interactive surface. Imagine a graphical widget on an interactive tabletop with interactive elements, such as buttons, sliders, lists etc. Now imagine one of its interactive elements not being digital, but physical, e.g., a wooden knob on the surface instead of a slider to adjust a specific value. This physical object is part of the entire widget (which thereby becomes a hybrid widget) and the graphical and the physical part are inseparable.

The presence of a physical part in this hybrid widget now has a number of advantages: For one thing, real physical effects, such as inertia, can be used in the interface. Then it also becomes very simple to identify multiple users around a digital tabletop: If each user owns their own physical input object, it can unfold into the full hybrid widget as soon as it is put down on the table, and then is clearly assigned to the owner of the physical part. This solves the identification problem in collaborative input on a desk surface, and also allows to orient the interface towards the respective user.

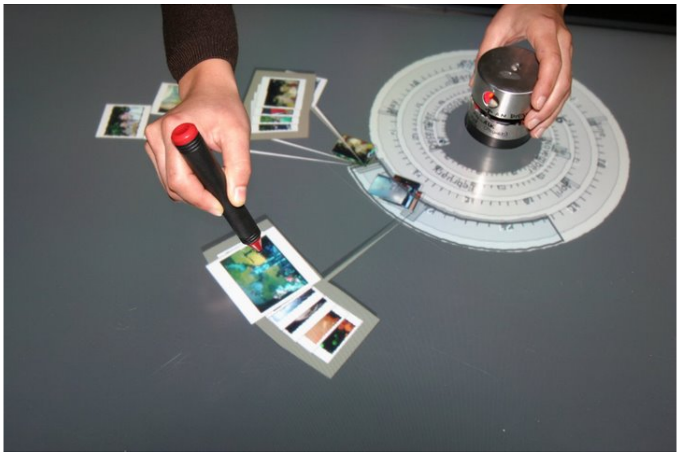

Fig. 12 The Photohelix: A hybrid physical-digital interface (Hilliges, Baur, and Butz, 2007a)

The PhotoHelix is exactly such a hybrid interface. It unfolds into a spiral-shaped calendar, on which the photos of a digital photo collection are arranged by capture time. The physical part is a knob which is meant to be held in the non-dominant hand and when it is rotated, the spiral rotates with it and different time intervals of the photo collection are selected. Scrolling far can be achieved by setting the knob in fast rotation and then letting it spin freely, thereby harnessing a true physical effect in this hybrid interface.

5.7 Summary and Perspective

The field of Human-Computer Interaction in Smart Environments is much wider than the contents of this chapter. Nevertheless, the preceding sections have tried to structure this field along the capabilities of the participating sides (Computer and Human), to briefly touch on the design and evaluation of such interfaces, and to showcase a few important areas and trends in this field.

With the steady increase in computing power and the stepwise appearance of new sensing technologies, entirely novel input technologies and concepts will inevitably appear. From the human point of view, it will always be important to be able to form a coherent mental model of the entire interaction possibilities. The understanding of Physicality is deeply rooted in human life from early childhood on. it therefore provides a very promising candidate for skill transfer and as a basis for such a coherent mental model. The question, what will become the ”WIMP interface” of Ambient Intelligence and Smart Environments, is, however, still open.

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