MAMMI
WP1: Review of existing systems

ENAC, IntuiLab

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Acronyms

The following acronyms are used in this document:

CSCW	Computer Supported Collaborative Work
Dpi	Dot per inch
Fps	Frame per second
GIS	Geospatial Information System
HCI	Human-Computer Interaction
KPa	Kilopascals
Ppi	Pixel per inch
SDG	Single Display Groupware
TUI	Tangible User interface

1 Introduction

In situations where co-workers interact with each other to achieve their tasks, such as in ATC on an en route traffic position, social interaction and collaboration are important. Traditional tables are an intuitive and common tool for co-located collaboration. Indeed, tables' horizontal surfaces afford the placement and organisation of objects, and collaboration amongst a group of co-located persons. As for desktop computers, they support remote collaboration through groupware but they do not support co-located collaboration efficiently. They are designed for a single person sitting in front of one or more displays using a keyboard and a mouse. That's why researchers and manufacturers have a growing interest in interactive tabletop displays. Interactive tabletop displays are an emerging technology that aims to combine the physical and social affordances of traditional tables with the advantages of computer technology. Computer technology brings several benefits such as the ability to access information from external sources via network connections, virtual tools and objects (electronic documents, etc.) and the ability to provide interactive outputs and feedbacks to users.

Tabletop systems rely on three concepts:

- they use a multi-input multi-user technology...
- ...large enough so that more than one person can interact with it at the same time
- ... and they run interactive systems designed to support collaboration.

They are an instance of the class of Single Display Groupware (SDG) systems [Stewart et al 1999]

This document provides an overview of the state of the art of interactive tabletop displays. Although this work does not claim to provide an exhaustive study of all the literature that considers interactive tabletop displays, we do hope that it will provide a concise overview of the domain. Prior works fall into three main categories: hardware support for interactive tabletop displays, social-sciences studies on the use of shared surfaces and collaborative activities, and user interface design.

After the introduction, the document focuses on hardware support for interactive tabletop displays (chapter 2). We try to present an overview of the different king of input sensing technologies and output displays. We then present the advantages and drawbacks of each combination.

Chapter 3 focuses on work on SDG, Computer Supported Collaborative Work (CSCW) and social science studies on the use of tabletop displays. This chapter discusses multi-user coordination policies and the impact of interactive tabletop displays on group dynamics.

In chapter 4, we discuss user interface design and interaction techniques for interactive tabletop displays, before concluding (chapter 5) and giving our references/a bibliography on interactive tabletop displays in chapter 6.

2 Tabletop hardware

In this chapter, we present an overview of existing interactive tabletop displays. Interactive tabletop displays can be broadly categorized based on the type of input sensing technology and on the output display they use.

In the following of this chapter, we introduce the important/well-known tabletop systems in each category. First, we focus on the different input sensing technologies used in these systems. Then, we investigate output technologies. Finally, we categorize existing systems based on relevant details on input, on output and other characteristics.

2.1 Input sensing technologies

There are several input sensing technologies that can be used to create interactive tables: mice, styli, touch-sensitive surfaces, vision-based systems, tangible objects, etc. Two main reasons for the wide disparity in choice of input devices are the variety of tasks that can be performed using an interactive tabletop display, and the inherent strengths and weaknesses of each input technologies.

Typically, tabletop systems combine a direct multi-input surface with an output display such that the input and visual space are overlaid. This affords a user interface where objects can be manipulated directly and helps to promote mutual awareness. Indeed, the use of a direct input device allows partners to more easily perceive what action the other is taking or is about to take. That is why our review of existing systems is mainly focused on systems on which input sensing and output display are superimposed.

2.1.1 Indirect multi-input systems

2.1.1.1 Multiple Mice

Multiple mice can be used to rapidly prototype Single Display Groupwares (SDG) [Tse and Greenberg 2004]. Multiple mice systems are interesting because mice are widely available and have an extremely low cost compared to innovative multi-touch devices.

Furthermore, mice are most appropriate for user tasks requiring a high degree of precision. Our hands and fingers have the dexterity to express many levels of interactions, both symmetrically and asymmetrically, but have a poor resolution when it comes to pointing and interacting with small items.

Multiple mice systems have been used to study kids' collaboration around games and educational software in developing countries [Pawar, Pal and Toyama 2006]

Figure 1: Multiple mice educational software, Microsoft Research India

For example, KidPad [Druin et al 1997], from HCI Lab University of Maryland is a collaborative story authoring tool allowing several children to create a story together. When used with multiple mice, KidPad associates a basic drawing tool to each mouse.

Figure 2: KidPad, HCI Lab University of Maryland

2.1.1.2 Knobs and dial

A rotary knob or a dial may be used as input device transmitting a value to the computer each time it is turned. For example, the Timetable project (Figure 3) uses dials to control a real-time 3D scene projected onto the central part of the table. The Timetable is composed of top-projected display onto a large circular table (2.75 meters in diameter) and twelve dials (US Digital rotary encoders). The range and meaning of the movement of a given dial depends on what is projected into it, i.e. it can easily be modified by software. Dials can become clocks, gauges, speedometers, switches, steering wheels, etc.

Figure 3: Timetable, Perry Hoberman

2.1.2 Tangible User Interface systems

Some tabletop systems allow user to use tangible tools or objects to interact with the system: they are called Tangible User Interfaces (TUI). TUI systems track the position and movement of objects on a flat surface and respond to user’s physical input with graphical output. The physical objects are sensed using mechanical, optical or electromagnetic sensors.

These systems take advantage of the user’s sense of kinaesthesia and skills in three-dimensional spacialization: it is easier to interact with real physical objects than virtual/digital objects because your hands get passive haptic feedbacks from the objects which help you move them without requiring a lot of visual attention.

2.1.2.1 MIT Media Lab: SenseTable

The SenseTable [Patten, Ishii et al 2001], from MIT Media Lab, is an interface prototyping platform for Tangible User Interface. It can wirelessly track the position of multiple objects on a flat surface. The tracked objects have a digital state which can be controlled by physically modifying them, using dials or push buttons.

The SenseTable uses a pair of modified Wacom Intuos digitizing tablets that are placed next to each other to form a 52 cm x 77 cm surface. Each physical object is associated with a radio-frequency (RF) tag with a 32 bit serial number to identify it. To allow the tracking of more than two objects, each RF tag has a circuit to switch it on and off randomly such as each RF tag is turned on about one third of the time. Furthermore, to reduce interaction latency, each object has a capacitance sensor to detect when is being touched. When the object is touched, its RF tag is turned on.

This technique provides a high input resolution (1000 dpi) and has a low latency. However, latency increases if more than two objects on top of one Wacom digitizing tablet are touched simultaneously.

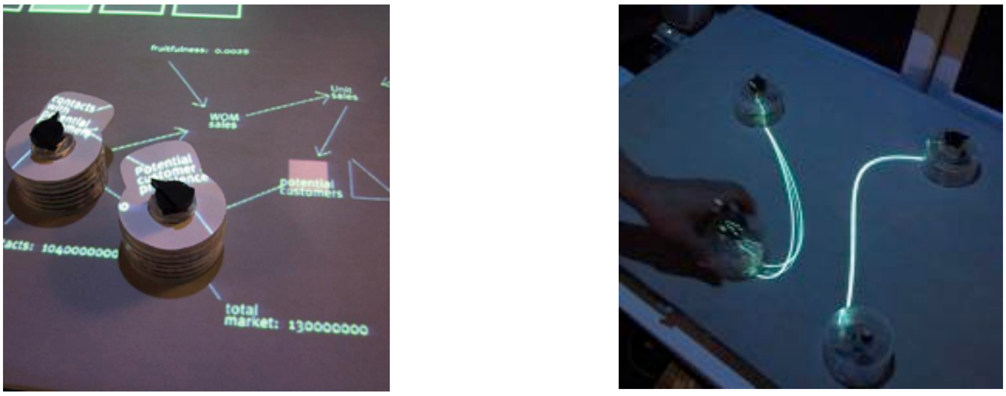


Figure 4: SenseTable, MIT Media Lab

The SenseTable platform has been used in different applications such as AudioPad, Tangible Disaster Simulator System and AirportSim.

AudioPad [Patten, Ishii et al 2002] is a composition and performance instrument for electronic music which tracks the positions of objects on a tabletop surface and converts their motion into music and visual feedbacks. Each object represents either a musical track or a microphone. Users can pull sounds from a giant set of samples, juxtapose archived recordings against warm synthetic melodies, cut between drum loops to create new beats, and apply digital processing all at the same time on the same table.

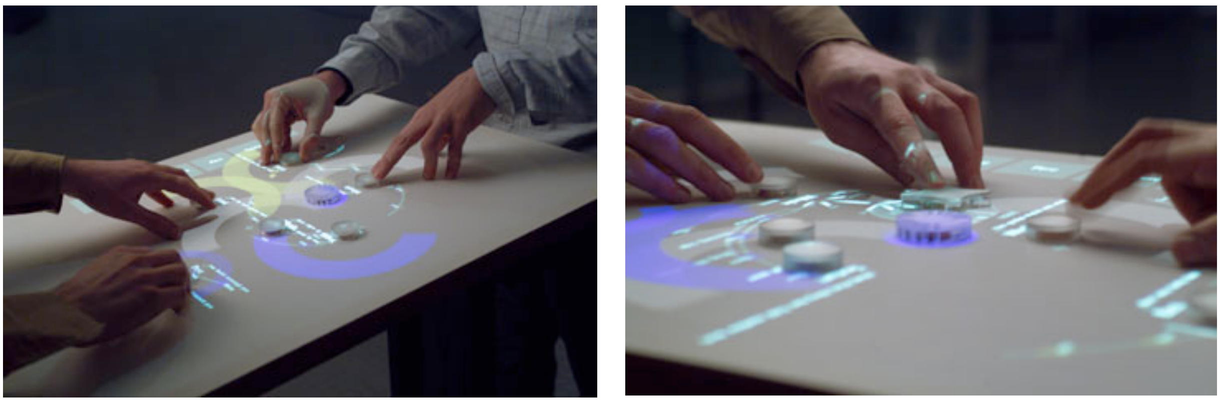


Figure 5: AudioPad, MIT Media Lab

Tangible Disaster Simulation System is a collaborative tool for planning disaster measures based on disaster simulation and evacuation simulation using Geographic Information Systems (GIS). It allows multiple users to directly input parameters such as the scale of disasters (tsunami, earthquake, fire, etc.) and the capacity of a shelter on a projected map. Then, it simulates and visualizes the disaster and the evacuation of people to shelters, under any conditions, helping users to examine how much damage from a disaster will be and what kind of measures could prevent the estimated damage.

Figure 6: Tangible-DSS, MIT Media Lab

AirportSim is a tool helping airport managers to distribute resources throughout a model airport, balancing cost with customer satisfaction. The application is made up of a number of movable objects that define the airport layout and parameters, such as check-in counters, waiting areas, and security checkpoints. Simulation controls affect the simulation globally, including a terror alert level control that allows managers to plan for different emergency alert levels as defined by the United States Department of Homeland Security. As passengers walk through the virtual airport, the manager can identify bottlenecks and make changes in real-time to increase the efficiency of the workforce.

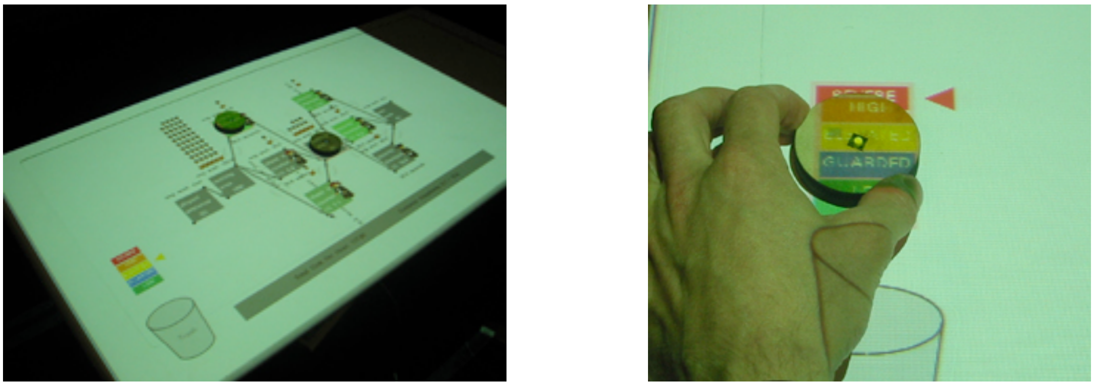


Figure 7: AirportSim, MIT Media Lab

2.1.2.2 MIT Media Lab: Illuminating clay and SandScape

Illuminating Clay and SandScape, from MIT Media Lab, are landscape analysis tools, for GIS analysis and modelling, based on interaction with a physical model made of clay (Illuminating clay) or sand (SandScape).

The architecture of these two tangible interface systems is based on the same principles. Users can alter the form of a landscape model by manipulating clay or sand while seeing the resultant effects of computational analysis generated and projected on the surface in-real time.

Users alter the form of a landscape model by manipulating clay or sand. The surface geometry/topography is continuously sensed. This information is analyzed by a GIS application and results are projected back on the landscape model to present information such as shadow, land erosion, water flow, etc. The whole interaction loop happens in near real-time.

This technique takes advantage of our natural ability to understand and manipulate physical forms while harnessing the power of computational simulation and provides an intuitive spatial mapping to landscape analysis.

The differences between Illuminating Clay and SandScape are in the material used for the surface and in the 3-dimensional sensing technology used to get the 3D model of the surface. Illuminating Clay uses a ductile clay support. Three-dimensional geometry is captured in real time using a triangulation based laser to be accurate.

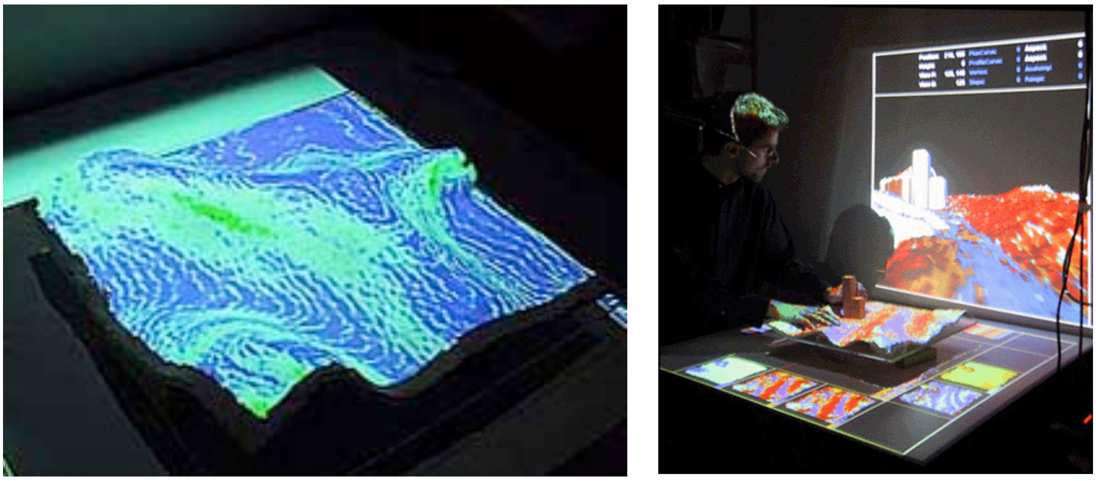


Figure 8 : Illuminating Clay, MIT Media Lab

SandScape uses a sand model to represent the terrain and an affordable surface sensing system. The model is lit from underneath with infrared lights. A monochrome infrared camera mounted above the model records the intensity of light passing through the model. From the image captured by the infrared camera it is possible to determine the surface geometry of the sand model.

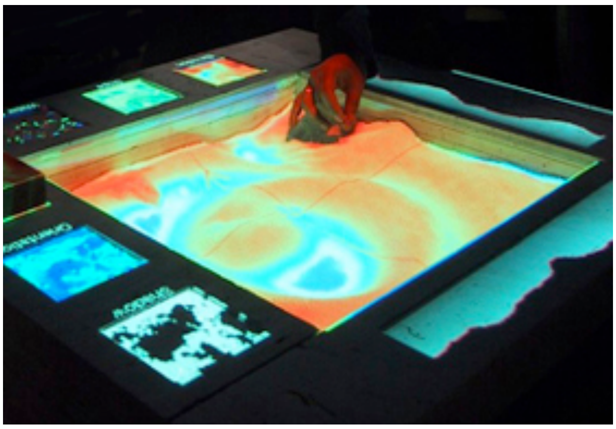


Figure 9: SandScape, MIT Media Lab

2.1.3 Vision-based systems

Vision-based systems use computer vision and image processing techniques to recognize objects on the table (object tracking) or user's interactions with the table (user tracking). The use of vision as sensing technology can provide a great flexibility in input sensing on the table: fingers, hands, sheet of papers, game pieces, etc.

But, vision-based systems often require a calibration phase to calibrate the transformation from the input tracking coordinate system to the display coordinate system.

2.1.3.1 Smart Technologies Inc: DViT

The DViT (Digital Vision Touch) SmartBoard, from Smart Technologies Inc., is an interactive overlay that can be used with flat-panel displays or video projectors. It uses four infrared cameras placed in each corner of the display. The cameras scan a small volume above the surface of the display and measure the azimuth of any object entering this volume. By triangulation of the four measures, the DViT calculates the location of the object on the surface.

Figure 10: DViT, Smart Tecnologies Inc

This DViT is only capable of detecting up to two points of contact along with their respective point sizes, i.e. it can be used to recognize a pen tip, a finger or a hand.

Furthermore, the DViT does not distinguish between different users.

2.1.3.2 Clips-IMAG: Magic Table

The Magic Table [Berard 2003], from CLIPS-IMAG University of Grenoble, is an interactive tabletop display based on the manipulation of tokens tracked by a vision-based mechanism.

The Magic Table combines a traditional whiteboard (100 cm x 75 cm) with horizontal orientation, a projector and one or two video cameras (768x576 pixels at 25 fps). The system can track either fingertips or coloured tokens (small disks of bright coloured plastic). The colour of tokens has no semantics; it is only used to simplify the tracking of tokens. Indeed, image processing techniques are performed on the camera output to detect tokens or fingertips based on colour detection

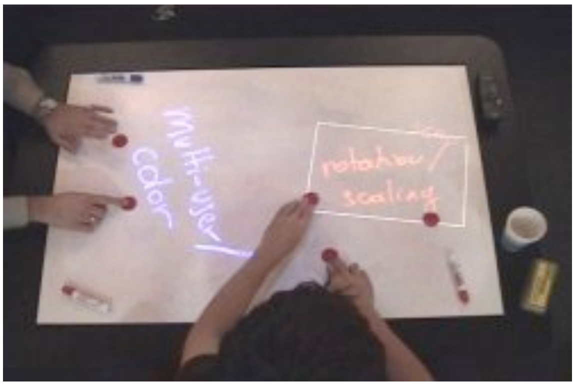


Figure 11: The Magic Table, CLIPS-IMAG University of Grenoble

In order to maintain near real-time input sensing with low latency, the video input is only processed at quarter definition (384x288 pixels). Input resolution is in the order of 0.4 cm.

2.1.3.3 Microsoft Research: TouchLight

TouchLight, from Microsoft Research, is an interactive display technology developed by researcher Andy Wilson. It combines a translucent holographic film projection material and computer vision techniques. A video projector, an infrared illuminator and two infrared video cameras are mounted behind the projection material.

The characteristic of the projection material that constitutes the screen make it possible to project onto the screen and see through it at the same time. With two cameras, the system has a stereoscopic vision and can use image processing to determine if a given object is on the display or above. The image becomes bright where objects are touching or nearly touching the screen.

Because of the transparency of the screen, it is possible to use a digital still camera behind the screen to capture a high resolution picture of an object placed on the surface and create a virtual copy of the picture. The user can then interact with this virtual copy, e.g. rotate or scale.

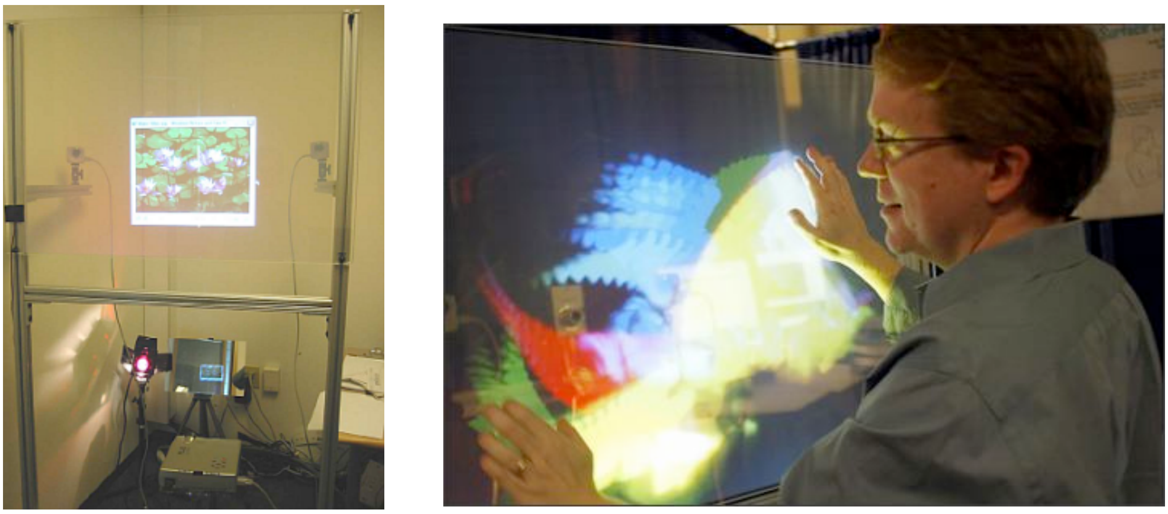


Figure 12: TouchLight, Microsoft Research

2.1.3.4 Media Research Laboratory: FTIR prototype

The multi-touch sensing through the Frustrated Total Internal Reflection (FTIR) technique is a research project at the Media Research Laboratory at New-York University by Jeff Han. The FTIR prototype is composed of an acrylic sheet (40.6 cm x 30.5 cm x 0.6 cm) used as a touch surface, a projector and an infrared video camera mounted under the surface and facing it.

The FTIR technique is based on optical principles used for optical fibres:

- when light encounters a medium with a lower index of refraction (e.g., going from glass to air), its refraction depends on the angle at which it hits the border,
- beyond a certain angle, light is not refracted, but instead reflects entirely within the material.

The four edges of the surface are lit by infrared LEDs to produced total internal reflection in the acrylic sheet. When the user touches the surface (or uses an object on it), the light bounces off its finger (or the object) making it visible by the camera. Image-processing techniques are performed on the camera output to detect the points of contacts.

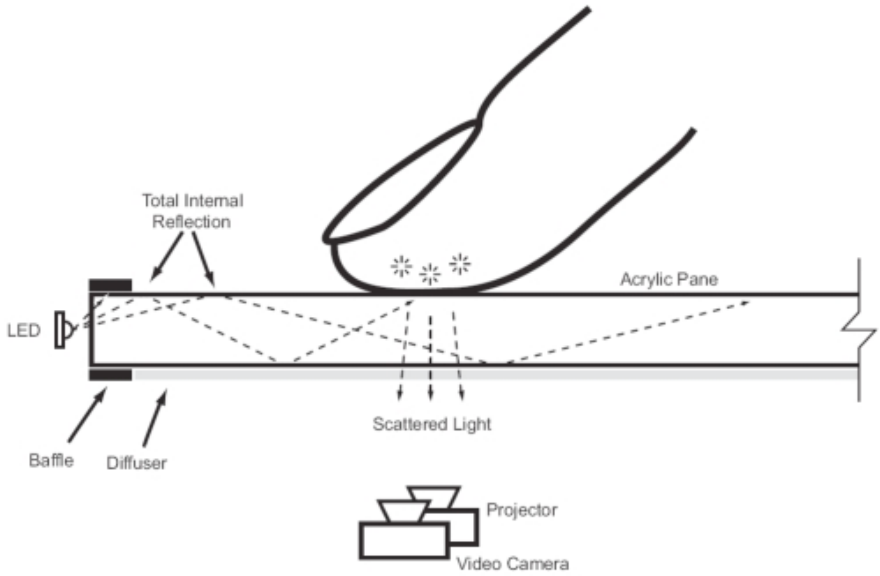


Figure 13: Schematic overview of FTIR prototype

Input sensing is performed in near real-time at 30 fps with a resolution of 640x480 pixels. Input resolution is in the order of 0.1 cm.

Advantages of this technique are that it is relatively cheap and that it is extensible to larger devices such as interactive walls (at the cost of a lower input resolution).

Weaknesses are that it can not identify users and that it requires significant space behind touch surface for video camera behind the display. Thus, this device can not be flat and is not easily portable.

The FTIR prototype has been used by Jeff Han as a multi-touch research platform for developing and testing novel interaction techniques.

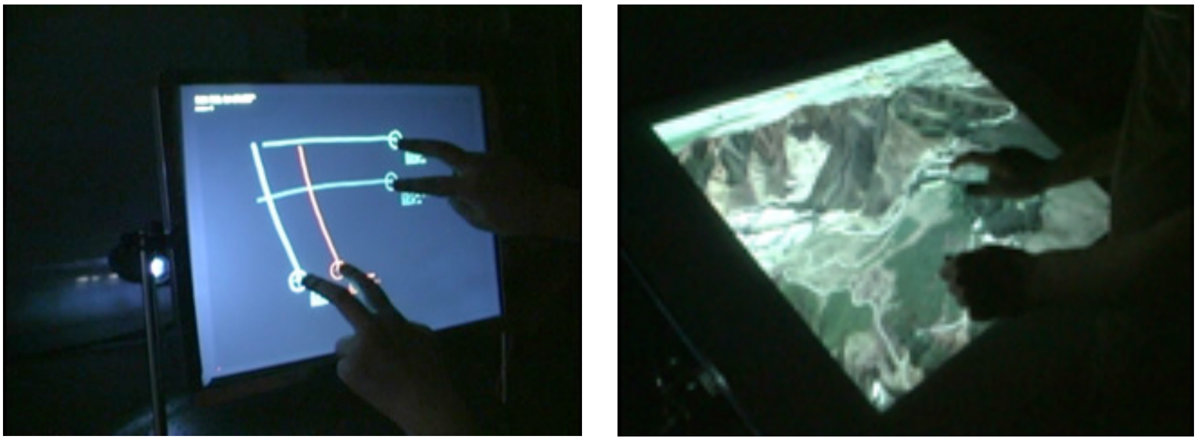


Figure 14: FTIR applications by Jeff Han

The Frustrated Total Internal Reflection (FTIR) technique is not yet used by a commercial hardware. But, it has been used to create interactive table in several project such as Tangent or TabulaTouch. All the hardware used by these projects seems mature enough, and due to the increasing number of researchers interested on this technique, it will not take so long to see further developments.

The Tangent project [Tangent 2006], by Christian Iten and Daniel Lüthi, is a multi-touch project concerned with developing new intuitive interaction techniques. Tangent supports different interaction techniques such as choosing and dragging, rotating, scaling, deleting, interacting with a phycon and more.

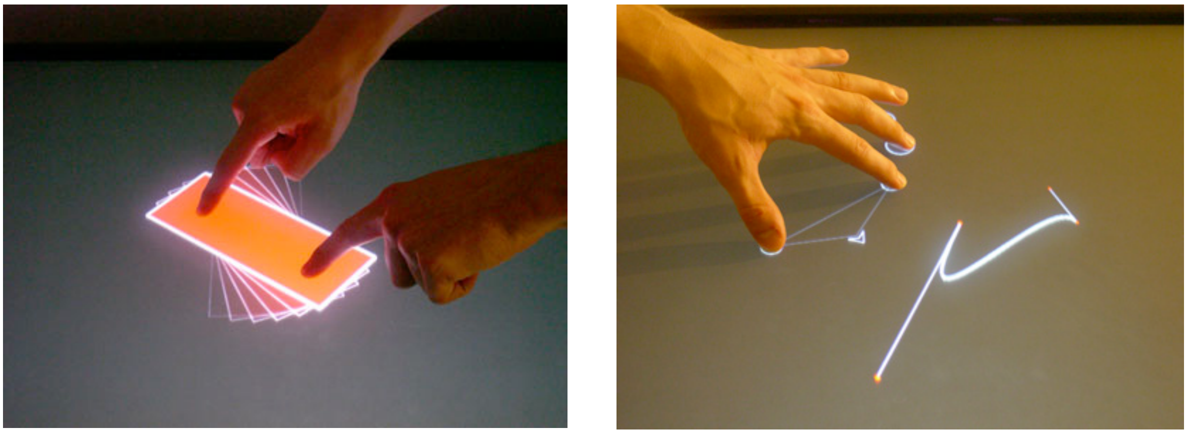


Figure 15: Examples of interactions with Tangent

The TabulaTouch [TabulaTouch 2006] is a table based on the FTIR technique developed by Stefano Baraldi at Natural Interaction IO Research Center in Tuscany (Italy). The research project was initiated in 2005 with the purpose of exploring the potential of the FTIR technique and interactions with multiple fingers. The project has so far led to the study of multi-touch interactions in two different contexts: browsing visual objects archives and viewing 3D maps (TabulaMaps).

Figure 16: TabulaTouch, Natural Interaction IO Research Center

2.1.3.5 Philips Research Homelab: Entertaible

The Entertaible, from Philips Research Homelab in Eindhoven, is a multi-touch tabletop games platform designed to bring the social interaction of board games into the electronic age. The Entertaible is composed of a 32-inch LCD display and a series of infrared LEDs and photodiodes mounted around the perimeter of the screen. It can detect several fingers and/or objects simultaneously.

Figure 17: Entertaible, Philips

The EnterTaible can recognize multiple touches and touch point sizes, but can not identify which touch is associated with which person.

2.1.4 Touch-sensitive systems

Some systems allow direct-touch with fingers and hands using tactile force or capacitive sensing technologies. These solutions generally have a degree of robustness and precision that is not achieved by vision-based systems

2.1.4.1 Canpolar East Inc.: Kinotex sensor

The Kinotex sensor [Canpolar East Inc. Kinotex], from Canpolar East Inc., is a tactile force sensor that measures pressure applied on its surface. It is composed of optical fibres embedded in foam and can be made to be flexible or rigid. A sensor contains an array of sensing elements called taxels which are comprised of a send and receive fibre. The sensor can sense each taxel independently or produce a pressure map that is interpreted as an "image" and used by computer vision techniques to estimate contact point and pressure for each finger.

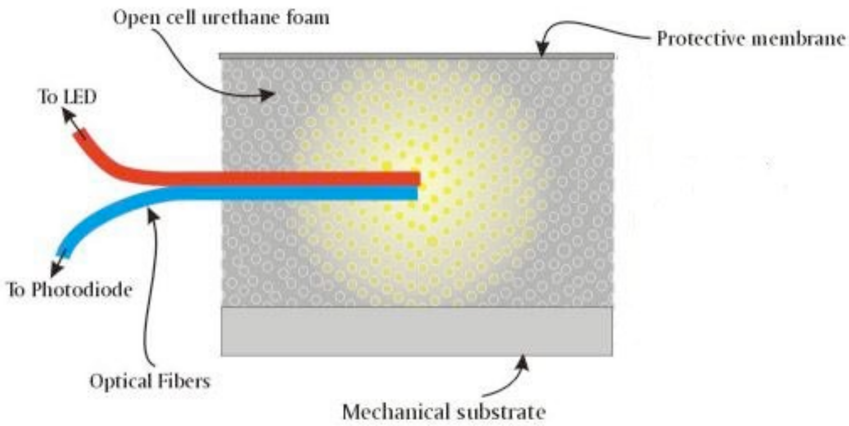


Figure 18: Kinotex sensor, Canpolar East Inc.

Tactex Controls Inc. [Tactex], one of the Kinotex licensees, has developed multi-input devices based on Kinotex sensor: touchpad, bed occupancy sensors, etc.

Figure 19: Tactex touchpad and flexible array sensor

2.1.4.2 JazzMutant: Lemur

The Lemur from JazzMutant [JazzMutant Lemur] is a multi-touch sensor that is integrated with a 12 inches LCD display (800x600 pixels). The device is sized for and functions as a software-configurable controller board. Using an interface editor (JazzEditor), the controller can be set up to simulate a number of different inputs (buttons, faders, keyboards, etc).

Figure 20: Lemur, JazzMutant

The Lemur lacks of precise control: inputs are detected with a low resolution (128x100). Furthermore, user interfaces are limited to the interface widgets provided by JazzMutant and the device does not give access to either the raw sensor data stream or to the raw display itself, limiting its usefulness for the development of novel interaction techniques and interfaces.

However, the Lemur communicates over an Ethernet cable using the OpenSoundControl (OSC) protocol, a message-based protocol developed for communication among computers and multimedia devices (sound synthesizers, electronic musical instruments, etc.). The Lemur can receive OSC messages from applications to modify the user interface (i.e. change the value or state of a given widget) or display numerical information send by OSC-capable applications. In addition, each object of the user interface sends the name of the parameter it controls as well as its numerical value. For example, if the interface is limited to a MultiBall widget (which can track up to 10 fingers), the Lemur acts as a multitouch pad for OSC-capable applications.

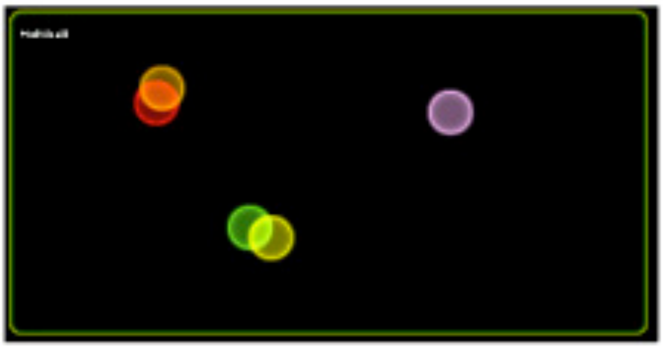


Figure 21: Lemur, Multiball widget

2.1.4.3 MitsubishiElectric Research Laboratories: DiamondTouch

The DiamondTouch [Dietz and Liegh 2001] from Mitsubishi Electric Research Laboratories (MERL) is a multi-touch input device that allows up to four users to simultaneously interact around a table using their fingers or hands. Currently, the DiamondTouch is commercially available in two sizes: 64x48 cm (DT81 model) and 86x65 cm (DT107 model).

Figure 22: DiamondTouch, Mitsubishi Electric Research Laboratories

The surface of the DiamondTouch device contains an array of conductive antennae. Each antenna sends a specific electric signal. When the user touches the surface of the table, signals that are used to determine what row and column the user has touched are transmitted through the user, into their receiver pad, and finally returns back to the table. Each antenna transmits a signal to the computer that corresponds to the strength of the capacitance between itself and the user. This capacitance is greater when the user is in direct contact with a particular antenna.

This technology provides an X and Y raw signal of each contact point and can determine which contact point belongs to who because each user is connected to a specific receiver pad. For example, right-side of Figure 23 illustrates the signals generated by two people: the red bounding box was generated by user0 and the green one by user3.

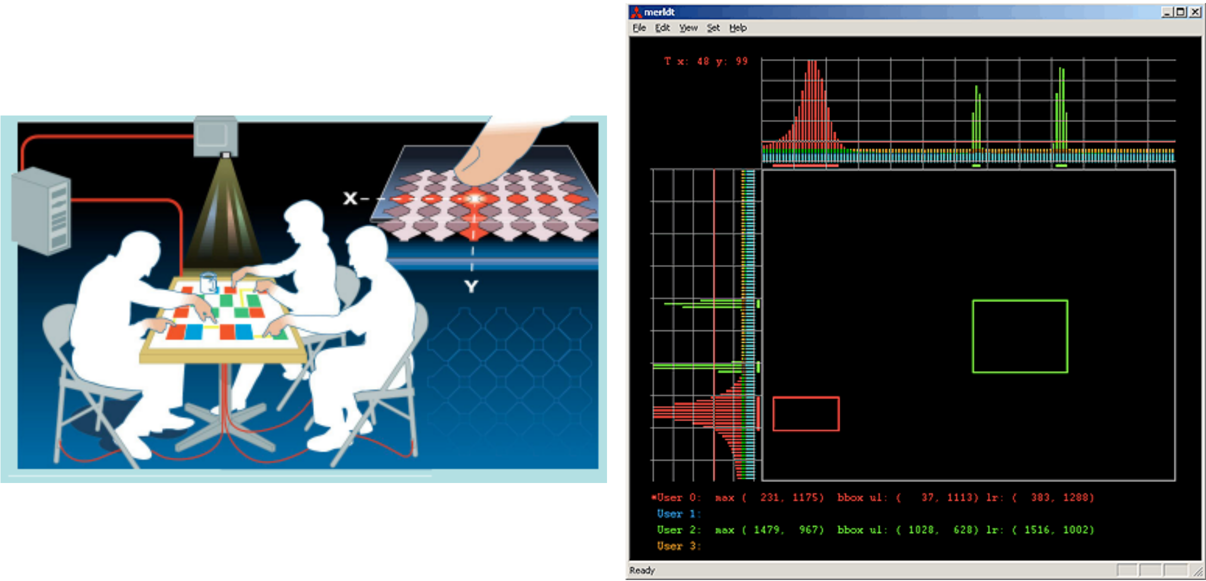


Figure 23: Overview of the DiamondTouch technology

The DiamondTouch SDK reads these raw data from the device and provides access to the raw data as well as interpretations of that data, such as the location of the touch point and the bounding box of the touched area. The DiamondTouch can handle up to four people simultaneously at 30 fps (DT107 model) or 40 fps (DT81 model).

Since the DiamondTouch uses electrical signals, users must maintain some electrical isolation (e.g.. avoid interaction with electric devices). On the plus side, this also means that users can also put many common items on the table without interfering with it, since it is not a pressure-sensitive surface.

The main advantage of the DiamondTouch compared to multi-touch systems is its ability to associate contact points with users. But, it has also some limitations.

First, it does not embed any display and should be use with a video projector displaying images on the table.

Then, due to its row/column pattern, the DiamondTouch can only return the rectangle (upper-left and lower-right corners) enclosing contact points for multiple touches by one person (i.e. with two fingers). For example, if a user touches point (2,3) and point (4,1) on the table (see Figure 24), two peaks are seen in the horizontal antenna array and two peaks are seen in the vertical. The DiamondTouch returns the rectangle defined by the two rows and columns: ((2,1), (4,3)) and this information can not resolve the ambiguity of which corners of the rectangle are actually touched. Thus, while the user is touching the upper right and lower left corners, the DiamondTouch can not differentiate it from if the user were touching the upper-left and bottom-right corners of the rectangle.

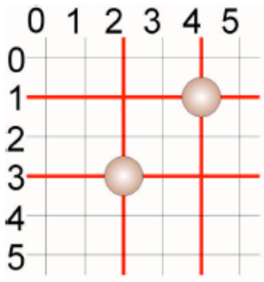


Figure 24: Input sensing limitation of the DiamondTouch

To disambiguate between these points, Wu et al. [Wu and Balakrishnan 2003] assume that no two fingers contact the surface at exactly the same time. They thus figure out which peak corresponds to each other by careful temporal examination when a new peak appears. The location of touch points are tracked by looking at each new image of data and comparing it to the previous image, predicting where touch points will likely be based on their speed and direction. This information is used to appropriately compute the location of the touches in the newer image should there be any uncertainty.

Finally, the users must be connected to the system through a receiver pad and take care to remain connected. This can be done by having each user sit on conducting chair connected to a receiver pad. Thus, users can not move easily or interact directly with the system (which is annoying for casual users).

2.1.4.4 Sony CSL: SmartSkin

The SmartSkin, from Sony CSL, is a multi-touch sensing architecture developed by Jun Rekimoto [Rekimoto 2002]. It can track the position and shape of fingers or conductive objects, as well as measure their distance from the surface, using electronic capacitive sensing.

Figure 25: SmartSkin, Sony CSL

The SmartSkin sensor consists of grid-shaped transmitter and receiver electrodes (copper wires). The vertical wires are transmitter electrodes, the horizontal wires are receiver electrodes, and each crossing point acts as a capacitor. When the user or a conductive object approaches a crossing point, it drains the electrical signal. The system periodically measures the signal received by each receiver electrodes and produces a two-dimensional array. Then, image processing algorithms are used to determine the proximity to the sensor, contact points and recognize the shape of the objects if the grid-mesh as a small pitch.

The SmartSkin platform is similar to the DiamondTouch except that users are not coupled to the system through a receiver pad. Thus, it can not associate contact point with users. But, it allows users to interact directly with the table (they don't need to connect themselves to the table) and has no limit, expect from physical space, to the number of users interacting simultaneously.

Furthermore, the SmartSkin sensor can detect various level of proximity. Thus, it can produce the same events than a single-button mouse: button press (i.e. contact with the table), button release (i.e. end of contact), button-motion (i.e. motion on the surface) and motion (i.e. motion above over the surface).

The SmartSkin sensing architecture can be used to turn a wide variety of physical surfaces into interactive surfaces. Two working interactive surface systems based on this technology have been developed by Jun Rekimoto: an interactive table and a gesture recognition pad, and various interaction techniques for them have been studied.

Interactive table

The interactive table combines a projector to display information on the table and a 8x9 grid mesh sensor covered by a sheet of plywood. Each grid cell is 10×10 cm. The entire mesh covers an 80×90 cm area of the tabletop. The interactive table detects the user's hands when they are within 5 to 10 cm from the surface. A bicubic interpolation is used to increase the effective resolution of the interactive table. Currently, the table has an accuracy of 1 cm, while the size of a grid cell is 10 cm.

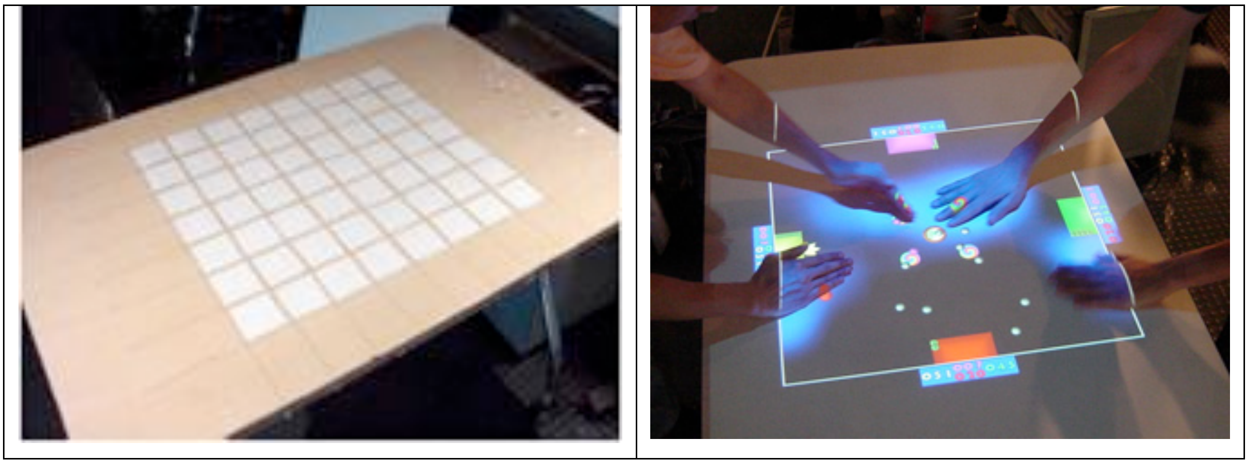


Figure 26: SmartSkin; Interactive table

Gesture recognition pad

The gesture recognition tablet contains a 32x24 grid mesh with a fine grid pitch to determine the position and shape of fingers or conductive objects more accurately. The grid mesh is covered by a plastic insulating film. Each grid cell is 1 x 1 cm. The entire mesh covers a 32x24 cm area.

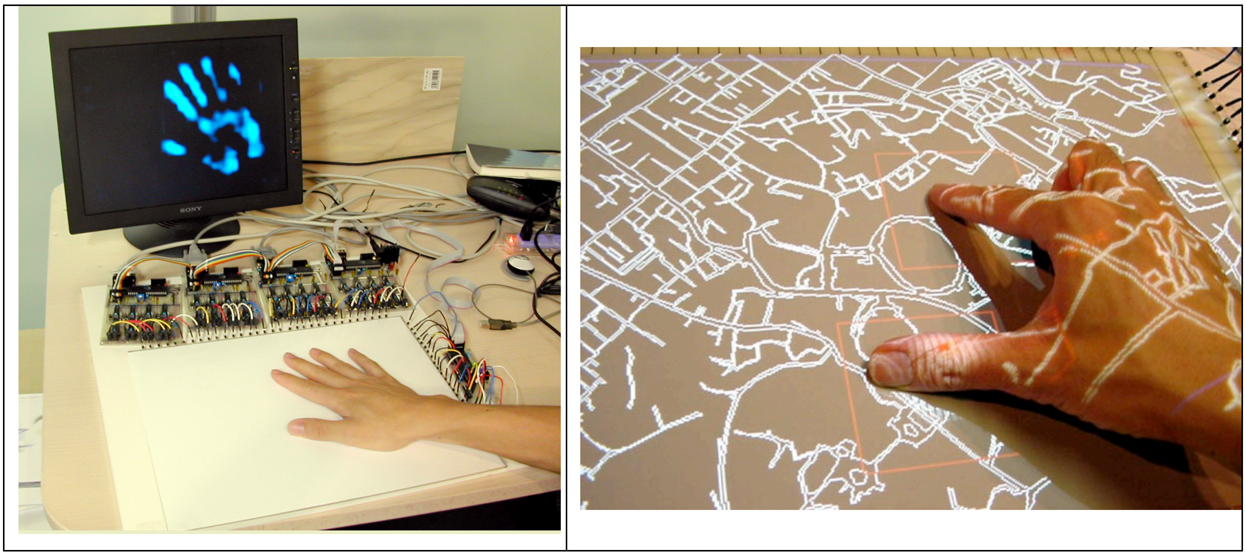


Figure 27: SmartSkin, Gesture recognition pad

2.2 Display possibilities/technologies

Typically, tabletop systems combine a direct multi-input surface with an output display such that the input and visual space are overlaid. That is why our review of display possibilities does not mention systems with several output displays (PDA for each user, Head-Mounted Display, etc.).

2.2.1 Video projector

Projection based systems are relatively cheap solutions to produce images with a large surface that can be seen by several users at a given time. Another advantage of the projection based approach is its scalability: it can easily be upgrade with new projector and it is easily extensible to larger (or smaller) surfaces.

However, the pixel-per-inch (ppi) resolution of tabletop displays is remarkably low with a projection based approach in comparison to the standard computer display. Indeed, due to the high cost of projectors with a high native resolution (above SXGA+ 1400x1050 pixels), projection based tabletops currently have a fairly low resolution (26-35 ppi when equipped with a XVGA (1024x768 pixels) projector) or moderately high-resolution (45-55 ppi when equipped with a SXGA+ projector) [Scott and Carpendale 2006]

Furthermore, projection based systems must be adjusted carefully and can not be moved easily once their installation is completed.

2.2.1.1 Top-down projection

Top-down projection systems use a video projector installed above the table to project an image on the table's surface. This technique allows projection onto real objects (which can be useful to extend real objects with application data).

But, top-down projection may suffer from bad lighting conditions and users can occlude the projected image with their body (head, hands, etc.) when they interact with the system. According to [Ryall, Shen et al 2006], occlusion caused by shadowing is not really a problem in practice because the shadowed area is not larger than the area that is naturally occluded by users' arms and hands.

2.2.1.2 Bottom-up projection

Bottom-up projection systems project an image on the back surface of the display which must be semi-transparent. The advantage of bottom-up projection is that users do not cast shadows on the projected surface.

However, it requires a projector with a high brightness to offset light loss. Unlike top-down projection, projection of information onto real objects can not be done.

2.2.2 Flat panel display

Some tabletop systems use a flat panel display on a table surface. They provide a high resolution, a high-quality image and their quality is independent of the lighting conditions.

Contrary to projection-based systems, flat panel displays don't have mobile parts and can be moved easily.

But, large flat panel displays are expensive.

2.3 Comparison of systems/Summary

The following table compares the different display possibilities.

<table>
<tr><td colspan="2">Type</td><td>Pros</td><td>Cons</td></tr>
<tr><td rowspan="2">Video projector</td><td>Top-down projection</td><td>- cheap
- projection on real objects</td><td>- occlusion issues
- image suffers from bad lighting conditions
- low resolution</td></tr>
<tr><td>Bottom-up projection</td><td>- cheap
- no occlusion</td><td>- light loss
- low resolution</td></tr>
<tr><td colspan="2">Flat panel display</td><td>- no occlusion
- high resolution</td><td>- expensive
- weight</td></tr>
</table>

Table 1: Comparison of display possibilities

The next table (Table 2) gives a short overview of the input sensing technologies described in this chapter.

System	Output possibilities	Surface size	Input resolution	Level of details / granularity	Intrusive input	Maximum number of users	User or pointer ID	Price or availability status
Multiple mice	Video projector or flat panel	No limit	High	Mouse pointer position	No	No limit	Yes	Low cost
Knobs and dials	Video projector or flat panel	No limit	Low	Knob value	No	Number of knobs	Yes	Low cost
SenseTable	Top-down projection	55 x 77 cm	High	Object's position and switch's status	No	Number of tangible objects	Yes	Not available
Illuminating Clay and SandScape	Top-down projection	No limit	Medium	N/A	No	No limit except from physical space	No	Not available
DViT	Video-projector of flat panel	Up to 169 x 107 cm	Medium	Position and shape (finger, hand, etc)	No	2 (one finger per user)	No	$3.000 to $5.000
Magic table	Video-projector	No limit	Low or medium (size dependant)	Position of fingers	No	No limit except from physical space	No	Not available but can be reproduced
TouchLight	Bottom-up or top-down projection	No limit	Low to high (size dependant)	Position and shape (finger, hand, etc)	No	No limit except from physical space	No	Not yet available
FTIR	Bottom-up or top-down projection	No limit	Low to high (size dependant)	Position and shape (finger, hand, etc)	No	No limit except from physical space	No	Not available but can be reproduced
EnterTaible	Built-in flat panel	70 x 40 cm	High	Position and shape (finger, hand, etc)	No	No limit except from physical space	No	Not yet available
Kinotex sensor	Top-down projection	No limit	Low to high (size and cost dependant)	Position an shape (finger, hand, etc)	No	No limit except from physical space	No	Prices on request
Lemur	Built-in flat panel	24 x 18 cm	Low	Position of fingers	No	No limit except from physical space	No	2.000 €
DiamondTouch	Top-down projection	64 x 48 cm 86 x 65 cm	High	Position and bounding box of contact points	Yes	4	Yes	$9.500 (DT81) or $12.500 (DT107)
SmartSkin	Top-down projection	No limit	Low to high (size dependant)	Position and shape (finger, hand, etc)	No	No limit except from physical space	No	Not available

Table 2: Comparison of input sensing technologies

3 Collaboration

Multi-users systems, such as a shared file system, usually hide the fact that multiple users use the system at the same time: any user thinks he is the only one to use it. In the opposite, groupware are a class of systems that make apparent the concept of group, so that users know and benefit from the fact that multiple users manipulate the same data. In other words, they support group awareness. Groupware have been extensively studied in the past and are out of scope of this state of the art [Beaudoin-Lafon 1999].

Single Display Groupware (SDG) systems are computer systems that enable co-present users to collaborate via a shared computer with a single shared display and simultaneous use of multiple input devices [Stewart et al 1999**]**. As such, they are designed so that the underlying interactive system helps people collaborate, and not only interact in parallel. SDGs using a tabletop system have particularities that have been explored in recent works:

- Touch screens as such support group awareness
- Collaborative coupling: people are located around the table, and their positions may influence their activity with other people
- Conflicts and coordination policies: since people interact with the same artefacts, they can run into conflicts. Specially designed coordination policies can help them resolve conflicts.
- Territoriality: they also may have different ability or incentive to work on different parts of the table
- Role of orientation: people are located around the table, and have different views on objects displayed on the table. The orientation of objects not only eases reading, but also has a meaning with respect to collaboration.
- Guidelines: guidelines help take into account important aspects when designing tabletop systems

3.1 Touch screen as support to collaboration

Virtuosi and DigiStrips are two user interface prototypes which make use of touch screens and served as a basis for research on the use of graphical design techniques in user interfaces [Mertz, Chatty and Vinot 2000]. They use touch screen because they support group collaboration:

Touch screens increase mutual awareness:

Since touch screens involve gesture, seeing what a colleague is doing with his hand on a touch screen provide many clues on his activity. Even if one does not focus his attention to other people, seeing others acting in peripheral vision help build mutual awareness, knowing that other people work together at the same activity. A user can also point on the screen to show something to his college.

Touch screens can be shared between users:

Mice are very difficult to grab from a co-worker, because it may be cumbersome to do so, or because it requires explicit negotiation encumbered by social hurders. Touch screens are shareable in a fluid manner, and afford seamless alternative or simultaneous interactions. As seen in Figure 28, a co-worker can interact both on his touch screen as well as on his colleague's.

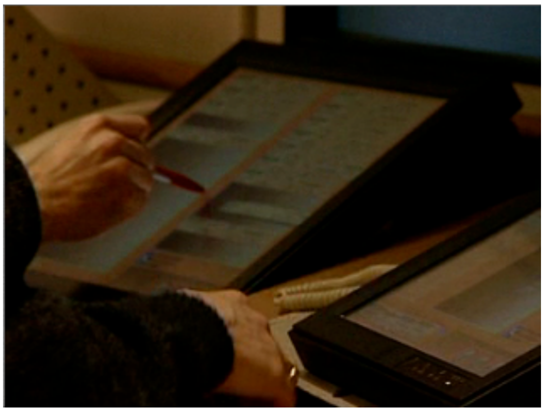


Figure 28: Two co-workers can interact with one another's touch screen

3.2 Collaborative coupling over Tabletop displays

Designing collaborative interfaces for tabletops remains difficult because we do not fully understand how groups coordinate their actions when working collaboratively over tables. [Tang et al 2006] presents two observational studies of pairs completing independent and shared tasks that investigate *collaborative coupling*, or the manner in which collaborators are involved and occupied with each other's work. The results indicate that individuals frequently and fluidly engage and disengage with group activity through several distinct, recognizable states with unique characteristics. The authors identified six coupling styles, with the first three (identified with round parentheses) being a "working together" style.

***(SPSA)**: (Same problem same area):* Collaborators are actively working together. Often, this is accompanied by conversation.

***(VE)**: (View engaged: One working, another viewing in an engaged manner):* The pair is working together, but only one is actively manipulating the display. Conversation often accompanies this style.

***(SPDA)**: (Same problem, different area):* Collaborators are working simultaneously on the same sub-problem, but are focused on different parts of the table. For instance, participants may be evaluating alternate solutions of the same sub-problem. This style is not accompanied by conversation.

***[V]**: (View: One working, another viewing):* One collaborator is working on the task, and the other is watching, but is not sufficiently involved to help or offer suggestions.

***[D]**: (Disengaged: One working, another disengaged):* One collaborator is completely disengaged from the task, not paying any attention to the task or partner.

***[DP]**: (Different problems):* Collaborators are working completely independently on separate sub-problems at the same time. Each person's interactions with the workspace are not related to the other in any way. In this style, participants often peeked at one another to maintain an awareness of the other's activities.

The authors also coded position arrangements around the table to check if they were correlated with the style of activity people were engaged in. Table 3 shows that when collaborators worked more closely together, they stood physically closer, and when they worked independently, they stood further apart. This can be seen as a dark diagonal trend from the top left to bottom right of Table 3. A notable exception to this observation is that Side by Side arrangements were physically closer than Straight Across, yet Straight Across was a very common arrangement for group work. This result is likely the consequence of the particular collaborative ergonomics of the table: working Straight Across the table yielded a good position to work on the same problem while providing smooth face-to-face communication. Face-to-face communication has been investigated by Ishii et al [Ishii and Kobayashi 1992]. They found that a lot of implicit coordination messages are conveyed through eye contact, which may explain the above results.

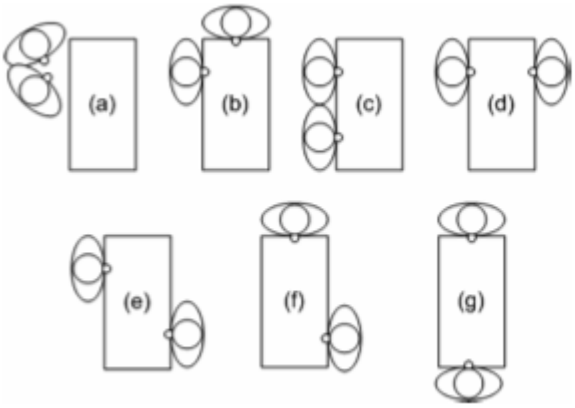


Figure 29: seven position arrangements around the table (based on relative positions): (a) together, (b) kitty corner, (c) side by side, (d) straight across, (e) angle across, (f) end side, and (g) opposite ends.

White: < 1%
Light grey: 1-4 %
Dark grey: > 4%

	SPSA	VE	SPDA	V	D	DP
(a)Together	7.8	1.6	3.4	0.5	0.2	0.5
(b)Kitty corner	9.4	1.9	5.2	2.4	0.9	1.9
(c)Side by side	2.5	1.0	2.3	0.9	0.9	3.1
(d)Straight across	9.2	2.3	8.7	3.3	2.3	1.0
(e)Angle across	3.8	1.4	2.4	2.3	1.4	6.2
(f)End side	0.5	0.1	0.1	0.3	0.3	4.9
(g)Opposite ends	0.0	0.0	0.0	0.1	0.0	3.1

Table 3: Percent time working in each coupling style and physical arrangement. Arrangement categories are in increasing order of average distance between participants. Coupling styles range from working closely together (left) to working independently (right)

The authors discuss several implications for Tabletop Design:

Support a flexible variety of coupling styles:

Since people engage in a variety of coupling styles, the interface should not prevent any.

***Provide fluid transitions between coupling styles*:**

Supporting mixed-focus collaboration requires supporting the *transitions* between loosely coupled independent work and tightly coupled group work. Providing only a single view of the workspace limits individuals' abilities to work independently, yet using separate copied workspaces may prevent many group collaborative dynamics, such as being able to see what others are doing, from emerging.

Provide mobile high resolution personal territories:

The observed interference was a direct result of individuals' desired working areas overlapping. Creating usable and useful personal territories could take several avenues, including a higher resolution workspace, or mobile regions of high resolution, or even using distinct displays for personal work (such as Tablet PCs or PDAs).

Support lightweight annotations:

Tabletop task spaces should support mobile, unobtrusive, and transient annotations. One of the affordances of the tabletop form factor is the ability to conduct independent work unobtrusively. Annotations help to generate and track independent work, and may be moved to be shared with the group.

3.3 Conflicts and coordination policies

People engaged in a collaborative activity may experience problems due to conflicts of access of shared ressources. Groupware systems often rely on existing social protocols for avoiding potential conflicts, instead of implementing complex interaction that would preclude fluidity: people see each other acting, and are unlikely to enter into conflicts on purpose. However, if this fact is true when interacting with physical objects, interacting with virtual objects is different, and lead to conflicts caused by accident or confusion, by unanticipated side effects of a user's action, or by interruptions.

	Proactive	Mixed-Initiative	Reactive
Global	privileged objects anytime	rank	no selections no touches no holding documents voting
Whole-Element	sharing explicit dialog	rank speed force	public private duplicate personalized views stalemate tear

Figure 30: coordination policies, grouped along the dimensions of conflict type (rows) and initiative (columns).

Authors of the papers found that conflicts arise either on global elements (such as the table, or the application or main view on the table), or on whole-element, such as shapes in a drawing program. The policies required to address conflicts in both are different. They classify them in three categories, either proactive (the user at the origin of the conflict decides the outcome), reactive (the user impacted by the conflict decides the outcome) or mixed-initiative (both users have a weight in the final decision, and must negotiate). For each case, a number of specific policies can be designed (Figure 30).

3.3.1 Global coordination policies

***No Selections, No Touches, No Holding Documents*:**

These three policies dictate conditions under which a change to global state will succeed – if none of the users have an "active" selection on the table, if none of the users are currently touching anywhere on the table, or if none of the users are "holding" documents (touching an active document with their hand).

***Voting*:**

This policy makes group coordination more explicit by soliciting feedback from all users in response to a proposed global change. Each user is presented with a voting widget that allows him to vote in favour of or against the change. Several policies (majority rules, unanimous, etc.) could determine the outcome.

***Rank*:**

This policy factors in differences in privilege among users and can be used in conjunction with other policies, such as “no holding documents,” thus changing the policy to mean that a global change will succeed if the user who initiated the change outranks other users who are currently holding documents.

***Privileged Objects*:**

Under this policy the determining factor is the way a change is initiated, rather than the circumstances of other users at the time of the proposal. For instance, there might be a special menu that must be used to make global changes, rather than including these options in each user’s individual menu bars. This might encourage more discussion among users by necessitating that they ask someone to pass them this privileged object. Also, requiring the use of a special interface mechanism might make people more aware of the effect their interaction is going to have on other users.

***Anytime*:**

This policy allows global changes to proceed regardless of circumstance – it is included for completeness and to provide an option for designers who want to rely on social protocols.

3.3.2 Whole-element coordination policies

***Public*:**

This policy places no limits on who can access an element, instead relying on social protocols.

***Private*:**

With this policy, any attempt by a user to manipulate a document he does not own or to select from a menu invoked by another user will be unsuccessful.

***Duplicate*:**

With this policy, the contested item duplicates itself. Three variants of this policy use different semantics for duplication: (1) creating a view linked to the original (changes made to either copy are reflected in both), (2) creating a read-only copy, or (3) creating a fully independent, read-write copy.

***Personalized Views*:**

This policy allows a user to obtain a document from another user or to select from another user’s menu, but it first transforms that document or menu to display content customized for the user who takes it. For instance, if user A’s menu has a list of bookmarks made by user A, and user B tries to use the menu, the menu would change to show user B’s bookmarks. Or, if user A had annotated a document and user B took it, the document would hide user A’s annotations and display only annotations made by B.

***Stalemate*:**

This is a “nobody wins” strategy for resolving conflicts. If a user attempts to take a document from someone else, the document becomes temporarily inactive to both users. This could encourage collaborative conversation.

Tear:

Inspired by paper, this strategy handles a conflict by two users over a single document by breaking the document into two pieces. This might encourage the pair to negotiate before reassembling the document so that work can continue.

Rank:

A higher-ranking user can always take documents from or select from the menus of lower ranking users.

Speed, Force:

These two policies are examples of policies that use a physical measurement (the speed with which each user pulls on the document, or the pressure each user applies to the document) to determine who is the "winner" of a contested item.

Sharing:

This policy allows users to dynamically transition an element between the "public" and "private" policies. To support sharing, authors have explored four interaction techniques – release, relocate, reorient, and resize, which are described in [Ringel, Ryall et al 2004].

Explicit:

When using this policy, a document's owner retains explicit control over which other users can access that document. For example, the owner can grant and revoke manipulation or write permissions on the fly by interacting with tabs on the edge of the document that toggle the permissions for individual users.

Dialog:

This policy offers standard WIMP semantics, responding to an attempt to "steal" a document by prompting the document's owner to allow or forbid the action via a popup dialog box.

3.4 Territoriality

Scott et al. explored territoriality on table shared by multiple users while they were collaborating. They ran an experiment where they observed two to three users collaborating on a real table at various tasks such as problem solving, or games.

They found that users were engaged in three types of interaction areas: personal, group, and storage. These areas appeared to help people organize their interactions with both task items and with others at the table. The boundaries between these areas were quite flexible. The areas appeared to be defined by their location on the table, but where one area ended and another began was often determined by the location of items on the table and the activity that was being performed. People naturally partition their interactions on a table with little to no verbal negotiation.

Authors make the distinction that a tabletop territory has both spatial properties (i.e. size, shape, and location) and functionality. They also make the distinction that a tabletop territory is not necessarily a separate partition in the workspace; that is, tabletop territories are not necessarily mutually exclusive. Thus, two tabletop territories can exist in the same partition of the tabletop workspace (e.g., a storage territory and a personal territory) and a tabletop territory can contain several partitions of the workspace (e.g., a group territory can contain several distinct work areas).

3.4.1 Personnal territories

Functionality:

Personal territories allow people to reserve a particular table area, as well as task resources for their own use. Ergonomically, personal territories serve to ease a person's actions related to the group activity, such as reading, writing, and drawing. People tend to write text and draw images intentionally small in these areas. Personal territory also provide a space for people to disengage from the group activity, for example to explore alternate ideas before introducing these ideas to the group. Finally, personal territories are an important group resource: participants appeared to monitor others' activities in their personal territories, offering suggestions or modifying their activities accordingly.

Spatial Properties:

Seating position strongly influences the location of personal territories. Personal territories appeared to expand and contract based on the number of people at the table and how they were arranged. The size of the table determines how much space is available for sharing, as well as how many people can sit comfortably around it. People expanded and contracted their personal territories based on whether they were currently working independently or in concert with the group.

3.4.2 Group territories

Functionality:

Interaction with task materials in the group territory appears to follow two basic patterns, depending on whether a task requires tightly coupled interactions or affords loosely coupled interactions.

When the task requires tight coupling of actions (e.g., creating a product design, assembling a jigsaw puzzle, assembling a Tangram silhouette), collaborators tend to orient items and workspace markings corresponding to separate ideas or group products. They also use orientation to provide context and support for information in the group territory and take full advantage of opportunities to build on and use others' work.

When the task affords loosely coupled collaboration (e.g., assembling a room layout containing many distinct furniture arrangements) collaborators tend to partition the workspace. The location of these partitions is strongly influenced by participants' seating positions.

Spatial Properties:

The group territory typically covered any tabletop workspace that was not occupied by the personal territories.

3.4.3 Storage territories

Functionality:

Storage territories served as areas to store task resources (e.g., tools, items not currently in use, customized items, reference materials) and non-task items (e.g., food, drinks). Participants used storage territories to organize these items in the tabletop workspace, to easily obtain the resources they need or to reserve resources for their own use by moving them from group territories to personal territories .

Spatial Properties:

The storage territories used by the participants were placed at various locations around the workspace, but generally migrated to the table edge as the task progressed. These territories sat atop the personal and group territories and were mobile in the workspace.

3.4.4 Consequences on design

Provide visibility and transparency of action:

Personal and group territories were often used by participants to monitor the activity of their collaborators. Such monitoring is an essential tool for maintaining workspace awareness during collaboration.

***Provide appropriate table space*:**

The size of the table can affect both the personal territories established on the table and the partitions established in the group territory. An inappropriately sized table may negatively impact the collaboration because collaborators may not have enough space to effectively disengage from the group activity or collaborators may need more explicit coordination to divide up an activity on the table.

***Provide functionality in the appropriate locality*:**

Each tabletop territory plays a specific role in the collaboration process. These roles can guide design decisions related to the location of system functionality. For example, personal territories serve to ease activities such as reading and writing. Thus, it should be easy to move items to and from the area directly in front of each person and tools related to editing task items should be located nearby.

***Allow casual grouping of items and tools in the workspace*:**

The ability to have mobile piles of resources enables collaborators to easily access these items when and where they need them. This mobility also enables people to reserve certain items for their personal use.

3.5 Roles of orientation

Digistrip mimicks the ability of actual strip boards to layout the electronic strips such as to convey information. For example, a planner controller may slightly shift a strip to the left to make it salient for the tactic controller [Mertz, Chatty and Vinot 2000]. Kruger et al discovered that orientation proves critical in how individuals *comprehend information*, how collaborators *coordinate their actions*, and how they *mediate communication* [Kruger et al 2003]. Table 4 describes the various use of orientation.

Role	Details
Comprehension	Ease of reading Ease of task Alternate perspective
Coordination	Establishement of personal spaces Establishement of groups spaces Ownership of objects
Communication	Intentional communication Independence of orientation

Table 4: Detailed roles of orientation

3.5.1 Comprehension

***Ease of reading*:**

Objects are not necessarily aligned with the edges, but aligned for best viewing.

***Ease of task*:**

Orienting objects can help interacting, such as orienting an artwork to ease drawing of a shape.

***Alternative perspective*:**

Orienting can help get another view in order to have new insights. For example, one can circle around a chess board to imagine new solutions.

3.5.2 Coordination

***Establishment of spaces*:**

There is no clear demarcation between personal or group space. Instead, people rely either on verbal communication (“this is mine, this is yours”), on location, and on orientation. Multiple group spaces can co-exist, and each can have a different orientation (Figure 31). Establishing group orientation proved to be a very social act. In every case, the person responsible for establishing the group orientation attempted to favour the other person by objects ‘right way up’ for their collaborator. People willingly and gracefully accept this compromise.

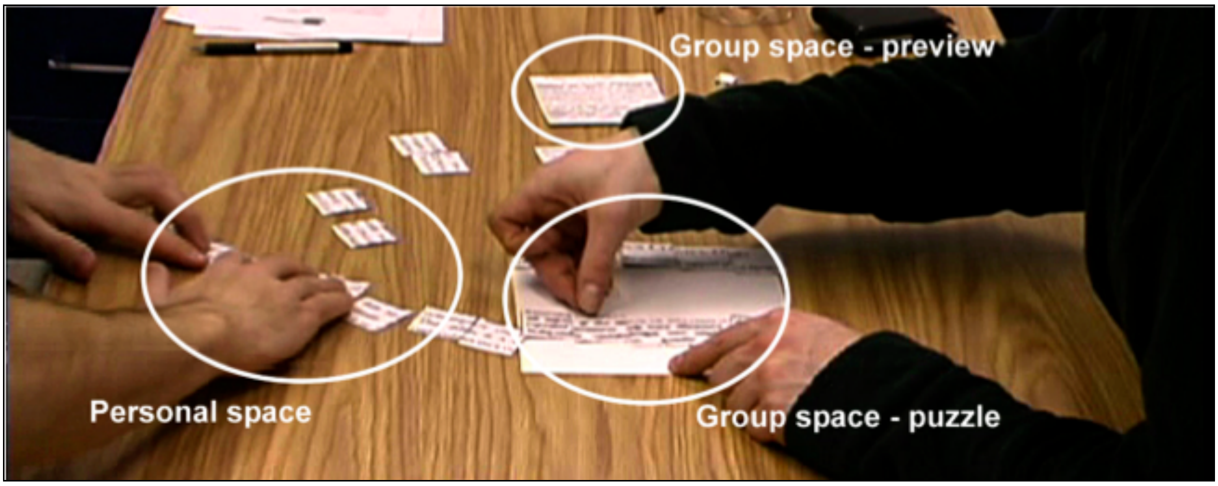


Figure 31: Establishment of spaces through orientation of objects

***Ownership of objects*:**

People are much more likely to pick up and use objects that are oriented towards them or at a compromised angle. The way people place an object suggests personal ownership/access if the object is oriented towards themselves, and shared ownership/access if it is oriented towards others or at a compromised angle.

3.5.3 Communication

***Intentional communication*:**

Orienting an object to oneself signals no intentional communication; that is, the person is doing their own personal work. *Orienting an object to another person* signals that the object, the person’s talk, and any accompanying gestures are being directed towards a particular person for communicative purposes. If the item is oriented directly towards the other person, this typically establishes an audience or indicates relinquishment of turn. If the item is oriented at some compromised angle, this almost invariably initiates a response in the form of discussion and a period of close collaboration. *Orienting an object to the group* is similar, except that the objects and any accompanying talk and gestures are now being directed towards the group (or sub-group).

***Independence of orientation*:**

Non-verbal conversational acts are often tied to other intentional communication as a way to explain or clarify that person's intentions or to remove ambiguity. For example, talk and gestures often work together, e.g., as in deictic references. Orientation, however, proves to be an understandable stand-alone act that does not require additional communication in the following cases. *Orientation independence as one repositions an object.* As people pick up, use, and reorient objects, they rarely comment or add gestures to explain such rotation actions. *Orientation independence of objects already positioned.* For an object already placed on the table, its orientation informs others as to whether or not it is available. No further requests for information are needed.

3.5.4 Consequences on design

Since rotation conveys so much support for collaboration, care must be taken when designing table top interactive systems:

- Free rotation must be supported.
- Rotation techniques must be lightweight, so as to be used seamlessly.
- Orientation of user-positioned items must be maintained.
- Rotation actions must have clear feedthrough: in order to preserve the non-verbal communicative role of orientation, it must be obvious to others when a user is performing a rotation action.Otherwise, the action may be missed.
- Automatic support for rotation and orientation must be handled carefully and allow easy user override. A common solution to the problem of easing read is to have the software reorient objects so that a given individual can view them 'right way up.' Kruger et al. show that this strategy is overly simplistic: while important, it is an incomplete view of how people exploit their ability to reorient objects.

Step A:

Participant 1 (left) reads the preview image.

Participant 2 (right) looks at puzzle pieces.

Step B:

Participant 1 rotates the preview image to an angle that is very compromised for him and slightly compromised for Participant 2.

Participant 2 immediately responds by tilting his head.

Step C:

Collaboration is established and the two participants proceed to work together. The image is now completely oriented towards Participant 2.

Figure 32: Orientation and collaboration

3.6 Guidelines for interactive tabletop displays design

Scott et al. [Scott et al 2004] have designed guidelines when designing a tabletop system. Though sometimes too general, or hard to respect with current hardware, they can serve as a reminder of important aspects. As often with interactive systems, small changes in system design can result in large changes in the ability of a system to support collaboration. The guidelines are as follows:

Support Interpersonal Interaction:

Technology designed to support group activities needs to support the interpersonal interaction at the heart of collaboration. Interfering with these interactions can cause breakdowns in collaboration, especially when the technology hinders the conversation

Support Fluid Transitions between Activities:

Technology should not impose excessive overhead on switching between activities performed on a table, such as writing, drawing, and manipulating artifacts. For example, paint programs often distinguish between textual and graphical marks, forcing users to explicitly indicate their intention to write or draw. Studies of traditional tabletop design sessions revealed that people do not make this distinction and that they rapidly transition back and forth between writing and drawing.

Support Transitions between Personal and Group Work:

Previous research has shown that people are adept at rapidly and fluidly transitioning between individual and group work when collaborating.

Support Transitions between Tabletop Collaboration and External Work:

Most collaborative tabletop activities are part of a larger group effort that exists beyond the tabletop environment. Co-located group interaction is only one part of daily collaborative activity, thus group members must be able to incorporate work generated externally to the tabletop system into the current tabletop activity.

***Support the Use of Physical Objects*:**

Tables are versatile work environments with a unique characteristic of providing a surface for people to place items during collaboration. These items often include both task-related objects (e.g., notebooks, design plans) and non-task-related objects (e.g., beverages, day-timers). Tabletop systems must support these familiar practices, as well as providing additional digital features.

Provide Shared Access to Physical and Digital Objects:

Tables are an ideal environment for sharing information and objects with others. It is common to see work colleagues, schoolmates, and family members gathered around a table discussing some object. For collaborative designers, sharing a work surface can enhance the design process. Furthermore, pointing or motioning to a shared object during a discussion provides a clear spatial relationship to the object for both the gesturer and the other group members, facilitating the group communication. In contrast, situations in which everyone has a copy of a digital object, a gesture made to one copy of the object forces the other group members to perform a spatial translation to determine the specified location on their own copies. This creates cognitive overhead to using important communicative tools such as gestures and deictic references

Consideration for the Appropriate Arrangements of Users:

During tabletop collaboration, people sit or stand around a table at a variety of locations, both in relation to the table and in relation to other group members. Several factors can influence people's preferred locations, which in turn can influence the interpersonal interactions within the group. Physical properties of the table, such as size or shape, can influence seating positions.

Support Simultaneous User Actions:

When multiple people engage in tabletop activities, they often interact with artifacts on the table surface simultaneously.

4 Multi-input and multi-user Interaction

This chapter focuses on the use of interaction techniques specially designed for tabletop:

- Multiple-point interactions: multi-finger and bi-manual interactions,
- Orientation: due to the lack of a predefined viewing angle, displaying and manipulating information on an interactive tabletop displays requires specific techniques,
- Territoriality: organization of the tabletop workspace and management of public and private space,
- Sharing of objects: interactions to help user to exchange objects with other users,
- Remote reaching: with a large surface, drag-and-drop is not always appropriate because it could require to walk some meters,

Tabletop systems also allow the use of free writing and gestures. These interactions interaction have been extensively studied in the past (especially with touch screen systems or pen tablet systems) and are out of scope of this state of the art.

***Tabletop systems permit writing*:**

Many different tabletop technologies allow the use of a stylus (either passive or active depending on the technology). This allows an easy implementation of free writing input, without any recognition. Other technologies prevent the use of a stylus, and may force the user to write with a digit. Though less comfortable, it is still possible. Writing may be important, as it can serve as a reminder, or as explanation for others through annotations linked to objects.

Tabletop systems favor gestures:

Tabletop displays are direct interaction devices: you point directly on the graphical object, on the screen, not via an indirect peripheral like a mouse or a trackball, which gives less proprioceptive clues about movements. Furthermore, pointing with hand is seamless, as opposed to using a mouse where one has to first home its hand to the mouse before any interaction can occur. A touch based system allows fluid transition between the table and other artefacts. For example, Rubine uses gesture recognition to interact [Rubine 1991], while Marking Menus use gestures to trigger actions in hierarchical pie-menus [Kurtenbach and Buxton 1994].

4.1 Multi-finger and whole hand interaction

Tabletop systems are designed to be used by multiple persons at the same time, but they also permit bi-manual interaction. A lot of research has been done in this area, such as the characterisation of the kinematics' chain [Guiard 1987], the invention of see-through tools, or the T3 systems [Bier 1993][Kurtenbach, Buxton et al 1997].

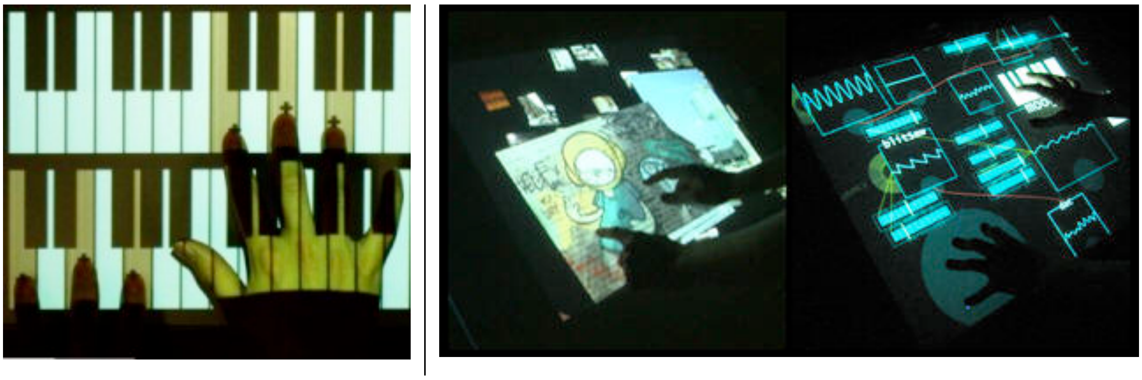
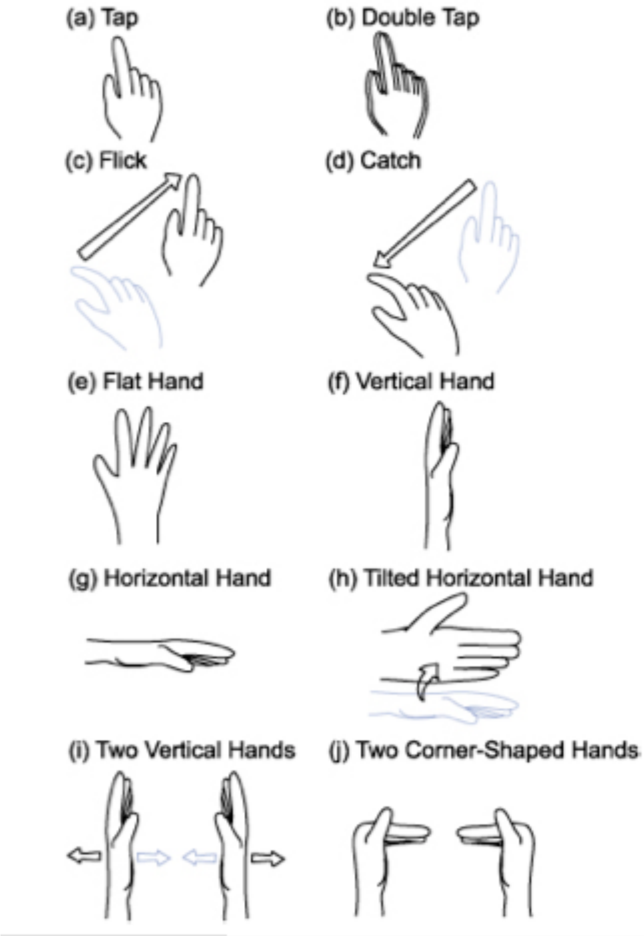


Figure 33: Examples of multi-finger and bi-manual interaction

In [Wu and Balakrishnan 2003], Wu et al. explore various gestures involving fingers and whole hand to interact with table top system (see Figure 34).



(a) Tap: single point touch.

(b) Double Tap: single point touch-release-touch.

(c) Flick: quickly slide single point away from self.

(d) Catch: quickly slide single point toward self.

(e) Flat Hand: lay hand flat on surface.

(f) Vertical Hand: side of upright hand touches surface in a vertical manner.

(g) Horizontal Hand: side of upright hand touches surface in a horizontal manner.

(h) Tilted Horizontal Hand: tilt top of horizontal hand away from self.

(i) Two Vertical Hands: symmetrically slide two vertical hands together or apart.

(j) Two Corner-Shaped Hands: each hand makes a corner.

Figure 34: Gesture set

4.1.1 Single finger interaction

Figure 35: After flicking a plan object, half of it sits on the touch-sensitive surface and the other half sits on the frame of the device

With a tap, a user can select an object. As with traditional point & click interfaces, he can also drag it to move it at another position. A double tap opens a contextual, control menu [Pook et al 2000]. A drag and a release with a speed superior to a threshold initiate a throw, or flick: the object moves by itself until it hits the opposite edge, and sits half on the surface, half on the surrounding frame. To catch it back, he has to do the opposite gesture, a flip towards himself.

4.1.2 Two fingers interaction

A sequence of two fingers can help select a function, and control it with a toolglass (Figure 36), or with a control menu (Figure 37). It can also provide a way to specify a rotation, with its centre first, then its angle (Figure 38).

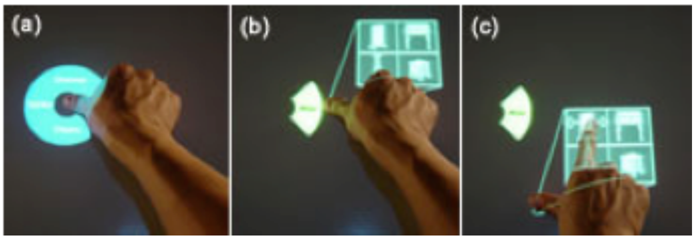


Figure 36: FurniturePalette tool. (a) A double tap on the table brings up a context-sensitive menu. (b) Sliding the finger in one of the four directions causes a corresponding toolglass to be attached to the finger. (c) A second finger is used to make a selection within the toolglass

In Figure 37, the widget displays six arrows arranged in three groups. Each group consists of two arrows that point in opposite directions. The arrows closer to the first finger are smaller than those farther away. When the user's second finger touches one of the arrows, the parameter is either increased or decreased by some amount. The distance between the two fingers determines the granularity of adjustment.

Figure 37: Parameter adjustment widget allowing two- fingered manipulation

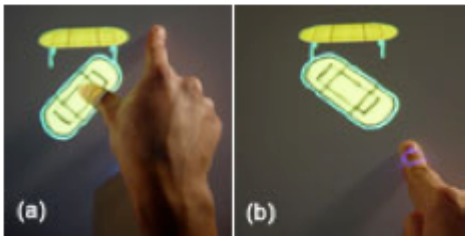


Figure 38: Freeform rotation. (a) Two fingers are used to rotate an object. (b) Though the pivot finger is lifted, the second finger can continue the rotation

4.1.3 Single hand interaction

Putting a flat hand on the surface initiates a rotation of the whole scene. A vertical hand sliding to the left or right helps sweep objects (Figure 39). A horizontal hand above an object displays a magic lens on object properties (Figure 40).

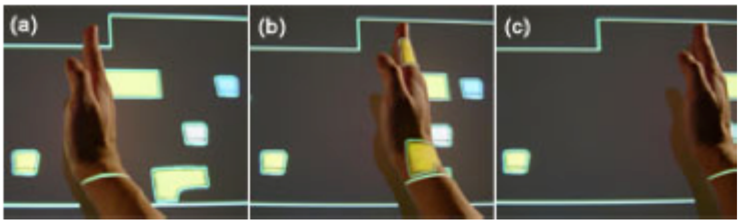


Figure 39: Vertical hand sweeping. (a) Initial position. (b) When the hand makes contact with furniture, the pieces move with it. (c) Final position after sweeping.

Figure 40: A horizontal hand displays a magic lense on the closest object

The Mitsubishi DiamondTouch is able to sense the tilt of the hand. Wu et al. [Wu and Balakrishnan 2003] use this to display personal data related to the objects directly on the hand of the user (Figure 41).

Figure 41: The tilted horizontal hand gesture uses the hand as physical space upon which to project information

4.1.4 Two hands interactions

Two vertical hands that join collect objects in the center; if they are spread apart, the objects are spread on the surface (Figure 42). Two corner-shaped hands define an editing rectangle (Figure 43).

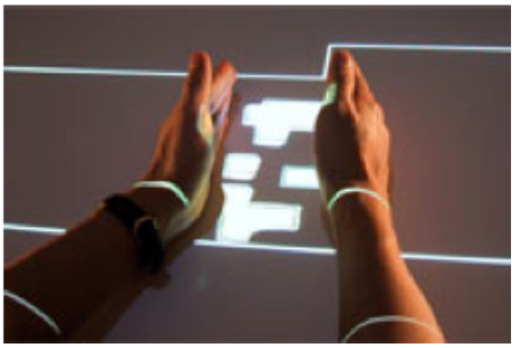


Figure 42: Sweeping two vertical hands together collects furniture pieces in the center

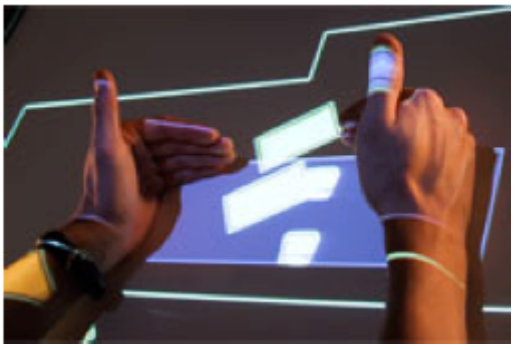


Figure 43: Two corner-shaped hands are used to define and move an editing plane

4.2 Orientation of objects

As described in section 3.5, Tabletop displays do not have a predefined orientation such as desktop computers which are used in a physical arrangement with the screen in the vertical plane. On vertical screens, the perceived upright orientation is always the same, independent of viewer location.

But, for a horizontal display the user's perspective is tied to his or her location: looking at the screen from a different location gives the information a different perceived orientation. For multiple users, the information would not appear upright for at least some of the users, unless they positioned themselves side-by-side. Thus, if objects can only be displayed at one orientation, users will not be able to sit across from one another if they manipulate orientation-dependant objects.

Furthermore, as stated in section 3.5, orientation of objects is meaningful, and must be supported in tabletop systems, as it supports:

- Comprehension: It is easier to comprehend objects when they are the "right way up."
- Coordination: Orientation is used to help establish personal and group territories and to signal ownership of objects.
- Communication: Orientation is useful in initiating communicative exchanges and in continuing to inform group members about collaborative work patterns.

In desktop computers, the most commonly used method of rotation is a rotation around the centre of the object. The user clicks on a corner of the object and rotates it.

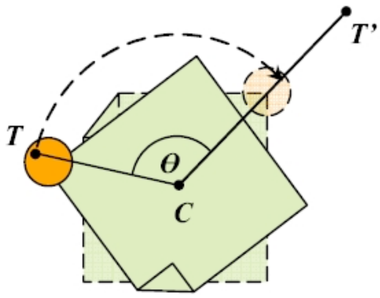


Figure 44: Common rotation technique

Rotation can also be done around a given point (position of the user or centre of the table) such as objects face a determined direction when they are rotated. If the rotation centre is the centre of the table, the system can automatically orient objects so that their top sides always face the centre of the table and their bottom sides faces the borders of the table (Figure 45). This technique combines rotation and translation into one motion: the rotation is defined by the angle formed by TOT' and the translation is defined by the length difference between OT and OT'.

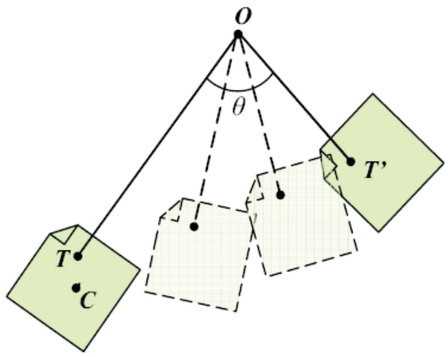


Figure 45: Automatic rotation around the center of the table

In [Kruger et al 2003], Kruger et al. state that rotation must be done by users, and not with an automated system as in [Ringel, Ryall et al 2004]. They present in [Kruger 2005] an interaction technique that also integrates rotation and translation, as they are inseparable [Jacob et al 1994]. This technique, the Rotate-and-Translate (RNT) mechanism, uses a physically based model to reproduce rotation and translation that occurs when manipulating a sheet of paper on the surface of a table. The choice of the interaction (rotation and/or translation) is based on the parts of the object that are picked and dragged by a user (see Figure 46, Figure 47 and Figure 48): the inner circle is dedicated to translation only and the outer space can be used for both rotation and translation depending on the control point used by the user.

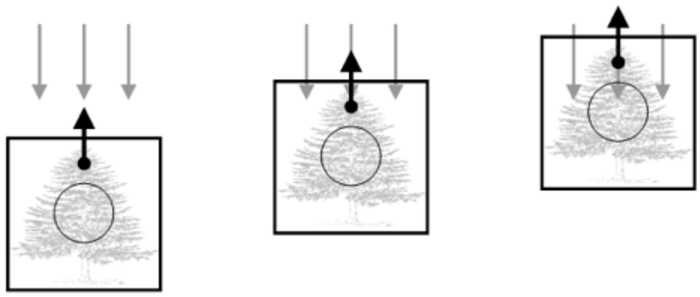


Figure 46: Balanced movement resulting in upward translation from a control point located in the upper-half of the object

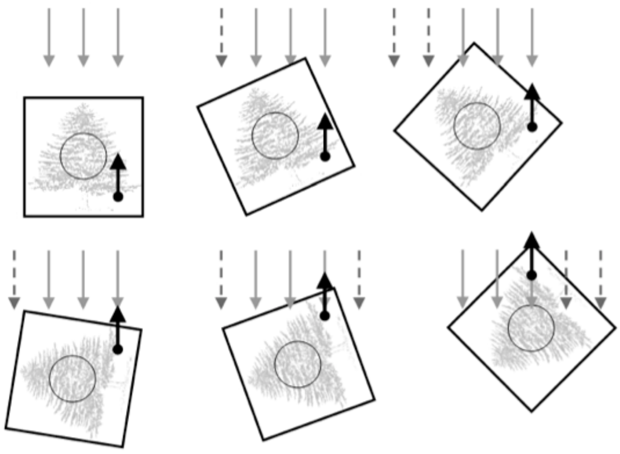


Figure 47: Unbalanced movement resulting in upward translation and counterclockwise rotation from a control point located in the lower-right corner of the object

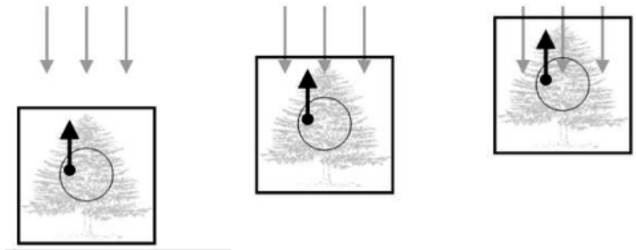


Figure 48: Upward translation from a control point located in the translate-only region

It is interesting to note that the RNT mechanism uses a simulated force to integrate rotation and translation. However, the simulated force relates more to ideas of alternate interface physics [Bederson and Hollan 1994] than to the more accurate physics of Drag, another rotation-based system. In adhering to a physics-based model, Drag models changes in friction depending on the location of the contact-point according a damping function. As a result of the damping function, less movement is required to produce changes in orientation towards the edges of the object. No such damping function is implemented in RNT. The separate evaluations of these two techniques produced considerably different empirical results. During Drag's evaluation, participants had significantly more difficulty operating Drag compared to the traditional mechanism that provides separate control of rotation and translation. Users felt that they did not have sufficient control of Drag and that they could not adequately predict its behaviour. These results stand in sharp contrast to results of the empirical evaluation of RNT: users found RNT easier, faster than and just as accurate as traditional-model rotation and translation interactions. Touching seems so natural that it tends designers to make their systems as closest to natural physics as possible. The Drag system experience shows that it is not necessarily the way to go, and alternate realities can give insights as which physics to use for design.

Translation and rotation can also be integrated with scale using two points interaction (two fingers or two hands). The rotation, translation and scale factor are determined by the transformation applied to transform T1T2 into T1'T2'i.e. a translation defined by T1T1' followed by a rotation around T1' by the angle defined by T2T1,T2' and a scale by a scale factor of T1'T2'/T1T2.

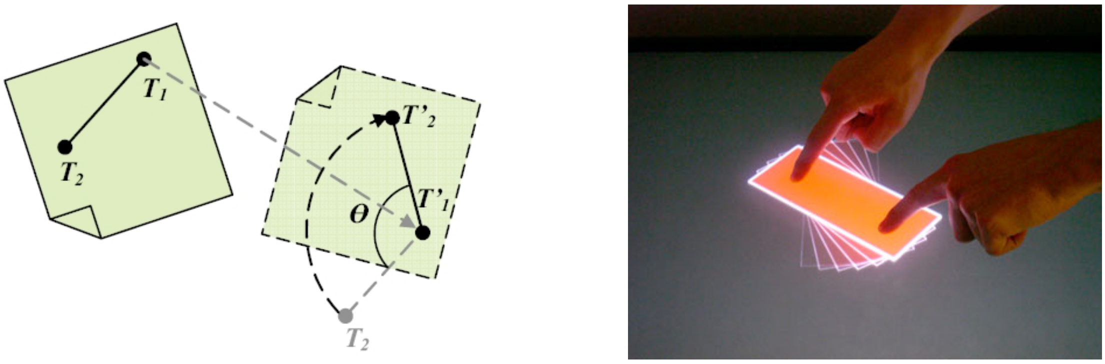


Figure 49: Two points translation, rotation and scale

4.3 Territoriality

As indicated in 3.4, in [Scott, Carpendale et al 2004], Scott et al. identified three types of territories (personal, group and storage territories) and the importance to provide techniques to help users to transfer and access objects in these territories. In [Scott et al 2005], they studied how people interact when using physical objects (sheet of papers, etc.) during tabletop collaboration. They observed the practice of piling to facilitate organisation and sharing of objects, i.e. creating and moving piles on the table surface. Based on these observations, Scott et al. propose a way to create and manage storage area on the tabletop: Storage bins. Storage bins provide the capabilities of a container, allowing people to add and remove objects as a group or individually. They can be resized to accommodate varying amounts of objects. Their mobility allows users to easily move a group of stored objects between territories: a user can take a storage bin in the group territory to add it to its personal territory.

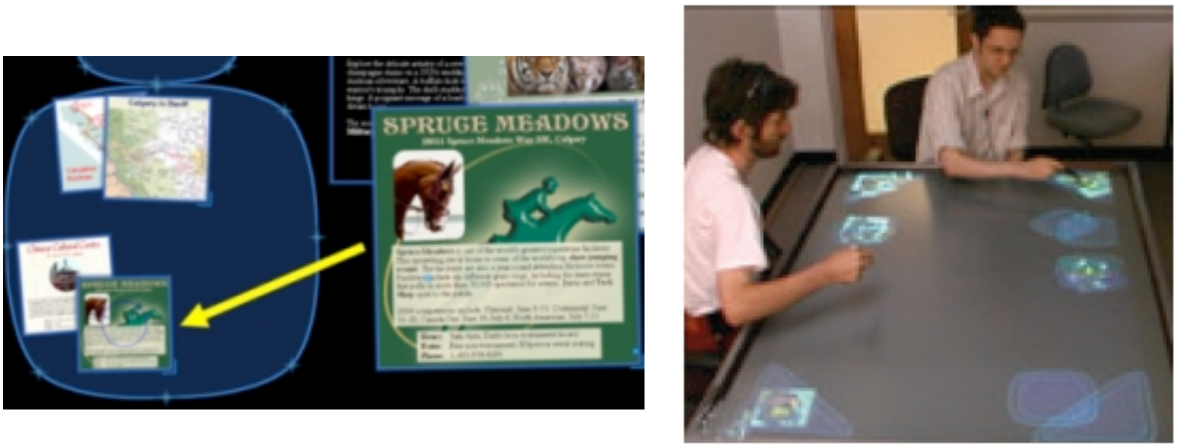


Figure 50 : Storage bins

In [Hinrichs 2005], Hinrichs et al. propose an extension to Storage bins called Interface current which provide a simple mechanism for automatically transporting a set of objects across the tabletop surface. An Interface current is component that is controlled by an ongoing flow. Objects such as pictures or documents that are placed on an Interface current are affected by the flow and move along inside the Current container, similar to leaves driven by a current in a river. They studied two king of current: pool current confined in a shape with only one boundary and stream current confined in a shape with two boundaries (i.e. a shape with a hole) (Figure 51). The flow direction and velocity as well as the shape of interface currents can be modified by users to enable them to adapt them to their task. For example, the flow can be stopped when users work independently and activated when users want to exchange objects.

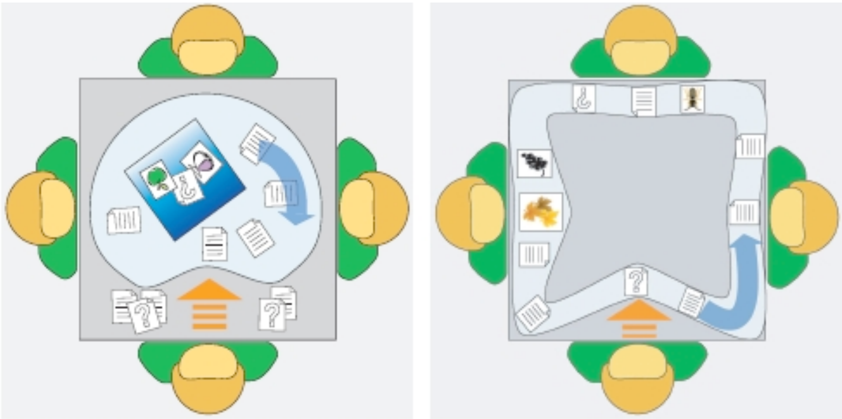


Figure 51: Interface current: Pool current (left) and stream current (right)

This study shows that in collaborative tasks involving a large amount of visual information the flow on Interface currents facilitates the exploration of and access to a group of objects. Indeed, it allows users to reach objects located across from them on the tabletop surface and to browse opportunistically through the information passing by while they are working on their personal space. Interface currents also support the organization of space within the tabletop surface: they can be used for both individual and group organisation (Figure 52).

Figure 52: Example of tabletop organisation with interface currents

4.4 Sharing of objects

In their guidelines for tabletop systems design (see 3.6 Guidelines for interactive tabletop displays design), Scott et al. [Scott et al 2004] identify the ability to share objects is a desirable trait for tabletop displays.

Ownership of an object can be transferred between two users using an ownership transfer coordination policy [Ringel, Ryall et al 2004]. If user A is the owner of the object and user B want to take it, user B must touch the object and user A must release it to transfer ownership to user B (Figure 53)

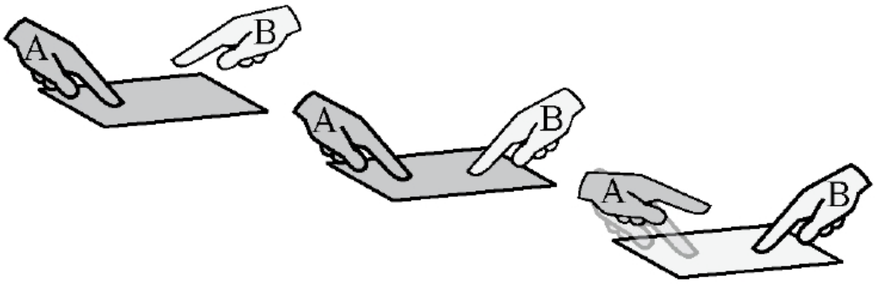


Figure 53: Ownership transfer coordination polivy

Another coordination policy is to create duplicate copies of objects when more than one user simultaneously tries to use it (Figure 54). Three variants of this policy can be defined using different semantics for duplication:

- creating a view linked to the original (changes made to either copy are reflected in both),
- creating a read-only copy of the original,
- creating a fully independent, read-write copy.

Figure 54: Duplicate coordination policy

4.5 Remote reaching

Due to the size of a tabletop display, it may be difficult to transfer objects hand by hand because the initial owner and the new owner might not be able to reach each other. Thus, many researchers have also investigated interaction techniques for long-distance reaching and remote object manipulation which is a possible solution for long distance transferring objects on tabletops. The literature provides different techniques to facilitate the access to remote objects.

In [Rekimoto 1997], Rekimoto proposes an extension of the traditional drag-and-drop technique: Pick-and-drop. With this technique, an object can be picked up by touching it and dropped anywhere by touching an empty space on the workspace. Unlike drag-and-drop, pick-and-drop does not require users to maintain users to maintain contact with the tabletop systems allowing them to easily move around the table or transfer objects from the tabletop to PDA or notebooks, and vice-versa.

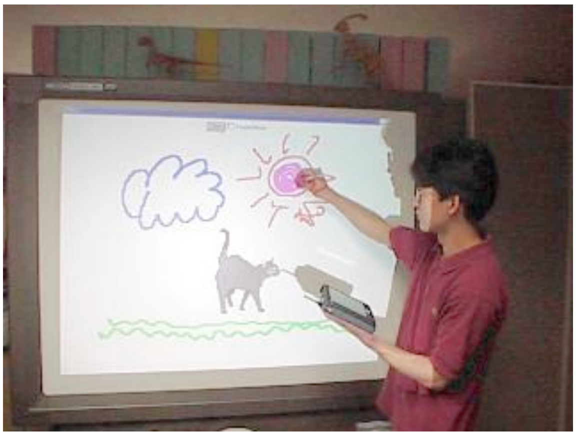


Figure 55: Pick-and-Drop between a PDA and a whiteboard display

In [Baudisch et al 2003], Baudisch et al. propose two techniques that bring proxies of potential targets into user's reach: drag-and-pop and drag-and-pick. Drag-and-pop brings remote objects that are in the direction of user's motion to the position of its finger or cursor allowing the user to interact with them using small movements. For example in Figure 56, as the user starts dragging a video clip icon, icons that are of compatible type and located in the direction of the user's motion pop up, i.e. each of these icons produces a tip icon that appears in front of the user's cursor. Tip icons are connected to the respective original icon using a rubber band. Drag-and-Pick extends the drag-and-pop interaction such that it allows activating icons, e.g., to open folders or launch applications.

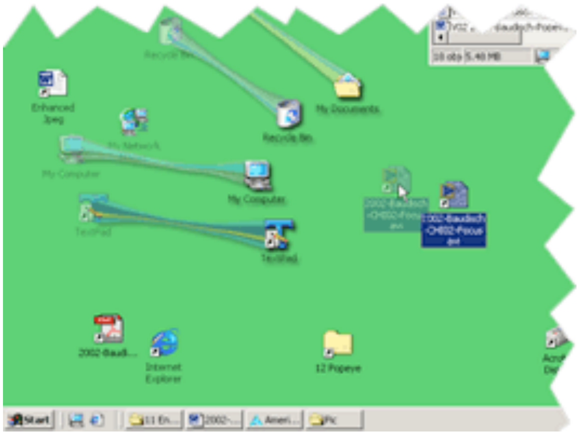


Figure 56: Drag-and-pop interaction

In addition, new widgets based on a proxy technique were imagined such as the Frisbee widget [Khan, Fitzmaurice et al 2004]. The Frisbee widget is a portal to another part of the display allowing the user to see and interact with remote objects. It is composed of two components: a "telescope" and a "target" (Figure 57). The "telescope" provides viewing and remote manipulation of the contents within the "target". The "target" is positioned at the focus of interest of the user giving the user a sense of where the target is. Its visibility also serves other users to have an awareness of the user's remote presence within the large display space.

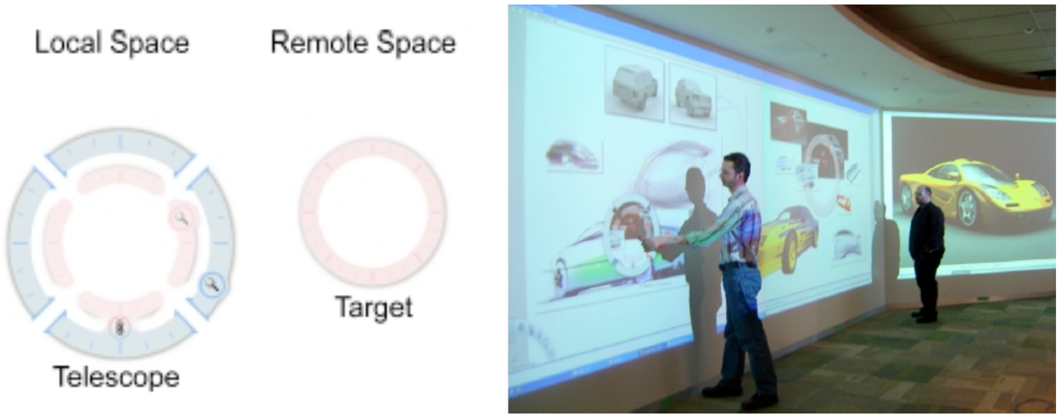
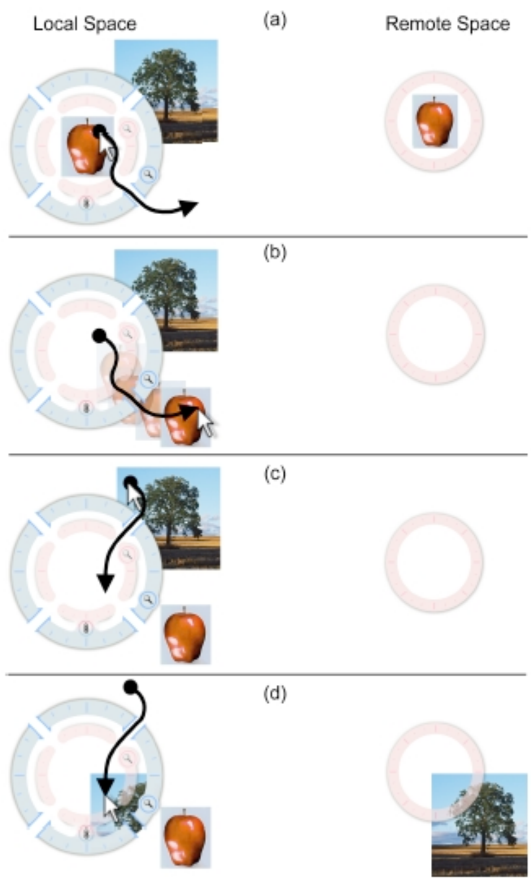


Figure 57 : The Frisbee widget

The Frisbee widget can be used to drag-and-drop objects between local space and remote space. If a remote object viewed through the telescope is dragged into the local space, it will warp to the local space. Correspondingly, if a local object is dragged into the telescope, it will warp at the position of the target (Figure 58).



(a) Dragging a remote image (apple) to local space by exiting the telescope

(b) The result of the drag

(c) Dragging a local image (tree) to the remote space by entering the telescope

(d) The result of the drag

Figure 58: Remote drag-and-drop with the Frisbee widget

Another solution is to use a radar view a.k.a. a workspace miniature. Instead of moving to the real target, the user can access the target by its representation inside of the radar view.

Figure 59: Example of radar view

5 Conclusion

In this document, we tried to provide a synthetic overview of state of the art of interactive tabletop displays mainly based upon a bibliographic research of scientific literature. Our sources included:

- Human-Computer Interaction and CSCW literature on tabletop and co-located systems,
- CSCW literature about co-located collaboration with CSCW systems,
- Social sciences literature discussing co-located collaboration and interpersonal communication

Initially, we began by a review of tabletop hardware. We presented different technologies for multi-input sensing and output display. As mentioned in chapter 2, there is an increasing number of interactive tables becoming available. But the DiamondTouch, from Mitsubishi Electric Research Laboratories, remains the most used off-the-shelf technology at the time of writing, although an increasing number of FTIR prototypes are built by researchers.

In the second part of the document, we treated the properties of group interactions with tabletop and the design challenges posed by interactive tabletops: solving conflicts, integrating coordination policies, managing public and private information, managing orientation of display elements, and mediating group dynamics.

Interaction on a tabletop display is significantly different from interaction on desktop computers which makes it difficult to simply use desktop software on an interactive tabletop display. Tabletop user interfaces must address specific issues, such as territoriality or orientation of objects, and define new metaphors and interaction techniques appropriated for the users' tasks. In chapter 4, we presented several novel interaction techniques for tabletop user interfaces.

There are several other interesting aspects of tabletop user interfaces design and use that remain beyond the scope of our overview of the state of the art of interactive tabletop displays. For example, we did not present factors that may impact tabletop usability, such as the impact of input sensing technology, table form-factor or pure social aspects such as group composition. These points are still an open field and major topic of research in Human-Computer Interaction.

Another important issue in the field of tabletop user interfaces is the lack of support in current toolkits for developing application. Indeed, nowadays, commercial toolkits assume the existence of a unique designation mean. These toolkits do not support several interaction flows in parallel for a single interface. Thus, researchers and developers usually build applications from scratch or create yet another HCI toolkit dedicated to a specific tabletop system, each time they design or want to evaluate novel interaction techniques.

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