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A Design Theme for Tangible Interaction: Embodied Facilitation

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Abstract. This paper presents parts of a design framework for collaboratively used tangible interaction systems, focusing on the theme of *Embodied Facilitation*. Systems can be interpreted as spaces/structures to act and move in, facilitating some movements and hindering others. Thus they shape the ways we collaborate, induce collaboration or make us refrain from it. Tangible interaction systems provide virtual and physical structure - they truly embody facilitation. Three concepts further refine the theme: Embodied Constraints, Multiple Access Points and Tailored Representations. These are broken down into design guidelines and each illustrated with examples.

Introduction

Tangible User Interfaces (TUIs) have become a hot topic in HCI. Until recently, research was mostly technology-driven, focusing on developing new systems. A special issue of 'Personal & Ubiquitous Computing' on 'tangible interfaces in perspective' (Holmquist, Schmidt and Ullmer, 2004) marks a change in focus towards conceptual analysis. Yet, there is still a lack of theory on *why* tangible interaction works so well (Dourish, 2001). Cooperation support might be the most important, domain-independent feature of TUIs, but this issue has attracted even less explicit attention. Many researchers agree that TUIs are especially suited for collocated collaboration and build systems aimed at group scenarios (e.g. Stanton et al, 2001; Ullmer and Ishii 2001). Nevertheless, conceptual papers (as in the mentioned special issue) tend to brush over this issue by briefly mentioning visibility of actions and distributed loci of control as collaborative affordances.

User studies focusing on group interaction are still scarce, even though we know from CSCW research that collaborative use often poses different (and possibly contradictory) requirements to single-user usability. We therefore lack concepts for analyzing and understanding the collaborative aspects of tangible interaction and design knowledge on how to design *for* collaboration.

This paper focuses on part of a framework that offers four themes and a set of concepts for understanding and designing collaboratively used tangible interaction systems (for an overview: Hornecker, 2004b). The framework builds on results from a PhD project on the collaborative use of tangible interfaces (Hornecker, 2004) and on recent studies in related areas (Hornecker and Stifter, 2004, Hornecker and Bruns, 2004). Just as interaction design aims to create opportunities *for* experience, one can design *for* cooperation and create a 'force field' encouraging and inducing collaboration. The framework aims to help in creating such 'force fields' by offering "design sensitivities" (Ciolfi, 2004, Fitzpatrick, 2003) and soft guidelines. The framework theme focused on here is *Embodied Facilitation*. Tangible interfaces/interaction systems embody facilitation methods and means by providing structure and rules, both physically and procedurally. Any application can be understood as offering structure that implicitly directs user behavior by facilitating some actions, and prohibiting or hindering others. It thus influences behavior patterns and emerging social configurations. With Tangible interaction systems, structure is not only in software, but also physical. They can truly embody facilitation.

I now describe what 'tangible interaction' means, summarize the overarching framework and present the *Embodied Interaction* theme. The following sections deal with the concepts relevant to embodied interaction and design guidelines derived, illustrated by examples. I conclude on open questions and related work.

A Framework for the Design of Tangible Interaction for Collaborative Use

From the characterizations of tangible interfaces/interaction found in literature, we can distinguish a data-centered view, pursued in Computer Science and HCI; a perceptual-motor-centered view, pursued by Industrial and Product Design; and a space-centered view influenced from Arts and Architecture:

- *Data-centered view:* Physical representation and manipulation of digital data (Ullmer and Ishii, 2000; Dourish, 2001) or the interactive coupling of physical artifacts with "computationally mediated digital information" (Holmquist, Schmidt and Ullmer, 2004). Research often explores types of coupling. These systems are usually referred to as *"tangible interfaces"*.
- *Perceptual-motor-centered view:* Bodily interaction with objects, exploiting the "sensory richness and action potential of physical objects", so "meaning

is created in the interaction" (Djajadiningrat, Overbeeke and Wensveen, 2004). Design takes account of skills and focuses on expressiveness of movement, e.g. rhythm, force and style (Buur, Jensen and Djajadiningrat, 2004). The design community prefers the term *'tangible interaction'*.

- *Space-centered view:* A combination of real space and real objects with virtual displays (Bongers, 2002). "Interactive systems, physically embedded within real spaces, which offer opportunities for interacting with tangible devices, and so trigger display of digital content or reactive behaviors" (Ciolfi, 2004). This is termed *'interactive/interactivating spaces'*.

The concept of *tangible interaction* has a much broader scope than Ullmer and Ishii's (2000) description of tangible interfaces: "giving physical form to digital information" and its subsequent physical control, which is often referred to or used as a definition (data-centered view). *Tangible interaction* is not restricted to controlling digital data and includes tangible appliances or the remote control of *real* devices. Because it focuses on designing the interaction (instead of the interface), resulting systems tend less to imitate interaction with screen-based GUIs (as does placing and moving tokens) and exploit the richness of embodied action (Buur, Jensen and Djajadiningrat, 2004). Interaction with 'interactive spaces' by walking on sensorized floors or by simply moving in space further extends our perspective on 'tangible' interaction. Instead of using a restrictive definition that excludes some of these interesting system variants, it seems more productive to address this larger design space. Thereby we leave the somewhat artificial confines of any definition behind, and can interpret these attempts at conceptualization as emphasizing different facets of a related set of systems.

The Design Framework Themes

The framework (Hornecker, 2004b) is structured around four themes, which are not mutually exclusive, but interrelated, offering different perspectives. Each theme consists of three or four concepts, which are broken down into concrete guidelines. In this section will present the four overarching themes and later focus on one. For each theme a short argument is given as to why it is relevant for tangible interaction (referring to the definitions given above).

Tangible Interaction Systems for collaborative use should carefully exploit:

- *Tangible Manipulation:* Tangible Manipulation is bodily interaction with physical objects. It is interacting with hands and the body. Tangible interaction is observable and legible, allowing for implicit communication and peripheral awareness. The objects react in a physical, material way. Design can deliberately exploit tangibility, emphasizing the direct interaction with physical objects, which have distinctive material qualities.
- *Spatial Interaction:* Tangible interaction is embedded in real space. We are spatial beings; we live and meet each other in space. Our body is a reference

point for perception. Spatial qualities have psychological meaning. Real space is inhabited and situated. Real places have an atmosphere. Spatial interaction is observable and often acquires performative aspects. Design can exploit the qualities of space and the resources it offers.

- *Embodied Facilitation:* With tangible interaction we act/move in physical space and in system space (software). Software defines virtual structure, determining the interaction flow. Physical space prescribes physical structure. Both types of structure allow, direct, and limit behavior. Tangible interaction systems embody structure. Design can enforce social structure and we can learn from facilitation and pedagogical methods how to do this.
- *Expressive Representation:* Tangible Interaction is about physical representation of data. Hybrid representations combine tangible and virtual elements. These communicate to us and have expression. In interaction we 'read' and interpret representations, act on, modify and create them. We share externalizations of our thinking, which provide shared reference, remember our traces and document common ground. Design can create legible, expressive representation.

The framework is organized on three levels of abstraction. The themes offer perspectives (or viewpoints) and argumentation of an abstract, theoretical level. They define broad research issues such as the role of space for tangible interaction. Themes are each concretized with a set of concepts. Concepts provide analytical tools for describing empirically found phenomena and help to summarize generic issues, to pinpoint design mistakes and successes. However, concepts are quite abstract and employing them to support design necessitates understanding the argumentation behind them. For a design framework, a level of more directly applicable design guidelines is needed. These should be easily communicable and comprehensible for people working on practical design projects, but not interested (or not having time) for the underlying theory.

Furthermore, different researchers and research communities might focus on different levels. To explain general phenomena or analyze empirical studies, themes and concepts might be most useful. When designing systems, one might experimentally follow some guidelines, testing their usefulness and exploring the design space. To quickly enable people to roughly understand what the more abstract concepts mean, 'colloquial versions' have also been developed. It should be emphasized that these are not strict rules, but rather soft guidelines, close to Ciolfi's (2004) "design sensibilities" or Fitzgerald's (2003) sensitizing concepts.

Embodied Facilitation

We can interpret systems as spaces or structures to act and move in, thereby determining usage options and behavior patterns. They enforce social configurations and direct user behavior by facilitating some movements and hindering others. Thus, they shape the ways we can collaborate; they can induce us to collaborate or make us refrain from it. From pedagogy and facilitation we can learn about how structure, both physical and procedural, can be shaped to support and direct group processes. With tangible interaction systems, which are embedded in real space and physically embodied, this space is both a literal one (physical space and objects) and metaphorical one (software determining action spaces). Tangible interaction systems can thus truly embody facilitation.

The background that underpins this approach is an exploration of analogies between interaction design and group pedagogy or facilitation (for details see: Hornecker 2004c). Both interaction design and facilitation/pedagogy can be interpreted as the design of 'spaces for human communication, interaction and experience'. Similar to architectural spaces, these are appropriated and inhabited by users. They furthermore offer and prescribe structure, predetermining feasible adaptation and movement paths. Interaction design cannot 'design experiences' just as the structure provided by facilitation can only foster certain experiences or processes, but not automatically produce them. I became aware of what can be learned from facilitation and pedagogy for interaction design when evaluating a system in a group setting (Eden, Hornecker and Scharff, 2002). Seemingly trivial design decisions (such as system size, placement and number of tools) had a huge impact on group behavior, session dynamic and atmosphere. My knowledge of facilitation methods helped to explain these phenomena and informed the systems redesign. With the theme of Embodied Facilitation, I propose to utilize this analogy by intent and to apply 'facilitation knowledge' to interaction design.

As stated previously, this paper focuses on the *Embodied Facilitation* theme. Each theme (offering a specific perspective on tangible interaction) is elaborated by a set of concepts. The three concepts related to embodied facilitation are now summarized as a question in colloquial language to give a quick, but rough idea of what they are about. Then the concepts are explained in detail and the corresponding design guidelines are presented and illustrated with examples.

Embodied Constraints: Does the physical set-up lead users to collaborate by subtly constraining their behavior?

Multiple Access Points: Can all users see what's going on and get their hands on the central objects of interest?

Tailored Representation: Does the representation build on users' experience? Does it connect with their experience and skills and invite them into interaction?

Concept: Embodied Constraints

Constraints restrict what people can do and thereby make some behaviors more probable than others. Embodied constraints refer to the *physical system set-up* or *configuration of space and objects*. They can ease some types of activity and limit what people can (easily) do. Thereby they determine probable trajectories of action. Some embodied constraints provide implicit suggestions to act in a certain way. Others require people to collectively work around them, leading to the adoption of interaction patterns that indirectly foster collaboration. Using such subtle mechanisms, we can encourage and induce people to collaborate. Shape and size of interaction spaces e.g. act as embodied constraints, which bring groups together, focusing on a shared object, or which hinder communication.

The design guidelines are:

- Exploit constraints that require groups to:
  - distribute the task - help each other out - coordinate action
- Provide a shared 'transaction space'

Guideline: Exploit Constraints that Induce Helping and Coordination

Sometimes constraints that at first sight seem restrictive and hinder usability have positive effects on social interaction. In evaluating and redesigning the Envisionment and Discovery Collaboratory (EDC) (Eden, Hornecker and Scharff, 2002, Hornecker, 2004) we started to use the term 'embodied constraints' to understand and pinpoint some of these phenomena.

The EDC was developed at the Center for Lifelong Learning and Design to support co-located participatory urban planning (Arias, Eden and Fischer 1997). It provides an augmented game board and allows tangible interaction with computational simulations projected upon an aerial photo. We assessed two system versions by having two groups use them in a role-play of a neighborhood meeting on re-design of a local bus route. The sessions and subsequent discussions were videotaped and an interaction analysis was carried out. One system version uses a horizontal SMARTBOARD™ that allows drawing with fingers to create, move or delete objects and pen sketching, but cannot handle simultaneous interactions or detect physical objects. The second system version, the PITA-BOARD, is based upon a chessboard grid (http://www.dgtprojects.com) that registers RFID tags embedded in objects. Thus it comes closer to the vision of a tangible interface with tangible manipulation.

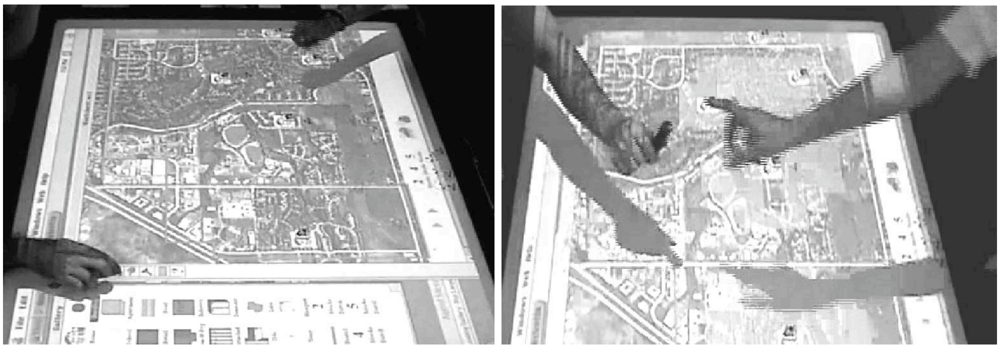

Figure 1. Embodied constraints by structure and size of EDC SMARTBOARD version: (a) helping each other to change interaction mode (menu in front) and (b) handing over of tools (a pen).

During analysis we found that constraints forced participants to coordinate actions, and as a result fostered group awareness and cooperation. Such constraints can consist of shared or restricted resources that must be coordinated, or of structures encouraging reciprocal helping. Examples are a menu for selecting interaction modes on the SMARTBOARD (create, move, delete…) or a limited supply of tangible tools. The sheer size of the SMARTBOARD necessitated mutual helping and handing over of tools (figure 1), indirectly fostering collaboration and awareness. It also made it physically impossible for one person to take over control of the entire interaction space. Participants found these to be valuable effects; they advised us to keep the system that large. With the much smaller PITA-BOARD we observed markedly less of these behaviors. From group dynamics it is known that situations requiring coordination and help do improve reciprocal liking and group cohesion. Such situations occurred at the very beginning of the session and initiated content-neutral cooperation, possibly making people more willing to cooperate on more salient issues later-on. Working with interaction modes (one global menu with create, move, delete… tools) had negative effects from a task-oriented view and led to frequent breakdowns, but required participants to be highly aware of each other and to coordinate activity. Here the annoyance was higher than the benefits. Nevertheless, participants could imagine employing similar (less disruptive) constraints to foster collaboration.

Physical or system constraints requiring coordination and sharing of resources thus embody facilitation methods that foster cooperation and structure group processes. From a viewpoint of task analysis, constraints seem counterproductive. However, easing the task is not the most important goal for all situations; less straightforward social or cognitive effects may be more critical. Nevertheless, as the modal interaction example demonstrates, constraints need to be carefully chosen so as not to disturb and irritate participants. Lessons learned for re-design included enlargement of the PITA-BOARD, so people would be forced to help each other and could not control the entire board. We also consciously provided enough tools for several participants to be active at once, but only a restricted number of each, so they would need to help each other and coordinate use.

Figure 2. The size of the CLAVIER necessitates several people for a more complex soundscape.

A further example for embodied constraints originates from a very different system. Seven installations created by students were shown on three nights in summer 2002 at a public festival in a park in Bremen. A description and analysis of the SENSORIC GARDEN, using concepts on interactivity to explain *why* some installations successfully attracted visitors' engagement and what made others fail, is given in Hornecker and Bruns (2004). Here I focus on the CLAVIER: a walkway with light sensors triggered by walking across it (figure 2). Colored spotlights reacted where one put one's feet. Triggered midi drums and beats produced an ambient sound environment. Visitors danced to the music, jumped from light to light and created music. This installation attracted many interactors and a constant gathering of observers. Some people even danced with umbrellas in the rain. Others used umbrellas and other objects to trigger multiple sensors.

In several ways the system encouraged people to implicitly and explicitly cooperate. Visitors, by inadvertently passing, interacted musically with intentional interactors. Furthermore, its size necessitated the activity of several people to produce a complex soundscape, as a single person could only trigger a few adjacent sounds. The installation in this way encouraged group creativity. While the CLAVIER exemplarily illustrates the spatial interaction theme, these effects also make it a good example for the embodied constraints given by the sheer size of an interaction area. Additionally, by necessitating large-scale bodily interaction, it transforms interaction into a public performance (a concept from the tangible manipulation theme), makes actions visible, and supports full body interaction (concepts from spatial interaction theme). This shows how the themes are interconnected, offering different perspectives on related phenomena.

There is considerable evidence that the physical set-up affects social interaction patterns, an issue getting relevant in research on distributed displays. E.g. Rogers and Rodden (2003) found that groups tend to nominate one participant for writing on a white board and line up before it. When sitting around a table, roles are more flexible. The physical constraints of a white board mean that standing in front blocks view and physical access for others. Only one or two persons can simultaneously have physical access. A point on a table can be accessed by more people. Buur and Soendergaard (2000) observed different behaviors and discussion styles for various room set-ups. Needing to stand up and go to a wall to show a video made people refrain from it. Discussions tended to be abstract and general. Being able to show clips while staying seated, people would quickly do so and referred more to concrete video clips and specific observations.

Guideline: Provide A Shared Transaction Space

Kendon (1990) introduced the term *transaction space* in his explanation of the F-formation. A persons' transaction space is formed by the half-circle before the upper body, that (s)he can see and act within. It is framed by body orientation and posture. "An F-formation arises whenever two or more people sustain a spatial and orientational relationship in which the space between them is one to which they have equal, direct and exclusive access“ (Kendon, 1990, p. 203). If people stand in a circle or surround a table, their transaction spaces overlap and create a shared one. Kendon found that establishing, changing and leaving an F-formation correlates with beginning, participating in, and ending social interaction and that changes of the configuration give subtle social signals (see also: Suzuki and Kato 1995). As people seem to interpret its establishment as indication that social interaction is appropriate, implicit creation of an F-formation might stimulate group interaction. This can explain why surrounding an image on a table produces a different atmosphere and interaction style than the same image on a wall.

A shared transaction space provides shared focus (if a representational object attracts attention), while allowing for peripheral awareness. Systems that render sides of a table unavailable to users affect the shape of transaction spaces (Scott, Grant and Mandryk, 2003) and thereby the interaction. A transaction space, by providing exclusive access, also limits communication to those sharing it. There is a natural limit to its size determined by visibility and audibility.

The focus-providing effect of the EDC’s shared transaction space can be seen well on evaluation videos. Even from only a bird’s eye view of the table, one can discern from the rapid activity and gesturing on the SMARTBOARD that people mostly look at the aerial photo. Nevertheless, the fluidity of interaction and conversation demonstrates high awareness. Figure 3 a shows a group surrounding the enlarged PITA-BOARD highly focused on the map and on group activity.

Figure 3. (a) The enlarged PITA-BOARD provides a shared transaction space. (b) Size and form of the Electrical Telegraphy hands-on exhibit support small group interaction.

An evaluation of a museum exhibition in Vienna on media evolution provided further examples of the effects of specifically formed transaction spaces (Hornecker and Stifter, 2004). The exhibition combines traditional object exhibits, computer-augmented hands-on exhibits, touch screens, interactive installations and computer terminals. Evaluation combined logfile analysis with qualitative observation and visitor interviews. Observation revealed interesting differences in interaction patterns with installations types, in particular in terms of group sizes. While most touch screens or computer terminals tended to be used by one visitor and only rarely by two, interactive installations were often surrounded by groups of up to five persons. Figure 3 b shows a family exploring a hands-on exhibit on electrical telegraphy. The image illustrates how its size and form limit the number of people able to focus on it. By providing a hands-on device in the foreground (not visible: Morse ticker and letter wheel) the screen is moved to the rear; focus shifts between device and screen. Size and form of an interaction space (or system) act as a specific type of embodied constraint delimiting access.

Concept: Multiple Access Points

Access points refer to the options to access and actively manipulate relevant objects. Access is an issue of power, highly influencing group dynamics. We can analyze systems in terms of the resources they offer for accessing and interacting with the objects of interest and in terms of privileges and limitations of access. Restricted resources affect the power play and may even entice people into conflict and competition for control. Sufficient resources and non-privileged access create a more egalitarian situation, allowing everyone to participate and to have a say (abstracting from factors such as hierarchies), making it difficult for individuals or subgroups to take over control. *Access points* determine the opportunities to observe and to become involved hands-on with relevant objects.

Researchers comparing single and multiple mouse conditions for children's games found different interaction structures (Stewart et al, 1998). In multi-mouse conditions significantly more cooperation and communication took place, conflict was reduced, children interacted more, were more on equal terms and did not drop out of the activity as much as in the single mouse set-up. Stanton et al (2001) conclude on a study with tangible props for children's storytelling: "If everyone has a prop, then everyone has a vote". Multiple input devices allow for simultaneous action, easing active participation, reducing time constraints and supporting fluent switches between individual and group work (Stewart et al, 1998). By allowing parallel and non-verbal contributions they shift power away from the verbally articulate, aggressive or self-assured members of groups.

Observational studies of design sessions often find fine-grained synchronization of simultaneous multimodal activities. Simultaneous activity not only speeds up interaction, it also displays shared understanding and distributes ownership (Hornecker, 2004). Visible representations provide focus and shared reference; they anchor discussions (Arias, Eden and Fischer, 1997, Henderson 1999). Public interaction triggers communication and negotiation. Access points are influenced by size and form of artifacts and shared space (Scott, Grant and Mandryk, 2003), determining the physical configuration or arrangement of a group and affect audibility, visibility and manual accessibility.

The design guidelines are:

- Give multiple points of interaction
- Allow for simultaneous action
- Give equal access - no privileges

Guideline: Give Multiple Points of Interaction

Multiple interaction objects distribute control in a group, make it difficult for individuals to take over control, and lower thresholds for shy or timid persons to become active. Whereas in the original PITA-BOARD version, bus stops were ‘stamped’ with a tool onto the map, the new version provided as many stop tokens as could be used (figure 4 a). This made it easier to relocate stops and to keep track of ‘unused’ stops. At the same time, it became difficult for a single participant to remain in control and set all stops.

There is reason to believe that touching objects creates a sense of ownership and aids cognitive and emotional appropriation (cp. Buur and Soendergaard, 2000). When distributing creation and manipulation of representations over a group, these can thus become truly shared objects. This belief was strengthened by observing the SMARTBOARD-group taking turns in drawing the final bus route at the end of the session, *explicitly* involving everyone. Members of a workshop using a redesigned PITA-BOARD version did the same. While access to the modal menu on the SMARTBOARD was limited to those next to it (an embodied constraint enforcing coordination and help), access to the board for other actions was not restrained. Not being forced to aggressively acquire control over interaction devices lowers thresholds. Even though there was no equal distribution (achieving this is probably illusionary), the more quiet or shy group members gestured lively and made important contributions in manipulating items.

The CLAVIER installation from the SENSORIC GARDEN provides another example for multiple points of interaction (figure 4 b + c). While here the visitors’ bodies constitute interaction devices, input points are distributed, allowing several persons to be active without being in each other’s way. This allowed for incidental simultaneous activity and for cooperative dancing and composing.

The setup as an embodied constraint often also limits access points. In the exhibition evaluation (Hornecker and Stifter, 2004) it was observed how different

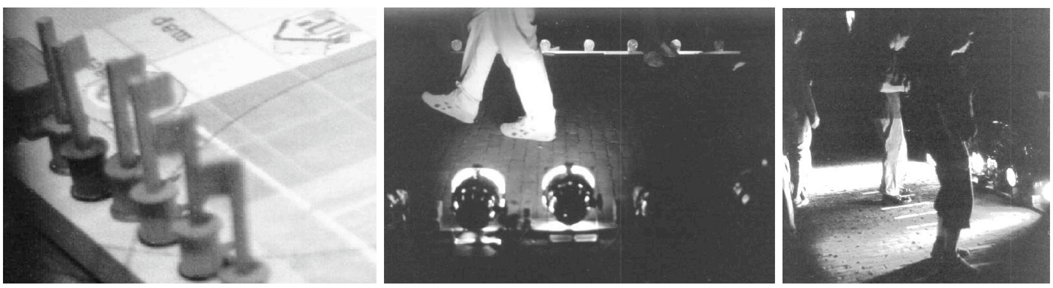

Figure 4: (a) Many interaction objects (PITA-BOARD) and (b, c) input at various loci (CLAVIER)

Figure 5: (a) Terminals suit single users. (b) The ORF-ARCHIVE is used by up to two visitors.

types of installations attracted different visitor constellations. Computer terminals were almost always used by single persons (figure 5 a), as screens and seating suit this best. Although of same screen size, the ORF-ARCHIVE (radio and TV clips) was quite often occupied by pairs. The seat and the small screen allow up to two people to see and be active. Having only two of these stations gave an incentive, and the seat seemed to provide a sense of intimacy while being comfortable enough for two because of sideward space. In contrast, hands-on installations were frequently surrounded by groups with several people interacting. Several visitors can move the physical beads of the ABACUS (figure 6 a) at once and the set-up provides space for observers. The large screens of the GLOBAL STORAGE (figure 6 b) installation are interacted with via laser beam pens. The large projection affords many observers and a number of laser pens are attached to long strings, allowing multiple visitors to move about and be active.

The idea of analyzing size and form of systems in terms of providing access points originated from observing students work with LEGO MINDSTORMS™. In several groups of five, two people only observed and soon got distracted. It was salient that more than three people can simply not touch the robots simultaneously (limiting participation in building and testing) and block view for others. The option to touch something can thus be a scarce resource to start with. Small objects or surfaces make it difficult to reference via gestures for large groups. Large objects on the other hand may provide many access points. Yet, their size means that one can only access a certain subset at a time. The CLAVIER provides an example where this effect is positive in fostering cooperation.

Figure 6: Hands-on exhibits (a) ABACUS and (b) GLOBAL STORAGE afford small groups

Guideline: Allow for Simultaneous Action

Multiple points of interaction ease simultaneous interaction, but do not necessarily permit it. Often systems provide several input devices, but require sequential input, ignoring parallel events or reacting delayed. The PITA-BOARD allows for simultaneous interaction, while the SMARTBOARD does not. Having to alternate and sequentialize actions caused multiple breakdowns, even though participants were highly aware of each other. Alternating actions was felt to be demanding. Simultaneous interaction speeds up work that can be done in parallel and thereby helps the group to concentrate on issues requiring negotiation and on developing shared understanding. It also allows less vocal group members to have a say, as they do not need to wait for a free time slot or need to interrupt.

Figure 7: Simultaneous action on new PITA-BOARD (a) introductory phase (b) mapping land use

Most examples given in the previous section for multiple points of interaction apply here as well. Simultaneous interaction thus supports multiple points of interaction. Yet, it is not a design guideline that should be followed slavishly. Physical constraints that sequentialize actions can serve to give necessary order to an interaction process or to ensure equal rights (e.g. a waiting queue).

Guideline: Give Equal Access – No Privileges

Privileged access to system features naturally gives more power to those privileged. Besides affecting the interaction process it changes the atmosphere by evoking certain assumptions and expectations, in particular by delivering implicit social signals on hierarchies and expertise. Equal access refers to giving everybody equal options; it does not mean everybody should have one of every tool or that all interaction devices should provide the same functionality.

In assessing the EDC (Eden, Hornecker and Scharff 2002) we found that privileged access of facilitators to system functions affected the power play of sessions. Facilitator access to PITA-BOARD features via mouse and keyboard, invisible and unpredictable to participants, made them feel as guests, not allowed to ‘own’ the system space. In comparison, the SMARTBOARD group quickly learned how to close error messages (appearing on the table) and took over this

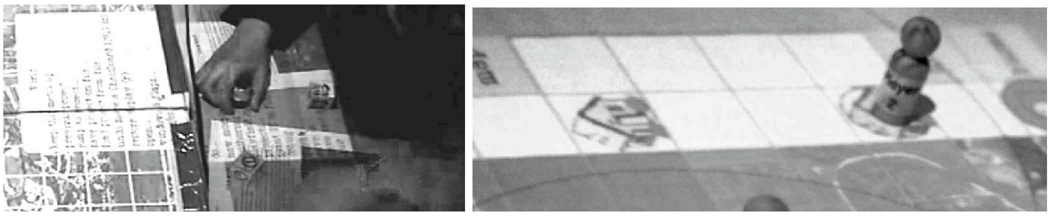

Figure 8. (a) A menu pops up unexpectedly within participants' manual space, who cannot see facilitator actions. (b) The new PITA-BOARD version has an extra 'admin-space'.

task. Making the means of controlling the system invisible and non-observable does not enable users to learn and become 'experts'. Providing privileged access to some group members gives implicit *signs of ownership*. When re-designing the PITA-BOARD, we eliminated privileged access by providing means to control the simulation by manipulating objects on the game board (Figure 8 b). Combined with other improvements, the new version provided a much better experience, allowed for equal access, and enabled everybody to take over system control.

Another kind of privilege relates to optimal viewpoints, due to e.g. a vertical screen next to a table (cp. Scott, Grant, Mandryk, 2003). With the EDC, there was no optimal, and therefore privileged place, as most icons were easily identifiable, even if upside down, and the aerial photo has no implicit orientation. Orientation and positioning are much more critical for text. Privileged viewpoints are a result of the type of representation used as well as size and form of interaction spaces.

Concept: Tailored Representations

The concept of *tailored representations* refers to a different type of access, which is cognitive and emotional instead of manual or visual. Discussions of tangible interfaces often highlight the intuitiveness of interaction. Focusing only on intuitiveness neglects the skills and knowledge of people (cp. Buur, Jensen and Djajadiningrat, 2004) and may result in systems that don't scale up to experienced users and complex domains. While intuitive usability is important in giving new users access, we also must consider expert users and specialists. Representations that connect with users' experiences and skills invite them into interaction and empower them. Representations that do not connect do exclude and silence users, who cannot relate, understand, and contribute. Representations need to be adequate for the task, the domain and the user group. Intuitiveness is thus relative.

Nevertheless, it is important to ease initial access on the basic level of manipulating relevant objects. If we cannot figure out how to interact with a system, it is of no help if the representation is legible. Users should be able to quickly explore the basic syntax of interaction. Over time they might acquire the more complex syntax of advanced interaction (learnability). Experience-orientation thus refers more to the semantics of interacting with a representation.

Representations that build upon users' experiences can become tools for thought as thinking prop or external memory, and can complement verbal communication by allowing people to gesture, refer to visible objects and manually demonstrate something (Norman, 1994; Hutchins and Klausen, 1998). Adequately chosen representations thereby ease participation in discussions. Henderson (1999) describes the gatekeeper function of design representations that control access, invite or discourage participation and define the range of allowed actions. Representations can privilege perspectives (different notations being easier to read and manipulate for specific professions) and become symbolically owned territory. Good representations offer several layers of legibility, are accessible for people with differing knowledge areas, and provide a shared reference. Then they can serve as boundary objects (Star and Griesemer, 1989).

Another aspect of representations and materials is that these trigger people's imagination and creativity (Rettig, 1994). The selection of materials provides a trajectory for thought, for the positive or the negative. What is not available or not visible will be thought of less. Similar to facilitators, system designers should be aware of the responsibility they carry in deciding upon available materials and representations, as these might affect the decisions of people using them.

The design guidelines are:

- Build on the experience of the group and its members
- Make the interaction intuitive enough for easy access
- Allow the semantics to rely on specific knowledge

Guidelines on Intuitiveness and Experience-Orientation

Interaction with the PITA-BOARD tokens was perceived by all participants as intuitive. In analyzing the videos, no interaction problems could be detected after an initial phase of finding out how to place tokens on the board. A new introductory phase for exploring the system in a playful way (figure 7 a) gave participants the opportunity to get accustomed to its reactions. Many common methods for citizen participation in urban design use aerials as maps distort and abstract geographical relations. Furthermore, map reading must be learned, it is an acquired skill. Aerials might relate more to inhabitants' experience, with landmarks being easy to identify and street shapes visible. Ernesto Arias (personal communication) emphasizes the importance of selecting an appropriate level of abstraction in participatory urban design, such as very literal, figurative building blocks: "Some laypeople need a tree-tree, not a green general block". After a while categories become well known and more abstract blocks can be introduced.

The systems introduced so far have all been of the 'walk up and use' kind, meant for public places or participatory meetings. A recent study provides a better example of the difference between intuitiveness and experience-orientation. Together with students I carried out a user study on the TANGIBLE IMAGE QUERY

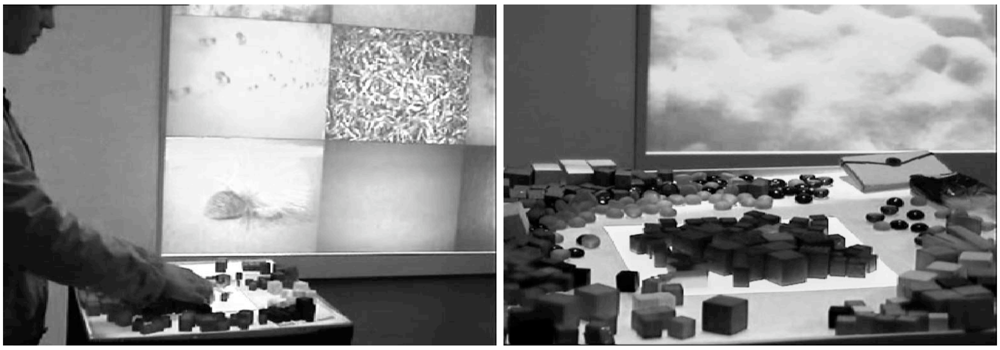

Figure 9. (a + b) Study participant at the TANGIBLE IMAGE QUERY with query results

(Matkovich et al 2004). This system offers architects inspiration through serendipitous searching in collections of images. Users define a search by laying colored objects onto the input area. The underlying algorithm searches for color distributions. The study participants were architecture and computing students. While manipulation of input and querying was intuitive, the search results required habituation and were initially irritating. One major finding was that the attitude of participants towards the system depended largely on their relation with images (as architects, art lovers or avid photographers) and their ability to find value in being inspired and surprised (instead of finding "what I searched for").

Examples for this concept are not yet sufficient, as the systems studied so far did not address specialized and experienced professional users and the TANGIBLE IMAGE QUERY has no collaborative use context. Nevertheless the concept is important to Embodied Facilitation, and therefore needs to be presented here.

Conclusions and Outlook

In this paper I presented a theme for design and analysis of collaboratively used tangible interaction. Tangible interaction encompasses a broad scope of system and interfaces sharing aspects of tangibility, physical embodiment of data, bodily or embodied interaction and embedding in real space. It encompasses approaches from HCI, computer science, product design and interactive arts. Following a short summary of the overall framework, I focused on the *Embodied Facilitation* theme. Its basic idea is that tangible interaction systems provide procedural as well as physical and spatial structure, which shapes the ways we act. It can induce collaboration, foster it or make us refrain from it. Thus, tangible interaction systems embody styles, methods and means of facilitation.

The theme of Embodied Facilitation was broken down into three concepts. These were concretized with design guidelines and illustrated with examples. *Embodied Constraints* are aspects of the physical set-up that subtly constrain peoples' behavior or provide implicit suggestions for action, encouraging collaboration. The guidelines suggest (a) employing constraints that require groups to distribute the task, to help each other out and to coordinate action, and (b) providing shared 'transaction spaces'. The concept of *Multiple Access Points* makes us consider systems in terms of how many people can see what is going on and lay hands on the objects of interest. The guidelines suggest (c) giving multiple points of interaction, (d) allowing simultaneous action and (e) giving equal access, not privileging some users. *Tailored Representations* take account of users' experiences and skills, inviting and empowering them. The guidelines suggest (f) building on experience and (g) making interaction intuitive enough for easy access, but (h) allowing the semantics to rely on specific knowledge.

In its current state, the overall design framework should be read as a proposal, backed by examples and arguments. There are several directions for future research. To demonstrate its utility as a *design framework*, practical design studies employing concepts and guidelines are required. These could involve design of new and redesign of existing systems, or adjusting a previously single-user system to collaborative use. Other studies could systematically explore the design space given by specific (sets of) guidelines. A further direction for research relates to the frameworks' general applicability to CSCW. Illustrative examples so far stem predominantly from entertainment, design and negotiation support. To demonstrate its general utility, examples from other application areas are required. It is furthermore open whether the framework covers collaboration distributed over time and space. Further research questions concern the relations between some of the concepts and guidelines. Transaction spaces and access points are clearly positively related. Seen as absolutes, multiple access points and constraints are in tension. Different configurations may prompt different interaction patterns, such as providing a tool for every second or third group member. Similar questions could be studied in detail empirically. The concrete influence of size and form of interaction spaces or the number of access points is still unclear. Is there a systematic relation between task, access points, number of actors and evolving interaction patterns? Considering the number of guidelines in the overall framework there will be many more detailed research questions.

It is important to remember that the guidelines are meant to sensitize designers, not to be slavishly followed. While it is tempting to make concepts operational, we need to be wary of transforming analytic terms, meant to sharpen perception, into rules and measurements. Design needs sensitivity and judgment. Sometimes it might even be best to temporarily discourage collaboration, prevent observation and restrict access, turning the guidelines from *do's* into *don't's*. Which guidelines should be applied and which take precedence over others, will depend on the task and the larger context of an activity, requiring further investigation on indicators for the applicability of guidelines and priorities in-between guidelines.

The contributions of this paper towards understanding the relation of embodied interaction and collaboration consist of: framework themes and concepts which support high-level analysis; complemented with guidelines to support design; and a research agenda. The framework is illustrated with several examples. It furthermore contributes to research on interactive exhibits, where space is an intrinsic issue (e.g. Ciolfi, 2004), as these served as major illustrative domain.

To round up, I will put my own framework into the context of related work. There are several frameworks aimed at the design for social interaction and a number of frameworks on tangible interfaces/interaction. With its soft guidelines and ‘design sensitivities’ my framework shares characteristics with others that offer concepts as ‘sensitizing devices’ and support designing for social interaction (Ciolfi, 2004, Dourish, 2001, Fitzpatrick, 2003). These frameworks are not prescriptive, do not offer recipes, and thus need to be interpreted and appropriated in response to concrete situations. Although operationalized to a greater extent, the framework presented here is meant to be continually evolving and open.

Previous frameworks on tangible interfaces/interaction have focused mainly on defining terms, categorizing, and characterizing systems (e.g. Ullmer and Ishii, 2000, some articles in ‘Pervasive & Ubiquitous Computing’ special issue 2004). While supporting the structural analysis of systems and detection of uncharted territory, these approaches offer little advice when designing for specific real world situations. Furthermore, these frameworks seldom address the human interaction experience or are restricted to solitary users. Suzuki and Kato (1995) and Arias et al (1997) did pioneering work on acquiring a better understanding of how tangible interaction affords social interaction and collaboration, but found few followers. Even though many TUIs supporting collaborations have been developed and some field-tested, analysis often remains domain-specific and yields few generalizable concepts (for a literature overview see Hornecker 2004).

This framework contributes to the larger research agenda of Embodied Interaction. While sharing the goal of understanding tangible interaction with Dourish (2001), my view on embodiment is more in line with Robertson (1997, 2002). Dourish’s perspective on embodiment focuses on the social construction of meaning, whereas Robertsons starting point (in the tradition of French phenomenologist Merleau-Ponty) is the living, feeling, responsive body as our primary means of experiencing the world, the world being its milieu. In embodied interaction the living body encounters and enters into dialogue with the world. Dourish (2001) states that social action is embedded in settings, which are not only material, but also social, cultural and historical, focusing his analysis on the latter. While the social has been elaborated, materiality has been less discussed. Understanding system embodiment in the sense of being *physically manifested* takes materiality seriously. I aim to unfold these aspects, inquiring into the interweaving of the material/physical and the social. Similar to Robertson (1997) and Fitzpatrick (2003) I am interested in how we accomplish communication and collaboration and how designed environments can support this.

Several framework themes and concepts not focused upon within this paper relate to topics discussed by other authors. E.g. social and atmospheric qualities of places (Ciolfi, 2004, Dourish, 2001) are part of the spatial interaction theme. The concepts of *non-fragmented visibility* and *performative action* are related to Dourish's (2001) discussion of accountability and observable action and build heavily on work from Robertson (1997). The concept of *embodied constraints* is at the same time related to and in intrinsic tension with *configurability*, focused on by other authors as an important system quality, but often with little reference to collaboration (Dourish, 2001, Jaccucci, 2004). This is a productive tension, as understanding the effects of embodied constraints makes the needs for configurability apparent. Moreover, it may give us insight on where exactly configurability is desirable and where (and how) system designers should provide structure – at least initially – in order for social processes to start evolving (cp. Hornecker 2004c). That "by configuring space in different ways, different kinds of behaviours can be supported" has often been stated (e.g. Dourish 2001). However discussion usually stops here. There have been only few attempts (e.g. Rogers and Rodden, 2003) to dig deeper and understand these relations. Affordances as 'exploitation of physical constraints' are often merely seen in terms of usability and provision of legible cues. With my framework and in particular with the theme of Embodied Facilitation presented here I extend the analysis to less straightforward, indirect (or second-order) social effects.

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