Physics on Display: Tangible Graphics on Hexagonal Bezel-less Screens

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ABSTRACT
In this paper, we present a tiled display system made out of hexagonal cardboard screens with no visible bezel. Use of a bezel-less hexagonal form factor allows users to build larger multiform displays out of smaller tiles. Individual display tiles can be picked up to allow tangible interactions with physics simulations that are rendered onto the individual tiles. The corners of each hexagon are marked with invisible infrared retro-reflective dots. Computer vision is used to track the 3D location and orientation of these tiles. Our prototype projects back images onto each individual display. This allows for a seamless interaction experience that anticipates wireless Organic LED technology. We discuss a number of applications and interaction techniques for compound cardboard displays, which include tilting, rotating, moving and touching of tiles.

Author Keywords
Tangible User Interface, Organic User Interface, Augmented Reality, Paper Interfaces.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Human Factors.

INTRODUCTION
The advent of paper-like display technologies like E-Ink [2] is ushering in new ways to interact with computers. Over the next few years, new display technologies such as Organic LEDs will come out that are expected to be as thin and high-contrast as printed paper [14]. One possibility for these devices is to move user interaction away from a keyboard-and-mouse interaction paradigm to a more seamless method of input that involves a variety of tangible objects, with displays affixed to them.

Figure 1: Hexagonal OLED displays simulated through tracking and projecting on cardboard tiles. Here, a marking menu is displayed on surrounding tiles upon obscuring an IR marker.

In this paper, we propose one such object, a prototype hexagonally tiled display (see Fig. 1). Our design emphasizes single-tile and multi-tile interactions enhanced with computer characters and imagery that respond to real-world physics. We discuss applications and a scenario focused on use of the system in electronic board games.

RELATED WORK
Our work extends Merrill et al.'s Siftables [7], which consisted of small, rectangular, bezelled OLED screens that reponded to physical gestures. One of the problems we tried to address is that bezels and rectangular form factors make it difficult to build a seamless display that is structurally sound. This problem is also evident when using Apple iPhones to build larger displays. For our design, we drew inspiration from Rekimoto et al.'s Datatiles, which used small translucent tiles to act as display controls on the surface of a large plasma screen. We used projection rather than transparency, allowing our display tiles to stand on their own when placed on a regular table. This means any

substitution of projection by OLED thin-film screens would not substantially alter the look and feel of our design.

Datatiles also lacked the real-world physics gestures, which we borrowed from Agarawala and Balakrishnan's Bumptop [1]. In contrast to that system, our displays provide a tangible hook to interact with virtual physics rather than Bumptop's mouse-based interface. Research is also being done into augmenting traditional games with computers, touch-screens, and Radio Frequency Identification (RFID) tags, however, most of these efforts do not involve a thin screen form factor [12,15]. Waldener et al. [15] and Rekimoto et al. [11] also investigated collaborative spaces that used a camera to track objects and a projector to overlay information onto the user's activity area. Note that their implementations required either visibly marked game pieces, or a rigid display surface that simulated projection. An example application of these technologies is in the Sony PlayStation®3 game "The Eye of Judgment," where players use visibly marked playing cards tracked by a camera to execute game actions [13]. This is an example of how a static card game is augmented with an external video display to produce a unique experience. By contrast, our game pieces go one step further: the display is on the tile, removing the separation between display and input device.

Another source of inspiration lies in Tangibles [5] and Organic User Interfaces [14]: the hexagonal tiles in our electronic board game prototype can be picked up, touched, and manipulated physically, where the display *is* the interface. Schwesig et al. [12] simulated interaction techniques for credit card-size flexible displays. Surface deformations of the display, such as bending, provide natural affordances that allowed users to zoom in and out of visual material, such as a map, presented on the display. To maintain integrity when building larger displays, we chose to forego flexibility as an input method in our design. Our tracking and projection methods are similar to Holman et al.'s PaperWindows system [4]. They projected a computer display onto real pieces of paper, and used Vicon motion capture to obtain input on shape and orientation of the paper [16]. However, that system was prohibitively expensive. Instead, our electronic board game prototype only requires a low-cost Xuuk Eyebox2 camera [18].

Another area of related research is in Tabletops. Magerkurth et al. survey a range of game augmentations, among them a hybrid board/video game that has the potential to enhance natural and enjoyable recreational interaction between friends [6]. As shown by Wilson et al., tabletop environments currently lack the capability for users to interact with the simulated physics using real objects that undergo physics in and of themselves [17]. We believe such embedding of physics action in a real-world haptic form factor will be increasingly important in future systems, because it enhances the believability and kinesthetic feedback inherent in such interactions.

DESIGN RATIONALE

Our design was based on the following considerations:

1) Our first design goal was that our tiles should have no visible bezel. This is difficult to achieve with the rigid substrate display elements used in [7], but straightforward when using projection on regular cardboard. Bezel-less display allows for the potential to construct larger, contiguous areas of display out of smaller tiled components.

2) Our second goal was to build a compound display that was structurally sound while contiguous. For this reason, we explored a hexagonal rather than a rectangular form factor. Hexagons are able to withstand greater force upon manipulation and handling, reducing the amount of shifting of display elements that occurs. It also provides a greater number of adjacency positions, as well as symmetry when arranging tiles.

3) Tangibility and physicality of graphics was another key design goal. Tangibility allows a user to pick up and view tiles, thus being able to move information about physically in any orientation or direction. Physicality allows the action of lifting, tilting and tossing the display to control the virtual physics of the graphics. We hoped this would further blur the boundaries between real and virtual physics in the interface [17].

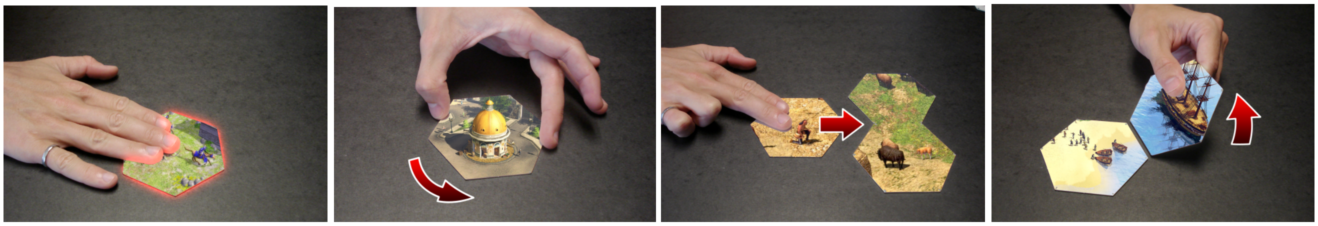
IMPLEMENTATION

Our hardware consists of four essential items: hexagonal cardboard tiles, an IR camera, a digital projector, and a computer. The camera and projector are mounted above the playing surface, while the tiles are arranged on the playing surface. Each playing piece in the prototype is a flat, stiff, cardboard hexagon. They are marked with seven IR markers, one at the center and one at each vertex (corner). There is no limit to the number of tiles that can be used, within the camera's field of view. The camera is a modified 1.3 megapixel Xuuk Eyebox2 active infrared camera [18].

Our working prototype uses a combination of established software packages and in-house algorithms to project images onto individual playing pieces. Game-play was implemented using the Glest engine [3], and we used the Nvidia PhysX real-time physics engine to implement physics [8]. Our method involves linking game software objects with simulated PhysX objects. In the physics engine, tiles were simulated as immovable blocks: Graphic objects can collide with tiles, but are not be able to move their graphics. After the game dynamics are calculated, appropriate images are projected back onto the tiles via a digital projector. Our system uses seven IR dots per tile; if a set of seven dots is not found, inference is made about confirmed past tile locations to determine if the user is touching or selecting a tile. If more than two dots are occluded on a tile, the tile is not detected.

INTERACTION TECHNIQUES

Figure 2 shows the basic gestures that provide a basis for all interaction techniques in our prototype:



a b c d

Figure 2: Illustrates physical gestures used in our Catan game: a) Touch, b) Rotate, c) Slide and d) Tilt.

Touch/Point: A user can touch a tile by placing a hand or finger on the tile. If touch is used to select a tile, a user must occlude a portion of the tile. Users can also point by positioning their finger, which is augmented with a marker, over a tile (see Fig 2a).

Rotate: A tile can be rotated about its centre. This gesture can be used to reorient the direction of an object or character on the piece, or to initiate context-specific actions (Fig 2b).

Slide: Two tiles can be placed adjacent to each other to connect them logically, or a tile's movement can be inferred as an action. This allows objects or game characters to be moved to a different area of the larger display. By virtue of a tile's shape, each tile can be adjacent to six other tiles (Fig 2c).

Tilt: Picking a tile up and tilting it so that it is at an angle to the horizontal playing surface (between about 0º and 30º to horizontal) allows dynamic content on the tile to be moved onto the adjacent tile. Pouring takes place when one of two adjacent tiles is tilted (see Fig 2d).

Menu: A marking menu can be activated by occluding the central IR marker on a tile for more than 1 second. Figure 1 shows how the individual menu items are projected onto adjacent tiles. Users can select menu actions by occluding markers in corresponding tiles. Marking menus can also be used to direct the behavior of any objects or animated characters on a tile. This is accomplished by occluding the marker that is closest to the object or character.

Throw: Certain objects or characters on a tile can also be moved through physics actions, and are simulated by the PhysX system. A rapid acceleration and deceleration of the display sends graphic objects flying through the simulated game space landing onto another tile, where they bounce and come to rest.

APPLICATIONS

Our tangible display surface has obvious applications in gaming and puzzles. We will discuss a sample electronic board game design in the next section. Beyond game control, our prototype is also well-suited for other, more generic user interface tasks. The system seems particularly suited for bringing real-world physics into Bumptop-style interaction techniques [1]. In a Bumptop implementation, each tile holds interface objects such as folders and files, or graphic elements. The larger compound display area would function as a desktop area that can be customized to fit the user's workspace constraints. Objects are moved within a tile via pointing and dragging gestures on the surface of the tile. Actions such as copy, open or paste, are executed via marking menus. Objects on tiles operate under virtual physics, and can be moved between tiles in two ways. Firstly, tiles can be picked up and placed at different locations in the desktop. This is particularly useful when the contents of the tile corresponds to that of a folder or directory. Secondly, objects on a tile can be thrown onto a different tile with a throw or tilt gesture. Applications also exist in Computer Aided Design, where the compound display typically contains a drawing. Elements of this drawing can be moved around by picking them up and placing them elsewhere. When augmented with pen input, tiles can also be used as electronic stickies in a concept-mapping tool. Ideas are scribbled onto tiles, and physically sorted by moving tiles around. Here, ideas are not limited to sketches, but may also consist of photos, sound, or video recordings of a meeting. While many of the above applications scenarios can be envisioned on tabletop displays, these lack the tangibility of the tiled display surfaces. Tangibility of the tiles seems particularly suited to group meetings as they facilitate re-orientation of views. Unlike tabletops, tiles can be physically pocketed and moved between different augmented desks, while retaining their graphical content.

A Sample Application: Electronic Game Boards

We focus our design discussion on the use of our compound tiled display as an electronic board game. Settlers of Catan is a turn-based board game, invented by Klaus Teuber, where players attempt to "settle" on the island of Catan faster than all other players. Game play consists of collecting and trading resources, and spending these resources on further resources such as settlements, roads, or specialized cards. The game involves a flexible board game design, made out of hexagonal tiles that are concatenated to make a larger board. This made the game a highly suitable sample application for experimentation with our tiled display system, and with physics-based interaction styles. Figure 1 shows a board game featuring 5 hexagonal tiles. With this design, game setup is instantaneous. Rather than having to sort through the cards, as is the case in the printed game board, cards can be laid out arbitrarily, with a computer algorithm deciding what game areas to render on each tile. Our electronic board game thus merges the tangible aspects of boardgames like the Settlers of Catan with software-generated action normally seen in strategy games such as Warcraft III.

Scenario

"John, Jack and Peter are playing the electronic version of Settlers of Catan. As soon as their hexagonal board pieces are placed onto the table the game lights up, with every tile automatically sorted. A randomly selected tile lights up to begin play. The players with property on that tile receive resources from that tile, which they can use for construction. The tile shows an animation of a lumberjack cutting a tree. John, who's next, picks up his tile and pours the wood where he wants to construct a village. Animations show buildings being constructed, and the village is populated by animated game characters. Next, Jack commands the citizens of his village to conquer the newly built village through a marking menu. Characters run out of their houses as Jack pours iron ore from a resource card onto his village. An animation shows the villagers smithing swords from the ore, and the arming of a band of men. He picks up the tile, and pours the band onto the village of Peter, which is easily overrun."

DISCUSSION AND CONCLUSIONS

In this sample gaming application we aimed to design a number of extensions to the Catan game that highlight interaction mechanisms of tiled dynamic displays. These additions were designed with the following questions in mind: What can we do with dynamic display tiles that we cannot do with tabletops? One issue with tabletop implementations of board games is that they lack the physical affordances of traditional board games. Users that tried out our board game commented that they suspended belief that this was an electronic game. The physicality seemed to ease immersion in game play, and made it easier to pick up action patterns through physical affordances of the tiles. As our game example shows, not having a bezel is critical in allowing seamless gameplay in a compound board game like Catan. The same would be true for puzzle games that rely on connections between game pieces. A bezel-less display surface is critical in this kind of strategy game, because it eases the connection between pieces and their graphical context. The hexagonal design seemed to encourage the use of physical gestures, such as lifting up and rotating elements of the game. Users commented that the correspondence between the physical action of the tile and the graphic content animation "made the game look real". For example, the pour technique in Figure 2d involves taking adjacent tiles and moving objects around. The resulting output is shown directly on the user's input (the tilting display tile), showing a resource such as water, or an army, flowing from one tile to the next. Users also reported problems that need to be addressed in future designs. These included occlusion of the projection by the user's hand, and the requirement to have an augmented projection surface, which limits use of the system in different locales. Occlusion is likely best addressed in future systems by choosing OLED technology over projection. This also resolves the second issue, with accelerometer-based input allowing better portability over computer vision.

In conclusion, we presented a system for borderless, tiled compound displays that anticipates very thin OLED display technologies of the future. The bezel-less hexagonal design of our tiles allows tangible interactions with physics simulations in a compound display space.

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