The cueTable: Cooperative and Competitive Multi-Touch Interaction on a Tabletop

Tom Gross, Mirko Fetter, Sascha Liebsch
Faculty of Media
Bauhaus-University Weimar
Bauhausstr. 11, 99423 Weimar
<firstname.lastname>(at)medien.uni-weimar.de

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Abstract
In this paper we explain how we built cueTable, a multi-touch interactive tabletop, as a base technology to explore new interaction concepts for cooperative and competitive multi-touch applications. We present the Puh game application. And most of all we report on user feedback to the cueTable and the Puh game.

Author Keywords
Interactive Tabletop, Cooperative Multi-Touch.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces—GUI, User-Centered Design; H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces—Computer-Supported Cooperative Work.

Introduction
Interactive tabletops provide horizontal large-screen surfaces that allow small groups of users to interact with software applications via touch. A number of interactive tabletops and a range of applications for interactive tabletops have been developed. For instance, Mitsubishi Electronics Research Laboratories have devel-

Figure 1. cueTable from inside and outside.

oped the DiamondTouch table for more than ten years and sell it commercially [9]; and Jefferson Y. Han has recently presented an approach for a low-cost touch-based solution for interactive screens. Among the special-purpose applications that have been developed typically for same-time same-place scenarios are particularly applications for sharing photographs [4], and for navigating maps and for planning cities [13].

Despite this wide spreading of interactive tabletops, developing a cooperative multi-touch interactive tabletop is not a straightforward task and the actual use in mixed—cooperative and competitive—multi-touch scenarios is under-researched.

In this paper we present cueTable—a cooperative multi-touch interactive tabletop we developed as base technology to explore new interaction concepts for cooperative multi-touch applications (cf. cueTable in Figure 1 with front side open to see the inside). We share technical information on the tabletop and a game application. And we report on and discuss user feedback to the tabletop and the application.

Related Work

Many touch-based interactive systems have been presented in the fields of HCI, UbiComp, and CSCW. Work that is technically most closely related with the cueTable is Jefferson Y. Han's multi-touch sensing based on frustrated total internal reflection [6]. Some studies such as [3] report on the usability of tabletops, and some studies such as [7, 12] also report on the interaction among users in cooperative settings surrounding tabletops. Finally, other authors have emphasized the importance of play for the design and evaluation of ubiquitous systems [2].

The cueTable

The cueTable supports small groups of up to seven users in same-time same-place settings. It allows cooperative multi-touch—that is, users can interact with the table in parallel with each other, and with a single touch of one finger and multi-touch of two or more fingers. It is low-cost and consists of hardware and mechanics, algorithms and software briefly described below (cf. [5] for more details).

The cueTable *hardware* is composed of: a self-made table with a surface of 136x112 cm (53.4x44 in) and a height of 100 cm (39.5 in) covered by tracing paper and with an acrylic glass sheet with a surface of 120x90 cm (47x35.5 in) and a thickness of 0.5 cm (0.2 in), equipped with 32 Osram SFH485 (880nm) LEDs, a Philips SPC900NC camera with a wide-angle lens and an IR filter, a Toshiba TLP-T60M projector with two mirrors, and a standard Macintosh PowerPC G4 1.8 Gigahertz or a standard PC Intel Centrino Dual 1.6 Gigahertz with a dual-core processor. The *mechanics* of the cueTable are based on the optical phenomenon of Frustrated Total Internal Reflection (FTIR) (cf. [5]). In our setup, the 32 LEDs are placed at two opposite sides of the acrylic sheet in order to cast IR light into it. Upon the touch of a finger, the light is frustrated and creates a light spot at the finger's area. The camera with the wide-angle lens captures the light spots created by the fingers on the acrylic sheet from below. The wide-angle lens allows covering a large area with the camera close to the table surface. The IR filter takes out the visible light from the captured image and only lets the IR light pass through. The projector on the backside of the table points downwards and its image is deflected by two mirrors onto the tracing paper that acts as a screen affixed under the transparent acrylic sheet.

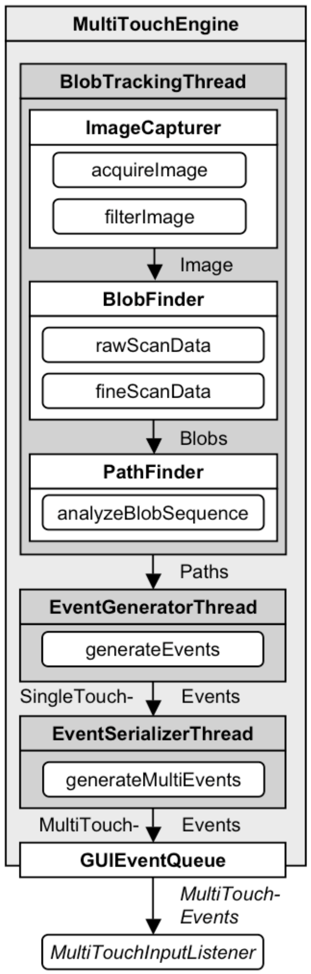

Figure 2. cueTable MultiTouchEngine.

To detect the places where touch occurs, a vision-based blob-tracking *algorithm* is used. This algorithm takes camera images, detects the IR light blobs, and generates events from these blobs. The blobs' relation is kept throughout successive frames to detect sequences of blobs (e.g., a drag gesture with a finger). The MultiTouchEngine (cf. Figure 2) consisting of three threads is responsible for blob detection and event generation. The *BlobTrackingThread* acquires camera images and filters them in the ImageCapturer. The images get analyzed by the BlobFinder, and blobs are identified and verified. The PathFinder detects paths of blobs. The *EventGeneratorThread* converts paths into single touch events (i.e., for single fingers) and aggregates these into multi touch events. The *EventSerializerThread* ensures that events originating from different frames are not confused. Finally, the multi touch events are inserted into the system's GUIEventQueue. Any Java application can use cooperative multi-touch just by implementing a MultiTouchInputListener to receive MultiTouchEvents from the MultiTouchEngine. The MultiTouchEngine was *implemented* on Java 2 SE 5.0. For image acquisition on Mac OS X 10.4.9 QuickTime 7.2, and on Windows XP SP2 the JMF 2.1.1e are used. Additionally, Macam 0.9.1 is required to use all cameras under Mac OS X. With QuickTime and JMF, most common USB and Firewire cameras can be accessed.

The cueTable has several strengths. The camera image is analyzed with a simple, yet quick algorithm, which uses a coarse and a fine raster. The MultiTouchEngine allows for quick parallel processing of the events of the images. The MultiTouchEvents generated are compatible with the existing Java concepts of AWT and Swing. They are treated like mouse events and can be used in any existing Swing application.

The cueTable Puh Game Application

To test the cueTable and to get user feedback in a cooperative and competitive multi-touch scenario we developed the Puh game application (cf. Figure 3). It is similar to Atari's Pong game, played by two teams each consisting of one or two players. Teammates stand next to each other at one short edge of the table, facing the other team. All players have personal playing zones, where they create paddles with their fingers to shoot the ball towards the other team's goal line. If the ball hits a paddle, it bounces back to the other side. If the ball hits the edge of a side of the table, the other team scores a point and a new ball comes in from the centre. The game can be played with one or two balls, at four speed factors: slow is 1, medium is 1.5, fast is 2, and fastest is 2.5. Balls cannot be touched. When a ball hits the side edge of the field, it bounces off.

The playing zones have the shape of half circles. If a team consists of only one player, the half circle spans the whole goal line; while for a team of two players, two smaller half circles next to each other are used covering the whole goal line. Difficulties can arise when the ball approaches the middle where the two playing zones of the team meet, as one's finger has to be placed carefully within one's playing zone.

A paddle is created by touching the playing zone with two fingers. Only one paddle per playing zone is created at any given time; using more than two fingers results in one paddle between the two closest fingers. Furthermore, a threshold limits the maximum size of the paddle to prevent a paddle spanning over the whole playing zone. If the fingers' distance is greater than the maximum size, the paddle is centered between the fingers.

Figure 3. cueTable, Puh game, and four users.

User Feedback to cueTable and Puh Game

Informal studies were made with about 100 users (about 25 settings of two teams with two players) at our Cooperative Media Lab Open house from 13 to 15 July 2007. Half of the users were students from diverse study programs, with an age of 19 to 27 years; and half were visitors of 27 to 50. The game was played 5 to 10 minutes. We asked the users to think-aloud while playing, and made unstructured interviews after the games. We report direct findings on: the users; the cueTable; and the Puh game.

Users. Fast-learners understood the concepts upon first explanation and were active in the game from the beginning; learners tried out the cueTable and understood the concepts after some explanation and then got active; and very few slow-learners stayed rather passive even after multiple explanations. Another learning effect concerned *latency*: the Puh game has an average latency of 70 ms to detect the multi-touch and create the paddle, so users have to react to the ball in advance. At the beginning most users touched the cueTable upon arrival of the ball and missed the ball, later they anticipated the trajectory and touched early enough. Finally, there was a wish for *increasing the ball speed* for all users: at the beginning of a game the new teams scored many goals, because players did not create the paddle fast enough, while later there were considerably less goals due to the learning effects.

cueTable. Users understood touching, but when they initially touched with a single finger, they wondered about the non-appearance of a reaction. Our interaction paradigm deliberately constrained the interaction to pure multi-touch, without single-touch. Over time users easily adapted their interaction. Several users held their hands in *exhausting positions*: although it was possible to lay the fingers flatly on the surface, users assumed they had to press hard, because they were used to it (e.g., from some ATMs and ticket vending machines in Germany).

Puh. The specific concepts of the Puh game and the *affordances of the paddle* were clear to most users. Some users did not like the restriction of only using two fingers; they tried to use more fingers in order to create multiple paddles. Users often tried to create the paddle with one or both fingers outside their personal playing zone. Some users took tangibility too literal: they tried to push the ball by moving the paddle towards it . Also, many tried to touch the ball itself.

Discussion

Besides the findings above several discoveries of social interaction with tabletops partly corroborate, partly extend, and partly contradict previous findings.

Cooperation and Communication. The observation reveals interesting insights of coordination and help in teams. Some studies of tabletop users have shown that the success of cooperation depends on a common view, multi-user direct input, mutual monitoring of others' activities, and verbal and gestural utterances [14]. Like [15] who studied a sheep game on an interactive tabletop the social interaction was dependent on group structure. The social interaction differed between when a group was active (and often had loud and clear communication) versus when the group was passive (and often had silent and more subtle conversations on gaming strategies). We found teaching situations where one player was instructing another player, and we found instances of assistance where one player was helping the other team player when the other one was in trouble. In contrast to the other study we did not find team members asking for help. Since, in our setting we had distinct playing zones for each player, tight collaboration in a common zone was not possible; in the sheep game tight collaboration was possible and found. Like in the sheep game, users reached out to assist their teammates or disturb the competitors.

The interaction paradigm of the cueTable and the Puh game reflects conceptual frameworks such as the "Framework on Physical Space and Social Interaction" [8]. This framework provides interesting concepts of embodied interaction. The concept of embodied constraints is the configuration of space and artifacts in the real world and can suggest, facilitate or restrict actions. The concept of multiple access points means multiple and concurrent user interaction with the system. And finally, the concept of tailored representations allows adaptation to individual users and their experience.

Competition, Attention and Awareness. The above-mentioned papers have cooperative scenarios in mind, where players have a common task and collaborate. The advantage of our setting is that we have both: co-operation in the teams, competition between the teams. One interesting finding is that like [14] we found gestures and speech interaction and gaze awareness among the players. However, gestures and speech interaction was primarily within the teams and subtle, since in many cases team members wanted to coordinate the team without revealing the information to the other team. Mutual awareness and gaze activities took place among all players, yet for different purposes. Some players said that they tried to have mutual eye contact and subtle mimics within the team for secret coordination, and they tried to capture the mimics of the competitors to understand the coordination of the others. Other systems and evaluations also address cooperation and competition, yet they do not address situations of hybrid settings with cooperation and competition at the same time. For instance, the SIDES system also supports four players of a tabletop computer game, but the motivation of this puzzle-like game is to stimulate the development of social skills among players with a competitive nature [10].

The attention was strongly influenced by multi-touch interaction in a social setting. The multi-touch interaction and the fact that users were looking and physically interacting with one single spot clearly reduced the cognitive load compared to GUIs where the users make input with keyboard and mouse and get the results on the screen, and consequently have to do eye-hand coordination between input and output devices [1]. This eye-hand coordination effort is drastically reduced, but at the same time mutual gaze awareness of players and focusing on the playing field requires a new type of gaze-hand coordination.

Territoriality. The analysis of territoriality on our tabletop was not the primary concern, since it was already thoroughly studied by others (e.g., [12]). The authors did a study on the organization of space on traditional tabletops while playing games. They found that in the personal territory there was most activity and it was performed independent of other users; in the group territory the players interacted together; and finally in the storage territory the players stored piles of resources. Our concept introduces clear borders between the users' personal playing zones, and the remaining space. It does not need group and storage territories.

As described above, in exceptional cases—that is, either in situations of help and assistance, or in situations of disturbance of a competitor—a player's personal zone was jointly used. So, our findings suggest a distinction of jointly used areas into team territories with cooperative joint interaction, and group territories with competitive joint interaction.

Dimensionality. The cueTable has a surface of 136x112cm, which is adequate for a four-player game. Others made similar findings. For instance, Ryall et al. [11] observed the use of smaller sizes and found that users had problems bumping into each others' arms and elbows. And, as described above successful embodied interaction requires a minimum tabletop size for multiple access points allowing multiple and concurrent user interaction with the system [8].

Summary and Conclusions

We presented cueTable, a low-cost interactive tabletop supporting cooperative multi-touch interaction. We reported on findings from a user test of the cueTable with the Puh game. We particularly aimed to contribute a discussion of discoveries of social interaction with tabletops that clearly shows that there is some convergence of finding, but that in several areas further research is needed—especially when mixed, cooperative and competitive, social interaction is involved.

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