Designing Hybrid Interaction through an Understanding of the Affordances of Physical and Digital Technologies

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ABSTRACT

In this position paper I present the topic and the on-going research of my PhD. With my work I aim at informing the design of hybrid interaction paradigms for interactive surfaces that integrate aspects of the physical and digital worlds so that more conscious choices can be made about the extent to which the integration of specific aspects of physical interaction makes sense. I suggest that different contexts of interaction imply different ways of integrating aspects of physical manipulation and that the affordances of both physical and digital media need to be identified and systematically analyzed.

Keywords

Hybrid Interaction, Affordances, User Interfaces, Interactive Surfaces, Design.

1. RESEARCH TOPIC

In everyday life, the environment around us is becoming more and more interactive. For example, interactive displays are increasingly becoming embodied in the very artifacts of our physical space such as tables and walls, having different scale and form factors, and supporting individual as well as social interactions. Additionally, a progressive "hybridization" of our everyday life interactions and experiences is occurring, which blends digital pictures, music, and documents with their physical counterparts in a variety of contexts. In such interactive environments, the general WIMP interaction paradigm is inadequate to support users' interactions.

In the desktop environment, the appearance of GUIs for widgets remains consistent across different types of applications, relying on office-related metaphors and visual cues in order to suggest affordances for mouse and keyboard interaction (e.g., 3D effects for clicking buttons, white fields for text entry, ripples on the moving part of scrollbars for dragging). When information is displayed for a different interaction style, and enters different domains of mixed reality, new affordances need to be designed for users' understanding of the interaction conceptual model. The design of physical metaphors and Tangible UIs (TUIs) addresses this issue by exploiting people's existing mental models about how things work in the physical realm, so as to encourage manipulation in a similar way. But we need to think thoroughly about how we can use physical affordances as a design resource while at the same time exploiting the new possibilities of digital media. This requires the understanding not only of people's expectations and mental models about digital versus physical media, but also an understanding of the different affordances for interaction in these different situations.

Thus, my work addresses the question: How-to, and what are the benefits (affordances) of integrating aspects of physical interaction in the design of digital information for hybrid interaction? On another level, I am also seeking to understand what it is about physicality, in terms of cognitive as well as multi-sensorial and emotional aspects, that affects the quality of hybrid experiences.

In order to address these questions, in my work I focus on:

- Identifying the affordances (comprehending *cognitive*, *functional*, *sensorial* and *social* affordances as considered in [20]) of both physical and digital media in a systematic way;
- Given that affordances are goal and context-dependent, understanding how the domain, the spatial context and the social context can affect the perception of such affordances;
- Understanding how the combination of physical and digital affordances in a specific context constitutes a resource for the design of novel meaningful experiences, that go beyond the ones that are possible in the purely physical realm.

2. RELATED WORK

The recent advances in the area of display technologies make the vision of ubiquitous computing closer to reality: novel technologies afford both input and output at the same point of interaction, for example [4, 13]; advanced computer vision techniques in combination with projection onto surfaces make it possible to recognize real objects, hand gestures and body movements, e.g., [14, 23, 22].

In tandem with these technological advances, more attention to the development of interfaces for wall and tabletop displays has driven a number of new and compelling applications in this area (for a review see [3]). Most make heavy use of physical metaphors as the basis for interaction, the increased size of display surfaces making it possible to represent virtual objects in a life-size way.

The use of metaphors for user interface design has been largely discussed in the literature, e.g., [2, 6, 12], its most familiar example being the graphical user interface of the "desktop metaphor" [16]. In the desktop metaphor, many elements of the interface are modeled on artifacts (e.g., wastebasket, folders, buttons) and behaviors (e.g., direct manipulation [10]) from the physical world. As computing moves beyond the desktop and becomes more integrated in our physical environment, the work on tangible user interfaces has provided different ways of integrating physicality in the interaction with digital media. Beginning with early work by Fitztmaurice, Ishii, Buxton, and others [8, 11], there have been many instantiations and variations of the TUI paradigm, e.g., [9, 22]. Fishkin [7] provides a useful taxonomy for the analysis of tangible interfaces based on the dimensions of "metaphor" and "embodiment".

Given the emerging popularity of interactive surfaces and the new interaction paradigms they make use of, it is a good time to examine more deeply what specific aspects of the physical world and physical interaction are being drawn upon as a resource in their design. In my work I investigate these aspects and analyze how they have an impact on users' mental model and experience of interaction.

3. BACKGROUND

Having an academic background in industrial design, I look at these issues from a design perspective, and investigate how to design and recognize affordances for digital information embedded in a real physical environment and social context. The users' possibility to move around in an interactive space and to directly manipulate objects and information needs to be supported by interfaces that are properly scaled to users' metrics, locations in the space, reciprocal distance among users and motor capabilities. Issues such as users' height, their visual angle, the proximity of displayed objects to the hands, the proportion between objects and hands sizes, imply ergonomic considerations that need to be included in the interface design so as to merge virtual and physical worlds.

My investigation develops in the context of the FLUIDUM research project, http://www.fluidum.org, at the University of Munich, Germany. The goal of the project is to develop interaction techniques and metaphors for differently scaled ubiquitous computing scenarios within everyday life environments. In such a context I can benefit of an infrastructure encountering an interactive room, which is instrumented with large interactive displays, both vertical and horizontal, and several other mobile displays.

My work is supervised by Prof. Andreas Butz, from the LMU University of Munich, and Abigail Sellen and Bill Buxton, from Microsoft Research.

4. APPROACH

The approach I've adopted so far is explorative and empirical at the same time. It builds on three main activities, using different methods of investigation: i.e., i) contextual inquiries about the use of displays, ii) design of experience prototypes, and iii) empirical assessments.

4.1 Contextual Inquiries

In order to frame my design space and gather a preliminary understanding of the roles of traditional displays in the everyday life environments, I conducted two contextual inquiries on the use of physical display artifacts (such as post-its, calendars, mirrors) in the home. Building on this work I constructed a taxonomy [15] of domestic displays and considered how physical displays could be digitally augmented. This was explored in the design of two systems (the LivingCookbook and the Time-Mill Mirror, see next section) which support different social and physical activities (i.e., cooking and browsing through pictures respectively). Both these systems were first evaluated in the lab and are going to be evaluated in real domestic environments so as to gather an assessment of the user experience, beyond usability issues.

4.2 Experience Prototypes

In this section I briefly introduce the projects I have been working on in order to unpack my main research question. These designs have acted as research tools for validation as well as elicitation of design issues to be considered, in line with a design research approach. I explore what specific aspects of the physical world and physical manipulation can be drawn upon as a resource in the design of novel interaction paradigms:

- A 3D space of manipulation, making possible different kinds of actions and feedback from those actions (e.g., the Learning Cube [17]).
- The use of physical metaphors in the way digital objects are graphically represented to suggest gestures and actions on those objects consistently with the conceptual model of their physical counterparts (e.g., the Mug Metaphor Interface [18]).
- The use of spatially multiplexed input (such as bimanual, multi-finger input) to interact with virtual objects (e.g., the EnLighTable, [20]).
- Continuity of action and richness of manipulation vocabulary in input, as distinct from discrete actions or gestures afforded by mouse and keyboard (e.g., Brainstorm, see below);
- Direct spatial mapping between Input and Output so that an action produces feedback at the point where the input is sensed (e.g., the Hybrid Tool, see below);
- Rich multimodal feedback, not limited to visual and audio feedback, such as it is possible in the physical world (e.g., the LivingCookbook, [19]).
- Physical constraints, which affect users' mental model of the possible manipulations with an artifact (e.g., the Learning Cube [17], the Hybrid Tool, the Time-Mill Mirror).

4.2.1 The Learning cube

The Learning Cube [17] is a tangible learning appliance which aims at providing a playful learning interface for children. Exploiting the physical affordances of the cube and augmenting it with embedded sensors and LCD displays placed on each face, we implemented a general learning platform that supports a multiple choice test where a question and 5 possible answers are displayed on the faces; the selection of an answer is possible by gestures, i.e., shaking the cube (see Fig.1, a). One of the applications is meant for learning spatial geometry, thus creating a semantic link between physical control, digital output and abstract concept, which provides a redundant learning interface.

4.2.2 The Mug Metaphor Interface

The Mug Metaphor Interface [18] was designed to support direct touch interaction on large displays. In this project I investigate the possibility of mapping the affordances of real world objects to gestures, relying on the manipulation vocabulary and on the conceptual model of such physical objects. Containers of information are graphically represented as mugs: such digital mugs and units of information, the latter represented as kind of drops, can be manipulated across the display in a way which is related to their physical counterparts. When manipulating a real mug, for example, we know we can move it around by holding its handle, and incline it to pour its content (see Fig. 1, b). Empty mugs are expected to be lighter than full ones (e.g., contain less data), smoking mugs are expected to be hot (e.g., contain recent data). In order to cope with the need of freedom of movement of the user, and to enable two-hands cooperative interaction, pie menus appear in correspondence of the hands (see Fig. 1, c), thus "following" the user while moving across the display, rather than being operable just in a fixed location on the screen.

4.2.3 The Living Cookbook

The Living Cookbook [19] is a kitchen appliance, similar to a family authored digital cookbook. It consists of a camera, a tablet PC with touch sensitive display mounted on a kitchen cupboard (see Fig. 1, d) and a projector connected to a server. On the tablet PC a multimedia digital cookbook is displayed and controllable. On the same interface people can either author a new recipe in their personal book, or consult the book and learn someone else's recipe. In the authoring/teaching mode, the video of the cooking session is captured by the camera: in the learning mode the video is projected on the wall above the counter and the learner can cook along. To create the link to domestic activities, the metaphor of a traditional cookbook is used. The book metaphorically offers the affordances of paper, where people can both write and read, and flip pages: this comes at hand to display both the authoring and rendering environment using a consistent conceptual model. In the interface different widgets are metaphorically referring to artifacts of a normal kitchen and semantically related to different functions (see Fig. 1, e). The digital pages can be turned by tipping a flipped corner; portions can be set by placing plates on a table, the video can be controlled on an egg-shaped timer.

4.2.4 The EnLighTable

The EnLighTable [20] is an appliance based on a table-top touch-sensitive display for creative teamwork in the selection of pictures and layout design, e.g., in advertising agencies. In this work I explore the affordances for collaborative creativity of large displays. The system enables multiple users to simultaneously manipulate digital pictures of a shared collection, and rapidly create and edit simple page layouts. By analogy to plates on a set table, the graphic layout suggests personal areas of interaction through the arrangement of three *Imagetools* in a predefined position (see Fig. 1, f), oriented towards the sides of the table. Imagetools are movable virtual tools for basic editing of digital pictures. In the center, a shared "tray" of information is displayed, which contains the thumbnails of a shared picture collection. Copies of the original slides in the shared collection can be edited with the Imagetool. This adopts the conceptual model of a magic lens, which in our case is controlled by two hands directly on the surface of the table.

Such virtual tool provides affordances for direct manipulation relying on the way we manipulate certain physical objects (see Fig. 1, g). The zooming gear on the left side of the tool, for example, can be "scrolled" with a continuous movement of one hand. Discrete interaction, such as tapping, is suggested by the 3D effect of the buttons for mirroring and saving changes, on the right side of the tool. The EnlighTable was evaluated through experience trials with graphic designers.

4.2.5 Brainstorm

Brainstorm is an environmental appliance based on one table-top and three wall shared displays (see Fig. 1, h). In our environment the central wall display has a higher resolution for focused interaction, while the two peripheral ones allow more coarse interaction supporting context awareness and spatial organization. In this set-up we developed a brainstorming application which metaphorically builds on the "idea card" method, i.e., the use of Post-its for brainwriting and clustering ideas later on, as participants stick them and group them on a flip-chart. The design of such a socio-technical environment aims at supporting co-located collaborative problem solving: the goal is to maintain the immediacy of face-to-face paper-based collaboration, which is fundamental for creative processes, while exploiting the benefits of tracking and storage afforded by embedded technology. Users can simultaneously start generating ideas in virtual Post-its on the table. Virtual Post-its can be edited, moved, deleted and copied by any participant at any time. As the participants create Post-its in their working area, the Post-its appear simultaneously on the vertical display, which is located next to the table: here they are automatically reoriented upright, i.e., readable for both readers, but they maintain a spatial mapping to the territorial setup on the table display, thus affording reciprocal activity awareness. When users move from the table (generative phase, divergent thinking) to the wall display (structural phase, convergent thinking), they can spatially organize their ideas by rearranging the virtual Post-its on the wall. In addition they can create clusters, which can be connected to each other or to single Post-its. Whole clusters can be moved across the display, thus moving all the Post-its they contain. This clearly extends the functionality of a physical whiteboard or flip chart, while it maintains the direct manipulation characteristics thereof, facilitating the creation of a structured knowledge representation. Brainstorm was evaluated in comparison to paper based brainstorming sessions.

4.2.6 Hybrid Tools

Hybrid tools, or simply *hybrids,* are handles for manipulation of

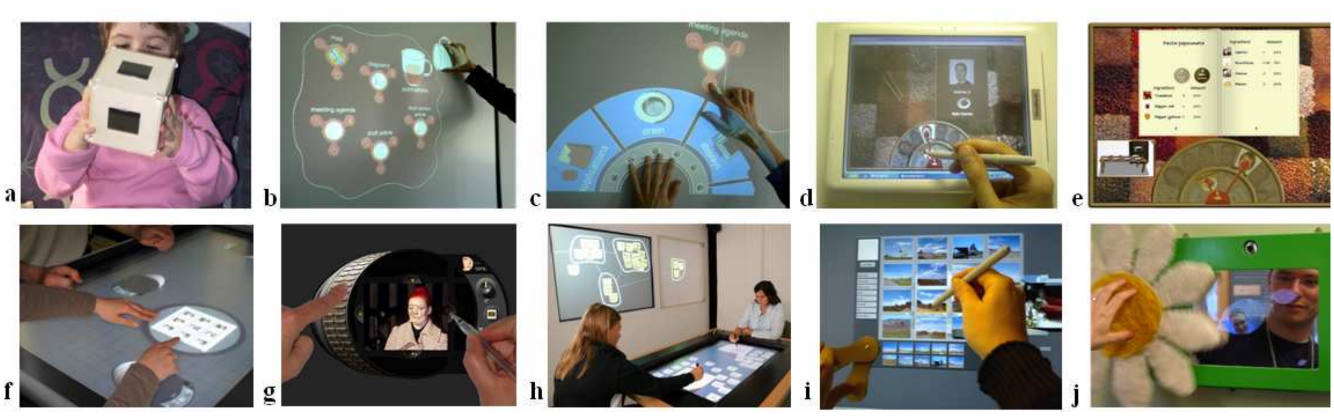

Figure 1: a) The Learning Cube; b), c) The Mug Metaphor Interface; d), e) The LivingCookbook; f), g) The EnLighTable; h) Brainstorm; i) Hybrid Tool; j) The Time-Mill Mirror

digital information on interactive displays. Hybrids consist of a physical and a virtual component which are tightly coupled, spatially and semantically (i.e., there is a direct spatial mapping between the physical and the digital element, and manipulation and effect behave in an isomorphic way). Some fundamental aspects afforded by physical handles are the shift from an absolute to a relative referential space, as well as haptic feedback and the possibility of a richer manipulation vocabulary. Furthermore, multiple physical handles create multiple access points and reference frames, thus supporting multi-user interaction. The virtual component of the hybrid appears and becomes coupled to the physical handle the moment the tool is placed on the surface, possibly overlaying the information on the table-top and delivering an alternative, user-dependent interactive visualization of the information displayed on the surface. Different instantiations of such a concept are being developed in our group. Currently I am working on a hybrid tool which aims at supporting collaborative picture browsing on a table-top display (Fig. 1, i).

4.2.7 The Time-Mill Mirror

Time-Mill is an interactive multimodal mirror which I designed in the context of an internship at the Microsoft Research Lab in Cambridge, UK, within the Socio-Digital Systems group. The motivation for the design and development of such an artifact is to explore the potential of multimodal mixed experiences, which blend physical and digital, past and present, to evocate domestic memories in an unpredicted fashion, and to stimulate people's reflection about time, space and its inhabitants. Like a traditional mirror, Time-mill dynamically reflects in real time the scenes taking place in front of such a situated display: but differently from a traditional mirror, it can capture and retrieve snippets of those scenes when people engage in the interaction, thus augmenting the present with traces of the past. The artifact consists of a physical wheel coupled with a mirror: a Tablet PC is mounted behind the see-through mirroring glass and a wide-angle digital camera is embedded in the mirror frame. When users rotate the wheel (see Fig. 1, j) a melody is played, similarly to the interaction with a music box, and an animation is displayed on the LCD: this shows flying leaves, which metaphorically evocate the flowing of time and the human possibility of capturing and remembering just some impressions. Within the leaves, pictures of the people who have been engaged with the display are shown, because the digital camera has been taking pictures when they started rotating the wheel, as they stayed in front of the mirror. Such pictures are randomly selected from bundles of pictures that were created along the time, and which are retrieved in a regressive chronological order.

4.3 Empirical Assessments

The designs presented are meant to enrich the understanding of users' expectations of hybrid interaction. To confirm the relevance of the identified aspects, and their design implications, I am complementing this work with two empirical evaluations in controlled experimental settings. One has been completed [21] which explores interaction in 3D vs 2D manipulation tasks, by comparing a sorting and a puzzle tasks with physical vs digital media on a table-top.

5. PARTICIPATION GOALS

In case of acceptance I would be keen on discussing and receiving feedback about my work from an expert audience such as the workshop committee and participants, and possibly getting some comments about the approach I adopted so far. Furthermore I would welcome suggestions about how to structure my work in such a way that clearly highlights its contribution to a scientific community, while recognizing its design research nature.

6. REFERENCES

1. Bier, E. A., Stone, M., Pier, K., Buxton , W., DeRose, T. Toolglass and Magic Lenses: the See-through Interface. In *Proc. of SIGGRAPH 1993*, 73-80.
2. Carroll, J.M., Thomas, J.C. Metaphors and The Cognitive Representation of Computing Systems. IEEE *Transactions on Systems, Man and Cybernetics*, 12 (2), 1982, 107-116.
3. Czerwinski, M., Robertson, G.G., Meyers, B., Smith, G., Robbins, D., Tan, D. Large Display Research Overview. In *Proc. of CHI 2006*, 69-74.
4. Dietz, P., Leigh, D. DiamondTouch: A Multi-User Touch Technology. In *Proc. of UIST 2001*, 219-226.
5. Dragicevic, P. Combining Crossing-Based and Paper-based Interaction Paradigms for Dragging and Dropping Between Overlapping Windows. In *Proc. of UIST 2004,* 193-196.
6. Erickson, T. Working with Interface Metaphors. In *The Art of Human-Computer Interface Design*, Ed. by B. Laurel, Addison-Wesley, 1990.
7. Fishkin, K. P. A Taxonomy for and Analysis of Tangible Interfaces. *Journal of Personal and Ubiquitous Computing*, 8 (5), September 2004.
8. Fitzmaurice, G. W., Ishii, H., and Buxton, W. A. Bricks: Laying the Foundations for Graspable User Interfaces. In *Proc. of SIGCHI 1995,* 442-449.
9. Hinckley, K., Pausch, R., Goble, J. C., and Kassell, N. F. Passive real-world interface props for neurosurgical visualization. In *Proc. of SIGCHI 1994,* 452-458.
10. Hutchins, E., Hollan, J., Norman, D. Direct Manipulation Interfaces. In D. A. Norman & S. W. Draper (Eds.) *User Centered System Design: New Perspectives in Human-Computer Interaction*, 1986.
11. Ishii, H. and Ullmer, B. Tangible Bits: Towards Seamless Interfaces Between People, Bits and Atoms. In *Proc. of SIGCHI* 1997, 234-241.
12. Laurel, B. Interface as Mimesis. In DA Norman & SW Draper (eds.), *User Centered Systems Design*, Hillsdale, NJ: Lawrence Earlbaum Assoc, 1986, 67-85.
13. Rekimoto, J. SmartSkin: An Infrastructure for Freehand Manipulation on Interactive Surfaces. In *Proc. of CHI'01*.
14. Ringel, M., Berg, H., Jin, Y., Winograd, T. Barehands: Implement-Free Interaction with a Wall-Mounted Display. In *Extended Abstracts of CHI 2001*, 367-368.
15. Schmidt, A., Terrenghi, L. Methods and Guidelines for the Design and Development of Domestic Ubiquitous Computing Applications. To appear in *Proc. of PerCom2007,* IEEE.

16. Smith, D., Irby, C., Kimbal, R., Verplank, B., Harslem, E. 1982. *Designing the Star User Interface*. Byte, 7/4.

17. Terrenghi, L., Kranz, M., Holleis, P., Schmidt, A. A Cube to Learn: a Tangible User Interface for the Design of a Learning Appliance. In *Personal and Ubiquitous Computing,* Springer Journal, 2005.

18. Terrenghi, L. Design of Affordances for Direct Manipulation of Digital Information. In *Proc. of Smart Graphics Symposium 2005*, 198-205.

19. Terrenghi, L., Hilliges, O., Butz, A. Kitchen Stories: Sharing Recipes with the Living Cookbook. In *Personal and Ubiquitous Computing*, Springer Journal, 2006.

20. Terrenghi, L., Fritsche, T., Butz, A.: The EnLighTable: Design of Affordances to Support Collaborative Creativity. In *Proc. of Smart Graphics Symposium 2006.*

21. Terrenghi, L., Kirk, D., Sellen, A., Izadi, S. Affordances for Manipulation of Physical versus Digital Media on Interactive Surfaces. To appear in the *Proc. of CHI 2007*.

22. Underkoffler, J., and Ishii, H. Urp: A Luminous-Tangible Workbench for Urban Planning and Design. In *Proc. of CHI 1999*, 386-393.

23. Wilson, A. PlayAnywhere: a Compact Interactive Tabletop Projection-vision System. In *Proc. UIST 2005*, 83-92.