Pers Ubiquit Comput (2004) 8: 291–293
DOI 10.1007/s00779-004-0292-9

EDITORIAL

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Tangible interfaces in perspective

Guest editors' introduction

Published online: 22 July 2004
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We are pleased to present this special issue of the Journal of Personal and Ubiquitous Computing on *tangible interfaces in perspective*. Physical interfaces to digital information have been a very active topic in human–computer interaction for much of the last decade. Terms that have been introduced to describe this area include *graspable interfaces*, *tangible interfaces*, *physical interfaces*, *embodied interfaces*, and many others, each with somewhat different orientations, but covering a closely related area. For this introduction and special issue, we use the term *tangible interfaces*, as it is arguably the most broadly accepted. Regardless of what name is used, it is widely agreed that by moving human–computer interaction from the *virtuality* of the screen into the *physicality* of the real world, the design space is significantly extended, enabling new and richer forms of interaction.

The use of physical objects as manipulable representations of information extends back to the dawn of civilization. In his PhD thesis, Ullmer [1] connects the concept with the Middle East usage of clay accounting tokens beginning some 10,000 years ago—thousands of years before the invention of writing and even the wheel. Alternately, John Maeda (personal communication, 2002) of the MIT Media Lab suggests that tangible interfaces' origin may be found in Marcel DuChamp's "Readymades" concept of 1913, where pre-existing manufactured objects were assigned meanings quite different from their intended function. Hiroshi Ishii [2], also of MIT, invokes the example of the abacus, which illustrates both a powerful integration of physical and digital properties, as well as various alternate applications—as useful as it is for accounting, it could also be employed to scratch ones' back, or even as a musical instrument.

Early research efforts toward tangible interfaces appear to have developed in parallel at several institutions. The notion of ubiquitous computing, introduced by Weiser [3] at Xerox PARC, was a key influence for many researchers. Also influential was Weiser and Brown's concept of calm technology [4]. For example, the Dangling String, created by artist Natalie Jeremijenko at PARC, was a compelling demonstration of how "virtual" information (such as network traffic) could be rendered into dynamic physical form [4]. Another influential concept is that of augmented reality [5]; e.g., Wellner's DigitalDesk used a projection display to augment paper objects on a desk.

Inspired by these and Bishop's 1992 Marble Answering Machine (and other work) from the RCA CRD [6], the use of "tangibles" was developed in several projects at Interval Research beginning in the early to mid-1990s [7, 8]. At roughly the same time, Fitzmaurice et al. [9] developed the concept of "graspable interfaces" at the University of Toronto; Hinckley et al. [10] developed "passive real-world interface props" at the University of Virginia; and Suzuki and Kato [11] developed "tangible programming languages" at NEC. Drawing on these and other predecessors, as well as new research at MIT, Ishii and Ullmer [2] identified and illustrated the concept of tangible interfaces.

While these efforts were conducted largely within the human–computer interaction community, earlier efforts toward "tangible interfaces" were conducted in other research communities as long as three decades ago. Notable examples include the education community, including the pioneering "Slot Machine" of Perlman [12]; the architectural community, led by Aish [13, 14] and Frazer [15, 16]; the mechanical engineering community, e.g., [17]; the product design community, with

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inspiring examples by D. Bishop [6] and Oba [18]; and the art community, including Naimark's "white room" [19]. The breadth of perspectives and variety of different communities illustrated by these early systems, largely in isolation both from each other and from the human–computer interaction community, is striking. This breadth is also suggestive of future prospects for diversity in the continuing development, evaluation, and deployment of tangible interfaces, both in partnership with the human–computer interaction community, and likely well outside it. Indeed, D. Bishop (personal communication, 1997) once provocatively asked, "don't you think that 'tangible user interface' might someday sound like 'horseless carriage?'"

Following these early efforts, many research papers in recent years have explored the tangible interface paradigm. However, while there is currently considerable interest and activity in tangible interfaces, we are likely only at the beginning of understanding the implications of this approach. With this special issue, we have sought contributions which help place this body of work in perspective, while simultaneously presenting some of the area's most recent findings. We are also interested in forwarding the understanding of tangible interfaces' properties by introducing new frameworks and theoretical results. An overarching ambition has been to move beyond the dominating single-point approach, which considers only individual systems by a single author or group, to introduce a higher degree of perspective and reflection. We feel all of the full papers in this issue are successful in this, while the shorter papers ("design sketches") illustrate the current breadth and variety of the field.

One aim for this special issue was in seeking papers that reflect upon the lessons and perspectives gained in developing and evaluating a series of tangible interfaces. We begin this issue with three such papers that present and reflect upon tangible interfaces, taking the work of a particular group or institution as a starting point. If tangible interfaces are seen as interactive couplings between representational physical artifacts with computationally mediated digital information, then perhaps the earliest "known" tangible interface is the 1976 "Slot Machine" of Perlman [12]. The paper by McNerney takes the Slot Machine as a departing point, and discusses an evolution of education-oriented tangible interface research at the MIT Media Lab. On the other side of the ocean, Djajadiningrat et al. use a series of design research examples produced at TU/Eindhoven and Delft in the Netherlands to show how tangible artifacts can express qualities that are not available to the designer of graphical interfaces. And Binder et al. discuss a series of efforts where tangible interfaces have been integrated into the working environment of students, under the auspices of a European project with partners from several countries. This last paper relates to the idea of open systems, which allow physical/digital content to migrate between and build upon multiple independent interfaces. We believe this is a key direction in the future of tangible interfaces.

Another area we feel has been lacking is theory with which to describe, understand, and perhaps even suggest new kinds of tangible interfaces. Toward this, we have selected three theoretical papers that introduce frameworks or further the theoretical understanding of tangible user interfaces. Sharlin et al. can be considered as an introduction to spatial tangible interfaces. Fishkin has created a framework from the perspective of human–computer interaction, which offers researchers new tools for describing and contrasting tangible interfaces. And Shaer et al. present a case for a specific class of tangible interfaces, drawing upon an early influential example, Bishop's Marble Answering Machine [6].

Finally, we have incorporated the category of design sketches—short, generously illustrated pieces, which communicate the essence of an implemented or proposed interface. The five sketches we present illustrate the wide breadth of design perspectives currently being pursued. Three of these couple physical artifacts with graphical mediation, while two are audio-centric. The first systems employ projective illumination, head-mounted displays, and handheld PDAs, respectively. The latter integrate audio into a room-scale integration of 24 independent instruments, and into a wearable toy for athletic use. Two of the sketches add computational mediation and functionality to diverse existing physical artifacts (the Go board game and a PDA/mobile phone); one makes extensions and improvisations to existing physical forms (gloves and tokens); while two develop compelling new physical forms. We feel that this diverse array of systems and techniques, originating from laboratories with widely ranging disciplines, all attending both to engineering implementation and physical + visual design, provides a compelling illustration for the present and (hopefully) future diversity of tangible interfaces.

We had a difficult time selecting the above papers from the submissions we received for this special issue. There were 29 submissions in all, many of high quality; even the papers we had to reject contained many interesting contributions that we hope to see presented in other forums. Each paper received a minimum of three external reviews, which were then summarized in a meta-review by one of the special issue editors. At an editorial meeting, all papers were discussed at length by the three editors. We aimed to create a balanced mix of submissions and to provide a range of perspectives on tangible interfaces. In some cases, this meant choosing among submissions that were similar in scope, and picking the one that best supported our intentions for the issue. We hope the result of this process will be useful both as a snapshot of the field as it stands today, and a jumping-off point for new research.

Finally, we would like to sincerely thank all the authors for giving us the privilege of reading their work and allowing us to present this special issue.

Lars Erik Holmquist, Albrecht Schmidt, and Brygg Ullmer

1 Reviewers

We would like to express our sincere thanks to all the reviewers for this special issue, who supported both the editors and the authors with a multitude of insightful comments. The reviewers were:

Stavros Antifakos	Hans Gellersen	Yvonne Rogers
Francois Berard	Kortuem Gerd	Sally Rosenthal
Mark Billinghurst	Matthew Gorbet	Johan Sanneblad
Durrell Bishop	Tom Gross	Bernt Schiele
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Ken Fishkin	Christian Mueller-Tomfelde	Kristof Van Laerhoven
George Fitzmaurice	Les Nelson	Pierre Wellner
Geraldine Fitzpatrick	Haruo Oba	Margaret Withgott
Morten Fjeld	Thomas Pederson	Tobias Zimmer
John Frazer	Thorsten Prante	Karl-Petter Åkesson
Lalya Gaye	Johan Redström	

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