Visual Immersion in the Context of Wall Displays

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Abstract
Immersion is the subjective impression of being deeply involved in a specific situation, and can be sensory or cognitive. In this position paper, we use a basic model of visual perception to study how ultra-high resolution wall displays can provide visual immersion. With their large size, depending on the position of viewers in front of them, wall displays can provide a surrounding and vivid environment. Users close to the wall can have their visual field filled by the wall and they are able to see clearly a large amount information with a fine resolution. However, when close to the wall, visual distortion due to large possible viewing angles, can affect the viewing of data. On the contrary, from far away, distortion is no longer an issue, but the viewers' visual field is not fully contained inside the wall, and the information details seen are less fine.

Author Keywords
Immersion; wall displays; field of view; visual acuity

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces – Graphical user interfaces.

Introduction
Immersion is a well studied concept in psychology [7, 21], with many different definitions that refer to the subjective impression of being deeply involved in a specific situation. This immersion can be sensory, related to the informa-

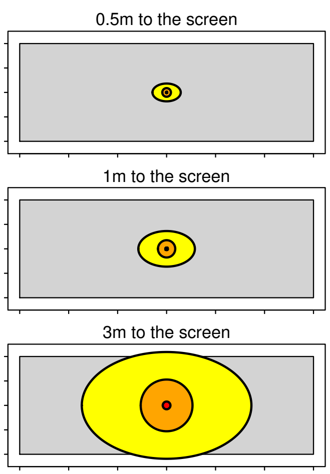


Figure 1: Representation of the visual field (red, orange and yellow) for a 6x2m wall display (grey) for different distances (0.5, 1, 3 m). The user "in the middle" of the wall looking straight ahead.

tion transmitted to our senses (e.g., when wearing a Head-Mounted Display HMD); or mental, related to a more cognitive involvement (like when you read a book) [20]. HMDs and CAVEs are considered to provide an almost perfect sensory immersion, as they surround viewers with virtual information. Nevertheless, in this paper we will study another kind of display that is becoming increasingly popular in data analysis, and that can provide a certain level of immersion due to its size: *wall-displays*. We focus on sensory immersion, as mental immersion relies more the content than on form. In particular we will discuss *visual immersion*. While other aspects (e.g., audio, type of interaction) can affect sensory immersion, they are less relevant to wall displays.

With their large size and high resolution, wall-displays can visualize a large quantity of data, compared to a traditional desktop [24]. Users can come up-close to the display to get details, or move farther away to get overviews. Due to their scale and space in-front of them, they can furthermore accommodate several collaborating users [9, 12, 17]. But wall display characteristics can also provide a better sense of engagement than on a traditional desktop, and a feeling of being more immersed in the data [5]. Due to their large scale, they can give users the feeling of being surrounded by data, as they cover a large part of their field of view [1], especially when viewed up-close. This feeling is reinforced by the fact that users can quickly explore data via small head movements [13]. Moreover, wall displays can provide more intuitive and immediate relationship between the user and the data, as they allow for direct interaction with the data using touch [10], and embodied interaction through simple physical navigation when walking [2, 19].

A display that surrounds users and provides vivid and clear visual information, can increase visual immersion [21]. Surrounding the user, implies that the visual information is displayed in a panoramic way around the user, and is not limited to a narrow field of view. Vivid and clear visual information means that users can view rich information content and with an appropriate display resolution. A wall-display can be both surrounding and vivid, because of its large size and high resolution. However, the degree of immersion depends on the position of the user, and in particular her distance from the display. At a short distance, close to the display, information will fill the user's visual field, and the quantity of viewed information will be both large and of fine resolution. Farther away from the wall, the visual information and the wall will fill only part of the user's visual field, and there will be less of it that is clearly visible, due to visual acuity as we will discuss next. In the first case, the user will be more immersed in the data than in the second, and thus the closer to the wall the user is, the larger the immersion. However, due to its large size, when viewers are close to the display, there is an important distortion for shapes that are at a large angular distance [3], which can in turn deteriorate the user's immersion. In this respect, the closer to the wall the user is, the larger the distortion will be.

In this paper, we are discussing simple models that can help us study the immersion trade-offs created between user position that affects the size of the visual field that is covered by the display, and the quantity of information and possible distortion based on this position.

Visual Field

The visual field is what a person sees instantaneously when looking straight ahead, this "image" is reflected on the retina of both eyes and then transmitted to the brain. The resolution of the retina is not uniform [23]. It is far higher in the central part, which is called the fovea. From there the resolution drops quickly towards the border of the retina. The visual field is divided in 4 areas: the first one is the

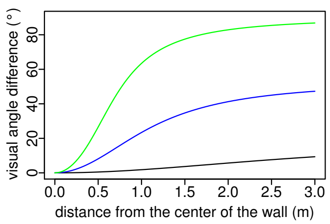


Figure 3: Difference between the visual angle at the origin and the actual visual angle for an object on the wall (of width $w = 1$m) in function of the distance x between this object and the center of the wall, for different user's distances d to the wall: 0.5m (green), 1m (blue) and 3m (black). The user is "in the middle" of the wall. $\theta(x,d,w) = \arctan(\frac{x+\frac{w}{2}}{d}) - \arctan(\frac{x-\frac{w}{2}}{d})$.

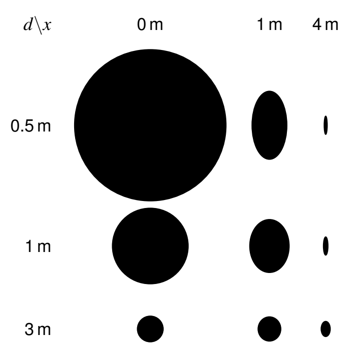


Figure 4: Distortion of a circle which is at a distance x from the center of orthogonal projection (0,1 and 4 m), viewed with normal vision at a distance d from the screen. See Figure 2 for parameters x and d.

Area	Visual Angle	Visual Acuity
Fovea	3°	100 %
Perifovea	20°	30 %
Plateau	H: 60° and V: 40°	10 %
Peripheral	200°	< 5 %

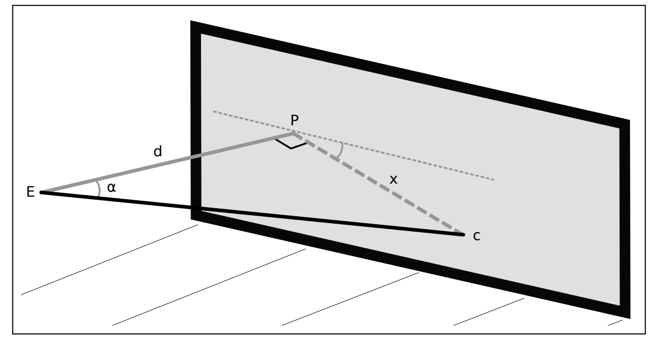
Table 1: Visual angles of each area of the visual field, and their visual acuity compared to that of the fovea. H stands for horizontal, and V for vertical.

fovea (in red in Figure 1 & 5), then surrounding it is the perifoveal area (orange), the plateau (yellow) and finally the peripheral area [16]. Table 1 gives for each area the visual angle [16] and the visual acuity compared to the fovea [23]. In the following sections, for simplicity, we won't consider the Peripheral area as its visual acuity is low, and it lacks of color and static sensitivity. However, peripheral vision is important for noticing dynamic information on wall displays [15].

The size of the orthogonal projection of the visual field on a screen (thus actually what we see on this screen) depends on the distance between the eyes and the screen (Figure 1). For instance, if a viewer is at distance d from a screen, the size of the projection of its fovea on screen is given by $2d \cdot \tan(\frac{v}{2})$, where v is 3° for the fovea (or 60° for the plateau). This formula was used to calculate the visual field of a user at different distances from the screen (see Figure 1). Reciprocally, the visual angular size of a circle of diameter w is $2 \cdot \arctan(\frac{w}{2.d})$.

Distortion

The above formulae are enough when studying desktop setups. However, in the case of large wall displays, viewing in perspective (visual angle α) has an effect on visual perception. Figure 2 provides formulae to compute the distortion caused by looking at a wall in perspective: a circle in the retina (corresponding to a visual angular size v) corresponds to an ellipse (w,h) on the wall (and reciprocally, a circle on the wall is viewed as an ellipse in the visual system). This perspective viewing causes a distortion that stretches the visual field, and it is specially strong in the gaze direction when the viewer is close to the wall. Figure 5 shows examples of visual fields for viewers at different distances from the wall, and with different head rotation angles.



$$w = d \cdot (\tan(\alpha + \frac{v}{2}) - \tan(\alpha - \frac{v}{2}))$$
$$h = 2 \cdot \frac{d}{cos(\alpha)} \cdot \tan(\frac{v}{2})$$

Figure 2: Imagine an ellipse at position (C) on the wall, with width (w, size in the PC direction) and height (h, size in the direction $\perp$ to PC). This ellipse is seen as a circle of angular size v, when viewed from position E, that is at distance d of the wall, with view angle α. For instance, if we wanted to compute what is the size of an object seen entirely in the fovea, we would use $v = 3°$, and $v =$ 1 minute of arc to compute the size of the smallest entity that can be distinguished with normal vision.

On the contrary, this distortion makes shape on the wall seem to shrink in size, mostly in the gaze direction. This is because distortion lowers the visual angular size of a shape. Figure 3 shows the effect of distortion on the visual

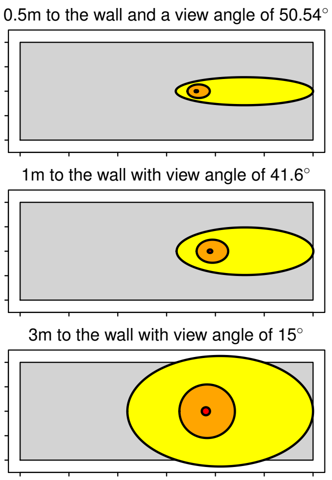


Figure 5: Representation of the visual field (red, orange and yellow) for a 6x2m wall display (grey) for different distances (0.5, 1, 3 m). The angle in each case is the "critical visual angle", i.e., the max angle where the entire field remains inside the display.

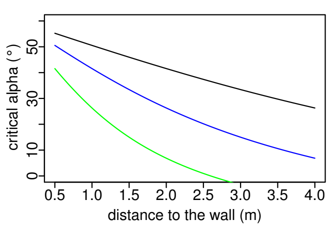


Figure 6: Critical head rotation angle α_c, for which the visual field is entirely on the display, as a function of the distance d to it, for 3 wall sizes s: 12m (black), 6m (blue) and 3m (green). The user in the middle. $\alpha_c(s,d) = \arctan(\frac{s}{2 \cdot d}) - \frac{\Pi}{6}$.

angle for a shape on the wall: the x-axis represents the distance between the shape and the center of the screen, and the y-axis the difference between the real visual angle of the shape and the perceived visual angle by the user, for three different positions of the user (0.5m, 1m and 3m from the display). We can see that the effect of the distortion is inversely correlated with the distance to the wall, and it becomes almost negligible when the user is at 3 meters from the wall. This is confirmed by the Figure 4, which shows how a user would see a circle on the wall as a function of the distance to the wall and the distance between the circle and the center of the wall. In order to show also the effect of distance, we also show how the circle looks in the center of the screen with the user at 0.5m as a reference. While the effect is important in the first line, it is less visible at 3m.

Note that the human vision system is aware of the distortion caused by viewing in perspective, and it corrects it “automatically” with more or less precision (see, e.g., [3] for large objects). However, this distortion clearly causes legibility issues especially when your are close to the wall.

Immersion

One characteristic of an immersive environment is that it surrounds the users, which means that it fills entirely their visual field. Several studies actually show experimentally that a screen with a large field of view is more immersive (see [6] for a meta-analysis). Given our calculations, we can use the size of the visual field and the position of the users to give us information about how they are immersed.

For a 6x2m wall display, the visual field is totally inside the wall for viewers at 0.5 and 1 meters. But it extends beyond the top and bottom of the wall at 3 m. At that distance, the user is no longer immersed. As we mentioned, the visual field changes also as a function of the head rotation: with a 6 meter wall, viewers are able to turn their head up until 50° when positioned at 0.5m from the wall, and still be immersed. Similarly, viewers are still immersed with head rotations of up to 41° at a distance of 1m, but only by15° at a distance of 3m (see Figure 5).

To evaluate the degree of immersion as a function of viewer distance, we compute the critical rotation angle for which their visual field is still entirely on the wall (see Figure 6). As expected, the closer viewers are to the wall, the more they are immersed. It is interesting to notice that the rate of decline is inversely correlated to the size of the wall. And that closer to the wall (touch interaction distance), the critical alphas are very similar, viewers are probably immerse regardless of the size of the wall.

Visual Acuity & Pixel density

Beside its size, an important property of a wall display is its resolution in pixels or its pixel density (that is independent of its size). Pixel density is usually expressed as the number of pixels by inch (dpi). Recent wall displays have a pixel density similar to an average desktop computer (e.g., 100 dpi). It is this high pixel density, together with their size, that make wall displays an interesting platform for data analytic. Regarding immersion, high pixel density is important to have a clear rendering, but, again, the quality of the rendering and the required pixel density depend on the position of the user in front of the wall.

We can use the formulae of Figure 2 to compute the size of a “visual pixel”, the smallest entity that can be distinguished by a human with normal vision by taking $v = 1'$ (one minute arc, i.e., $\frac{1}{60}$°, the usual value that define 20/20 normal vision [23]). In front of the wall ($\alpha = 0$), this size is about 0.145 mm at a distance of 0.5 m, 0.44 mm at 1.5 m and about 0.87 mm at 3 m (see the first column of Figure 7).

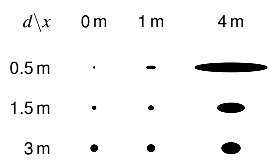


Figure 7: Smallest entities that can be viewed with normal vision at a distance d from the screen [0.5 m (first line), 1.5 m (second line) and 3 m (last line)], as a function of the distance x (horizontal direction) to the orthogonal projection of the eyes (0 m, 1 m and 4 m). See Figure 2 for parameters x and d.

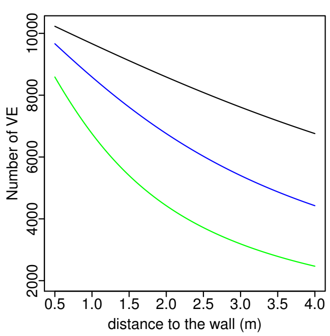


Figure 8: Number of visual entities that can be seen by a user on a horizontal line on the wall in function of the distance to the wall (x-axis), for three wall size: 12 m (black line), 6 m (blue line) and 3 m (green line). The user is “in the middle” of the wall and the line is at the height of the eyes of the user.

In particular, we can argue that the ideal pixel density of a desktop screen or a wall display at touch distance (0.5 m) should be about 170 dpi (pixels of 0.145 mm). Reciprocally, given a screen, we can compute the ideal distance to view this screen, as a function of the pixel density. We want the visual angular size of a real pixel of the screen to be 1° (to match the eye’s resolution, i.e., maximum information quantity, with "no" pixelisation): $\frac{w}{2} \cdot \mathrm{cotan}(0.5')$, where w is the size of a pixel. This formula gives, for example, 87 cm as the ideal viewing distance for a 100 dpi screen, and 1.45 m for a 60 dpi screen.

When viewing the display at an angle ($\alpha > 0$ in Figure 2) the shape of a "visual pixel" (the shape on screen that produces the minimal visual angular size $1'$) grows, in particular in the view direction. This is the inverse distortion phenomenon described in the previous section. Figure 7 shows some examples when looking at a wall at different angles.

To summarize, when the viewer is close to the wall, she can see clearly a lot of details in front of her. But when she turns her head (or body) to look at other parts of the wall, she can see the displayed details in far lower quality. On the other hand, when the viewer is far from the wall, she can see less details directly in front of her (first column of Figure 7), but more details when looking at other part of the wall (last column of Figure 7).

To evaluate this trade-off, we computed how many visual pixels (i.e., entities that have a visual angle of 1°) can be put on an horizontal line on the wall, depending on the viewer’s distance. To this end we covered the line, without intersection or gaps, by ellipses that represent visual pixels. This number of visual pixels can be considered as a measure of the quantity of information provided by the wall to the user when she moves her head.

Interestingly, as shown in Figure 8, the closer the user is to the wall, the more visual entities can be distinguished (we assume an “infinite” dpi, but the ideal minimal distance depends on the real dpi of the wall, see above). The large quantity of visual pixels that can be viewed just in front of the user ($\alpha \sim 0$) when they are close to the wall prevails over the larger quantity of visual pixels provided by looking in perspective ($\alpha \ggg 0$) when far from the wall.

However, to take advantage of all the visual pixels when close to the wall, the information needs be presented to the user in a non homogeneous manner (the density of the information should decrease with the view angle α). In other words, the information needs to be inversely distorted.

Moreover, the above do not take into account several factors, such as the accuracy of the distortion correction made by the human visual system, the luminosity and reflection of the screen, and colors deterioration when viewing in perspective [4, 22].

Movement
Visualizations rendered on wall displays provide usually a uniform amount of detail across the visualization (e.g., maps) the above analysis can be combined with physical traveling: (1) travel close enough to the data to see desired details; and (2) use head movement to navigate the data. Head movement is obviously faster than physical traveling, but physical traveling is also needed.

For instance, Liu et al. [13] suggest that one of the main factors that allow a wall to be faster than a desktop (in cases where the information viewed is small, e.g., 12pt letters) is the ability to reach quickly fine details on the wall by simple head movement (see Figure 8 of [13]). However, physical traveling is needed to be close enough to the data so that head movements is enough to view the desired details.

Thus, an important factor regarding where and how a user should navigate is the level of details of the data displayed on the wall (we have studied in this section the limit of the vision system by considering the “smallest visual entities”).

Discussion

In this paper, we studied two conditions that characterize visual immersion: field of view and quality of the rendering (that depends on visual acuity).

To be immersed in the data, the user’s visual field should not exceed the wall surface, and, obviously, the closer the user is to the wall, the more they can rely on head movements to explore the information space without breaking the immersion. For example, with a 6 m wall seen at 0.5 m, the user can rotate their head up to $50°$ and continue to be immersed. They can rotate their head up to $41°$ at 1 m and only $15°$ at 3 m and remain immersed. These angles get bigger with the size of the wall.

The visual acuity should also be high enough to have a fluid rendering, but also to display a large amount of information that can be clearly seen at the same time. The quantity of information can be measured by the number of visual entities a user can see clearly using eyes and head movements. Our model shows that the closer we are to the screen, the more information can be seen, and that the best minimal distance depends on the pixel density of the wall (smaller with higher pixel density).

Note that, a meta-analysis of a set of experimental studies suggest that the size has a stronger impact on immersion than image quality [6].

Both conditions prescribe to be close to the wall. However this doesn’t take distortion into consideration. When the user is close to the wall, a large part of what she can view is distorted by a perspective view effect. When the user is very close to the wall (e.g., at touch distance 0.5 m) this distortion can be very strong and become a serious problem in data analysis. The formulas allow for computing this distortion, and possible corrections to it. Thus it is necessary to find a good balance between immersion and distortion.

A way to deal with distortion is to build a curved wall instead of a flat one, but this solution can’t be adapted to existing flat walls. Moreover, it is not clear that curved walls are beneficial in a collaborative context. Indeed, wall curvature reduces the space available in front of the wall and may cause more occlusions between the users and the wall. Nevertheless, it would be interesting to apply the method above to better understand the advantages of curved walls.

Another way to fight against distortion is to use wall-specific rendering techniques, such as lenses and DragMag’s (or combination of them [11, 18]), perspective correction [14], and multi-scale images [8]. We hope that our analysis could help to inform the parameterization of existing techniques, and help inspire new ones.

As a future work, we would like to validate empirically the models developed in this paper, by measuring experimentally what participants can see as a function of the wall resolution and their position. Finally, we would like to better understand immersion in a collaborative context and, in particular, its links with group awareness.

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