

To **Frame** or Not to Frame: The Role and Design of Frameless Displays in Ubiquitous Applications

Claudio Pinhanez, Mark Podlaseck

IBM Research, T.J. Watson
19 Skyline Drive, Hawthorne, New York 10532, USA
pinhanez@us.ibm.com, podlasec@us.ibm.com

Abstract. A *frameless display* is a display with no perceptible boundaries; it appears to be embodied in the physical world. Frameless displays are created by projecting visual elements on a black background into a physical environment. By considering visual arts and design theory together with our own experience building about a dozen applications, we argue the importance of this technique in creating ubiquitous computer applications that are truly contextualized in the physical world. Nine different examples using frameless displays are described, providing the background for a systematization of frameless displays pros and cons, together with a basic set of usage guidelines. The paper also discusses the differences and constraints on user interaction with visual elements in a frameless display.

1 Introduction

Look again at the title of this paper. What is the impact of framing the first instance of the word “frame” in comparison with its second instance on the title? Does the first instance look detached from the page, as if in its own world? In comparison, the second instance looks completely integrated to the whole page. In fact, as detailed later, that is exactly what visual design theory teaches: a frame creates and indicates spatial disruptions.

This paper examines how the elimination of the frame in visual displays can contribute to the ultimate ubiquitous computing goal of making “[*computer systems*] weave themselves into the fabric of everyday life until they are indistinguishable from it.” (from [32], pg. 94). As an example, Figure 1 invites a simple comparison between a framed display (left) and a frameless display (right). The framed advertisement is less integrated in the environment than the character depicted in the frameless display.

Our main hypothesis is that frameless displays connect with the surrounding environment and objects better than framed displays, contextualizing the information presented in them. Of course, frameless displays should be mostly used when this connection or contextualization is needed and avoided otherwise. Given that many ubiquitous applications aim to be contextualized to the user’s environment, frameless displays have the potential to become an important interface technique and therefore should be understood more thoroughly.



Figure 1. A framed (left) and a frameless (right) projected display.

Frameless displays can be easily created through projection systems by simply projecting visual elements surrounded by black pixels, as shown in Figure 2. If the projection system is bright compared to the ambient light (at least 10 times brighter [10]) and has enough contrast to maintain the darkness in the projected black (in the case of LCD projectors), human eyes tend to not perceive the black background of the projected image. Similarly, a head-mounted display, connected to a wearable computer can use the same technique to create personal frameless displays.

There has been a long history of use of frameless displays in the art community (for example [1, 14] and, more recently, in ubiquitous applications [11, 24, 26, 29, 35], among many. A major contribution of this paper is to analyze these applications and our own experience designing and building about a dozen frameless display-based systems and extract rules about when and how to use them.

A more recent trend, however, is to create frameless displays that allow user interaction directly with the visual elements of the display [3, 12, 18, 21, 23, 27, 28, 30, 33]. A typical example is the *Jumping Frog* game-like application we built, where the image of an animated frog is projected on random objects in an environment. Whenever a player tries to catch the frog, the frog jumps to another surface (see Figure 2). As in real life, it is not possible to see the frog during the jump but only when departing from or landing on a surface.

Observations and results of previous studies [22] report that interaction with frameless displays involves different constraints than that with traditional displays. We discuss the possible implications of the studies showing that the interaction with a frameless projected display and its recollection is affected by object(s) in the vicinity of where the interactive element is placed. The impact of this and other issues, and the lessons learned in our own experience with frameless displays are discussed in terms of applicability and guidelines for interactive frameless displays.



Figure 2. (left) Image of a frog (part of an animation sequence) with black background. (right) *Jumping Frog*, a game-like application where participants chase an animated-projected frog that jumps to multiple surfaces in an environment. The black pixels of the image of the left disappear when the image is projected on a normally lit environment.

2 The Use of Frames in Visual Arts and Design

In visual art, *frame* has a number of closely related meanings. In its most general sense, the frame (sometimes called the *visual frame*) refers to the rectangular boundary that separates an image from its surroundings (as defined in [6], pg 11). Visual artists use this frame to orient the viewer's perspective relative to the subject being depicted. In this regard, the visual frame provides a metaphorical window into another world which is disconnected from the viewer in space and/or time.

Over a century ago, visual artists began minimizing the window effect of the visual frame. Paul Cezanne, Pablo Picasso, Piet Mondrian, Kasimir Malevich, and Marcel Duchamp used a number of techniques, such as demolishing the illusion of perspective, to establish that their paintings were not windows into other spaces; rather they were objects that *occupied the same space as the viewer* [19]. Robert Rauschenberg and Jasper Johns further reinforced the physical presence of their paintings by integrating physical objects into the canvas, thereby breaking the visual frame (as in "*Watchman*", Figure 3, left). Shortly thereafter, artists such as Allan Kaprow [13] and Chris Burden [9] removed the visual frame entirely, creating works embedded in and sometimes indistinguishable from the physical reality of the viewer. For example, Burden's "*Shoot*" (1971) is described by the artist as: "*At 7:45 p.m. I was shot in the left arm by a friend. The bullet was copper jacket 22 long rifle. My friend was standing about fifteen feet from me.*" (from [9], pg. 53).



Figure 3. (left) In Jasper Johns's "Watchman" (1964) a three-dimensional chair and human leg extrude from the canvas and break the frame of the painting. (right) A frame from a comic book about comic books, *Understanding Comics* [15], defining itself¹.

By bringing phenomena such as these into the physical space of the viewer, the artists coerced their audiences into becoming emotional and sometimes physical participants, rather than voyeurs gazing through windows at events divorced from their reality. Subsequent theorists in both art [13] and computing [4] have observed that as visual phenomena establish a presence or *embodiment* in the reality of the viewer, their participatory status increases. Furthermore, they note, embodied, and therefore participative, phenomena need not be *physically* present in the time and space of the viewer, as in the works discussed above; they merely need to possess the possibility of occurring in the time and space of the viewer and to be represented as if they did. A prerequisite for this kind of representation is the elimination of the visual frame.

The evolving status of a slightly different kind of frame, the *picture frame*, exemplifies the changing role of the frame in the embodiment of visual phenomena. The picture frame traditionally has served to underline or exaggerate the separation of the image from its immediate environment. Speaking of a lushly carved, 16th-century Venetian frame for a 15th-century Giovanni Bellini painting, a museum curator says: "This frame actually adds to the illusion that you see Bellini's figures in three-dimensional space with the frame forming a wonderful window." [17] As modern artists began to emphasize the embodiment of their works in real time and space, picture frames became less substantial and were frequently abandoned altogether.

¹ Reprinted with the permission of the author. Copyright 1993.

Frames of an altogether different kind, frames in comic strips and comic books, inherit, magnify, and exploit many of the qualities of visual frames and picture frames. By separating the image inside the frame from the space and time outside the frame (Figure 3, right), comic *frames* (or *panels*, or *boxes*) are able to tell narratives [15]. Comic artists vary the number, shape, and size of their panels in order to establish the rhythm of their stories and to express the passage of time (as detailed in [7], pg. 28). When the box is not drawn explicitly, the “...*non-frame speaks to unlimited space. It has the effect of encompassing unseen but acknowledged background.*” (from [7], pg. 45). Here again, the deletion of the frame serves to merge the visual phenomenon with its surroundings, in this case, the rest of the page.

One may even observe an analogous trope in non-visual narratives such as novels. *Metalepsis* is a literary term that refers to the technique of manipulating representational layers. In a metalepsis, the represented begins to take control of the act of representation [16]. When metalepsis occurs in visual narratives such as film, not surprisingly the visual frame of the screen is used to delineate the boundary between the film’s story and the viewer’s. For example, in Woody Allen’s *The Purple Rose of Cairo* (1985), a character in a Hollywood “B” movie (played by Jeff Daniels) notices a repeat viewer in the theater audience (Mia Farrow) and literally climbs out of the film frame to meet/connect with her.

Finally, the windowed panes introduced in the Xerox Star operational system and now ubiquitous in almost all computer interfaces are also an excellent example of using frames to encapsulate space and time. How upset does one get when a web pop-up opens a frameless window occluding the whole desktop, virtually taking over the one’s personal workspace?

3 Interactive Frameless Displays

Although the concept of embodied *virtuality* was first articulated by Weiser [32], the powerful effect of the non-frame in interactive displays was perhaps first practically demonstrated by the *DigitalDesk*. [33]. Here, a frameless projection of a computer desktop seamlessly merged with and augmented a physical desktop.

Subsequently, the *I/O Bulb* [30] enabled “*computer-driven graphical constructs to escape the strictures of the rectangular screen and take their place as denizens of real-world architecture.*” (from [30], pg. 391) The elimination of the frame (what the authors call *boundarylessness*) is deemed critical to displaying digital imagery that has a “*direct correspondence with pre-existing physical artifacts.*” The *Language-Learning Tool* [11] shared a similar approach, labeling physical objects in a room with new words in a foreign language.

Not all frameless digital phenomena are directly associated with physical artifacts. Sometimes the correspondence is symbolic, such as in some versions of *PingPong-Plus* [34], or even poetic, as in the fountain in the *Hall of Ideas* [8]. Occasionally, pragmatic designers acknowledge laptop computers and their displays as physical artifacts and attempt to extend both their physical and virtual properties using localized frameless displays as in the *augmented surfaces* of Rekimoto and Saitoh [26].

User studies in this area are few. Pinhanez et al. [21] anecdotally observed several hundred demonstration attendees successfully pressing “buttons” projected onto neutral surfaces, such as tables. When directed to press a similar “button” projected onto the side of a paint can, the same attendees became confused. This confusion points to open questions about when interactive *physical* and *digital* objects begin to merge (or perhaps collide) within the space of the user. How do users negotiate the overlapping realities? When does one reality assume primacy over the other? How possible is to change the interaction modality of certain objects and surfaces? How does the psychological phenomenon known as *functional fixedness* [5], whereby people are unable to ascribe unfamiliar functions to a familiar object, affect a user’s ability to interact with merged spaces?

Two studies trying to uncover how frameless displays affect interaction are briefly reported by Podlaseck et al. in [22]. Subjects were asked to choose the most appealing color from frameless clusters of colored buttons projected onto various objects. Their color choice consistency was then compared to equivalent choices on a desktop monitor to determine whether the projected objects affected the interaction. While the studies demonstrated that (1) the background objects affected the subjects’ interactions with the digital objects and that (2) the digital objects affected the subjects’ recall of the physical objects, the mechanism of these connections was elusive. For instance, a significant number of subjects in the object group (10%) appear to have been blind to the existence of one of the five background objects, a glass of milk; these subjects never selected colored buttons projected on the milk and did not even recall the presence of the milk when debriefed. These studies indicate that the use of frameless displays and their connections with real-world objects on interface design is anything but straightforward.

4 Examples of Use of Frameless Displays

In spite of the challenges and unknowns in using frameless displays, we have tried to experiment with them in a variety of situations. We have designed and built more than a dozen applications that use frameless displays few years since 2001, including systems that are experienced by new users every day, applications that run in real-world environments without assistance, as well as prototypes designed for and widely demonstrated in trade shows and business meetings. So far we have not used frameless displays to create disruptions in time; all of our applications deal with the spatial effects of using or not frames.

Based on our experience, we structure our presentation of applications that use frameless displays considering two dimensions:

- **Connection type:** a frameless display can be used to embed the application in the environment or to connect it to particular objects that exist in the environment.
- **Interactiveness:** a frameless display can be interactive or not.

Table 1 shows how some of our applications can be classified by their connection type and interactiveness. The top-left quadrant refers to the simplest kind of applications that are **non-interactive and embedded in the environment**. For example,

Table 1. Classification of the developed applications according to connected type and interactiveness.

	non-interactive	interactive
embedded in environment	Wall Comics Baby Steps Attractor Loop	Jumping Frog Traveling Tic-Tac-Toe Health Food Motivator
connected to objects	Multimedia Diaper Changer Wine Locator	Diaper Selector Interactive Cereal Boxes

Wall Comics involves comic-strip characters with speech balloons used for advertising purposes (as shown in Figure 1, right). Not using a frame in this case eliminates the spatial separation between the character and the background wall, producing the effect of embedding the character in the physical environment.

Similarly, we developed a visual merchandising system for floor displays which attracts customers to a particular shelf in a store. This application, called the *Baby Steps Attractor Loop*, projects animated baby footsteps on a floor as if a baby is walking towards a shelf (see Figure 4, left). When the steps reach a shelf where diapers are located, a sound of a baby hitting a package is heard and the image of a package of diapers dropping on the floor is seen. In this case, the embedding of the baby steps in the environment naturally provides a direction for the user to follow, without the need for maps. In other words, the frameless display can eliminate the need of an intermediate, symbolic, representation such as a map: it indicates direction by making the “baby” follow the direction itself.

Let’s look into another quadrant of the application classification shown in Table 1, the one corresponding to **non-interactive applications connected to objects in the environment**. A straightforward application in this category is the *Multimedia Diaper Changer*. In an advertisement piece created for this application, a video of a crying baby is projected without a frame directly onto the padded surface of a baby changing table. The video is followed by a scrolling text that describes the safety provided by diaper changers and the characteristics and price of that particular model. To increase realism, the baby imagery was captured in a way that the perspective effect was correct for a user standing in front of the diaper changer. The result is the *de facto* integration of the baby imagery and sound with the furniture, almost as if the baby was there, creating a powerful emotional connection with viewers (especially with parents). During a demonstration of this application, we needed to turn off the audio because a number of attendees became emotionally overwhelmed by the exhibit. We doubt that the same video on a traditional monitor would have this kind of effect.

A more interesting but less straightforward example is the *Wine Locator*, an application that has been running since October of 2004 in the Metro Store of the Future in Germany. This application extends a kiosk-based wine recommendation system that had a fundamental problem: after the user had spent many minutes browsing wine information on the kiosk screen, the only way to find the recommended wine was to look for the selected wine among the 250 wines featured in the wine section, having

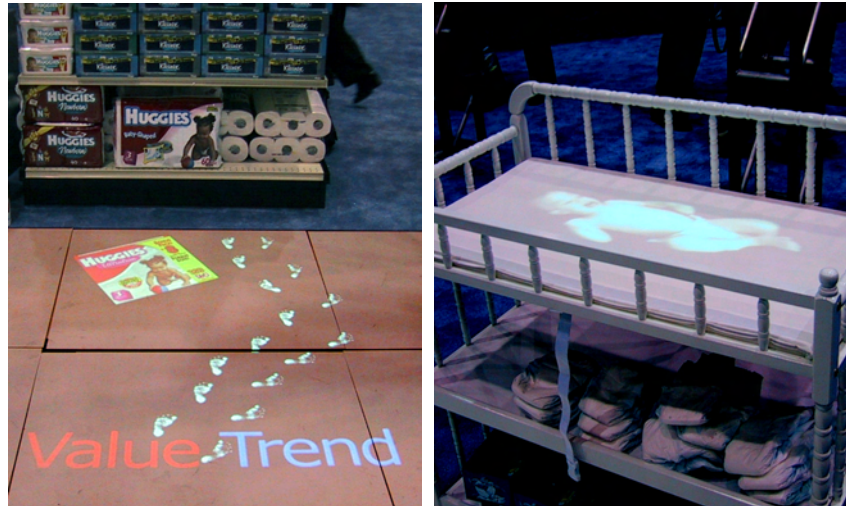


Figure 4. (left) *Baby Steps Attractor Loop*; (right) *Multimedia Diaper Changer*.

only the wine's name printed on a sheet of paper. Many times, the customers could not locate the wine and would get extremely frustrated.

Our application adds a "where" button to the kiosk interface (as seen in Figure 5), and uses a steerable interactive projector system similar to [20] to help locate the wine. When the "where" button is pressed, the projector is veered towards the floor space in front of where the selected wine is. It then projects the image, name, and price of the wine, attracting the customer towards that area. The projected image of the wine, as shown in Figure 5, makes it easy for the user to scan the shelves and find his selection among them. The incorporation of the "where" button has, according to the store manager, increased significantly the use of the kiosk and very likely the volume of wine sales.

Notice, however, that in this application there is an implicit frame created by the projected white background. First, the white background is necessary to increase the visibility of the projected image when the user is still away from the wine, in front of the kiosk. Also, since the wine may be stocked anywhere on the shelf, the frame helps to create some disconnection between the information and the bottommost wine. An alternative could have been to highlight the wine itself by projecting directly onto it (as in [2]). This option was discarded since light can compromise the quality of wine. However, we still consider that this application uses frameless display techniques, especially because the whole floor of wine aisle can be regarded as the actual display area of this application and the projected area simply as a visual pointer to it.

The remaining applications we describe in this section use frameless displays that have interactive elements in them. First, let us examine cases of **interactive applications embedded in the environment**, as listed in the top-right quadrant of Table 1. A good example of this kind of applications is the *Jumping Frog* described earlier in this paper (Figure 2). There, the frameless display increases the embedding of the ani-



Figure 5. *Wine Locator*.

mated frog onto the surface it is projected on, contributing to increase the feeling that the frog inhabits the user environment.

Another of such applications, called *Traveling Tic-Tac-Toe*, has been running since 2003 in the IBM demonstration area of the Epcot Center in Orlando, Florida. It is a variation of the traditional tic-tac-toe game where the game grid is moved after each turn to a random surface in the environment, to walls, cabinet doors, floor, etc. Each player has to find the grid before selecting a square to play (see Figure 6). This demonstration is run many times a day with the assistance of a presenter. The presenters have reported us that it has become one of their most popular attractions and that users are extremely comfortable with the interface and the game concept.

Projecting interactive frameless elements on the floor has been explored in the *Health Food Motivator*, developed for a demonstration of new supermarket technologies for a TV show. The goal here is to motivate people to improve their diet not only by showing them the location of healthier products, but also by engaging them through an active commitment process. Figure 7 shows the application which projects on the floor the message “Take the first step toward” and presents three choices: “lower sodium”, “higher fiber”, or “low cholesterol”. When the user steps on one of these buttons, the application projects footprints on the floor that lead him to the appropriate area.

A frameless display, in this case, is used to embed the projected footsteps in the environment and to intuitively ask the user to follow them. We also believe that projecting the initial message and options without a frame encourages interaction. If a frame was used in this case it could have given the impression to the user that the circles with choices are not to be stepped on. In fact, this demonstration was also shown in an environment where, due to dark lighting conditions, it required the projection to be done on a “framed” rug with a white background. In this situation, it was noticed (anecdotally) that people were less willing to step on the “buttons”.

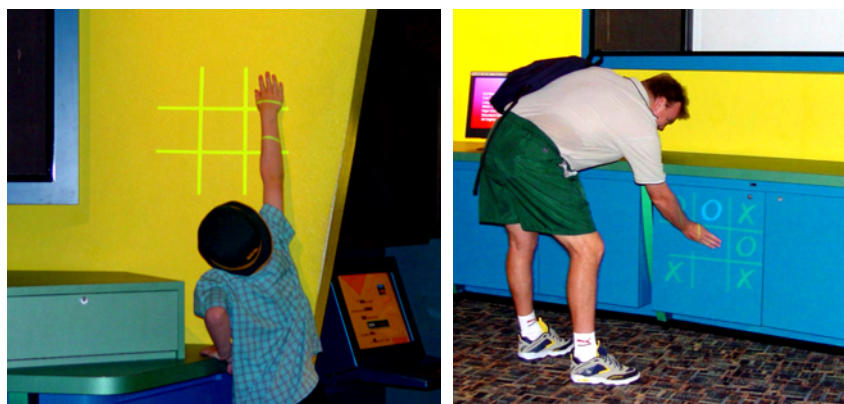


Figure 6. *Traveling Tic-Tac-Toe.*

The last quadrant to explore on Table 1 corresponds to **interactive applications connected to objects in the environment**. These applications achieve, to some extent, the goal of transforming everyday objects into animated agents able to provide information about them. In the first of such applications, the *Diaper Selector*, a user is presented initially with samples of different types of toddler diapers. We exploit here the user's natural impulse to touch the diaper to feel its texture and volume. When a diaper is touched, it is *spotlighted* and information about it is displayed on the central surface (see Figure 8, right). To further entice users to touch the diapers when nobody is using the interactive display, an inviting message is projected on the central surface and image of hands are projected directly onto the diapers (see Figure 8, left). No frame is used to connect the highlighted diaper and its descriptive text.

This application demonstrates the use of spotlighting as an interface technique available for projected frameless displays connected to objects. As shown in Figure 8, it is possible to illuminate the object as if a spotlight had been directed to it. Spotlighting is another technique to create a reference to the object itself without the need of an intermediary symbol (for instance, an image, thumbnail, or textual description).

These ideas are taken further in the *Interactive Cereal Boxes* application created to complement the *Health Food Motivator* described above. This application transforms a shelf with cereal boxes and a printed panel with nutritional contents information into an interactive informational system. As shown in Figure 9, touching a cereal box makes the system highlight the information panel column of nutritional information corresponding to the box. Also, we use spotlighting to create user feedback so it becomes evident to which type of cereal that information relates. Finally, the system highlights (with a projected red bar) the best features of that particular cereal type compared to others on the shelf. Unlike in the *SearchLight* experiment [31], we focused the design of this application in a more realistic scenario where neither the shelf, the product, nor the user are instrumented directly.

As mentioned, this application has been shown together with the *Health Food Motivator* (see Figure 7). First, the system tries to attract customers to the cereal shelf by

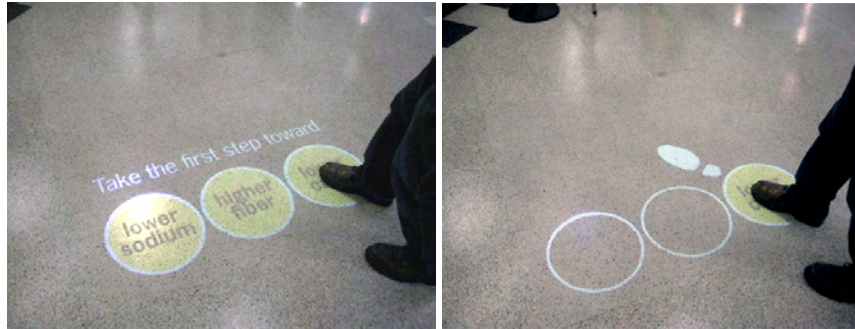


Figure 7. Health Food Motivator.

inviting them to select a specific diet. After the selection, it leads them with footsteps projected on the floor that lead to the cereal box shelf. As the footsteps approach the shelf, the *Interactive Cereal Boxes* application is started and commanded to spotlight the cereal that is most appropriate for the diet selected by the customer. Since all cereal boxes are interactive, the customer can naturally explore the nutritional content of other types of cereal as described above. Again, the use of a frameless display and the spotlighting technique create a direct connection between the object and the information about it.

Before going ahead, we would like to comment on a complimentary technique used in some of these applications to increase the embedding of the projected display in the environment and the connection to nearby objects. This technique, which we call *real world framing*, involves the use of frame-like elements of the environment or an object to create a visual frame encompassing real world and display elements. This technique is used, for example, in the *Diaper Selector*. As seen in Figure 8, the diapers and the information area are mounted on a white panel bound by the upper and lower shelves. When the application is active, the boundaries of the panel are perceived as a container for the information and interaction, creating a virtual display frame mixing real and virtual objects that has basically the same properties of a traditional framed display. In other words, with the real world framing technique, it is possible to separate part of the real space and transform it into a mixed reality display. We also playfully experimented with this technique in the *Traveling Tic-Tac-Toe* application. Notice that in Figure 6 (right), the grid is projected on a cabinet door, making it less embedded in the environment than when the grid is projected on the wall (Figure 6, left).

5 The Usage of Frameless Displays in Ubiquitous Applications

In all the applications listed above, we were able to gather informal data about the user response, understanding, and acceptance of each application. This feedback,



Figure 8. Diaper Selector.

together with ideas from the literature, has allowed us to compile some pros and cons of using frameless displays and to provide basic design guidelines on their usage.

We should emphasize that we are not making a definitive assertion of the validity of the pros, cons, or guidelines, since our evidence is only anecdotal or derived from practical experience. In spite of the possibility, even likelihood, of being incorrect in some cases, as it may be shown by scientific studies in the future, we nonetheless find that this collection of ideas provides a framework to guide practice until better information is available. It also may serve as a draft research agenda for the field.

Let us start with an enumeration of the basic pros and cons of frameless displays.

POSITIVE PROPERTIES OF FRAMELESS DISPLAYS:

- **Embed characters into reality:** in applications embedded in the environment, such as the *Wall Comics* (Figure 1, right) and the *Jumping Frog* (Figure 2) applications, a frameless display seamlessly embeds a flat character into the environment.
- **Connect information to objects:** in applications connected to objects, such as the *Multimedia Diaper Changer* (Figure 4, right) and in [11, 25, 30], positioning information near an object causes immediate, strong associations between the two.
- **Enable the creation of very large virtual displays:** the absence of boundaries removes any reference to where the display actually starts and ends. Therefore if multiple or steerable projectors are used, as in the case of the *Wine Locator* (Figure 5 and in [8]), it is possible to create the sensation of a high-resolution, seamless display area that covers a very large portion of the environment.
- **Create a strong sensation of direction:** projecting arrows or other directional elements in the environment such as in the *Baby Steps Attractor Loop* (Figure 4, left) and in [29], provides an intuitive and, in many cases, unambiguous way of indicating direction. This can be an attractive alternative to maps.
- **Enable direct pointing to an object:** the *Wine Locator* (Figure 5) illustrates the value of pointing directly to an object in a densely populated environment, eliminating the need for maps and directions.



Figure 9. Interactive Cereal Boxes.

- **Transform an area or an object into a symbol of itself:** techniques such as spotlighting, used in the *Diaper Selector* (Figure 8), can eliminate the use of intermediate symbols when referring to an object. A display disconnected from the environment — for example, a typical kiosk — uses thumbnails and other visual imagery to help the user connect the displayed information to the concrete object which it refers to. Spotlighting an object, and/or using the object as a trigger, as in the *Interactive Cereal Boxes* (Figure 9), eliminates the “middle-man” symbol from the communication, potentially contributing to increase the association of ideas to the object and possibly enhancing its ability to be remembered.
- **Transform positively the perception of an object:** by illuminating or coloring an object, or displaying appropriate content such as in the *Multimedia Diaper Changer* (Figure 4, right) or in [24], it is possible to make the object(s) more interesting visually. Interaction may induce similar transformation as in the case of the *Jumping Frog* (Figure 2).

CONCERNS WHEN USING FRAMELESS DISPLAYS:

- **Creating undesirable connections between information and objects:** for example, if the animated frog of the *Jumping Frog* (Figure 2) lands on the surface of food (for example, a pizza slice), queasy feelings may be accidentally elicited. Also, designers should be aware that people can find unexpected, frequently undesirable connections between the display content and its surroundings.
- **Making performance and usability of an interface less predictable:** as discussed in Section 3, characteristics of the environment may affect the desirability to interact with the display. Also, the environmental lighting can render parts or the whole display invisible, unrecognizable, or altered.

- **Invading people’s personal space:** in the *Health Food Motivator* (Figure 7), a customer remarked that he thought the buttons displayed on the floor in front of him implied that he needed to diet. Because the connections to the environment, objects, and people are enhanced by a frameless display, it is easier to inadvertently create situations where a user is made self-conscious by the contents of a display.
- **Negatively affecting the perception of object:** in the case of applications connected to objects, as much as the perception of an object can be improved as discussed before, there may be situations where objects negatively affected by the display. For instance, in the *Interactive Cereal Boxes* (Figure 9), the color and the brand legibility of the cereal boxes were somewhat affected by the yellow circle used to spotlight them.
- **Difficulties creating perspective and 3D effects:** the detachment from the environment created by a framed display simplifies the creation of the illusion of 3D through perspective. A frame defines implicitly two candidate horizon lines parallel to its boundaries; in most cases, this hint is sufficient to enable viewers to “parse” the perspective. Conversely, frameless displays lack the ability to create references to anchor the vanishing points that are essential for the perception of perspective, making it harder for the viewer to understand perspective images especially when she is not positioned correctly. For example, the video of the crying baby projected on the padding of the *Multimedia Diaper Changer* (Figure 4, right) only works when the viewer is positioned exactly in front of the diaper changer.
- **Challenging the established vocabulary of design:** as detailed in the next paragraphs, many commonly used techniques in visual design, such as scrolling and sliding content, do not work well in the absence of a frame. For example, the use of a scrolling text in the *Multimedia Diaper Changer* (Figure 4, right) had to be softened by using fading in and out on the top and bottom of the scroll, respectively.

In our experience, the actual practice of creating ubiquitous applications using frameless displays faces a considerable obstacle: it is hard for print- or web-trained visual designers to work with frameless displays. Years of professional experience in composing and transitioning visual elements within a frame are hard for one to immediately abandon. Similarly, narrative devices derived from cinema, such as close-ups, fast editing, or over-the-shoulder shots do not translate well, in our view, to texts and images that are highly connected to the physical world (as observed also by Underkoffler et al. [30]). We have seen in many of our engagements that it takes professional designers many design iterations to start thinking outside the frame.

To support the training of the visual designers, we have been compiling some “rules of engagement” for frameless displays in ubiquitous applications. In reality, “they are more what you’d call ‘guidelines’ than actual rules”². But, nonetheless, here follows a first attempt to capture some of the parameters governing the design of ubiquitous frameless interfaces; notice that some of these guidelines apply primarily to applications that are either embedded in the environment or connected to objects.

² From *Pirates of the Caribbean: The Curse of the Black Pearl* (regarding the pirates’ strict code of conduct).

DESIGN GUIDELINES FOR FRAMELESS INTERFACES

GENERAL CASE:

- **Use the environment, its objects, and the surface elements as part of the interface:** the best way to connect to the environment is to integrate it to the visual design; frameless displays cannot do it all.
- **Design, if possible, the real world together with the interface:** sometimes it is easier to change an object's position than to fix the visual design. The environment and the objects in the proximity of the display are as integral to the display as the text and graphics.
- **Be aware of the surface being projected on and its effects:** in the case of projected displays, consider and, if possible, use the texture of the surface being projected. For instance, we once obtained a striking effect when we projected a picture of a Monet painting (which originally had a lot of texture) on a white furry carpet. Also, try to use saturated colors to ensure greater contrast.
- **Eliminate the “middle” symbol whenever possible:** as discussed above, one of the most striking properties of frameless displays is the possibility of directly connecting the real with the virtual world and eliminating the need for symbolic reference imagery and text. For instance, if text is projected on the side of an object, there is no need for the image of the object. Similarly, it is possible to indicate directions by showing them directly in the environment, instead of using maps.
- **Avoid implicit frames:** for example, in Figure 1, right, the bottom part of the character profile is cut horizontally, creating an invisible line of reference that implicitly determines a frame. An irregularly shaped cut often works better to keep the display frameless.
- **Be cautious when using cinema-inspired visual techniques:** sliding and panning texts and imagery, fast cutting, close-ups, and over-the-shoulder shots heavily rely on the reference from the frame. When used, they tend to create implicit frames as discussed above. Instead, use fade-in/out, images that expand from and contract to a single point, etc.
- **Avoid using scrolling:** at the heart of this technique is the existence of frame boundaries.
- **Be careful when using navigation mechanisms:** if the interface includes buttons or links that bring additional information or services, check whether the coming information is still connected to the environment or to the object: if not, consider framing it. Similarly, be careful when navigating back from the virtual to the real world.
- **Shoot video against a black background and keep the actors' figures whole:** the background of a video implicitly defines a frame. Also, avoid framing the video subjects, or using close-ups, since they can break the illusion of connection. If cutting the body is absolutely necessary, consider post-editing effects that create irregular or fuzzy boundaries.
- **Be cautious using imagery with perspective:** as discussed in the previous section, the illusion of perspective requires either a framing reference or the correct positioning of the viewer. This is particularly important when using perspective-based imagery on non-vertical surfaces, since people tend to better parse perspec-

tive on vertical imagery (probably from years of exposure of movies and television). Notice that in most cases, photos and videos have implicit perspective.

- **Use sound effects:** whenever possible, use sound effects that increase or soften the connection between the real and the virtual, as needed. For example, in the *Jumping Frog* game (Figure 2), the illusion that the frog jumps is dramatically enhanced by cartoon-like sound effects when it jumps, travels through the air, and lands.

APPLICATIONS EMBEDDED IN THE ENVIRONMENT:

- **Do not use frameless displays when information is disconnected from the environment:** for instance, if the display is showing world news, there is probably no connection with the environment, so the content should be framed.
- **Be careful when jumping from one surface to another surface:** as discussed by Sukaviriya et al. in [29], it can be difficult for users to follow the path of interfaces that jump discontinuously from one surface to another. Be sure, at least, that the surfaces are not too apart.

APPLICATIONS CONNECTED TO OBJECTS:

- **Be careful about the distance from the object to display:** the easiest way to ensure connection between an object and the information on the display is to have them very close to each other. If that is not possible, and if confusion with other objects is likely, consider using soft frames and symbolic imagery to increase the likelihood of the desired connection as used in the *Wine Locator* example.
- **Have mechanisms/sensors to ensure the connected object is there:** if the interface requires the presence of an object to be understood, it is better that the object is there. To be sure, consider the use of sensors or check points that determine the presence of the object. In case the object is not present, or not likely to be present in a specific situation, the system can start operating in a safer mode displaying, for instance, an image of the object.

6 Conclusion

While working together with visual designers and software developers to create the nine applications described in this paper, we often encountered enormous difficulties to communicate our understanding of how frameless displays work. It is very hard for visual designers to stop using the amazing possibilities provided by their lifetime-companion frame, and for software developers to take in account the actual environment the application will live on. Our main goal with this paper is to systematize as much as possible our knowledge about frameless displays in their role and usage in ubiquitous applications so: (1) the communication and discussion with visual designers and software developers becomes easier and based on palpable guidelines; and (2) a possible research agenda in this area is proposed to the ubicomp community.

We believe we convincingly argued that frameless displays increase the connection between the information in the display and the environment and that new possibilities for interface design have become available. For example, the elimination of “middle-man” symbols from the interface, as seen in the *Interactive Cereal Boxes* application, is a good example of a new paradigm that is probably very useful in ubiquitous appli-

cations. At the same time, this increased connection is likely to modify some of our ideas of how interaction is addressed in an ubicomp world, given, for instance, how the nature of an object seems to impact the willingness to interact with visual elements rendered on and around it.

We are keenly aware of the need for further refinement and scientific validation of our design guidelines for frameless displays. But, most important, we see them as a portal for an exciting visual design and HCI research agenda. For instance, we just touched in this paper the problem of how to do hotlink-style navigation in a frameless display. The basic question, in this case, seems to be the development of mechanisms to clearly separate information that is contextualized in space from information that is not. Also, although we have focused so far in spatial issues, in future work we plan to experiment with the disruption of time created by framing content.

Finally, understanding the role and design of frameless displays in ubiquitous applications may also help other areas of HCI research. For instance, in applications based on tangible interfaces it is very hard to associate to an object a function or property that is not mapped directly in its natural usage. What is a natural way to ask a cereal box its price? How can a refrigerator in a store connect a customer with the help desk? These and similar problems lead us to believe that creating visual mechanisms to contextualize and decontextualize information is a more fundamental research issue in ubiquitous computing applications than currently understood.

References

1. Anderson, L.: *Empty Places*. Harper Perennial. New York, New York (1991)
2. Butz, A., et al.: *SearchLight - A Lightweight Search Function for Pervasive Environments*. In: *Proceedings of Pervasive 2004*. Vienna, Austria, April 21-23 (2004) pgs. 351-356
3. Chikamori, M., Kunoh, K.: *KAGE*. In: *SIGGRAPH'98 Electronic Art and Animation Catalog*. Orlando, Florida, July 19-24 (1998) 14
4. Dourish, P.: *Where the Action is : the Foundations of Embodied Interaction*. MIT Press. Cambridge, Massachusetts (2001)
5. Duncker, K.: *On Problem Solving*. *Psychological Monographs* 270 (1945)
6. Duro, P.: *The Rhetoric of the Frame : Essays on the Boundaries of the Artwork*. Cambridge University Press. Cambridge, England ; New York, NY, USA (1996)
7. Eisner, W.: *Comics & Sequential Art*. Poorhouse Press. Guerneville, Calif. (1985)
8. Hall, P.: *Starting Small*. *Metropolis* (metropolismag.com). <http://www.metropolismag.com/cda/story.php?artid=626> (2004)
9. Henger, S., Kosenko, P.: *Chris Burden: A Twenty Year Survey*. Newport Harbor Art Museum. (1988)
10. Hoffman, D.: *Visual Intelligence: How We Create What We See*. W. W. Norton (1998)
11. Intille, S., et al.: *Ubiquitous Computing in the Living Room, Concept Sketches and an Implementation of a Persistent User Interface*. In: *Proc. of the Video Session of UbiComp'03*. Seattle, Washington, Oct. 12-15 (2003)
12. Iwai, T.: *Composition on the Table*. In: *SIGGRAPH'99 Electronic Art and Computer Animation Catalog*. Los Angeles, California, August, 8-13 (1999) 10
13. Kaprow, A., Kelley, J.: *Essays on the Blurring of Art and Life*. University of California Press. Berkeley, California (1993)
14. Krueger, M. W.: *Artificial Reality II*. Addison-Wesley (1990)
15. McCloud, S.: *Understanding Comics*. Kitchen Sink Press. Northampton, Massachusetts (1993)

16. Meister, J. C.: The Metalepton: a Computational Approach to Metalepsis. Universität Hamburg. <http://www.jcmeister.de/downloads/texts/jcm-metalepton.html>. Sep 3 (2003)
17. Morton, A.: A New Frame of Mind. International Institute for Frame Study. <http://www.iifs.org/framehunt.html>. Feb 26 (2000)
18. Murata, K., Yamauchi, E.: Fisherman's Cafe. In: SIGGRAPH'99 Electronic Art and Computer Animation Catalog. Los Angeles, California, August, 8-13 (1999) 12
19. Nowlin, S.: Less About Appearances. *Skeptical Inquirer* (2003) 1-2
20. Pinhanez, C.: The Everywhere Displays Projector: A Device to Create Ubiquitous Graphical Interfaces. In: Proc. of Ubiquitous Computing 2001 (UbiComp'01). Atlanta, Georgia, September (2001)
21. Pinhanez, C., et al.: Ubiquitous Interactive Graphics. IBM Research Report RC22495 (W0205-143), May 17 (2002)
22. Podlaseck, M., et al.: On Interfaces Projected onto Real-World Objects. In: Proc. of CHI'03 (short papers). Fort Lauderdale, Florida, April 5-10 (2003)
23. Raskar, R., et al.: RFIG Lamps: Interacting With a Self-Describing World via Photosensing Wireless Tags and Projectors. In: Proc. of SIGGRAPH'04. Los Angeles, California, August 8-12 (2004)
24. Raskar, R., et al.: iLamps: Geometrically Aware and Self-Configuring Projectors. In: Proc. of SIGGRAPH'03. San Diego, California, July 27-31 (2003) 809-818
25. Rekimoto, J.: A Multiple Device Approach for Supporting Whiteboard-based Interactions. In: Proc. of CHI'98. Los Angeles, California, April 18-23 (1998) 344-351
26. Rekimoto, J., Saitoh, M.: Augmented Surfaces: A Spatially Continuous Workplace for Hybrid Computing Environments. In: Proc. of CHI'99. Pittsburgh, Pennsylvania, May 15-20 (1999) 378-385
27. Shen, C., et al.: DiamondSpin: An Extensible Toolkit for Around-the-Table Interaction. In: Proc. of CHI'04, April 2004 (2004) 167-174
28. Small, D., White, T.: Stream of Consciousness. In: SIGGRAPH'98 Electronic Art and Animation Catalog. Orlando, Florida, July 19-24 (1998) 50
29. Sukaviriya, N., et al.: Embedding Interactions in a Retail Store Environment: The Design and Lessons Learned. In: Proc. of the Ninth IFIP International Conference on Human-Computer Interaction (INTERACT'03). Zurich, Switzerland, September, 1-5 (2003)
30. Underkoffler, J., et al.: Emancipated Pixels: Real-World Graphics in the Luminous Room. In: Proc. of SIGGRAPH'99. Los Angeles, California, August 8-13 (1999) 385-392
31. Wasinger, R., et al.: Integrating Intra and Extra Gestures into a Mobile and Multimodal Shopping Assistant. In: Proc. of the 3rd International Conference on Pervasive Computing, Munich, Germany, May 8-13 (2005) pgs 297-314
32. Weiser, M.: The Computer for the Twenty-First Century. *Scientific American* 265 (3) (1991) 94-100
33. Wellner, P.: Interacting with Paper on the DigitalDesk. *Communications of the ACM* 36 (7) (1993)
34. Wineski, C., et al.: PingPongPlus: Augmentation and Transformation of Athletic Interpersonal Interaction. In: Proc. of CHI'98. Los Angeles, California (1998) 327-328
35. Yotsukura, T., et al.: Hypermask - Projecting a Talking Head onto a Real Object. *The Visual Computer* 18 (2) (2002) 111-120