Tangible User Interfaces in Visualization

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Abstract

In this paper we compare and analyze different Tangible User Interfaces. TUIs move away from the common input devices like mouse and keyboard and towards a direct interaction with physical objects in order to make the operation with devices more natural. This includes for example the handling of physical objects on table-tops, projections of information onto pieces of paper [Holman et al. 2005] or using additional devices to get more detailed data. The examples we are going to cover in this paper include applications in architecture, information visualization and learning tools.

CR Categories: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

Keywords: tangible user interfaces, visualization, user interfaces, report

1 Introduction

The graphical user interface (GUI) with the input devices of mouse and keyboard falls short in embracing the rich interface modalities between people and the physical environment they inhabit [Ullmer and Ishii 1997]. Therefore attempts habe been made to interweave the virtual world with the physical world. These attempts are reflected in the achievements of Tangible User Interfaces (TUI).

One of the main goals in using Tangible User Interfaces is to combine visualization of data with direct interaction. In common user interfaces the ineraction is limited to indirect input methods such as mouse and keyboard. However, indirect pointing devices fail to utilize the powerful capabilities of the human motor system. Therefore researchers attempt to find way of interaction where the user can directly touch and manipulate the objects of interest.

In the first section we give a general overview on how TUIs work and what the main challenges are. Furthermore wel regard different design spaces an application areas. We describe different approaches in implementing Tangible User Interfaces and take a look at how a system setup could look like. Therefore we take a look at the metaDESK system by Ullmer and Ishii [Ullmer and Ishii 1997], one of the early advances in TUIs. Then wel describe a more lightweight interaction system called 'Tangible Views' by Spindler et al. [Spindler et al. 2010]. We conclude the section with a discussion of the work of Hornecker and Buur [Hornecker and Buur 2006] who strive to integrate social aspects into tangible user interfaces.

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In the next section wel give some examples of TUIs and describe how some of the challenges can be solved. This section is divided into three parts:

- Table-top environments - namely the reacTable, used for the visualization of music, and the TARboard, a table-top game environment.
- Urban Planing Workbenches - namely Urp, designed to simulate different environmental influences like shadows or wind effects, and the Luminous Table, which extends the functionality of Urb even further.
- Other forms of Tangible User Interfaces - like Portico, enabling tangible interaction on and around tablet computers, and Paper Windows, simulating digital paper by projecting digital content onto physical paper.

Section 4 focuses on Tangible User Interfaces in Visualization. It examines

- the work of [Spindler et al. 2010] and describes interaction patterns and the practical use of the system.
- the Steerable Tangible Interface for Multi-Layered Contents by [Jun Lee and WooHyun Kim 2009] in regards of configuration and application.
- the G-nome Surfer by [Shaer et al. 2010], a multi-user, multi-touch table for collaborative exploration of genomic data.
- Augmented Chemistry - A Tangible User Interface for Chemistry Education by [Fjeld 2002], a TUI for working and interacting with molecular models.

This is followed by a discussion in which we evaluate the beforementioned systems.

2 Typical designs of Tangible User Interfaces

In this section we will discuss different hardware implementations of tangible user interfaces and take a look on the different design spaces they are used in.

Design spaces that we discuss in this paper include but are not limited to

- Information Visualization
- Architectural Contexts
- Geographical Contexts
- Entertainment

Shaer and Hornecker [Shaer and Hornecker 2010] also give the following list of possible application domains:

- TUIs for Learning
- Problem Solving and Planning
- Information Visualization

Figure 1: metaDESK

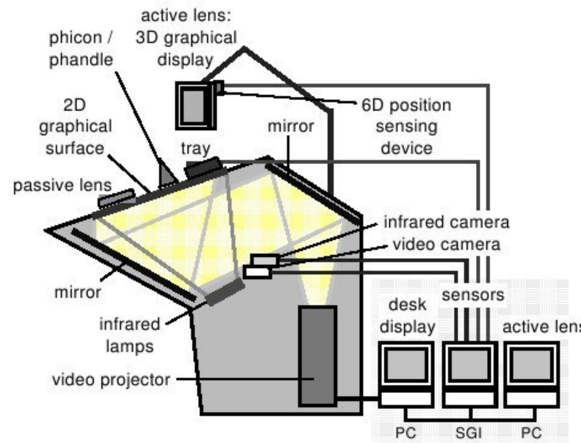

Figure 2: metaDESK Hardware Overview

- Tangible Programming
- Entertainment, Play, and Edutainment
- Music and Performance
- Social Communication
- Tangible Reminders and Tags

For the hardware description we will retain at two implementations: the metaDESK system by Ullmer and Ishii [Ullmer and Ishii 1997] and Tangible Views by Spindler, Tominski, Schuhmann and Dachselt [Spindler et al. 2010] The metaDESK system hereby depicts a system whose components are fixed and attached to the system, whereas in the Tangible Views system the views are simple physical surfaces with no restrictions on size and shape.

The last part of this section is a view on social aspects of Tangible User Interfaces.

2.1 metaDESK

One of the attemps in broadening the input possibilities to different devices is the metaDESK system introduced by Ullmer and Ishii [Ullmer and Ishii 1997]. They describe a ”Tangible User Interface” (TUI) as a user interface employing physical objects, instruments, surfaces, and spaces as physical interfaces to digital information. The metaDESK system consists of: a desk, a nearly-horizontal backprojected graphical surface; an active lens an arm-mounted flat-panel display; one or more passive lenses, an optically transparent surface through with the desk projects; and an assortment of physical objects an instruments which are used on the desk's surface. The components are sensed by an array of optical, mechanical and electromagnetic field sensors. An image of such a setup can be seen in Figure 1 an an outline of the hardware positioning in Figure 2.

The focus lies on the use of real physical objects as driving elements of human-computer interaction. The approach of Ullmer and Ishii allthough tries to take elements of the GUI and bringing it into the real world as well as pushing forward from the unaugmented physical world, inheriting from vaious historical instruments and devices often ”obsoleted” by the advent of the computer, like the active lens which is based on a jeweler's magnifying lens. The models for the objects are taken from everyday objects from home, scientific instruments or drawing and design tools. The material they used was transparent machined acrylic, designed to minimize occlusion of the desk surface.

The GUI icons are instantiated as ”phicons” (physical icons), menus and handles are instantiated as TUI ”trays” and ”phandles” (physical handles), scales and scrollbars as TUI instruments such as a rotation constraint instrument.

To test the system they implemented a prototype application called ”Tangible Geospace” allowing interaction with geographical space. The models themselves act as information containers about the object they represent as well as physical handles for manipulating the map.

The arm mounted active lens is coupled to the models and displays three-dimensional views of the scene and moving the lens makes it possible to navigate throu 3D space. This allows a seamless interaction with three spaces at once: the physical space of the object, the 2D graphical space of the desk's surface and the 3D graphical space of the active lens.

It is also possible to place a second object on the table, allowing the user to scale or rotate the map by moving the objects with respect to each other. This also allows collaboration as each object may be manipulated by an individual user. The sensing is performed by a computer-vision system inside the desk unit, along with magnetic -field position sensors and electrical contact sensors.

The passive lenses consist of a transparent surface that functions as an independent display when augmented by the back-projected desk. Since they are passive transparent surfaces, many vaiously afforded lenses might be used simultaneously with no additional active display resources.

As alternative to the two phicon scaling/rotation interaction, a rotation constraint instrument made of two cylinders mechanically coupled by a sliding bar might be used. Albeit the extension of input methods it is not the goal of metaDESK to replace GUIs, but rather to complement them by providing new opportunities for human-computer interaction.

2.2 Tangible Views

Spindler, Tominski, Schuhmann and Dachselt [Spindler et al. 2010] introduce 'tangible views' for use in Information Visualization as spatially aware lightweight displays that can be interacted with by moving them through the physical space on or above a tabletop surface.

The motivation for their project is the difficulty of encoding all information in a single image once a data set exceeds a certain size or complexity. This problem can be solved spatially by providing multiple views on the data or embedding additional local views in the visualization or it can be solved temporally by changing the representations over time. They define a tangible view as a physical surface, that users can hold in their hands with no restrictions on size and shape.

Tangible views serve two purposes: It is used as a local display in conjunction with a tabletop display, and as an input device. The specific graphical information is projected onto the tangible view and three dimensional manipulation of a tangible view is tracked in space to make six degrees of freedom available: position (x, y, z) with respect to the interaction space and local orientation of the tangible view (α, β, γ). It is also possible to use multiple tangible views at the same time.

In summary tangible views:

- Integrate display an interaction device.
- Enhance common 2D interaction with additional 3D interaction
- Replace virtual views by physical, tangible views.

Tangible views do not exist on their own, but are integrated into an environment of one or more stationary displays of arbitrary size, shape and orientation. They also describe a basic display configuration consisting of a horizontal tabletop for the main context view and tangible views as local views into the information space. This relates to the focus and context concept.

As Tangible Views play an important role in Information Visualization we will treat this subject in section four in more detail.

2.3 Including social aspects

Hornecker and Buur [Hornecker and Buur 2006] extend the thought of tangible user interfaces further to 'tangible interactions'. They introduce a framework that focuses on the interweaving of the material/physical and the social, laying the ground for collaboration-sensitive tangible interaction design. It relies on tangibility and full-body interaction and gives computational resources and data material form, embedding computing in the everyday environment, digitally augmenting physical space and supporting intuitive use.

Designing tangible interfaces requires not only designing the digital but also the physical, and their interrelationships within hybrid ensembles, as well as designing new types of interaction that can be characterized as full-body, haptic, and spatial. Applications previously not considered interfaces are turning into such and computing is increasingly embedded in physical environments.

They distinguished three different views on tangible interfaces:

- Data-centered view: Here 'tangible interfaces' are understood as utilizing physical representation and manipulation of digital data, offering interactive couplings of ohysical artifacts with "computationally mediated digital information", Eg. Ullmer and Ishii
- Expressive-Movement-centered view: Aiming to design interaction itself by emphasizing bodily interaction with objects, exploiting the "sensory richness and action potential of physical objects" so that "meaning is created in the interaction". ¡–!!quote!!
- Space-centered view: 'Interactive spaces' as "Interactive systems, physically embedded within real spaces, offer opportunities for interacting with tangible devices" and so "trigger display of digital content or reactive behaviours" The body is used as interaction device and display.

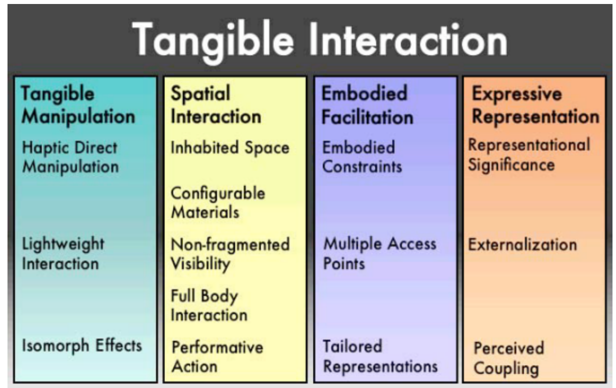

Figure 3: Tangible Interaction

Tangible interaction encompasses a broad range of systems and interfaces, building upon and synthesizing these views. These share the following characterisitcs: tangibility and materiality, physical embodiment of data, embodied interaction and bodily movement as an essential part of interaction, and embeddednes in real space, designing the interaction itself and exploiting the richness of bodily movement.

Their framework is structured around four interrelated themes:

- Tangible Manipulation: material representations with distinct tactile qualities which are physically manipulated.
- Spatial Interaction: tangible interaction is embedded in real space and therefore occurs by movement in space.
- Embodied Facilitation: how the configuration of material objects and space affects and directs group behaviour.
- Expressive Representation: material and digital representations employed ba tangible interaction systems, their expressiveness and legibility.

Figure 3 shows the design spaces of tangible interaction from specific on the left to the more general on the right.

3 Examples of Tangible User Interfaces

There is a wide variety of Tangible User Interfaces (TUIs). Possible applications for TUIs are literally endless. Many systems of TUIs have been explored and published in the past, but still a lot of new a ideas are coming up and new applications for TUIs are going to be explored. In this section, we will give examine some examples of TUIs and give an overview of different domains where TUIs have been successfully deployed.

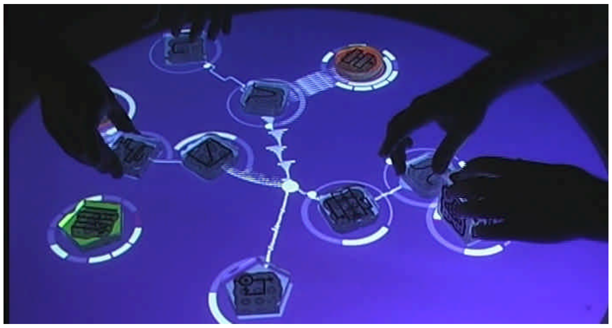

Figure 4: The reacTable in action (compare [2007])

3.1 Table-top environments

Many TUIs rely on table-top environments as their interaction technique. In these environments, a IR camera is set underneath the table-top to track fiducial markers placed onto the table. The camera can also track touch interactions of users. Marker and touch-based interactions are used as user input to the TUI system. The system responds to the user interactions by projecting visual feedback onto the table-top. Figure 4 shows the reactAble in action. Multiple users work together on a digital performance.

3.1.1 reacTable

The reactAble, presented by [Jordà et al. 2007], is a musical instrument based on a table-top TUI. Fiducial Markers represent musical objects, which generate sound according to their relation to each other. The markers are tracked by an IR camera. According to their attached symbol, each object has a dedicated function. The objects can be categorized in six different functional groups: audio generators, audio filters, controllers, control filters, mixers and global objects. [2007]

ReacTIVision, the computer vision system behind reactAble, tracks the fiducial markers and sends the output data to an audio synthesizer. The waveforms generated by the synthesizer, as well as the data from the ReacTIVision tracker are sent to a visual synthesizer. The visual synthesizer projects visual feedback back onto the table-top. The audio lines that connect objects show the real resulting waveforms. Visual feedback is also used to monitor the objects state and internal parameters. Fingers can be used to either modify the objects parameters, or to cut (i.e. mute) audio connections between objects. [2007]

Modular synthesis is used for the sound generation process. Modular synthesis is based on the interconnection of sound generators and sound processor units. In reactAble, automatic connections between objects are made depending on the type of objects involved and the proximity between them. By moving objects around and bringing them into relation to each other, performers construct and play instruments at the same time. reactAble is also a collaborative tool for interactive live music. Because of the rather big size of the table-top, multiple artists can perform together on a single reacTable. [2007]

3.1.2 TARboard

TARBoard is a tangible augmented reality system designed for table-top game environment. The purpose of TARboard is is to let users enjoy games in a more interactive and intuitive way and to make games more realistic and immersive. [2005]

Markers are attached to objects or cards used in a game. Similar to reactAble, these markers are tracked on a table-top environment by a camera underneath it. The augmenting camera is placed above the table-top. It provides the video stream for augmenting a game with virtual objects. [2005]

[Lee et al. 2005] implemented a card game as a prototype for TARboard. Each player has cards which represent mystic creatures. The marker on the bottom of each card is tracked by the tracking camera. When the players flip a card and place it near the battle zone, the creatures get augmented on the battle zone and fight against each other.

3.2 Urban Planning Workbenches

In urban planning, designers usually employ three forms of representation: Two-dimensional drawings on sheets of papers, three-dimensional physical models and computer models, which can be two and three-dimensional. Each of these representations are created and displayed independently. Urban planning workbenches try to bridge the gap between these forms of representation, by simultaneously layering 2D drawings, 3D physical models, and digital simulation over each other. First, the 2D drawings and sketches are laid out on a table. Next, the 3D models are placed on top of the drawings. Finally, video projectors project digital simulations onto the surface. Video cameras capture the activity on the table and adjust the dynamic representation according to the position of the drawings and models with optical tags. [Ishii et al. 2002]

The advantage of urban planning workbenches lies in the combination and fusion of digital and analog content. The dynamic simulation of features like shadows, traffic and wind bring the analog content placed on the workbench to life. Users gain a more thorough understanding of the implications of their designs. Furthermore, the two- and three-dimensional physical representations together with the digital projection add to a more realistic simulation of an urban design space.[Ishii et al. 2002]

3.2.1 Urp

Urp is an implementation of an urban planning workbench. Urp is classified as an luminous-tangible interface. The accurate casting of shadows and reflections of the 3D models is a very important part of the system. The Urp urban planning workbench consists of the following five key functions:

- Shadows: Urp casts accurate shadows of the 3D models onto the projection table. With a clock object, the user can change the position of the computational sun and see how the shadows of the models change accordingly.
- Distance Measurements: With the distance-tool, a line between two buildings can be drawn. The drawn line connects two structures, with the lines length displayed beneath. This number continuously changes as the connected structures are moved.
- Reflections: When a user touches any building with a transparent wand, its facades become glass, so that solar reflections are generated and projected onto the table.
- Wind Effects: Urp is able to project an airflow simulation onto the workbench. The user can choose between eight quantized wind directions. The simulation is displayed as a regular array

Figure 5: Students using the Luminous Table (compare [2002])

of white segments, whose direction and length correspond to the instantaneous direction and magnitude of the wind at that position.

- Site Views: Since the model buildings 3D forms are already resident in the system (because of the shadow generation), they can be rendered in perspective and with simple shader arguments. Placing a camera object in the workspace results in a real-time rendering of the current arrangement of buildings in the site, viewed from the height of a pedestrian and the position and orientation of the camera. [1999]

Urp can also simulate traffic on roads, when traffic strips are placed onto the workspace. When two plastic strips cross each other, the simulation creates an intersection with implicit traffic-control signals. Cars come to a halt in one direction, while the traffic in the other direction flows. [1999]

3.2.2 The Luminous Table

The luminous table is based upon the Urp urban planning workbench, but extends its functionalty to a more mature form. The luminous table software allows more flexibility in the computation of shadows by allowing users to interactively change the latitude (Urp has a fixed latitude) and set the time of the simulation more precisely. The traffic simulation in the luminous table is also more advanced compared to Urp. Users can change the road length, road width, traffic density and traffic cycle time of the simulation. Furthermore, the luminous desk supports more geometry formats for models of urban structures and implements the ability to save and restore work. Figure 5 shows students interacting with the luminous table. [2002]

3.3 Other forms of Tangible User Interfaces

There are many other different forms of Tangible User Interfaces for a variety of devices. We will discuss some of them in this section.

3.3.1 Portico

Portico is a portable system for enabling tangible interaction on and around tablet computers. Two cameras mounted on small, foldable arms are positioned above the display to recognize a variety of physical objects. These objects can be placed on the tablet or around it. The cameras have a large field-of-view, so the interaction can be extended beyond the tablet. The prototype developed by [Avrahami et al. 2011] uses a 12” inch tablet, but the interaction space is six times the size of the tablet screen. Portico allows tablets to increase both their interaction space and sensing capabilites, without sacrificing portability. Portico can be used for games or educational purposes. Because physical objects are more graspable than touch surfaces, Portico would be suited as a learning device for young children. [**?**]

3.3.2 Paper Windows

Paper Windows simulates the use of digital paper displays by projecting digital content onto physical paper. IR cameras track the motion and the shape of the paper for an accurate projection. Pens, fingers, hands and other objects are also tracked by the computer vision system to allow enhanced interaction with the paper documents. [Holman et al. 2005] introduce a set of new interaction techniques to allow interactions between different paper documents. The rubbing technique for example allows users to transfer contents between paper documents. The flipping interaction allows users to navigate through the document by flipping the paper in their hands. Paper can also be stacked to organize them in piles on a desk. On the paper document itself, items can be selected through a one handed pointing gesture. Interactions like Copy & Paste, Scrolling, Browsing and Sharing are also possible. [2005]

3.3.3 3D Tractus

[Lapides et al. 2008] present a three-dimensional user interface to monitor and control a team of independent robots in a spatial tasks. The 3D Tractus is a tangible user interface, which allows to change the height in a three-dimensional environment. It is a mechanical device consisting of a table surface that slides up and down on four vertical tracks. A tablet is placed on top of the table surface to control a 2D map. The user can move the table surface up and down to change the height in the environment. The purpose of the system is to control a robotic team inside a three-dimensional building, where a bomb has to be defused. A single human operator controls multiple robots by giving them instructions on the tablet PC. The tablet provides a topdown view of the building. [2008]

4 Tangible User Interfaces in Visualization

The purpose of this chapter is to introduce Tangible User Interfaces which are settled in the domain of Visualization. We will give an overview of TUIs in Visualization we consider noteworthy. In the previous chapter, some of the presented TUIs could also be labeled as TUIs for Visualization, because some output is visualized by the system. In the reacTable for example, the sound waves between different musical objects are visualized on the tabletop. However, the reactAble is designed as a musical instrument. In this chapter, we will focus explicitly on TUIs, which sole purpose is the Visualization of data.

4.1 Tangible Views for Information Visualization

Tangible Views is a Tangible User Interface for Information Visualization presented by [Spindler et al. 2010]. It consists of several handheld displays, which allow to interact with the visualized data in a more direct way. Similar to Paper Windows, a TUI presented by [Holman et al. 2005], the information is project onto cardboard displays (Tangible Views) as well as a tabletop. The setup also consists of several IR cameras, which track the Tangible Views and make them spatially aware. Gestures performed on the Tangible

View are recognized by the system as well. Tangible Views are enhanced with IR markers, to simplify tracking. The cardboard displays are cheap in production. Therefore, it is easy to produce tangible views in different shapes and sizes. Figure 6 shows applications of Tangible Views in practice. [2010]

4.1.1 Representational aspects

The stationary tabletop display, which can be of arbitrary size and shape, acts as a contextual background. Graphical information is displayed on the tabletop display. In this information space, the Tangible Views serve Oas local views in context with the tabletop display. Tangible Views can be used with other Tangible Views simultaneously. They can be seen as a multiple view environment with each Tangible View representing a unique physical view into a virtual information world. This makes them an ideal tool for collaboration or comparison tasks. Since Tangible Views can be easily produced, different shapes may contribute to different visualization tasks and take a special role during interaction. shortcitespindler10

4.1.2 Interaction with Tangible Views

The design of Tangible Views was aimed at an easy and natural usage, which is inspired by everyday life interaction principles. The interaction takes place within the physical space defined by the tabletop display. In this three-dimensional space, Tangible Views are moved around by the users and provide appropriate feedback. Six degrees of freedom are available for interaction, this includes the position and the local rotation of the Tangible View. Corresponding interactions are translation and rotation, which are easy to learn and simple to execute. [2010]

4.1.3 Interaction Patterns

[Spindler et al. 2010] define eight Interaction Techniques for interaction with Tangible Views. The interaction techniques have been tailored to fit the needs of Information Visualization. Some of the techniques rely heavily on the available six degrees of freedom. The following eight techniques are defined in Tangible Views, figure 7 shows the interaction techniques graphically.

- Translation: In this technique, shifts and movements of the Tangible Views are interpreted as interaction. The resulting three degrees of freedom (3DOF) can be utilized by using all 3DOF or by restricting them to one or two axes.
- Rotation: Another way of interaction is to use the Tangible Views local orientation. This includes 3DOF. [Spindler et al. 2010] distinguish between two types of rotation: horizontal rotation around the z and vertical rotations around the x and/or y axis.
- Freezing: In certain situations, it can be useful to move a Tangible View without the intention of interacting with the system. This can be the case when users want to study a specific view in more detail or keep it for later examination. When the Tangible View is frozen, the system ignores its movement. Freezing can affect all three 3DOF, or only the z-axis or the x-y axis.
- Gestures: The concept of gestures include more complex types of interaction techniques. This includes flipping, shaking and tilting the Tangible Views. These techniques enhance the range of interaction possibilities wit the system.
- Direct Pointing: In addition to interacting with Tangible Views, it is also possible to interact on them. Multi-touch and digital pens can both be used on the Tangible Views and the stationary display. Multi-touch is used for interacting with the user interface elements, digital pens can be utilized for more precise input such as writing or exact pointing.
- Toolbox Metaphor: The main idea is to assign specialized tasks to physical properties of Tangible Views. In particular the shape and the visual appearance of Tangible Views are relevant. Specialized tools can be mapped to Tangible Views with certain physical properties. Depending on the their aim of interaction, users can switch tools by simply exchanging tangible views.
- Visual Feedback: Visual Feedback is important for interacting witch a visual system. Therefore, instant feedback is provided on a Tangible View or on the tabletop display.
- Multiple Views: Multiple local views are supported within the space of the global stationary display. Tangible Views can interact side by side independently, or overlap each other. Overlapping Tangible Views influence each other. The visual output of one Tangible View may depend on the output of another one. [2010]

4.1.4 Tangible Views in practice

[Spindler et al. 2010] studied the usefulness of Tangible Views in several case studies. Different types of information Visualization tasks were implemented in the system.

Scatter plots visualize correlation in a multivariate data set by mapping two variables to x-y position of graphical primitives. Color, size and shape of these primitives can be used to encode further variables. In a dense plot, graphical primitives could become very tiny, making it hard to differentiate between them. The tabletop display shows the scatter plot as whole mapped to its x- and y axis. A zoom lens and a fisheye lens serve as Tangible Views. With the zoom lens, the user can zoom in and out of the visualized data. The fisheye lens temporarily sacrifices the positional encoding to disentangle dense parts of a scatter plot. By rotating it horizontally, the degree of displacement can be controlled. [2010]

In Graph Visualization, node-link diagrams and hierarchical abstraction are used to interactively explore large graphs. In Tangible Views, a rectangular Tangible View servers as a local abstraction view for the graph shown on the tabletop display. The degree of abstraction can be changed by vertical translation. This way it is possible to explore the graph at different levels of detail. The tabletop display gives visual feedback of the position of the Tangible View in the graph. [2010]

4.2 Steerable Tangible Interface for Multi-Layered Contents

[Jun Lee and WooHyun Kim 2009] propose a steerable tangible interface (STI) to intuitively interact with multi-layered content projected onto a tabletop display. Users can move a ring to locate to a region of interest and rotate the ring for navigating through different layers of visual information. The interaction can be compared to a magnifying glass, which is used to examine different layers of visualization content. [2009]

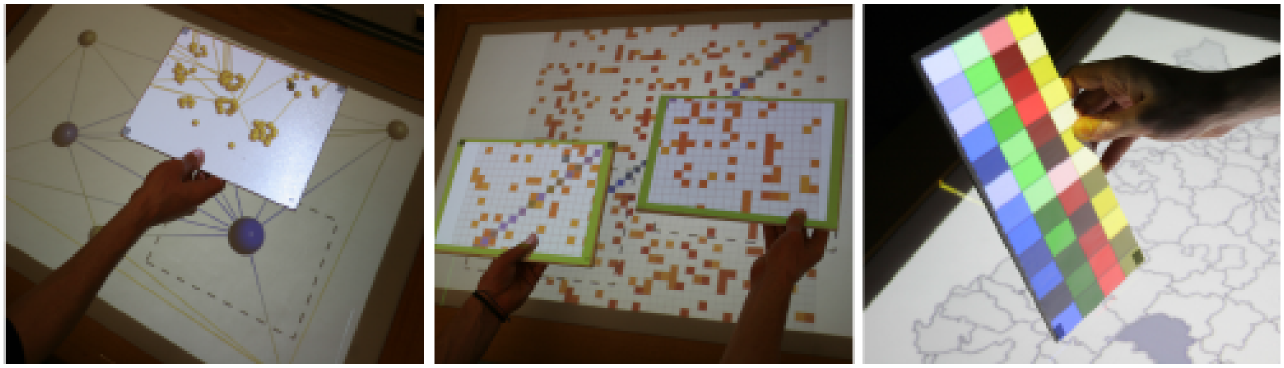

Figure 6: Tangible Views in practice (compare [2010])

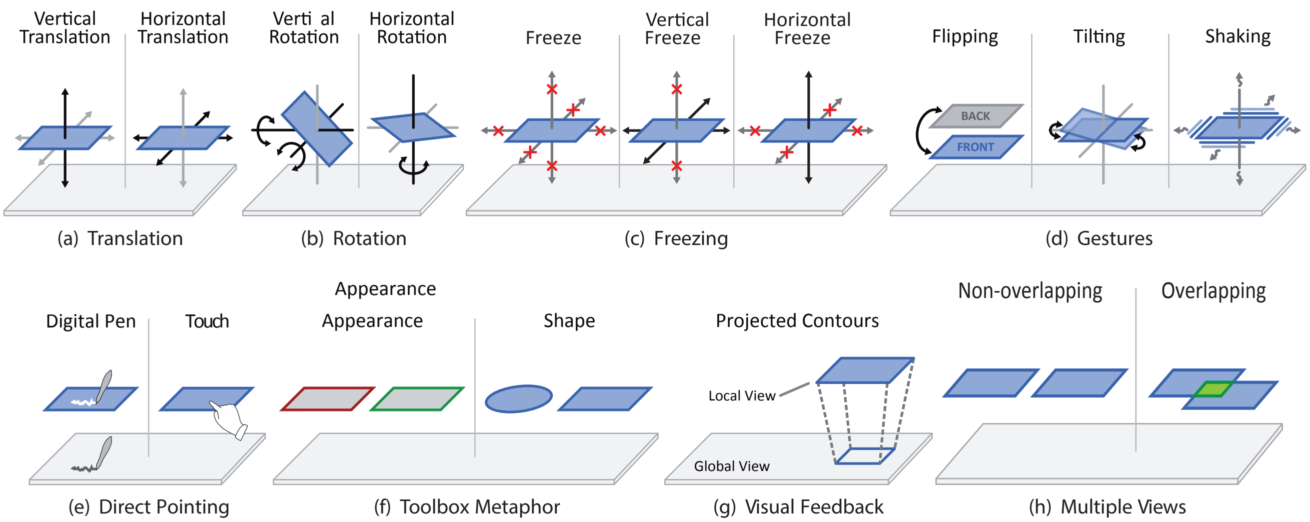

Figure 7: Interaction techniques in Tangible Views (compare [2010])

4.2.1 Configuration of the System

The steerable tangible interface consists of a ring with 18cm in internal radius, 1.5cm in thickness and 1cm in height. The internal circle represents a focus region, where detailed information is displayed. The ring is equipped with two LED lights to track its position and orientation. Moving the ring relocates the visualization area to the region in focus. By rotating the ring, a user can select a layer to be displayed. A Nintendo WiiRemote, installed on the ceiling, tracks the STI. It recognizes the position of the two LEDs. With this information, the system computes the position and rotation angle of the STI. The information is displayed on tabletop display, similar to the ones described in 3.1. [2009]

4.2.2 Application of the Steerable Tangible Interface

The STI can be used for educational purposes. [Jun Lee and WooHyun Kim 2009] implemented a multi-layered medical education content on the system. Users can navigate through different layers of human body organs. If a user wants to see more detailed information beyond the skin layer, he puts the ring to the specified region. In the focus region, different views of human body information are visualized. By rotating the ring, different layers can be visualized in the region of the STI. [2009]

4.3 G-nome Surfer

G-nome surfer is a multi-user, multi-touch table for collaborative exploration of genomic data, presented by [Shaer et al. 2010]. G-nome surfer allows users to compare, annotate, share, and relate genomic data. The data presented by the system includes genome visualizations, publications and gene expressions.

4.3.1 Motivation

With G-nome surfer, scientists can collaboratively explore genomic information. Heterogeneous information can be related to each other, which simplifies comparison. Information from science databases, like abstracts of publications related to a particular gene, are also published. Through the use of touch gestures, intuitive interactions are used to simplify the exploration of complex genomic material. [2010]

4.3.2 Implementation

G-nome Surfer is implemented on the Microsoft Surface tablet platform. Several databases serve as information providers for the genomic data. [2010]

4.3.3 Navigation in G-nome Surfer

G-nome Surfer supports navigation of both eukaryotic and prokaryotic genomic data at multiple zoom levels. To access such data, a user selects an organism and then specifies a chromosome, range, or gene name. The view is then updated to display a portion of the chromosome with the specified gene in the center. For prokaryotes, a circular representation of the chromosome is displayed as a wheel beneath the chromosome track. With gestures, user can search through the chromosome track. With the chromosome wheel, prokaryote data can be traversed coarsely. Visual feedback is given all the time. By tapping on a gene, the genes sequence can be accessed. Sequences are displayed in separate windows. By snapping sequences together, a new windows opens with the information aligned beneath each other. [2010]

4.4 Augmented Chemistry - A Tangible User Interface for Chemistry Education

Augmented Chemistry (AC) is a TUI for working and interacting with molecular models. It consists of a set of interactive tools, which work within the system. Since many tools can be used concurrently, multiple users can work with the system at a time. [2002]

4.4.1 System Setup

Augmented Chemistry is an augmented reality workbench consisting of a table and a rear-projection screen. Below the screen sits a camera, pointing in the users direction. The images of the camera are projected onto the screen. Therefore, the display acts as a mirror for the user. The mirror image is augmented with a virtual environment. A booklet, a cube, a platform and a Gripper act as the tools for interaction. Each of this tools carries one or more fiducial markers to interact with the system. [2002]

4.4.2 Interaction Techniques

Bringing together two elements, triggers the composition of a molecular model. The booklet shows elements by a printed picture and a name. The user browses the booklet with one hand. With the other hand, he can pickup an element using the Gripper. When the Gripper, charged with an element, is positioned near a platform holding a molecule, the element is connected with the molecule. With a rotation of the cube, users can determine where and how (single- double- or triple-binding) the element shall connect to the molecule. [2002]

4.4.3 Visualization of Molecules

Augmented Chemistry employs the ball-stick model for the visualization of molecules. In the booklet, working as an interactive menu, the valence of an atom can be seen. Atoms are visualized with a nucleus and the outmost valence shell. This representation of atoms is in accordance with the model of Bohr. [2002]

5 Discussion

In the previous section, we have presented several Tangible User Interfaces in the domain of Visualization. Each of these TUIs follows a different approach in visualizing data. Furthermore, the presented are all settled in different areas of Visualization. This ranges from Information Visualization in Tangible Views to Visualization of atoms and molecules in Augmented Chemistry. In this section, we will evaluate and discuss advantages and drawbacks of the different systems.

5.1 Portability

Most of the TUIs rely on tabletop environments to display visualized content. This systems may be intuitive in terms of interaction with the displayed content, but they don't seem to be very portable. To install and use such a system, large tabletops have to be constructed and a projector has to be installed under the tabletop or on the ceiling. All TUIs except the Augmented Chemistry system and the G-nome surfer rely on this environment. The G-nome surfer is implemented on a Microsoft surface, a big multi-touch screen. It does seem portable ,

6 Conclusion

We have examined different designs of Tangible User Interfaces in this work. Furthermore, we have presented and discussed several examples TUIs. Although the focus of this work lies in Tangible User Interfaces for VIsualization, we have also presented TUIs for other domains. A discussion about the pros and cons of the different TUIs followed their presentation.

TUIs can be intuitive tools for the examination of visualized data. Instead of using the classic mouse and keyboard interaction, they enable users a more natural way of exploration and interaction with digital content. By using graspable objects and multi-touch gestures, users learn the interaction patterns more easily. This results in a faster and more comfortable way of examining visualized information. The TUI interaction paradigms work especially well for huge amount of data with multiple layers. However, TUIs are normally specialized on certain Visualization tasks. Therefore, TUIs can only interact with certain styles of Visualizations effectively.

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