Switching Dual Layer Display with Dynamic LCD Mask

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ABSTRACT

The Switching Dual Layer Display with a Dynamic LCD Mask is a multi-layer three-dimensional display capable of independent layer content and occlusion between layers. The display consists of a spaced stack of transparent LCD panel and LCD monitor synchronously switching between content, mask, and backlight states. In the first state, the back layer displays white and the front layer displays its content. The back layer acts as a backlight for the front layer, making the front layer content visible. In the second state, the back layer displays content and the front layer displays a mask. The back layer content is occluded by the front layer mask. Rapidly alternating between states, the viewer perceives opaque high-contrast foreground content occluding the background. Besides multi-plane imagery, depth-blending using opacity allows for smooth 3D volumetric imagery at the cost of reduced field of view. The addition of a relay mirror and a phantom mask allows solid appearing front layer content to optically float above and occlude the back layer. The floating front layer is non-physical, so both display layers are accessible for interactive applications.

Keywords: Dual Layer Display, Multilayer Display, occlusion, real image, opacity depth blending

1. INTRODUCTION

Dual Layer Displays are simple and effective means of creating dimensional imagery. One basic implementation is a stacked and spaced combination of a front layer transparent liquid crystal display (LCD) panel and a back layer LCD monitor [1]. Foreground and background content are physically separated in depth (see figure 1a). The resulting image stack exhibits parallax and correct accommodation cues. Typical content is planar foreground and background images or layered projections of a 3D object.

However, the transparent LCD panel does not emit its own light. It acts as a programmable transparency or filter over the back LCD monitor. White pixels on the transparent monitor are clear, blacks are opaque, grays are semi-transparent (similar for color pixels). Visually, the front and back layers' images combine multiplicatively (color component-wise). As a result, front layer content does not appear over a black back layer content; red front layer content does not appear over green back layer content. With bright back layer content, the front layer content is dark, low contrast and semi-transparent [1] (see figure 1b).

The appearance of the front layer content is dependent upon the back layer's content and is view dependent because of parallax between the two layers. The content creator must carefully compose the front and back layer contents so their images don't visually interfere with each other.

In more complex schemes, the front and back layer contents visually interact intentionally to display an apparently smooth volumetric image rather than just basic planar objects on each layer. This additional gain is achieved at the expense of field of view of the display and the need for careful alignment of the displays. In some applications, this effect is desirable and worth the tradeoff.

In modern interactive applications, the display is increasingly used as a input device i.e. touch screen and gestural interfaces. When the dual layer display is considered in this context, a user would likely want to interact with content on both layers. However the back display is physically inaccessible to the viewer/user; the solid front screen prevents the user from touching the back screen.

Our desired Dual Layer Display would produce solid high-contrast front layer content that is independent of the back layer content. It would have a wide field of view and be simultaneously viewable by multiple people. It would also be capable of producing a floating real-image front layer, so the user can interact with both layers. The floating front layer would be capable of occluding the back layer content, exhibiting appropriate parallax between layers, as well as presenting natural accommodation cues. The optional ability to display smooth volumetric images should be possible. The display would also be extensible to multiple layers while maintaing the aforementioned desirable qualities.

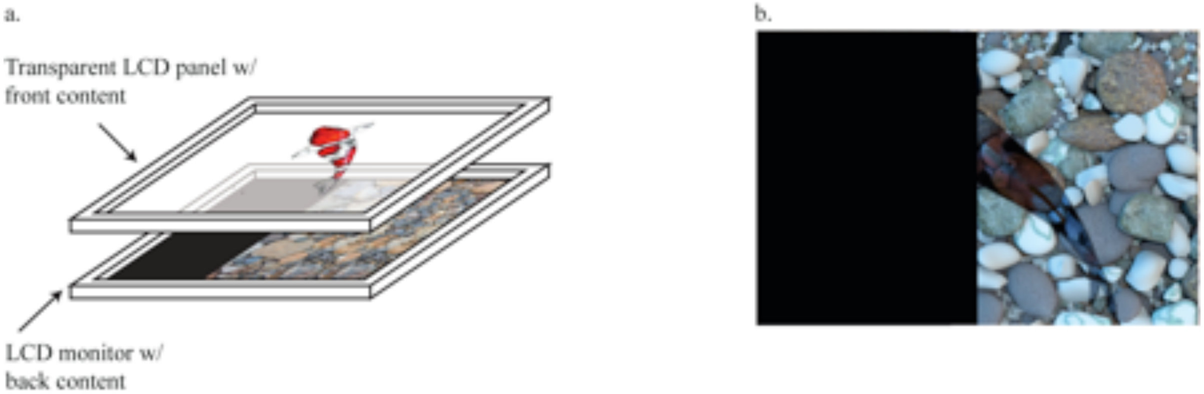


Figure 1a. A basic dual layer display using a transparent LCD panel stacked and spaced over a LCD monitor.
b. Stacked LCDs combine multiplicatively. Front layer content does not appear over dark background content (left), and front layer content appears dark, low-contrast, an semi-transparent over bright background content (right).

2. RELATED WORKS

2.1 Pure Depth

The PureDepth Multi-Layer Display [1] is a commercial Dual Layer Display that uses a stacked and spaced combination of a front layer transparent LCD panel and a back layer LCD monitor.

To make objects in the front layer content appear visible against dark back layer content, Pure Depth places a white silhouette of the front layer content in the back layer content. The white silhouette acts as a local backlight for the front layer content (see figure 2a). This also makes the front layer content appear opaque because part of the background content is removed. The front layer depends upon the back layer content for visibility, opacity, and occlusion.

Figure 2a.Pure Depth's Multilayer Display makes the front layer content visible and apparently opaque (when viewed on-axis) by aligning front layer content with a matching white silhouette on the back layer. b. A halo appears when viewed slightly off-axis due to parallax between layers. c. White silhouette apparent when viewed off-axis.

When viewed off-axis, however, the white silhouette on the back layer is no longer aligned with the front layer content (see figure 2b). The silhouette appears as a white halo on one edge of the front layer content, and a dark semi-transparent halo on the opposite side. When viewed further off-axis, or by other viewers, the back layer silhouette and front layer content are so misaligned due to parallax that the silhouette no longer serves its function. The front layer content again appears as a transparency over the background content, and the silhouette hole in the background content is readily apparent (see figure 2c). Disocclusion of the background is not possible, since previously hidden content does not exist. For large depth separations between the front and back layers, perspective also come into effect. The silhouette only aligns with the front layer content at certain viewing distances.

2.2 Depth Fused Displays

Depth Fused Displays are a class of layered displays that visually blend the layers to present an image volume rather than a stack of planar images. To increase the apparent number of layers, depth-weighted blending can be used. Virtual pixels can be placed at depths between the layers by splitting the virtual pixel's luminance between the front and back layer proportional to its depth. The front and back layer content visually combine additively and the viewer will accommodate on the virtual layer. For slight off-axis viewing, there is correct parallax and disparity.

There are several ways to implement such a display including beam-combined LCDs, multiple scrim projection, and two or more layers of stacked liquid crystal cells [2][3][4]. Many of these displays can be used as dual layer displays with stacked planar images, and only the content needs to be changed to display depth fused images.

A Depth Fused Displays uses two non-transparent LCD monitors optically combined using a 45° half-silvered mirror, also known as a beam combiner. The reflection of one display in the mirror appears stacked and spaced in front of (or behind) the direct view of the other display. Each layer is emissive, and the layers visually combine additively (color component-wise) because they are combined with the half-silvered mirror. White pixels of the reflected monitor are bright, blacks are transparent, grays are semi-transparent (and similar for color pixels).

Other Depth Fused Displays use two scrims stacked and spaced apart with two projectors projecting front layer and back layer content onto the appropriate scrim. The two layers also visually combine additively. The front and back layers' contents are semi-transparent and low-contrast.

A compact Depth Fused Display use a stacked and spaced combination of a front transparent LCD without a polarizer and a back LCD monitor without an analyzer [3]. Depth fusion is a result of the additive combination of the polarization rotation angles between the two spaced displays, which appears as if the luminances of the two layers are added.

Pure Depth also has a depth fused Dual Layer Display composed of a transparent emissive layer (e.g. edge lit scattering plastic) between the front transparent LCD monitor and rear LCD monitor [4]. The transparent emissive layer backlights the front transparent layer, which visually combines additively with the back layer. No switching of the backlight or content is used.

Depth Fused Displays tend to have small fields of view due to parallax creating too large a misalignment between the two layers. Increasing the number of layers increases the field of view. Other techniques include layering autostereoscopic displays [5] or angularly tiling depth fused displays using optics.

Depth fusion also fails when the two layers' are too far apart that the viewer cannot fuse the depths. This may even occur for small layer separations, if the display is viewed up close.

2.3 Multilayer Displays

Multilayer Displays have multiple image planes (e.g. foreground, midground, and background planes), and typically produce volumetric images of 3D objects by placing cross-sections of the object at each layer. The use of multiple layers provides smoother looking objects (with or without depth-weighted blending) and a larger field of view for apparently opaque objects than dual layer displays.

The LightSpace Depth Cube uses a spaced stack of twenty (20) liquid crystal shutter panels and a high speed projector [6]. Each shutter panel is switched from transparent to scattering in sequence with the appropriate image projected for that one scattering layer. The Depth Cube uses depth anti-aliasing, a form of depth-weighted blending, to smooth the transition between layers.

Lumierie's photostereosynthese [7] was an early attenuation multilayered display in which stack of transparencies, each with a cross section (or small depth of field image) of an object, created a volumetric image. Modern attenuation multilayered displays use multilayered LCDs [8] and optimally compute the attenuation of each display (treating each LCD as a programmable attenuator) via tomography (integrated attenuation along a light ray path through the volume) to produce the desired light field (multiview images) emitted by the display. Unlike depth-weighted blending, tomographic methods do not require depth maps to compute. Similar to depth-weighted blending, the field of view is limited. This limitation has been mediated by using a switching directional backlight to allow multiple tomographic projections to be displayed in sequence with each projection only visible from a limited view.

2.4 Floating Images in Layered Displays

The “Volumetric Display Using a Rim-Driven Varifocal Beamsplitter” uses varifocal optics to relay real images of a high-speed selectively backlit transparent monitor at different depths [9]. This display exhibits correct accommodation-vergence cues of twenty-four (24) floating layers the user can interact with. Multiplanar images have been created, as well as three-dimensional hulls of objects. For occlusion capability, the varifocal display’s monitor is replaced with a multiview integral display whose real image is optically scanned in depth [10].

Immaterial Depth Fused Displays project images onto layered fog screens [11]. The use of a non-solid screen allows users to interact with both layers. IR cameras track a single user to ensure the layers are visually overlapping correctly as the viewer moves.

Both Depth Fused [12] and attenuation multilayered displays [8] report the ability to have layers float outside their stack of LCD layers. The latter method produces different images in different viewzones creating a stereoscopic image of the floating layer. These floating layers are not composed of real focused/scattering points of light at different depths and hence likely do not have correctly coupled accommodation-vergence cues for a realizable number of viewzones.

We propose a Switching Dual Layer Display with a dynamic mask that provides high-contrast front layer content with programmable opacity that is independent of the back layer content. Besides discrete planes, apparently smooth volumetric objects may be displayed using opacity-based depth blending between layers. This proposed display is also capable of displaying a floating front layer whose content may selectively occlude the physical back layer. A multilayer extension will also be described.

3. METHOD

3.1 Switching Dual Layer Display

The Switching Dual Layer Display uses two stacked-spaced LCDs (see figure 3a); however, the layer content is time multiplexed using displays with fast refresh rates (less than or equal to 5ms refresh). The two monitors sequentially, oppositely, and synchronously alternate between content and a white image.

In the first state, the back layer displays content and the front layer is transparent (displaying white). The back layer content is visible. In the second state, the display switches; the back layer displays white and the front layer displays its content. The back layer acts as a backlight for the front layer, so the front layer content is visible. A white front layer object can now appear over a black back layer. The front layer still appears low contrast and semi-transparent over bright back layer content (see figure 3b). With the advent of 120Hz 3D capable LCD displays, each layer can be displayed at 60Hz, fast enough to avoid flicker.

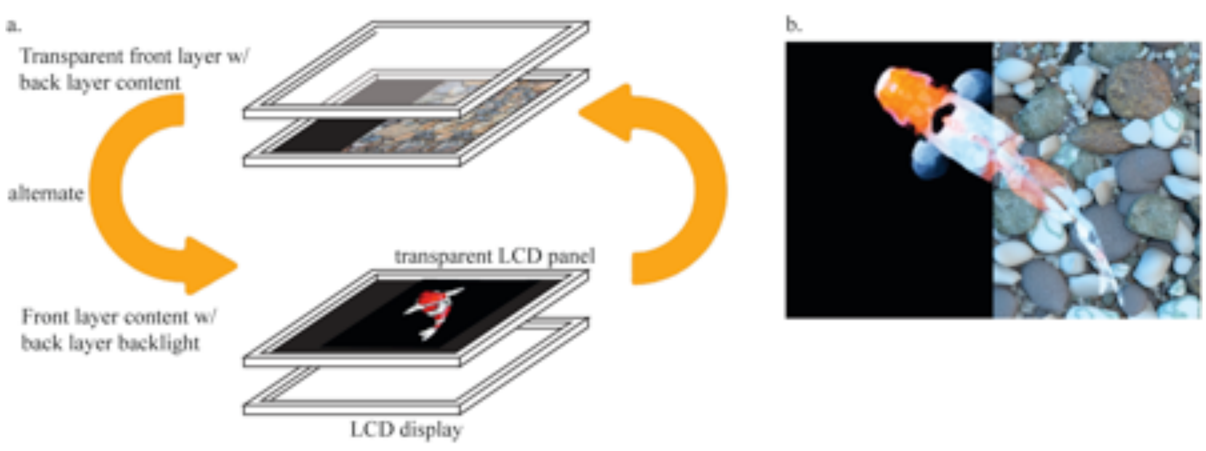


Figure 3a. A Switching Dual Layer Display alternates between front layer content with back layer backlight, and clear front layer with back layer content. b. Stacked LCDs combine additively. Front layer content appears over dark background content (left), and front layer content appears semi-transparent and low-contrast over bright background content (right).

3.2 Front Layer Mask

The front layer content can be made opaque and high contrast (white to black luminance levels) making it independent of the background content.

In the first state, the back layer displays content and the front layer displays a mask (white where transparent, black where opaque, and gray where semi-transparent). The back layer content is occluded by the front layer mask. In the second state, the displays switch and the back layer displays white and the front layer displays its content. The back layer acts as a backlight for the front layer, making the front layer content visible.

The front layer mask blocks the background content making the front content appear opaque. The front layer mask provides a black level for the front layer content, making the front content high-contrast. The front layer content and mask are generated on the same display, so are they always aligned and the monitors do not need calibration to each other.

For two discrete layers, the time multiplexing of content and backlight/transparency provides two independent layers of high contrast 2D content with variable opacity of the front layer, viewable by many observers over a wide-field of view. Disocclusion of the back layer content is possible with change in viewpoint.

The LCD panels need response times less than 10ms so each sequential frame has a clean complete image. LCD scan their image from top to bottom [13]. At some instances in time, two sequential frames are displayed simultaneously. For displays with slower response times, there are always two sequential images on the screen at the same time. This makes the mask ineffectual, and makes the images low contrast. For displays with faster response times, there are extended periods where only one image appears.

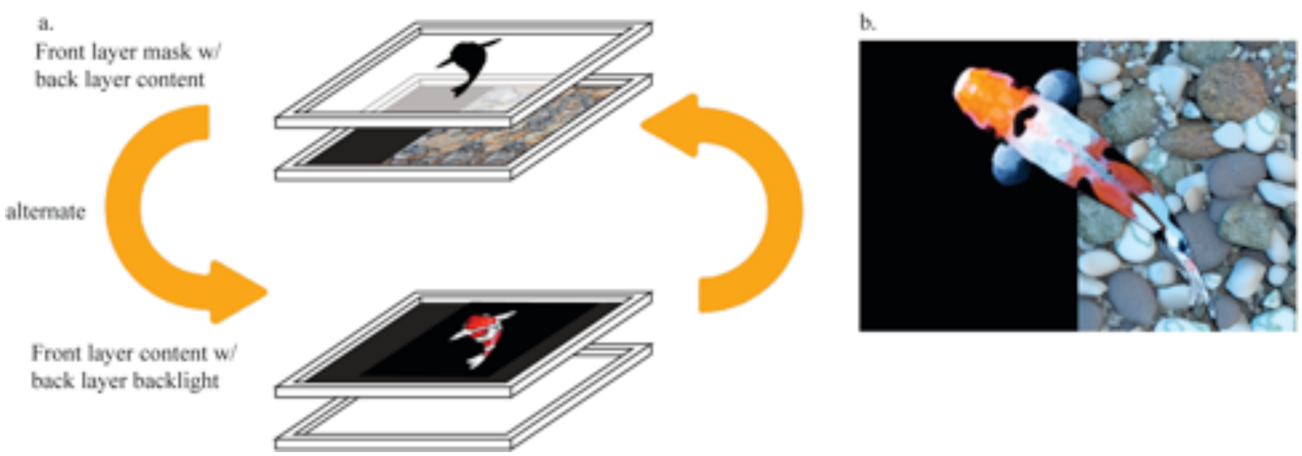


Figure 4a. A Switching Dual Layer Display with a Dynamic Mask alternates between front layer content with back layer backlight, and front layer mask with back layer content. b. Front layer is independent of back layer content. Front content appears over dark background content (left), and front layer content appears opaque and high-contrast over bright background content (right).

3.3 Opacity Depth Blending

For a 3D object whose thickness spans both layers, the object would appear to be separated into two cross-sections, one on each layer. Using depth-weighted blending, the 3D object can be made to appear to be contiguous in depth, but viewable over a reduced field of view. Virtual pixels can be placed at depths between the layers to increase the apparent number of layers by splitting the virtual pixel's luminance between the front and back layer proportional to its depth. This is described as depth anti-aliasing in the Depth Cube and as depth fusion in Depth Fused Displays. The Switching Dual Layer Display is also capable of splitting the luminance between the switched front and back layer content to achieve depth-weighted blending.

The Switching Dual Layer Display may also use the mask with the switched content to achieve a different means of blending the layers in depth. Both the opacity and luminance of the foreground pixel may be modulated based on depth, while the corresponding background pixel remains at full luminance. The result is a selective combination of multiplicative and additive blending. The semi-transparent mask multiplicatively attenuates the background pixel which is then additively blended with the foreground pixel. Unlike other forms of depth-weighted blending, a pixel located at the front layer will be opaque with full luminance regardless of viewing angle.

3.4 Real Images

It is possible to make one layer float above the other, such that viewers may pass their hands through the floating layer to touch the layer behind it. This allows users to interact with the entire volume rather than just the front surface. To accomplish this, two stacked and spaced displays are used with relay optics (e.g. spherical lens, Fresnel lens, or concave mirror) placed between them.

In the first state, the relayed display shows foreground content, and the transparent display is clear (shows white). The lens relays the image of the relayed display through the clear transparent display. The viewer sees a floating real image of the relayed display (with foreground content) in front of the transparent display (see figure 5a).

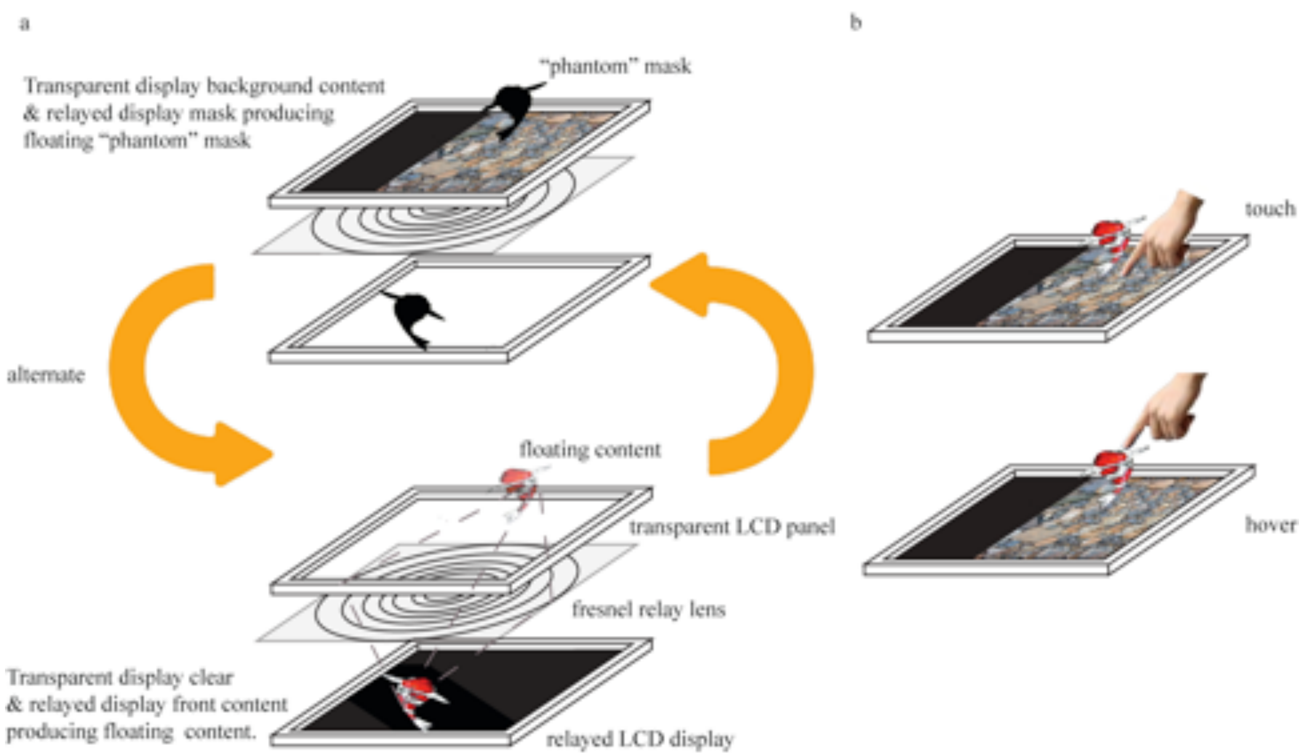


Figure 5a. A Floating Switching Dual Layer Display uses a relay optic between transparent LCD panel stacked and spaced over a LCD monitor. The display alternates between front layer content on the relayed monitor with the transparent layer clear, and front layer mask on the relayed monitor with back layer content on the transparent display, creating a phantom mask. b. The front layer floats above the back layer content allowing the user to interact with both layers. (Content appearing outside the display boundaries are shown for illustrative purposes only.)

In the second state, the displays switch and the relayed display shows a black mask of the foreground content over a white field, and the transparent display shows the background content. The white field acts as a backlight for the transparent display so that the transparent display's image (the background content) can be seen. The black mask will be relayed through and in front of the transparent display, appearing as an opaque floating "phantom" (black object) above the background content. The viewer may look around the phantom to see the background, but not through it.

For any viewpoint in which a ray passes from the eye, through the phantom, and through a point on the background content, that ray will land on the mask on the relayed display. No light will illuminate the background content for that position and viewing angle. From a different viewing angle for a ray that doesn't pass through the phantom, the ray passes through the point on the background content and will land on white content on the relayed display. The background content will be backlit and visible for that position and viewing angle. Note the same point on the background content may be illuminated and visible for one viewpoint but not from another.

The phantom acts as a mask for the floating color content. It blocks the background content (shown on the transparent display) making the foreground content opaque while also allowing disocclusion. It also acts as an aligned black silhouette to increase the foreground content contrast.

The user can accommodate/focus on either the floating layer or the background content. The user can pass his/her hand through the floating image and touch the background content (see figure 5b). The foreground content and its mask are generated on the same relayed display and pass through the same optics, so they are always aligned even in the presence of optical aberrations from lenses or mirrors.

3.5 Switching Multilayer Display

Multiple monitors can be stacked and spaced to produce a Switching Multilayer Display. This configuration allows for multiple planes of content, or more depth weighted blended levels with a larger field of view. The switching sequence of content, backlight, and masks is such that each layer content is backlit in turn and has appropriate masks in front of it.

A switching three layer display, with foreground, mid-ground, and background layers, would require a three state switching sequence. In the first state, the back layer displays content and the middle and front layers are masks (displaying white where transparent, grey or black for the masks). The viewer sees the back layer content masked by the middle and front layer mask. In the second state, the displays switch and the back layer displays white, the middle layer displays its content, and the front layer displays its mask. The back layer acts as a backlight for the middle layer, and the front layer's mask occludes the middle layer. In the third state, the back and middle layer display white, and the front layer displays its content. The back layer acts as a backlight for the front layer, the middle layer is transparent allowing the backlight to illuminate the front layer content. The sequence repeats quickly enough that the viewer perceives a single combined image.

Since the display is time multiplexed, the time to display an entire sequence would increase linearly with the number of layers. For a three layer display using monitors driven at 120Hz, the entire sequence would be repeated forty times a second, possibly resulting in slight flicker. Due to color filters, the layer's images on would be attenuated as they pass through multiple layers.

4. IMPLEMENTATION

4.1 Dual Layer Display

A Dual Layer Display is constructed using two 55-inch Samsung 3D capable televisions (UN55C7000) with 2ms response times. One television is made into a transparent television by removing its backlight, then it is framed and positioned seven inches (7”) in front of the other television (see figure 6).

Foreground (swimming koi) and background (rock wall) imagery are CG prerendered separately each at 1280x720 pixel resolution. The koi is mostly white with red and black patches. The rock wall is illuminated with a virtual spot light, so one side is well lit and the other is in the dark. The foreground image is displayed on the front television, and the background image is displayed on the rear television.

Figure 7 shows an image of the display with the koi half over the brightly lit background, and half over the dark background.

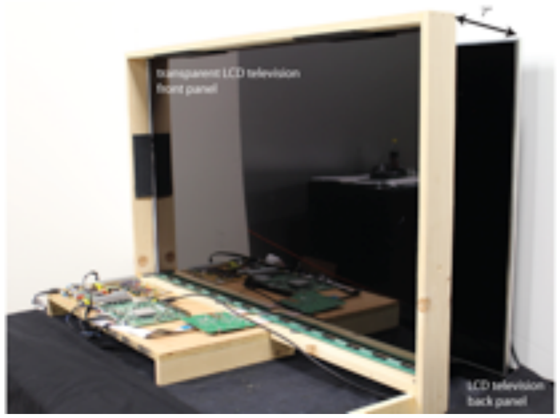


Figure 6. A Switching Dual Layer Display using two stacked and spaced 55” LCD televisions.

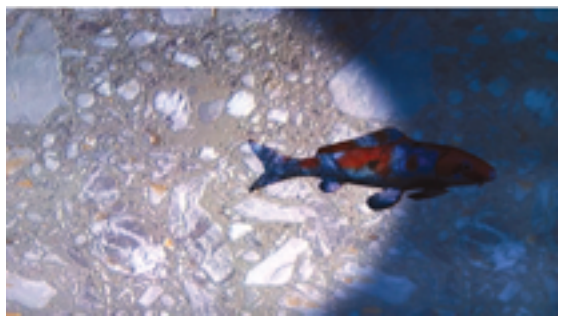


Figure 7. Image from the Switching Dual Layer Display acting as a basic Dual Layer Display (without switching), where front and back content are multiplicatively blended. Front layer content does not appear over dark background content, and appears semi-transparent, dark and low contrast over bright background content.

4.2 Switching Dual Layer Display

To implement the Switching Dual Layer Display with a foreground mask, the setup of the Dual Layer Display from §4.1 is retained; only the content is changed. The two televisions are set to frame sequential 3D mode. Foreground (swimming koi) and background (rock wall) imagery are CG prerendered separately each at 1280x720 resolution. The two movies and two blank images are tiled together into a 2560x1440 resolution movie using Premiere (Adobe). The upper left quadrant contains the foreground movie, the lower right quadrant contains the background image, and the remaining quadrants are blank white (see figure 8a).

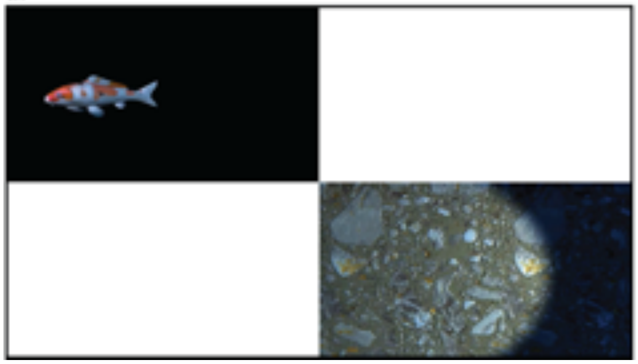
The resulting movie is played using Bino, an open-source stereoscopic video converter and player, on a HP Z800 computer with a triple head Quadro 2000 (Nvidia) graphics card with each of two heads connected to one of the televisions of the Dual Layer Display. Bino takes the 2560x1440 movie, considers it a over-under double-wide 3D movie, and converts it to a quad-buffered frame-sequential double wide movie output across the two televisions (the left side displayed on the front television, and the right side displayed on the back television).

For one frame, the top half of the over-under movie is displayed: the left side of the double wide image contains the foreground content and the right side contains a white blank field. The back television displays the white image, acting as the backlight for the transparent front television displaying the foreground content.

For the next frame, the bottom half of the over-under movie is displayed: the left side of the double wide image contains a white blank field and the right side displays a background content. The front television displays the white image making it totally transparent to the back television displaying the background content. The two frames repeatedly alternate at 120Hz.

Figure 8b shows an image of the display with the koi half over the brightly lit background, and half over the dark background.

a.



b.

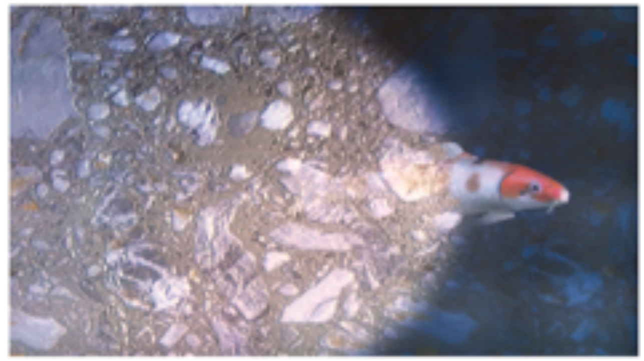


Figure 8a.Double-wide over-under image format for switching Dual Layer Display. Left frames displayed on front transparent LCD panel; right frames displayed on rear LCD monitor. Displays alternate between top frames and bottom frames at 120Hz. b.Image from the Switching Dual Layer Display, alternating between front layer content with back layer backlight, and transparent front layer with back layer content. Front and back content appear additively blended. The front layer content appears semi-transparent and low contrast over bright background content.

4.3 Switching Dual Layer Display with Mask

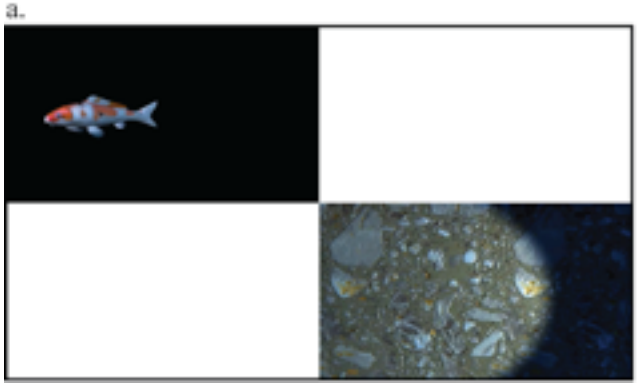
To implement the Switching Dual Layer Display with a foreground mask, the setup of the Dual Layer Display from §4.1 is retained; only the content is changed. Foreground (swimming koi), a matching foreground mask (black silhouette of the swimming koi) and background (rock wall) imagery are CG prerendered separately each at 1280x720 resolution. The three movies and a fourth blank image are tiled together into a 2560x1440 resolution movie using Premiere. The upper left quadrant contains the foreground movie, the lower right quadrant contains the background image, the lower left quadrant contains the foreground mask movie, and remaining quadrant is blank white (see figure 9a.)

For one frame, the left side of the double wide image contains the foreground content and the right side contains a white blank field. The back television displays the white image, acting as the backlight for the transparent front television displaying the foreground content.

For the next frame, the left side of the double wide image contains the foreground mask and the right side contains background content. The front television displays the mask image with the white areas of the mask transparent to the back television displaying the background content, and the black areas of the mask blocking the view of the background image. The two frames repeatedly alternate at 120Hz.

Figure 9b shows an image of the display with the koi half over the brightly lit background, and half over the dark background.

a.



b.

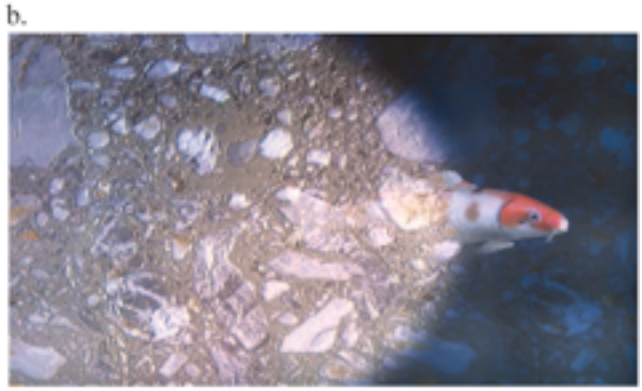


Figure 9a.Double-wide over-under image format for switching Dual Layer Display with Mask with front layer content (upper left), front mask (lower left), and background content (lower right). Left frames displayed on front transparent LCD panel; right frames displayed on rear LCD monitor. b.Image from the Switching Dual Layer Display with Mask, alternating

between front layer content with back layer backlight, and front layer mask with back layer content. Front and back content are independent. The front layer content appears high-contrast and can occlude background content.

4.4 Switching Dual Layer Display with Opacity Depth Blending

To implement the Switching Dual Layer Display with opacity depth blending, the setup of the Switching Dual Layer Display from §4.1 is retained; only the content is changed. A color image and aligned 11-bit depth map of a teddy bear is acquired using a Kinect (Microsoft). The depth map is scaled and biased so the adjusted depth range spans the depth of the visible portions of the teddy bear. The resulting adjusted depth map is encoded into an 8-bit grayscale image with white being nearest and black being farthest.

The foreground content image is computed by multiplying the color image with the adjusted depth map image. The foreground image mask is the inverted adjusted depth map image. The mask is grayscale exhibiting partial transparency. The background content image is the color image.

The three images and a fourth blank image are tiled into a movie using Premiere (Adobe) (see figure 10a). The upper left quadrant contains the foreground content image, the lower right quadrant contains the background content image, the lower left quadrant contains the foreground mask, and remaining quadrant is blank white. The resulting movie is played using Bino, which takes the over-under double-wide 3D movie and converts it to a quad-buffered frame-sequential double wide movie output across the two televisions. The front layer content is positioned so it aligns with the back layer content when viewed on-axis.

For one frame, the left side of the double wide image contains the foreground content and the right side contains a white blank field. The back television displays the white image, acting as the backlight for the transparent front television displaying the foreground content.

For the next frame, the left side of the double wide image contains the foreground mask and the right side contains background content. The front television displays the mask image with its grayscale values defining the amount of partial transparency to the view of the background image. The two frames repeatedly alternate at 120Hz.

Figure 10b shows an image of the opacity depth blended content on the display viewed on-axis.

Figure 10a. Double-wide over-under image format for Switching Dual Layer Display with opacity depth blending.
b. An image of the opacity depth blended content on the display viewed on-axis.

4.5 Floating Switching Dual Layer Display with Phantom Mask

A Floating Switching Dual Layer Display is constructed from a 36” diameter, 15” focal length concave mirror and two 23-inch Samsung 3D capable monitors (S23A950D) with 2ms response times (see figure 11). For ease of construction, the concave mirror is placed on the floor with its mirrored concave side facing upwards. One monitor is placed 30” above the vertex of the mirror and off-axis so its 1:1 relayed real image is also 30” above the vertex of the mirror and on the opposite side of the mirrors optical axis. The other monitor is made into a transparent display by removing its backlight and anti-glare film. The transparent monitor is arbitrarily placed seven inches (7”) below the real image of the other monitor relayed in the concave mirror. Both monitors are set to frame sequential 3D mode and to accept 720p 120Hz HDMI video inputs.

Floating foreground (swimming koi), matching foreground mask (black silhouette of the koi on a white background) and background (rock wall) imagery are CG prerendered separately each at 1280x720 resolution. The three images and a fourth blank image are tiled into a movie. The upper left quadrant contains the floating foreground movie, the lower right quadrant contains the background image, the lower left quadrant contains the foreground mask movie, and remaining quadrant is blank white (see figure 12a). The resulting movie is played using Bino, converting the over-under double-wide 3D movie into a quad-buffered frame-sequential double wide movie output across the two monitors: the left side displayed on the relayed monitor, and the right side displayed on the transparent monitor.

For one frame, the left side of the double wide image contains the foreground content and the right side contains a white blank field. The relayed monitor displays the foreground content and the transparent monitor is transparent allowing the relayed real image to pass through it and float in space.

For the next frame, the left side of the double wide image contains the foreground mask on a white background and the right side contains a background content. The relayed monitor displays the mask image on the white background acting as a selective backlight for the transparent monitor displaying the background content. The two frames repeatedly alternate at 120Hz.

Figure 12b shows an image of the display with the koi half over the brightly lit background, and half over the dark background.

Figure 13ab shows two views of the floating layer content over the background from two different viewpoints.

Figure 14a shows an image of the display with the focus on the background layer. Figure 14b shows the same view of the display with the focus on the foreground layer.

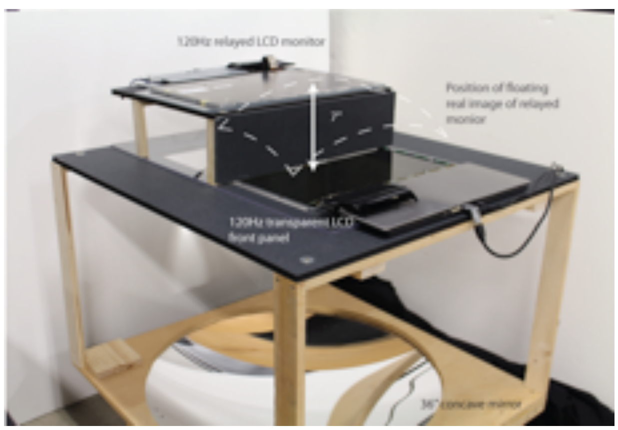


Figure 11. A tabletop Floating Switching Dual Layer Display using a 36" diameter, 15" FL concave mirror and two 23-inch 120Hz monitors. The mirror relays an image of the relayed monitor so it floats above the transparent monitor.

a. b.

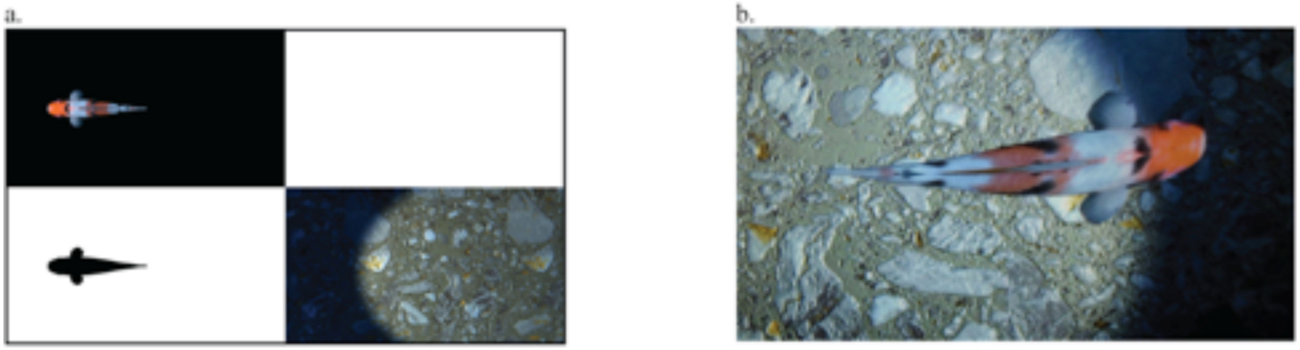


Figure 12a. Double-wide over-under image format for Floating Switching Dual Layer Display.
b. An image of the floating opaque hight-contrast front layer image occluding the background layer content.

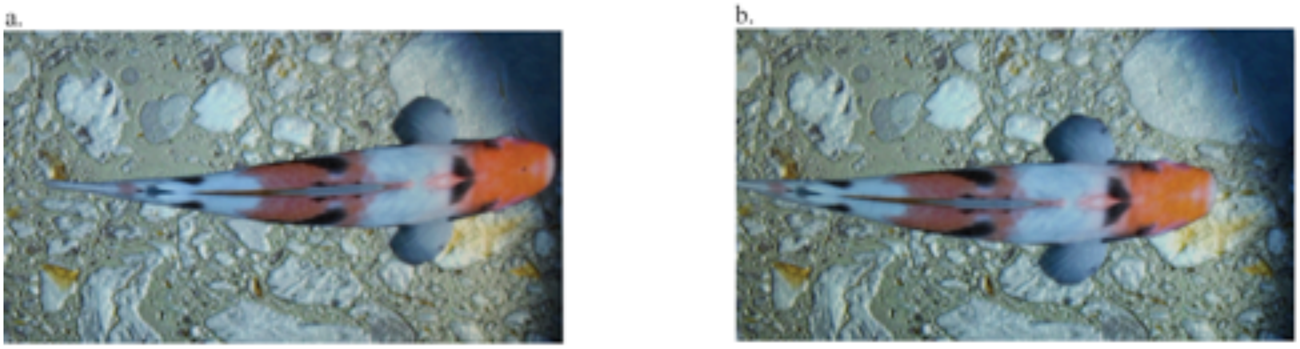


Figure 13a,b. Two views of a static frame displayed on the Floating Switching Dual Layer Display exhibit parallax, occlusion, and disocclusion between floating layer and background content as the viewpoint moves. The mask and floating layer content remain aligned even with parallax and optical aberrations.

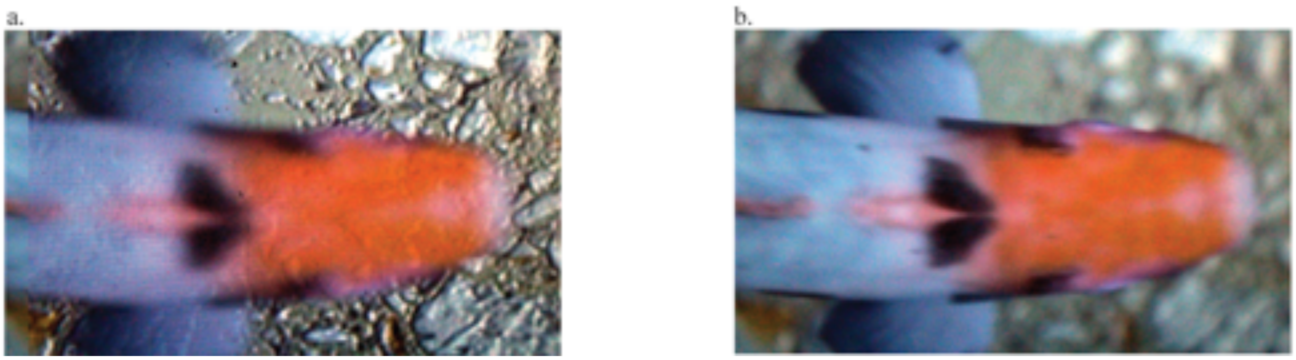


Figure 14a. A view of the Floating Switching Dual Layer Display focused on the background layer content with the foreground layer content out of focus.
b. A view focused on the foreground content with the background out of focus.

5. RESULTS

5.1 Dual Layer Display

As the example content placed on the basic dual layer display shows, the koi appears dark, low contrast and semi-transparent over the light background and does not appear over dark background content (see figure 7). The images' two luminances are combined multiplicatively because the front display acts as a transparency. This image is comparable to what a basic dual layer display would show without the white silhouette on the background.

5.2 Switching Dual Layer Display

With switching content, the white body of the koi appears over the dark background; however, the koi still appears low contrast and semi-transparent over the light background (see figure 8b). The images are similar to those of a dual layer display combined using a 45° half-silvered mirror. Although the two systems' images look similar, the switching dual layer display is more compact than a beam-split dual layer display; the former occupying only the volume of the stack, while the latter requiring the space for the 45° half-silvered mirror and monitors arrangement.

5.3 Switching Dual Layer Display with Mask

With the inclusion of the dynamic mask, the white body of the koi appears over the dark background and the koi appears opaque and high contrast over the light background (see figure 9b). Because the front display alternates between the content and mask, they always stay aligned. The foreground content is visible and occludes the background even when viewed far off-axis. The foreground content and mask do not depend upon the background content (other than the blank white backlight frame); therefore, the front and back displays do not need to be carefully aligned or calibrated to each other. Disocclusion of the back layer occurs naturally with changing viewpoint without the need for view tracking.

Although the input to frame sequential 3D mode is at 60Hz, the television appears to be running at 120Hz without flicker. The television apparently double flashes or repeats frames. This is similar to the television's standard multiple flashing of 24Hz frame packed 3D formatted content to achieve 120Hz. Side-by-side, over-under at 60Hz, or frame packing at 24Hz were attempted, but conversion to 120Hz occurs independently on each television. As a result, the two monitors do not stay synchronized in these modes, even though two identical televisions (same make and model) were used. In frame sequential mode, the two monitors appear to stay synchronized indefinitely.

5.4 Switching Dual Layer Display with Opacity Depth Blending

Using opacity depth blending and when viewed from approximately twelve feet (12') away, the teddy bear appears to contiguously and smoothly span the depth between the front and rear televisions. The effect appears similar to depth fusion or depth anti-aliasing when viewed on-axis (see figure 10b). When viewed off-axis, the layers become misaligned and the bear becomes blurry, then looks similar to a multiplanar image because of the variable opacity. A typical depth fused image viewed off-axis appears blurry then breaks down into a double image. With opacity depth blending, the teddy bear's nose, which is located near the front layer, is black and opaque. In an depth-fused display, the same black nose appears as a hole in the front layer, and off-axis the back layers would quickly appear through the hole.

5.5 Floating Switching Dual Layer Display with Phantom Mask

Using the relay mirror and phantom mask with the Switching Dual Layer Display, the front layer is opaque and high contrast floating above solid appearing background layer content (see figure 12b). The front layer floats 7" above the back layer. The floating image is opaque and occludes the background, but the background can be revealed by shifting the point of view (see figure 13a,b). Even with the back layer at arm's reach, the user can easily and naturally focus and verge on either front or back layer content (see figure 14a,b). The user may also pass his/her hand through the opaque floating layer to touch the back.

The mirror is placed on the floor with optical axis point upwards resulting in a table-top dual layer display. The display is viewable from all sides, however, there is one preferential side due to the arrangement of the monitors. When using a spherical mirror, relaying the image on-axis results in less aberration than relaying the image-off-axis. The relayed monitor is placed on-axis horizontally, and off-axis vertically, so there is less aberration in the horizontal direction. The viewer's eyes are naturally arranged horizontally for stereo vision, so there is less visible aberration when the display is viewed from the side in which the monitors are in this arrangement. This aberration is mainly field curvature -- the relayed image of the flat monitor forms on a slight bowl shaped surface concentric with the mirror. However, the relayed monitor is situated horizontally on-axis but vertically off-axis, so the front image content lies on a portion of a spherical quadrant. Although there is field curvature in the front layer image and none in the back layer content (because it is viewed directly on the flat transparent LCD), the front layer content and mask are always aligned because they are generated on the same monitor and pass through the same optical path.

The relayed image also looks more planar and parallel to the rear display near the top-center portion of the front floating display. Restricting floating content to be located over this portion of the display would reduce the effects of curvature and vignetting. Without adding additional optics, the actual field curvature can be reduced by increasing the focal length of the mirror, at the expense of increasing the overall size of the display assembly.

A mirror was chosen as the relay optic because glass lenses with large diameters were too heavy and couldn't easily be obtained. Fresnel lenses suffered from scattering and chromatic aberrations leading to low-contrast blurred images. Other optical systems are being investigated, such as a birdbath optical relay [7], to relay the image on-axis in both directions so there is less visible effects of curvature but with reduced luminance.

Although the presented content was prerendered, formatted, and played back using the Bino stereoscopic movie player, real-time content has been rendered and displayed on the Switching Dual Layer Display. Only standard rendering and tiling of color foreground content, a foreground mask, and background content is required without the need for further intensive computations. Although quad-buffering is desirable to ensure flicker-free display regardless of rendering update rates, frame sequential switching of content and mask/backlight has been used. Flicker and flashing occur if the rendering frame rate is not maintained at or above 120Hz.

6. CONCLUSION

The Switching Dual Layer Display uses temporal multiplexing of content, masks and backlight to produce new capabilities in Dual Layer Displays. High-contrast opaque front layer content is independent of back layer content. Front layer content is also capable of occluding the back layer content, and disocclusion occurs naturally with change in view point, observable for a wide field of view and multiple viewers. An extension to multiple layers has been proposed.

Although the display is ideally suited for multi-planar imagery, an optional use of opacity depth-blending allows for virtual interstitial planes and smooth 3D volumetric imagery at the cost of reduced field of view.

With the addition of the relay optics and a phantom mask, a floating layer with occlusion and coupled accommodation-vergence cues becomes possible. The entire volume of the display between floating and back layer is accessible for gestural and touch applications.

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