Putting Tangible User Interfaces in Context: A Unifying Framework for Next Generation HCI

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ABSTRACT
Here, we propose the notion of *Reality-Based Interaction* (RBI) as a basis for understanding the role of tangible user interfaces (TUIs) within the broader context of emerging human-computer interaction styles. We are developing a Reality-Based Interaction framework to understand, compare, and relate current paths of HCI research. Viewing tangible interaction through the lens of RBI may provide insights for designers and may allow us to find gaps or opportunities for future development. Furthermore, we are using RBI to develop new evaluation techniques for features of emerging interfaces that are currently unquantifiable.

INTRODUCTION
Over the last two decades, we witnessed a proliferation of interaction techniques that have redefined our understanding of both computers and interaction. Motivated by both advances in computer technology and an improved understanding of human psychology, HCI researchers have developed a broad range of new interfaces that diverge from the "window, icon, menu, pointing device" (WIMP) or Direct Manipulation interaction style (DM). As TUIs allow users to collaboratively interact with physical objects in order to access and manipulate digital information, they provide an important example of such emerging interaction techniques. Some other emerging post–WIMP interaction styles include ubiquitous computing, perceptual and affective interaction, mixed reality, augmented reality, and virtual reality.

Although some may see these interaction styles as disparate innovations proceeding on unrelated fronts, we propose that they share salient and important commonalities, which can help us understand, connect, and analyze them. First, they are all designed to take advantage of users' well-entrenched skills and expectations about the real world. That is, interfaces are behaving more *like the real world*. Second, these interaction styles are transforming interaction from a segregated activity taking place at a desk into a fluid, free-form activity that takes place in our everyday environment. That is, interaction takes place *in the real world*. In both cases, new interaction styles draw strength by building on users' pre-existing knowledge of the everyday, non-computer world to a much greater extent than before. We propose that these emerging interaction styles can be understood together as a new generation of HCI through the notion of *Reality-Based Interaction* (RBI). Viewing interaction through the lens of RBI can provide insights for designers, can uncover gaps or opportunities for future research, and may lead to the development of improved evaluation techniques.

To date, work that attempts to explain or organize emerging styles of interaction has focused more on individual classes of interfaces than on ideas that unify several classes [1-5, 10, 12, 15, 16]. Our RBI framework is inspired by the work that helped to define the GUI generation [6,13] and considers a wider range of emerging interaction styles.

REALITY-BASED INTERACTION
The post-WIMP generation of human-computer interaction is unified by an increased use of real world interactions over previous generations. By "real world", we mean the undigital world, including physical, social, and cultural reality outside of any form of computer interaction. We introduced the term Reality-Based Interaction for emerging interaction styles that share this common feature. We have identified two overlapping classes of reality-based interactions: those that are embedded *in the real world*, and those that mimic or are *like the real world*. Both types of interactions leverage knowledge of the world that users already possess.

Interactions in the Real World

With ubiquitous, mobile and sensor technology, computation has moved out of the lab or office and into the greater world. While portability is a major part of this shift, we believe that both the integration of devices within the physical environment and the acquisition of input from the environment, serve as factors contributing to it as well. As interaction takes place within the real-physical world, users are allowed to engage their full bodies in the interaction and use their physical environment to organize information (figure 1). Indeed, research has found evidence of distributed cognition involved with reality-based interaction [17]. Furthermore, interaction in the real world often involves multiple users interacting in parallel with multiple devices.

Figure 1. As interaction moves into the real world, users are allowed to engage their full bodies and use their environments to organize information.

Interactions like the Real World

As technology moves into the real world, we also observe that interactions are becoming more *like the real world* in that they leverage prior knowledge and abilities that users bring from their experiences in the real world. For example, virtual reality interfaces gain their strength by exploiting the user's perceptual and navigational abilities while tangible user interfaces leverage users' spatial skills. The idea of *transfer of knowledge*–that it is easier to transfer already learned skills to a new task rather than learning completely new skills–is well known in psychology literature [11]. Although the user may already know more arcane facts, such as pressing the Alt-F4 command to close a window on a desktop computer system, it seems intuitively better to exploit the more basic knowledge that the user obtained in childhood rather than exploiting less innate knowledge. Information that is deeply ingrained in the user, like navigational and spatial abilities, seems more robust, more highly practiced, and should take less effort to use than information learned recently.

IMPLICATIONS FOR DESIGN

We believe the trend toward more reality-based interaction is a positive one. Basing interaction on the real world can reduce the mental effort required to operate the system because the user is already skilled in those aspects of the system. For casual use, this reduction might speed learning. For use in situations involving information overload, time pressure, or stress, this reduction of overhead effort could conceivably improve performance.

However, simply making an interface as reality-based as possible is not sufficient. A useful interface will rarely entirely mimic the real world, but will necessarily include some "unrealistic" or artificial features and commands. In fact, much of the power of using computers comes from this "multiplier" effect, the ability to go beyond a precise imitation of the real world. We therefore propose a view that identifies some fraction of a user interface as based on realistic knowledge or abilities plus some other fraction that provides computer-only functionality that is not realistic. As a design approach or metric, the goal would be to make the first category as large as possible and use the second only as necessary.

For example, consider the character Superman. He walks around and behaves in many ways like a real man. He has some additional functions for which there is no analogy in real humans, such as flying and X-ray vision. When doing realistic things, he uses his real-world commands, walking, moving his head, looking around. But he still needs some additional non real-world commands for flying and X-ray vision, which allow him to perform tasks in a more efficient way, just like a computer provides extra power. In the design of a reality-based interface, we can go a step further and ask that these non real-world commands, be analogous to some realistic counterpart. For example, in a virtual reality interface, a system might track users' eye movements, using intense focus on an object as the command for X-ray vision [14] or in a tangible user interface, crumpling a piece of paper might correspond to deleting a file from a digital storage system.

We can thus divide the non-realistic part of the interface into degrees of realism (x-ray by focus vs. by menu pick). The goal of new interaction designers should be to allow the user to perform realistic tasks realistically, to provide additional non real-world functionality, and to use analogies for these commands whenever possible.

There is a tradeoff between power and reality. Here we refer to "power" as a generalization of functionality and efficiency. The goal is to give up reality only explicitly and only in return for increasing power. Consider an interface that is mapped to point A in figure 3. If the interface is redesigned and moves to the upper left quadrant, its power would increase, but its reality would decrease, as often occurs in practice. According to RBI this is not necessarily bad, but it is a tradeoff that must be made thoughtfully and explicitly. The opposite tradeoff (more reality, less power) is made if the interface moves to the lower right quadrant. However, if the interface is redesigned and moves anywhere in the grey area, RBI theory claims that this interface would be worse, since both power and reality have been decreased. Similarly, moving anywhere in the top right quadrant is desirable, as it would make the interface better on both counts.

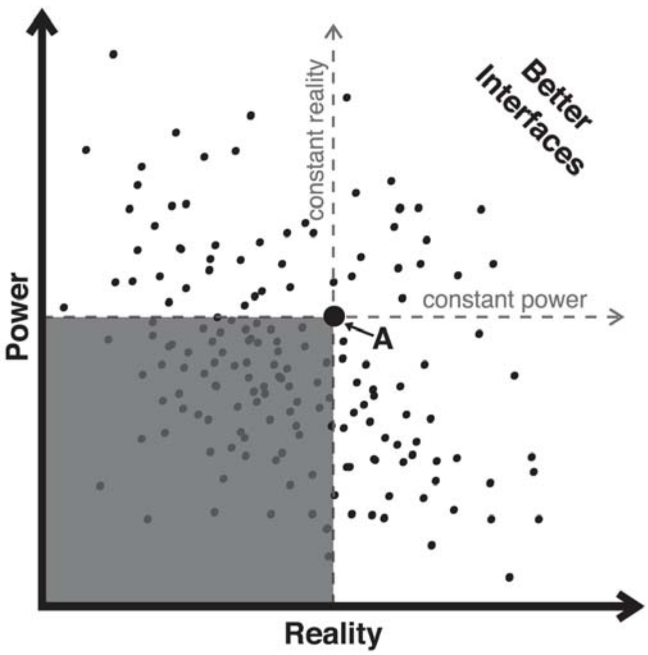

Figure 2. *Power vs. Reality Tradeoff*: each data point represents a hypothetical interface. Consider the point marked A. The dashed horizontal line represents interfaces with equivalent power. The dashed vertical line represents interfaces with equivalent levels of reality. RBI suggests that adding reality to these interfaces without loss of power will make them better, and that giving up reality to gain power should be done

FUTURE WORK

To perform experimental evaluations of the RBI framework, we are developing interfaces designed in different interaction styles and intended to differ primarily in their level of reality. We will conduct a study to determine the effects of each interaction style on users' time, accuracy, and attitudes while completing a given task. This can provide some quantitative measure of the effect of reality on the interaction.

Another important consideration for the new generation of HCI is how new interfaces themselves should be evaluated. At the CHI workshop, "What is the next generation of Human-Computer Interaction?" [8, 9] we brought together researchers from a range of emerging areas in HCI. A prevalent concern among the participants was that evaluation techniques for direct manipulation interfaces may be insufficient for the newly emerging generation. Many new interfaces claim to be "intuitive," which is often difficult to quantify, but listing and measuring the extent to which they use pieces of knowledge and skills that the user has acquired from the real world may help.

Furthermore, in addition to commonly used user interface measurements (e.g. speed and accuracy), other measurements such as workload, engagement, frustration, and fatigue may also be valuable for RBI. However, these measurements are generally only measured subjectively. More quantitative tools are needed. We use a relatively new non-invasive, lightweight brain imaging tool called functional near-infrared spectroscopy (fNIRs) to objectively measure workload and emotional state while completing a given task. This tool has been shown to quantitatively measure attention, working memory, target categorization, and problem solving [7]. We hypothesize that an objective measure of cognitive workload may prove useful for evaluating the intuitiveness of an interface. We further conjecture that reality-based interfaces will be associated with lower objective user frustration and workload than non reality-based systems.

CONCLUSION

We seek to advance the area of emerging interaction styles by providing a unifying framework that can be used to understand, compare and relate emerging interaction styles. Viewing tangible user interfaces through the lens of reality-based interaction allows us to focus on creating designs that leverage users' pre-existing skills and knowledge.

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