Portal: Design and Fabrication of Incidence-Driven Screens

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Abstract

We introduce "Portal", an optically-illusive screen panel with a grid of mirrors serving as its pixels. The RGB values of each mirror are obtained from its environment using the law of reflection. Specifically, we employ two images: one target image for the mirror panel, and another which serves as a palette to lend mirrors its RGB values. Our methodology uniquely orients each mirror in the grid to reflect a particular region of the palette image to a specified viewpoint. The holistic image from the mirror grid composes the target image. Within the process, we need to satisfy a set of rules to secure the maximum approximation of the result with the intended images.

We also propose a methodology to fabricate Portal using laser cuttings. As a proof of concept, we created a Portal equipped with 540 mirrors. Based on the physical and digital simulation results, we speculate possible applications of Portal in a range of disciplines, including computer graphics, art, and architecture.

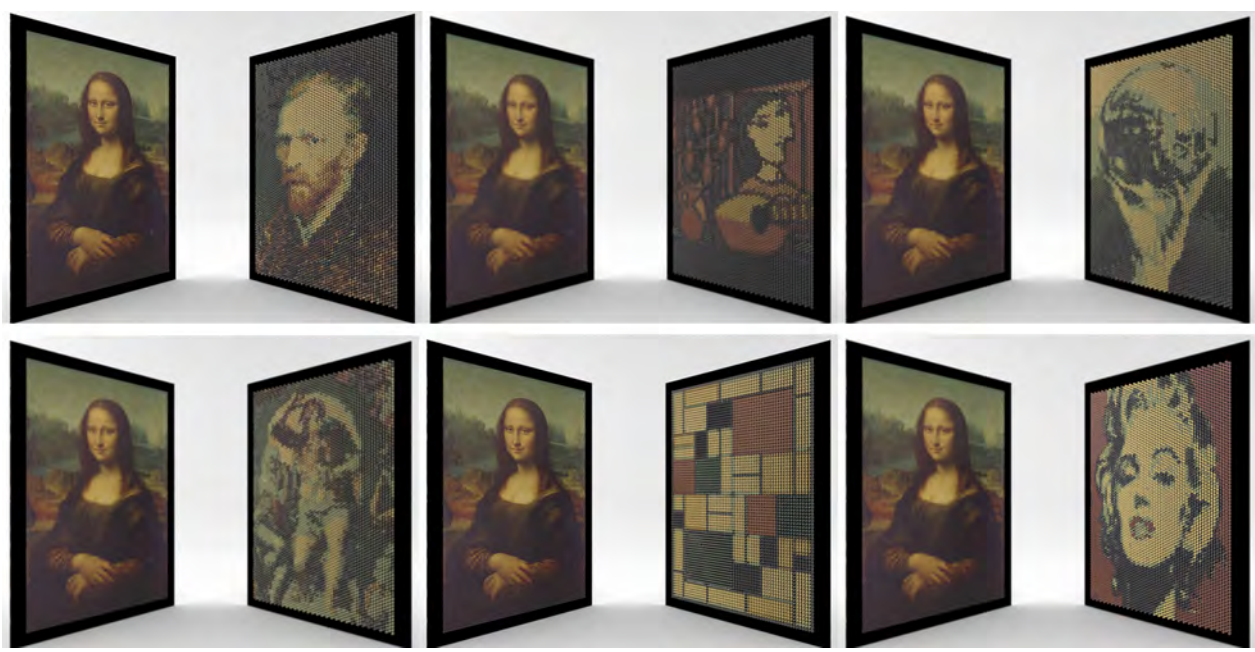


Figure 1: *Portal is a structure composed of cellular mirrors that creates an image by reflecting colors from another image that acts as a palette. Here, the Mona Lisa (left, in each panel) is our palette image that is used to produce other artworks.*

Introduction

"Remember that the Mirror shows many things, and not all have yet come to pass."

J.R.R. Tolkein

Our perception of the world is fundamentally influenced by our viewpoint. Prior work in graphics has explored the subjectivity of viewpoints through effects that emerge based on a unique *privileged point*. There are many examples of leveraging privileged points to create meaningful images by using shadow; even in shadow puppetry (Figure 2a), a performer's hand arrangements against a source of light create recognizable shadows on a background. Along the same idea, several artists have produced sculptures that cast meaningful shadows that are uniquely different from the sculpture or installation itself (Figures 2b and 2c). In computer graphics, this concept has been elaborated upon further, to automatically design and fabricate an object that generates multiple shadows along different directions [31] (Figure 2d).

(a) **(b)** **(c)** **(d)**

Figure 2: *Shadow puppetry (a), Wire sculpture by Matthieu Robert-Ortis (b), Dirty White Trash by Tim Noble and Sue Webster (c), and ShadowArt [31] (d).*

In these shadow examples, the privileged point is the source of light; however, it can also be the point where hidden images are revealed to a viewer. We can use other perceptual techniques – like reflection – to produce images that are not apparent from the source object itself. In literature, characters encounter magic mirrors that show them distant objects or scenes from futures that do not yet exist (e.g., Galadriel's mirror from *The Lord of the Rings*, Figure 3).

Figure 3: *Mirror of Galadriel, by Alan Lee, 1992.*

Inspired by these components – privileged point and reflection – we designed and fabricated "Portal", a structure composed of a grid of mirrors. These mirrors, viewed from a specific viewpoint, collectively reflect and reconstruct a meaningful *target* image that does not exist in the environment. To reproduce this image, the mirrors are meticulously oriented towards a *palette* image which is the source of color for each mirror pixel (see Figure 1).

The main visual attribute of Portal is a screen panel composed of cellular mirrors arranged along a grid. The color of each mirror is obtained from the palette considering the law of reflection. Our proposed

methodology preserves the features of the target image as much as possible. This is plausible by searching within the palette to find certain areas with specific colors and assigning those colors to each cellular mirror in the Portal. Since finding the exact desired color might be a futile attempt, our method alternatively finds the areas of the palette with minimal color discrepancies, and links them to the corresponding color on the target image. This search and assignment takes place under a privileged point towards Portal, meaning that Portal generates the target image when it is seen from a specific viewpoint.

Since Portal is a precise optical device, any degree of deviation from the privileged point, results in the imperfection of the generated image. Accordingly, to improve Portal's functionality, we have provided solutions to pick colors from regions that are more uniform and less susceptible towards slight viewpoint perturbation.

In this paper, we offer two contributions: first, we present the Portal technique as an optically-illusive structure that generates an image that does not exist in the environment. Second, we propose a fabrication strategy, using accessible machinery and materials, to produce real-world Portal structures. We also discuss the challenges and solutions we faced throughout the process.

The paper is organized as follows. We first discuss related work. Next, we describe the methodology and introduce notations. There is also a section, devoted to detailed fabrication strategies, followed by a section to discuss results and limitations. Finally, in the last section, we conclude with proposed future research.

Related Work

Although our problem statement is novel, there exist related works, tackling similar problems in computer graphics as well as art and architecture. As the construction of our structure is based on the light and reflection phenomena, we first discuss related works that try to manipulate light (shadows and reflections) to produce optically-illusive effects. Next, we review a category of anamorphic, and privileged-point-oriented works in which one object can resemble multiple visual and physical paradoxical characteristics under distortion, transformation, or reflection, when viewed from different privileged points (multi-character objects). Eventually, we highlight a number of recent advances in computational fabrication to suggest the possibilities that these techniques offer (computational fabrication).

Light and Shadow

An interesting line of research has been spent on the study of lights and shadows to reproduce a given image. For instance, fabricating surfaces with controlled appearance has been the subject of several previous works [27, 24, 29, 37, 4, 32, 33]. In these works, the material property is modified at micro scale in order to replicate a specific image or pattern on a surface under light. In this line of work, SHADOWPIX [5] is the most related research to our application, where one single fabricated object produces several images under different light directions.

Although related, the main idea of these works is different from ours as we are making a screen composed of cellular mirrors to generate an image from another given image by means of reflection. In addition to our work, the idea of cellular or micro mirrors has been also used in some other applications with completely different purposes. For instance, Hoskinson et al. [17] have used micro mirrors to improve the contrast and brightness of conventional projectors by reallocating the light of dark parts to the bright parts that need improvements in contrast.

As mentioned earlier, reflection and shadows are tightly related. A number of research works have investigated the potential of shadows in generating fascinating structures. For instance, Mitra and Pauly [31] have introduced ShadowArt in which an object is generated, capable of having meaningful shadows under lights from different orientations. To make such a structure, they find the intersection of a number of given images under various privileged points (e.g. directional lights) in a 3D visual hull to construct a 3D structure

with shadows the same as the given images. The idea of manipulating shadows to reconstruct a given image is also used in [41] in which perforated lampshades are constructed so that their shadow produces a given image. To build such lampshades, a set of cylindrical micro structures are arranged on the lampshade to control how much light passes through. Although our work shares some commonality with [41], as well as ShadowArt [31] and SHADOWPIX [5], we propose different approaches towards fabrication and application.

A number of relevant precedents to this research can be found in the arts, where artists harness light and the law of reflection to create meaningful forms and shapes. For example, there is an art installation at The Israel Museum, by artist Daniel Rozin, called Broken-Mirror, where a series of mirror fragments are thoughtfully oriented to reconstruct an image scattered across a wall [10]. In addition, Floating Point is the name of an urban-scale installation, designed by Esteban Serrano, in which three computer-controlled mirrors track sun path to form an elliptical pattern onto an adjacent building [15].

Moreover, there is a series of projects conducted by Art+Com studio where a team of artists and scientists collaborate to generate forms by means of reflections and light; two noteworthy projects are Anamorphic Mirror [2] and Á la Recherche [3]. The former is a wall-sized arrangement of mirrors, each of which in a particular direction, to construct a form when viewed from a certain point in space. The latter is a giant rotating sculpture covered with mirrors that compose a message using reflected light.

Multi-character Objects

This is a category of optically-illusive works in which the visual entity of an object contradicts its physicality. In other words, any object, other than its physical characteristic, manifested by the actual geometry, owns a variable visual characteristic, based on the viewpoint from which it is represented. The potential discrepancy between these characteristics incorporates an optical illusion. The core concept behind most of the works under this category is the principle of anamorphic projection. More specifically, one or more privileged points in space are defined through which a specific effect is perceived. The emergence of anamorphic projection has been thoroughly discussed in [34, 39, 40]. Nonetheless, there is a wide range of recent precedents in various disciplines, in which a visual effect is dependant on the audience's point of view. In addition to ShadowArt [31], and SHADOWPIX [5], we can refer to [35] in which an object inherits multiple meaningful visual attributes through multiple viewpoints. Moreover, there are research regarding an application of *collineation* [16], as well as a ray-casting technique [11] to generate anamorphic effects.

Anamorphosism has also been a remarkable subject in architecture. For instance, optically illusive architecture [19] is an architecture-oriented research toward manipulating perception of depth by suppressing three-dimensionality in a built environment. In addition, in [21] an anamorphic brick wall is designed that resembles a given image from a defined viewpoint. An in-depth technique to generate and digitally fabricate anamorphic effects on more complex surfaces is provided by [12]. Another approach in this field is an application of mirror-assisted anamorphic projection to reconstruct a set of 2D data distributed within an architectural space [18].

Artistically approaching the topic of anamorphic projection, we acknowledge "Wire Sculpture" by Matthieu Robert-Ortis, "Dirty White Trash" by Tim Noble and Sue Webster (Figures 2b and 2c), and also mirror-assisted optically-illusive works of Kokichi Sugihara [25], and Markus Raetz [30], to name a few.

Computational Fabrication

Computational fabrication is now prevalent in a wide variety of applications. For instance, in [28, 13] reversible shapes are reproduced as a jigsaw puzzle pieces so that one shape can be transformed into another.

Also, Chen et al. offer a fabrication method to fasten a set of patch elements together, to form a given surface [8]. Computational fabrication is, however, not limited to additive fabrication methods. For example, [6] presents laser-cut results of their proposed technique to synthesize vector patterns with visual appearance. In [7] an application has been defined that reconstructs a given mesh with wooden pieces, using a laser cutter.

Likewise, [36, 20] utilize 2D laser cuttings for physical visualizations.

Methodology

The inputs to our problem are a privileged point P, and two images: palette image I and target image $\acute{I}$. The goal of our work is to design a structure, which is an incidence-driven screen — or Portal — composed of a grid of cellular mirrors. Every single mirror m_i is assigned a unique orientation to reflect a specific region or block b_i of image I. Reflections of all cellular mirrors compose image $\tilde{I}$, when viewed from P. It is desired that image $\tilde{I}$ be as close as possible to target image $\acute{I}$.

Since constructing a structure with the same level of detail as a given image requires many tiny cells, we sample images with coarser cells to provide an approximation for target image $\acute{I}$. This also facilitates the subsequent fabrication process. Sampling takes place by averaging the pixel values covered by a cell on an image.

First, target image $\acute{I}$ is divided into a number of cells called c_i (see Figure 4). Each cell c_i corresponds to a cellular mirror m_i in Portal. It is desired that the colors that m_i attains, be close to the color of cell c_i in the target image. By default, c_i are chosen to be hexagonal in Portal. However, the core of our algorithm is independent of cell type and other cellular shapes can also be incorporated. Later in this section, we discuss the choice of cells based on the shape of the target image.

(a) **(b)** **(c)**

Figure 4: *Image I (a) is divided into a number of blocks b_i. Image $\tilde{I}$ (b) is produced by Portal. Each cell of image $\tilde{I}$ corresponds to a mirror on Portal. Target image $\acute{I}$ (c) is sampled coarsely by cells c_i. The color of each mirror m_i in Portal should be as close as possible to c_i.*

The palette image I is also divided into a number of blocks called b_i to facilitate the search over its color space (Figure 4). For each block, we save the average of pixel values of that block and its neighborhood. Then, to assign the right color to mirror m_i, our algorithm searches and selects a number of blocks on the palette (i.e. images I) whose colors are closest to cell c_i on $\acute{I}$. Among these blocks, the algorithm later chooses the one with more color consistency with c_i (i.e., lower variance). It is worth noting that our algorithm uses Euclidean colour difference metric, treating RGB values as coordinates in the space. However, perception-oriented metrics that are based on human's sight sensitivity could also be employed [9].

For b_i, we choose quadrilateral grids, since we do not modify image I and quadrilateral blocks simplify our calculations. However, other cells such as hexagonal cells are also applicable.

Law of reflection

To formulate and solve our problem, we take advantage of the well-known laws of reflection. The laws of reflection govern the reflection of light-rays off smooth conducting surfaces, such as a mirror. Essentially,

there are two primary statements in the laws of reflection:

- The incident ray, the reflected ray, and the normal of the mirror lie in the same plane ρ.
- The angle of the incidence ray, θ, with respect to the normal n is the same as γ, the angle that the reflection ray constructs with the normal n (i.e. $\theta = \gamma$)

The laws of reflection are the core of many rendering techniques, most notably ray tracing [38, 1]. In this work, using the laws of reflection, a ray is cast from point of view P and the plane ρ_i of each cellular mirror c_i is oriented in such a way that the desired color from image I is sampled. We assume that the mirrors are fully reflective and environmental shading effects are negligible.

Structure

To sample image I and reconstruct image $\acute{I}$, Portal is built by a set of cellular mirrors m_i whose centers are placed on the centers of previously-generated blocks of image $\acute{I}$ (Figure 5). Since the number of cells corresponds to the number of blocks into which the images are divided, higher number of cells results in better approximation of image $\acute{I}$ but makes the fabrication process more difficult and expensive (Figure 6).

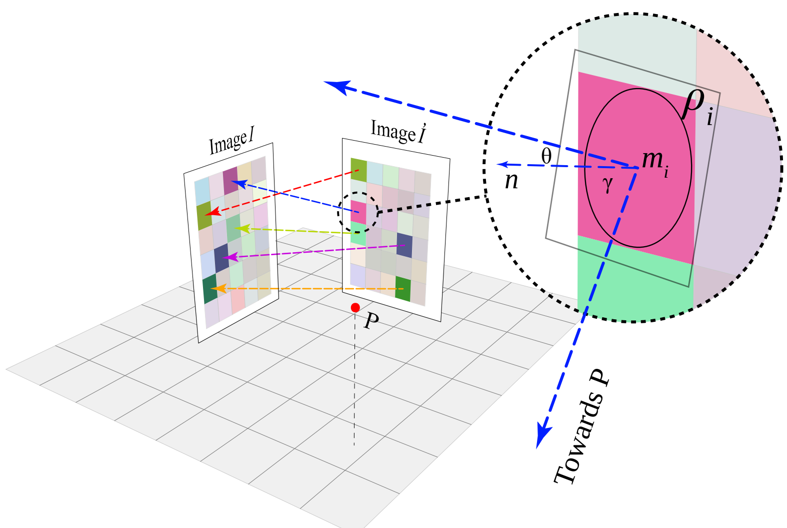


Figure 5: *For every block, hosting c_i, within image $\acute{I}$, the algorithm finds a matching block within image I. Next, m_i is oriented to reflect that specific block of image I to point of view P.*

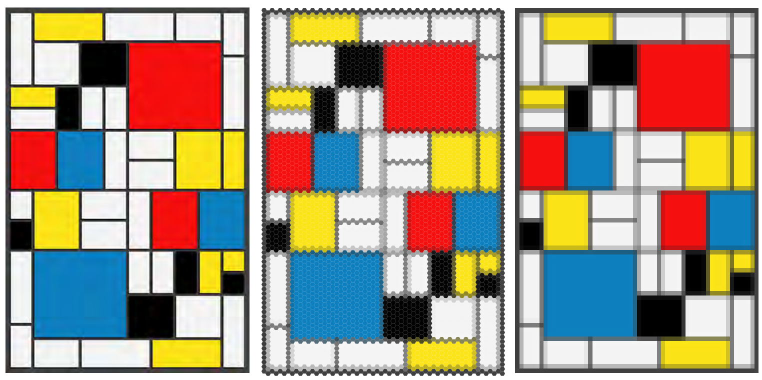
Hexagonal grids have lower quantization error in comparison with quadrilateral and triangular grids [23]. However, since our methodology is not dependant on the form of the grid, we can choose the grid form with respect to features of image $\acute{I}$. For example, in specific paintings with sharp edges and straight lines, such as compositions of Dutch painter Piet Mondrian, representation through a quadrilateral grid is more accurate as opposed to a hexagonal grid (Figure 7).

Point of View

The privileged point P can be selected anywhere as long as both images are visible within human's cone of vision, and there is no occlusion from one image to another. Therefore, we define it to be on the bisector plane of the two planes hosting image I and image $\acute{I}$. Another concern here is to ease the fabrication process. Accordingly, we set P to be equidistant to both images such that when an individual is looking through the privileged point, both images remain within their arm's reach.

(a) (b) (c)

Figure 6: *Vincent van Gogh self-portrait, 1887 (a). Higher resolution is plausible through higher number of blocks and consequently higher number of mirror cells. Images generated by our method with 4800 blocks (b), and 540 blocks (c).*



(a) (b) (c)

Figure 7: *Composition, by Piet Mondrian (a). A hexagonal grid (b) may fail to flawlessly represent straight lines as opposed to a quadrilateral grid (c).*

Mirror Orientations

To find the best orientation for each mirror, we need to consider several factors. First, any degree of deviation from the privileged point would cause imperfection of the result (i.e., color of m_i). To tackle this issue, we optimize the match-finding portion of the methodology to maintain the readability of Portal, once viewed within a privileged space surrounding the privileged point P. Toward this end, for every block b_j of image I, the algorithm saves the average color (τ_j) of the block and its adjacent blocks. Figure 8 illustrates how this step affects image I by fading borders of colors and blending them together. This is equivalent to applying an averaging convolution filter to the image.

Next, these blocks, with their τ_j values, undergo match-finding process with those cells of the image $\acute{I}$ to assign the right block to mirror m_i. It is desired that a chosen block b_j (with average color τ_j) for mirror m_i will have small color difference with c_i. Meaning that we are looking for blocks b_j minimizing the following quantity: $E_{color} = |\tau_j - c_i|$. For each mirror m_i, a set of candidate blocks B are chosen. In practice, we choose ten blocks with the lowest E_{color} values.

After filtering many blocks by only considering their average color, we can now choose the appropriate block among blocks in B. Note that averaging the colors of a block may cause deficiency to the readability of

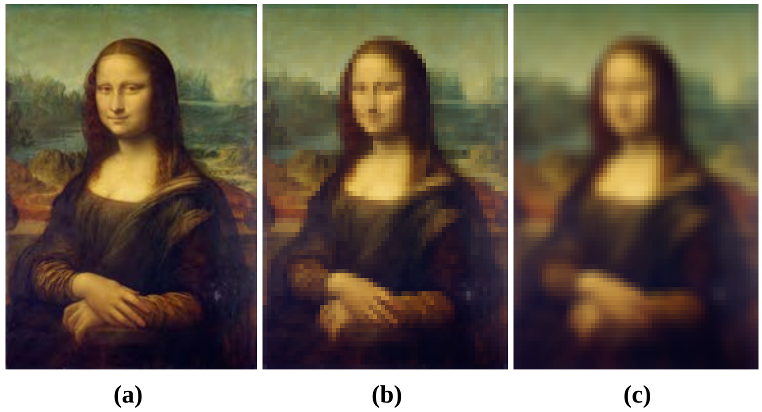


Figure 8: *Mona Lisa, by Leonardo da Vinci 1500s (a). Image I is generated with 4800 blocks, each of which is assigned average RGB value of its own pixels (b), and average RGB value of a neighborhood, embracing the block and its adjacent blocks (c).*

Portal. For instance, in an extreme scenario, the average color of a block with a checker pattern is grey. However, every single pixel has extreme distance with the average. To replicate the correct and consistent colors in Portal, it is desired that each pixel p_k of the block $b_j \in B$ is close to its average. Deviation of each pixel from its average can be captured in an energy term called E_{smooth} which is equivalent to variance of the pixel colors in each block. E_{smooth} for b_j is defined as follows: $E_{smooth} = \frac{\sum_k (p_k - \tau_j)^2}{N}$, where N is the total number of pixels in block b_j and its neighborhood, and p_k are the individual pixels that are in block b_j and its neighborhood. Among blocks in B, we choose the block with smallest E_{smooth}.

In addition to these color-based energies, we could orient the cells to follow a smooth variation in the normal to avoid gaps between cells. This means that it is desired that the normal of a cell c_i be as close as possible to the normal of its adjacent cells. In our experiments, even without this consideration, our methodology provides a level of smoothness in the normals of the cells (further details provided in section "Results"). As a result, we did not consider this additional term for our algorithm.

Now that we know the block, each mirror needs to reflect, we can find the right orientation for each cellular mirror. Towards this end, we consider two vectors extending from the center-point of each cell c_i on the screen panel. One, hitting the center-point of the corresponding block on the palette, and the other one, targeting the privileged point. Having placed a mirror at the center-point of the cell c_i, and reorienting it in a way that its normal becomes the bisector of the two vectors, the mirror will reflect the corresponding block on the palette (Figure 5). Algorithm 1 summarizes the above discussion. In this algorithm we set M equal to 4800 blocks (80×60) to yield the results shown in Figure 1.

Fabrication

As mentioned earlier, the quality of the result of this work significantly relies on the utmost precision of the process. Accordingly, we use a subtractive fabrication method, and specifically 2D laser-cuttings, whereas it provides sharper edges and more accurate surfaces as opposed to additive fabrication methods (such as 3D printing), alongside being faster, cheaper, and more accessible [14, 26, 22]. Toward this end, we designed a notch-stem mechanism to be laser-cut out of flat sheet medium-density fibreboard (MDF). This snug-fit mechanism consists of a base, embracing notches, upon which stems are mounted. On top of the stems, mirrors are glued and fixed in their positions (Figure 9).

To secure the specific position and orientation of the mirrors, every notch must be uniquely oriented,

Algorithm 1 Palette image I, Target image $\acute{I}$, and privileged point P are given. This algorithm finds orientations (i.e., normals) n_i for each cell m_i.

```
Sample Image Í by M hexagonal cells, c_i;
Segment Image I into M number of blocks b_k;
Assign the average color of b_k and its four neighbors to τ_k;
for each cell c_i do
    Place ten blocks with lowest E_color values in set B;
    Choose block b_j from B with smallest E_smooth;
    Assign b_j to m_i;
    v is the vector connecting the center of m_i to b_j;
    w is the vector connecting the center of m_i to P;
    n_i is the bisector of v and w;
return all n_i's.
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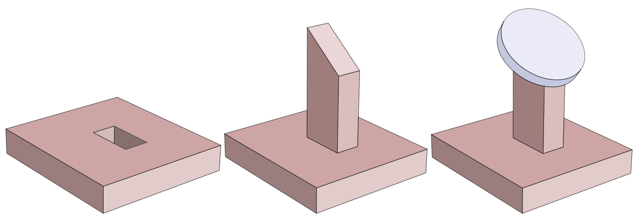


Figure 9: *The notch-stem mechanism. Mirrors are the only parts that need to be glued in their positions.*

and the top of each stem must be cut in a particular angle. To host notches, we define plane π, parallel to image $\acute{I}$ and behind it. Direction of each notch derives from $\vec{n}_i$ which is its corresponding mirror's normal. Next, having $\vec{n}_i$, projected on plane π (i.e. $\vec{n}_i'$), we extend a curve, on both sides, along $\vec{n}_i'$, and project it back towards the corresponding mirror. The intersection of each projection and mirror, returns diameter d of the mirror. The surface, confined with d and its projection on π (i.e. $\acute{d}$), forms a uniquely-tapered stem to hold the mirror. Regarding the dimensions, the projected diameter $\acute{d}$ refers to the length of each mirror's stem and notch.

Moreover, the material sheet thickness defines the width of the notches as well as the stems' thickness. In this fabrication process, we used MDF sheets with 5 millimeters of thickness. Figure 10 illustrates this entire process.

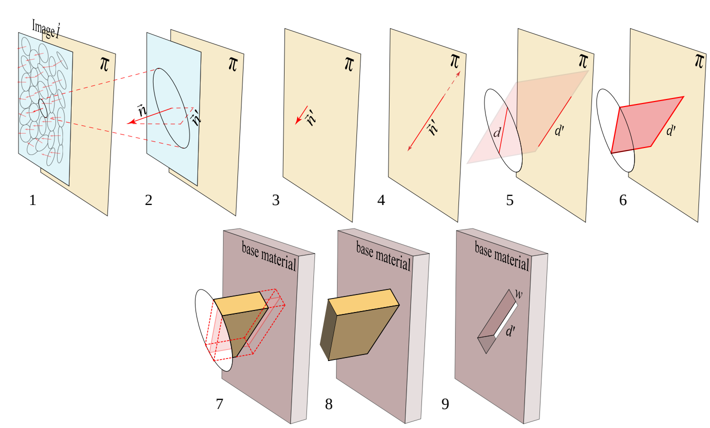


Figure 10: *Stems and notches are derivatives of the mirrors' normals.*

As stated above, we defined plane π behind image $\acute{I}$. The distance between π and the image $\acute{I}$, affects the height of the stems. Stems are designed to be perpendicular to their base. On the other hand, loose notch-stem connections may cause inclination of the stems, and therefore, imprecision of the mirrors' positions. We take two steps to avoid this issue as much as possible.

First, we run an experiment to achieve an efficient snug-fit joinery. In this regard, we inward-offset a notch outline in steps of 0.005mm, within the range of 0.000mm to 0.040mm, and then, in steps of 0.001mm, within the range of 0.020mm and 0.025mm. Next, we run an experiment to set the distance of the plane π to the image $\acute{I}$. Short distances make fabrication process harder due to the lack of hand-grip of the stems. Long distances, on the other hand, would put the precision at stake whereas any possible inclination of the stems would drastically change the mirrors' positions. Based on our experiment we set the distance at 15 mm.

As a proof of concept, we design and fabricate two small prototypes (Figure 11). We replace a grid of labelled holes instead of image I, and provide a checklist to correspond mirrors and holes. It is crucially important to label the joinery, even in these small prototypes with 25 unique stems and notches. To avoid lengthy labels, we divide the cells/mirrors to rows (r) and columns (c).

The labeling is also used to detect the right orientation of stems and notches, whereas any stem can be placed in its notch in two directions. Accordingly, we laser-engrave labels to the right side of the notches, as well as the front side of the stems. Another sign to indicate the orientation of the notches is the laser-engraved line representing projected normal $\vec{n_i}'$ on plane π (Figure 11).

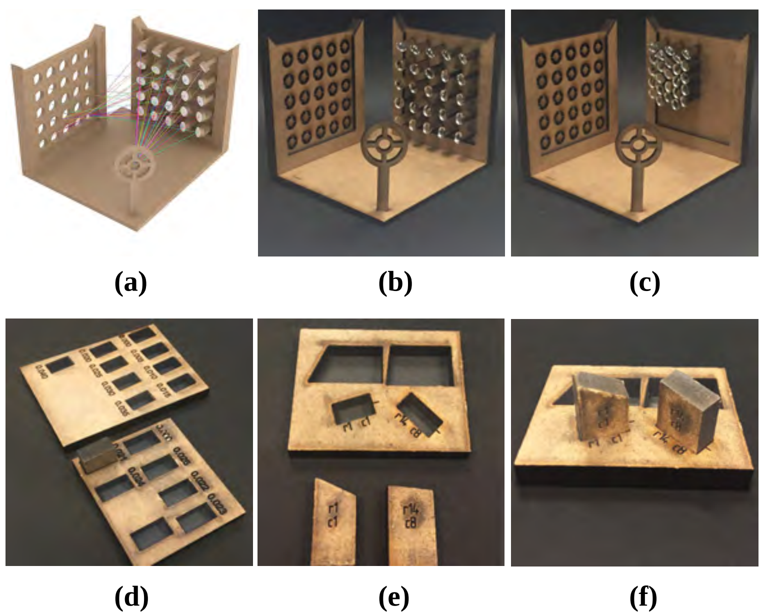


Figure 11: *A digital model with a quadrilateral grid (a). Its physical model (b). The second prototype with hexagonal grid (c). Based on our experiment, the ideal notch inward-offset for snug-fit joinery out of 5mm-thick MDF sheet is 0.021mm (d). Labelling on front side of the stems, and right side of the notches, as well as a line representing $\vec{n}_i'$ (e) and (f).*

Results

As established before, Portal harnesses the law of reflection to generate images through its grid of mirrors. We employed the iconic Mona Lisa painting, as the palette for Portal, to generate a number of classic paintings using 4800 mirrors scattered in grids (Figure 1). Type of the grids comply with features within the represented

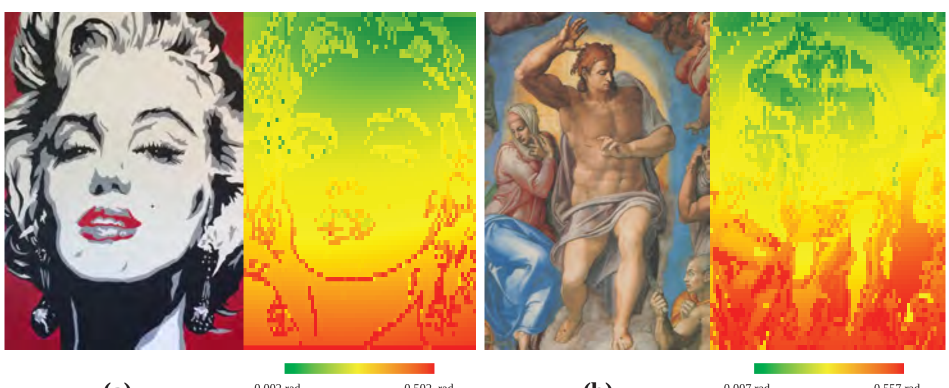
image. As shown in Figure 1, all Portals are equipped with hexagonal grids, except the one with quadrilateral grid representing the compositions of Dutch painter Piet Mondrian.

To improve the images generated by Portal, we performed a number of experiments. For example, we explored the possibility of introducing a privileged space surrounding our privileged point, aiming that our Portal does not fall apart, once viewed with slight deviation from the privileged point (Figure 12).

(a) **(b)** **(c)** **(d)**

Figure 12: *An image generated with slight deviation from the privileged point before optimization (a), after optimization (b), and the image generated from the privileged point (c). The target image, Homage To Picasso II, by John Nolan, 2007 (d).*

In addition, we discussed the concept of orientation smoothness, that refers to the difference between the normal of cell c_i and the normal of its neighbors. Accordingly, we provide a visual mapping from angles to colours that illustrates how much each mirror has to rotate from its default position (i.e. mirrors' normals being perpendicular to image $\acute{I}$) to reflect a specific portion of image I. As it is seen in Figure 13, the transition of colors within the spectra is smooth, in accordance with the color transition smoothness of the images. This resonates the consistency of mirrors' orientations within the Portal. Nonetheless, our algorithm excludes this parameter, and therefore we cannot confidently extrapolate the orientation smoothness, from a few tests of this work.



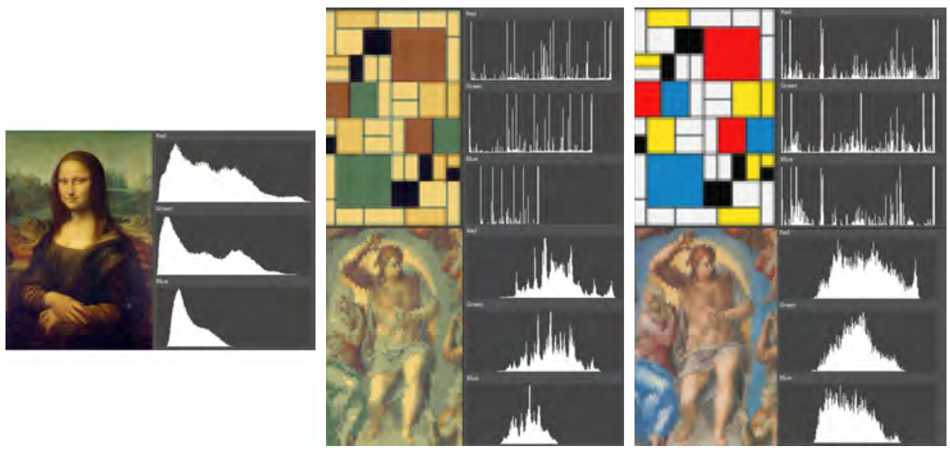
(a) **(b)**

Figure 13: *A visualization of mirrors' reorientation compared to their default positions. Source images: Hand-painted portrait of Marilyn Monroe, by Danny Raisor-Micheletti (a). The Last Judgment, by Michelangelo, 1541 (b).*

Moreover, our histogram analysis of the images, generated by Portal, shows that these images inherit certain characteristics from their parental image I and image $\acute{I}$. As shown on Figure 14, these constructed images have the color range, identical to the palette image I, while they receive shape attributes, represented by

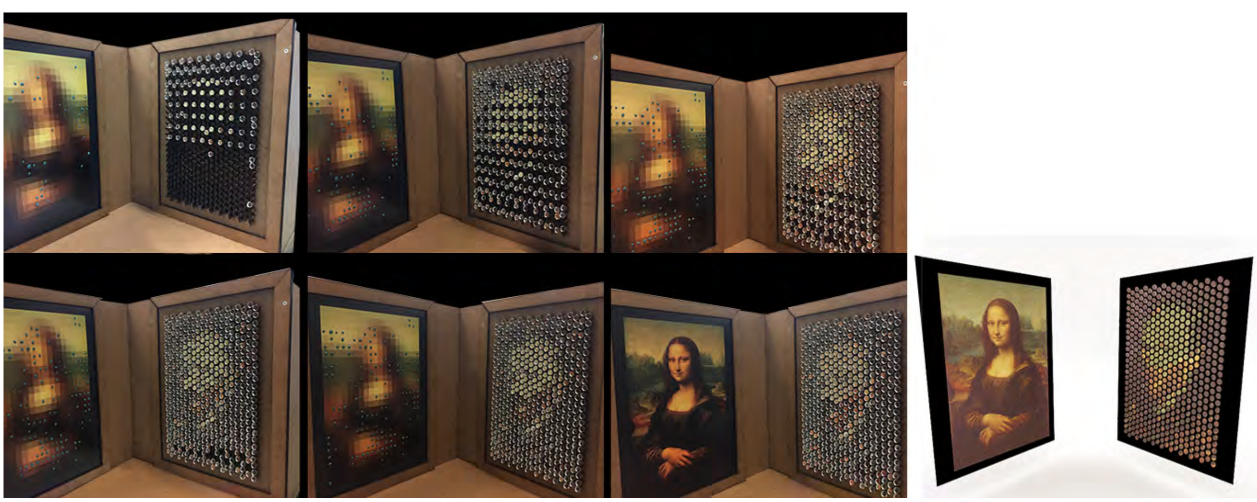
spikes in histograms, of the image $\acute{I}$.

Our work also casts light on various fabrication methods and, as a proof of concept, proposed a walk-through to fabricate a prototype using 2D laser cuttings out of MDF with 5 millimeters of thickness (Figure 15). In this prototype, we have designed a hexagonal grid of 540 mirrors, to maintain the aspect ratio of both image I and image $\acute{I}$. The entire model fits within a cube of 60 by 60 by 45 centimeters. Unlike the cutting time, that was barely three hours, the installation became a bit tedious (approximately ninety man-hours). This was due to the unforeseen impact of glue thickness on mirrors' positions. Accordingly, we had to take extra measurements to calibrate all mirrors and making sure they are all precisely oriented.



(a) **(b)** **(c)**

Figure 14: *Histogram analysis. An input image serving a palette (a), constructed images by Portal (b). Images that Portal aims to reconstruct (c).*



(a) **(b)**

Figure 15: *Portal equipped with a hexagonal grid of 540 mirrors, represents Vincent van Gogh's self portrait using Mona Lisa as its palette. The process of physical fabrication, and calibration using assisting dots on the palette, as well as the result in the lower right corner* (a), and the virtual model (b).

Conclusion and Future Work

As suggested by its name, Portal acts like a gateway that bridges between two media. Throughout this investigation, we benefited from a diversity of precedents, manifested by different disciplines. This provides an opportunity to speculate on possible application for the study. Inherently, optical illusions are engaging phenomena. Accordingly, we can approach Portal as a medium that effectively communicates with audience. As a future scope of our work, this triggers new studies in terms of social behaviour towards such art-forms.

Moreover, there are several ways in which the algorithm can be improved. More specifically, in the match-finding portion of the algorithm, we can set criteria to consider additional candidate blocks or explore the impact of perceptual color-spaces such as CIE L*a*b*. We can also search over the entire source image rather than discretizing it into blocks.

Another possible approach towards future work of this study is to upgrade Portal as a dynamic set-up where servo motors, or robotic arms are employed to reorient mirrors to generate an infinite number of images. Alternatively, the palette could be an animation on a digital display, and Portal transforms the animation into an entirely different animation.

In addition to the arts, architecture can also benefit from this work in various scales and environments. The scales can range from ornaments of interior spaces to glazed facades of the buildings, that are salient media to employ this application. Through the lens of computer graphics, Portal can serve as a key that establishes connection between two distinct concepts. One prominent example of these concepts would be the three-dimensional projection of Earth and its distorted, yet meaningful, two-dimensional projection.

Last but not least, Portal can take advantage of one historical application of anamorphic projection where hidden messages were embedded within a distorted image. Hypothetically by altering a few blocks of the palette, in a way that the palette remains relatively untouched, we might be able to make drastic changes within the image represented by Portal. This could found significant studies relevant to steganography domain.

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Image Credits

- Figure 2 and 3: Credits provided in the captions.
- Figures 6,7,8,12, and 13: Generated effects by the authors. Artforms' credits provided in the captions.
- All other drawings and images by the authors.

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