Challenges for Designing the User Experience of Multi-touch Interfaces

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ABSTRACT
Advances in technology have led to an increased presence of multi-touch interfaces in consumer products in recent years. Still, many challenges remain that designers need to face when designing for multi-touch interaction. As multi-touch interfaces are becoming more ubiquitous it is important to investigate not only their performance for certain tasks, but also the user experience of interacting with such interfaces. In this paper we discuss eight challenges that need to be considered when designing the user experience of multi-touch interfaces. The challenges also reveal potential areas for future research in the field of multi-touch interaction.

Keywords
Multi-touch interaction, surface computing, touch interaction, touch screens, interaction design.

INTRODUCTION

In the last few years multi-touch interfaces have gained a lot of attention, not only due to their application in mobile phones but also because of the advantages that come with this technology. One of the most important advantages compared to other interfaces is the possibility to directly interact with information on screen using fingers for input. This provides users with a stronger feeling of having control over their interactions rather than being controlled by the system. Another aspect of direct interaction is that it makes interacting with digital interfaces accessible to a broad spectrum of users. Furthermore, the technology enables concurrent co-located collaboration, especially on larger surfaces. Multi-touch interfaces that provide physical behaviour (such as gravity or inertia) also lead to higher performance [13]. Combined with visually appealing interface elements and graphics this might also lead to an increased overall user experience. However, multi-touch interaction also has its disadvantages, resulting in several challenges that need to be addressed when designing for multi-touch. Whereas multi-touch is good for specific use cases in certain contexts, it is not a general remedy for interaction design problems. Interfaces designed for mouse and keyboard interaction cannot be easily augmented with multi-touch capability without redesigning the interface accordingly.

This paper provides a general overview of existing challenges that need to be considered when designing multi-touch interfaces. It focuses on implications to user experience rather than purely technological issues, such as improved algorithms for finger tracking. The challenges are on the one hand derived from practical experience with the development of multi-touch applications and supervising student projects at our research group. On the other hand, the theoretical background is formed by an extensive literature review as well as presentations by experts in the field of multi-touch, human-computer interaction and natural user interfaces.

Screen-based challenges	Affordance of screens
	Tactile user feedback
User-based challenges	Ergonomics
	Individual differences
	Accessibility
Input-based challenges	Gestures and patterns
	Supporting data input
	Multi-user support

Table 1. Overview of the eight multi-touch challenges discussed in this paper, divided into three categories

In this paper, we present eight multi-touch challenges, classified into three categories (see Table 1): Screen-based, user-based and input-based challenges. The screen-based challenges describe problems related to physical properties of touch screens. The user-based challenges explore the use of fingers for direct input as the origin of problems users are facing when interacting with multi-touch interfaces. Finally the input-based challenges outline the difficulties in interpreting and supporting the input to enhance the user experience of multi-touch interfaces.

SCREEN-BASED CHALLENGES

Challenges from within this category are divided into challenges relating to the affordance of screens and challenges related to the lack of tactile user feedback.

Affordance of Screens

One fundamental challenge of designing multi-touch interfaces lies in the natural affordance of screens. The physical appearance of screens is responsible for affording touch [16]. As not all screens are capable of detecting touch, there are two undesired scenarios: a) the user touches a normal screen that is not capable of responding to this interaction technique and b) the user fails in recognising a touch screen as such. Hardware-specific details (e.g. the existence or absence of keyboard and mouse) can help the user to determine the touch capabilities of a screen. If the designer cannot influence the hardware design of a screen, the use of written or symbolic instructions (Figure 1) or already learned user interface conventions (e.g. a button with three-dimensional appearance) is necessary to provide visual cues. According to Norman [16], instructions or conventions do not affect the physical affordance of the screen itself, but the perceived affordance by the user.

Figure 1. Written instructions to affect the perceived affordance of touch screens

Once users become familiar with a screen or device, the importance of communicating its touch capability decreases. This is apparent when comparing the design of public screens (e.g. terminals) to personal devices that are used regularly (e.g. the *Apple iPhone*).

Tactile User Feedback

The absence of tactile user feedback related to multi-touch technology is one of the most discussed and investigated challenges in the area of multi-touch interfaces, yet there is no conclusive solution to this problem. Current touch screen technology does not provide tactile feedback when touched, compared to the press of a key on a physical keyboard. Therefore the use of adequate visual feedback, including the simple visualisation of the detection of the users' fingers, is essential when designing touch screen interfaces. Acoustic feedback can enhance the effect, but can also harm the experience when used in collaborative setups [6] due to the fact that sounds target all users at the same time.

In addition to patents by large companies (e.g. [12], [22]), there are several research approaches for simulating tactile feedback. Technological approaches include vibration, piezoelectric actuation, solenoid, pin matrices, or ciliated surfaces [7]. Problems of these approaches include high costs, scalability and the lack of support for multiple concurrent users. For instance, the vibration of the screen to provide feedback to an individual user would interfere with other collaborating users. A completely different approach [15] employs the users' mobile phones for distal tactile feedback through vibration. Harrison and Hudson [7] use pneumatically actuated physical buttons. However, this approach is limited by the preliminary assignment of fixed buttons, which stands in contrast with the typical adaptability of multi-touch interfaces.

Many studies (e.g. [9], [11], [14]) have proven that tactile feedback can improve performance and decrease error rates regardless of the technology used. Lee and Zhai [14] discovered that the combination of vibration and acoustic feedback does not result in further improvements.

USER-BASED CHALLENGES

Challenges from within this category are separated into challenges related to the ergonomics and individual differences of users and accessibility.

Ergonomics

The use of fingers for direct input and manipulation also entails challenges where different screen properties are concerned. One important thing to consider when designing interfaces for multi-touch applications is partial occlusion of the screen caused by fingers, hands and arms when users interact with a touch screen [18]. In contrast to the use of a computer mouse, users specifically occlude those parts of the interface they are interacting with when touching interface elements with their fingers. While this is also the case when typing on a keyboard, the problem is more severe on touch screens due to the additional lack of tactile feedback (see section *Tactile user feedback*).

This problem is exacerbated on small screens, where touch targets are also smaller. One approach to address the problem of occlusion is the so-called back-of-device interaction (e.g. [2], [24]) where the user can touch the screen on its backside. Either semi-transparent screens or a digital visualisation of the fingers help the user locate the target. Unfortunately this technique does not scale to larger screens. A very general approach is the *Shift* technique [19] which displays the occluded part above the finger while touching, sometimes even magnified.

Another important effect to consider is muscle fatigue while interacting with large touch screens. With a mouse, users can reach distant positions of the screen with minor movements of their hands. On touch screens users have to cover larger distances with theirs arms and hands. This problem increases when designing applications that support multiple different hardware platforms. Also, movements on vertically arranged touch screens might even be more strenuous. Therefore it is important to consider hand and arm movements for the positioning of user interface elements to prevent early muscle fatigue.

Individual Differences

Individual differences between users play an important role when designing multi-touch interfaces. For instance, different hand sizes will not lead to different sized touch screens, compared with the production of different sized computer mice. Therefore, different physical properties have to be considered while designing the interface (e.g. size of buttons). Not only hand size and finger size vary from one person to another, the fingers on one hand have different pointing properties (such as size) as well. The decision which fingers will be used for which gestures (e.g. object rotation) is dependent on finger properties and ergonomics. This leads to important design considerations as well as to technological challenges. As an example, a touch target should be greater than 11.5 mm, according to Wang and Ren [21]. This presents a challenge when designing touch screen interfaces for mobile devices with small screens. Other considerations [18] include handedness of users, fingernails that can make the detection of touch points difficult, gloves, which can prevent the detection of fingers in capacitive-based touch setups, and fingerprints that make users swipe over a screen, which is still listening for deliberate input.

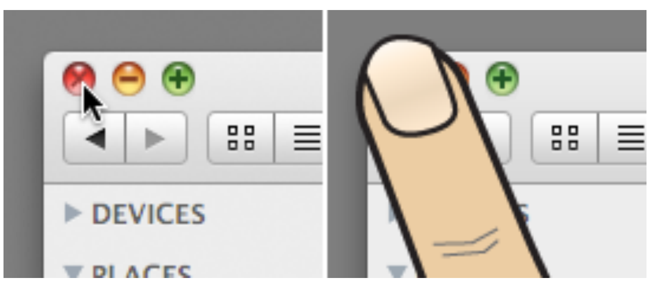

Figure 2. Accuracy and conclusion of mouse (left) compared to finger (right)

Another important consideration is the accuracy of fingers compared to a computer mouse. A computer mouse has a target zone of one pixel, whereas targeting a specific single pixel with a finger can become nearly impossible (Figure 2). Techniques for helping users to target the right spot exist (e.g. [1], [17]) and should be considered when designing touch interfaces. Different accuracy and touch target size of finger and mouse emphasise that existing interfaces should not be reused or enabled for touch interaction without appropriate adaption.

Accessibility

The lack of tactile user feedback (see section *Tactile user feedback*) also impacts the accessibility of touch screens. Especially blind and visually impaired people face barriers when interacting with touch screens. Existing products, such as the *Apple iPhone 3GS*, try to solve this problem by providing screen readers that give synthesised speech feedback when touching the screen. However, if more complex tasks need to be accomplished, screen readers might not be sufficient. Kane et al. [10] use the advantages of gestures for helping people with disabilities to navigate trough menus, but although the tasks could be solved more quickly compared to button-based interfaces, the error rate was higher. Another approach uses relative inputs for text-entry on a touch screen [26]. The first touch at any position on the screen represents the central position of one of three layers. A swipe into one of the eight basic directions chooses the according character. Staying in the central position exchanges the three layers in rotation.

Other disabilities have to be considered as well when designing multi-touch applications, particularly in a public context. For instance, physical disabilities could especially cause problems when interacting with larger touch screens or complicated gestures.

INPUT-BASED CHALLENGES

Challenges from within this category are divided into challenges related to gestures and patterns, supporting data input and multi-user support.

Gestures and Patterns

With the success of multi-touch enabled devices, gestures in use are increasingly becoming inconsistent [23] across different manufacturers. Patents that protect specific gestures for a manufacturer aggravate this development. As a result, competitors can either provide no gesture or invent an alternative. Therefore standardisation becomes difficult to achieve. However, approaches to provide de facto standards do exist. Wobbrock et al. [25] propose a user-defined gesture set for tabletops as well as a taxonomy of surface gestures.

When gestures get more complex, the number of people that are able to perform these gestures without instructions decreases. According to Saffer [18], "the complexity of the gesture should match the complexity of the task at hand". Major challenges have to be faced when trying to define intuitive, self-revealing gestures for complex tasks that go beyond zooming, rotating and swiping. Saffer [18] proposes that complex tasks should be realised with simple gestures (e.g. with buttons or menu systems), and additionally provide more sophisticated gestures for expert users.

The context of interaction with a multi-touch interface has to be considered when defining gestures as well. For instance, the use of complex gestures with more than one finger is not always possible on mobile devices due to different hand-held positions and usage.

When designing applications that support multiple different hardware platforms, screen and hardware properties have to be included in gesture considerations. This can include the number of concurrent trackable fingers, the screen size or the general touch screen technology and related accuracy.

Supporting Data Input

The lack of tactile user feedback also affects the user experience of data input on multi-touch interfaces. There are no methods available that make use of the advantages of multi-touch for data input while also overcoming this problem. One big advantage of virtual keyboards is the ability to dynamically change buttons related to the desired input (for instance an adapted keyboard for an email address field where certain characters are forbidden), the context, or the users' abilities (e.g. QWERTY versus ABCDEF layout). Furthermore, multi-touch enhances the user experience compared with single-touch since keys do not have to be pressed consecutively.

The dispute over the use of virtual versus physical keyboards in mobile devices has resulted in a variety of different concepts[1,2,3] for virtual data input methods. Nevertheless, small screens imply small virtual keys and therefore high error rates combined with lower performance. Adaptive algorithms (e.g. [5]) try to counteract these problems by resizing touch targets according to predictions of preceding inputs in the background. Other approaches (e.g. [8]) address problems like occlusions and resting palms which have to be classified as invalid input, and try to reduce finger movements on larger surfaces. Again, the *Shift* technique [19] is a very common approach to handle occlusions. Zhai et al. [27] examine the performance of virtual keyboards on the basis of *Fitt's Law* and the corresponding learning curve.

Multi-user Support

One of the most obvious technological challenges when designing a system for several co-located users, who interact simultaneously, is the ability to distinguish between individual users. Still there is no conclusive solution for multi-user support that works for different touch screen technologies. *DiamondTouch* [3] is a well-known approach that uses an array of antennas to distinguish between users, each hooked up to a capacitive receiver. However, the approach is limited to a very specific tabletop setup. It does not use distinguishing characteristics of the users themselves (such as fingerprints) and therefore requires initialisation.

As collaborative multi-touch applications often do not specify dedicated zones for each user, the distinction between individual users would allow further enhancements to improve the user experience. The position of the user(s) (e.g. around a multi-touch tabletop) cannot be determined reliably in every situation and with every hardware setup, although a few approaches exist. Wang et al. [20] analyse the orientations of the contact shapes (fingertips) to detect the corresponding users but suffer from the fact that not every contact point in multi-touch interaction is an oblique touch (i.e. touch with the finger pad instead of the fingertip). Dohse et al. [4] augment a multi-touch tabletop setup with hand tracking by mounting an additional camera above the table to distinguish between users. Although very promising, the approach only works when users stand on opposite sides of a tabletop.

[1] http://www.retype.ch

[2] http://www.shapewriter.com/iphone.html

[3] http://www.touchtype-online.com

CONCLUSION

In this paper we presented an overview of currently existing challenges that have an impact on the user experience of multi-touch interfaces. The eight identified challenges are based on our experience with designing multi-touch interfaces as well as an extensive review of recent literature and presentations from this field. There are three different groups of solutions to these challenges: 1) challenges that need to be addressed through technological innovation, 2) challenges that can be solved through interface design, and 3) challenges that need to be tackled both through interface design and on a hardware level.

The first group covers challenges that require solutions in terms of new technology. To provide real, authentic *tactile user feedback* the challenge is to invent reliable, scalable touch screen technology. To enable *multi-user support*, unique characteristics, such as fingerprints, need to be incorporated. The second group covers challenges that can be addressed through interface design solutions. *Individual differences* of fingers, hands and arms should be considered when designing multi-touch interfaces. Further, the user experience of different *gestures and patterns* defined to perform specific actions can be supported through appropriate interface design. The third group covers the remaining challenges that can be approached through interface design but also partly in terms of technology or hardware development. The physical affordance of a touch screen is defined by its hardware appearance, but perceived affordance can be manipulated by changing the visual appearance of interface design elements. *Ergonomics* of touch screens should be considered when designing multi-touch interfaces, but technological advances also need to be made to prevent occlusions. Similarly, *accessibility* can be approached with hardware solutions or sophisticated interaction methods. Finally, the support of high-performance, reliable data input can be partly implemented using intelligent keyboard interfaces, but are also dependent of technological issues such as tactile user feedback.

The list of challenges discussed in this paper not only reveals current challenges for designing the user experience of multi-touch interfaces, but also suggests possible directions for further research.

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