Move, Beam, and Check! Imagineering Tangible Optical Chess on An Interactive Tabletop Display

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This article presents Tangible Optical Chess, a tangible version of Optical Chess, a strategy game implemented on an interactive tabletop display. We discuss the design and implementation of both systems and report our evaluation game play sessions and our observations during the open house demonstration events at our research center.

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Additional Key Words and Phrases: Interactive tabletop interaction, strategy game, chess

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1. INTRODUCTION

Optical Chess is a strategy board game that uses the metaphor of lasers and mirrors, the basic optical reflection rule, as well as many of the concepts and terminology from the more standard game of chess. Optical Chess draws from the idea of laser-and-mirror interaction. The game was originally implemented with a conventional GUI interface. The first version of Optical Chess was on a PC. Players can point and click the game window by turn to move the pieces with a mouse. Ideally, this game should be played on a chessboard, like regular chess, with real lasers and mirrors. However, using real laser for game play presents a potential danger to the eye because laser beam can burn the retina

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of the eye. Moreover, seeing the path of an actual laser is not feasible under normal conditions; a laser beam can only been seen when it is scattered by particles (e.g., a wall, dust in the air).

As a result, some type of digital visualization of the laser beam can be used to allow safer game play and the enhancement of multimedia can improve the playfulness of a laser game. An interactive table is an ideal interface to build Optical Chess. It is a tabletop interface that can display digital information and track multiple tagged objects on top of it. Furthermore, the graspable physical objects provide tactile feedback, which is similar to holding a chess piece. Therefore, we created the Tangible Optical Chess by combining two discrete systems into one interactive tabletop game. The Tangible Tracking Table provides a medium for demonstrating the otherwise difficult-to-prototype Optical Chess; while the Optical Chess game provides an example application for presenting and demonstrating the capabilities of an interactive tabletop display.

Tangible Tracking Table [Mazalek et al. 2009] is a physical table with a projected screen that uses cameras and unique visual markers to track items placed on top of it. This implementation allows the game to be played on a table, similar to other board games, while the computing power simulates the game mechanics.

We demonstrated the game to several different groups of students, and observed their interaction with both the game and the table. We also showed Tangible Optical Chess to visitors on our research center's demo showcases. We gained more general feedback from the players and the audience on these occasions. In the following sections we will first describe the two systems (the table and the game) and then report observations about the play interactions with both.

2. RELATED WORKS

Optical Chess borrows its name and terminology from the classic game of chess. It focuses on a turn-based, strictly-strategic, gridded game played on a board.

2.1 Board Games

The idea of a board game dates back thousands of years; the earliest recorded board game is evidenced in Egyptian wall murals dated 5,500 years ago [Piccione 1980]. For millennia, board games have played an important role in our lives for entertainment, education, and relaxation. In recent years, board games combining computer technology with classic mechanics have generated more complex and dynamic games with enhanced audio and visual effects that do not exist in the classic implementations. For example, Settlers of Catan [Teuber 1995] is a traditional multiplayer strategic board game, which subsequently inspired many other computer-based strategy games such as Age of Empires [Ensemble Studios 1997], a multiplayer game published by Microsoft Game Studios in 1997 which shares many of the same game mechanics. In many ways similar to this, traditional board games have evolved from the physical world towards the digital world.

Khet [Innovention Toys 2007] is a commercially produced Egyptian-themed board game. The game uses lasers and mirrors in its design, and similarly revolves around the idea of "capturing" one's opponent's "King" by striking it with one's own laser. It has a much more complicated rule-set featuring multiple types of pieces, multiple movement rules, and multiple mechanics regarding pieces "capturing" one another.

2.2 Laser Games

Beyond chess, however, Optical Chess possesses surface-level similarities to a few other laser-and-mirror-based games conceived in recent years. For example, Mike Duppong's Laser Chess [Wilk 2007], was a computer board game that invoked the concepts of lasers and mirrors, as well as a piece system identical to chess. In Laser Chess, each piece has a different function. Players take two actions with their pieces by turns. An action can be moving a piece for one square, firing the laser or rotating a piece 90 degrees.

Another Laser Chess game by [de Sande et al. 2001] focused more on a method for creating the game physically than the game mechanics, creating the game on a 4-foot-tall table with real lasers and mirrors. Instead of having specific game rules, de Sande encouraged players to create their own rules. Since a laser beam is hard to see when it propagates in the air. de Sande et al. added dry ice, that is, a solid form of carbon dioxide as small particles for the laser beam to scatter. However, the smoke from dry ice decayed the laser, so the laser beam became invisible again after it passed through some thick smoke. Nonetheless, de Sande et al thought that this could be part of the game rules.

[Laser Prisms 2010] is an online single-user optical game whose goal is to line up all optical instruments so that the laser beam can hit the mark of the same color. The game starts with a red laser, a rotatable mirror, and a red mark. The solutions for lower levels are quite obvious: using mirrors to bounce the laser to the mark. At higher levels, there is more than one laser; there are prisms that can split light, color filters that allow only a certain wavelength of light to pass through, as well as other optical instruments such as color filters, prisms, and two-way mirrors.

2.3 Interactive Tabletops

[Scott et al. 2000] pointed out several major benefits of using tabletop interfaces for collaborative activities. Hence board games built on interactive tabletops should overcome the drawbacks of the GUI version. In addition, many pervasive games and applications use tangible pieces, rather than GUI, as the tangible feedback to support interaction and for the more natural interactions they provide [Bohn 2004; Fitzmaurice et al. 1995; Jung et al. 2005; Magerkurth et al. 2004]. Tangible Optical Chess is implemented on an interactive tabletop display, the Tangible Tracking Table (TTT). Many interactive tabletop systems have been developed [Jordà et al. 2007; Microsoft Surface 2010]. Most of them share common characteristics: they can track multiple objects and multiple finger touches and simultaneously project interactive information on the tabletop. The APIs provided by TTT allowed rapid prototyping of tabletop applications.

Besides, moving tangible pieces on a tabletop provides an experience closer to moving chess pieces on a chessboard. We use these capabilities to deploy multiple chess pieces and get visual feedback on this tangible platform.

Another interactive tabletop worth mentioning is the Tangible Viewpoints (TView) and Tangible Spatial Narratives, which make use of tagged pawns to navigate stories on a tabletop display [Mazalek and Davenport 2003; Mazalek et al. 2002]. The idea of this type of tabletop display is to use active tangible objects to communicate with the table and locate the positions of the objects on the tabletop. However, the tangible objects require complicated electronic fabrication, which is not suitable for fast prototyping.

The recent proliferation of interactive tabletops has led to an explosion of possible applications. Many individual systems have been developed for experimentation, including entire frameworks dedicated to implementing board games on interactive tabletops (such as the STARS system [Magerkuth et al. 2003]) and facilitating other tabletop software (such as the reacTIVision system [Kaltenbrunner and Bencina 2007]). One especially relevant project is the Illuminating Light project [Underkoffler and Ishii 1999], in which users move around various optical elements on a workspace to create different laser paths. This interface serves as an interface for optics education. This lets users learn and use optical concepts in a simulated environment, allowing them to see laser paths without the need for actual lasers. Unlike Mazalek's interactive tabletop display, these tabletops use passive computer vision patterns, the fiducial markers, to tag physical objects. One benefit of using fiducial markers is that they are low cost and easy to create. However, the pattern recognition of the markers is easily affected by the lighting condition of the environment.

3. OPTICAL CHESS

The initial design of Optical Chess resulted from careful analysis of existing games. The four goals for the Optical Chess are: (1) to be easy to learn; (2) to be very difficult to master; (3) to be strictly strategic (no randomness, and thus no dice or cards); and (4) to lend itself to complex strategies that emerge from a simple rule set. This analysis led to the fundamental building blocks of the game: namely, that the game will feature lasers, mirrors, and a "king" that will serve as the target for the opponent.

3.1 Game Rules

Game rules affect the playfulness of a game tremendously. A minor change of one rule can change players' strategies. In Duppong's Laser Chess, each player is allowed to take two actions in one turn. Due to the simplicity of chess pieces in Optical Chess, the game allows only one action per turn; but the rules are changeable.

The game is played on a square grid made up of some tiles by two players (green and red). Each player has three types of pieces that can be placed upon the board: one "king" (the target for one's opponent); one laser (the mechanism for attacking one's opponent's king); and several mirrors (used for reflecting the lasers around the board). The game begins with each player (green first) placing their king on any space on the board, except spaces bordering the edge. After each player places their king, the players take turns. On a player's turn, they may do one of four things:

—place, move or remove their laser;

—place a mirror at 45-degree angles to the grid on any unoccupied game space;

—rotate one of one's own mirrors 90 degrees; and

—remove one of one's own mirrors from the grid.

The objective of the game is to hit the opponent's king with one's own laser, using at least one mirror. Similar to chess, one must announce "check" before placing a winning move.

3.2 GUI Version

Initially, the game was prototyped with a GUI (graphical user interface). Figure 1 shows the graphical user interface for Optical Chess. The circles represent Kings, the slashes (\ and /) represent Mirrors in different orientations and the triangles are symbols for the lasers. Players have to share a mouse to point and click on the icons by turn. One can place a mirror in " \"or "/ " orientation, place the king, place and fire the laser, rotate one mirror or remove one mirror by selecting the six icons from the toolbar. The laser beam travels in a straight line and changes its direction 90 degrees when deflected by a mirror.

3.3 Tabletop Version

As soon as the game's viability was confirmed on the GUI version, a full implementation was designed using the Tangible Tracking Table (TTT).

3.3.1 *The Tangible Tracking Table.* The TTT is an interactive table, runs on a modified version of the reacTIVision system [Kaltenbrunner and Bencina 2007], which offers a library of unique visual fiducial markers that can be attached to the base of tangible objects, such as chess pieces – or, in our case, the tokens of lasers and mirrors. The table uses Diffused Illumination (DI) against a translucent surface to enable a camera to read the fiducial markers and recognize their identity (each game piece has a unique marker), position, and angle of rotation. To create a 60-inch projection screen in a 39-inch-tall table, two parallel mirrors are used. Placed correctly, these mirrors create a 72-inch optical path, which results in a 60-inch projection area. In front of the camera is an infrared filter that allows reflected light from the infrared lamps to come through while eliminating light from other sources. Another filter is placed in front of the projector lens to keep only visible light and remove infrared light. The display dimension of the table is approximately three feet by four feet.

The reacTIVision provides a library of unique visual fiducial markers that can be attached to the base of objects. The fiducial library is limited to 180 markers, which is more than sufficient for Optical Chess. The pieces used on the TTT may be as small as a 2-inch diameter circle. TTT can also detect fingertip gestures; but we did not use finger touches in Optical Chess. In addition to

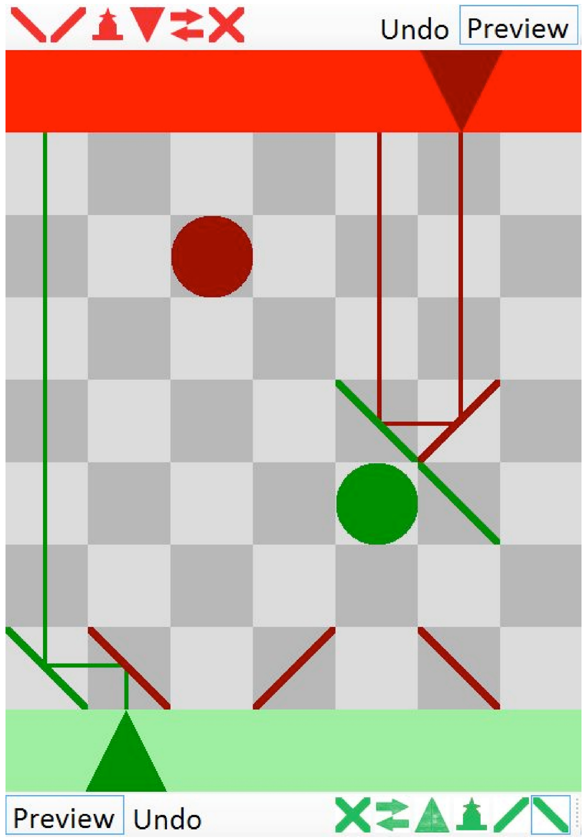

Fig. 1. The GUI version of Optical Chess.

computer vision- based detection, TTT has wireless capability, and some TTT's applications use active objects, which can talk to the table wirelessly.

3.3.2 *The Tangible Optical Chess.* The chessboard is designed in 7 by 7 squares, whose sides are about 4.5 inches. Each chess piece is about 4 inches wide. There are three types of pieces, one king, one laser, and several mirrors, and each affects the simulation differently. According to Bakker et al. [2007], these iconic physical pieces are fundamental to a tangible tabletop game, to which they bring more fun. We model our game pieces after real-life optical components in a laboratory. Hence the laser piece has a black laser tube sitting on top of a black box (see Figure 2 and the mirror has a black round base with a colorful frame to identify its campaign.

The laser object has a simple mechanical arm and an electric circuit inside. On top of the black box, right under the tail of the black laser tube, there is a switch. When one switches on the laser, the LED inside the tube turns on and the arm inside the box lowers the base with a fiducial marker to the tabletop. When it is switched off, the arm lifts the base, and the fiducial marker leaves

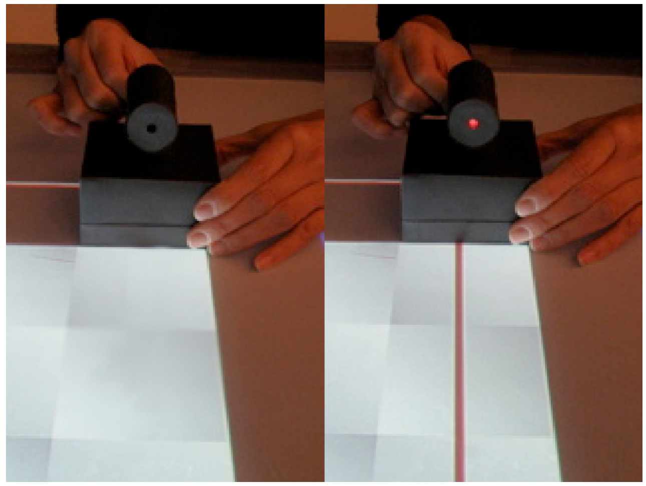

Fig. 2. The user turns on the laser (right). The table detects the fiducial and shows the laser path. The laser is turned off (left).

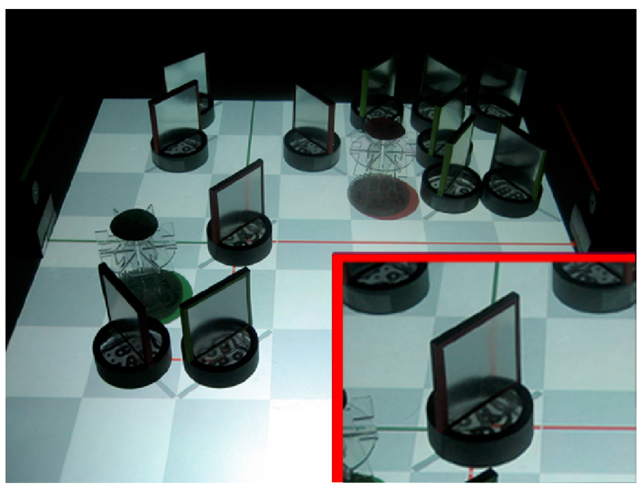

Fig. 3. The end of one game and a close look at a mirror.

the tabletop. Therefore, one can turn the laser on and off and see the reactions of the LED and the beam on the tabletop simultaneously.

The "mirror" of the physical mirror object is made of silver reflective paper; all the physical objects are made of acrylic sheets and colored paper. The fiducial markers can be seen clearly, since the base of a chess piece is made of a transparent acrylic sheet. A closer look at the red mirror shows the laser beam reflected on the tabletop. Still, the silver reflective paper on the mirror surface images the laser beams (see Figure 3).

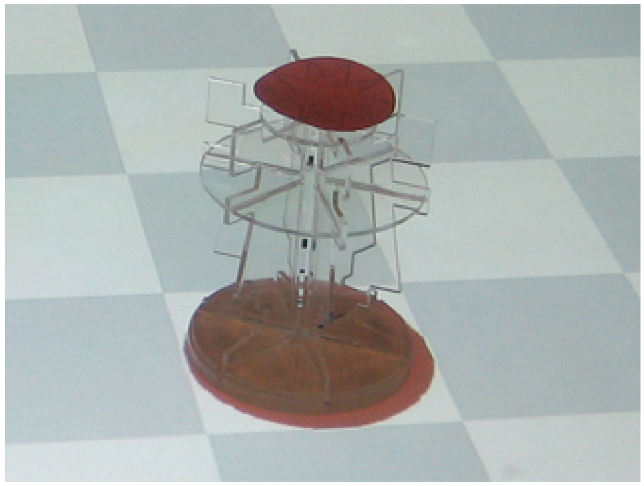

Fig. 4. The red king, the target of the opponent (green).

We designed the kings (see Figure 4) using the combination of a king's crown and castle battlements. Once placed, the player cannot move it. Laser beams stop propagating when they hit any side's king.

3.4 Game Software

The game software was written in C# and runs in full-screen mode atop TTT. The game is based on a simple grid. Every piece takes up exactly one spot on the grid, and only one piece can occupy a spot at a time. As such, the table detects the locations of all the pieces and rounds their locations to the nearest grid spot, aligning the pieces properly to the grid. The rotation of the pieces is significant as well, for rotating a mirror changes the path of a laser beam. However, the game rules stipulate that pieces must be placed at one of only two rotation angles (diagonal in the cell, e.g., 45 degrees slants to the left or right, / or \), and as such the game software rounds the rotation angles of the pieces to the nearest of these two angles. The game software, in conjunction with the reacTIVision system, differentiates pieces based on the identity of their fiducial markers. reacTIVision uses the TUIO protocol, based on Open Sound Control (OSC), allowing for easy communication with application-level software.

4. EVALUATION

Many people have played with the Tangible Optical Chess on the Tangible Tracking Table during open house demonstration events. During these sessions, players were given a printed set of rules for the game. Researchers then briefly explained the workings of the TTT and answered questions or clarified the rules. Three groups participated in demonstration game play: a group of HCI professionals, a group of college students, and a group of high school students. The professional and college groups were made up of a couple dozen players, and played the game in an informal live demonstration; the high school students played the game as part of an impromptu demo after hearing the game described in conversation.

4.1 GUI Evaluations

The nontangible version was utilized in one particular demonstration, and several challenges were observed. Several players had trouble predicting the path of the laser, and wanted to test their moves by pressing the preview button. Players also had difficulty understanding that the "laser" piece was placed at the baseline rather than on a board tile, despite specific instructions. The players generally considered these challenges to be shortcomings of the software rather than their own misunderstandings. Interestingly, one student—unaware of the tangible version of the game—said that, *"This would be a lot easier with real lasers and mirrors"*.

We had few observations on strategy in the GUI interface; even after particular players played multiple games with the presenter, they still acknowledged their own lack of a specific strategy, likely due to limited experience. Players commented on playing turn-to-turn without a long-term multiple-move plan in mind. However, we also frequently observed them making wise defensive moves, such as blocking against two possible attack angles when the more obvious move would be to block only one. While players claimed to be unable to devise strategies of their own, they were able to identify the strategies of the presenter, frequently making exclaimations like, *"Oh, I see what you're doing!"* It appears that while players were unable to synthesize their own moves into a longer strategy, they were still able to recognize the strategies of others. This suggests that the players had some strategic ideas, but simply had not yet developed them enough to apply them in their own moves. This is an interesting discovery, since the revaluation on tabletop version has different results.

4.2 Tangible Evaluations

Regarding the table, players had no apparent troubles interacting with the table. Players seemed to recognize the grids and the tangible pieces with ease. One player commented that the interface looks just like a giant chessboard. Many players upon seeing the table immediately started to move and rotate the game pieces on the tabletop to see what would happen. People seemed to be able to "pick up and play" – they had no trouble associating how the movements of the game pieces on the board affected the changes on the tabletop viewing screen. This was quite different than the nonetangible version. This is very encouraging.

Part of this success is derived from the design of the physical pieces using acrylic that provides translucency underneath the pieces (see Figure 3), allowing players to see the simulated laser beam itself. Because the beam is projected onto the board, players could accurately identify the beam location and decide how certain pieces should be placed.

The most notable part of the players' interaction with Tangible Optical Chess is how they needed almost no instruction for using it. After a brief statement that the table would identify the positions of the game pieces, students were

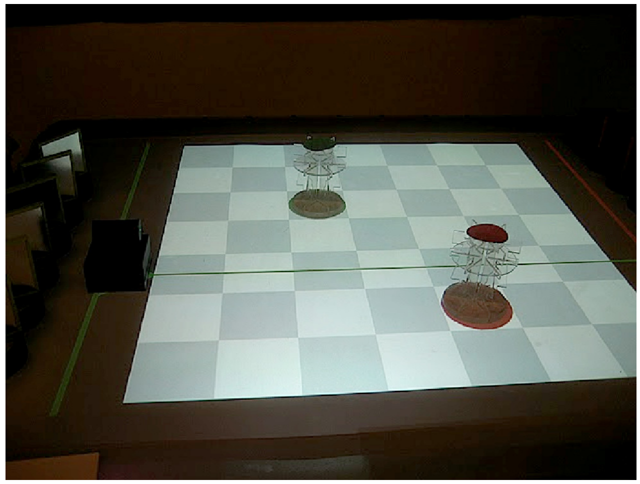

Fig. 5. The beginning of one game. The two kings are placed on the tabletop.

able to start playing immediately: they did not need any further explanation. The fact that the player interaction with the tabletop was executed smoothly shows that this interaction seems intuitive. Players did not ask questions about how to handle the game pieces on the tabletop display; they only asked questions about the inner workings of the table, showing their interests in the system.

The most interesting finding, however, came from the observations about how interaction with the table differed from interaction with the GUI interface used in initial play-testing. Several problems were observed during the play sessions with the GUI interface. Many players were unsure in which direction to place a mirror to achieve the result they wanted, and often thought that laser pieces actually took up board space, like mirrors and kings, rather than sitting on the edge. Interestingly, neither issue arose during the play sessions with the Tangible Optical Chess on the Tangible Tracking Table, suggesting that players benefited from being able to see and manipulate the three-dimensional, tangible tabletop pieces to place them in the intended positions with ease. Figures 5 to 7 show the beginning, the middle, and the end of a game. The green player started the game by placing his king on the table. The green player placed the laser on his second move and called "check" (see Figure 5). The Red player placed a red mirror to deflect the green laser beam away. After that, both sides placed two more mirrors (see Figure 6). The final view of the game is shown in Figure 7. The red laser beam passed two red mirrors and three green mirrors and hit green side's king.

People interact with this tabletop game differently than with regular board games. In contrast to Western chess games where players always sit at the two opposite sides of the chessboard, players of Tangible Optical Chess often walk around the table to place the tangible pieces. It is interesting that some players feel they can predict the path of the laser beam better if they look along the imagined laser beam and turn when that beam hits a mirror. In a regular

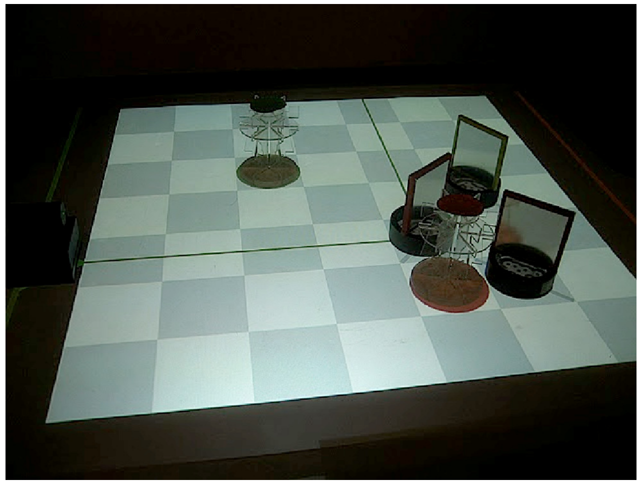

Fig. 6. The same game as in Figure 5. More Optical Chess pieces are placed on the tabletop.

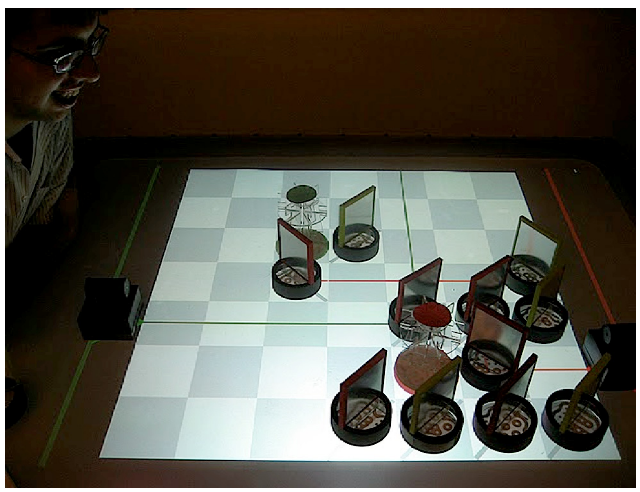

Fig. 7. The green side lost; but apparently the green player enjoyed playing the game.

chess game, players are not allowed to reverse a move. In our study of Tangible Optical Chess, at least three players asked their opponents *“May I test the position of my next move?”* and their opponents granted the requests. They then explored and tried placing the piece at different locations on the chessboard to see the result before making the real move. In the tryouts, many players tried to put their hands in the path of the laser beams to block them. After they failed to block the digital laser beams, they all laughed loudly. Apparently, the digital laser beams confused some of them. But some thought because Optical Chess could provide this type of hand interaction, it made it very interesting.

There was no end to the game notifications in the system. After one player announced a checkmate, both sides had to examine the pieces carefully to confirm that. One player suggested, *"You should create some special effects when the laser beam hits the king!"* (Yes, this feature could be implemented. However, we found it interesting that because there is no notification from the system, both players would actually spend time verifying the results and carry out conversations. This also seems to increase the playfulness of the game and a player's enjoyment of the other player.)

Overall, player interactions with the Tangible Tracking Table were observed to be as simple and intuitive as interacting with a standard board game; TTT allows the digital media to successfully provide some additional features (such as a visible laser beam, which are mostly unfeasible in an actual laser-and-mirrors implementation) without introducing any major drawbacks, for example, the misalignment of lasers can endanger the users' vision.

4.3 Game Observations

During the demonstrations, players were able to learn the rules quickly. In most cases, the players only read the rules once before the game play. While game rules seemed clear and straightforward to most players, some found problems and asked for clarification during the play sessions. For example, several players did not realize that the mirrors could only be used to deflect the laser beam at 90 degree angles. A couple of players did not realize that a laser beam stops when it hits a player's own king, and wanted to direct the laser beam through their own king in order to attack the opponent's king. Aside from these challenges with the game's geometrical optics (predicting a laser beam's path), all of which were easily resolved, a few players had issues with the concept of "check". Typically, for these players, verbal explanations of "check" were futile, but a simple demonstration with game pieces always cleared up all the questions.

Due to time constraints, most visitors played Optical Chess for only a few minutes. A lot of them stayed at the table after their games and watched others play. They discussed with others the strategy for beating the opponents. In fact, a lot of visitors learned the rules by making mistakes or incorrect assumptions. The most common one was "*I don't know if I can deflect his laser beam with my own mirrors!*" Several players asked similar questions such as "*May I have a preview?*" or "*If I keep holding my mirror, that doesn't count as a move, right?*" However, players with more experience, such as the students from a game class who had more opportunities to play Optical Chess talked more about their game strategies. One graduate student shared his strategy: "*When I see a chance to attack the king from the left, I place my mirrors on the right first. The final strike will be from the left, but my opponent has already been distracted".*

The physical mirrors and lasers really helped players to merge with the game. The silver paper on a mirror reflects some of the image close to the mirror. Many players became confused after they played for a while: they thought the mirrors did reflect the laser beams. (In future work, we could discuss learning and coming up with a strategy and a winning move in short sessions, and continuous game play could be observed and analyzed to see how a player's strategy has changed over time.)

5. DISCUSSION

We noticed on several occasions that players tended to learn the rules of the game much faster when using the tangible version of the game. The result shows that the Tangible Optical Chess facilitates faster learning because players are able to experiment more naturally with tangible game pieces. GUI players did not develop multiple-move strategies, but tangible players did > We observed that players at TTT spent a much longer time planning their next moves. GUI players tended to only look at the current board, while tangible players would plan subsequent, later moves. We verified this in our demo showcases by asking players what they were thinking while they paused during the game. The tangible players also tested their moves often, especially when they first approached the table. (Furthermore, the tangible pieces were attractive to people).

The Tangible Tracking Table was a very engaging platform for implementing the Optical Chess game. Players engaging in the game associated the strategy in Optical Chess with other games. Even though the TTT appears to be an ideal platform for this game, we did not fully exploit its capability. The study results between the GUI and tangible versions also showed us that tangibility is a factor that improves playability in Optical Chess.

6. FUTURE WORK

The Tangible Optical Chess project was motivated by two different factors. One researcher wanted to design a board game that was similar to chess, easy to learn but hard to master. The other researcher's goal was to create a game that facilitates students to learn Optics with the help of digital media. Play-testing Tangible Optical Chess shows that players found it easy to play the game, and they exhibited learning behaviors in the game play. However, the second goal was not fully accomplished, as the game uses only two basic optical metaphors, lasers and mirrors. A player can only rotate a mirror 90 degrees, which does not help much on understanding optics. One of the future challenges is to include more optical components such as prisms, color filters, or beam splitters and maintain the playfulness of Optical Chess.

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