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Fostering co-located collaboration through large interactive displays

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Large interactive displays are increasingly placed in public (or semi-public) locations, including museums, shops, various city settings and offices. This article analyzes how large interactive displays are changing the concept of human-computer interaction through new modalities, focusing on their capability of increasing the collaboration of people interacting with them. By surveying the literature on systems using these displays, relevant features were identified and used as classification dimensions. The analysis provided may inform the design and development of future installations with a great potential for collaborative experiences in many contexts. A discussion on research challenges concludes the article.

Categories and Subject Descriptors: H.5.2 [**Information Interfaces and presentation**]: User Interfaces – *Interaction Styles*

General Terms: Design, Human factors

Additional Key Words and Phrases: Public installations, Multi-touch displays, Touchless interaction

1. INTRODUCTION

The first prototypes of touch screens were already presented in the '60s, but significant installations of large touch screens and other large interactive displays appeared only in the new millennium. Thanks to the great advances in technology, these displays are now available at affordable prices, so they have moved from laboratories to public (or semi-public) settings, like museums, tourist information centers, offices, shopping malls and various urban locations. People are stimulated to interact with such displays through new and engaging modalities, in order to retrieve information and/or to perform some useful tasks, possibly collaborating with other people. These new uses are raising many challenges for both designers and users, especially because public displays attract people who are very diverse in age, skills and experience with technology. As we will see in this article, many features of such installations affect users' experience.

Since the year 2000, several workshops have been organized to discuss topics related to large interactive displays. Journal special issues have been published: one appeared already in 2000 and addressed research and experience in building large display systems, which were very innovative at that time [Li et al. 2000]. Another considered the applications of large displays [Kurtenbach and Fitzmaurice 2005] and a third one published in 2006 looked at digital tabletops [Scott and Carpendale 2006]. More recently, Hinrichs et al. [2011] edited a special

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issue on interactive public displays, which actually range from large-scale media facades, requiring user interaction from a distance through some kind of device, to large interactive displays that can be directly touched by users. In this article, we do not consider facade displays, i.e. displays integrated into architectural structures like buildings and usually of very large scale, since they have different requirements.

A comprehensive overview of the research on systems using large interactive displays is very challenging, due to the great amount of papers published on this topic. Only surveys limited to specific aspects have been presented so far. The one reported in [Greimel 2011] focuses on interaction techniques for public displays, distinguishing between interaction based on input devices and interaction based on direct-touch technology and haptics. Some interactive tabletop exhibits in museums and galleries are discussed in [Geller 2006]. A few other publications refer to specific technological issues, e.g. touch point detection and tracking [Chang et al. 2010], and target selection in touch-sensing devices [Yang et al. 2010]. Very recently, a review of the state of the art of tabletop computing is presented in [Bellucci et al. 2013].

This article surveys 181 papers that describe systems using large interactive displays developed over recent years; they were selected after an accurate search of the literature, as described in Appendix A. Its aim, rather than being a comprehensive survey, is to show how these systems are changing the concept of human-computer interaction (HCI), increasing collaboration among co-located groups. Specific features of these systems are identified and the surveyed papers are classified on the basis of such features. We believe that the analysis presented in this article could provide hints for the design and development of new installations able to foster collaborative experiences in many contexts.

The article is organized as follows. Section 2 briefly reports the history of interactive displays before the current millennium. Section 3 addresses the potentialities of large interactive displays to foster collaboration. Section 4 describes the five dimensions we identified to classify the surveyed papers. These dimensions are illustrated in more details in Section 5, together with examples of some particular systems; each dimension is reported in a separate sub-section. Section 6 discusses research challenges and Section 7 concludes the article.

2. ORIGINS OF INTERACTIVE DISPLAYS

The first proposals of touch-screen devices appeared in the ‘60s and used cathode-ray tube technology. One of the pioneers was Eric Arthur Johnson, an engineer at the Royal Radar Establishment in Malvern, England. He proposed a display with very novel input/output capabilities, thanks to wires, sensitive to the touch of a finger, that were put on the surface of a cathode-ray tube [Johnson 1965; Johnson 1967]. This approach is still used today in several common devices. At that time, such touch displays were experimented primarily for air traffic control [Orr and Hopkins 1968].

A prototype of a flat plasma display, called PLATO IV, was already built in 1972 at the University of Illinois at Urbana-Champain [McWilliams 1972; Sherwood 1972]. It was an 8.5 inch display with a tactile surface based on an infrared emitter matrix of 16 × 16 sensors. The prototype was used to allow a student to answer multiple-choice test questions by touching the screen.

In the late ‘70s, several researchers worked to improve the touch-screen technology, for example by taking into account touch pressure and the angle of the finger touching the screen [Herot and Weinzapfel 1978; Minsky 1984]. Various technological solutions were proposed in the ‘80s, creating the first multi-touch displays capable of detecting the touch of multiple fingers. One such prototype is described in [Mehta 1982]; it used a projector to display images on a frosted-glass panel with specific optical properties. A finger-touch generated a black spot, whose size depended on the finger pressure, while the rest of the screen was white. Such black spots were detected by a camera that, with the projector, was located behind the panel. The user could draw images by touching the panel. This technology is at the basis of today's commercial solutions, e.g. FTIR (Frustrated Total Internal Reflection) [Han 2005]. Other researchers investigated how to interact with the display not only through several fingers of one hand, but also through the use of both hands by multiple users; an example is provided by Krueger et al., who implemented many of the hand gestures for zooming and rotating objects, which are very popular today [Krueger et al. 1985].

Almost all prototypes developed up to the end of the '80s were monitors that used either cathode-ray tube or plasma technology. Due to the limited size of such monitors, several researchers were willing to develop solutions for much larger displays. The early '90s were influenced by the famous papers of Mark Weiser [Weiser 1991], in which he clearly says that ubiquitous computers have to be of different sizes, each suited to a particular task, since real power emerges from the interaction of all the different devices. This pushed researchers towards the construction of very large displays, which could be set up vertically, and thus used as an interactive wall, or horizontally as a tabletop. One of the first examples of a tabletop display was *Digital Desk* [Wellner 1991], which used both optical and acoustic finger detection on the display and also introduced the possibility of tactile manipulation of physical objects on the display. A "graspable" user interface on a tabletop display was presented in [Fitzmaurice et al. 1995]: some physical artifacts, called *bricks*, were the input devices operating on the display; they could be attached, i.e. tightly coupled, to virtual objects for manipulation or for expressing actions. *Portfolio Wall* was a system that used a vertical touch-screen display developed at the end of the'90s [Buxton et al. 2000]; it was proposed as a digital corkboard for sharing work within a design team. The users could sort and annotate images shown on the display, which was about two meters wide.

As shown in this paper, the new millennium brought a considerable proliferation of large interactive displays, thanks also to their capability to promote activity and social awareness [Huang and Mynatt 2003]. Moreover, the first commercial solutions appeared. One of the first products is *Lemur*, released by Jazz Mutant in 2004, which is still on the market; it is a multi-touch display used by deejays as a music controller [Lemur 2013]. *DiamondTouch* is a multi-touch table produced by Mitsubishi and is well-known because it is one of the few products capable of identifying users during the interaction [Dietz and Leigh 2001]. This is possible because users are sitting on chairs around DiamondTouch and there is a micro-electric contact to each chair. Up to four users at a time can touch the screen; the system recognizes each user by detecting the electrical frequency going through the user's body to the fingers touching the display. Some years later, in 2007, Microsoft introduced on the market *Microsoft Surface*, another multi-touch table that allows multiple users to interact through either gestures or some real world objects. However, it does not identify the touch of a specific user. Many other products are now on the market, especially tabletops.

3. FOSTERING COLLABORATION

Even though large interactive displays are increasingly used in public or semi-public spaces, it is still a challenge to model people's behavior when faced with such displays. What are the main triggers for starting interaction? Are people intimidated by the social context? Are they willing to collaborate with other people? Our focus in this paper is on people collaboration, which is important in several contexts. In particular, collaboration increases people creativity, and tools for supporting creativity are needed, i.e., tools that extend users' capabilities to make discoveries or inventions [Shneiderman 2007]. We see a large interactive display as such a tool. Indeed, creativity is crucial for solving problems and much creativity results from interacting with artifacts, tools and collaboration with other individuals [Csikszentmihalyi 1997; Norman 2006]. Large displays could also be used to provide interactive creative workspaces that let groups of individuals work collaboratively, express their creativity, and share their ideas and solutions.

Before presenting the overall survey, we report some significant field studies that investigated how people approach interactive displays, what their overall behavior is and whether socialization and collaboration are fostered.

Peltonen et al presented *CityWall*, a large multi-touch display installed in a shop window next to a café in the center of Helsinki, Finland [Peltonen et al. 2007]. It allowed citizens to browse photos and videos downloaded from social networks such as FlickR and YouTube, thus anyone could contribute with contents of interest. A study was performed in Summer 2007, collecting data on 1199 people [Peltonen et al. 2008]. It revealed that the large display tended to encourage collaborative activities of different groups (up to seven), which used the system in parallel, i.e. at the same time, possibly for different tasks. In several cases, groups of strangers had fun together even if they started interacting separately.

Similar results were obtained with *World of Information*, a system which visualized six globes containing themed information, in the form of images, videos and texts [Jacucci et al. 2010]. A field evaluation was conducted during an exhibition of advanced technological products; during three days, 101 people were observed. Data collected through survey and video analysis confirmed that people tended to use the system in parallel, either working individually or collaborating (in pairs or in larger groups). Analysis of the relationships among people near the display showed that they had a positive social experience.

In the case of *Tourist Planner,* an application on a tabletop display installed in the tourist information center in Cambridge (UK) [Marshall et al. 2011], a field study conducted for 32 days showed that the system changed people's behavior in the physical environment. Indeed, the system acted as an aggregator for a group of people coming together to the information center: they were going to interact together with Tourist Planner to define their itinerary, rather than being dispersed in the environment, as usually occurred. Differently of what was observed in [Jacucci et al. 2010; Peltonen et al. 2008], social interaction was here focused towards pre-existing groups and users actually felt discomfort when strangers came to the tabletop.

FizzyVis is a system proposing a game that people can play in parallel or together to obtain information about venues, artists and concerts [Coutrix et al. 2011]. A study was performed by involving 130 people at a music festival for 9 days; observations, video analysis and questionnaires were used. Results showed that FizzyVis was able to arouse curiosity, enable easy and explorative information browsing and encourage collective play. Indeed, games are a type of application that has a great potential to foster collaboration. An educational game, designed to be played by children interacting with a multi-touch vertical display installed in their school laboratory, is described in [Ardito et al. 2013]. It is called *History-Puzzle* because groups of pupils collaborate to reassemble puzzles to discover historical elements of interest. The game requires the users to answer specific questions about history or to associate concepts. It is part of an educational format inspired by the Discovery Learning technique defined by Bruner in his Constructivism theory [Bruner 1990]. A field study was conducted involving 107 pupils, aged 10-12 years old; it showed that the game was very engaging, able to stimulate pupils to work together and to collaborate on learning tasks. Teachers appreciated that even pupils who were usually timid in class were very much involved and actively collaborated with their companions.

The analysis reported in Section 5, which considers many systems, confirms what emerges from the studies above: with proper applications, greater size and multiple interaction possibilities facilitate groups of people to carry out a common task jointly. If the display is in a public context where people do not know each other, there is often an initial time span in which people, primarily the older ones, are hesitant and stand nearby, attracted by others' interaction and possibly learning about the functionality offered by the system. However, most of them soon approach the system and are keen to collaborate with others.

4. THE CLASSIFICATION DIMENSIONS

By surveying the literature of the last years, the goal of this article is to show the evolution of large interactive displays by looking primarily at their use and at their possibilities of supporting people collaboration, rather than at the technology that made them possible. The procedure to identify in the literature the papers to analyze is described in Appendix A: we selected 181 papers, whose distribution according to the publication year is shown in Fig. 1. The sixteen papers in the first column were published in the years up to 1999 (this is indicated by the symbol "…").

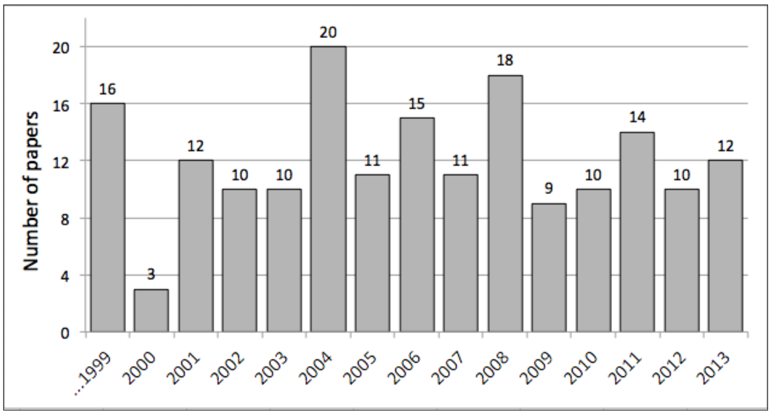

Fig. 1. Distribution over the years of the surveyed papers.

In analyzing the selected papers, we identified the relevant features of the systems described, which are used as dimensions for classifying such systems. These dimensions are briefly illustrated in the following, while more details are reported in the next section, where examples of systems belonging to the specific categories are described.

1. **Visualization technology**. This is the only dimension that refers to technology, since it addresses the solutions used to visualize the computer output on displays of very large size. As we will see, it affects the cost of both the display and the overall system, so it has a significant influence on where and how the display can be used. The two main technologies are based on projection (front or rear projection) and monitors (LCD or Plasma, cathode-ray tubes in the very first prototypes [Johnson 1965; Johnson 1967]).
2. **Display set-up**. Set-up is related to the physical installation and orientation of the display [Pedersen and Hornbæk 2012]. We will see that the orientation actually affects the collaboration possibilities offered to users. Most interactive displays are installed with a *vertical* orientation, like the traditional PC. This position is that of wall displays (Fig. 2a). Many systems also adopt a horizontal set-up, e.g. tabletops (Fig. 2b). A few systems propose a *diagonal* set-up (Fig. 2c), a *floor* display (Fig. 2d) and some project the computer output on any surface.

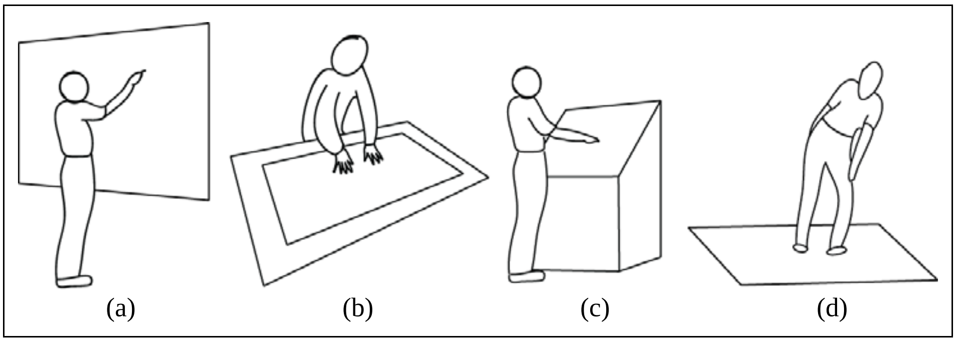

Fig. 2. Display set-ups: (a) vertical, (b) horizontal, (c) diagonal, (d) floor.

3. **Interaction modality**. The adoption of new post-WIMP interaction modalities is an important feature of large interactive displays. We distinguish: a) interaction by touching and/or manipulating objects visualized on the display (*Touch* in Table I), b) interaction through remote devices, c) through tangible objects and d) through body movements (including movements of arms, gaze, etc.).
4. **Type of application**. The first uses of large interactive displays were for entertainment or to perform specific tasks, which were usually very simple. More recently, they have been used for more complex tasks and also for social interaction, games, learning, etc.
5. **Location**. Another important feature to analyze the collaboration possibilities offered by interactive public displays is the location in which they are installed, namely: office, city, university and school, shop, conference, museum or any cultural heritage site and the so-called third place, i.e., a location where people get together to socialize (like a café).

Table I reports the percentage of papers within each category. The sum exceeds 100%, since a single paper may describe one or more systems that have different features and thus can be classified into more than one category per dimension. The label *Projection (unspecified)* in the first column indicates that some papers describe systems whose visualization technology is *Projection*, but it is not specified if it is *Rear* or *Front*. The label *Unspecified* is used in the first column, since in some papers the visualization technology is not specified. It is also used in the last column, since some papers describe prototypes that have been used only in laboratories and their possible location is not specified. The label *Other* in the second column indicates that the described systems do not belong to any of the listed categories.

Table I. Percentage of papers in each category

Visualization technology		Display set-up		Interaction modality		Type of application		Location	
Category	%	Category	%	Category	%	Category	%	Category	%
Rear Projection	37	*Vertical*	71	*Touch*	71	*Useful tasks*	44	*Office*	26
Front Projection	22	*Horizontal*	25	*Remote devices*	27	*Entertainment*	42	*City*	15
Projection (unspecified)	4	*Diagonal*	2	*Tangible objects*	21	*Social interaction*	25	*University/school*	10
Monitor	33	*Floor*	2	*Body*	15	*Game*	15	*Cultural site*	6
Unspecified	6	*Other*	7			*Advertisement*	7	*Conference*	4
						Learning	4	*Shop*	4
								Third place	4
								Unspecified	30

5. LARGE INTERACTIVE DISPLAYS ALONG THE CLASSIFICATION DIMENSIONS

This section analyzes the surveyed papers according to the five classification dimensions, providing examples of relevant systems. Each sub-section refers to a dimension and concludes by showing a graph of the temporal trend, in order to highlight the evolution of large interactive displays over the years.

5.1 Visualization technology

Visualization technology refers to the technological solutions adopted to create displays of very large size. The two main technologies are denoted as *projection (rear/front)* and *monitor*. Only a few papers (6%) do not specify the adopted solution. The first column of Table I shows the percentage of papers classified within each visualization technology category.

5.1.1 Projection (Rear/Front)

Projection technology is based on the use of one (or more) projector(s) and a surface, such as a wall, a canvas or a special material, on which the output of the computer is projected. If the projector is behind the surface, it is called *rear projection* (37% of papers), if it is in front, it is called *front projection* (22% of papers, see Fig. 3). In 4% of the papers, it is not specified whether the adopted projection technology is rear or front. An advantage of front projection is the absence of the box, behind the screen, containing the projector(s). However, the user's shadow on the surface does not allow them to see the occluded area. In the case of *rear projection*, a disadvantage is that the box with the projector(s) might be very big.

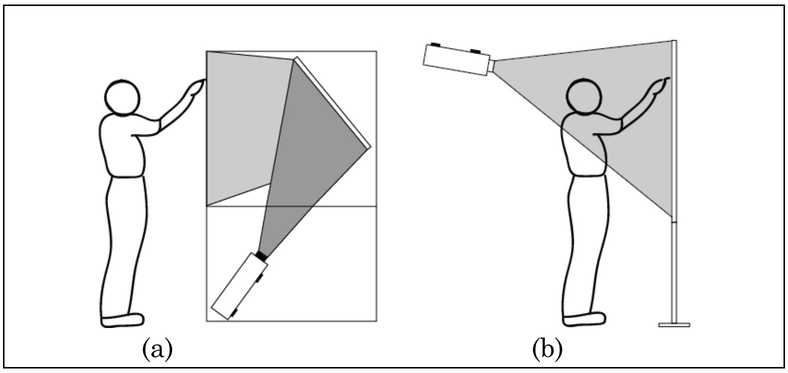

Fig. 3. Two different projection solutions: (a) the projector is behind the visualization surface, (b) the projector is in front of the visualization surface.

Projection technology is very popular, since it is usually economical and quite effective, as discussed in [Hereld et al. 2000; Schöning et al. 2010]. A significant limitation with respect to LCD and plasma monitors is the low image resolution, making it difficult for users to perceive image details. Very large interactive displays may be easily built, since several projectors can be combined, projecting the output image on a surface of tens of meters, like the interactive wall installed at the Hard Rock Café in Las Vegas. Thus, several individuals or groups of people can interact in parallel. In [Schikore et al. 2000] 15 pro jectors were arranged in a 5 × 3 array (Fig. 4b), producing a display of 6,400 × 3,072 pixels across 5 × 2.5 meters. A key goal was to edge-match the output image of each projector to its neighbors without either overlap or separation lines. Other similar displays were presented in [Ojala et al. 2012; Peltonen et al. 2008; Shinohara et al. 2007].Because such wall displays require a complex structure for the projectors and a specific technology has to be used in order to properly align the outputs of all projectors, the overall cost of such displays is still very high.

Different technical solutions are adopted to make the surface interactive; a detailed description of such technologies is out of our scope. We only mention that, for detecting the touch of users' hands and fingers (and also tangible objects) some solutions are based on: 1) infrared emitters and an infrared camera [Schöning et al. 2008]; 2) ultrathin overlay placed on the visualization surface [FlatFrog 2013; PQ Labs 2013]; 3) ultrasound emitters and sensors [Ashdown and Robinson 2004]. As discussed in Section 5.3, in some cases the interaction occurs through remote devices, by exploiting technologies such as Bluetooth, Wi-Fi, IrDA (infrared), etc.

(a) (b)

Fig. 4. The wall display (a) is built by 15 rear-projected panels (b) [Schikore et al. 2000].

An unusual projection technique is described in [Rakkolainen and Lugmayr 2007], where the authors present experiments with a kind of immaterial display, called *FogScreen*, in order to provide visually compelling advertisements. FogScreen forms a projected image on a mid-air immaterial image plane. Thus, the viewer can even walk through the display, since it is actually made of air (Fig. 5). This kind of projection is visually intriguing and can also be made two-sided, so that the opposing viewers on each side see their side of the screen and each other through it. The interaction with the immaterial 2D or 3D graphical objects occurs by virtually "touching" them. The application is able to track the position of the viewer who has "touched" the screen, thanks to a commercial laser scanner, which emulates the functionality of a mouse device. The reported experiments revealed some affordance problems: the concept of an immaterial, mid-air display was unusual for viewers and they would have needed hints for using it, for example a projected text saying "touch me".

Fig. 5. The interactive FogScreen [Rakkolainen and Lugmayr 2007].

5.1.2 Monitor

Another popular visualization technology adopts a *monitor*. The first prototypes that appeared in the '60s were cathode-ray tube monitors [Johnson 1965], soon replaced by LCD and plasma monitors, whose prototypes were already proposed at the beginning of the '70s. LCD and plasma monitors are greatly used today, since they are ultra-thin and provide very high resolutions, greatly improving the quality of the displayed image. However, their high cost severely restricted their diffusion until a few years ago; costs are now quickly decreasing. The size of a *monitor* reaches 110 inches. This limitation may be overcome by combining several monitors side by side. This solution is often called "tiled panel": it consists of a set of monitors arranged in a 2D array. The array can be organized like a wall display, like a table or in other configurations. An example is *Lambda display*, a 100 MPixel wall display. It was developed at the Electronic Visualization Laboratory, University of Illinois [Krumbholz et al. 2005]. This large display can be used both in a vertical and in a horizontal set-up (see Section 5.2).

A wall display conceived by NASA is called *Hyperwall*, a very large display built with 49 LCD panels tiled in a 7 × 7 array. Each flat panel display is 18 inches long and the entire array is driven by 49 rack-mounted dual-CPU nodes, each with its own high-end graphics card [Sandstrom et al. 2003]. Hyperwall helps researchers to display, analyze and study high-dimensional datasets in meaningful ways, allowing the use of different tools, viewpoints and parameters to look at the datasets from different perspectives. In recent years, NASA updated this display by developing a larger version called *Hyperwall-2* (Fig. 6): it consists of 128 LCD panels tiled in an 8 × 16 array, which measures 10 meters in width and 3 meters in height [Bo-Wen et al. 2011; NASA Division Website 2013].

Tiled LCD panels have the advantage of being easier to align into the array and to adjust the colors, compared with projectors, which require a complex structure in order to be composed together in a single large display. Thus, tiled LCD panels might even be cheaper than projection-based tiled displays. However, the resulting image has a visible border between adjacent monitors [Koppel et al. 2012], even if recent commercial solutions, such as the *MultiTaction with ultra-thin bezel*[2], are reducing this problem.

Fig. 6. The 8 × 16 LCD panels of the Hyperwall-2 display [Bo-Wen et al. 2011].

5.1.3 Temporal trend of visualization technology

In order to highlight the evolution of large interactive displays over the years according to the visualization technology, Fig. 7 shows the graph of the distribution of the surveyed papers. Before 2004, both technologies were used, while in the successive years projection has been more frequent than monitors. This might be due to the fact that large displays are still more economical with projection technology.

It is evident that the display's wider size encourages the simultaneous use by more individuals or groups of collaborating people [Pavlovych and Stuerzlinger 2008].

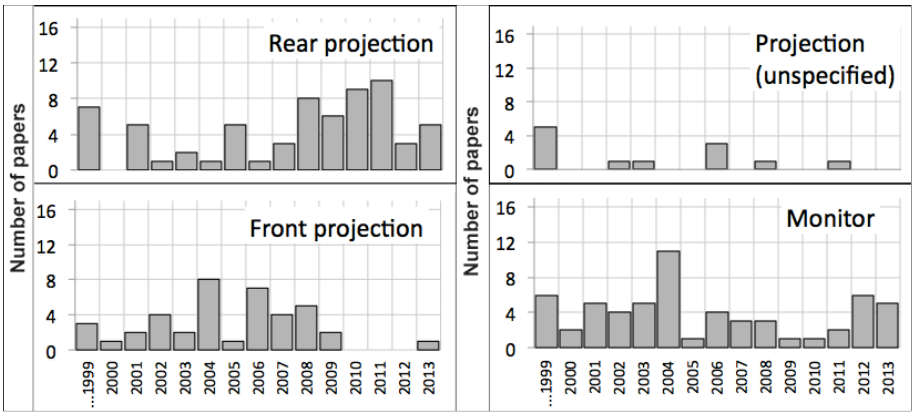

Fig. 7. Distribution over the years of the surveyed papers according to the *visualization technology* dimension.

5.2 Display Set-up

The display of traditional PCs has a *vertical* set-up. For large interactive displays, besides the vertical one, horizontal and diagonal set-ups have also been used. More recently, *floor* installations have been presented, primarily for entertainment. Furthermore, there are systems that project the computer output over any surface: spherical, cylindrical or even irregular.

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[2] http://www.multitaction.com/products/ultra-thin-bezel/

5.2.1 *Vertical*

As shown in Table I, most papers in our survey (71%) describe displays that are vertically installed (Fig. 2a). This set-up is often used in a city context, since it is suitable for passers-by who remain only a short time in front of a display located, for example, in a shop window [Perry et al. 2010], or also at a university [Hardy et al. 2011]. A vertical set-up is convenient for easily reaching a very big size, such as the already mentioned wall displays [Guimbretière et al. 2001; Li et al. 2000]. Koppel et al. [2012] presented *Chained Displays,* a flexible combination of vertical LCD displays, which have been evaluated in a university setting in order to see how the shapes influence people's behaviors. The displays can be combined to create different shapes: hexagonal, flat and concave (Fig. 8). The experiments performed showed that a hexagonal shape prevents users in front of the display from seeing what other users are doing on the other portions of the display, resulting in low collaboration and sociability, a flat arrangement triggers the strongest honey-pot effect, attracting other people to interact, while the concave arrangement does not stimulate simultaneous interactions.

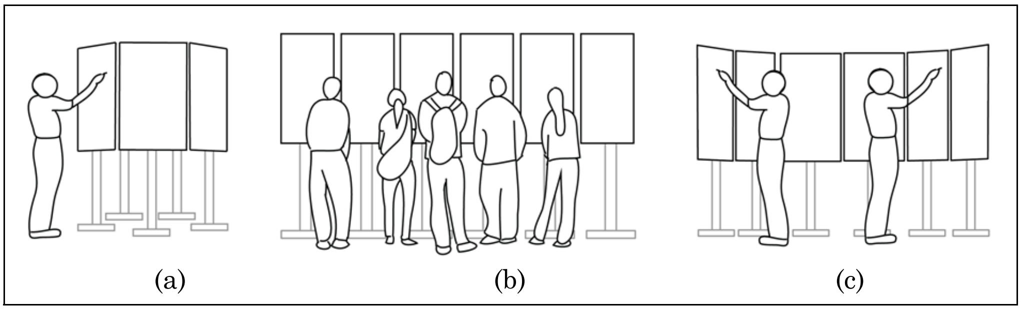


Fig. 8. Chained Displays: (a) hexagonal, (b) flat and (c) concave, adapted from [Koppel et al. 2012].

5.2.2 *Horizontal*

In several cases, it is useful to set the display horizontally, like the top of a desk (Fig. 2b), so that users can interact even for a long time while sitting around it. This set-up is presented in 25% of the papers and, after the vertical set-up, it is the most used, especially in locations like offices [Bi et al. 2006], museums [Hinrichs et al. 2008], schools [Piper et al. 2006] and in general when the activities require some time, so user comfort becomes important. It appears more appropriate for collaborative tasks, because multiple users can discuss and share the display while comfortably sitting around it [Shen et al. 2003]. Unlike the vertical set-up that allows users to easily look at other areas of the display, two users sitting on opposite sides of a tabletop display see contents reversed with respect to each other.

Some studies focused on how to enhance people collaboration by using a horizontal set-up [Morris et al. 2006; Shen et al. 2003]. The work in [Rogers and Lindley 2004] analyzed collaboration around vertical and horizontal large interactive displays. The results show that horizontal surfaces better support collaborative activities that closely couple the resources used and/or created during the various activities, while vertical displays are better at providing a shared surface that allows a group of people to view and annotate information to be talked about and referred to. The study reported in [Pedersen and Hornbæk 2012] also compared vertical and horizontal set-ups to analyze their influence on users' performance, satisfaction and general behavior. For example, it showed that a tapping task was performed 5% faster on the vertical display, whereas a dragging task was performed 5% faster and with fewer errors on the horizontal display. In general, many users preferred the horizontal set-up because they felt less tired when using that surface. The few users that preferred the vertical surface explained that it offered a better overview and hands were less likely to occlude objects on the screen.

5.2.3 *Diagonal*

A few papers (2%) present displays with a *diagonal* set-up (see Fig. 2c). It is a trade-off between the previous two. The display is installed with the lowest side at a height similar to a horizontal set-up. It has been shown that this solution improves the interaction of user(s) placed at the lowest side, while it greatly limits the collaboration with users standing at the other sides, even if they have a common task to perform [Shen et al. 2003].

Other studies show that the angle of the display has a strong impact on user interaction and collaboration (e.g. see [Inkpen et al. 2005]). Specifically, a diagonal display can provide a better viewing angle, but does not afford people gathering around it [Buxton et al. 2000], thus limiting collaboration possibilities. Instead, collaboration is better supported by both horizontal and vertical displays. The former allow several possibilities for user arrangement, also providing a flat surface for placing objects. The latter give all viewers the same perspective on the task and provide a holistic view of the data.

5.2.4 *Floor*

New fascinating set-ups have been implemented, especially when the system's main purpose is entertainment. Specifically, some systems (2% of the papers) use the *floor* as the projected surface, with a projector and a camera mounted on the ceiling. The camera tracks users' movements, as in *iFloor*, a prototype that encourages the interaction of people standing around the interactive floor [Krogh et al. 2004]: they may use their mobile phones to post messages on the floor that they want to exchange with others (Fig. 9).

Another interactive floor is able to show, in front of each user walking on it, the forecasted trajectories that presumably a user will follow [Ozturk et al. 2012]. Recent technological solutions have investigated how to build a more accurate floor display by mounting tracking cameras inside the floor, like in *Multitoe*, a high-precision interactive floor display able to sense per-pixel pressure of users [Augsten et al. 2010]. This technology allows the floor to locate and analyze users' soles, to recognize foot postures and thus to identify users.

Fig. 9. Using iFloor a group of users can discuss and interact, by using personal mobile phones to write SMSs that are visualized on the floor [Krogh et al. 2004].

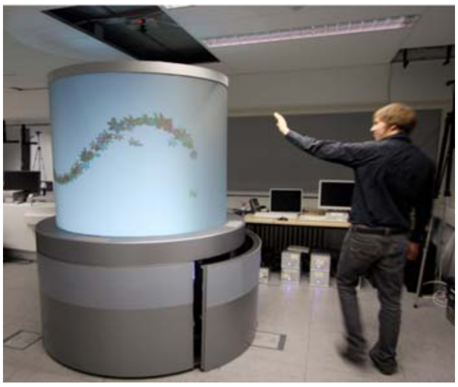
5.2.5 *Others*

7% of the papers examined present special set-ups not classifiable within those previously described. Indeed, some projection technologies permit the visualization of the computer output on a surface which has not been chosen a priori, so that it is adaptable to different situations; thus, the output can be projected on a wall, a floor, or any surface, such as the interior of an umbrella or a fan, see for example Fig. 10 [Lee et al. 2008]. These types of set-up are used in conjunction with special touch-sensing technology that can detect the gestures of the users on the projected surfaces [Lee et al. 2005; Pinhanez 2001].

Fig. 10. Projecting the image on different surfaces, including uneven surfaces such as the interior of an umbrella or a fan [Lee et al. 2008].

Other systems present spherical (e.g. [Bolton et al. 2011; Bolton et al. 2012]) or cylindrical displays (e.g. [Beyer et al. 2011; Lin et al. 2009]), as shown in Fig. 11. A comparison among spherical, cylindrical, vertical and horizontal displays is provided in [Benko et al. 2008]. With both spherical and cylindrical displays, each user can see at most one half of the display; thus, these displays, rather than fostering collaboration, allow different users to interact without disturbing each other and with more privacy, since each user sees only the portion of the display in front of him/her.

(a)



(b)

Fig. 11. Example of: (a) spherical display; (b) cylindrical display [Benko et al. 2008].

5.2.6 Temporal trend of display set-up

Fig. 12 shows the graph of the distribution over the years of the papers surveyed, according to the display set-up dimension. The first systems used the vertical set-up, which is still the most popular. The horizontal set-up, i.e. the one for tabletop displays, is the second most used. There are commercial solutions available on the market for both vertical and horizontal set-ups (e.g., [FlatFrog 2013; Lemur 2013; ZaagTech Inc 2013]). The remaining set-ups are still in an experimental phase.

For various reasons, vertical and horizontal set-ups are the most prone to people collaboration. People may easily collaborate also on floor displays. The choice depends very much on the type of applications implemented, i.e. on the tasks people have to perform.

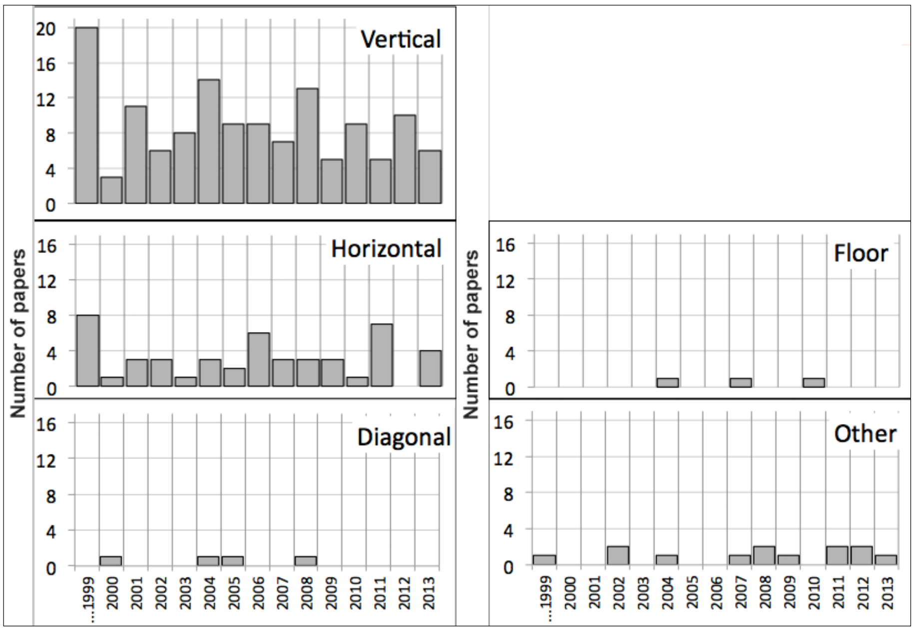


Fig. 12. Distribution over the years of the surveyed papers according to the *display set-up* dimension.

5.3 Interaction modality

Systems equipped with large displays adopt several innovative interaction modalities, in order to engage people as much as possible. Most installations have the potential to support different interaction modalities, but usually only a primary interaction modality is provided to users. We distinguish four main categories, denoted as *touch*, *remote devices*, *tangible objects* and *body* (see Table I).

5.3.1 Touch

71% of the surveyed papers refer to systems whose interaction modality is based on the touch of users' fingers and/or users' hands on the display surface, in order to move, zoom, rotate, annotate objects or provide other types of input. For a few systems, touch is limited to one finger at a time (e.g. [Vogel and Balakrishnan 2004]), while most systems allow users to interact using many fingers simultaneously (e.g. [Kim et al. 2010]). The system described in [Peltonen et al. 2008], besides detecting more fingers at a time, is also capable of recognizing hand touch. This is useful, for example, to rotate a sheet of paper shown on the display: the user touches a sheet with his/her hand oriented in a certain direction and the system is able to recognize this orientation and rotate the sheet to be aligned to the hand. Finally, there are systems able to disambiguate users' hands over the display when many users interact simultaneously with it. This is particularly useful when more users collaborate in a common task. The first product that appeared on the market capable of distinguishing the touch of each user is Diamond Touch, described in Section 2 [Dietz and Leigh 2001]. Today, other systems do the same, but they use other approaches: one is proposed in [Wang et al. 2009], which analyzes the orientations of the fingertips to identify the user; another one, described in [Dohse et al. 2008], combines a multi-touch tabletop with a camera mounted above the table, which tracks the hands in order to distinguish users. This approach works well when users stand on opposite sides of the tabletop.

5.3.2 Remote devices

A considerable number of papers (27%) describe systems that allow users to interact by using an external device, which is not in direct contact with the display surface, but communicates with the surface through wireless technologies (e.g. Bluetooth, Wi-Fi, SMS). These techniques are useful when the display is very big, thus it is impossible for users to touch the highest parts of the display. The device could be a smart-phone or a tablet, provided it is equipped with specific software. For example, the 3D motion sensors of the Nokia 5500 are used in [Vajk et al. 2008] as a "Wii-like" controller for playing games on a large public display. However, it is difficult to actually use personal devices, due to the requirements of their specific configurations, so this approach is only applicable to private or semi-public settings. Boring and Baur created a conceptual framework and implemented techniques that leverage cell phone cameras to enable from-a-distance interaction with any public-display technology [Boring and Baur 2013]. Other remote devices are purpose built, for example, *uPen*, a device composed of a laser pointer combined with a contact-pushed switch, three press buttons (as on a mouse) and a wireless communication module. Users may interact with a large display either from a distance or directly by touching the surface, i.e. using uPen as a mouse. Interestingly, each user may hold a uPen, thus more users can interact together, possibly collaborating, and the system is able to identify them and provide personalized services [Bi et al. 2006]. It is worth noting that the use of remote devices helps to solve some privacy problems: people can input personal data, passwords, etc. through the device, without worrying about others looking at the display (see for example [Magerkurth and Tandler 2002]).

5.3.3 *Tangible objects*

21% of the surveyed papers describe systems that allow users to interact by manipulating real objects on the display (e.g. [Lucchi et al. 2010; Tuddenham et al. 2010]). This modality is used, for example, to implement workspaces that support collaborative tasks: the system presented in [Rogers et al. 2006] recognizes miniature models of street furniture (e.g. flowers, trees, shrubs, benches, chairs, statues) placed on an interactive table, thanks to an RFID tag attached under each object. During a collaborative activity to design a layout plan of a public garden for a new university building, users select objects and decide their best position. Recent systems are more sophisticated and capable of recognizing complex objects. In *BlueTable,* a combination of computer vision and Bluetooth technologies is used to connect a mobile device to a tabletop display, in order to exchange specific data. The user establishes the connection by simply placing the device on the display and the system is able to retrieve the contents stored in the mobile device, like photos or a calendar, and show them on the tabletop (Fig. 13). Any change the user makes on the tabletop, e.g. editing the calendar, is automatically reported in the mobile device. A photo is transferred by simply dragging it from one device to another. Removing the device breaks the connection [Wilson and Sarin 2007].

Fig. 13. User interface of a calendar application that spills out of a mobile device onto BlueTable [Wilson and Sarin 2007].

5.3.4 Body

A smaller percentage of papers (15%) describe systems that enable interaction through the user body, not only the whole body but even just a part of it, like arms or facial expressions. Since the number of papers is small, we indicate *body* as the only category. However, there are already various body interaction modalities (see also [Müller et al. 2010]) and they are a clear indication of how human-computer interaction is changing, so we describe them in more details.

Body presence. Different types of sensors (e.g. cameras, microphones, Bluetooth and RFID scanners, pressure sensors, Microsoft Kinect, etc.) are used to detect body presence in the proximity of a display, so that the system reacts to user presence by activating an implicit interaction. One of the first examples of presence sensing is provided by *GossipWall* [Streitz 2003]: the users' presence in the proximity of the display is identified because users carry RFID-based *ViewPorts*, which triggers the visualization of information on the display. In [Reitberger et al. 2009], a 3D virtual mannequin is described, located in an interactive shop window, that reacts to the presence of a person by changing its body posture and looking at the person (Fig. 14). The goal is to capture the attention of potential customers and increase the time they spend in front of the shop window.

Fig. 14. Interactive mannequins in a shop window [Reitberger et al. 2009].

Body position. Cameras available in the environment or pressure sensors installed in the floor are often used to detect the exact position of a user with respect to the display; this information provides hints to adapt the displayed content to the user. An example is *EDs Urban Carpet,* which uses a grid of LEDs embedded in a carpet to make it interactive; the carpet can be located in an urban context [Briones et al. 2007]. When users walk on the carpet, different patterns of lights are generated depending on the users' movements on the carpet. A recent paper describes a prototype of a very long display located along a corridor and a model of the perception area in front of the display, so that the system, thanks to cameras available in the environment, is capable of sensing human position and predicting from where that person can read the content on the display. Starting from this model, a technique called *Screenfinity* has been implemented to automatically rotate, move and zoom content, so that it actually follows people while they are walking in front of the displays, making it possible for them to comfortably read it [Schmidt et al. 2013]. One of the uses of this system could be to show advertisements and commercials to people while they are walking along a path e.g. in an airport, a metro station, etc.

Body posture. More recent interaction modalities exploit users' body orientation and movements, thus the system may assess how a user approaches a display, whether he/she faces it or simply passes by and also interprets his/her postures. Müller et al. [2012] described a study on an interactive shop window aimed at comparing different visual feedbacks that communicate shop window interactivity to passers-by. In particular, the shop window grabs the user attention by reproducing an image of the user in front of it. The study compared 4 different user representations: mirror image (interactive colored image of the user on a black background), silhouette (a white-filled silhouette of the user), avatar (a 2D avatar including head, torso, and hands) and abstract representation (just the head of the user, with abstract eyes and mouth). The field study showed that mirror and silhouette representations are equally effective in attracting people and both more effective than the avatar and the abstract representations. Other systems enable people to interact with advertisements on a large display through body and touch gestures (e.g. see [Fukasawa et al. 2006]).

Hand gestures. They refer to familiar and conventional *hand* movements used to perform some tasks. Several gesture classifications are proposed in the literature of interactive displays. For example, Bellucci et al [2013] distinguish: a) *surface gestures*, which imply touching the display surface; b) *remote gestures*, performed by the user without any contact with the display; c) *motion gestures*, performed while the user is carrying a device, e.g. holding a mobile phone or wearing an ad-hoc device. Systems exploiting surface gestures and motion gestures have been classified in the *Touch* and *Remote Device* categories, respectively (see Table I). Thus, in hand gestures we classified systems whose interaction modality is through remote gestures. They are also called mid-air or simply air gestures.

Facial expression. Software and hardware components are available today to recognize facial expressions. The *eMir* is a display that shows the face of a human character. A camera installed on top of the display observes and classifies facial expressions of the passer-by and detects whether someone watches the display, to allow the system to react to the audience's emotion. This information is used to let a human character on the screen react accordingly and encourage interaction with the face [Exeler et al. 2009].

Gaze. Sophisticated technologies, such as eye-tracking, permit the precise detection of users' gaze paths. This information may be used in various ways for user-display interaction. Already in 1999, Zhai et al. proposed an approach called *MAGIC* (Manual And Gaze Input Cascaded) *pointing*, since it exploits the user's gaze for fine manipulation of widgets on the display [Zhai et al. 1999]. This work considers that overloading the vision perceptual channel with a motor control task is unnatural. Thus, gaze is used to set the cursor position on a target, i.e. on what the user is looking at. Once the cursor position is set, the user has only to make small movements to the target with a usual manual input device and click on it. This approach reduces the cursor movement to select targets. *ReflectiveSigns* uses gaze detection to learn which content the user is looking at, in order to display the next contents according to his/her preferences [Müller et al. 2009].

5.3.5 Temporal trend of interaction modalities

The temporal trend of interaction modalities is shown in Fig. 15. Touch-based interaction is the oldest and still most used modality. However, thanks to advanced sensor technology, several other modalities have been proposed more recently and the interest in recognizing user's body positions, postures, movements, etc. keeps increasing to meet the desire of a more intuitive but still effective interaction.

The studies reported in the literature show that interaction modalities based on touch, remote devices and tangible objects are all capable of fostering people collaboration. Instead, collaboration based on body interaction is not yet properly investigated.

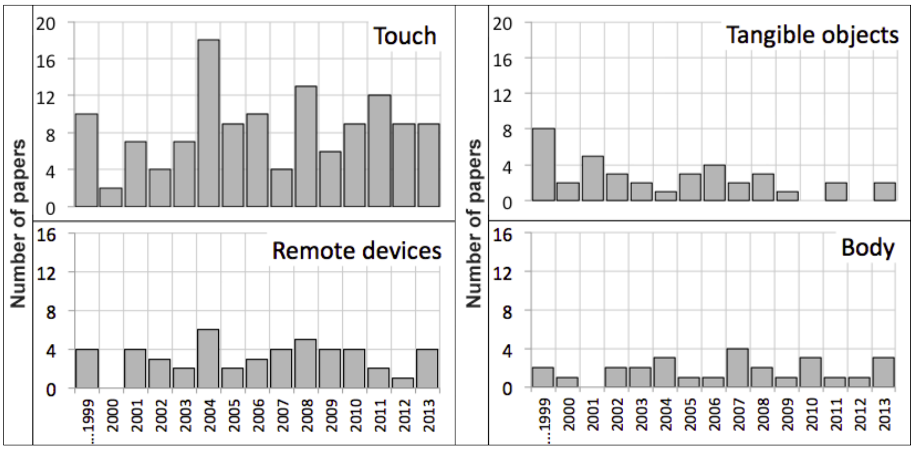


Fig. 15. Distribution over the years of the surveyed papers according to the *interaction modality* dimension.

5.4 Type of application

Type of application refers to a classification based on the main purpose of the application(s) described in the surveyed papers. The first applications developed for large interactive displays were quite simple because researchers focused on technological aspects, as well as on defining new interaction modalities. With the consolidation of technology, researchers implemented applications of increasing complexity and for different purposes, as reported in the following.

5.4.1 Useful tasks

44% of the papers refer to applications that, besides being attractive and engaging, have a specific utility for their users, i.e. support them in performing tasks that go beyond mere entertainment. Examples of such tasks are: browsing pages and manipulating content in a particular browser [Johanson et al. 2001], mixing and manipulating multiple video streams in real-time with multi-touch gestures [Hawkey et al. 2005], creating and mixing music tracks [Taylor et al. 2009] and searching for information about cultural heritage and defining touristic itineraries [Ardito et al. 2010]. Many of such tasks can be successfully performed in collaboration, e.g. defining a touristic itinerary, since often people travel in group.

5.4.2 Entertainment

A considerable number of papers (42%) describe applications designed to entertain people and let them enjoy themselves. Such applications permit simple tasks like browsing the pages of a newspaper [Denoue et al. 2003], recording personal messages on an interactive bulletin board installed in a café [Churchill and Nelson 2007] and walking on an interactive floor that shows glow shapes when people walk on it [Briones et al. 2007]. In several cases, entertaining applications are designed to be performed in collaboration with other people.

5.4.3 Social interaction

25% of the papers report applications that, by allowing multi-user interaction, trigger social interaction and the creation of virtual communities through the use of the display. One of the most recent examples is in [Hosio et al. 2012]: the system enables young people to give personalized feedback on municipal issues to local workers; it also facilitates discussion through modern social networking services. Another example is the already mentioned *iFloor* [Krogh et al. 2004] (see Section 5.2.4). Morris et al. discuss motivating scenarios for the use of cooperative gesturing and describe some initial experiences with *CollabDraw*, a system for collaborative art and photo manipulation [Morris et al. 2006]. Another system allows people to post information on a public display, to acquire information from it, and to modify and annotate previously posted contents, in order to create publicly observable threads [Carter et al. 2004]. For example, by using a personal mobile device, a user may post a photo and later other people may annotate it with their own comments.

5.4.4 Game

Games are often for mere entertainment and fun, but sometimes for other purposes, such as learning and/or training. In this category, we include papers (15%) that describe game-based applications; however, educational games are classified in the learning category. *Polar Defense* is a game for shared entertainment, inviting a large audience to play in a public space [Finke et al. 2008]. Users send SMSs using their own cell phones to indicate the coordinates where to play six towers on a virtual field visualized on the display: the towers defend the field by firing bullets against the enemies. The Poker game was implemented on a multi-touch tabletop: each player holds a mobile phone displaying his/her own cards, while other cards and coins are on the tabletop and each player can interact with them [Shirazi et al. 2009]. An implementation of Sudoku, available through a multi-touch display, is presented in [Echtler et al. 2009]; of course, more people can play together.

5.4.5 Advertisement

Large displays have been installed in several contexts, in order to make advertisements. However, in most cases such displays are not interactive. A few papers (7%) describe systems whose display is interactive. One of the most appealing examples is the interactive mannequin already described in Section 5.3.4 [Reitberger et al. 2009]. Authors carried out a three-day field study to assess the persuasive effect of this solution. The results gave useful insights to make the system more engaging.

5.4.6 Learning

Some papers (4%) describe applications, which have an explicit learning purpose. The example reported in [Hornecker 2008] refers to the *Tree of Life* tabletop display, which supports learning during a visit to the Berlin Museum of Natural History by asking visitors to answer questions about the museum contents. We also included in this category educational games, for example, *Futura*, a simulation game for tabletop that allows different young people to work with the other players to support a growing population over the years [Antle et al. 2011]. Players have to learn how to meet the needs of an ever-increasing population in the game world without compromising the environment, since they are responsible for providing people with food, shelter and energy. The aim of the game is to help players to improve their understanding of the importance and difficulty of achieving sustainable development through active participation in a simulated land use activity.

5.4.7 Temporal trend of type of application

Fig. 16 shows the distribution over the years of the surveyed papers according to the *type of application*. In recent years, the number of both game-based and learning applications has increased. Indeed, games are complex applications and they require mature technology.

As we have seen in the reported analysis, most applications of different types either require or encourage collaboration of people, who even do not know each other; the results of studies observing this aspect confirm that collaboration is actually successful.

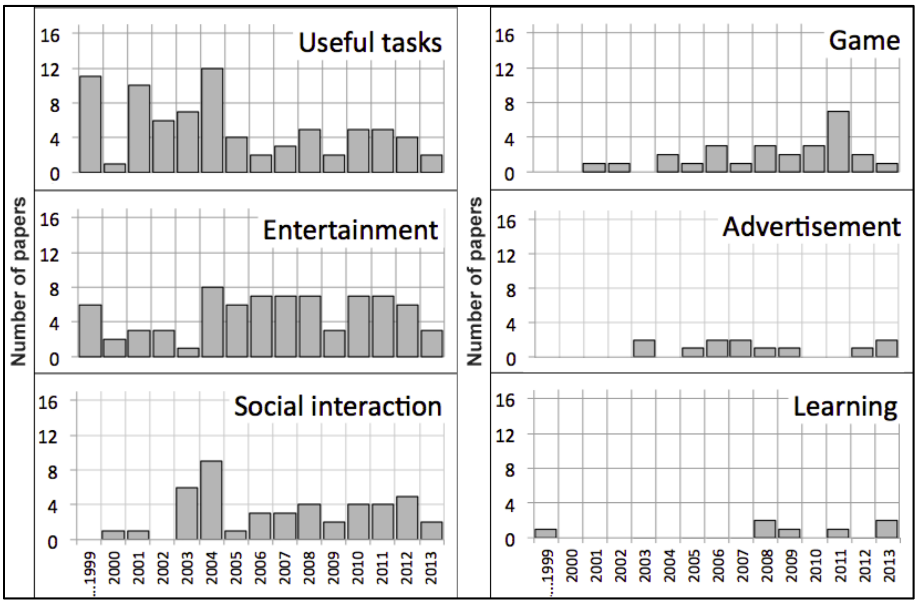


Fig. 16. Distribution over the years of the surveyed papers according to the *type of application* dimension.

5.5 Location

Location refers to the place where a large display is installed. It affects the behavior of people in the environment around the display, depending very much on whether the location is public (a city street) and thus accessible to unknown people, or semi-public (an office), where most people know each other and could thus be less inhibited to work together. Large interactive displays modify the traditional person-system interaction paradigm, not only because different people may interact at the same time, but also because the display may attract the attention of other people who are standing nearby. There are different zones of interest around a large display (see for example [Streitz 2003; Vogel and Balakrishnan 2004]). The model of the physical space around the display described in [Ott and Koch 2012] considers four zones (see Fig. 17): 1) the Active Zone, immediately in front of the display, where people interact with the system; 2) the Communication Zone, in which users actively monitor other people and might talk to them while they are interacting with the system; 3) the Notification Zone, where people are not directly involved in the interaction, but their attention is attracted by the users interacting with the display and/or by what is visualized; 4) Ambient Zone, where users start to be aware of the interactivity of the display.

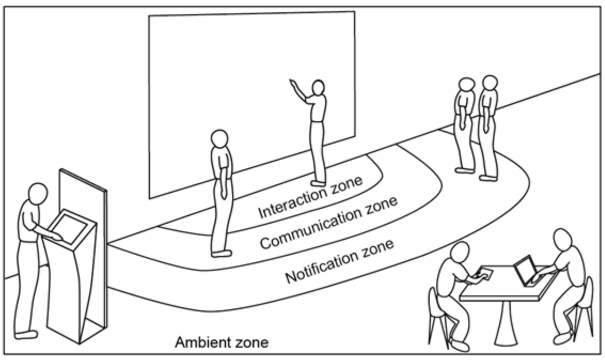


Fig. 17. Different zones in the large display social surrounding, adapted from [Ott and Koch 2012].

From the analysis of the surveyed papers, the following locations are identified: *office, city* (referring to streets and other urban locations)*, shop*, *university/school*, *conference*, *cultural site*, *third plac*e. Moreover, 32% of the papers describe prototypes that were tested only in laboratories and did not explain the possible location in a real situation (see, for example, [Rogers et al. 2006]). This category has been labeled *Unspecified* in Table I.

5.5.1 Office

This location is indicated in 26% of the papers. In most cases office is a semi-public environment [Huang and Mynatt 2003; Peltonen et al. 2008]. In an office, a large display can be installed in different workplace contexts. For example, in [McCarthy et al. 2001], three contexts are considered: i) within an individual office, where the display is used by the person in that office (the office "owner"); ii) immediately outside the office, in order to display information that the owner intends to show to others, e.g., project information, favorite URLs, etc.); iii) in a common area, in order to provide interaction opportunities to people passing in front of the display. The aim of the display in the common area, rather than supporting the performance of primary work activities, as in [Streitz et al. 1999], is to create greater awareness among people that gather together in the same physical space; the displayed information should encourage them to initiate a conversation with someone, leading to an increasing sense of community.

An interesting system located in an office, which provides the means to let more people to collaborate, is the one using *uPen* as an interaction device [Bi et al. 2006], already described in Section 5.3.2. *Don't Touch Me* supports the operators of a crisis management unit, who can collaboratively coordinate the activities of the forces in the field by analyzing geo-referenced information displayed through a large interactive display [Bellucci et al. 2010]. Each operator interacts with the display by hand gestures performed with a personal Wiimote device held in one hand. The Wiimote also permits to distinguish the actions performed by different users.

5.5.2 City

This category refers to displays installed in urban locations like streets, squares or other specific points of a city, depending on the type of application that, in several cases, is implemented to satisfy the needs of citizens and/or tourists. This category includes 15% of the surveyed papers. One of the earlier examples is in [Grasso et al. 2000], where the display, called *CommunityWall,* is the back-rest of a bench, where users can write their own messages with a pen or manipulate virtual objects by hand touch.

We already discussed in Section 3 the CityWall system installed in the center of Helsinki [Peltonen et al. 2007]. Still in Finland, at Oulu, several studies have been carried out to analyze the impact of a network of 12 multi-touch displays (six indoor and six outdoor), available in the city streets and squares to allow citizens and tourists to get information, socialize with other people and play games [Hosio et al. 2010; Ojala et al. 2010; Valkama and Ojala 2011]. Such studies provided interesting results about the importance of the location: it emerged that displays, in places like swimming baths, are more used than those in 'business-like' locations, like municipal halls. The reason is that users prefer to interact when they are in a relaxed mood with some spare time. Another interesting finding regards the type of application: fun applications and games were the most used, because the most frequent users were children and adolescents, who appeared much less inhibited than the adults when trying out the hotspots.

5.5.3 University/school

A significant amount of surveyed papers reports that large public displays have been situated in universities or in schools (10%), in halls, corridors, etc. Researchers are facilitated in accessing real users in a safe, public location (displays in a city could suffer vandalism acts), which offers a controlled context for conducting studies. For example, *BlueInfo* was installed and evaluated at a bus stop on a university campus and later in a city; its interactive display delivers information to users' mobile devices through Bluetooth [Kukka et al. 2011]. *History-Puzzle*, the system proposing the educational game described in Section 3, was installed in a middle school laboratory [Ardito et al. 2013]. *USIAlumni Faces* is a vertical display used during a university alumni event, organized to reconnect old friends and colleagues [Rubegni et al. 2011]. It visualizes a virtual yearbook (i.e. photos of the alumni organized according to year and faculty), whose pages can be browsed by means of a 'page flip' gesture performed using a custom-built input device (i.e. a Wii remote control and an infrared pen hidden inside a toy torch casing). This interactive installation acted as an 'ice breaker' and stimulated people to interact in groups. Moreover, researchers observed a spontaneous way of propagating gesture patterns, i.e. users learn/understand how to interact through an observe-and-learn model.

5.5.4 Cultural site

This category refers to displays installed in locations of cultural interest, like museums, cultural heritage sites, art galleries and aquariums. Here we classified 6% of the papers, revealing the interest in interactive displays in such contexts. *EMDialog* is a diagonal interactive display installed at the Glenbow Museum in Calgary during the Emily Carr (a Canadian artist) exhibition with the goal to both inform and provoke discussions [Hinrichs et al. 2008]. Visitors were observed over fifteen days to study how they approached and interacted with the system. A close connection between the age of visitors and their motivation to interact with EMDialog was found: children were very keen on touching the interactive display, while adults were hesitant and careful in approaching it. From the returned questionnaires, it emerged that the characteristics of EMDialog that motivated people to approach the system were: display technology, appealing visualizations and seeing other people interacting with it (the "honey pot" effect in [Brignull and Rogers 2003]).

An example of a system for artistic purposes is *Doodle Space*, a front-projected display that allows different users to collaboratively paint 3D curves on a projected wall using personal camera phones [Zhong et al. 2009]. People could not only doodle, but also manipulate their doodles by dragging, rotation and zoom gestures. The participants in a laboratory study reported that the interaction techniques implemented by Doodle Space made the painting intuitive, convenient and enjoyable. *Collection Viewer* is a system installed at the Vancouver Aquarium to provide information about the Arctic environment on a tabletop display [Hinrichs and Carpendale 2011]. A field study involving 20 children and 20 adults focused on the gestures used for interacting with the system. It revealed that the choice of gestures was influenced by social factors, such as the number of visitors around the display and social relationships among them. Age also had an influence: differences were observed between the interaction of adults and children with the digital table.

5.5.5 Conference

Another public location for large displays is a conference venue. In fact, 4% of surveyed papers have been classified in this category. An example is *MobiToss*, a system installed at a social event of an international conference [Scheible et al. 2008]. It allowed users to create and share multimedia contents, interacting with the system through a mobile phone, equipped with built-in accelerometer sensors, allowing gesture control. People took photos or captured videos using the phone and, using a 'throwing' gesture, transferred them onto the large public display, where they could be manipulated by tilting the phone in different directions. The evaluation study revealed that MobiToss worked reasonably well in terms of engaging users and stimulating their creativity. The users also declared that they would have liked the possibility of manipulating photos and videos together with other people. A system using a 46 inch wide LCD multi-touch display was installed during a four-day international conference in the transit zone from the conference hall to the foyer where coffee breaks were held, so that people could comfortably interact with it while they were not busy in the conference sessions [Ardito et al. 2012]. Three applications offered different services to conference participants: 1) *Taxi Sharing* to book a taxi/shuttle or share it with other people; 2) *Conference Photos* to visualize photos of the conference available in FlickR; 3) *Interactive Program to interact* with the conference program to gather various information about the sessions and the presented papers. An observational study was performed during the four days, revealing that these applications were very much appreciated by the conference participants. Even if the limited display size did not allow simultaneous interaction of a large group of people, the study showed that social interaction was very much fostered, i.e. people often discussed their interaction experience with others standing by them or passing nearby.

5.5.6 Shop

In 4% of the papers, shops are often chosen to assess the impact of large interactive displays in commercial contexts, e.g. to evaluate the benefits on merchandising, advertisement and communication among a community of people. In one of the first examples, the prototype was actually installed in a laboratory replicating a shop, to analyze the deliver of different kinds of information [Sukaviriya et al. 2003]. The prototype used steerable projectors to create an interactive shelf and sensors to recognize gestures and users' positions. *Nnub* is a noticeboard consisting of a 40 inch wide multi-touch LCD panel, which was installed in a general store [Redhead and Brereton 2009]; it aimed at creating a digital-community, collecting and displaying local information and communications provided by people living nearby the store. An innovative installation is the one using a mannequin in a shop window [Reitberger et al. 2009], as described in Section 5.3.4.

5.5.7 Third place

Third place refers to a location where citizens gather together to socialize and spend time [Oldenburg 1989]. Typical examples are cafes and pubs. eyeCanvas is a system implementing an interactive bulletin board on a large vertical display installed in a cafe [Churchill et al. 2006]. This system was running over a year and showed interactive contents related to the cafe, including menus, nightly events and artists' work, also giving users the possibility to write comments or to sign up for the cafe newsletter. Another example is *Jukola*, an interactive display used like a juke-box [O'Hara et al. 2004]: it is an interactive MP3 Jukebox device, designed to allow a group of people in a public space to democratically choose the music being played, to nominate songs which are subsequently voted on by people in the bar using networked handheld devices.

5.5.8 Temporal trend of location

Fig. 18 shows the distribution over the years of the surveyed papers according to *location.* In the first years, installation in offices prevailed, possibly because they offered a more controlled environment. In more recent years, systems are increasingly installed in cities, universities, schools and sites of cultural interests. By *unspecified*, we refer to papers that describe lab prototypes, without specifying the real life location in which they could be installed.

It appears that the location has not a direct influence on people collaboration, which depends much more on the type of application implemented in the system. If the display is installed in a location where people do not know each other, it is observed an initial time span in which people are a bit reluctant to approach the display [Brignull and Rogers 2003]. However, once they start interacting, in most cases they soon socialize and collaborate with other, if required.

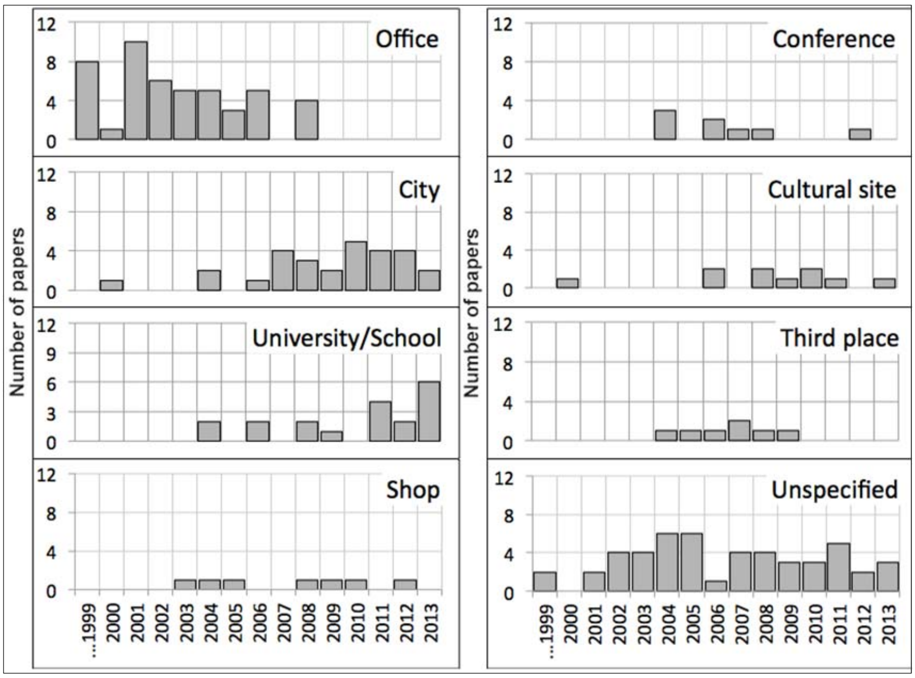


Fig. 18. Distribution over the years of the surveyed papers according to the *location* dimension.

6. FUTURE CHALLENGES

Large interactive displays are considered among the most promising technologies that will become ubiquitous over the next 20 years [Schmidt et al. 2012]. Since such devices can augment everyday pieces of furniture, such as tables or panels, they can be used in public spaces, indoor as well as outdoor, where many people may be exposed to them. The design of new installations poses many challenges; some significant ones are addressed in the following. They reveal potential areas for future research in the field.

6.1.1 *Blended interaction in ubiquitous environments*

The design and placement of large displays have to be conceived according to user tasks and context, the latter including the physical space augmented by heterogeneous networked devices. There are already several examples of systems designed to blend the power of digital computing with work practices and collaboration styles. These systems are usually set in the typical pervasive scenario of supporting collaborative human work in a meeting room, as in the case of *Augmented Surfaces*, one of the first ubiquitous systems for exchanging information among laptop computers, tabletops, wall-projected displays and physical objects [Rekimoto and Saitoh 1999]. Still in 1999, the *i-LAND* project provided a vision of offices of the future by describing an environment to support the cooperative work of dynamic teams with changing needs, which included an interactive wall, an interactive table and computer-enhanced chairs, on which data and applications could easily migrate [Streitz et al. 1999]. More recently, Wigdor et al. [2009] presented *WeSpace*, a ubiquitous system which integrates a tabletop display, a large vertical display and users' laptops to support collaborative scientific discussions. Public displays are sometimes used in large-scale pervasive games like *Manhattan Story Mashup* [Tuulos et al. 2007], which combines the Web, cell phones and a large display installed in Time Square.

As pointed out by Oulasvirta [2008], the device ecologies in which large interactive displays are integrated are characterized by an infrastructure which is not homogenous or seamless. A potential problem is that users might feel frustrated by the wide variety of interactive options offered by cross-device and multi-user interfaces. The goal is to achieve an ideally natural and unobtrusive computational support during collaborative activities, by designing significant scenarios in which interactive systems are powerfully blended with the real context and the work activities carried out. Recent proposals go in this direction. Specifically, in order to support designers of ubiquitous computing environments, Jetter et al. [2013] have presented the *Blended Interaction* conceptual framework, which aims at supporting designers in creating spaces that tie together users' familiar concepts with the power of digital computing. In his Ph.D. thesis, Bellucci proposes another conceptual framework and its software implementation, which facilitates the rapid prototyping of ubiquitous systems by allowing designers to abstract from the specific hardware [Bellucci 2013].

6.1.2 Privacy

Privacy problems in the information society are a major concern. Managing how to display information, which contains both public and private components in shared information spaces, is fundamental for the success of interactive public display installations. Some solutions used passwords to preserve user's privacy during the input of confidential data. In the early approaches, the password was provided through a personal device, such as a mobile phone or a tablet (e.g. see [Magerkurth and Tandler 2002]). More recently, techniques have been introduced that permit password input based on the combination of gestures and typing on a virtual keyboard [Kim et al. 2010].

In some situations, e.g. defining an itinerary or booking a hotel through a tourism application, some people do not like to have strangers looking at their preferences, cultural interests, accommodation possibilities, etc. To avoid this, an approach consists in distinguishing between private and shared contents. In *Ubitable*, the distinction is physically implemented, since the private data is visualized on a personal device (e.g. a tablet or a laptop) and possibly shared with others by transferring them onto a tabletop device [Shen et al. 2003]. The *Permulin* solution is very promising when there are two users interacting on the opposite sides of a tabletop display [Lissermann et al. 2013], because it permits the coexistence of visible output and simultaneous input, which is partly shared and partly private. By wearing active shutter glasses, each user can see her/his private view, while the shared view is visible to everybody. The *Permulin* approach can be adopted not only to preserve privacy, but also to support collaborative tasks, because it allows users to collaborate in the manipulation of the shared information, possibly augmented by the private visualization. Chan et al. [2008] suggested the adoption of a virtual panel, visualized in front of each user around a tabletop display, which reproduces the optical properties of a convex lens to avoid the others looking at the displayed private information. The virtual panel was used for both visualizing and inputting private data. It could also be a way to support collaborative tasks, even if the authors did not consider this possibility in their paper.

6.1.3 Accessibility

Making interactive public displays accessible to disabled people is an issue that has been sparsely investigated. The technology most commonly used in current installations is not able to provide a tactile feedback when touching the display, and this causes interaction errors even with not impaired users, as demonstrated in [Hoggan et al. 2008; Koskinen et al. 2008; Lee and Zhai 2009]. A tactile feedback is useful, for example, to give the feel of a button on the keyboard, which could represent a first rough interaction help for visually impaired users. Harrison and Hudson [2009] proposed a visual display that contains deformable areas, able to produce physical buttons and other interface elements. Another hardware-based proposal for interfaces that allow the user to feel virtual elements through touch is *TeslaTouch* [Bau et al. 2010], a technology that provides a wide range of tactile feedback sensations to fingers moving across a touch surface, by means of electro-vibrations. Hardware-based approaches are successful, but present problems related to cost, scalability, and support for multi-user interaction. In the literature, some software-based approaches are reported; for example, *Slide Rule* is a set of audio-based multi-touch interaction techniques that enable blind users to access touch screen applications [Kane et al. 2008]. *Access overlays* presents three software-based techniques that enable blind people to explore and interact with applications on tabletops [Kane et al. 2011].

Undoubtedly, accessibility is a challenging aspect of designing both the hardware and the software of public displays, because each kind of disability requires a different solution. Most research is focused on supporting visually impaired users, but other disabilities should be considered. For instance, people in a wheelchair cannot interact with vertical displays, thus interaction modalities based on remote devices or gaze control should also be available.

6.1.4 Gesture interaction

In [Kurtenbach and Hulteen 1990], a gesture is defined as a motion of the body that contains information. The goal of many HCI researchers is to enable more natural and intuitive communication between people and devices, more closely resembling human-human communication. Gestures appear intuitive and powerful, as they take advantage of features such as naturalness, adaptability and dexterity. Interacting by gestures, users do not think in terms of manipulating an input device, but move parts of their body to execute the task. However, enabling people to use gestures typical of their everyday life does not necessarily results in an optimal interaction modality; this was also pointed out by Norman [2010], who critiques the naturalness of gestural interfaces in terms of their claimed intuitiveness, usability, learnability and ergonomics. Several other issues have to be addressed to achieve successful gesture interaction. In particular, no single method for automatic gesture recognition is suitable for every application. Gesture recognition algorithms depend on application domain, user cultural background and specific context [Wachs et al. 2011]. For displays in a public space, it is also an issue to communicate to users which is an initial gesture to start interacting. This is investigated in a recent paper that describes *StrikeAPose*, an interactive public display that allows users to play a game using air-gestures [Walter et al. 2013]. The authors explored three different approaches to reveal the initial gesture: 1) *spatial division* that permanently shows the gesture on a dedicated screen area; 2) *temporal division* that interrupts the running application to show the gesture; 3) *integration* that embeds gesture hints directly in the application. They found that a large percentage of users prefer spatial division (56%). They also observed that users intuitively discover a gesture vocabulary by exploring variations of the initial gesture by themselves, as well as by imitating and extending other users' variations.

Hand gestures have been studied since longer time. Many designers and researchers focus on creating and evaluating natural gesture sets for multi-touch interaction and on improving the visual feedback and learnability of hand gestures (see for example [Freeman et al. 2009; Nacenta et al. 2013]). Sets of *symbolic gestures* are primarily proposed. To each symbolic gesture is associated a semantic, through which user communicates a command to the system. For example, gestures for "accept" or "reject" are performed by drawing with a finger respectively a check ('✔') or a cross-out ('✕') symbol. It is worth remarking that the need for users to learn the gesture language is a real issue, especially because the interaction with public displays is often occasional: gestural interfaces are not self-revealing, forcing the user to know beforehand the set of allowed gestures. Some authors actually remark that a gesture issues a command, as it happened in command line interfaces, thus gestures are a step backward into the era of learning a command language [Jetter et al. 2010]. Designers should also consider the dependence of gestures on the cultural and social environment in which the interactive display will be installed. Indeed, for applications in a specialized context, where tasks are performed frequently, it is worth the investment of learning a particular set of gestures; instead, in everyday life, users will not be interested in a device that requires them to learn specific gestures. Some authors suggested that interaction based on symbolic gestures may gain more acceptance if users are allowed to expand or create their own sets of gestures (e.g. [Lü and Li 2012; Oh and Findlater 2013; Wobbrock et al. 2009]). Symbolic gestures can be useful for supporting the collaboration of a co-located groupware: such cooperative gestures can add value to applications by increasing participation, drawing attention to important commands and enhancing social aspects of an interactive experience [Morris et al. 2006].

Jetter et al. [2010] distinguish *manipulations* from symbolic gestures and question the naturalness and the cognitive aspects of the latter. They say that "*symbolic gestures* are close to the keyboard shortcuts of WIMP systems. They are not continuous but they are executed by the user at a certain point of time to trigger an automated system procedure". Instead, "manipulations are continuous between manipulation initiation (e.g. user fingers down) and completion (e.g. user fingers up). During this time span, user actions lead to smooth continuous changes of the system state with immediate output. Typical examples of manipulations are the dragging, resizing and rotating of images". In their view, manipulations are more natural than symbolic gestures, since the former are closer to direct manipulation, the latter are indirect and require learning an artificial sign language to interact with the system.

Summarizing, for natural user interfaces it is not enough to create and evaluate natural gesture sets. We agree with [Jetter et al. 2010] that gestural input requires fundamental changes to the structure and visualization of content and functionality, thus appropriate visual metaphors and consistent conceptual models in which users can act naturally should be proposed.

6.1.5 Evaluation

Interaction with large displays in public spaces presents specific challenges related to the social dynamics elicited by the co-presence of different users. The first studies explored the use of such displays in controlled settings, like laboratories or offices. In the last few years, field studies have become the most popular, investigating spontaneous social dynamics that are difficult to assess in laboratories, i.e. how people approach the display, what their overall behavior is, if and how they socialize and possibly collaborate. Indeed, the actual impact on users can be evaluated only in the field, because environmental factors, e.g. the physical space where the display is located, as well as other specific factors like display size, orientation and supported applications, influence people's interaction with such systems [Marshall et al. 2011; Ojala et al. 2010]. It is also difficult to simulate the environment in which the display is located, because behavioral models are still lacking.

A work to provide guidelines for evaluating public displays is presented in [Alt et al. 2012]. Its main motivation is that there are many different objectives when evaluating public displays and to pick up the most suitable evaluation method becomes a challenging task. The work is based on the analysis of many papers concerned with the evaluation of public displays. Actually, the authors ended up with very general guidelines, rather than indications for specific guidance. They indicated five types of methods, two more appropriate for informing the design of a prototype, namely methods based on ethnography and those asking questions to users (interviews, questionnaires, focus groups), and three for evaluating a prototype, namely lab studies, field studies and deployment-based research. The latter refers to a kind of action research, which consists of introducing a public display in the envisioned location for a certain time, during which users are observed and the findings are discussed with them, in order to involve users in an iterative process to improve the deployment. The most popular research questions to be answered during an evaluation study were also identified and summarized with the following terms: Audience Behavior, User Experience, User Acceptance, User Performance, Display Effectiveness, Privacy, Social Impact.

We suggest going toward some more systematic frameworks to guide the evaluation of large display systems, taking into account all their peculiar aspects. The paper by Ardito et al. [2012] provides some insights into an evaluation framework, whose aim is both to highlight factors of interest at the design time and to organize a systematic approach to the evaluation of large display installations in public settings. The framework indicates three types of factors that mainly influence the overall behavior of users:

- *Environmental* factors: they consider the physical location where the display is installed (e.g. city street, museum hall, fair or train station) and include how the display is positioned in the environment (e.g., whether it is in a visible location, in a crowded place, etc.).
- *Hardware* factors: they directly address the type of technology adopted, and its configuration. Among important variables there are screen size and orientation (e.g., tabletop and wall display).
- *Software* factors: they include interface features as well as other software features, like software functionality and performance.

The framework specifies a number of behavioral and psychological variables, which are influenced by these factors and should therefore be addressed to analyze and understand the behavior of users with interactive displays. Each variable can actually be influenced by more than one primary factor. For example, a variable influenced by all three factors is *motivation to initiate interaction*, i.e., how people are motivated to interact and how they approach the display. A variable influenced primarily by software and hardware factors is *screen sharing*, i.e., how people share portions of screen and physical space during the interaction. This evaluation framework was used to guide the design of a field study to analyze users' behavior and their experience with a large display installed at an international conference. Analysis of the results provided support to the evaluation framework, it confirmed the influence of environmental factors on the user behavior with the display and further stressed the need to take into account psychological variables elicited by the physical context. Frameworks like this one might indeed be useful for researchers when designing studies to evaluate public displays. However, a number of experiments should be performed to assess the actual validity of such frameworks in giving proper guidance.

7. CONCLUSION

This article has provided an overview of the use of large interactive displays installed in public or semi-public spaces. Such displays emerge as media to create new spaces for interactive experiences, enabling new forms of engagement with digital content. The analysis has shown that they provide interaction possibilities that go beyond the traditional desktop, which was based on the use of mouse and keyboard and limited the dialogue to a user and his/her own computer. Large displays allow more people to interact at the same time, fostering socialization and collaboration. Moreover, various interaction modalities are emerging, in particular those based on movements of different parts of the human body, not only hand gestures, but also movements of head, arms, legs and feet.

All new technologies have great potential for more creative uses of computing than ever before; large interactive displays play a major role on this, as shown in this article. They can provide creative workspaces that stimulate the collaboration of groups of individuals, supporting them to share their ideas to reach a common goal. They can be used to visualize and reason about complex problems and information in new ways. More importantly, they are able to captivate the interest of people, enabling new forms of creative engagement in several contexts.

We see the value of a large display not only as a single device, rather as part of an ecology of different devices in pervasive scenarios, realizing Marc Weiser's vision of Ubiquitous Computing, which stresses that the real power does not come from any single device, but it emerges from the interaction of all of them [Weiser 1991]. We have highlighted some significant challenges that have to be addressed, in order to fully exploit the potentialities offered by large interactive displays and to give people the possibility of a seamless interaction with real-world things and with other people.

APPENDIX A. LITERATURE SEARCH

In order to retrieve the most relevant articles discussing large interactive displays, a careful literature search was carried out. Positive and negative aspects of different academic search engines were considered. Eventually, the chosen search engines were: 1) the search engine of the *ACM Digital Library*[3]*;* 2) *Google Scholar*[4]. ACM Digital Library includes important scientific papers in computer science, i.e. those published by ACM. Google Scholar is considered one of the top search engines on the Web thanks to several factors. From our point of view, its main advantage is that it searches on the largest databases of scientific papers.

The keywords used to query the two search engines were *interactive public display*. We started by examining 400 papers, which were the first 200 results retrieved by each search engine. Indeed, with a first quick analysis we noticed that, after the first 150 articles, the results were no longer relevant. In any case, to make sure that we would not miss significant papers, we decided to examine the first 200 papers returned by each search engine. This search was performed in January 2013. We started with Google Scholar and, by reading title and abstract, we selected 114 relevant publications. Of the 200 publications retrieved by ACM search engine, we first removed those already considered by Google Scholar and we read title and abstract of the remaining ones to identify those of interest. As a result of this first screening, a total of 180 publications were selected. After reading the full papers, we reduced the selection to 94 papers. We then looked at the proceedings of very relevant conferences held after January 2013 (e.g. CHI 2013, INTERACT 2013) and at the last issues of journals that usually publish articles on large displays (e.g. IEEE Computer Graphics and Applications). Moreover, we complemented the automatic search performed through the search engines with a manual search based on the analysis of the references of the papers we read: if a referred paper appeared relevant, we retrieved it and read the abstract first and in most cases the full paper to decide if it would be in our selection. Our final set consisted of 181 papers. It is worth noticing that only those explicitly mentioned in this article are reported in the References.

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