Evaluating the Advantages of Physical and Digital Elements in Hybrid Tabletop Games

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I. Abstract

Digital games have constantly become more popular over the last decade, while board games are still relevant with local communities and conventions dedicated to them. With the advent of multitouch devices for the mass market, the genre of digital board games has become more and more viable. Less prevalent however are hybrid games that combine physical and digital elements, despite the potential they offer: By combining the advantages of both, unique games can be created that could not exist otherwise.

This thesis attempts to find the advantages that physical and digital elements provide. Based on these findings, game concepts and prototypes are created. Finally, comparative user tests between hybrid versions and purely digital touch-only versions are conducted to see how the addition of physicality changes the games.

Keywords: Hybrid Game, Tabletop Game, Tangible User Interface, Multitouch Table

Kurzfassung

Digitale Spiele existieren nun seit weit über einem Jahrzehnt und werden zunehmend beliebter. Brettspiele bleiben ebenfalls relevant, mit lokalen Communities und größeren Messen, die ihnen gewidmet sind. Seit Multitouch-Geräte gebräuchlich geworden sind, sieht man auch immer mehr digitale Gesellschaftsspiele. Weniger gebräuchlich jedoch sind Hybrid-Spiele, die physische und digitale Aspekte miteinander kombinieren, obwohl diese doch neue Möglichkeiten eröffnen: Die Erstellung von einzigartigen Spielen, die die Vorteile beider Welten kombinieren und sonst nicht existieren könnten.

Diese Arbeit versucht die Vorteile zu finden, die physische und digitale Elemente bieten. Auf der Basis dieser Erkenntnisse werden dann Spielkonzepte und Prototypen erstellt. Schließlich werden Benutzertests durchgeführt, die diese Hybrid-Prototypen mit rein digitalen touchbasierten Versionen vergleichen, um herauszufinden, wie die physischen Komponenten die Spiele verändern.

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1 Introduction

1.1 Motivation

Digital games have constantly become more popular over the last decade, while board games are still relevant with local communities and conventions dedicated to them. With the advent of multitouch devices for the mass market, the genre of digital board games has become more and more viable. Less prevalent however are hybrid games that combine physical and digital elements, despite the potential they offer: By combining the advantages of both, unique games can be created that could not exist otherwise.

While there has been literature written about hybrid tabletop games, not many authors focus on the unique aspects the physical and digital elements can bring to a hybrid game beyond the purely tactile aspect. While many comparisons between WIMP[1] interfaces and TUIs[2] have been made, most authors compare the usage of mouse and keyboard against tangible elements on a surface. A more direct comparison might be of interest: Between a TUI and a multitouch interface, to find out if the tangible aspects add to the game experience.

This is the goal of this thesis: Find the advantages that physical and digital elements can bring to hybrid tabletop games and compare the results against touch-only versions.

1.2 Goals

This thesis has two goals.

The first goal is to research what kind of advantages the physical and digital worlds have concerning games. Afterwards, tabletop game prototypes are created that reflect those results. For those prototypes, it is important that the physical aspect is not just added for the sake of tangibility but by deliberately choosing interactions that have advantages in the physical world (for example: using the sense of touch to quickly and intuitively manipulate objects without directly looking at them, real-world physical interactions between pieces or using other properties of physical artifacts – e.g. objects can look different depending on the viewing angle). Likewise, the digital aspect is not just used for the sake of technology, but to add gameplay elements that are only possible by using technology. To summarize, the tabletop game prototypes should make use of the physical and digital advantages to create gameplay that is improved by the combination.

The second goal is determining whether the physical aspect truly improves the gameplay as much as expected. Because the thesis focuses on creating tabletop games using fiducial marker

[1] "window, icon, menu, pointing device"
[2] Tangible User Interface, an interface that uses physical means to interact with the digital world.

recognition (see "Fiducial Markers", page 21), only movement in 2 dimensions (unlike a game where one could stack physical pieces) can be recognized – and as such, all resulting games can also be converted to touch versions with appropriate design changes. Afterwards, the digital-physical hybrid game prototypes will be tested in test sessions against the purely digital touch versions to find out how the physical aspect changes the game.

1.3 Structure

First a few underlying terms used in the thesis will be defined in chapter 2. Afterwards, chapter 3 lists related work.

After this preparatory part, the theoretic part follows. First, the field of Tangible User Interfaces that concerns itself with the creation of hybrid applications in general is described in chapter 4 with example uses and devices. This is then followed by a description of the board game genre, the advantages of physical/digital games from a game design and production viewpoint, examples of existing hybrid games and a section about pervasive games in chapter 5.

The practical part begins with descriptions of the game concepts in chapter 6 and the rationale behind their design. Afterwards, chapter 7 describes the tools and libraries used and details from the implementation that are believed to be generally useful for marker-based tabletop games. The practical part ends with chapter 8 on the user testing of the finished prototypes and its results and chapter 9 presenting the conclusions drawn from these results.

2 Definitions

Before it is possible to talk about the properties of games and compare different types, certain terms have to be defined.

2.1 Physical/Digital/Hybrid

"Physical" in the context of this thesis means something tangible without electronics. In this thesis, it will usually be used in the sense of a "physical game", meaning a game that does not make use of electronics to be played, or as a "physical element", i.e. an element that can be physically touched (contrary to an element shown on a computer screen).

"Digital", on the other hand, is used to denote the aid of a computer or another electronic device.

"Hybrid"[3] in the context of this thesis is used to talk about a combination of physical and digital components. A "hybrid game" is a game that combines physical and electronic components, for example a game that takes place on a completely non-electronic board, but uses a smartphone to

[3] "Something of mixed origin or composition […]" (Houghton Mifflin Company, "The American Heritage Dictionary.")

display additional gameplay-relevant information or a game where one moves physical playing pieces on a screen which can recognize objects and which uses the piece movement and positions as input.

The objective of this thesis will be to examine the aspects of physical and digital games to facilitate the creation of such hybrid games in a meaningful way, i.e. the physical and digital aspects complement each other and neither can be removed without changing how the game is played.

2.2 Tabletop Game

The fourth edition of American Heritage Dictionary defines the adjective "tabletop" as "made or designed for use on the top of a table […]"[4]. "Tabletop game" thus refers in this thesis to any game played on a table (or a similarly flat surface), whether purely physical with touchable pieces, involving technology or a combination of both.

2.3 Board Game

The term "board game" holds different definitions. The strict definition usually involves the board as a core component, for example the Random House Webster's College Dictionary defines "board game" as "any game played on a board"[5]. This, for example, excludes games that do not include a board and are played solely with dice or cards.

In this thesis, the word is used in its non-strict common parlance version as for example used by BoardGameGeek[6] (a popular board game website that also contains games that use no board at all), /r/boardgames on Reddit[7] (same) or Amazons "Board Game" section[8]: "Board game" includes all kinds of physical (and some digital: see "Digital Board Game") non-role-playing[9] tabletop games independently of used components and other indoor games that can be played without components or table, for example party games like Charades[10].

2.4 Digital Board Game

Traditionally, board games were defined by their usage of physical pieces, but also by certain gameplay-related attributes. This gave rise to a digital game genre generally referred to as "digital board games". In an article on the topic, Soren Johnson remarks:

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[4] Ibid.
[5] Random House, *Random House Webster's College Dictionary*.
[6] BoardGameGeek, "BoardGameGeek | Gaming Unplugged Since 2000."
[7] Reddit, "/r/boardgames."
[8] Amazon, "Amazon.com: Board Games: Toys & Games."
[9] "A game in which players assume the roles of characters and act out fantastical adventures, […]" (Houghton Mifflin Company, "The American Heritage Dictionary.")
[10] BoardGameGeek, "Charades."

> The two formats are intermixing such that the artificial line separating the two is blurring, with many digital games now built to resemble board games.
>
> Consider the recent mobile games Cabals or Hero Academy; both contain the trappings of board games – including turn-based play, a shuffled deck of game pieces, a visible board divided into tiles, and transparent rules with no hidden modifiers – even though these games only exist in digital form.[11]

A detailed look at the common attributes of physical games and digital games will be taken in the chapter "Physical/Digital/Hybrid Games" (page 32).

While this thesis is about creating hybrid tabletop games and not specifically games that fall into the board game genre, looking at this genre and its physical games can provide insight into what game mechanics and properties physical games enable.

3 Related Work

In this section, related work will be referenced. Two kinds of literature are considered relevant: Literature concerning hybrid gaming experiences and literature that compares physical-digital hybrid experiences to either touch-based or purely physical versions.

3.1 Hybrid Games

An early game that combines physical and digital elements is PingPongPlus by Wisneski, Orbanes and Ishii. A video projector is put over a ping pong table and tracks where the ball hits the table through sound. Various augmentations are used. Some augmentations are just visualizations with sound and despite not changing the gameplay of ping pong, the paper reports some of these visualizations changed the way people play the game. Other augmentations suggest the use of the table as a means to create visual artworks or sound. One mode in particular experiments with changing the gameplay by using the projector as a light source in a dark room, with spots that are hit blacked out, adding another strategic layer on top of the game.[12]

Pirates! is an early proximity/location-based game by Björk et al. using handheld computers in a previously prepared room. Every player represents a pirate ship, with several locations in the room being islands that can be travelled to by directly walking there. Player vs. player combat is also possible if the players are near each other. The paper concludes that players enjoyed the

[11] Johnson, "When Digital Versions of Board Games Surpass the Originals."
[12] Wisneski, Orbanes, and Ishii, "PingPongPlus"; Ishii et al., "PingPongPlus."

game and that it has shown "how location-aware technology can enhance multi-player games that are carried out in the physical world ".[13]

"False Prophets" by Mandryk, Maranan and Inkpen is an early example of a hybrid tabletop game. The game has a projected map upon which each player moves a character that the board can sense. Apart from the publicly projected information, each player also has a handheld computer for private information. A focus is set on player-player interaction: The use of the handheld computer is limited to what cannot be expressed via the movement of game pieces. Additionally, private communication and trading of information is not mediated by the game system.[14]

STARS is a platform for augmented tabletop games. In their initial paper, Magerkurth, Stenzl and Prante describe it this way: "STARS dynamically couples multiple types of interaction devices such as personal digital assistants (PDAs) or headsets with an interactive game table. STARS augmented tabletop games provide a number of features like dynamic game boards or private communication channels that go beyond traditional tabletop games, but at the same time preserve the human centered interaction dynamics which makes playing board games a joyful group experience."[15] They also list advantages for the game design like persistency, complex game rules, and dynamic information visualization, and mention that using their system can help developers concentrate on creating the game itself instead of the infrastructure around it.[16] The system itself lists several possible input modes (table pawns, speech, table gestures, table WIMP and a PDA) and several output modes (table display, wall display, PDA display, loudspeaker audio and earphone audio) and details their capabilities and qualities.[17] Another paper elaborates on the implications of extending the virtual domain into the physical world and touches on game design and physical interfaces before it lists implemented games on the STARS framework.[18]

In their paper "Pervasive games: bringing computer entertainment back to the real world", Magerkurth et al. list existing hybrid genres and games as of 2005 with extensive comments and examples.[19]

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[13] Björk et al., "Pirates!–using the Physical World as a Game Board."
[14] Mandryk, Maranan, and Inkpen, "False Prophets."
[15] Magerkurth, Stenzel, and Prante, "Stars-a Ubiquitous Computing Platform for Computer Augmented Tabletop Games."
[16] Ibid.
[17] Magerkurth et al., "A Multimodal Interaction Framework for Pervasive Game Applications."
[18] Magerkurth, Engelke, and Memisoglu, "Augmenting the Virtual Domain with Physical and Social Elements."
[19] Magerkurth et al., "Pervasive Games."

TARBoard by Lee and Woo is a tabletop game environment that uses a camera under a glass table combined with a mirror to see markers under cards laid on the table. A separate camera is used to control the augmentation of the game. They argue that the usage of a camera under the table solves occlusion problems.[20]

Another system made for tabletop usage (albeit not explicitly for games) is TViews by Mazalek, Reynolds and Davenport. TViews has a display instead of a projector, and does not use any cameras but a combination of acoustic and infrared communication to locate physical pucks on the table.[21]

Bakker et al. conducted a study comparing the use of iconic (visually representing what they stand for) and symbolic (abstract) pieces in tabletop games and how either relate to fun and understanding. The study comes to the conclusion that neither type is more suitable for understanding or fun, but the icon pieces are preferred "presumably because they fit with the theme of the game and their appearances are recognizable". Meanwhile, symbolic pieces have the advantage of being reusable.[22]

"Dynamic Rules: Towards interactive games intelligence" by Frapolli, Hirsbrunner and Lalanne compares physical, digital and hybrid games to find out which advantages they bring and lists existing tabletop systems that support each to show the state of the art as of 2007. Afterwards, the authors suggest possible research agendas.[23]

Al Mahmud et al. created a digital tabletop game especially for senior citizens and compared it in play sessions with a conventional board game experience of the same game to assess the effects on such aspects as immersion, flow, affect and challenge. The digital experience "was generally rated to be as more immersive and engaging by the participants".[24]

In "Surface-poker", Dang and André take a so far unusual way to add a hybrid experience: They add EEG sensors to a digital tabletop poker game to find out if displaying the nervousness of the other player would affect the gameplay. Players reported that their strategy was not influenced by the sensors, but the authors speculate that this might be due to the players' short experiences.[25]

[20] Lee, Woo, and Lee, "Tarboard."
[21] Mazalek, Reynolds, and Davenport, "TViews."
[22] Bakker et al., "Tangible Interaction in Tabletop Games."
[23] Frapolli, Hirsbrunner, and Lalanne, "Dynamic Rules."
[24] Al Mahmud et al., "Designing and Evaluating the Tabletop Game Experience for Senior Citizens."
[25] Dang and André, "Surface-Poker."

3.2 Comparisons between Input Modes

Jacob et al. created the Senseboard, a TUI used to organize information in a grid. They then developed an application to group conference papers, a task previously done manually without any electronic help by printing out papers: "Despite having excellent computer support at this meeting (held in a computer-enhanced meeting room at Microsoft Research), having all the relevant data already in electronic form, and needing to produce our final results in electronic form, the committee found it more effective to use manual/tangible interaction to perform this task this year, as in previous years."[26] They then proceeded to compare different versions of it: One purely physical with paper, one with a Pen-GUI on a digital whiteboard that closely matches the Senseboard configuration, the Senseboard-TUI with physical pucks and projections on top of it and a reduced version of the Senseboard with projections, but less computational enhancements. They found a weak preference for the Senseboard-TUI and a dislike for the purely physical paper version.[27]

To study the benefits of tangibility, Terrenghi et al. built a hybrid tabletop system called "PhotoLens" used for browsing and organizing photos using different physical tools. They compare the usage of this hybrid version to a purely touch-based version, list how users behaved and measured the perceived user experience via questionnaires. In the different "ease of" categories, the hybrid version measures better in varying degrees, but regarding fun, the touch-based version measures slightly better. Some users described that they experienced the touch version as more direct interaction as opposed to have a physical tool as an intermediary.[28]

Xie, Antle and Motamedi conducted a comparative study with children, comparing purely physical, graphical and tangible user interfaces for the playful activity of solving a puzzle in pairs. While the children's self-reports show similar enjoyment for all the interfaces, solutions using the GUI interface generally took longer. The paper suggests that this is due to easier collaboration in the TUI and PUI[29] interfaces. In line with that, children using these modes also showed more tendencies to play again. Additionally, gender differences were found; boy-boy pairs had significantly higher scores in enjoyment and perceived competence in the GUI condition compared to girl-girl and girl-boy pairs, while the values are much more similar for the TUI.[30]

Tory and Kincaid compared the use of physical controls, touch-screen controls and a touch-screen with an overlay as guidance. Differences were found depending on which controls were

[26] Jacob et al., "A Tangible Interface for Organizing Information Using a Grid."
[27] Ibid.
[28] Terrenghi et al., "Physical Handles at the Interactive Surface."
[29] Physical User Interface
[30] Xie, Antle, and Motamedi, "Are Tangibles More Fun?"

used; for dials, the physical controls had the fastest acquisition and movement times, followed by the touch with overlay and touch interfaces. For sliders, generally no significant differences were found.[31]

4 Tangible User Interfaces and Tangible Interaction

This thesis attempts to highlight which elements are best suited for the physical and digital sides of games. Before coming to that, it is useful to look at the Human-Computer Interaction (HCI) field of Tangible User Interfaces (TUI) that deals with physical/digital relations and to give examples for hardware that makes hybrid interactions possible.

4.1 Introduction

Tangible Interaction and their related definitions and frameworks are a wide field. Shaer and Hornecker give a good introduction into the topic:

> [Tangible User Interfaces are] an emerging post-WIMP interface type that is concerned with providing tangible representations to digital information and controls, allowing users to quite literally grasp data with their hands. Implemented using a variety of technologies and materials, TUIs computationally augment physical objects by coupling them to digital data. Serving as direct, tangible representations of digital information, these augmented physical objects often function as both input and output devices providing users with parallel feedback loops: physical, passive haptic feedback that informs users that a certain physical manipulation is complete; and digital, visual or auditory feedback that informs users of the computational interpretation of their action. Interaction with TUIs is therefore not limited to the visual and aural senses, but also relies on the sense of touch.[32]

4.2 Frameworks

There are different frameworks in which one can view the associated HCI styles – some more narrow, some more inclusive.

4.2.1 Tangible User Interfaces

First characterized by Fitzmaurice, Ishii, and Buxton as "Graspable User Interfaces"[33] in 1995, the associated vision was later refined by Ishii and Ulmer in "Tangible Bits"[34] in 1997.

[31] Tory and Kincaid, "Comparing Physical, Overlay, and Touch Screen Parameter Controls."
[32] Shaer and Hornecker, "Tangible User Interfaces."
[33] Fitzmaurice, Ishii, and Buxton, "Bricks."
[34] Ishii and Ullmer, "Tangible Bits."

Ulmer and Ishii list the following key characteristics for Tangible User Interfaces:

1. Physical representations (rep-p) are computationally coupled to underlying digital information (model).
2. Physical representations embody mechanisms for interactive control (control).
3. Physical representations are perceptually coupled to actively mediated digital representations (rep-d).
4. Physical state of tangibles embodies key aspects of the digital state of a system.[35]

To summarize, TUIs allow the physical representation and manipulation of digital data. This differentiates them from traditional interfaces like keyboards and mice, which are also physical and touchable but do not represent associated information and are generalized; in Graphical User Interfaces (GUI), the information state is mainly shown in visual form, with input devices just manipulating it. If the power was cut from a system, the physical state of keyboard or mouse would not give any information about the previous digital information state.[36] On the other hand, for example a steering wheel controller is much more specific in its use, can represent and control a digital steering wheel inside a car and also at least shows the last direction the wheel was steering towards.

Even more closely matching the characteristics is an example named by Ulmer and Ishii: Urp, a tangible interface for urban planning, has physical models of buildings placed on a table, which are then augmented digitally. This is highly specific, and if the system is switched off, a big part the configuration can still be seen in the physical model.[37]

4.2.2 Tangible Interaction

"Tangible Interaction" termed by Hornecker and Buur encompasses the key characteristics of Tangible User Interfaces listed earlier, but purposefully provides a wider scope. In "Getting a Grip on Tangible Interaction", they say:

> Tangible interaction is not restricted to controlling digital data and includes tangible appliances or remote control of the real world. This approach focuses on designing the interaction itself (instead of the interface) and on exploiting the richness of bodily movement. Interaction with 'interactive spaces' by walking on sensorized floors or by simply moving in space further extends our perspective on 'tangible' interaction, the body itself becoming an input 'device'. Instead of using a restrictive definition that excludes

[35] Ullmer and Ishii, "Emerging Frameworks for Tangible User Interfaces."
[36] Ibid.
[37] Ibid.

some of these interesting system variants […], it seems more productive to address this larger design space.[38]

Tangible Interaction "encompasses and synthesizes" what they call the data-centered view (TUIs: physical artifacts representing and manipulating digital data), the expressive-movement-centered view (from a product design school perspective: focusing on interaction itself) and the space-centered view (based on interactive arts and architecture around spatial interaction in "interactive spaces").[39]

The framework is "structured around four themes that are not mutually exclusive, but interrelated, offering different perspectives on tangible": Tangible manipulation (interaction with physical objects which serve as input), spatial interaction (moving objects, but also one's body in space, and other things shared space makes possible), embodied facilitation (shaping interaction by using a specific physical setup and representation) and expressive representation (representing digital data well, and other elements of the representation).[40]

4.2.3 Reality-Based Interaction

Another concept which draws upon many interaction styles is Reality-Based Interaction (RBI) as proposed in a paper by Jacob et al., unifying a vast variety of post-WIMP (defined by van Dam as "containing at least one interaction technique not dependent on classical 2D widgets such as menus and icons"[41]) interfaces, for example "virtual, mixed and augmented reality, tangible interaction, ubiquitous and pervasive computing, context-aware computing, handheld, or mobile interaction, perceptual and affective computing as well as lightweight, tacit or passive interaction"[42].

The focus of the RBI framework is on four themes which Jacob et al describe as follows:

- Naïve Physics: people have common sense knowledge about the physical world.
- Body Awareness & Skills: people have an awareness of their own physical bodies and possess skills for controlling and coordinating their bodies.
- Environment Awareness & Skills: people have a sense of their surroundings and possess skills for negotiating, manipulating, and navigating within their environment.
- Social Awareness & Skills: people are generally aware of others in their environment and have skills for interacting with them.[43]

[38] Hornecker and Buur, "Getting a Grip on Tangible Interaction."
[39] Ibid.
[40] Ibid.
[41] van Dam, "Post-WIMP User Interfaces."
[42] Jacob et al., "Reality-Based Interaction."
[43] Ibid.

The goal of the framework is to further understanding of and comparisons and relations between interaction styles. It also suggests that using real-world skills and knowledge users already possess is a good idea because it might require less mental effort, speed up learning and improve performance. On the other hand, it also draws attention to possible drawbacks of using RBI principles in the areas of expressive power, efficiency, versatility, ergonomics, accessibility and practicality.[44]

4.3 Uses of Tangible Interfaces

This chapter will briefly describe the areas Tangible Interfaces are used in and what their benefits are. It is structured after Shaer and Hornecker's "Tangible User Interfaces: Past, Present, and Future Directions" application domains chapter.[45]

One of the primary uses of Tangible Interfaces is learning. They engage more senses and thereby support child development.[46] O'Malley and Fraser list multiple examples where locomotion and physical objects helped children in areas such as categorization, recall and solving fraction problems. They also argue that physical materials can help with abstract tasks by forming mental images, thereby guiding and constraining.[47] Learning tools include digital manipulatives (such as construction kits or building blocks), computationally enhanced construction kits (tools that make concepts more accessible, like e.g. the concept of volume and surface of 3D objects) and storytelling. Another area of usage is learning for children with special needs.[48]

Closely related to that is tangible programming where physical blocks are used for commands and can be put together in various ways. While a study by Horn et al. comparing between such an environment with a GUI-based interface in a museum showed that both environments were equally easy to use and neither yielded more complex or longer programs, most children and especially girls were much more interested in engaging with the hybrid exhibit, and that teamwork made the children use it for a longer period of time as opposed to the one-mouse GUI environment.[49]

Shaer and Hornecker also list TUIs as useful in problem solving and planning, especially when epistemic actions ("Epistemic actions are the non-pragmatic manipulations of artifacts aimed at better understanding a task's context."[50]), physical constraints that limit the solution space well or tangible problem representations are involved. Named examples are tools made for urban

[44] Ibid.
[45] Shaer and Hornecker, "Tangible User Interfaces."
[46] Ibid.
[47] O'Malley and Fraser, "Literature Review in Learning with Tangible Technologies."
[48] Shaer and Hornecker, "Tangible User Interfaces."
[49] Horn et al., "Comparing the Use of Tangible and Graphical Programming Languages for Informal Science Education."
[50] Shaer and Hornecker, "Tangible User Interfaces."

planning and architecture where physical representations work well while augmentations highlight complex calculations like wind or a pedestrian simulation, optics, logistics and organizing and grouping data.[51]

TUIs are also used for music and similar performances, as the later named Reactable (see page 22). Apart from being more visually interesting for an audience, Tangible User Interfaces also allow for new and interesting interactions like the uPoi where a ball tied on a string is swung around one's body, making music by reading the acceleration data.[52]

Another use for tangible interfaces is entertainment. Commercial tangible devices include the Nintendo Wii or the Microsoft Kinect (by transforming the body into a tangible input device) which enable new ways of interaction. Shaer and Hornecker also mention devices more strictly fitting the TUI definition in the areas of storytelling, building of robotic creatures, creativity-enabling devices and interactive playgrounds.[53]

Apart from these, other areas listed by Shaer and Hornecker are information visualization, social communication and tangible reminders and tags.[54]

4.4 Example Devices

The following chapter describes a few devices that are used in Tangible Interaction or extensions to existing devices which improve their Tangible Interaction capabilities. This list does not claim completeness; its purpose is to show an array of diverse examples. A focus was set on recent innovations and suitability in a gaming context.

For a wider array of examples in different categories, see Shaer and Hornecker[55].

4.4.1 Multitouch Tables with Marker Recognition

A multitouch table is a table-sized horizontally mounted display that allows tracking of multiple finger touch points at the same time. Some tables also allow the recognition of fiducial markers, making them suited for use as a Tangible User Interface.

4.4.1.1 Fiducial Markers

A fiducial marker is a small image that allows the marker to be identified uniquely and to precisely calculate its position and rotation. These markers can then be attached to physical objects. That allows the table to indirectly track this object in an optimized and robust way.[56]

[51] Ibid.
[52] Ibid.
[53] Ibid.
[54] Ibid.
[55] Ibid.
[56] Ibid.

Since the markers are recognized instead of the objects themselves, the objects can have any form that allows putting the marker side on the surface without needing further definition on the side of the recognition software.

Fiducial markers can take different forms. The example shown here is generated with the MarkerFactory of the Cornerstone SDK[57], which is used with the later described MultiTaction Cell.

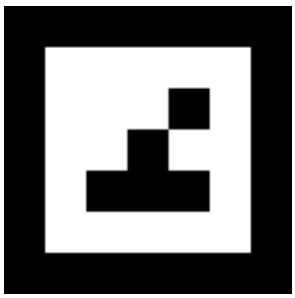

Figure 1: A fiducial marker

Attaching markers under physical objects effectively means that the physical object can now be seen as an input object for a tangible interface. Provided that a device recognizing these fiducial markers is available, adding new tangible objects this way is inexpensive and easy.

4.4.1.2 Reactable

The initial paper written by Kaltenbrunner et al. describes the Reactable (back then written as "reacTable*") as a "novel multi-user electro-acoustic musical instrument with a tabletop tangible user interface". According to the paper, it allows tracking of fiducially marked objects on the table via a camera underneath the translucent surface. A projector that is also situated underneath the table then provides visual feedback. As already mentioned, its main use is the creation of music; the different objects form parts of a modular synthesizer.[58]

As part of the development of the table, the open-source framework reacTIVision was created and is still used by the Reactable. Its software part features several engines to recognize different kinds of fiducial markers and publishes the results via the TUIO protocol – which was also originally made for the reacTIVision framework. The paper also describes how to build the accompanying table interface. It is also mentioned that the camera has to work in the infrared spectrum so it does not interfere with the projection; IR lighting from underneath the table surface ensures that the camera picks up the markers.[59]

[57] MultiTouch Ltd., "MultiTaction: Creating Markers."
[58] Kaltenbrunner et al., "The reacTable*."
[59] Kaltenbrunner and Bencina, "reacTIVision."

In 2009, a spin-off company called Reactable Systems was formed, which further develops the Reactable and sells products based on the original research.[60]

Figure 2: Reactable Live! (Photography by Massimo Boldrin)

4.4.1.3 TUIO

According to its website, TUIO is "an open framework that defines a common protocol and API for tangible multitouch surfaces". Its protocol enables tracker applications to transmit touch or marker states to a TUIO client. While it was originally made in the context of the reacTIVision development, it is now widely used and has many implementations both on tracker and client side.[61]

The TUIO protocol is encoded using the Open Sound Control[62] format, which according to the TUIO.org website "provides an efficient binary encoding method for the transmission of arbitrary controller data".[63]

The TUIO 1.1 protocol allows for three different components to be tracked: Objects (for example fiducial markers), which have an ID, a position and a rotation, cursors (for example touches), which only have a position, and blobs (untagged objects) with position/rotation and an additional extension approximated by an ellipse. Additionally, each component gets a unique

[60] Universitat Pompeu Fabra, "Reactable Systems and Ongoing Research"; Reactable Systems, "Reactable - the Electronic Music Instrument, the Music App and DJ Tool."
[61] Kaltenbrunner, "TUIO"; Kaltenbrunner, "TUIO Implementations."
[62] Wright, "The Open Sound Control 1.0 Specification."
[63] Kaltenbrunner et al., "TUIO Protocol Specification 1.1."

session ID until it vanishes. Velocity and acceleration for position and rotation are also computed and transmitted.[64]

The message types contained are ALIVE, SET, FSEQ and SOURCE. ALIVE contains all session IDs that are currently recognized. SET informs of the current status of attributes and contains a session ID and a space-separated list of the attribute values in a certain order. FSEQ contains a unique frame ID to separate frames. The SOURCE message is optional and identifies the source application/address to allow the client to distinguish between different trackers.[65]

The specification describes their implementation as using the UDP protocol. To ensure that packet loss can be dealt with gracefully, there are no "add" or "remove" messages – instead, an ALIVE message is sent to update the client, which can then deduce additions or removals. ALIVE and SET messages are regularly resent even if no changes occur to ensure that the client has the most recent state even in case of packet loss. To completely use the space provided by a UPD packet, messages are bundled. Each bundle optionally starts with a SOURCE message. It then contains an ALIVE message and multiple SET messages, and closes with an FSEQ message.[66]

Also included in the specification are parameter profiles and details about the attributes and how they are computed.[67]

The Reactable uses reacTIVision, which uses the TUIO protocol[68], and the MultiTaction devices (see next chapter) allow the use of TUIO too[69]. The later named Samsung SUR40 that uses Microsoft PixelSense™ does not support TUIO, but it can be made available by using a TUIO server as a bridge.[70]

4.4.1.4 MultiTaction

Contrary to the Reactable, MultiTaction displays do not use a projector but a technology MultiTouch Ltd. calls Computer Vision Through Screen (CVTS) that allows a camera system to see through an LCD display. An Integrated Backlight Emitter Camera (IBEC) emits infrared light that passes through the display and is reflected off hands and objects. Objects above the table can also be seen, which allows the system to detect the hands that belong to touching fingertips. This also allows having the displays behind safety glass as the displays do not need to be

[64] Ibid.
[65] Ibid.
[66] Ibid.
[67] Ibid.
[68] Kaltenbrunner and Bencina, "reacTIVision."
[69] MultiTouch Ltd., "MFTO – Multi Format Tracking Output."
[70] eilsoe, "Surface2TUIO v. 1.0 - NUI Group Community Forums."

touched directly. Depending on the size of the display, the input of multiple cameras is then merged by a so-called Matrix Tracking System (MTS) before it is further processed.[71]

Following from there, an embedded computer uses the Extensible Hybrid Tracking Engine (EHTE) to track information. EHTE can be configured to alternate between using the reflections of infrared light and the shadows cast by passive ambient light every other frame, combining those images to improve the quality under difficult lighting conditions, i.e. powerful infrared light sources like sunlight or halogen light spots. According to their website, the EHTE can track "finger points, fingers, hands, objects (shapes), optical markers (fiducials, tags) and proximity (presence of users in front of display)" and it says that "developers have the possibility to further extend the tracking system using the available SDK".[72]

The MultiTaction Cell outputs its data in various formats, including the TUIO protocol, Windows 7 Native Touch and an XML stream. The TUIO protocol has extended non-standard capabilities, for example to receive hand detection information. All outputs are sent over an Ethernet connection.[73]

4.4.1.5 Samsung SUR40 (using Microsoft PixelSense™)

Microsoft PixelSense displays also uses an infrared light that goes through the LCD display, but there are no cameras behind the display – the display itself contains tiny sensors that sense the reflected IR light and report it to create a picture of what is situated over the display. The image and processed information like fingers, blobs and tags are then sent to the connected PC.[74]

4.4.2 castAR

While multitouch tables with marker recognition have the advantage of being useable any time by virtually any number of people, they are hard to transport or are not transportable at all – and very expensive. The Reactable Live! for example, the cheapest of the previously named tables, costs €6100 (which at the time of writing amounts to approximately $8214) according to the Reactable shop, without bags and shipping[75].

Designed as a system to solve the problems of affordability and transportability, castAR is a glasses-based augmented reality system with a sheet laid out on a table or floor as a focus point. The glasses have a micro-projector for each eye which casts a stereoscopic perspective view on the sheet – made possible by the retro-reflective sheet material which bounces light directly back to the glasses. This allows multiple users at the same time. The sheet also contains infrared

[71] MultiTouch Ltd., "CVTS – Computer Vision Through Screen"; MultiTouch Ltd., "IBEC – Integrated Backlight Emitter Camera"; MultiTouch Ltd., "MTS – Matrix Tracking System."
[72] MultiTouch Ltd., "EHTE – Extensible Hybrid Tracking Engine."
[73] MultiTouch Ltd., "MFTO – Multi Format Tracking Output."
[74] Microsoft, "The Power of PixelSense™."
[75] Reactable Systems, "Reactable: Products."

identification markers which are read by a camera attached to the glasses, allowing them to find out the user's head position and rotation relative to the sheet.[76]

Recognition of physical objects is also possible, but not by using infrared tags – probably because they wanted to ensure that objects can also be recognized precisely and independently of how many people (if any) are looking at them. An RFID Tracking Grid can be laid out underneath the sheet, and RFID tags are put under physical objects to enable them to be recognized.[77]

A so-called "Magic Wand" allows for positional 3D input and also contains a joystick.[78]

At the time of writing, the system is available for preorder. Glasses are $345 each, also containing a 1x1m sheet, the RFID Tracking Grid is $85 and a pack of 10 RFID tags costs $10. A game for two players containing 10 tags for each player would be $785 without shipping, which is less than a tenth than the previously named Reactable.[79] Additionally, the glasses project stereoscopic 3D images, and the whole setup is easily transportable. On the other hand, every player needs to glasses to put on as opposed to multitouch tables which work immediately after turning them on for everybody surrounding them. This makes multitouch tables better for public settings and castAR more interesting for game rounds with a low amount of players and no spectators.

4.4.3 Multitouch Tablet Accessories

Some devices or techniques are not meant to be used alone, but enable multitouch tablets without fiducial marker recognition for more tangible applications.

4.4.3.1 Touchcode

Touchcode uses t+ink's conductive ink signatures on cards and other objects to enable a capacitive touch screen (like on multitouch tablets) to recognize them and their position by touching the ink.[80]

This could for example be used to place playing cards and figures on the tablet and enable normal capacitive multitouch screens to recognize their identity and position similar to the fiducial markers in the previous chapter.

[76] Technical Illusions, "castAR."
[77] Ibid.
[78] Ibid.
[79] Technical Illusions, "Technical Illusions: Store."
[80] PT Forschung und Entwicklung GmbH, "Touchcode: Toys and Games"; t+ink, "T-Ink.com Technology."

4.4.3.2 Lenovo Horizon Multimode Table PC: Joystick, Striker and E-dice

The Lenovo Horizon 27" multitouch table PC that explicitly mentions gaming in its description. It also has accessories that one can buy additionally which are directly made for gaming: joysticks, strikers and electronic dice.[81]

The striker (for example useable for hockey) and assumedly the joysticks are just put on the screen and work on the same principle as the previously mentioned Touchcode: A conductive material, in this case plastic, is put on the capacitive touch screen, and the touch screen deduces the striker's position and the joystick's tilt from that.[82]

The E-dice are wirelessly connected to the PC and report their result when dropped. Up to three E-dice are simultaneously supported.[83]

4.4.3.3 DICE+

DICE+ is also an electronic dice, this time geared towards mobile phones and tablets. It uses Bluetooth and is according to their FAQ compatible with several iPads, iPhones and Android devices.[84]

On their developer site, they list the dice's capabilities: An accelerometer with magnetic field sensor, six touch-sensitive sides each with an LED that can glow in any color (illuminating the respective number printed on that side) and a thermometer.[85]

This allows the dice to be used as a dice input device for mobile phones tablets – and also as a game controller that can sense movement, orientation and touch and can give visual light feedback.

4.4.4 Siftables/Sifteo Cubes

Sifteo Cubes are small blocks with 16bit color depth 182x182 pixel LCD screens. The screens are clickable and the cubes have 3-axis accelerometers, but what makes the cubes really interesting in the context of TUIs is that they are aware of really close neighbors via proximity sensors including which side the neighbors are touching – and they can communicate with each other via a shared base, enabling them to get their whole neighbor configuration. This, in combination with the accelerometers, allows for rich gestures – for example cubes could be bumped into each

[81] Lenovo, "Lenovo Horizon Table PC | Multi-User Fun."
[82] Lenovo, "Joystick & Striker(2 Sets)."
[83] Lenovo, "E-Dice GA800 (CN/US/UK/EU)."
[84] Game Technologies S.A., "FAQ - DICE+."
[85] Game Technologies S.A., "Developers at DICE+."

other to transfer elements, or be tilted next to each other to "pour" something into another cube. Additionally, the base can output sound.[86]

Figure 3: Sifteo Cube interactions (Photography by Sifteo)[87]

Figure 4: Sifteo Cubes (Photography by Sifteo)[88]

Merrill, Kalanithi and Maes first described the then-named Siftables in their paper "Siftables: Towards Sensor Network User Interfaces". Their intention was to bring interaction with digital information closer to how people interact with physical objects after observing "the skill that humans have at sifting, sorting, and otherwise manipulating large numbers of small physical objects". Their original Siftables were smaller and thinner and the gestures in the paper focus on data associations – grouping data by pushing Siftables together, thumping the user's fist on the table to swap associations as well as a gesture to let one Siftable represent a group and yes/no gestures.[89]

When Sifteo Cubes were released later, there was a shift in focus – it is now marketed as a game system.[90] The original Sifteo Cube generation still needed a wirelessly connected computer to play games, but that also allowed communication with the computer and the cubes could be used as controllers. The current Sifteo Cube generation contains a base which runs the games – a

[86] Sifteo, "The Inner Workings of Sifteo Cubes (i.e., Tech Specs)"; *Toy Tiles That Talk to Each Other*.
[87] Sifteo, "Sifteo Press Kit."
[88] Ibid.
[89] Merrill, Kalanithi, and Maes, "Siftables."
[90] Sifteo, "Sifteo Cubes"; Sifteo, "Sifteo - Games."

computer is only needed to buy and update games, making the Cubes more autonomous as a game system.[91] On the other hand, live communication with the computer is not possible anymore, but is a requested feature.[92]

4.4.5 Thumbles

The TUIs named so far could only communicate the state of physical objects to the digital side, not the other way around. Their output was non-physical, and the interaction with the physical objects was only limited by their natural properties. Thumbles provide a way to add physical output, for example to marker objects.

Thumbles are small robots with so-called "omniwheels" that allow them to drive in any direction without turning, and also to turn on the spot. Their flat bottom allows them to place fiducial markers underneath. When communicating with the computer, they can match what's happen digitally or provide physical feedback: For example, they can rearrange themselves when the interface changes, move or turn as values change or pull against the users push to denote that the intended action is not possible.[93]

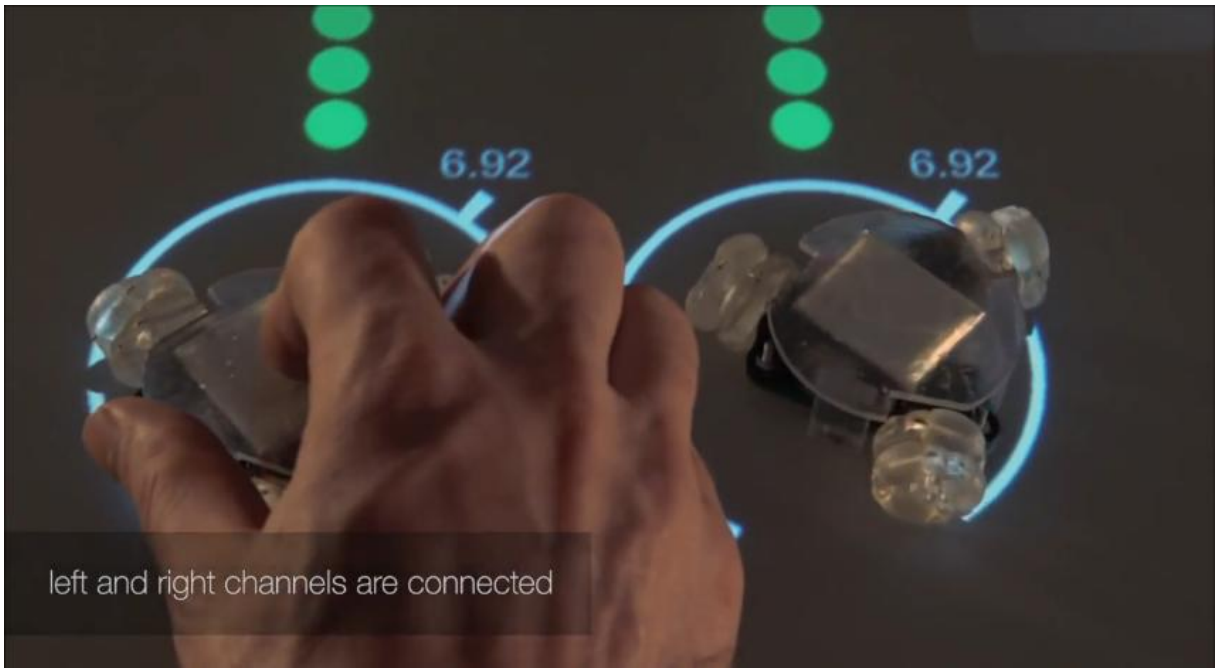

Figure 5: When one of the Thumbles turns, the other one turns too (screenshot of a video by James Patten)[94]

In games specifically, this can allow pieces to react automatically to events such as being pushed back or being destroyed in a fight, without the user having to move the piece to match the new digital state. Another use would be to simulate physical forces, which, although probably being

[91] Sifteo, "Sifteo Cubes vs. Original Sifteo Cubes."
[92] Russell, "Allow I/O through USB Connection."
[93] "Patten Studio: Design and Technology for Interactive Experiences"; *The Best Computer Interface?*.
[94] *Thumbles - Robotic Tabletop User Interface Platform*.

too light to be a physical obstacle, could serve as an indicator – and if the digital object does not move due to digital forces, the player would not have any reason to push despite that being physically possible.

4.4.6 inFORM

Also providing physical feedback and dynamic interfaces is inFORM, a 2.5D shape display. It has a matrix of 30x30 9.525m^2 white pins that are motorized and can pushed up a distance of 100mm. The pins can detect pulling and pressure as input as well as change their resistance to this external motion. Also included in the setup is an overhead projector to overlay an image on the shape display and a Kinect to see objects and hands with their corresponding heights over the display.[95]

According to the video depicting use examples of the project, "inFORM is a step toward [their] vision of Radical Atoms"[96] which was originally formulated in "Radical Atoms: Beyond Tangible Bits, Toward Transformable Materials" by Ishii, Lakatos, Bonanni and Labrune. In the vision, they are using what they call the "iceberg metaphor" to illustrate what they want to achieve, with the water symbolizing the digital world and everything above the physical world. The "painted bits" of a GUI are then like watching something under water, with the user looking at the digital information through a screen and interacting only remotely. Following, the "tangible bits" of a TUI are like the tip of an iceberg: A part of the digital work is made physical, but a huge part is still purely digital, remote and underwater. Their vision for the future is now what they call "Radical Atoms": using "hypothetical dynamic materials", all of the digital information could be interacted with in a physical manifestation.[97]

On their website, they further describe those Radical Atoms:

> Radical Atoms takes a leap beyond Tangible Bits by assuming a hypothetical generation of materials that can change form and appearance dynamically, becoming as reconfigurable as pixels on a screen.
>
> Radical Atoms is a computationally transformable and reconfigurable material that is bidirectionally coupled with an underlying digital model (bits) so that dynamic changes of physical form can be reflected in digital states in real time, and vice versa.[98]

The inFORM paper proposes "utilizing shape displays in three different ways to mediate interaction: to facilitate by providing dynamic physical affordances through shape change, to

[95] Follmer et al., "inFORM."
[96] *inFORM - Interacting With a Dynamic Shape Display*.
[97] Ishii et al., "Radical Atoms."
[98] Tangible Media Group, "Tangible Media Group: Vision."

restrict by guiding users with dynamic physical constraints, and to manipulate by actuating physical objects."[99] "Physical affordance" was described by Hartson as a "design feature that helps users in doing a physical action in the interface"[100].

The facilitation of dynamic physical affordances works by creating physical UI elements on the fly, such as a raised binary button, a raised 1d touch track, a raised 2d touch surface or a handle by extending a pin far enough to make it pull- and pushable. Pins can also change their resistance, so an element might be easy or hard to move, pull or push.[101]

The restrictions apply to objects that can be moved over the surface and are sensed by the system through the Kinect, or depending on its weight, possibly by the pins. By extending some pins, physical obstacles can be created to guide and restrict the movements the user can execute without lifting the object – for example a well or a slot where the user can only move the object along an axis. A constraint does not need to deny though: A ramp could for example be used to make it harder to move in one direction and easier to move in the other.[102]

Lastly, physical objects placed on the surface can be manipulated. An example for this is a slide which moves a ball, or lifting only one side of a brick to tilt it.[103]

The display pins itself only support 1D movement though, which means that created UI elements cannot be pushed, rotated physically or lifted off the surface like the previously named Thumbles. The paper suggests adding these and other interactions by adding passive physical tokens: "The spatial relationship between objects is an important parameter for TUIs. While these can be dynamically modified, users cannot easily grasp, lift and rearrange objects on 2.5D shape displays. Therefore, we propose to complement them with passive physical tokens that enable these interactions, while they can also be constrained and actuated by the display surface shape."[104]

[99] Follmer et al., "inFORM."
[100] Hartson, "Cognitive, Physical, Sensory, and Functional Affordances in Interaction Design."
[101] Follmer et al., "inFORM."
[102] Ibid.
[103] Ibid.
[104] Ibid.

5 Physical/Digital/Hybrid Games

5.1 "Board Games" as a Genre

While a "board game" was traditionally physical by nature, computers, smartphones and tablets have long since adopted board games as a genre. These physical and digital board games often share traits which this chapter will talk about. Note that those traits are just indicators and usually have exceptions even in the physical world.

Soren Johnson mentions "turn-based play, a shuffled deck of game pieces, a visible board divided into tiles, and transparent rules with no hidden modifiers" as exemplary properties of board games.[105]

5.1.1 Transparent Rules

A trait shared by all purely physical board games is that the rules have to be executed by the players. This leads to an interesting consequence: Usually all the rules are entirely known and transparent to each player at any point of the game, allowing them to make informed decisions. Note that this only applies to the rules itself: The gameplay might become less transparent by hidden state (like the players holding hidden cards), not knowing how one's opponent will react and by randomness introduced for example through dice or hidden elements.

Many video games, on the other hand, do not tell the player the exact rules and just execute them behind the scenes. For example, a video game might have an armor rating and while the player knows that a higher armor rating helps the played character take less damage, he might not know how exactly that reduction is calculated.

5.1.2 Limited Complexity

For players to be able to understand and execute the rules, they need to be of limited complexity. While there are certainly board games that are very complex and need a long time to be understood and played, most feature easy formulas, low numbers, a limited number of calculation steps between actions and a limited set of actions. Also, since a board game cannot be easily saved like a video game, most board games are meant to be played from start to finish in a matter of hours.

5.1.3 Physical Components

Apart from the gameplay mechanics, there are certain components that are associated with physical board games and which are often emulated in digital board games too.

[105] Johnson, "When Digital Versions of Board Games Surpass the Originals."

5.1.3.1 Board

Among the most prevalent is the component that the name "board game" is derived from: The board which marks different zones, thereby allowing players to give pieces they put on it extra meaning, for example "this worker piece now harvests grain" or "this score piece marks that my score is 100". One of the main advantages of using a board with zones is that these zones allow pieces to move in discreet space.

The physical world has continuous space – however, it is hard to restrict movement in practice without using tools like rulers, and often the complexity of "moving a piece 6 centimeters" is not needed. Instead, board games often restrict movement into separate tiles, a grid or just locations connected by a graph or a similar structure, thereby allowing players to move "3 steps" or "into an adjacent tile" with ease. Having a board divided into discreet spaces also makes the game state and the possibilities easier to understand – for example, it is easy to understand that two pieces can attack each other if they are 3 spaces or less away just by looking at them, but if their attack range is stated in centimeters, one might need a ruler again.

Some exceptions to the "movement only between discreet spaces" rule are games that are actually ruled by physics (which will be mentioned later in the chapter "Physical Advantages"), games where the movement is a key mechanic and therefore actually uses rulers or similar devices and games that do not rely on a board at all.

5.1.3.2 Dice

While there are many board games where everything is entirely determined by the players' actions, other games feature randomness – often by using dice.

Video games use randomness too, but again there is a difference in transparency. When a dice is thrown, for example, the player can be relatively sure that it has six sides with equal probability and knows exactly how the result is used – for example, a dice thrown in combat might do the shown amount of damage, unless it is a six, in which case it is a "critical hit" and the player can roll a second dice adding to the first result. In a video game, this is often obscured with only the results being shown and the player cannot be sure why her attack did this exact amount of damage.

There is also often a perceived difference in control: In board games, the player is throwing a dice, thereby seemingly determining his own fate; in a video game on the other hand, it might look to the player like the computer is "deciding" the outcome. While there is often no difference in mechanics (as the player cannot really control the physical dice result and a digital random number generator can produce similarly "random" results), the experience might differ in perception and feeling.

5.1.3.3 Shuffled Pieces/Cards

Shuffled pieces or cards are other elements that give the player a randomized set of choices which are often hidden from the other players. Many games are based entirely on cards, for example Magic The Gathering[106], a collectible card game where cards represent resources, units, spells and similar elements, or Dominion[107], where the building of the players' own card decks is actually part of the game, and since the deck is regularly reshuffled, the players are tasked to manipulate their chances by adding cards to and discarding cards from the deck.

5.1.4 Turn-Based Play

Video games usually artificially limit the playing speed by using movement speeds and timers – for example, a player's avatar can only move 5 ingame meters per second, or a weapon reload timer is 1 second. This allows for simultaneous play without reducing the gameplay to the pure ability to execute as many actions as possible in the shortest possible timeframe. Furthermore, video games usually have different input interfaces for different players.

On the other hand, it is hard to enforce timed movement and actions in physical board games and people are often playing in the same space and would physically get into each others way. These constraints lead to board games usually being turn-based, i.e. having only one active player while the other players simply observe or plan their own turn.

If a game features simultaneous actions, it is usually in a restricted way: For example, there might be a phase where players simultaneously decide on a secret action before everyone reveals theirs at the same time, or players operate simultaneously in their own private restricted space without obstructing other players. Examples of those are Race for the Galaxy and Identik:

The card game Race for the Galaxy has a secret action selection phase before a round is played and the actions that each player selects influence how the round plays out for every player.[108]

Identik is a game where a player describes a hidden image while the other players simultaneously try to draw the described image on their own piece of paper.[109]

5.1.5 Interesting Exceptions

As mentioned before, most of these traits have exceptions. To illustrate this point, some shall be mentioned here.

[106] Wizards of the Coast LLC, "Magic: The Gathering."
[107] BoardGameGeek, "Dominion."
[108] BoardGameGeek, "Race for the Galaxy."
[109] BoardGameGeek, "Identik."

5.1.5.1 Transparent Rules

In purely physical games, the rules have to be executed by the players, but that does not necessarily mean that all players know all rules yet or that the rules cannot change in unexpected ways.

Legends of Andor is a cooperative game where, according to the accompanying booklet written by Michael Menzel, players try to win against the game together, but the game introduces the rules while playing with an event-based tutorial-like system.[110] This way the game forces the players to make decisions without knowing the complete rule set, which eases starting out and can increase suspense and surprise.

Another example is Fluxx, a card game with very simple core rules, but players play cards which modify these rules as long as they are lying on the table.[111]

Another game in this category is Haggle by Sid Sackson and Robert Billingsley. It is a trading game which features a secret rule set – each player gets trading goods and a small rule subset determining what the goods or certain combinations of them are worth. Players may trade goods and rule knowledge freely. At the end of the game, all the rules apply, not only those known to each player.[112] This makes it essentially a game where each player has to achieve transparency by playing.

5.1.5.2 Limited Complexity

Regarding complexity, there are several notable exceptions.

Advanced Squad Leader is a very complex war game, which has BoardGameGeek's rule classification "Rules length - Heavy (300+ pages)"[113]. War games in general often feature immense lengths spanning hours upon hours, with 7 Ages for example mentioned as "8 hours playing time" on BoardGameGeek[114].

Some examples are even more extreme and this one is just listed for how curious it is: The Campaign for North Africa is a game for which BoardGameGeek lists the play time as "60000 minutes"[115], which would be 41 days and 16 hours if played nonstop.

Risk Legacy is very interesting in that it has a form of persistence between independent rounds: Among other things, playing cards are permanently destroyed by physically ripping them to

[110] Menzel, "Begleitheft."
[111] BoardGameGeek, "Fluxx."
[112] BoardGameGeek, "Haggle."
[113] BoardGameGeek, "Advanced Squad Leader."
[114] BoardGameGeek, "7 Ages."
[115] BoardGameGeek, "The Campaign for North Africa."

pieces, the game board is altered permanently and the rulebook has free spaces for rule changes and additions to be written in, all happening through player choices and game outcomes.[116]

5.1.5.3 Turn-Based Play

Reaction-based games often feature simultaneous play in the same physical area – e.g. the players in Ligretto are playing cards in the same area on the table simultaneously, favoring those who react faster to the changing circumstances.[117]

Other games have only certain simultaneous phases in a shared physical area. For example, Galaxy Trucker has a phase where everyone builds their own space ship at the same time out of a shared pool of pieces.[118] This has consequences for the other players: If one player takes a piece, other players cannot use it anymore.

Many communication-based party games feature real-time play in form of a countdown in which players having to accomplish a task as fast as possible, often with multiple players at once – for example in Taboo, a team of players has to guess a word a single team member tries to describe without using commonly associated words.[119]

5.2 Physical Advantages

Since the goal of this project is to combine physical and digital elements, the advantages of physical games and digital games in general should be analyzed. A focus shall be laid on physical tabletop games; for physical advantages of games that are not played in tabletop environments, but for example with the body or the environment, see “Pervasive Games” (page 54).

5.2.1 Physical Interaction

While the interaction with most pieces can be easily emulated in a digital environment, it feels different if one does not get any physical feedback from moving a piece. Touching a piece gives a tactile response that allows manipulation without directly looking at it – or additional information if one does. Most dexterity games go further though and integrate the physical interaction deeply into the gameplay up to a point where the game cannot be ported to a digital version anymore without changing those mechanics.

5.2.1.1 Finger Flicking

The first mechanic in this category is flicking away pieces on the board with one’s finger.

[116] BoardGameGeek, “Risk Legacy.”
[117] BoardGameGeek, “Ligretto.”
[118] BoardGameGeek, “Galaxy Trucker.”
[119] BoardGameGeek, “Taboo.”

A famous example of this is Carrom, which is similar to pool. Players have to sink wooden discs of their own color into holes at the corners of the board – not by touching them directly, but by flicking a bigger and heavier disc at them.[120]

Another example is Crokinole. In this game, the board is divided into zones awarding points, with players trying to flick discs into them. Interesting here is that with each shot a player's new disc has to hit another's player's disc, which makes every turn different – and one can bump enemy discs out of the zones they are in, thereby costing the enemy player points.[121]

There are thematic flicking games too – for example Catacombs, a cooperative dungeon crawler where players hit monsters by flicking their characters at them[122] and PitchCar/Carabande, a racing game centered on flicking[123].

There are two ways to emulate flicking on a digital device, both with their own drawbacks: The first is trying to recognize a flicking motion with a touch screen, but missing physical feedback makes this hard to guess. A more precise variant is to use a pull-back mechanic like in digital versions of pool or Angry Birds[124], but replacing a finger flicking mechanic with pulling back a string feels vastly different – just as physical and digital pool feel very differently when played.

5.2.1.2 Gravity

Some games involve gravity in some way, for example by balancing pieces on top of other things, often on other pieces.

An example of this is Bausack, a game where players are each building a tower-like structure out of pieces they receive from their enemy, trying to be the last players whose tower still stands.[125]

On the other hand, Jenga starts with the tower already in place, and players take turns removing pieces and placing them on top of the tower until it finally falls down, which gets increasingly harder as the tower loses crucial pieces. The winner is the player before the player whose action caused the tower to collapse.[126]

Games like these with their subtle movements and physical feedback cannot be truly ported to digital devices. While there are many digital 2d physics games, movement on a digital screen feels and plays very different than in physical space.

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[120] BoardGameGeek, "Carrom."
[121] Kelly, "Crokinole Rules."
[122] BoardGameGeek, "Catacombs."
[123] BoardGameGeek, "PitchCar."
[124] http://chrome.angrybirds.com
[125] BoardGameGeek, "Bausack."
[126] BoardGameGeek, "Jenga."

5.2.1.3 Tools

There are some board games where utilities play a major role in the feel of the game.

Pick Up Sticks, for example, has long thin sticks on lying in a tangled pile on top of each other. Players try to remove them one by one without disturbing more than one stick at a time by using another long, thin and pointed stick.[127]

Gone Fishin' is a game where the players try to catch fish using fishing poles with little magnets instead of hooks.[128]

Another example is Operation, a game in which players use tweezers to extract body parts out of holes without touching the sides of these holes. The game uses electricity to detect that; the tweezers and the patient form a circuit via cables, with a buzzer sounding if it is closed.[129]

This kind of game is basically defined and made interesting by the tools used, and as such a port while keeping the spirit of the game is not possible.

5.2.2 Hidden State in a Shared Space

Another thing the physical nature of board games make possible is hiding information from other players in a shared space. This is mostly due to pieces being independently physically movable (unlike on a single digital screen), allowing players to pick them up and look at them at an angle that obscures the information from anyone else.

A very prevalent example of this are cards which players hold hidden in their hands. Other ways include cardboard screens behind which a player can hide tokens, or just turned-over tokens on a table that a player can look at secretly by picking them up and looking at them without showing them to anyone else.

This is also possible in digital scenarios, but if there is a lot of hidden information, it is only feasible when there is one exclusive screen per player. If there is only one shared screen available, either a physical cardboard screen has to be used or players have to look away frequently, breaking the flow of the game.

5.2.3 Player Interaction

Interacting with other people is much easier when it does not only happen through text or speech, but when players can also see each other and are physically in the same space. Some games are entirely based on interaction between players.

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[127] BoardGameGeek, “Pick Up Sticks.”
[128] BoardGameGeek, “Gone Fishin’.”
[129] BoardGameGeek, “Operation.”

Technology can try to achieve this, but displaying webcam feeds on screen means that there is less space to show the game itself – and it is just a tiny window and not a good replacement for really being there together.

5.2.3.1 Communication and Party Games

Many games use communication as a core mechanic. Popular examples of this are Taboo, Pictionary and Charades. In Taboo, one player has to describe something using neither its name nor commonly associated words. Meanwhile, his team tries to guess the word in a limited timeframe. Pictionary does the same guessing game with drawing instead of speaking – and Charades does it with silent acting.[130]

Another party game based around interaction is the improv game Freeze. Four of the players get cards and have to improvise acting out a scene. After a certain time frame, players have to guess the power relationships the others were acting out.[131]

While Pictionary can be played digitally and online[132] since drawing and guessing single words is easily transferable to the digital world, it is hard to impossible with other games, especially when acting is involved. Some of these games can benefit from a digital helper though – Pantoparty as described on their website, for example, supplies words, scoring and the timer for a charade-like game that is still played with everybody being in the same room.[133]

5.2.3.2 Reading People's Faces

There are other types of games where it is very helpful to be able to observe fellow players: Games in which one has to find out what the other players' intentions are.

The Werewolf/Mafia family of games is a good example of this. As described on BoardGameGeek, games in this family are about deduction and bluffing, usually with a moderator to ensure the flow of play without cheating. Simplified, the gameplay is like this: Each player gets a secret role, either on the village or werewolf side. At "night", all villagers close their eyes, but the werewolves who know each other choose a villager to kill. When it is "day", the villagers choose somebody to lynch, hoping it is a werewolf. The goal is for one faction to survive alone. Certain skills help the villagers – the seer, for example, can find out the identity of another player each night while everyone else has their eyes closed. Other roles are available too.[134] Following from there, at the day, the seer could help the villagers – but if she openly admits that she is the seer, she will probably be killed by the wolves next night. On the other hand, a wolf might pretend to

[130] BoardGameGeek, "Taboo"; BoardGameGeek, "Pictionary"; BoardGameGeek, "Charades."
[131] BoardGameGeek, "Freeze."
[132] iSketch, "iSketch"; Dewsbury, "XSketch."
[133] Pantoparty, "Pantoparty - Online Charades."
[134] BoardGameGeek, "Werewolf / Mafia."

be a seer to make the villagers lynch one of their own. In the end, Werewolf/Mafia is a game about trying to read other peoples' faces, finding out who to trust and, if necessary, concealing one's own identity.

Another type of game where judgment of people is needed is any game which allows alliances without enforcing them. Junta is a game that has this – and much more that fits into the deduction/bluffing category. According to the Junta Rulebook, the game features elections, random secret budgets that have to be distributed, bluffing/assassinations and a war game phase where people can declare factions at the end.[135] Since nobody can win without help, people have to form alliances, but there is no gameplay mechanic in place to ensure that these alliances are honored, and only one single player can win in the end. On top of that, the distribution of a random secret budget keeps players guessing whether they really got the share they were promised. This game lends itself well to plotting against each other, and to talks happening away from the table.

Some of these games are playable online in a more restricted form. Online Werewolf is sometimes played in forums – BoardGameGeek, for example, has a whole forum area dedicated to it.[136] In this form, the game is much more about who defends whom and about argumentation lines than about reading people's faces. It also takes much longer because it usually involves a lot of typing and is played over days instead of in half an hour.

5.2.4 Flexibility

Digital games can execute very complicated processes perfectly and fast – but most of the times, all the rules there are fixed and only customizable in predefined ways in an options menu. Board games, on the other hand, have a fixed rule set most of the times, but it is up to the players to execute those rules – and as such, up to the players to change them, if desired. That gives board games a great deal of flexibility.

5.2.4.1 House Rules

One of the things this flexibility brings is house rules. If a game is imbalanced, components are missing or players just think that the game would be more fun with an additional rule or without another, they are free to adopt this changed rule set.

5.2.4.2 Games about Making Rules

Some games go one step further: They explicitly include player-made rules in the game.

[135] Pegasus Spiele, "Junta - Rules."
[136] BoardGameGeek, "BoardGameGeek | Werewolf | Forum | BoardGameGeek."

1000 Blank White Cards, for example, is a card game that has no initial rules and a set of the eponymous blank cards. The game is public domain and variants differ from each other, but generally, players draw and text cards, which are then either played by the creating player or shuffled into a deck and drawn.[137]

Hex Hex is mostly a card game about trying to get rid of a token by playing cards that may, for example, move the token, disarm it or detain another player. When a player wins the game though, he can add a new rule for the next rounds.[138]

1000 Blank White Cards and similar games could be played in digital form over the internet provided that the digital system only provides minimal assistance during the game, i.e. does not enforce any rules.

5.2.5 Other Advantages

Following are advantages that do not fit well into the previous categories, but do not warrant their own category either.

5.2.5.1 Components

Components for physical board games often are, especially when considering a big group of people, relatively cheap and dependable. Considering a group of 10+ people, for example, a purely digital game might need many devices – and many devices, even if already available, have a higher chance to fail at a certain point in the game, for example by losing the network connection or by running out of battery. Devices like smartphones cannot be taken for granted either. In India, for example, only every 7th to 8th person owns a smartphone according to Google's Our Mobile Planet 2013 study[139]. Playing a completely physical board game is possible without requiring anybody to own devices.

Another advantage is that the components are already there and available, whereas a digital game might need time to register or install. This depends entirely on the game and whether it is been played for the first time by participants though; if the game needs a lot of setting up in the physical world, it might be faster to start a digital version of it, especially if the game one is already installed and all the players are registered (if needed).

Lastly, most physical board games need no electricity at all and are as such always playable, while digital devices might run out of power.

[137] BoardGameGeek, "1000 Blank White Cards."
[138] smirk & dagger games, "Hex Hex Version 1.5 Rules."
[139] Google, "Our Mobile Planet."

5.2.5.2 Available Space

When playing a digital board game together with people who are in the same room, it is usually done either on a bigger mounted screen with remote controls like a keyboard or a mouse, or more popularly on a rather small tablet computer. Table-sized touch screens are available, but rather expensive and difficult to transport. If the screen is small, details have to be omitted and be made available on request, for example by zooming in, moving around or showing a popup information window.

Physical boards, on the other hands, are comparable cheap to produce in any reasonable size, and people often have big tables in their home already – and if not, the floor is as good a place as any. This gives physical games the opportunity to have a lot of space available, allowing everything to be visible at once and in reasonable detail.

5.3 Digital Advantages

The digital world has lots of advantages too with its processing power, programmability, reactivity, connectivity and the complete control the game has over everything that happens. Most of what is written in this chapter applies to every digital game, but the focus will be on differences between physical and digital board games.

5.3.1 Tutorial

In the board game world, learning a new game usually means reading a rulebook – or being taught by somebody who already knows the game. In the digital world, the learning companion can be the game itself.

Digital games often feature tutorials that guide the player step by step through the game. This means less investment before the game starts, which opens the possibility to immediately pick up an unknown digital game with a group of friends without much downtime for everyone involved.

Tutorials can also be reactive: They can teach the rules when it is appropriate and correct wrong actions with a remark why a move is not possible and what can be done instead. Being able to see the rules as they are needed makes the lesson more compelling and in the end more memorable as it does not feel like theory anymore, but one sees the practical application of the rules.

Another possibility that digital games offer is to use audio in addition to text. Even if one does not like reading, the rules still get conveyed. This can also offer great atmospheric possibilities if the voice acting of the tutorial fits the genre of the game.

It is noteworthy that even board games can use a form of tutorial if it fits the game. For example, some games have rules for first-time players, which often lead to fewer things to read before the first game.

Other board games go one step further: Legends of Andor only has a two-page quick start rule sheet and then teaches the rules step by step while playing the game via events that happen. This has been tied directly into a story, so it does not even feel like a tutorial. In an interview, its creator Michael Menzel mentions that he got the inspiration from computer games:

> As an illustrator I had suggested this way of learning rules a few times for other games, but no one was interested or believed that this approach could work. My experiences with computer games made me think it would be possible. […] In the end I'm very satisfied with it. The heroes in Legends of Andor begin their adventure immediately after the two pages of Quick-Start rules have been read, and then have to fulfill their first (and of course easy) tasks.[140]

Legends of Andor got multiple awards, among others the "Kennerspiel des Jahres 2013" which is awarded to games for more experienced players as opposed to pure family games. In their explanatory statement, the jury remarks positively on the innovative rule organization and the quick start among other things.[141]

5.3.2 Control

One of the major difference between purely physical and purely digital games is that in the latter, the experience is fully controlled by a computer which takes input and uses it as it sees fit. This loss of control for the player means that the experience cannot be changed from what was programmed, but it also has a lot of good sides. Above all, it allows the game to take care of menial tasks automatically and gives players more time to play the actual game itself.

5.3.2.1 Setup Time

Apart from reading the rules, most games still take time to be set up each time they are played: Components have to be placed on the table, cards and other pieces have to be separated and shuffled, players need to get their starting components, the board has to be prepared and similar things.

Digital games need to be installed and for some games the player has to register before she can use them for the first time, but one only has to do that once; afterwards, setting the game up is almost instantaneous.

[140] Fantasy Flight Games, "A Look Inside the Legends."
[141] Spiel des Jahres e.V., "Kennerspiel Des Jahres 2013."

5.3.2.2 Automatic Data Processing

In physical board games, players have to keep track of the score manually. Since the game has full control in digital form, it can do that for the players.

In the same way, the game can quickly find out what the result of an action is, for example, how much damage a player does or how much money he gets.

This allows more calculation-intensive gameplay, but it might come at the cost of transparency: The more the computer has to do, the harder it can be for players to predict what will happen when choosing an action.

5.3.2.3 Information Display

While digital games might make it harder for a player to estimate the result of an action, games can show helpful predictions. Other types of information, like how far an active unit can move or which actions are available, can be shown on demand and hidden when not needed to avoid that the display becomes too crowded.

5.3.2.4 Distance Calculation

Board games are often divided into tiles to make movement easier and to avoid using tools like rulers or other distance measurement devices. Digital games on the other hand can easily measure distances and show the results instantly.

5.3.2.5 Real Time Play

Automatic data processing also allows real-time play since it can instantly compute outcomes and it can limit players action, for example via a cooldown delay or resource usage.

Assassin's Creed Recollections is an example for an iOS card game that uses real-time interaction. Players place cards at any time, but cards need a certain amount of time to execute actions, and the players gain money in timed intervals.[142]

5.3.2.6 No Room for Player Errors

In many complex physical board games, situations arise which either are not explicitly described by the rules or where the rules just are not clear enough. Furthermore, misinterpretations can happen. Since the game flow is executed by the players according to their understanding, the game is accidentally played in an unintended way.

Digital games on the other hand can perfectly control the game flow, leaving no room for player errors.

[142] Assassin's Creed Wiki, "Assassin's Creed: Recollection."

5.3.2.7 Cheating Inhibition

In the same way, video games can prevent cheating (like looking at enemy cards or switching components). In the physical world, the rules are just agreed upon while actually executable actions are only restricted by the laws of physics; in the digital world however, possible actions can be restricted so that players cannot even execute moves that are not allowed by the rules.

On the other hand, technical cheats are now possible, from hacking to digital helpers and automatically playing bots, especially in online play. This is done in a much less casual way though and often requires a lot of knowledge. It also needs uncontrolled access to a device and is, for example, hardly possible when playing together on a touch screen device which the player who wants to cheat does not own.

5.3.2.8 Impartial Judgment

Knowing everything that happens perfectly at any time and favoring nobody, digital games can also easily judge results. Players may not always be content with the results and accept responsibility, but at most times, they can be sure that the result did not occur because the game was missing information (unlike a human judge who might not being able to follow fast movement or might be distracted by something else) or favoring another player. Online play is a bit trickier though; in online play, it is actually possible that information is missing or comes too late to the server or client, which might lead to different clients having different states.

5.3.2.9 Artificial Intelligence

Full control by a computer makes it also possible to play against the computer in the same way one would play against a human player. While that lacks social interaction and sometimes the surprising flexibility a human player has, it can be interesting if one does not like competition, needs a bit of training – or just wants to play a round and does not have a human player available.

There are many physical board games which feature solo play already – and others that pit multiple players cooperatively against the game. These are mostly based on events or randomness via dice or cards to provide progression, intensifying difficulty and reactions. An AI could enhance those reactions, easily providing different progressions or playing styles and give the “enemy” more of a perceived personality and intelligent, informed decisions. Additionally it is much faster – the players do not have to look up tables or move each piece by hand, but the computer can execute its moves instead, just like a real human opponent would.

Due to the processing power available, artificial intelligences can also search a vast amount of possible future game states, and by optimizing for that and using other algorithms, they can provide stronger opponents than most humans would be in some games.

5.3.2.10 Hidden State

Having full control over data also enables computers to work with hidden state in a truly hidden way. Considering a shared screen space, a game could still process what a hidden card does, for example mining one gold nugget per turn which the player can later claim.

This would still be possible with a board game, but in a more work-intensive way: The player could place a token per turn on every hidden card and reveal later if and what those tokens do.

5.3.2.11 Hidden Actions/Communication

When a player has their own device available, they can take hidden actions with the game verifying that this action is actually possible – thereby allowing hidden actions without fearing that the other player cheats.

In the same vein, this could allow communication between players without a third party knowing that this takes place at all. One could use this, for example, to form secret alliances and plan combined actions.

5.3.2.12 Sensors

On another note, digital processing allows games to use sensors and integrate them into the gameplay.

As an example, Surface-poker is a hybrid tabletop game that uses an EEG to show the nervousness of a player to the opposite player, experimenting with how exposing that could alter the way poker is played.[143]

5.3.3 Content

In physical games, all components have to be manufactured and are often stored in a transportable box, thereby limiting amount and size of said components. In digital games, all components are information which can be saved on a very small physical storage and which can even be generated or manipulated at runtime.

5.3.3.1 Storage Capacity

The huge storage capacity that modern devices have enables games to contain much more content than physical games would allow, while still being easily transportable and reproducible.

5.3.3.2 Procedural Generation

Another way to provide content is to generate it on the fly via algorithms – be it just that chunks of content are chained or that everything is generated at runtime.

[143] Dang and André, "Surface-Poker."

The most prominent feature this enables is replayability. Even if a player has already played a game multiple times, the fact that the game features a new map in each round allows him to play the game again without knowing everything about the current map or the game state. Optimal strategies might be different on each map depending on the placement of elements. Additionally, hidden elements can provide uncertainty each time.

Note that many board games feature comparable randomness via event cards and map pieces which are arranged concealed. This is mostly blind though; video games allow the generation to be informed. An example of this could be a map with keys and locks – a video game could create a map in which a solution path is guaranteed to exist, either by algorithmic design or by checking for plausibility after generation. Generation can also easily be tuned to constraints, for example an adventure game in which easier monsters are near the players' starting point and reasonable placement of stronger monsters throughout possible routes with health potions distributed throughout.

Procedural generation also allows the creation of seemingly unlimited maps on which players can play, creating more content on the fly when the player comes near a border.

5.3.4 Presentation

Compared to fully physical board games, digital games also allow new forms of presentation.

5.3.4.1 Animation

Typically, physical board games mostly contain static visual elements. The first thing that digital games can improve here is animation – changing visuals according to actions or game state.

Note that while animated movement of pieces might be more pleasant to look it, it generally should not take much longer than in a hypothetical physical version. If it does it will drag out gameplay – especially when the associated action is executed often.

5.3.4.2 Sound Feedback

Another thing digital games can add is sound feedback. Purely digital games provide no haptic feedback, so sound feedback can serve as a replacement and even add to the game feel to enhance what is seen by the player.

Sound can also more directly contribute to the game – for example, provide instructions. An example of this is Space Alert. It is a cooperative real-time hybrid board game that uses a CD player to serve as the "board computer", working as a timer, giving instructions and informing of threats that alter the gameplay.[144]

[144] Czech Games Edition, "Space Alert Rulebook."

5.3.4.3 Atmosphere

Lastly, changing visuals and added music can greatly increase the atmosphere for a game. Especially in the absence of social interaction (for example in single player mode or real-time online play), this can improve the playing experience.

5.3.5 Logistics

Being digital also changes some of the logistics of playing a game.

5.3.5.1 Location

Popular targets for digital board games are tablet computers. Those usually have a screen smaller than most board games, allowing games to be played on a much smaller table – or no table at all. There are also no pieces that can fall down, allowing a game easily to be played, for example, in the backseat of a car.

Another interesting consideration is that tablet computers attract less attention than board games in a public setting and digital games can often be played faster than their physical counterparts. Soren Johnson writes on that topic: "[…] digital board games require no set-up time or record-keeping, which means that games can be played much faster and in new environments; suddenly, Memoir '44 can be played in a coffee shop without scaring away the other customers."[145]

5.3.5.2 Availability

Not only is the screen smaller than most boards, a tablet computer can also store a multitude of games while still taking less space than a single average game cardboard box. A tablet can essentially be an extensive game collection that can easily be taken anywhere.

Acquiring new games is equally easy compared to their physical counterparts. Those have to be ordered and delivered or bought in a store. Most digital games on the other hand, can be bought in an online store and are instantly available and playable after downloading.

This also has advantages for the developers of the games: No components have to be physically produced, which eases financial strain and gets rid of possible advance payment when manufacturing games before they are sold.

5.3.5.3 Updatability

Being available online and not having physical components that have to be produced also allows seamlessly updating elements to balance the game or to fix mistakes. New content, like for example new maps, can also be easily distributed.

[145] Johnson, "When Digital Versions of Board Games Surpass the Originals."

5.3.5.4 Persistence

With the whole game being digital it is also possible to save the current game state and restore it at a later point without any effort on the players' side. This way, the continuation of a game round can be easily delayed for an indefinite amount of time or the game can be moved to another location.

When physical games have to be paused for a while, they either have to be kept in their state (taking up physical space often not being transportable) or the whole state has to be recorded manually and restored by hand later if the complexity allows for that at all.

5.3.6 Online Play

Digital gaming devices are often connected to the internet which enables playing with people who are not sharing the same room. This enables play with friends who cannot meet personally at the moment, but it also allows strangers to play together.

The mode that best resembles the way physical board games are played is real-time online play. Every player is connected at the same time, taking actions, waiting for their turn and watching the game unfold.

Another mode is made possible by the persistence a server offers: Asynchronous online play. Here, players only go online to make a move and can then leave again, while the next player is notified that it is their turn. This way, a player can take part in multiple games at the same time while still using the downtime to concentrate freely on things not related to the games. It also enables the players to think about their turns as long as they need.

Soren Johnson writes about that:

> Another advantage of digital board games is asynchronous play. One of the challenges of board gaming is finding a way to get people together for long, uninterrupted blocks of time. Asynchronous play circumvents this issue by letting people run games at their own pace; the program simply waits for the next player to make her move.
>
> […]
>
> Optimization while under social pressure to finish faster may not be fun, but finding just the right move to handle a tricky situation is exactly why these types of games are so rewarding. Analysis paralysis, after all, is also known as intense engagement in single-player games! The problem with playing in person is not wanting to slow down the game while also fearing that rushing will lead to the wrong move.

> Both asynchronous and single-player versions of board games solve this problem by giving the player all the time he needs to perfect his plan.[146]

Asynchronous play is not exclusively done online and with digital games, but these properties make it easily accessible, cheap and much faster by instantly delivering and executing other players' moves.

Play-by-mail games have been around for a long time, for example Correspondence Chess for which the Correspondence Chess Bibliography lists games as early as 1822.[147] Rick Loomis describes early games of Diplomacy and similar games being played by mail with a referee and gives a first-hand account of running a play-by-mail company dedicated to managing such games. Some of these games were computer-assisted with a game master interpreting player moves while others were fully computerized.[148]

5.4 Hybrid Games

There are already hybrid games on the market that combine physical and digital components in some form. First some examples will be named where the combination works well or is otherwise noteworthy. Afterwards some common problems of hybrid games will be explained.

5.4.1 Examples

5.4.1.1 Stop Thief

A very early example of hybrid board games is Stop Thief. It was published in 1979 and is a deduction game in which players are detectives that try to catch a thief to get reward money. The first player to get $2500 wins the game. The thief and the players move across the board which contains a neighborhood with streets and subways, and houses with different elements like doors and windows. Interesting is how the thief moves: It happens entirely electronically in a device the game calls an "electronic crime scanner" which simulates the thief moving invisibly over the map – but the devices makes sounds from which players can deduce where the thief has moved, such as breaking windows, footsteps or a using the subway.[149]

In this example, both the physical and the electronic part play a meaningful role. Making the game wholly digital was not feasible at the time it was created and is unnecessary as the physical components work well as they are. Likewise, the electronic part simulates and indicates movement in a way that fits the game well and could not happen without having a player dedicated solely to playing the thief.

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[146] Ibid.
[147] Pagni, Meissenburg, and Harding, *Correspondence Chess Bibliography, 1822-2005*.
[148] Loomis, "The History of Play-by-Mail and Flying Buffalo [By: Rick Loomis]."
[149] BoardGameGeek, "Stop Thief."

5.4.1.2 Dark Tower

Dark Tower is a fantasy adventure board game published in 1981. In this game, players are tasked with defeating the tyrant king in his tower. To achieve that, they are moving across a board with different locations like tombs, ruins or a bazaar. In the center of the board, a physical tower looms – and this tower contains a computer. When a player moves, she can input her location on the keypad, and from there the computer takes over and shows the results via a numeric display and spinning discs with images that light up to show events or give meaning to the numbers, for example "x troops" or "x gold". Sometimes additional input is possible – for example at a bazaar the player can buy warriors for gold, but she chooses that number of warriors and can try to haggle the merchant down.[150] Many actions and events are also accompanied by sounds and the occasional jingle.[151]

In this game, the electronic component could be replaced by dice and lookup tables, but the electronic component gives the game a special flair. Instead of dice throwing, table lookup and keeping up with resources it makes the events look interesting with the visual elements and gives them atmosphere with the sound effects.

5.4.1.3 Space Alert

Space Alert is a cooperative real-time game in which a team of players has to react to various situations and threats that arise while their spaceship is scanning the sector they are in. A complete game consists of the action part and the resolution part. In the action round, players are informed of the arising situations and can react. It takes exactly 10 minutes and is divided into five phases in which players can each perform one action. The action does not happen instantly though – after the 10 minutes, the resolution round begins and players start to resolve what actually happens step by step. This might be different from what they envisioned because players might accidentally block each other on the board, be delayed or it might just not be possible to execute an action due to damage the ship has already taken.[152]

What makes the game a hybrid game is the CD that serves as the "board computer", informing the players of the various events that happen in real time, working as a timer and adding atmosphere at the same time. It has a high number of tracks and it does not announce specific events, but uses decks of cards as a randomizer. The cards are turned over when an event is announced.[153]

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[150] Well of Souls, "The Dark Tower Page"; Well of Souls, "Dark Tower Challenge"; Well of Souls, "Dark Tower Gameplay"; Well of Souls, "Dark Tower Locations."
[151] Farris, "Nostalgia or Solid Game?"
[152] Czech Games Edition, "Space Alert Rulebook."
[153] Ibid.

The CD could be replaced by a player with a timer and a scenario card, but as the reviewer Paolo Ciardulli remarks, "The CD adds a lot of realism to the game and also enhances that sense of confusion and panic that the game creates in simulating a spaceship thrown in very hostile environment for 10 minutes".[154]

Having the missions read by an external source also lends itself well to using an app on a mobile device or computer. There are several fan-made versions available, for example for iOS[155], Android[156] or in the browser via Flash[157] that generate missions, some of them with customizable options.

5.4.1.4 Golem Arcana

Golem Arcana is a tabletop miniatures game in which players place their figures on a grid to fight each other. It features a stylus with an infrared camera that can read microcode on the figures and terrain, thereby identifying them. It transmits data to a smartphone and tablet to display information and allows inputting movement or an attack in the same way.[158]

In their Kickstarter video the creators say that by doing that, they want to improve accessibility to make rules easier to learn, minimize record keeping and shorten the time to play a round without "dumbing the game down".[159]

The focus is on the physical game with the digital companion app serving as a helper and rulebook. On their page, they state:

> Our goal in the design of Golem Arcana is to keep your focus on the figures and the tactical situation on the board and not on the mobile device's screen. We view the use of the device screen like the scoreboard is used at a baseball game presenting the information you need at each moment, including the chances of success of any action, and to guide the players through the phases of each turn.[160]

5.4.1.5 LEADERS: A Combined Game

LEADERS: A Combined Game is a war game that combines a board and pieces with a smart device. The board mainly features troop movements and fights: Information that every player can see. The smart device app on the other hand represents headquarters in which players can take secret actions. Some of them just affect the player himself; others apply to other players like

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154 Ciardulli, "Space Alert - a Different Game Dimension."
155 Play Again Games, "Space Alert Mission Generator."
156 Boarbeard, "Space Alert Mission Generator - Android Apps on Google Play."
157 phipsisoftware.com, "Space Alert - Flash Mission Player."
158 Harebrained Schemes, "Game Overview."
159 *Golem Arcana*.
160 Harebrained Schemes, "Game Overview."

espionage or sabotage – or forming a secret alliance with another player. Each player is informed in his event phase of what happened to him, but not necessarily which player is the source if the action succeeded.[161]

By having secret actions done digitally, players can execute actions and coordinate without giving any information to players who should not know. Additionally, the devices do a fair amount of hidden bookkeeping like how many new troops a player gets in a new turn without allowing players to cheat there.

5.4.1.6 PainStation

The PainStation[162] is a version of pong displayed on a table screen where both players have to put their hands unto what the creators call a "Pain Execution Unit", or short PEU. If a player loses a point, various kinds and levels of pain are inflicted on that player – either her hand is being whipped or heat or electro shocks are applied. The goal of the game is not to win by points, but for the other player to be the first to take her hand away.[163]

While a big part of the gameplay is still purely digital, the players' real bodies are involved in the game and losing a point has real-life consequences. In the end, not only the players' skills in the game, but also their pain thresholds decide the winner of the game.

5.4.1.7 Fingle

Playable on an iPad, Fingle[164] offers the players another kind of physicality: Intimately touching each others fingers and hands. The game is similar to a cooperative Twister[165] but for the fingers: The game has the players touch certain points of the screen with fingers, and then the players have to follow the points' movement without letting go, often touching the other's players hand.[166]

Apart from the other player's hand being an obstacle for gameplay, the physical experience of touching might also be experienced as "intimate" which can provide experiences beyond gameplay. Another physical action beyond normal touch input shown in the trailer[167] is having a third player rotate the device to counter a twisting movement the touch points are doing on screen.

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[161] rudy games GmbH, "LEADERS a Combined Game"; rudy games GmbH, "Regeln & FAQ | LEADERS a Combined Game."
[162] Morawe and Reiff, "The Artwork Formerly Known as PainStation."
[163] McGrath, "No Pain, No Game."
[164] Game Oven, "Fingle."
[165] BoardGameGeek, "Twister."
[166] Game Oven, "Fingle."
[167] *Fingle Gameplay Trailer*.

5.4.2 Problems

One of the main questions that designers have to ask themselves when designing a hybrid game is: Are all physical and digital elements of the game meaningful, or should it rather be fully physical or digital? This can be helped by using the advantages from the physical or digital realm that were listed earlier.

Another thing to keep in mind is how the physical and digital worlds integrate with each other. Is the gap well bridged? Does data transfer between the two worlds happen automatically and fast, does it have detection that does not always work well or does it have to be input manually? The more friction there is, the more it distracts from the actual playing experience.

Some problems that can arise are pretty specific. For example, The Eye of Judgment is a card game where actions are processed via the PlayStation Eye camera on a PlayStation 3. The cards are physical and the publishers want people to buy booster packs, but according to the reviewer Chris Gravelle, cards can be printed from scans as well[168] – which probably hampers sales, and is also a problem in online play since it might give the cheating player an advantage.

Lastly, hybrid games are harder to access if they need components that are not included, like for example smart devices. Players do not only need to own the physical components like in physical board games or only a digital device like in digital games, but they need digital devices and the physical components at the same time. This naturally limits the amount of people who are willing to buy and play the game.

5.5 Pervasive Games

While this thesis focuses on games playable on tabletop, it is still interesting to look at other advantages the physical world and digital extensions brings to games in other genres.

In "Exploring the Edge of the Magic Circle", Markus Montola defines pervasive games: "Pervasive gaming is a genre of gaming systematically blurring and breaking the traditional boundaries of game. The limits of the magic circle are explored in spatial, temporal and social dimensions."[169] Spatial extension means that the game might not be played on a prepared or easily defined playground, but instead for example in a city or on the internet spanning an undefined number of different web pages. Temporal expansion refers to the game session extending into ordinary life, e.g. a game where players carry on with what they would normally do, but then an event like another player executing a play action prompts them to answer in a playful way too. Social

[168] Gravelle, "The Eye of Judgment."
[169] Montola, "Exploring the Edge of the Magic Circle."

expansion blurs the line between players and non-players, letting non-players influence the gameplay, sometimes without them knowing that they do.[170]

5.5.1 Physical Elements

5.5.1.1 Using the Player's Body

A core concept of many of those games is that the player's own body is their avatar – so if they want to move "ingame", they actually have to move. This opens up a wide variety of actions: For example, the players can move at different speeds just as their stamina allows, without the game having to mention different movement speeds explicitly.

This can make a game more immersive and more direct. For example, in a game of Killer one is given a target (who is playing the game, but does not know whose target they are and might not even know the other players) and tries to "kill" it, using things like water guns or substitute knifes such as a banana. On the other hand, the player is also the target of somebody else. Whether one is hunting or is looking around for who behaves suspiciously, it is not just some avatar doing it; the player himself is doing it.[171]

Markus Montola describes this as "immediate experience":

> Looking at the immediacy through the glasses of semiotics, we can say that the experience of immediacy is partially created by an indexical relationship between the physical world and the game world. Sneaking in Killer is accomplished indexically through the act of sneaking; the sneaking player has a direct relationship with the sneaking assassin. Many other games rely on a symbolic relationship, where the action and game world action are connected through a contract or convention; in a board game, you would play a sneaking card to symbolically convey the act of sneaking. Finally, some games use an iconic relationship, where the player and the game world are connected through similarity, like when you push the "up" arrow in order to sneak ahead in digital games.[172]

Apart from being immersive, this direct relationship can also need a lot of play skill; for example in Turtle Wushu, players balance a little plastic turtle on their hand and try to knock down other players' turtles. This game needs a sense of balance while players look around, move and ultimately attack or defend.[173]

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[170] Ibid.
[171] Montola, Stenros, and Waern, *Pervasive Games*.
[172] Ibid.
[173] Invisible Playground, "Turtle Wushu - Ludocity."

5.5.1.2 Using the Physical Environment

Pervasive games can also give the environment new meaning, instantly transforming an ordinary space into a game environment.

For example, the game Mont Trottoir transforms a sidewalk into a mountain that has to be scaled – two steps at a time, with furniture like benches or railings as safe spots one can hold on between turns, otherwise they "fall" back to the home base. Other players that are safe can serve as a safe spot too, even when connected by a rope.[174]

Using the environment can also extend to the people who are in the environment, but not participating in the game.

The aforementioned Mont Trottoir for example has an action in which a non-player needs to be persuaded to temporary take the role of a "Sherpa", holding a rope on which one can move freely without spending steps. Another action calls for the role of a "Yeti", in which a non-player has to do a monster impression, ideally next to the target a player specified – which then "falls" down to their home base.[175]

These non-players could be for example pedestrians who just happen to walk by and do not even know the rules of the game currently going on. Persuading them to take part and do something out of the ordinary becomes part of the game.

5.5.1.3 Using Actors

Some pervasive games use actors. For example, a life role playing game might have characters that are played by people who are not players, but have instructions on how to behave according to their role in the game. As those actors are real-life humans, interacting with them can feel much more immersive than interaction with a digital non player character would allow.

This becomes particularly interesting if the game is for example being played in a city and players are not sure if they are currently talking to an actor or somebody unrelated to the game.

5.5.1.4 Integration into the Ordinary Life

Pervasive games often are not played from start to end in a single defined session, but fade in and out according to the state of the game while players go on with their ordinary life.

The already mentioned game Killer is a good example for that, as the assassin might strike at any time, for example on the way to the target's workplace.[176]

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[174] Fono, "Mont Trottoir - Ludocity."
[175] Ibid.
[176] Montola, Stenros, and Waern, *Pervasive Games*.

Another example is BotFighters, a game played on mobile phones in which one can attack the other player's bot when one is physically close enough to them – at any time that happens.[177]

5.5.1.5 Integration of Real-World Events and Data

The game can be influenced by events happening in and other data applying to the real world.

Hollywood Stock Exchange® (HSX for short) is a web-based game that uses virtual money to buy and sell virtual shares of movies, stars and other Hollywood-related things. It uses real-life data, which allows the players to base their predictions on any information they can acquire – making it much more complex than most purely digital games as the changes are based on real-world events. It also blurs the line between ordinary life and the game in that any information the player gains (for example, reading an article in the newspaper or watching a trailer) can influence their ingame actions.[178]

5.5.2 Digital Elements

5.5.2.1 Usage of Media

Firstly, the use of technology allows the games to use real-world media like websites or telephone calls.

As an example, The Beast was an alternate reality game that used fabricated websites to immerse players and to hide clues that players needed to progress further into the game.[179]

5.5.2.2 Communication between Players

Technology also allows players to communicate even if they are not near each other – for example via mobile phones in a game that spans the whole city, or in forums and chat in a game that is played online/internationally over a longer amount of time.

The aforementioned The Beast used puzzles that are too hard to be solved by a single player. Instead, whole forums were dedicated to solving them, with many players giving their insights.[180]

5.5.2.3 Processing, Sensors and Data Usage

Digital elements can also enable gameplay as already mentioned in the chapter "Digital Advantages" (page 42ff.), e.g. by processing complex data, introducing uncertainty by furthering the gameplay procedurally on its own or by using sensors or other data sources as input.

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[177] Ibid.
[178] HOLLYWOOD STOCK EXCHANGE, "HSX.com – Help : What Is HSX?"; HOLLYWOOD STOCK EXCHANGE, "HSX.com – Help : The Basics"; Montola, Stenros, and Waern, *Pervasive Games*.
[179] Montola, Stenros, and Waern, *Pervasive Games*.
[180] Ibid.

An example of this is again BotFighters which uses location-based data to notify a player that a fight is possible because another player is physically close, processes the fight itself and persistently stores the results.[181]

5.5.3 Pervasive Hybrid Games

To illustrate the points previously mentioned, this chapter describes two pervasive games that use both physical elements and technology. There are many more; those two just serve as an example, with one being local multiplayer and centered around physical body contact and the other one being an massively multiplayer location-based game.

5.5.3.1 Johann Sebastian Joust

Die Gute Fabrik describes their game Johann Sebastian Joust as a "no-graphics, digitally-enabled playground game designed for motion controllers"[182]. Each player gets a motion controller and music is played. The faster the music plays, the faster the players are allowed to move, and vice versa. If one moves their controller too fast, they are out of the game – this can be the fault of the player himself, or it can be that another player attacked him by pushing his body, making him shake his controller. The goal is to be the last player standing.[183]

Figure 6: A player is attacked in Johann Sebastian Joust (Photography by Brent Knepper[184])

Because this is partly a physical game in which the players' bodies play a vital role, these simple rules (basically only "Do not move your controller faster than the music moves.") make for intricate gameplay – the actions players take, like keeping balance, pushing, shoving, hitting,

[181] Ibid.
[182] Die Gute Fabrik, "Johann Sebastian Joust."
[183] Ibid.
[184] Knepper, "Brentknepper.com."

defending, moving towards and away from other players, teaming up or watching other players are not defined by the game itself, but actions that the players can take because the game is played in the real world.

5.5.3.2 Ingress

Ingress[185] is, as the blogger Albao puts it in an article, an "augmented reality massively multiplayer online GPS-dependent game"[186]. Players choose one of two factions and move through the real world to claim, hack or attack so-called "Portals", link them together to create a "Control Field" and ultimately gain "Mind Units" for their teams. The game is much more involved than this, with items, portal modifications, weapons and more actions than listed above, but for the context of this thesis, this description shall be enough.[187] More information can be found on the official Google help page[188] or the Ingress Manual on DecodeIngress.me[189].

The gameplay of physically moving around is not the only element that makes the game pervasive. Ingress has a rich storyline that is told through cryptic clues on NianticProject.com[190] and the companion Twitter account[191]. Current events in the community and updates are also told through a realistic/futuristic-looking news report called "Ingress Report" on the Ingress YouTube channel[192] and other video footage. All of those are made in a way that does not stress the fact that it is a game – the players are meant to feel like agents of the two opposing factions. As the Ingress trailer "Ingress - It is Time To Move" mentions: "Ingress is not a game."[193]

Ingress inspires people to build communities and to work together. As Albao says in his blog entry: "I myself have met people from different places whom I never would have had the chance to meet and interact with if not for Ingress. This game became a reason for me to travel more, be more open to friendships and teamwork, and write this article with much excitement for Filipinos, gamers and non-gamers alike."[194] Others are similarly influenced to do things out of the ordinary in real life, like a player chartering a plane to a town Alaska just to execute a powerful ingame action[195], players in hostile countries creating a control field across real life closed borders[196] or climbing the highest mountain in Taiwan to claim a portal there[197].

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[185] Niantic Labs, "Ingress."
[186] Albao, "Ingress."
[187] Niantic Labs, "Initial Briefing - Ingress Help"; Decode Ingress, "Ingress Manual."
[188] Niantic Labs, "Ingress Help."
[189] Decode Ingress, "Ingress Manual."
[190] Niantic Labs, "Niantic Project."
[191] Niantic Labs, "Niantic Project (NianticProject) on Twitter."
[192] Niantic Labs, "Ingress - YouTube."
[193] *Ingress - It is Time To Move*.
[194] Albao, "Ingress."
[195] Totilo, "A Game You'd Go To The Ends of the Earth To Play."
[196] *Resistance Claim #Minotaur | INGRESS REPORT - EP20*.
[197] *What Is #13MAGNUS? | INGRESS REPORT - EP27*.

6 Game Concepts

To put the design advantages found in the previous chapters into a practical context and to evaluate their usefulness, prototypes were produced which use selected concepts. Each of these prototypes combines physical and digital components to form game experiences which are a) not possible in a purely physical setting and b) diminished in a purely digital setting. The digital components in each game make it impossible to create a physical version of the game without changing core mechanics. The physical components are believed to improve the game experience. To test that assumption, each prototype also has a purely digital counterpart which tries to stay as close as possible to the hybrid version.

6.1 Finger-Flicking Game

The first prototype is a real-time two-player versus game which combines the physical concept of flicking discs with one's finger with digital real-time score counting.

6.1.1 Concept

The game consists of these elements:

- A starting zone for each player to the left and right where the player places new tokens.
- Tokens, which are flicked by the player towards the scoring areas. The digital representations of the tokens are directly underneath the physical tokens placed on the table. (See Figure 9.)
- Scoring areas with a certain value.
- A timer, which allows for new tokens to be placed every 10 seconds.

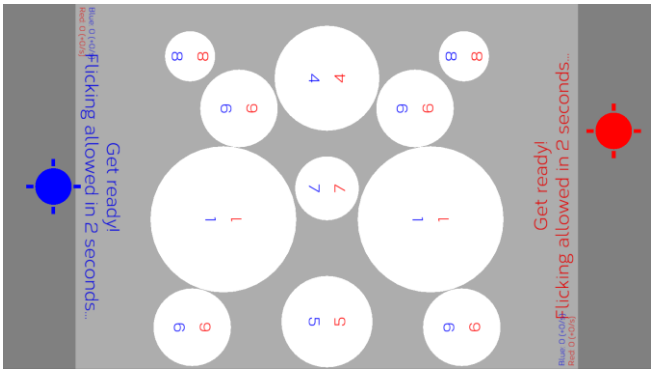

Figure 7: A screenshot the beginning of a round: Players prepare to flick their discs.

At first, each player must place one token, and after a short cooldown, both can flick the token towards the scoring areas in the center part of the playing field. Each second, scoring areas give score points towards the player with the most tokens touching it. Every 10 seconds, each player can place an additional token. After 40 seconds, the game is over and the player with the higher score wins.

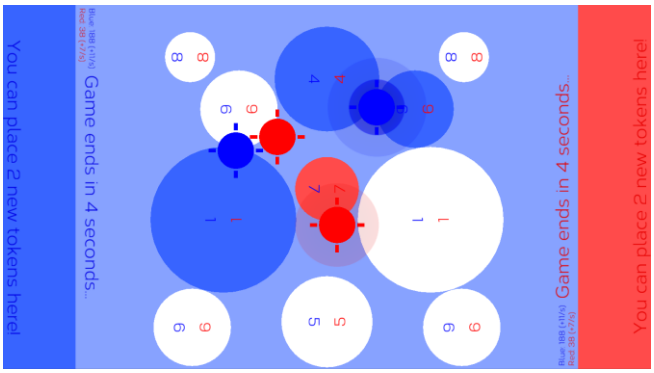

Figure 8: Tokens scoring. Blue gets 11 points per second, Red gets 7p/s. The area with the 6 does not score because no player has an advantage there.

The real-time element adds time pressure and a strategic to the game. Each player has to decide when it is best to flick the next token: Should she flick immediately so the token can start scoring? But if she does, the other player might flick towards her token afterwards – and because the tokens are physical, it might knock her token out of the scoring area. If she currently has a score advantage, she might want to wait until the other player flicks. Or she might just target a location close to her side of the table so that the other player cannot easily hit it. The players also have to choose a target carefully because multiple scoring areas can be touched at the same time – but some locations might be easier to hit than others.

6.1.2 Physical Part

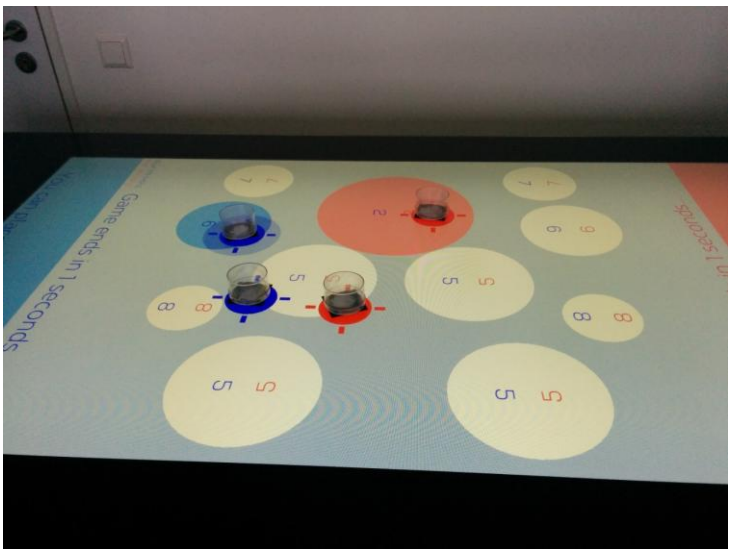

Figure 9: The physical tokens of the Finger Flicking-Game on the touch table

The game uses physical tokens to be flicked. Those tokens are believed to be more engaging than using a purely touch-enabled version by adding tactile sensations and real-life interactions between the tokens on the table. It is also believed that it is easier to get used to how much force is necessary to flick them towards target locations because of the player's intuitive understanding of naïve physics and because of the haptic feedback the tokens give the player.

6.1.3 Digital Part

The main digital parts are a) the real-time scoring and b) the timer which allows the placement of new tokens. While the latter could be emulated in a purely physical version by using a clock, the digital version is clearer and enforces the rules by prohibiting the placement of tokens on the table when or where one should not. The real-time scoring cannot be easily transferred into a purely physical version without either making it turn-based or adding a human judge assisted by counting tools.

The digital part also contains elements that make the game easier to understand, e.g. the background is tinted in the color of the player which currently has more points, and tokens which are scoring higher amounts emit bigger visual "waves".

6.1.4 Purely Digital Touch-Based Version

In the touch-based version, the interactions with the physical tokens are replaced by interactions with the digital representations:

- Moving a token inside the starting zone is possible by tapping the token once, then dragging it and lifting the finger at its destination.
- Flicking a token with the finger was replaced by a swiping gesture (touching a token, dragging swiftly in a direction and lifting the finger).

It was also tested to replace the flicking with a slingshot gesture (dragging the token back, as if pulling back a slingshot, and then "letting go" of the slingshot by lifting the finger), but the swiping gesture felt closer to the physical version.

6.2 Spaceship Game

The second prototype is a real-time two-player cooperative game. It uses tokens which are physically connected to each other. The tokens represent parts of a spaceship, which players need to control to get rid of attacking enemies.

6.2.1 Concept

The core of the game is the spaceship which the players manipulate. It consists of the mother ship and connected satellite components. The mother ship and the satellites are physically laid out on the table and control the position and rotation of the digital representations directly underneath them. The satellites are connected to the mother ship with physical constraints, which means that if a player moves a satellite and is not careful, the force can also affect the mother ship and other satellites. Each player gets to move two satellites, so they have to communicate when they want to make big movements, especially when they want to move the whole spaceship.

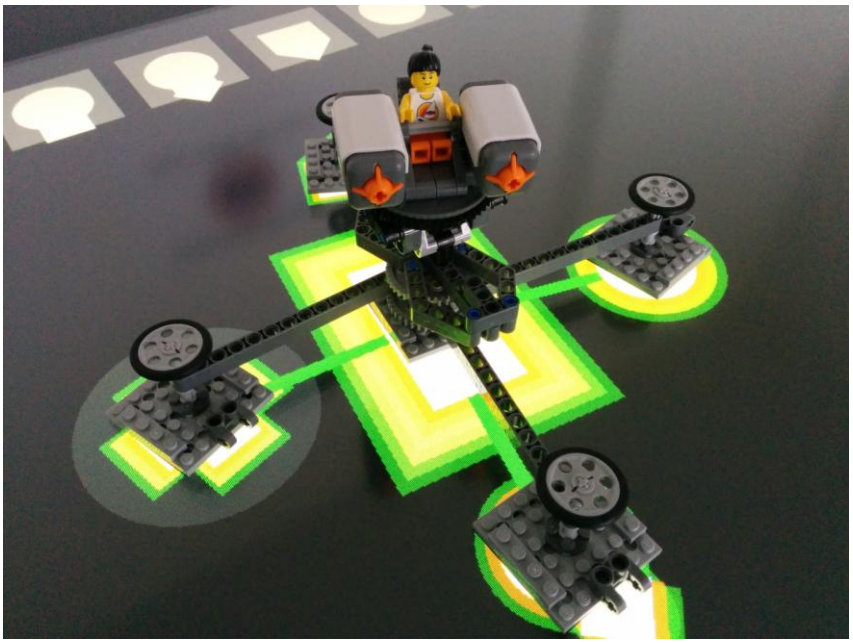

Figure 10: The physical construction for the Spaceship Game.

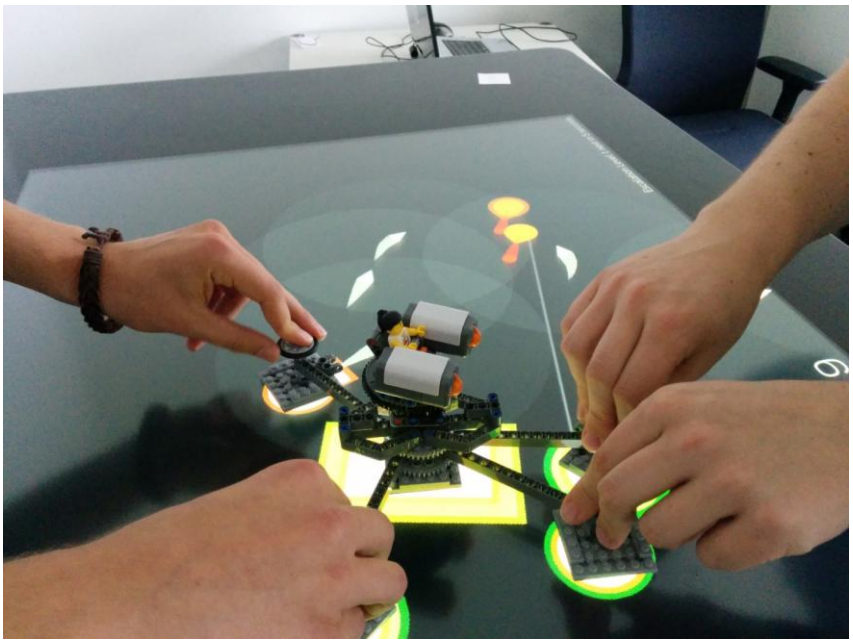

Figure 11: Cooperatively playing the Spaceship Game.

The digital representations are directly underneath the physical components and show the hit points of that part (the colored layers around the white representations) and which function was assigned to each satellite. When hit by a projectile or by an enemy, the mother ship or satellite loses a hit point. If they have no hit points left, they explode.

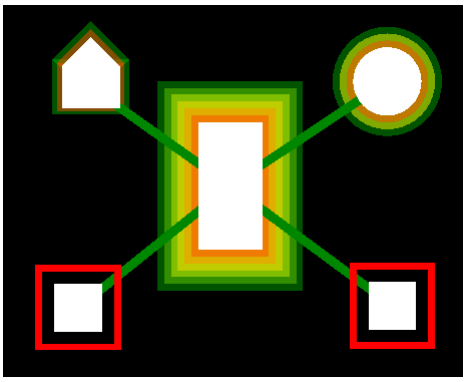

Figure 12: A screenshot of a spaceship with a shooter, a shield and two unconfigured satellite components.

The game starts with the preparation phase in which the mother ship and its satellites are placed on the table. At that point, the satellites do not have a function assigned to them – this can be done by dragging digital role tokens next to them.

Figure 13: The roles satellites can fulfill. Left to right: Shield, Shooter, Laser, Rocket Launcher and Repairer.

The first role is the Shield. Normally, when the mother ship or a satellite loses a hit point, that hit point is gone for good. The shield on the other hand recharges its hit points every few seconds and is useful to block enemy projectiles.

The Shooter shoots bullets straight in the direction it is facing. The bullets travel very fast, so the Shooter is good on quickly hitting weak enemies that just entered the playing area.

The Laser shoots a continuous beam of energy for a few seconds and then has a few seconds cooldown until it shoots again. The beam does a lot of damage and can also destroy bullets and rockets.

The Rocket Launcher shoots slow-moving rockets in its facing direction. They are slightly homing: When the rockets come near an enemy, they change course towards that enemy. The Rocket Launcher shoots more rapidly than the Shooter, but the rockets take more time to reach the enemy, which is sometimes detrimental.

The Repairer continuously regenerates the hit points of nearby satellites.

Once the spaceship is fully configured, the round can start. Enemy groups will spawn one after another; sometimes only a single enemy, sometimes bigger swarms of enemies.

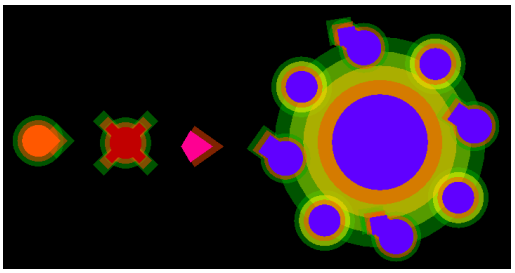

Figure 14: The 4 enemies. Left to right: Straight, Swarmer, Jumper and Behemoth

Straight goes, as the name suggests, straight towards the players' mother ship and shoots bullets in an interval at it.

Swarmer comes in from the sides and then circles around the playing area in a huge circle, regularly attacking with rockets.

Once Jumper appears, it waits a few seconds and then flies swiftly directly towards the mother ship. It has only to be hit two times to destroy it, but it is shortly invincible after being hit, so if it is not hit before colliding with the mother ship, it will do damage, go right through, and repeat the process again. It has to be dealt with quickly.

Behemoth is a big multi-part enemy, comparable to the players' mother ship and its satellites. It slowly rotates and circles around the playing area, regularly firing lasers and rockets at the players' mother ship.

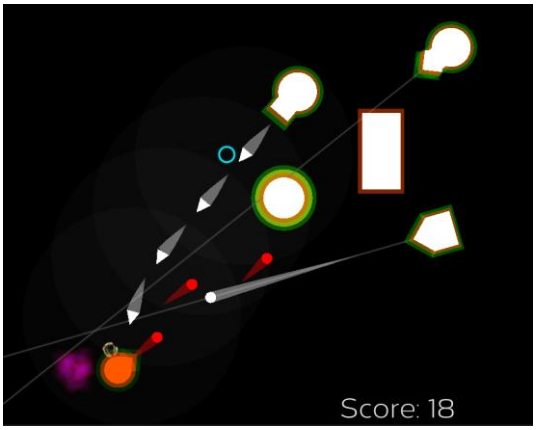

Figure 15: A swarm of enemies has been decimated to only one. The enemy bullets will hit the shield.

Destroying an enemy gives the players score points according to the enemy difficulty. Enemies are spawned at random and get progressively more difficult the longer the round lasts. The round ends when the mother ship lost all of its hit points. Until then, new enemies are spawned, so the game cannot be "won"; players just strive for a high score and to survive as long as possible.

6.2.2 Physical Part

The game considers the satellites to be a movable part of the spaceship. This is reflected in the physical components, which physically connect the mother ship and its satellites. This allows a player to get tactile feedback on his actions and those of the other player when the part currently touched is being pushed or tugged at. The feedback is believed to make it easier to cooperate. The physical parts might also make it easier to precisely move and aim the satellites.

6.2.3 Digital Part

The game simulates enemies coming at the player in real-time while also operating weapons, moving projectiles, resolving collisions and keeping track of hit points. This cannot be reasonably done in a non-digital tabletop version while keeping the real-time element.

6.2.4 Purely Digital Touch-Based Version

The touch-based version only uses the digital representations of the tokens, which can be moved and rotated by touching them. Rotating is possible by placing two fingers on an element and turning them around an imaginary focus point. Elements that need to be rotated (like the Shooter) have bigger touch areas than the Shield or Repairer which work the same at any angle.

Figure 16: Touch areas in the purely digital touch-based version of the Spaceship Game. The right one is not visible because it has only the size of the Shield – it does not have to be rotated.

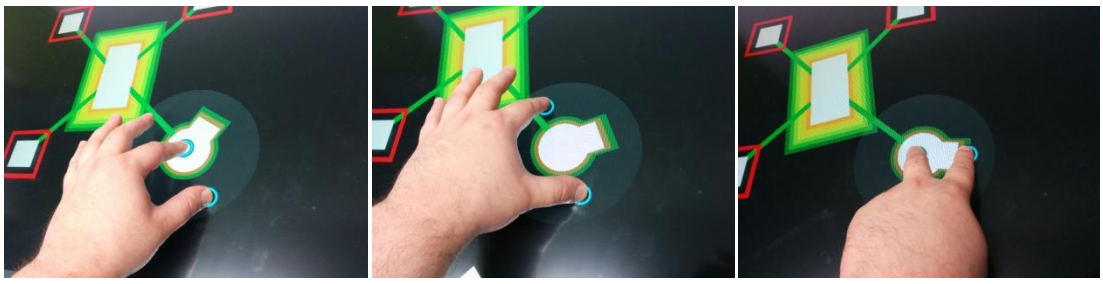

Figure 17: Different touch styles are possible to rotate the satellite.

6.3 Duel Game

The third prototype is a turn-based two-player versus game about hidden information. Players have five different hidden tokens with different abilities to attack, defend and find out information about the tokens of the enemy. Physical paper screens shield the token information from the eyes of the other player while still allowing both to play vis-à-vis on the same screen directly using the same physical tokens. The game ends when one player has lost all of his tokens.

Due to the game mechanics used (hidden information and bluffing) this game is the most complex of all the prototypes.

6.3.1 Concept

6.3.1.1 Game Areas

The Duel Game consists of two main parts: The player information areas and the playfield in the center. The player information areas are to the left and right, with the left part showing logs of what happened (e.g. “Enemy token #4 attacked your Guard and dealt 4 damage.”) and the right part giving information about the current phase and allowing input like skipping movement or secret actions. In the center playfield, the tokens are placed and moved.

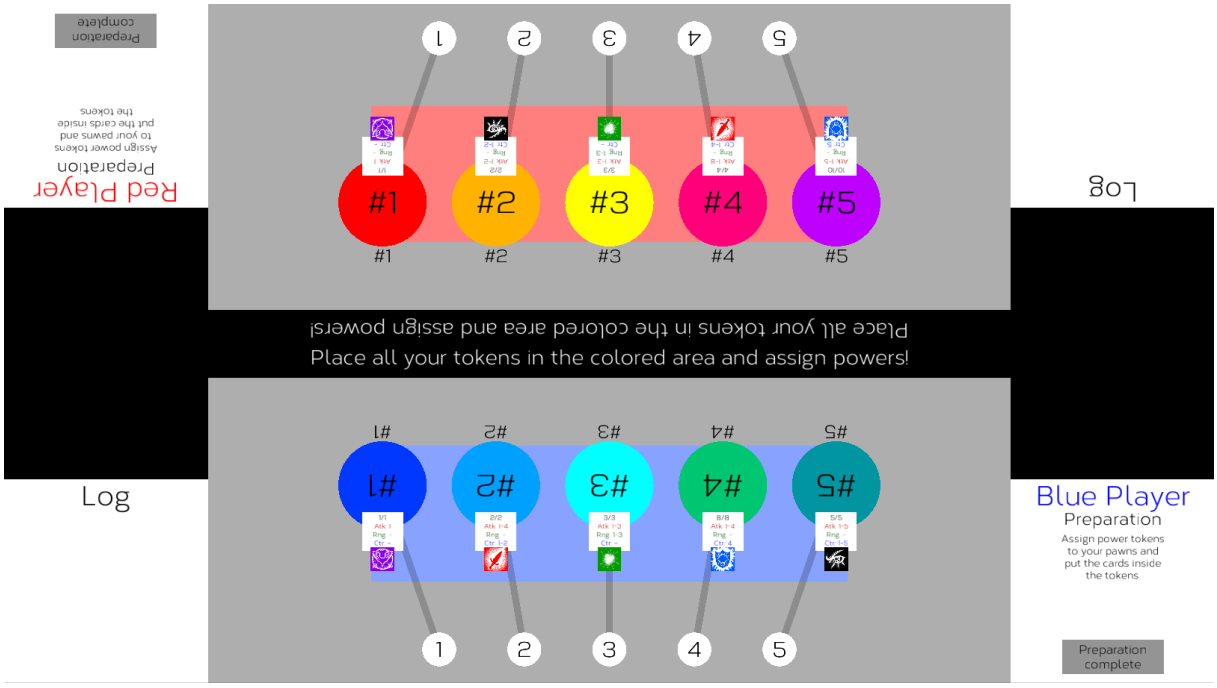

Figure 18: Preparation phase. The colored circles are digital representations of physical tokens with information in the white boxes, hidden from the enemy by physical screens. The little numbered white circles are powers that can be dragged around.

6.3.1.2 Preparation Phase

The game starts with the preparation phase. All physical tokens are placed on the table and the five token roles each player has are randomly assigned to the tokens. Then, players assign levels from 1-5 to their tokens to determine how strong each token is.

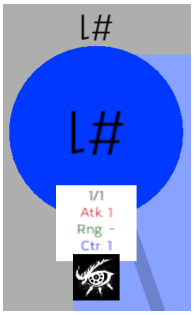

Figure 19: A close up of a token with the role Spy, with health, melee attack, ranged attack and counter attack values. The role icon will be hidden once the physical stand-up is in place and the preparation phase ended.

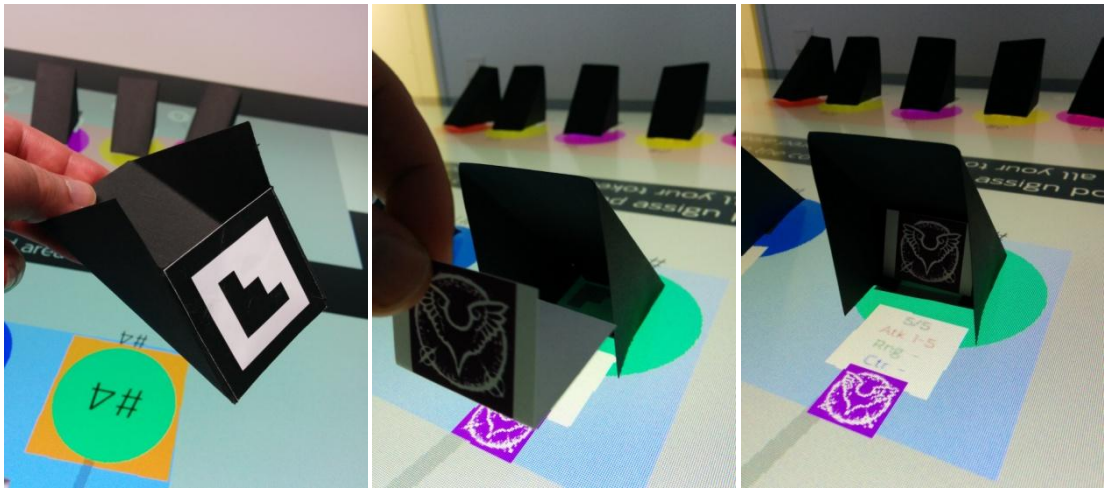

Figure 20: Putting the token role info inside the physical Ninja token.

When the players are done with that, they put the little token role info cardboard stand-ups inside the token screens. Once the preparation phase is complete and the stand-ups are inside the token screens, the icon will vanish. (If it would not, the cardboard screens would need to be bigger.)

6.3.1.3 Placement Phase

Once both players finish the preparation phase, the starting player is chosen – either randomly, or by some other way, e.g. "the loser of the previous game can choose".

Afterwards, the starting player places his tokens freely on his side of the board. Once he is done, the other player does the same, and the game begins.

6.3.1.4 The Five Token Roles

The fives roles, briefly described:

- The Berserker does most melee damage. It can counterattack.
- The Guard has most health (i.e. it take most hits), does melee damage and his counterattacks always hit for full force instead of with a random amount of damage.
- The Marksman can attack from a distance as well as in melee range, but cannot counterattack.
- The Ninja can try to jump out of any attack before it hits, even ranged attacks and counterattacks. It can also switch with any other token once per game.
- The Spy can get information about enemy tokens.

For more details on the roles, see Appendix B: Duel Game Role Overview (page 110) which was given to players so they can quickly check while playing.

Details on how the game's turns work, how ranged attacks are targeted, the ninja switch (allowing the ninja to switch with another unit) and how the game deals with the first move advantage can be found in Appendix C: Duel Game Details – Player Turns, Ranged Attacks, Ninja Switch, First Move Advantage (page 111).

6.3.2 Physical Part

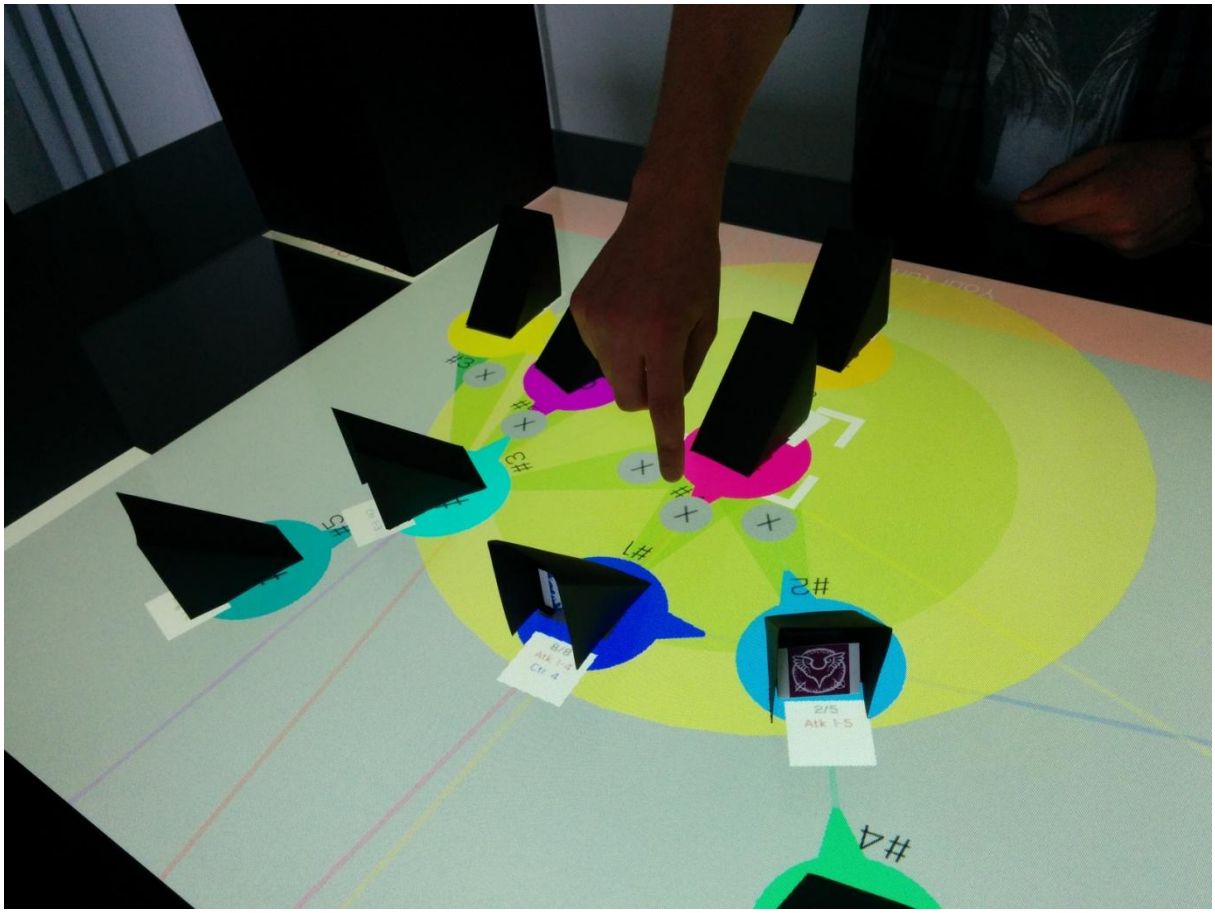

Figure 21: The cardboard screens on the tokens and the bigger ones in the corners hide information from the enemy while still playing on the same playing field.

Apart from being tangible tokens, the core physical part of this game are the cardboard screens that prevent the enemy from seeing information hidden on the screen behind one's tokens and in the information areas. This allows to players to play vis-à-vis on the same playing field without any indirection like looking away – and still have hidden information.

6.3.3 Digital Part

The rule set of interactions and reactions of this game is a bit complicated. The game alleviates this by keeping track of phases and reactions. So far, this could be done in a physical game too though, but there are some elements that cannot be reproduced in a physical game without having another player who serves as a judge and mediates those elements in secret.

The first of those parts are the fights. Each player knows how big the range of damage they deal is – for example, 1-6 damage – but they do not know how much damage they actually dealt. ON the other hand, the enemy knows how much damage they took, but not the range of damage the token could have dealt. There is no non-electronic way to reproduce this and keep track of it without giving the other player information, like for example what kind of dice has to be used. (It could for example be reproduced by having a device in which one can input any range, and which then calculates a random number in that range with a delay, so one can let one's opponent see and execute it.)

Another part is the Spy. With the Spy, a player can get information about enemy pieces without the opponent even knowing that she was spied upon.

Lastly there is the ninja switch, allowing the secret switching of the ninja with another character exactly one time per game. It could probably be reproduced in a physical way, but would present an incredibly easy way to cheat unless done correctly (i.e. only executable once and saving the exact time so that no player could pretend that a switch did not happen if it is inconvenient to him).

In the end, a physical version would need to change core parts of the game, employ non-trivial components, or a judge which executes secret actions.

6.3.4 Purely Digital Touch-Based Version

Unlike the other two game prototypes, in this prototype the physical tokens could not be just straight up replaced with digital tokens because of the hidden information. The closest digital representation would use two touch screens that are angled in a way that each player can see only one – a layer of indirection, but the players could still stand in front of each other. Because of time constraints, an easier solution is used: The game is just displayed two times on the touch table, one for each player with their respective information, and a physical cardboard screen is

dividing both areas it in such a way that each player can only see their side of the screen – thereby effectively simulating two screens. An unwanted side effect was that the game display became smaller. Apart from this, the game stayed the same.

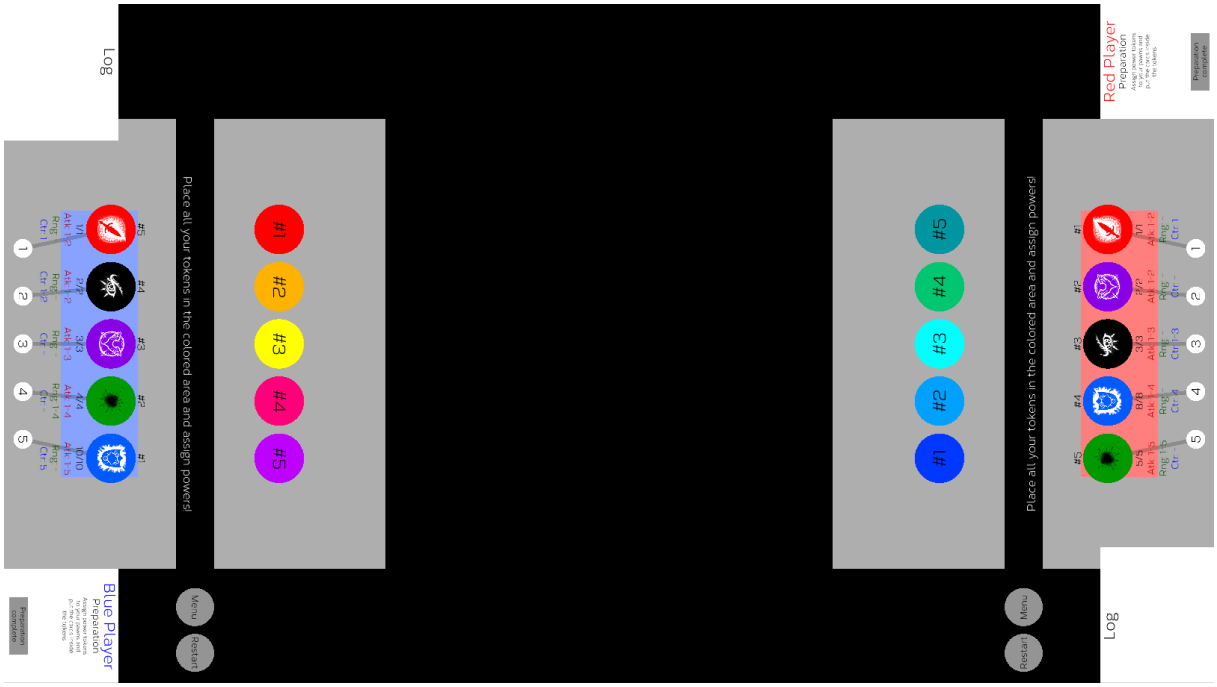

Figure 22: A screenshot of the touch version of the Duel game

Figure 23: The physical cardboard boxes divide the screen, making it effectively a two-screen game.

7 Implementation

7.1 Technical Foundation

7.1.1 MultiTaction Cell

The device used to implement the prototypes is a MultiTaction Cell multitouch table. It has a 55" LCD display and can recognize touches and fiducial markers via infrared cameras. More information about the technology behind it can be found in the chapter "MultiTaction" in the Tangible User Interfaces and Tangible Interaction section (page 24).[198]

7.1.1.1 Challenges

While a multitouch table such as the MultiTaction Cell provides many new opportunities for tangible interaction, it also provided some challenges.

Firstly, the cameras inside the MultiTaction Cell form a grid. On the edges and especially at the points where four cameras meet, the marker recognition is sometimes compromised, not recognizing markers at all or misrecognizing markers as having another marker ID[199]. Since moving markers around on the table often crosses those borders, markers are at times lost and are later recognized with another session ID. Sometimes the marker even reappears with another marker ID. These cases have to be dealt with in the application.

Another challenge are the physical markers themselves. Markers should not just be printed and used in their thin paper version because when the markers are moved on the table, having fingers and hands too close to the table around the markers lowers the recognition quality. Therefore, the markers should be attached to objects that are a few centimeters high to make moving the markers without coming close to the table surface possible.

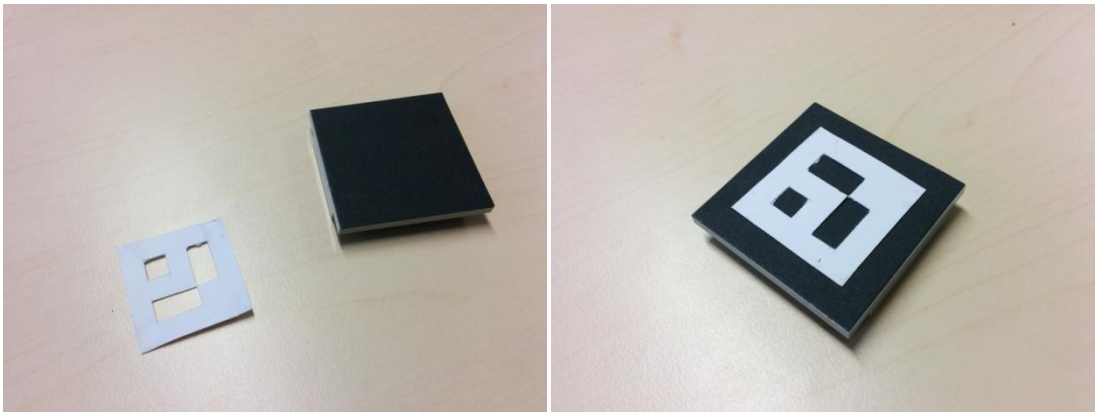

Figure 24: Markers made from black construction paper and white cutouts.

[198] MultiTouch Ltd., "MultiTaction Cell Displays."
[199] A number assigned to the pattern of the marker.

It also turns out that it is very important that the material used for the markers is well chosen. Even printed with a laser printer on thicker paper, the recognition often did not work well. It was vastly improved once the white parts of a marker were cut (by hand) and glued on black construction paper – see Figure 24. The hypothesis is that the deeper black color and the opacity of the construction paper lead to better recognition; meanwhile, small imprecisions due to cutting seem to be no problem.

If markers have a white part around their black border, the recognition worsens. (Note: This mostly applies to the laser printed markers. Construction paper markers were much more reliable even with white parts around them, but this was discovered too late to change the prototypes.) This makes it a challenge to design a card-based game in which the played cards should be secret – the information what a card does cannot be printed on the marker side to ensure recognition, but printing on the backside would expose the information to the other player once the card is played (and the marker side would be revealed too while the card is held in the player's hand). A possible solution is printing the information on the backside and placing tokens over the markers once they are put on the table to obscure that information – and taking care of not exposing the backside to the other player while holding it in one's hand by using a cardboard screen. This obscures the information for both players though once put on the table. Another solution is to replace the cards with tokens that look like this:

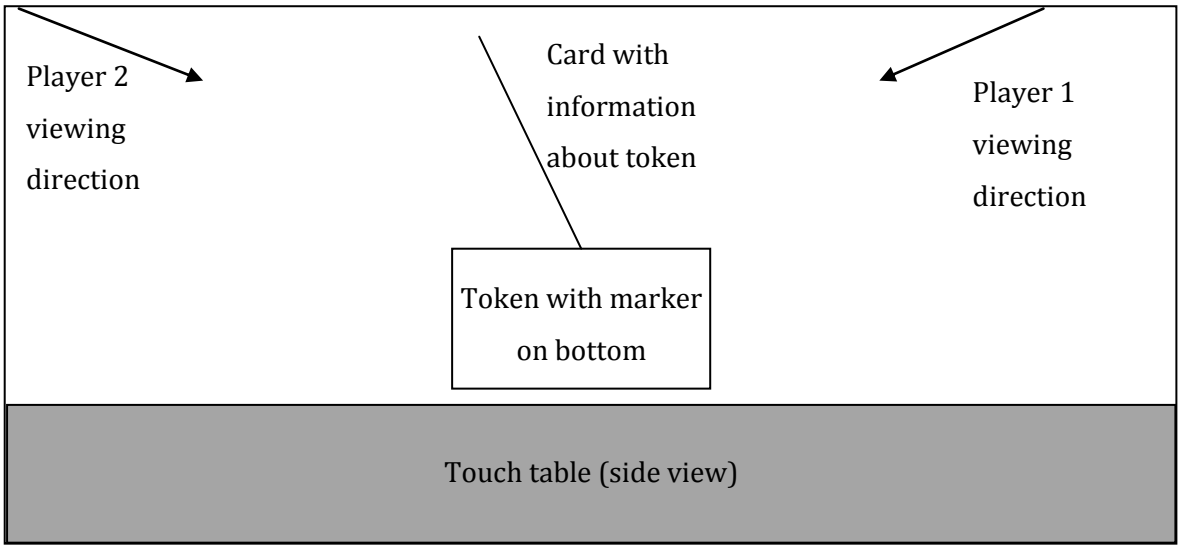

Figure 25: A token that only shows information to one player

This way, only player 1 can see what the token does, and she can easily access that information at any time. Unlike cards, those tokens cannot be drawn from a pile though.

Another problem both of these solutions have is that markers might be recognized as another marker – but unlike games without hidden information, the screen cannot show an indicator of which ID the marker was recognized as because that information should be known only to one player. Ultimately, the solution was to construct something akin to Figure 25, but with an additional cardboard screen that hides digital screen information directly behind the token. An image of this can be seen in Figure 20 and Figure 21 (pages 68 and 69 respectively).

Marker recognition is worse when the black part is not quadratic but round. This would have been desirable for a finger-flicking game. Having the round part in another color like white worsens recognition even more. Using a translucent material for the rounded part of the markers works well.

Not only markers, but also touches experience problems when crossing the border. They are immediately recognized again, but report a change in the session ID, which an application usually interprets as lifting the finger up and putting it (or another finger) right down again. When moving slowly, the position is close to the old position though, so a slight delay in dealing with the end of a touch and using new touch information to restore the touch state can fix this problem.

Touches are sometimes recognized when a finger is close to the surface despite not touching it. An application can deal with that by introducing a delay when pressing buttons to avoid them being pressed accidentally.

While the official product page lists sensitivity to external lighting as "eliminated"[200], the table seemed to work much better when sunlight, whether direct or indirect, was blocked out by blinds.

7.1.2 Unity3D

Unity3D[201] is a game engine that enables the rapid creation of 2D and 3D games. Apart from being an extensive library, it also comes with an editor which allows the composition of scenes (which can represent levels, or game states like a menu) out of game objects.[202]

A game object has a position, a rotation and a scale and can contain other game objects in a hierarchy. It can also have and components. Many different things can be a component– like a mesh renderer, a light, an audio source, an ingame camera or a user-written piece of code (in C#, in a JavaScript variant or in Boo) that gets executed per frame and has event methods that are

[200] MultiTouch Ltd., "MultiTaction Cell Displays."
[201] Unity Technologies, "Unity - Game Engine."
[202] Unity Technologies, "Unity - Integrated Editor."

automatically called. This allows Unity3D projects to be very flexible by writing small, modular components that can interact with each other and compose bigger game objects.[203]

There are also "prefabs": Game Objects that are saved as sort of a template and that can then be shared among multiple scenes or be created at runtime.[204]

Unity3D is used in to create the prototypes in this thesis mainly because it enables prototypes being built very rapidly. The editor allows tweaking exposed variables in scripts without recompiling. It also has great debugging capabilities: The game can be executed right in the editor and paused at any time to inspect all the game objects and their current states and optionally modify any values.[205]

Code can be written in any text editor, but SyntaxTree/Microsoft provide integration into Microsoft Visual Studio with their Visual Studio Tools for Unity – allowing for example to display the error console in Visual Studio and debugging with breakpoints.[206]

7.1.3 Libraries and Tools

7.1.3.1 Uniducial

Uniducial[207] is a library that serves as a good entry point to using markers with TUIO-based multitouch tables. It uses the C# TUIO Client Reference Implementation[208] to receive the TUIO stream and provides an example implementation on how to transfer the events received into the Unity coordinate system.

When the MultiTaction surface reevaluates a marker and its marker ID changes in the progress, it just keeps the session ID and updates the marker ID via TUIO. The TUIO Client Reference Implementation does not support this per default, but it was possible to add this functionality with minimal changes to the TuioClient class. To enable the using application to deal with it properly, two events are now sent from the TuioClient instance in case a marker is reevaluated: A removal of the old marker with the old marker ID and an addition of a new marker with the new marker ID, while still keeping the session ID.

This is similar to what MultiTouch seems to be planning for a firmware update.[209]

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[203] Ibid.; Unity Technologies, "Unity - Scene Building"; Unity Technologies, "Unity - Scripting."
[204] Unity Technologies, "Unity - Scene Building."
[205] Ibid.; Unity Technologies, "Unity - Integrated Editor"; Unity Technologies, "Unity - Rapid Iteration."
[206] SyntaxTree, "Visual Studio Tools for Unity."
[207] Gröschel, "Uniducial - Fiducial Marker Support for the Unity3d Engine - Google Project Hosting."
[208] Kaltenbrunner, "TUIO Implementations."
[209] Wehrum and esa MultiTouch Ltd, "Triggering a Refresh of Wrongly Recognized Marker IDs?"

7.1.3.2 TouchScript

TouchScript is a multitouch library for Unity that comes with a set of pre-defined gestures and unifies multiple sources, like mouse, native touch or TUIO.[210]

To make the TUIO integration run with Uniducial (which already opens a socket to listen for TUIO data), a custom TUIO input source class had to be written.

7.1.3.3 DOTween

DOTween[211] is an "animation engine": It allows animating properties like position, rotation or color from to other values over time without much effort.

7.1.3.4 reacTIVision TUIO Simulator

To develop without always having the touch table present, the Java based standard TUIO Simulator application listed on the TUIO implementation page[212] was used. It serves as a TUIO server, allowing the simulation of a multitouch table with marker recognition by creating markers that one can move around and rotate with the mouse. Simulating multiple touch points is also possible.

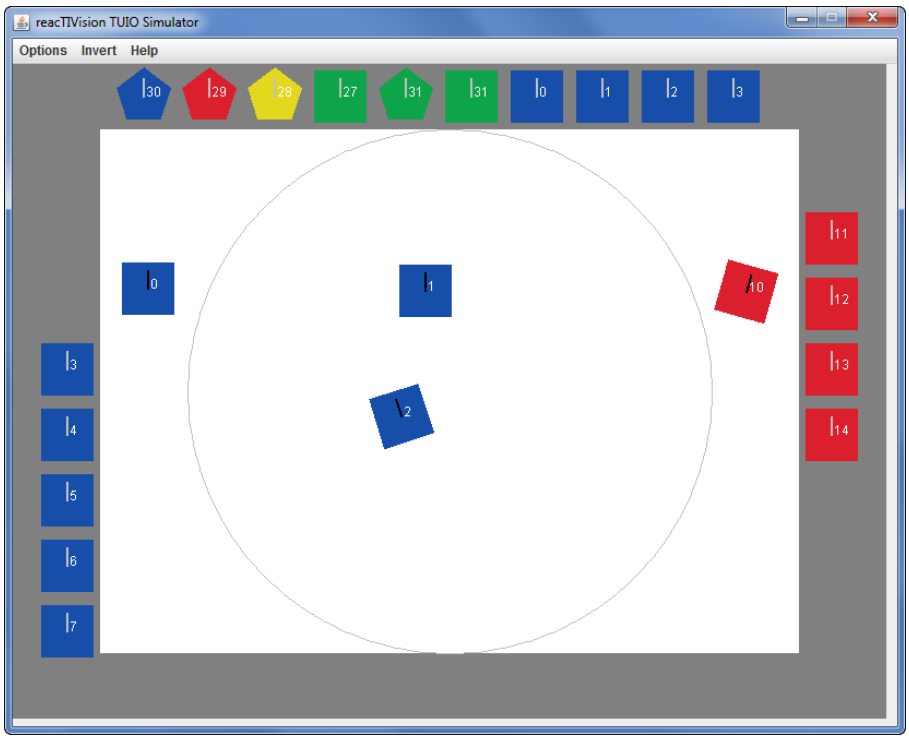

Figure 26: The reacTIVision TUIO Simulator

[210] Simonov, "InteractiveLab/TouchScript."
[211] Giardini, "DOTween (HOTween v2)."
[212] Kaltenbrunner, "TUIO Implementations."

7.1.4 Credits

The prototypes mainly use geometric forms and effects included in or provided by Unity. Apart from that, the following assets were used.

The Duel Game icons are modified versions of graphics included in "Painterly Spell Icons" by J. W. “eleazzaar” Bjerk[213].

All prototypes use the font Corbert Regular by The Northern Block[214].

The prototypes also contain sounds effects by Moritz Ufer[215], Iwan “qubodup” Gabovitch[216] and carbilicon[217].

In the videos, music by Kevin MacLeod[218] is used.

7.2 Prototype Implementation

While implementing the game prototypes, several game-specific challenges had to be tackled, e.g. the turn order and action-reaction system in the Duel Game. Albeit interesting, those are very specific and will not be mentioned in this part of the thesis. Instead the focus will be on topics generally useful for creating hybrid games, like how to deal with lost or wrongly recognized markers.

The source code is provided on the accompanying CD-R and (apart from the used libraries and media assets) licensed under the MIT License[219].

7.2.1 Marker Handling

When creating a hybrid game, the presence, position and rotation of physical pieces have to be communicated to the digital program. In this case, fiducial markers (see also page 21) are used; visual patterns printed and attached under physical objects which are then placed on the touch table and can be recognized by cameras underneath.

From there, the table sends the data over network via the TUIO protocol to the computer executing the game. It is then read by the TUIO Client Reference Implementation[220] used in the Uniducial[221] library.

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[213] Bjerk, “Game Craft.”
[214] The Northern Block, “The Northern Block - Font Foundry.”
[215] Ufer, “Nexus’ Child on SoundCloud.”
[216] Gabovitch, “Freesound.org - Qubodup.”
[217] carbilicon, “Freesound.org - Carbilicon.”
[218] MacLeod, “Incompetech.”
[219] http://opensource.org/licenses/MIT
[220] Kaltenbrunner, “TUIO Implementations.”
[221] Gröschel, “Uniducial - Fiducial Marker Support for the Unity3d Engine - Google Project Hosting.”

While Uniducial provides an implementation of a digital representation of a marker, it has no capabilities to deal with lost or wrongly recognized markers and is missing other features needed for the prototypes. For this reason, the Uniducial library was only used as a base and the additional layer described in the following chapters was created on top of it.

7.2.1.1 Definitions

First, a few terms have to be explained.

When the following chapters talk about a "marker", the physical printed fiducial marker is meant. On the other hand, "marker object" means the digital representation inside the game.

Each marker has a "marker ID" according to its fiducial tag. If a marker is "recognized", it means that the touch table sees the marker. "Wrongly recognized" means that it sees the marker, but thinks it is a different marker; the marker ID is reported wrongly. A recognized marker gets a unique "session ID" for as long as it is recognized; if it is lost and recognized again, it gets a new session ID.

A marker that is "known" by the game prototypes is one that has a marker ID that the application can use, e.g. it is a game token. It is possible that the prototype does not accept the marker at the current state of the game though, but it knows how to deal with the marker. "Unknown" markers are markers that the application does not expect at all. This could be a reason to pause the application because it either means that a) the player placed the wrong marker on the table, expecting something to happen, or b) a marker is recognized wrongly. More on this will be written in the chapter "Dealing with Not Detected or Wrongly Detected Markers" (page 80ff.).

Lastly, marker objects have properties. Some of those make it easier to deal with detection problems and to restrict the marker usage. Those properties are:

- Temporary/Persistent: A temporary marker object is destroyed once the marker is not recognized anymore. A persistent marker object whose marker is not recognized anymore will stay there until the marker is somehow recovered. A marker object can be temporary when created and be made persistent at a later stage and vice versa.
- Unique/Non-Unique: A unique marker object can only have up to one instance spawned at any time, while a non-unique marker object can have as many as there are markers recognized.

Knowing that a marker should not be removed or that it should only be laying once on the table makes it possible to recover it – or to display an error and further react accordingly. For details, see "Dealing with Not Detected or Wrongly Detected Markers" (page 80ff.).

7.2.1.2 Overview and MarkerManager

When the TUIO Client/Uniducial library receives new marker data (new recognition, update or removal), they are sent to and stored in a *MarkerManagerFeed* implementation specialized on TUIO data.

Later on, the *MarkerManager* updates and reads through the entries in the MarkerManagerFeed. It then decides what to do with the new marker data. Is the marker already recognized? Update the marker object. If not, maybe it can recover another marker object? If it cannot do that either, the MarkerManager checks if it knows the marker and if there is a *MarkerStartingZone* willing to accept the marker. If so, a new *MarkerObject* is created; if not, it might show an error object, depending on the situation and its settings.

7.2.1.3 MarkerManagerFeed

A MarkerManagerFeed is assigned to the MarkerManager. It stores events which can later be consumed by the MarkerManager when it updates. Keeping that outside of the MarkerManager allows switching to a different source on the fly.

There are two implemented MarkerManagerFeeds. The first one is *MarkerManagerFeedTuio* – it subscribes to the Uniducial *TuioManager* and puts the marker events coming from there in a queue. TuioManager events are created in a different thread; the MarkerManagerFeedTuio also serves as a bridge by locking the queue as long as it is written or read.

The other implementation is the *VirtualMarkerSimulatorBase* which is used for the touch prototype versions to emulate TUIO events based on touches. More on this can be found in the chapter “Touch Versions” (page 87).

7.2.1.4 MarkerStartingZone

Because a hybrid game bridges the physical and the digital world, it is possible that markers are placed on the tables at times or places where/when they should not be – the game has no control over that. What it can do though is to control if it accepts the Marker depending on place, ID or internal state. For that, MarkerStartingZones are used.

When a new marker is added, the MarkerManager asks all MarkerStartingZones in their order of priority whether they want to accept that marker. If they do, the marker object is created and assigned to the accepting MarkerStartingZone, which in turn notifies any subscriber that a new marker object was added.

MarkerStartingZones can employ different strategies for adding. Useful strategies might include accept-all, accept only in a certain screen area (to limit, or for example to make sure that the marker ID really belongs to the player who places the marker) or more complex queries of

internal state, like “Is the game in its preparation phase?” or “Can the player this marker belongs to add another marker?”

Note that a MarkerStartingZone is only asked when accepting a marker; afterwards, the marker is free to stay, even if the conditions of the zone (e.g. position) no longer match.

7.2.1.5 MarkerObject

Every marker object created by the MarkerManager is spawned out of a Unity prefab with the component MarkerObject. A MarkerObject defines out of which marker IDs it can possibly be created, whether it is unique or persistent and whether its position and rotation should automatically update. It also provides events for when it is recognized, removed, lost, recovered or updated, and saves its last TUIO recognition state (like e.g. position and velocity).

7.2.1.6 Dealing with Not Detected or Wrongly Detected Markers

When using a touch table it is inevitable that markers are lost temporarily or recognized as another marker ID. This mostly happens at the edges and corners of the cameras and can often be remedied by moving the marker away from those areas, but until then, the marker ID will not likely be refreshed. In that timeframe, the software side has to deal with handling these moments gracefully.

Helping to treat those cases are the persistent/unique marker states and the establishing of starting zones that accept new markers.

There are many different cases to consider, as detailed in the following chapters.

7.2.1.6.1 Recovery of a Lost Persistent Marker

Firstly, there is the problem of how to treat persistent markers that vanish and possibly reappear later. Note that this only applies to persistent markers – if a marker is not persistent, removing it is a valid operation. For persistent marker recovery, these cases have to be looked at:

- A persistent marker is lost and all other markers are already assigned to marker objects.
- A persistent unique marker is lost and later newly recognized elsewhere.
- A persistent non-unique marker is lost and later newly recognized elsewhere.
- A persistent marker is lost and another marker is newly recognized elsewhere.

The first case happens often when a marker is moved: A persistent marker is lost and all other recognized markers are already assigned to marker object. There is nothing that can be done to recover this marker in that moment, but if the marker continues to be unrecognized for a certain

timeframe, this can be treated as a fail state. An appropriate reaction to that could be pausing the application until the marker is recovered by one of the following means.

If a persistent unique marker is lost and later newly recognized elsewhere, it is easy to recover: The marker object is bound to this new marker session. Note that the marker does not have to be in a starting zone to be used for recovery.

If a persistent non-unique marker is lost and later newly recognized elsewhere, it has to be determined whether this should result in a new marker or whether it should be used to recover the old marker object. This could be determined by distance to where the marker object lost its marker, by whether the new marker is recognized in a starting zone or by a combination of both (e.g. considering distance first to recover the marker object, if too far away checking whether the marker is accepted by a starting zone to make a new marker object, and if that's not the case either, recovery of the closest fitting lost marker object despite the new marker being too far away – this is how it is implemented in the current application). Note that when a persistent non-unique marker is wrongly used to create a new marker object, two persistent marker objects exist – and the superfluous one will not vanish as long as it is persistent, so that state is not easily recoverable. Even when restoring, it is not clear if the lost closest marker object was necessarily the one this marker lost. Due to their ambiguous nature when recovering, the use of persistent non-unique markers is best avoided if possible and unique persistent markers are preferred. Despite the earlier named procedure being implemented in the current application, no case was found where the non-unique/persistent combination was necessary.

If a persistent marker is lost and another marker is newly recognized elsewhere, it should first be looked whether this new marker passes validation for being a new marker. If that is not the case, it could be used to recover a nearby lost persistent marker instead – ideally if it is in a certain range to the last known position of the lost persistent marker. Additionally, the new marker's session must not be older than the time the persistent marker was lost, i.e. the persistent marker was not lost after the new marker was first recognized. Note that this works on arbitrary markers IDs, independently of whether the new marker ID was not accepted elsewhere or whether the new marker ID is known or unknown to the application or is recognized as a unique duplicate.

When recovering lost persistent markers from other marker IDs, the first ones recovered are the ones with the smallest distance between marker position and lost marker object. After that, the process is repeated until no new pairs can be made.

If a persistent unique marker object is recovered from another ID and the "real" marker with the correct is recognized, there is a pretty high chance that the newly recognized marker is not

wrongly recognized and the previously recovered persistent unique marker object is paired with that newly recognized marker.

7.2.1.6.2 Validation of a Newly Recognized Marker

If a marker is not used to recover another marker, it is treated as a newly recognized marker and should be validated to find out whether it is allowed to be become a new marker object. This is not the case when:

- A marker is recognized by the touch table, but its ID is not registered to the application.
- A unique marker is recognized multiple times.
- A marker is recognized, but not accepted by any starting zone.

If a marker is recognized by the touch table, but its ID is not registered and assigned to a marker object prefab in the application, it cannot be accepted. Since the user likely expected the marker to be recognized, it might help to display a visual error object informing that this marker was not recognized and which ID it has. Depending on what this error object shows, the user can decide whether she actually used a wrong marker or whether the marker was wrongly recognized and can be fixed by moving it around until it gets reevaluated. Depending on the application, this might also be a possible fail state, which might for example pause the application until the correct state is recovered again.

If a unique marker is already recognized and another one is added, the new one will be rejected. Again an error object should be shown with the reason and the marker ID, allowing the user removal or trying to recognize the marker again by forcing reevaluation through movement. Like before, this can be a possible fail state. If the other unique marker object vanishes while the rejected marker is still lying on the table, this rejected marker will be reconsidered for validation.

When a marker is recognized and has a registered ID, it still needs to be accepted by a starting zone. Like described in “MarkerStartingZone” (page 79), this can be a certain space on the table, but it could also differentiate by other criteria, e.g. number of markers placed or another part of the game state. All starting zones are asked in priority order to accept the marker, and if none accepts, no marker object is created. An error object is created to show the user that this happened, but without a specific reason as the marker manager cannot easily determine what the internal reasoning of the different starting zones was. If needed, this could be implemented by the application by creating an accept-all starting zone with the lowest priority which further analyzes game state and placement. Furthermore, having an unrecognized marker can also be considered a fail state. The rejected marker’s request is saved and will be repeated until the

marker is removed, so if the game state or the marker's location changes appropriately, the marker will be immediately accepted.

7.2.1.6.3 Flickering Inhibition for Non-Persistent Marker Objects

If a marker object is not persistent, it will be destroyed immediately when it is not recognized anymore. While developing, there were cases when a marker would start to flicker: Recognized for a short time, then not recognized for a short time, recognized again et cetera. This does not look good and can lead to unwanted behavior (e.g. in the Finger-Flicking Game, a marker object that is flickering cannot score while it is not recognized and therefore only earns a fraction of its score per second). Therefore, one can set a default keep-alive time for non-persistent markers in the MarkerManager or an individual time per MarkerObject.

If a marker is now lost, its marker object will not vanish until this delay passed. If the marker returns before the allotted removal time, the marker object is recovered if is still close enough to the potentially new position of the marker.

If a marker object is unique, lost and waiting to vanish and is recognized elsewhere, it will either be recovered (if close enough) or immediately destroyed and recreated at the new position (if far enough).

7.2.1.6.4 Game-Specific Solutions

Depending on their needs, games differ in how they handle persistent marker recovery and fail states. The following paragraphs show these reactions and the reasoning for the implemented game prototypes.

7.2.1.6.4.1 Finger Flicking Game

In the flicking game, markers might physically leave the table at any time by being flipped off it, so they cannot be persistent. It is not even safely possible to make them persistent when near the center and non-persistent once they get to the sides of the table as they might be flicked in a way that they move too fast to be recognized – or that the marker sides leave the table on hit because they are flung slightly into the air on impact. Because they cannot be persistent, recovery does not apply. Instead, the marker objects are recreated once the markers reappear. Consequently, the game has one catch-everywhere starting zone which accepts the range of playing token markers because markers might reappear anywhere if they started in their player's zone before.

All the markers are unique though, so the "multiple unique" and "unknown ID" fail states still apply and pause the game in any state – after a short delay to avoid blinking (as the game shows an overlay in its pause state) if the error immediately vanishes because the marker is

reevaluated upon moving further. The pause allows the players to restore the game state without any lost score.

In the beginning of the game, the game shows instructions to place exactly one starting marker in each of the players starting areas and no other markers on the field. Once this is the case, the game begins after a 3 second countdown; if this is not the case anymore at some point before the 3 seconds are over, the countdown is reset and repeated once everything is in order again. The countdown is also stopped if any fail state is set. This special phase gives the players the opportunity to clean up the table from a previous game and to review the playing field.

Once the game starts, all subsequent new tokens have to start inside the player's starting area because flicking them from outside would give a player an unfair advantage. If a marker is placed outside a player's starting area, the fail state "not accepted" is set and the game is paused until it is either removed or moved to the correct starting zone. Previously, this case was handled by giving a penalty to the offending player (the marker would not score anymore for the duration of this game and instead, the player is losing points per second). This penalty was replaced with pausing the game after considering that markers are sometimes recognized as other IDs. In that case, it sometimes happened that for example a token the red player places in his starting zone is recognized as a token of the blue player – thus giving the blue player a penalty for supposedly placing one of her tokens outside his starting area. The pause feature still impedes accidental cheating (and calls the other player's attention upon possible willful cheating) while giving the players the chance to gracefully recover from the previously described case.

Additionally, the fail states "unknown ID" and "duplicate unique" also pause the game to ensure that all possible points are always scored.

There is one case left that cannot be handled because it cannot be properly recognized: If a marker is not recognized at all, the player token subsequently does not score because it does not exist ingame. A timeout could be constructed because markers should be recognized every few seconds when they stop moving, but that does not account for markers being thrown off the table, and since that is a valid state too, it should not cause any friction by having the players manually deregister a token. In the end, this situation is left to the players to recognize and rectify by moving the marker around until it gets reevaluated.

Another case is not handled well, but only happened once during the whole development and testing time: If a marker placed in a starting zone is wrongly recognized as a token of that player, but with a different ID (for example if the player has the tokens 10 and 11, the token might be an 11, but is recognized as a 10 when placed in the starting zone), it will probably later be

recognized as its actual ID – but then the game will complain this supposedly new marker was placed outside a starting zone. This might confuse the players and prompt them to restart the round because the needed action (switching out the token in the field with the right one still in the starting zone) is too unclear. Allowing the players to switch out their tokens inside the starting zone and only mark them as "used" once they touch the field does not fix the problem either because in that moment it is as just as likely for the marker to be recognized with a wrong ID.

Since all the marker objects in the Finger Flicking game are non-persistent, the flickering inhibition described in "Flickering Inhibition for Non-Persistent Marker" (page 83) is important for this prototype.

7.2.1.6.4.2 Spaceship Game

The Spaceship Game has three phases: The preparation phase, the playing phase and the game over phase.

In the preparation phase, players can freely add and remove spaceship and spaceship part markers. All the markers are unique. The start button only appears when the players have configured their spaceship(s) completely. Additionally, the button does not appear while a marker ID is unknown or if a unique marker is recognized multiple times so the game can always start in a clean state.

A problem in the preparation phase is that markers cannot be persistent and are sometimes not recognized for a while, and when they are recognized correctly again, what the users equipped there is gone because the marker object is recreated. The flickering inhibition takes care of that if it happens for a short time. For longer times, the equipment is saved and restored when the marker object appears again.

When entering the playing phase, all active marker objects are made persistent and no new markers are accepted. If a marker is lost, the game will try to recover it, even from another ID in a certain distance range. If a marker is not recovered in a certain timeframe, the game will be paused until it is. This ensures that players can react appropriately to recognition failure. It is not desired to react to an unknown marker ID, a duplicate unique or a marker that was not accepted – if all needed playing tokens are correctly recognized, the game can go on and should not be paused.

When a spaceship or a spaceship part explodes, the player is free to leave or remove the marker if that is made possible by the physical construction. It cannot just be destroyed and made non-persistent though, as it would then trigger the "not accepted by any zone" fail state the next time

it is recognized. Instead, its marker ID is blocked from being added again. Its ID can still be used to recover another persistent marker object if another marker faultily becomes that ID – it is just blocked from being regularly added. A problem that cannot be easily solved is if that marker is faultily used to recover other spaceship parts if its ID changes – in that case, it is up to the user to move the marker until it is correctly recognized again. It would also throw a fail state if it becomes a duplicate of another ID or an unknown ID. This is solved by the fail state not pausing the game if all spaceships and spaceship parts have markers associated.

Another variant would be to retain the marker object as a persistent invisible object still bound to the marker ID while marking it as "does not trigger fail state for not being recognized despite being persistent". This solves the problem of the associated marker becoming a duplicate or unknown ID – it would just restore the invisible object. It poses a far less transparent problem if the user removes the marker though: The invisible object would stay at its position, and when another marker object faultily is recognized as the ID of the invisible object, it would be bound to that object – or might be bound to that object in an attempt to recover from a different ID if the invisible object is closer than the real partner of that marker. For the user, it is not clear why it cannot restore the real spaceship and that she has to force reevaluation by moving the marker. To avoid this, the solution described in the previous paragraph was used.

In the game over phase, only the ingame menu marker which allows restarting or switching to the menu will be recognized. Pausing on any fail states is not necessary anymore because no ingame player interaction is possible.

7.2.1.6.4.3 Duel Game

In the Duel Game, each player has 5 tokens, which have to be placed in their respective starting zone at the beginning of the game – mostly to ensure that all tokens are actually what the table reports. When all tokens are recognized correctly, the token information is made visible. Tokens are persistent until they are killed – then they can be removed.

In this game it is important that no information hidden behind the tokens' screens is revealed to the enemy. For that reason, all associated information is hidden while a marker is being moved or the marker is not recognized.

As this game is not real-time, it is not necessary to pause the game on any fail state. Tokens that are not recognized are just marked so the players can remedy the situation.

7.2.2 Touch

While most of the interactions in the hybrid games take place with physical tokens, some (like assigning the satellite roles in the Spaceship Game and the power levels in the Duel Game) are

handled via touch as they would lead to an unneeded amount of physical tokens and make the hybrid prototypes unnecessarily cumbersome. Additionally, there are the purely digital touch-only versions. For these reasons, touch input needs to be handled properly. Most of that is taken care by TouchScript (see page 76), but some error handling remains to be done.

7.2.2.1 Error Handling

Touch error handling is relatively straightforward compared to markers because there are no marker IDs to be considered. Touches can still be lost though when crossing camera borders though – and because on the MultiTaction Cell touches are done via computer vision instead of actually checking for contact with the surface, touches might be recognized when there are none.

7.2.2.1.1 Lost Dragging Touches

When crossing camera borders, a touch might be lost and reappear with a different session ID. This is especially problematic when dragging an object and something should happen when it is regularly dropped. In the prototypes, this is solved by giving the object a short delay until it activates/vanishes and allowing for another touch (in this case, the same touch with a different session ID) to take over.

7.2.2.1.2 Accidental Touches

Sometimes the recognition does not work correctly and touches are recognized despite there not being any – for example by a marker not recognized correctly or by fingers still hovering in the air. To prevent triggering accidental button presses, every button has a delay. While the button is being touched, it slowly vanishes, providing immediate feedback that the touch is recognized, but the execution is delayed. This assures the user that the touch is recognized if it is desired while also giving him the opportunity to remove the accidental touch if it is not.

7.2.2.2 Touch Versions

Each of the hybrid game prototypes has a purely digital touch-based version to be able to evaluate the differences the physical elements make. Due to the short timeframe available for the product, they needed to be produced as fast as possible. This lead to the current design: The games themselves stay mostly unchanged, and virtual markers are created that react to touch and produce fabricated TUIO events which are piped via an instance of VirtualMarkerSimulator-Base to the MarkerManager.

7.2.2.2.1 Finger Flicking Game

In the Finger Flicking Game, tokens are added one by one in certain intervals. For that, each player has a zone that they can tap where they want the token to appear.

Each virtual marker token has, when spawned, an interactive part and a virtual-physical (as in "uses the physics engine" – it is not there in the real physical world) part. The interactive part is used to move the token in the starting zone, and ultimately flick it forward via swiping. The gestures use TouchScript. When the interactive part is moved, the virtual-physical part is moved too, and when it is flicked, it gives the impulse to the virtual-physical part and removes itself. The virtual-physical part in turn is the "real" virtual marker, applying forces, colliding with other virtual-physical parts and sending TUIO updates to the VirtualMarkerSimulatorBase.

Because the touch-version should be useable without any physical tokens, little menu/restart buttons are placed on both sides of the screen. This also applies to the other touch versions.

7.2.2.2.2 Spaceship Game

In the Spaceship Game, all tokens are already created at the beginning of the game.

All tokens are pre-created when the touch-version starts: A spaceship with four satellites. Since the real world physical restraints are not in place, they are simulated by virtual-physical distance joints.

The tokens are moved and rotated by placing one/two fingers on them on moving them. Some tokens are just to be moved (like the shield) and have a smaller touch range. The tokens that need to be rotated have a bigger range to enable comfortable rotation movements – see also Figure 16 (page 66).

7.2.2.2.3 Duel Game

In the Duel Game, tokens are treated similarly to the Spaceship Game: All tokens are created at the beginning and are movable, albeit not rotatable.

Contrary to the other prototypes, in the Duel Game it is not possible to just keep the same visual configuration. The hybrid version of the Duel Game uses physical paper screens to obscure details while allowing players to look at the same screen – and when those physical paper screens are taken away in the purely digital version, both players can see the hidden information. The ideal solution would be to have the game on two screens or two devices connected by network. To make it easier to create the purely digital version, the big touch table screen is simply divided into two by a big physical obstacle, with each screen side showing only the information relevant to this player – see Figure 22 and Figure 23 (page 71).

7.2.2.2.4 Menu

Lastly, there is the menu. Normally, the menu is used via the Menu Marker (see next chapter) which displays the options around itself. This makes sense for the hybrid versions, but with the

touch versions, this would be inconsistent. For that reason, the main menu always displays a touch version button for each prototype, ready to be touched.

7.2.3 General Considerations and Application Flow

7.2.3.1 Menu Marker/Ingame Menu Marker

The main menu and the ingame menu appear around a physical marker that can be put on the table. The choice to do that has multiple reasons:

- In a digital game, the menu might be opened by a key press. Putting a marker on the table is a possible virtual equivalent of that. The alternative is using touch buttons, which would take screen space.
- Since the thesis is about adding physical elements to games, it seemed interesting to add a physical token as a menu. The hybrid versions use physical tokens as game pieces too, so this adds consistency by using a physical token for game flow too.
- The table is too big to have one menu button easily accessible – especially the Finger Flicking Game where the players are standing on the horizontal sides would have needed multiple menu buttons. With a physical token, the menu is always where the player with the token wants it to be, and control can be transferred by transferring the menu token itself.

In the end, this menu approach is recognized as interesting, but more cumbersome: To restart a game, one has to a) put the menu token on the table, b) touch the "Restart" button and c) remove the token again, as opposed to just touching the restart button. It can also lead to people being disoriented for their first playing rounds, wondering how to restart the game.

7.2.3.2 User Interface Alignment

It is also important to think about the different positions players are standing around the table and which information needs to be seen by both players. Since text is better readable when facing the player, many user interface elements have to be displayed two times, once for each player. Some of those are mirrored across the center axis of the table (for example a text reading "Game Over!"), others are mirrored on the elements (for example how much score a goal area brings per second in the Finger Flicking Game – see Figure 8, page 61).

An alternative to just mirroring general status elements like the current state of the game could be to attach screen elements to a marker for each player so they can place their interface anywhere they want. This would be especially useful for a variable amount of players (also possibly denoting how many want to take part in a preparation phase) or when the players are moving around the table, but this is neither needed nor used in any of the prototypes.

8 User Testing

8.1 Introduction

To find out whether the physical components and gameplay mechanics used in the prototypes actually improve the gameplay over purely digital touch-only versions, user tests were conducted, comparing each prototype pair of hybrid version and digital touch-only version.

The project did not have any budget or other means of recruiting testers without personally knowing them. Most participants were recruited at local game development events, already knew the author of this thesis, and wanted to at least learn the topic of the thesis and a few facts about the games before accepting to participate. This might skew the results; the following chapters provide thoughts about how the author tried to remedy this. This recruitment process lead to most of the participations being game developers or interested in game development. The participants were 3 women and 9 men aged between 20 and 40.

The lack of budget combined with the author being the only person to organize the tests also lead to a low number of participants (8 testers each for the Finger-Flicking Game and the Spaceship Game, 6 testers for the Duel Game). A higher number would have made the results more representative.

Technical problems with the touch table might skew the results. Markers are not always recognized correctly, leading to unneeded friction that does not have to be inherent in hybrid games. On the other hand, the touch-only versions might suffer from the touch being recognized via computer vision, sometimes leading to fingers hovering above the table being recognized as touches too. The glass of the table that is available for testing does not lend itself well to sliding either. This makes certain gestures harder, especially in the Spaceship game where precise targeting is needed.

Each test session consisted of two testers playing against each other. This approach was taken to avoid a possible bias when playing against the author of this thesis. An evaluation session contained one or multiple games. Each evaluation session started alternating with the digital touch-only or the hybrid version to counterbalance a possible bias for the first version played.

A typical evaluation session looked like this:

- The author of the thesis explains the game (5-10 minutes, depending on complexity)
- The participants play a version of the game (5-20 minutes)
- The participants separately fill out an AttrakDiff form for this version (5 minutes)
- The participants play the other version of the game (5-20 minutes)

- The participants separately fill out an AttrakDiff form for this version (5 minutes)
- The participants separately answer the comparison questionnaire (5 minutes)

Usually, participants chose between two game packs: Pack A with the Finger-Flicking Game and the Spaceship Game or pack B with the Duel game. Each of those sessions took about 1½ hours, so the Duel game was more extensively played due to its complexity. Some players chose to play both packets, totaling at 2½ hours.

Since the purpose of the tests is neither to find out how self-explanatory the games are nor to find out how well this particular multitouch table works, the author assisted in resolving rule questions or technical problems as they came up. This is meant to bring the experience closer to how it should be: Testing a self-explanatory game (instead of a prototype) without any technical failures to concentrate on the comparison between the core experiences of "hybrid" versus "digital touch-only".

8.2 AttrakDiff

AttrakDiff is a questionnaire used to measure the pragmatic quality, the hedonic qualities of stimulation and identity and ultimately the attractiveness of a product.[222]

These dimensions are described as follows in the AttrakDiff Evaluation Report Demonstration:

- Pragmatic Quality (PQ): Describes the usability of a product and indicates how successfully users are in achieving their goals using the product.
- Hedonic quality – stimulation (HQ-S): Mankind has an inherent need to develop and move forward. This dimension indicates to what extent the product can support those needs in terms of novel, interesting, and stimulating functions, contents and interaction- und presentation-styles.
- Hedonic Quality – Identity (HQ-I): Indicates to what extent the product allows the user to identify with it.
- Attractiveness (ATT): Describes a global value of the product based on the quality perception.[223]

In short, the results help to quantify the usability and design of the product – or, like in the case of this thesis, help compare between two products. The users rate the products one by one on 28 scales with opposites like technical/human, "separates me from people"/"brings together" or

[222] Hassenzahl, Burmester, and Koller, *AttrakDiff Evaluation Report Demonstration*.
[223] Ibid.

conventional/inventive. This is done via the attrakdiff.de website in German or English. At the end, a report is automatically generated.[224]

The fact that most of the participants know the author could make them rate the prototypes more highly than unacquainted testers would – therefore the individual test results of the hybrid and touch-only versions should be taken with a grain of salt. All prototypes are created by the same author though, so they should be affected in the same way. This should make the comparative results between the prototype pairs reliable.

8.3 Comparison Questionnaire Hybrid/Touch-Only

While the AttrakDiff tests tries to get an indirect comparison by rating each prototype independently, it might also be insightful to ask the participants to directly compare the two versions of each prototype. To this end, the following questions were asked to be rated on a scale from 0 to 6 with "0" being "Hybrid" and "6" being "Touch-only". Additionally, testers could detail why they felt that way. The italic text explains the motivation of certain questions and was not part of the questionnaire sheet.

1. "Which version was easier to use?"
2. "In which version did you feel more in control?" *(In games, loss of control does not always equal bad usability. The Finger-Flicking Game might be easier to target in the touch-only version, which might make feel people more in control there, but the hybrid version might be easier to use due to less indirection.)*
3. "Which version was more fun?"
4. "Which version was more interesting?" *(This question tries to find out whether the hybrid version provides novelty value beyond pure gameplay.)*
5. "Which version felt better?" *(This question tries to capture whether the sensations provided by the tactile feedback add to the experience. It is deliberately vague to refrain from influencing people towards the hybrid version.)*
6. "In which version did you feel closer to the other player?" *(This tries to contribute to two questions: Do digital games feel more like playing "with the screen" instead of "with another player"? Does playing together on one screen in the hybrid version of the Duel Game make a noticeable difference?)*
7. "If you had to play again, which version would you choose?"

Additionally, people were asked how many and which technical errors they encountered with either version to see if the result might be skewed.

[224] AttrakDiff, "AttrakDiff - AppliedHassenzahl, Burmester, and Koller, *AttrakDiff Evaluation Report Demonstration*. Areas."

A possible bias in this questionnaire is that all of the participants knew the topic of the thesis and could deduct from the tests that the physical components are meant to improve the game. This might make testers overrate the hybrid versions to do the author a favor. To prevent this, the author clearly states before starting the tests that he is interested in getting truthful answers and that there are no specific results needed to make this thesis a success.

8.4 Hypotheses

The prototypes were created with the hope that the physical parts of the hybrid versions are improvements over the purely digital touch-based versions. Preliminary internal testing suggests that those goals are met with varying levels of success or failure. Taking into account the design of the games, the intentions behind them and the results of playtesting the games internally, the following hypotheses are formed.

8.4.1 Finger-Flicking Game

In the hybrid version of the Finger-Flicking Game, the physical tokens are easier to handle as people can quickly figure out how they behave physically. The tactile feedback and the physical interactions between tokens feel gratifying and make the game interesting, but also a bit unpredictable. Only a limited amount of tokens needs to be introduced and recognized by the table at any time, so the friction between physical and digital world is kept to a minimum.

The moves in the digital version are a bit more predictable. Flicking by swiping is easy to figure out and easy to execute, but it takes more tries to learn how far a swipe will take the token. Moving a token by tapping it first is a bit harder to learn because it is not intuitive.

Depending on the players' preference, they might prefer the tactile feedback and unpredictability of the hybrid version or the predictability of the digital version. The hypothesis is that the games will be fairly evenly rated with a preference for the hybrid version.

8.4.2 Spaceship Game

In the Spaceship Game, the physical feedback provided by the components in the hybrid version is essential. The tangibility allows for faster targeting than in the digital version (albeit it sometimes lags slightly behind), and grabbing and turning a wheel is easier to execute than constantly rubbing two fingers over the glass to turn and move a token. The physical constraints help players feel the movement restrictions and coordinate activities – for example when a player tries to evade a bullet by tugging, the other player might loosen his touch to allow the movement to happen. Additionally, the Spaceship Game has only 5 physical tokens in total – the mother ship and 4 satellites. These tokens can be made unique/persistent which improves the chance to recover from recognition errors, and they only move slowly compared to the Finger-Flicking Game. This should help to reduce the friction between the physical and digital worlds.

The hypothesis here is that the hybrid version of the game will be strongly preferred.

8.4.3 Duel Game

The hybrid version of the Duel Game is the prototype that suffers the most from wrongly recognized tokens, as it contains 10 tokens that have to be properly recognized at the correct positions before the game can even start. This often involves moving around multiple markers to trigger a refresh and having some markers in unstable conditions. Putting the physical role info cardboard stand-ups into the tokens makes the setup phase lengthier, and there is a certain chance that a wrongly detected marker shows a hidden token to the enemy. When that happens the game has to be restarted and the token role info cardboard stand-ups have to be taken out and reassigned again. After the preparation, the game progresses more smoothly, but one still sometimes has to adjust unrecognized markers and wait for markers lagging behind so that the level/health etc. information does not get exposed to the enemy.

In the digital version, players are more distanced as they are not playing directly on the same playing field, but ease of preparation and play might make this version much preferable. It is therefore the hypothesis that in this game, the digital version will be preferred.

8.5 Results

8.5.1 AttrakDiff

The AttrakDiff results only show minimal changes.

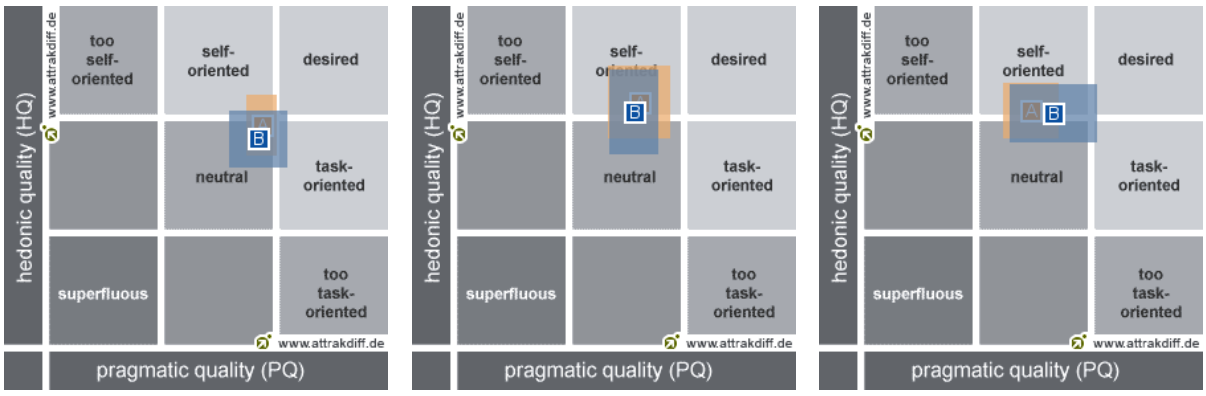

Figure 27: AttrakDiff results. From left to right: Finger-Flicking Game, Spaceship Game, and Duel Game. "A" is the hybrid version; "B" is the touch-only version.

The result reports (available on the CD – see Appendix A: CD Listing, page 109) deem none of the differences in the comparison significant – all of them be the result of small random answer fluctuations between filling out each AttrakDiff questionnaire. The reason might be that there is no big difference at all or that AttrakDiff is not a good tool to evaluate only input style changes – or that the amount of peoples in the study just was not high enough.

Because the changes are so small, the AttrakDiff results are not further analyzed here.

8.5.2 Comparison Questionnaire

The comparison questionnaires had players compare directly between the hybrid and touch-only version of each prototype on a scale from 0 to 6 – 3 steps to each side, with 3 in the center. The following diagrams each show the averaged values of these answers.

In the following text a "clear" tendency towards a version means 0 or 6 respectively, a "strong" tendency is a 1 or 5 and a "slight" tendency is a 2 or 4.

8.5.2.1 Finger-Flicking Game

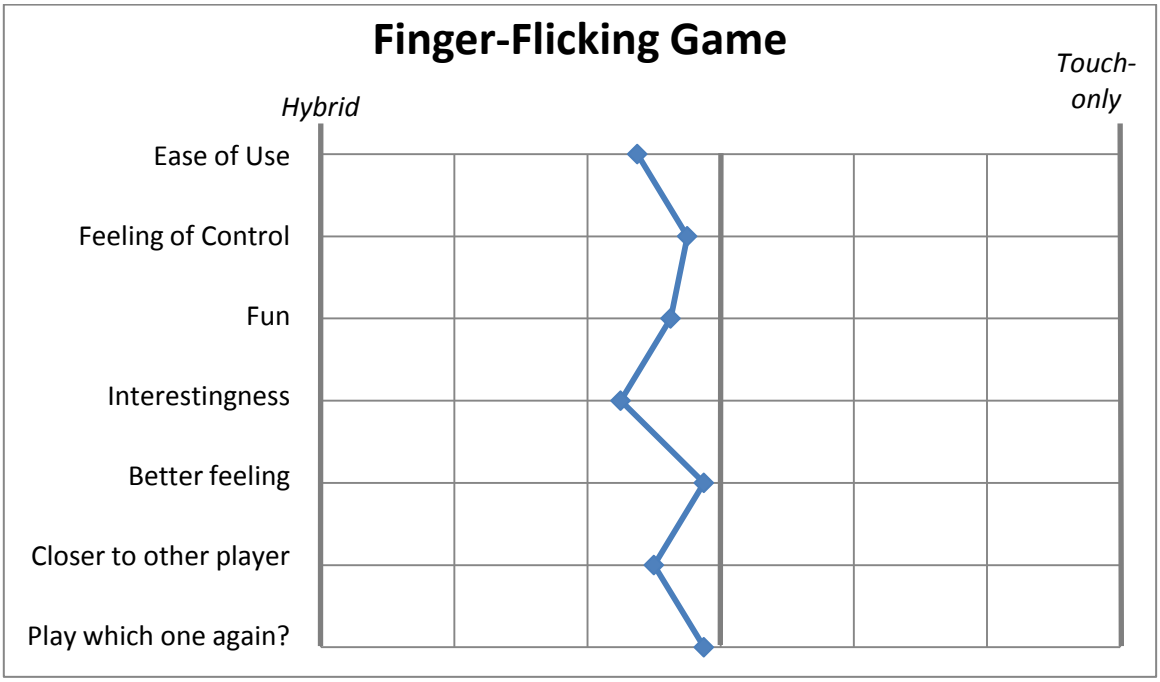

Figure 28: The average comparison questionnaire results for the Finger-Flicking Game.

The Finger-Flicking game had 8 testers. All values tend slightly towards the hybrid variant in various degrees. Especially interesting was the wide range of answers – for example in the "Feeling of Control" category, 3 of the 8 players answered that the Hybrid version is clearly superior while 3 tended slightly and 2 strongly towards the touch-only version. Here it seems to come down to preference, which is in line with the hypothesis for this prototype.

It is worth noting that both of the versions proved to be imperfect. The physical tokens in the hybrid version could be weightier and slide better and especially two testers had recognition problems; meanwhile, the digital version has a lag (by recognition algorithm design) when flicking, with the token not moving until the flicking gesture ended. The author believes that if the recognition was stable and the physical properties of the hybrid version were more optimized that the hybrid version would be more strongly preferred. It would have been

interesting to do more iterations of each version to finally compare "idealized" versions where each is as good as possible.

8.5.2.2 Spaceship Game

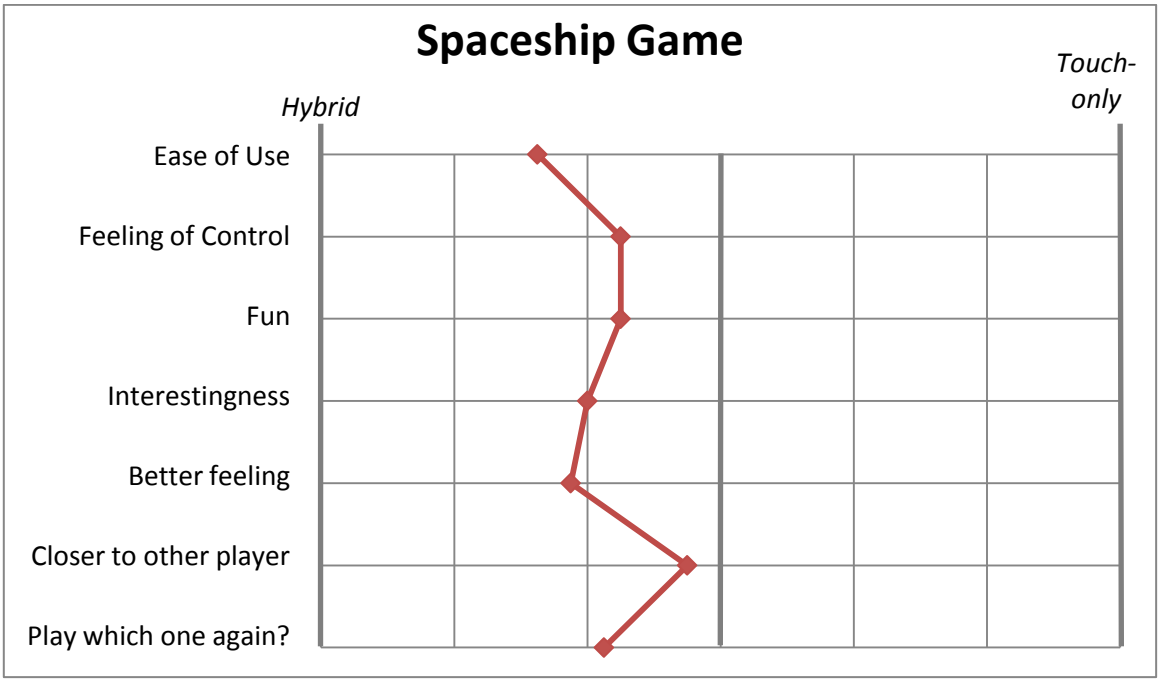

Figure 29: The average comparison questionnaire results for the Spaceship Game.

The Spaceship Game also had 8 testers. Here, the tendency towards the hybrid version is even stronger, especially for in the "Ease of Use" category. It matches with the hypothesis, although not as strongly as expected.

Players said that the rotation in the digital version was very hard (a direct turning with touch points was used, as if one was touching points on physical objects – maybe a rotation speed multiplier would have been good here) and one tester remarked that the hybrid version had an unfair aesthetic advantage, with the simple graphics on the screen being the same, but the Lego model (see Figure 10, page 63) looking more interesting. One player said that the Lego model was obstructing his view and because of that he preferred the touch version, while others liked the look and feel of the model.

8.5.2.3 Duel Game

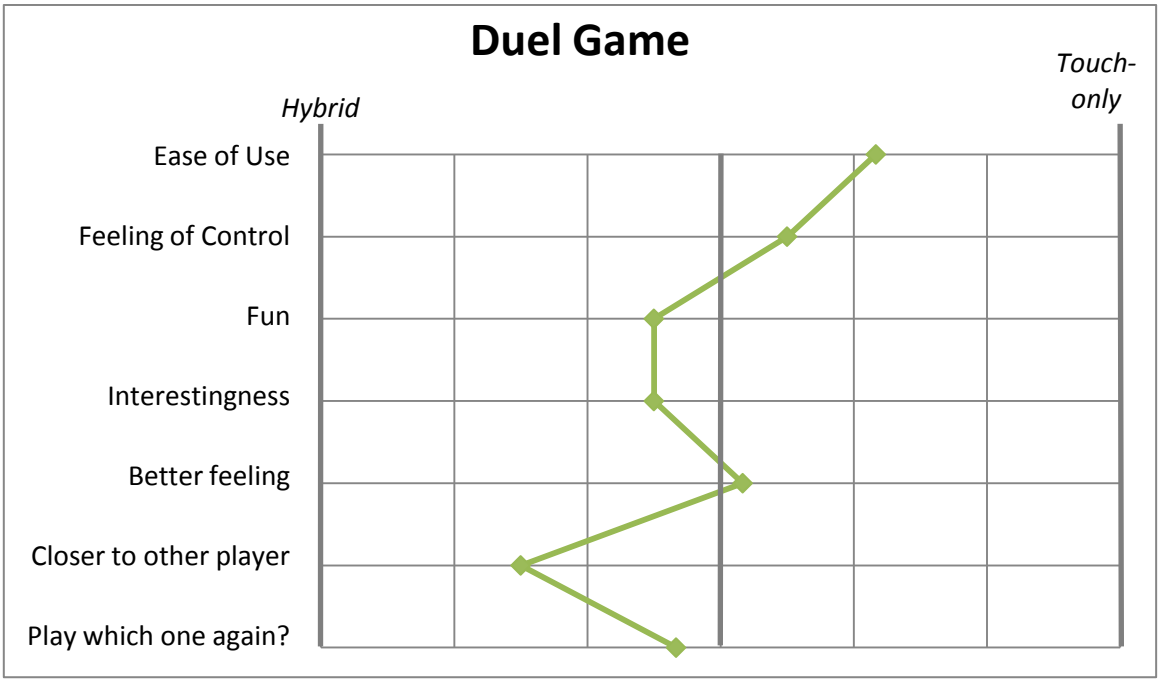

Figure 30: The average comparison questionnaire results for the Duel Game.

The Duel Game had 6 testers. As expected, the touch-only version is preferred when it comes to ease of use and players feel slightly more in control. Despite players not showing strong tendencies about which version to play again, the goal of the hybrid version was reached: Players feel closer to each other because they play on the same field and see each other moving the tokens. One player in particular remarked that he felt that he was playing against the computer in the digital touch-only version, saying that his opponent is "right over there", but he is still watching the screen instead of talking to him. In general, it seemed like more personal interactions were happening between the players in the hybrid version.

8.5.2.4 Comparison between the Prototypes

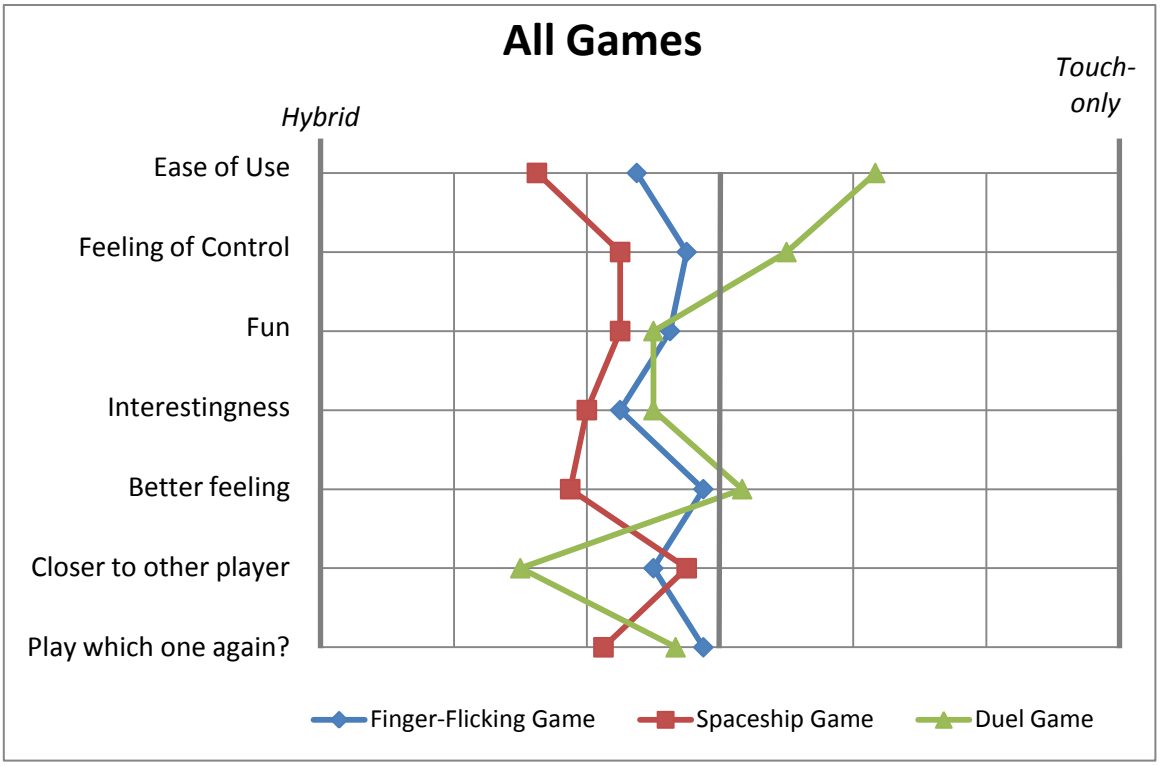

Figure 31: All average comparison questionnaire results.

In general, the differences between the games are rather small and might be due to random fluctuations, but they are not surprising. The hybrid version in the Spaceship Game provided a bigger improvement over the touch-only version than the Finger-Flicking Game, and the Duel game had more control problems in the hybrid version, but also brings the players closer together.

In general, the differences between the hybrid version and the touch-only versions are not very strong though, and individual testers preferred games on either side with just the average tending slightly towards the hybrid side.

8.6 Possible Future Evaluations

A problem identified during the evaluation was that most prototypes had version-specific problems which could be fixed by further improvements (e.g. in the Finger-Flicking Game, the physical tokens could have had better sliding properties and the touch version had delayed reactions when it came to flicking). For future tests, it might be a good idea to have multiple testing/improvement iterations to create the best possible versions of each prototype to enable a better comparison of the potential of the hybrid/touch-based versions.

The evaluation used here was only a very short-term test, more akin to first impressions. Long-term experiences might wear off possible novelty and show other problems that either version

of the games have. (Conversely, it might be interesting to see if the physical parts make the product more attractive when first seen compared to a touch-only version in a setting where people can freely choose, i.e. an exhibition.)

All the game prototypes used in the tests had the physical components added in a way that is believed to add gameplay value through certain interactions (flicking, physical constraints and physical cardboard screens). The results point slightly towards them being an improvement, but there was no control test with a game that used physical components that are believed to be without any added gameplay value. An example for such a control test game could be a traditional board game as a digital variant with physical tokens, like Chess. Without such a control test, it is hard to differentiate between whether the physical tokens improved the games because the specific physical gameplay mechanics also added gameplay value, or whether those results would have been the same with any digital game with physical tokens just by adding the tangible aspects.

The results of the tests came solely from direct and indirect questions. To reduce bias, a more indirect approach might be useful instead – for example letting players play the different versions in a non-laboratory setting as long as they want and recording statistics about which version is played longer, which version is approached more often and how the play styles differ.

The tests also focused on comparing hybrid games to digital touch-only counterparts. Instead, it might also be interesting to compare hybrid games to purely physical counterparts to find out whether the digital components add any value; possibly a test with physical-only, digital-touch-only and hybrid versions.

There are also other evaluation scenarios that might be interesting. An example for this is to look for or compare specific audiences, e.g. people who like certain physical/digital games (Do board gamers like the digital elements? Do video gamers like the physical elements?) or comparing the experiences of children with those of adults.

9 Conclusion

In conclusion, this thesis could not demonstrate a strong player preference for physical elements in tabletop hybrid games, despite trying to give these elements meaningful gameplay character. However, on average a slight preference towards hybrid versions was found, more strongly for some players, while others preferred the digital touch-only versions – in the end, it might come down to individual player preference.

It is questionable whether this slight average tendency towards hybrid games justifies the added effort needed to design, produce and distribute physical tokens compared to offering a touch-only game that players can download from the internet and play immediately. A touch-only version also opens up the game to a wide range of additional devices. A hybrid version on the other hand might offer additional benefits at more permanent locations like a museum or an exhibition in that it could possibly attract more people. (See Horn et al.[225]) It might also offer an experience new to many people who are only used to WIMP-interfaces and touch devices.

It is worth noting that there were hardware-related problems that introduced friction between the physical and digital worlds. With improved and more stable marker recognition, preference towards the hybrid versions might become stronger.

But even apart from that, it was rather difficult to find advantages on the physical side that a) work with a touch table, b) are not easily replaced with touch-only on a touch table and c) do not just add physical tokens for the sense of being tangible, but for gameplay-related reasons. Many gameplay advantages of board games can be carried over to purely digital versions on a multitouch table without the need to use physical tokens, and a touch table makes it possible that everyone sits or stands around it like they might in a purely physical game. On the other hand, it was easy to find digital advantages that cannot be easily created in purely physical games.

It might be more promising to look at hybrid games away from the 2D interface of a touch table – games that are played in 3 dimensions, be it a stacking/building game (see "Gravity", page 37) or a pervasive games where people use their own body and their environment (see "Pervasive Games", page 54). In games like these, a digital version should be a wholly different experience – unlike the prototypes presented here, where a touch-only version was believed to be inferior, but still easily creatable and comparable. Another approach could be to concentrate even more on the physical-tactile aspect, for example by making a game that does not use visual output at all, but takes physical input and creates auditory and possibly tactile (vibrations, movement) output.

In the end, it is the author's hope that the game design impulses, implementation details and evaluation results contained in this thesis provide others with a basis for further work, be it in the academic or the creative sector.

[225] Horn et al., "Comparing the Use of Tangible and Graphical Programming Languages for Informal Science Education."

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Appendix A: CD Listing

The enclosed CD contains the following folders, with descriptions of the contents in italic:

- **Documents**
  - *AttrakDiff evaluation results*
  - *Duel Game role info cardboard stand-ups*
  - *Duel Game role overview*
  - *Printable markers*
- **Executable**
  - *An executable containing the three prototypes*
- **Media**
  - **Photos**
    - *Photos of the prototypes*
  - **Screenshots**
    - *Selected/cropped screenshots of the games (used in this thesis)*
  - **Videos**
    - *Short video clips showing people playing the games*
- **Source Code**
  - *The complete source code of the project, published under the MIT License*[226]
- *This thesis as a PDF*

If the CD is missing or does not work anymore, the content is also available at the following URL:

http://dragonlab.de/projects/thesis_hybrid_tabletop_games

[226] http://opensource.org/licenses/MIT

Appendix B: Duel Game Role Overview

Berserker

Strong attack.

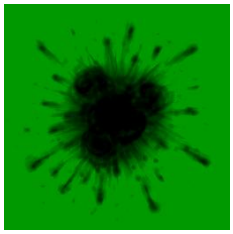
Health: 1x
Melee: 2x
Counter: 1x

Guard

High health.
Non-random counterattack.

Health: 2x
Melee: 1x
Counter: Full 1x

Marksman



Ranged attack at beginning of turn. Not counterattacked if target is out of melee range.
Health: 1x
Melee: 1x
No counter
Ranged: 1x

Ninja

Can jump away from attacks and counterattacks.

Health: 1x
Melee: 1x
No counter

Spy

Spies information:
Ranged at beginning of turn.
Ranged at end of turn.
When attacked.
When attacking.

Health: 1x
Melee: 1x
Counter: 1x

Other things:

- Dead tokens can still be attacked and counterattack until they are removed at the end of the turn.
- Ninja switch can be done between turns – and when any player is moving.
- Ranged attacks always target the closest token in front of it (=away from the player).

Appendix C: Duel Game Details – Player Turns, Ranged Attacks, Ninja Switch, First Move Advantage

A Player's Turn

A player's turn looks like this:

1. If the Spy has a target in its targeting sightline, the log displays information about that target.
2. If the Marksman has a target in its targeting sightline, it shoots.
    a. If the target is in melee range and has a counterattack, it will counterattack.
    b. If the target is a ninja, it can try to evade by changing the way the Marksman is targeting. If the Marksman gets a new target this way, it'll shoot that target and a. applies.
    c. If the target is a Spy, the enemy log displays information about the Marksman.
3. If the Spy has a target in its targeting sightline, the log displays information about that target.
4. The player can optionally move exactly one token. Meanwhile, any player can do a ninja switch.
5. The player can optionally attack with exactly one token another token in melee range.
    a. If the target is a ninja, it can try to evade by moving out of melee range.
    b. If the target can counterattack, it counterattacks.
        i. If the attacking token is a Ninja, it can try to evade the counterattack by moving out of melee range.
    c. If the attacking token is a Spy, the log displays information about that target.
    d. If the attacked token is a Spy, the enemy log displays information about that attacker.
6. Any tokens that died during this turn are removed from the board.
7. Ninja switch is possible for any player for a short while.
8. The other player's turn starts.

Melee Attacks and Counterattacks

After the player moved a token, she can attack in melee range.

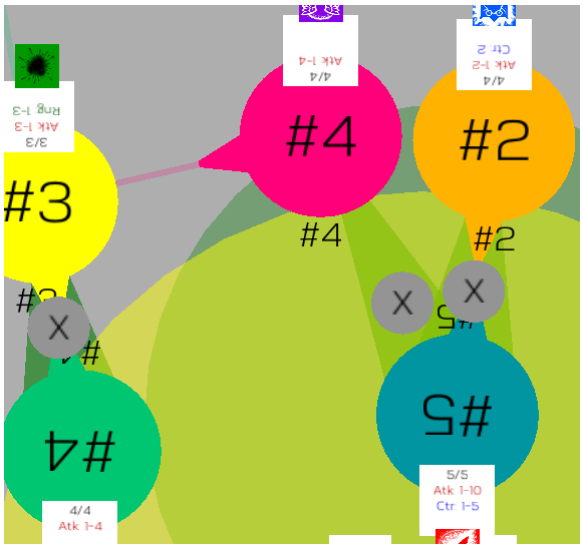


Figure 32: Here, the blue player (bottom) moved the Berserker (the turquoise #5). She can now attack the orange #2 or reddish #4 - or attack with her Ninja (the green #4) because it also has targets in melee range.

In the picture above, the yellow circle is the movement range and the green circle around the #5 is the range of melee attacks. The player can now press any of those X' to actually attack. If she uses the #5, it will deal 1-10 damage – she does not know how many damage is dealt exactly. If the attacked token has counterattack, it will counterattack the #5, possible killing it.

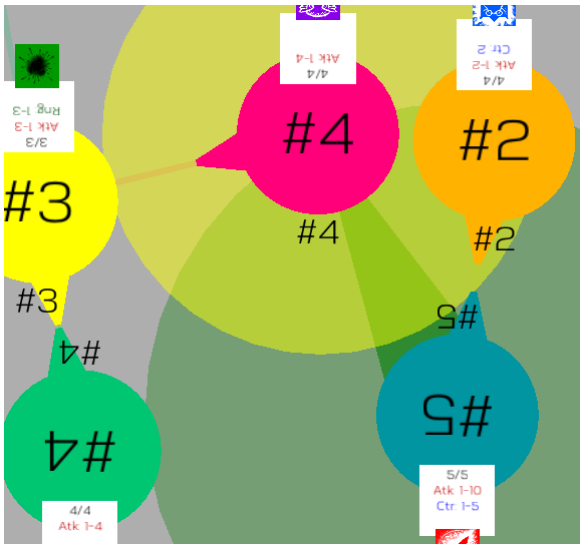


Figure 33: The attacked token #4 was a ninja. It can now evade inside the yellow circle around it to get out of the green attack range around #5.

Ranged Attacks

Ranged attacks are a bit more complicated. They happen according to the current target sightline of the attacking token. The players cannot influence the sightline directly by turning the tokens. Instead, the tokens always look at the nearest token away from the player's standing position.

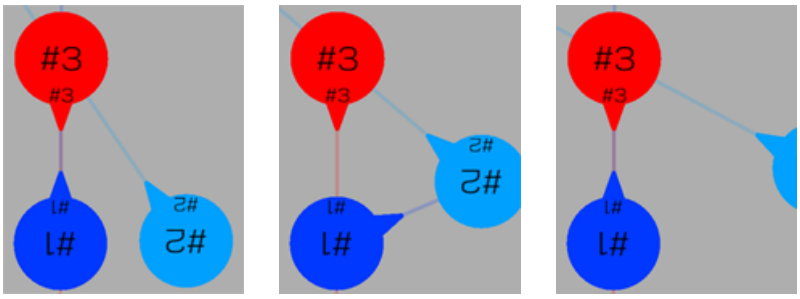


Figure 34: Targeting changes according to distance and y delta of the tokens

Figure 34 shows how the targeting changes when a token is moved. First, Token #1 is targeting #3 – #2 is closer, but it is not in front of it (away from where the player would be standing). When the #2 is moved forwards, #1 target sightline changes to it because it is still closest. Finally, in the picture on the right, #2 is still in front of #1, but #3 is closer to #1.

This might sound overly complicated at first, but it allows for a lot of strategic movement by the player and counterplay by the enemy.

Firstly, the player has to choose between setting his Marksman at the front line where it would always target an enemy token, but is more vulnerable, or in the back line.

If she places the Marksman in the front line, the enemy cannot completely evade, only choose which target the Marksman should have by placing another token near the Marksman. This is very risky for the Marksman – it might die due to being attacked in the enemy's turn, or its new target might be close enough to counterattack when being shot.

If the player instead places the Marksman in the backline, she has to use another token to target the Marksman. Shooting happens after the enemy's turn at the beginning of one's own turn, so if the Marksman is in the back line, the enemy can evade being shot by moving out of its target line – that is, if the enemy knows which token the Marksman is.

Being in the backline has another nice feature though: One can target by moving the Marksman obviously, but one can also move its nearest character to target – so one can also retarget the Marksman without moving it at all. This is useful when the Marksman is still unknown, and especially useful for targeting with the Spy without letting the enemy know that one is doing that.

Ninja Switch

Between the turns and while a player is moving and not yet attacking, any player can execute a ninja switch – but only once per game. This is executable in the command center and lets the ninja switch with any other character that is still alive.

Figure 35: Player command center with ninja switch. Icons based on a free set by J. W. Bjerk[227].

This move adds more tactical possibilities. For example, a player could shoot with her Marksman, and when the enemy comes to get her Marksman, she could switch Marksman and Ninja. The Marksman can do a ranged attack from an unexpected place, and the Ninja will just evade the attack. Similarly, just before the Ninja is attacked, switching it with the Guard would probably take the enemy off-guard with its strong counterattack.

First Move Advantage

Most turn-based games have to deal with the advantage the player who's starting the game has. In the Duel game, the player who is starting could theoretically kill up to three pieces in his first turn before the other player can even start moving a piece: One with the Marksman, one by attacking with another token and one by placing a Guard in front of the enemy Marksman to counterattack.

The game alleviates that a fair bit because moving first is better, but placing one's tokens as the second player is better than placing them first. The second player sees in which formation the tokens of the enemy were placed – and he can see the target lines. By avoiding target lines, he can prevent the enemy marksman and the spy to do anything in the first turn. Additionally, the second player can often place their Marksman and Spy so that they will always hit once the second turn starts by targeting multiple tokens in row, if he desires to do so.

Internal playtesting rounds suggest that the first move advantage is no problem with this mechanic in place. The way to correctly gauge this would be to conduct far more playtesting sessions and collect statistical data, but since the main purpose of this game prototype is to evaluate how much physical pieces improve the gameplay and general feeling of the game, it is not needed to perfectly balance the game in the context of this thesis.

[227] Bjerk, "Game Craft."

Declaration of Academic Honesty

I hereby confirm that the present thesis on

"Evaluating the Advantages of Physical and Digital Elements in Hybrid Tabletop Games"

is solely my own work and that if any text passages or diagrams from books, papers, the Web or other sources have been copied or in any other way used, all references – including those found in electronic media – have been acknowledged and fully cited.

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(Place, Date)

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(Signature)