# An Encompassing View on Tangible Interaction: A Framework

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**ABSTRACT**
Our current understanding of human interaction with hybrid or augmented environments is very limited. We here focus on 'tangible interaction', denoting systems relying on embodied interaction, tangible manipulation, physical representation of data, and embeddedness in real space. This synthesis of prior 'tangible' definitions allows us to address a larger design space integrating approaches from different disciplines. We introduce a framework that contributes to understanding the (social) user experience of tangible interaction. This understanding lays the ground for evolving knowledge on collaboration-sensitive design.

**INTRODUCTION**
Tangible User Interfaces (TUIs) and Tangible Interaction are terms increasingly gaining currency within HCI. Through embedding computing in the everyday environment and supporting intuitive use these approaches share goals with other novel approaches to HCI. Variations have been pursued over the last two decades as 'graspable user interfaces' [7], 'tangible user interfaces' [19], or 'tangible interaction' [3, 5]. Design in this domain requires not only designing the digital but also the physical, as well as designing new types of interaction: these are new challenges for design and HCI. Through various effectws these systems lend themselves to the support of face-to-face social interaction, reflected in a considerable number of systems aimed at cooperative scenarios [1, 18, and see 19].

Research until recently focused on developing new systems. A move towards concepts and theory can be detected from a special issue on 'tangible interfaces in perspective' [10]. However, attempts to develop frameworks have concentrated mainly on defining terms or on categorizing and characterizing systems (e.g. [17, 19]). While supporting structural analysis, mapping out the design space and detecting uncharted territory, these offer little advice when designing for real world situations and seldom address users' interaction experience. There is still a need for conceptual frameworks, that unpack why 'tangible interaction' works so well for users [6]. Equally there is a need for principled approaches supporting research and design of these new hybrid environments.

We have chosen to use 'tangible interaction' as an umbrella term, drawing together several fields of research and disciplinary communities. This view encompasses a broad scope of systems relying on embodied interaction, tangible manipulation and physical representation of data, being embedded in real space and digitally augmenting physical space. It covers approaches from HCI, computing, product design and interactive arts. The proliferation of computing into everyday appliances draws product designers towards IT product design [3, 5]. Artists and museums experiment with hybrid interactives. Increasingly systems are developed by users e.g. in architecture or biology. This becomes even more prominent with computing moving beyond the desktop and 'intelligent' devices spreading into all fields of life and work. Thus a conceptual understanding of this new interface type and knowledge supporting design becomes even more important.

In this position paper we can only give a short overview of our framework that focuses on the user experience of interaction and aims to unpack the interweaving of the material/physical and the social aspects of interaction. It is described in more detail in [13]. The framework contributes to the larger research agenda of Embodied Interaction [6, 15], offering four themes and a set of concepts. It builds upon results from a PhD project [11] and recent studies. One theme is described in detail in [12].

**A BROAD VIEW ON TANGIBLE INTERACTION**
We now give an overview of the dominant views and approaches on 'tangible interaction' and propose a deliberately broad, encompassing view. A look at the above mentioned approaches from other disciplines reveals that the 'tangible interface' definition frequently used in HCI is too narrow to encompass these. From the characterizations found, we can distinguish a data-centered view, pursued in Computer Science and HCI; an expressive-movement-centered view from Industrial and Product Design; and a space-centered view from Arts and Architecture:

- *Data-centered view*: [6, 10, 19] define 'tangible user interfaces' as utilizing physical representation and manipulation of digital data, offering interactive couplings of physical artifacts with "computationally

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mediated digital information" [10]. This characterization of TUIs is dominant in HCI publications. Conceptual research from HCI and computer science tends to explores types of coupling and representations [19].

- *Expressive-Movement-centered view:* An emerging 'school' in product design aims to go beyond form and appearance and to design the interaction itself. This view emphasizes bodily interaction with objects, exploiting the "sensory richness and action potential of physical objects", so that "meaning is created in the interaction" [5]. Design takes account of embodied skills, focuses on expressive movement and 'rich' interaction with 'strong specific' products tailored to a domain [3, 14]. The design community prefers the term 'tangible interaction'.
- *Space-centered view:* Interactive arts and architecture increasingly talk about 'interactive spaces'. These rely on combining real space and real objects with digital displays or sound installations [2, 16]. "Interactive systems, physically embedded within real spaces, offer opportunities for interacting with tangible devices", and "trigger display of digital content or reactive behaviors" [4]. Full-body interaction and use of the body as interaction device or display are typical for this approach.

*Tangible interaction,* as we understand it, encompasses a broad scope of systems, building upon and synthesizing these approaches from different disciplinary backgrounds. These share the characteristics of tangibility/ materiality, physical embodiment of data, embodied interaction and bodily movement as an essential part of interaction, and embeddedness in real space [2, 3, 4, 5, 6, 10, 19].

This concept of *tangible interaction* has a broader scope than Ullmer and Ishii's [19] description of tangible interfaces: "giving physical form to digital information" and its subsequent physical control, which is often used to define TUIs. Tangible interaction includes tangible appliances or remote control of the real world [14]. This approach focuses on designing the interaction itself (instead of the interface) and exploiting the richness of bodily movement [3]. Interaction with 'interactive spaces' by walking on sensorized floors or moving in space [2, 16] further extends our perspective, the body itself being used as input 'device'. Instead of using a restrictive definition, it seems more productive to address this larger design space and to interpret these attempts at conceptualization as emphasizing different facets of a related set of systems.

## RELATED WORK ON 'TANGIBLE' FRAMEWORKS

Previous attempts to develop frameworks have focused mainly on defining terms, categorizing and characterizing systems, on types of coupling. Most frameworks take a structural approach, systematically mapping out an abstract design space, but seldom address the human interaction experience. The most notable push towards a theory of tangible interaction and an understanding of the interaction experience, was provided by Dourish [6]. He emphasizes how social action is embedded in settings, focusing on the social construction of meaning. Thus materiality itself, and its relation to the social has been less discussed.

Support of social interaction and collaboration might be the most important, domain-independent feature of tangible interaction, but this issue has attracted little explicit attention. The pioneering work by [1, 18] of analyzing social use of TUIs and identifying social affordances found few followers. Even though many researchers agree that TUIs are especially suited for co-located collaboration, conceptual work often only briefly mentions visibility of actions and distributed loci of control as collaborative affordances. Evaluations often assess individual use, or give primarily anecdotal accounts of field use.

The research community therefore lacks concepts for analyzing and understanding the social aspects of tangible interaction and design knowledge on how to design so as to support social interaction and collaboration. This has motivated the development of our framework, which focuses on the (social) interaction experience, addressing the broader design space of 'tangible interaction'.

## OUR FRAMEWORK ON TANGIBLE INTERACTION

The framework is structured around four themes (figure 1) that are not mutually exclusive, but interrelated, offering different perspectives on tangible interaction. A set of concepts elaborates each theme, providing more concrete handles for understanding their implications. Themes are:.

- *Tangible Manipulation*
- *Spatial Interaction*
- *Embodied Facilitation*
- *Expressive Representation*

We now (briefly) present the four themes, explaining each theme's relevance for tangible interaction and presenting the related concepts, characterized with a short question in colloquial language. A more detailed description of themes and concepts can be found in the authors' CHI paper [13].

### Theme: Tangible Manipulation (TM)

*Tangible Manipulation* refers to the reliance on material representations with distinct tactile qualities that is typical for tangible interaction. Tangible Manipulation is bodily interaction with physical objects. These objects are coupled with computational resources [19] to control computation. The main concepts, colloquially phrased, are:

*Haptic Direct Manipulation:* Can users grab, feel and move 'the important elements'?

*Lightweight Interaction:* Can users proceed in small, experimental steps? Is there rapid feedback during interacting?

*Isomorph Effects:* How easy is it to understand the relation between actions and their effects? Does the system provide powerful representations that transform the problem?

### Theme: Spatial Interaction (SI)

*Spatial Interaction* refers to the fact that tangible interaction is embedded in real space and interaction therefore

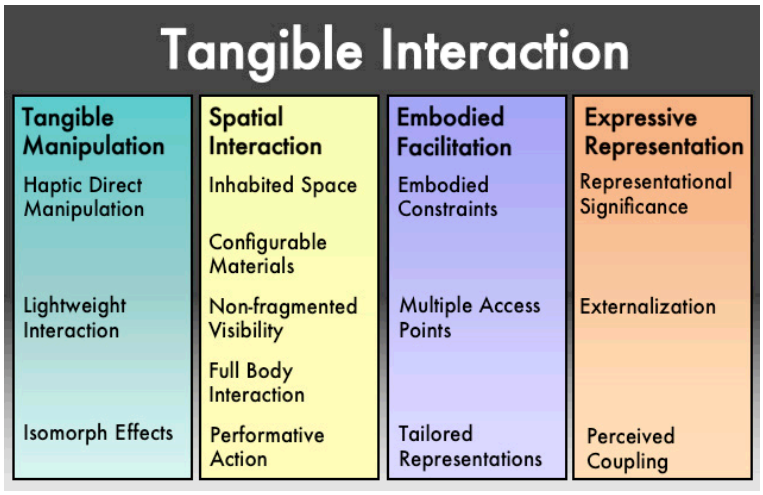


**Figure 1. Tangible Interaction Framework with themes and concepts**

occurring by movement in space. The interfaces take up space and they are situated in places. Interaction with spatial installations or interactive spaces can be interpreted as a form of tangible interaction that is not restricted to moving objects in space, but relies on moving one's body. The main concepts for Spatial Interaction are:

*Inhabited Space:* Do people and objects meet? Is it a meaningful place?

*Configurable Materials:* Does shifting stuff (or your own body) around have meaning? Can we configure the space at all and appropriate it by doing so?

*Non-fragmented Visibility:* Can everybody see what's happening and follow the visual references?

*Full-Body Interaction:* Can you use your whole body?

*Performative Action:* Can you communicate something through your body movement while doing what you do?

#### Theme: Embodied Facilitation (EF)

*Embodied Facilitation* highlights how the configuration of material objects and space affects and directs emerging group behavior. We literally move in physical space and metaphorically in software space. Tangible interaction embodies structure and thereby styles, methods and means of facilitation. We can learn from facilitation methods how to shape physical and procedural structure so as to support and subtly direct group processes (for details see [12]). The main concepts are:

*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?

#### Theme: Expressive Representation (ER)

*Expressive Representation* focuses on the material and digital representations employed by tangible interaction systems, their expressiveness and legibility. Often hybrid representations combine material and digital elements, each with distinct representational qualities, In interaction we 'read' and interpret representations, act on and modify them. Here the main concepts are:

*Representational significance:* Are representations meaningful and have long-lasting importance? Are physcial and digital representations of the same strength and salience?

*Externalization:* Can users think and talk with or through objects, using them as props to act with? Do they give discussions a focus and provide a record of decisions?

*Perceived Coupling:* Is there a clear link between what you do and what happens? Are physical and digital representations seemingly naturally coupled?

#### On the Framework

Frameworks focus our view, providing us with concepts that systematize our thinking. We feel that our approach is distinct from other frameworks by not offering taxonomies, but perspectives and themes for analysis and as conceptual guidance for design. Perspectives allow for systematic shifts of focus, highlighting different aspects of one object. The themes and concepts summarize our experiences from system assessments and reflections on design, in combination with a literature review on the use of material artifacts in social situations, distilling a set of social affordances [11]. The overall framework thus is the result of a synthesis of previous works and concepts developed by us. Recurrent themes or insights from literature have been integrated and fused into a larger framework focusing on the (social) use experience of tangible interaction.

Figure 1 can be read from left to right as referring to the design space of tangible interaction from the specific to the general. *Tangible Manipulation* is the most specific theme, relying on the use of material objects. It applies best to systems usually referred to as tangible interfaces [19] and tangible appliances. *Spatial Interaction* and *Embodied Facilitation* provide insights relevant for the broader research area of 'embodied interaction' [6], where movement in space and physical configuration of computing resources are central characteristic, e.g. mobile interaction and ubiquitous computing. *Expressive representation*, insofar as it concerns tangible representations, is specific to tangible interaction, but can be generalized to mixed reality representations. The *Embodied Facilitation* and *Spatial Interaction* themes are the most concerned with understanding and supporting social interaction. The other two themes address aspects of the user experience that support social interaction in

indirect ways, e.g. lowering participation thresholds, making action publicly available, or providing shared references, while being important for single users as well.

The framework is organized on three levels of abstraction. The themes offer perspectives at an abstract level and define broad research issues such as the role of space. Themes are each elaborated by a set of concepts that provide analytical tools, summarize generic issues, help to pinpoint design mistakes and successes or to guide design on a conceptual level. A level of more directly applicable design 'guidelines' is in development for practical purposes. These are not meant to be strict rules, they rather act as 'design sensibilities' [4, 8], inspiring and thought-provoking suggestions.

## CONCLUSION

Several previous frameworks have aimed at design for social interaction (e.g. [8]) or at tangible interfaces. Few have combined both fields of interest. Our framework contributes to the larger research agenda of *Embodied Interaction* [9], providing insight into the relation of embodied and social interaction. It integrates and fuses relevant recurrent themes and concepts from previous attempts at conceptualizing tangible interaction. For example the seminal work of Fitzmaurice [7] addressed issues strongly related to the tangible manipulation theme, albeit focusing on the usability and effectiveness of haptic directness. In recent years more emphasis has been directed to the aesthetic and expressive aspects of manual interaction with objects [3, 5]. Yet these attempts have mostly investigated the individual user experience. While all of these are important contributions that have inspired us, they often considered isolated aspects. Our aim has been to integrate these into a wider framework that focuses on the overall (social) use experience. Our aim has been to develop a better understanding of the user experience of tangible interaction and concepts for analyzing its social aspects along with knowledge aiding collaboration-sensitive design.

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