Tangible User Interfaces: Past, Present, and Future Directions

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Orit Shaer

Wellesley College
Wellesley, MA 02481
USA
oshaer@wellesley.edu

Eva Hornecker

University of Strathclyde
Scotland, G1 1XH
UK
eva@ehornecker.de

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Orit Shaer[1] and Eva Hornecker[2]

[1] Wellesley College, 106 Central St., Wellesley, MA, 02481, USA,
oshaer@wellesley.edu

[2] University of Strathclyde, 26 Richmond Street, Glasgow, Scotland,
G1 1XH, UK, eva@ehornecker.de

Abstract

In the last two decades, Tangible User Interfaces (TUIs) have emerged
as a new interface type that interlinks the digital and physical worlds.
Drawing upon users' knowledge and skills of interaction with the real
non-digital world, TUIs show a potential to enhance the way in which
people interact with and leverage digital information. However, TUI
research is still in its infancy and extensive research is required in
order to fully understand the implications of tangible user interfaces,
to develop technologies that further bridge the digital and the physical,
and to guide TUI design with empirical knowledge.

This monograph examines the existing body of work on Tangible
User Interfaces. We start by sketching the history of tangible user inter-
faces, examining the intellectual origins of this field. We then present
TUIs in a broader context, survey application domains, and review
frameworks and taxonomies. We also discuss conceptual foundations

of TUIs including perspectives from cognitive sciences, psychology, and philosophy. Methods and technologies for designing, building, and evaluating TUIs are also addressed. Finally, we discuss the strengths and limitations of TUIs and chart directions for future research.

Contents

1

Introduction

"We live in a complex world, filled with myriad objects, tools, toys, and people. Our lives are spent in diverse interaction with this environment. Yet, for the most part, our computing takes place sitting in front of, and staring at, a single glowing screen attached to an array of buttons and a mouse." [253]

For a long time, it seemed as if the human–computer interface was to be limited to working on a desktop computer, using a mouse and a keyboard to interact with windows, icons, menus, and pointers (WIMP). While the detailed design was being refined with ever more polished graphics, WIMP interfaces seemed undisputed and no alternative interaction styles existed. For any application domain, from productivity tools to games, the same generic input devices were employed.

Over the past two decades, human–computer interaction (HCI) researchers have developed a wide range of interaction styles and interfaces that diverge from the WIMP interface. Technological advancements and a better understanding of the psychological and social aspects of HCI have lead to a recent explosion of new post-WIMP

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interaction styles. Novel input devices that draw on users' skill of interaction with the real non-digital world gain increasing popularity (e.g., the Wii Remote controller, multi-touch surfaces). Simultaneously, an invisible revolution takes place: computers become embedded in everyday objects and environments, and products integrate computational and mechatronic components,

This monograph provides a survey of the research on Tangible User Interfaces (TUIs), an emerging post-WIMP interface type that is concerned with providing tangible representations to digital information and controls, allowing users to quite literally grasp data with their hands. Implemented using a variety of technologies and materials, TUIs computationally augment physical objects by coupling them to digital data. Serving as direct, tangible representations of digital information, these augmented physical objects often function as both input and output devices providing users with parallel feedback loops: *physical*, passive haptic feedback that informs users that a certain physical manipulation is complete; and *digital*, visual or auditory feedback that informs users of the computational interpretation of their action [237]. Interaction with TUIs is therefore not limited to the visual and aural senses, but also relies on the sense of touch. Furthermore, TUIs are not limited to two-dimensional images on a screen; interaction can become three-dimensional. Because TUIs are an emerging field of research, the design space of TUIs is constantly evolving. Thus, the goal of this monograph is not to bound what a TUI is or is not. Rather, it describes common characteristics of TUIs and discusses a range of perspectives so as to provide readers with means for thinking about particular designs.

Tangible Interfaces have an instant appeal to a broad range of users. They draw upon the human urge to be active and creative with one's hands [257], and can provide a means to interact with computational applications in ways that leverage users' knowledge and skills of interaction with the everyday, non-digital, world [119].

TUIs have become an established research area through the contributions of Hiroshi Ishii and his Tangible Media Group as well as through the efforts of other research groups worldwide. The word 'tangible' now appears in many calls for papers or conference session titles.

Following diverse workshops related to tangible interfaces at different conferences, the first conference fully devoted to tangible interfaces and, more generally, tangible interaction, took place in 2007 in Baton Rouge, Louisiana. Since then, the annual TEI Conference (Tangible, Embedded and Embodied Interaction) serves as a focal point for a diverse community that consists of HCI researchers, technologists, product designers, artists, and others.

This monograph is the result of a systematic review of the body of work on tangible user interfaces. Our aim has been to provide a useful and unbiased overview of history, research trends, intellectual lineages, background theories, and technologies, and open research questions for anyone who wants to start working in this area, be it in developing systems or analyzing and evaluating them. We first surveyed seminal work on tangible user interfaces to expose lines of intellectual influence. Then, in order to clarify the scope of this monograph we examined past TEI and CHI proceedings for emerging themes. We then identified a set of questions to be answered by this monograph and conducted dedicated literature research on each of these questions.

We begin by sketching the history of tangible user interfaces, taking a look at the origins of this field. We then discuss the broader research context surrounding TUIs, which includes a range of related research areas. Section 4 is devoted to an overview of dominant application areas of TUIs. Section 5 provides an overview of frameworks and theoretical work in the field, discussing attempts to conceptualize, categorize, analyze, and describe TUIs, as well as analytical approaches to understand issues of TUI interaction. We then present conceptual foundations underlying the ideas of TUIs in Section 6. Section 7 provides an overview of implementation technologies and toolkits for building TUIs. We then move on to design and evaluation methods in Section 8. We close with a discussion of the strengths and limitations of TUIs and future research directions.

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