Breaking the Shower Glass

Gershon Elber
Technion, Israel Institute of Technology

Abstract

We present a simple method that is based on inverse ray tracing, to reconstruct the original image, given the image seen through a shower–glass. The simplicity of the presented approach is quite astounding, considering the wide spread use of shower–glasses as a filter for image blurring and distortion.

Keywords: Ray Tracing, Optics, Reconstruction.

1 Introduction

Computer graphics is a young, yet successful, field of research that has significantly promoted a whole variety of applications from simulation to animation and from visualization all the way to industrial movies. Computer graphics has been highly instrumental in the understanding and the emulation of the physics of optics, by bringing to life the ability to synthetically stimulate the most important sense for all, namely vision.

The success of synthesizing realistic and super realistic rendering is unquestionable nowadays. Photo realistic synthetic rendering is a common tool in contemporary movie making and television industries. Special computer graphics effects are also frequently employed with great success, at various places. Virtual reality and scientific visualization are two additional examples of applications that employ core technologies that were developed by computer graphics related research.

In the light of all this success, it is somewhat surprising, that the capabilities that were developed by the computer graphics community are almost unemployed toward the resolution of real life optical problems. Few exceptions can be found to this ignorance, such as the geometric design and simulation of progressive lenses in [2], that mostly employs differential geometry tools.

In this work, we investigate the use of the available computer graphics capabilities toward a different real life physical problem. Shower–glasses are designed with the intent to blur, distort and hide pictorial information, while giving away some low quality hints on the real imagery. Two types of shower–glasses are in frequent use. The first type is a white matted glass with a planar surface while the second is completely transparent but with a rough surface area. It is this second type of shower–glasses that we will be considering, in this work. Herein, we would like to investigate the possibilities of undoing this blurring filtering, reconstructing the original images. We will try to get a grasp at the data that is required toward a successful reconstruction, as well as the type of assumptions that must be made.

This paper is organized as follows. In Section 2, the proposed approach is presented, while in Section 3, some results are presented and several extensions are considered. Finally, we conclude in Section 4.

2 Proposed Approach

It is evident that very little can be improved in an image through a shower–glass without the exact geometry of the shower–glass and without a complete understanding of the optical behavior of the specific glass in use. We will therefore assume that the completely transparent glass in question has a rough surface area, yet it follows Snell's law [1] for the entire visible spectrum. Otherwise, one could split the spectrum into, say, the red, green, and blue domains, separately solve these three cases with different indices of refraction, and then superposition the three resulting images together. Finally, we will also assume homogeneous glass material. That is, a ray inside the glass moves in a straight line. In the ensuing discussion, we will refer to a glass that satisfies all these constraints as a *Uniform Shower-Glass* or *USG*.

Armed with these assumptions, a ray traversing the *USG* would bend only when it penetrates or leaves the glass. With an exact model of the shape of the surface of the glass, one could emulate the view of an object behind the *USG*. The (forward) ray tracing [4] is obviously feasible and could be efficiently computed. Figures 2 (a), 3 (a) and 4 (a) were constructed using forward ray tracing.

Nevertheless, the question one would like to consider as part of this work, is the inverse problem:

Problem 1 ***Image Reconstruction of a Uniform Shower–Glass*** *(***IRUSG***): Given a view of some geometry as seen through a* USG*, and the geometry of the surface of the* USG*, how well, if at all, could we reconstruct the image as if the* USG *was eliminated?*

Without loss of generality, assume that the view is orthographic in the $-Z$ direction. Consider the unit size direction vector of incoming ray $\mathcal{V}_{in} = (0, 0, -1)$. $\mathcal{V}_{in}$ hits the surface of the glass at some location $\mathcal{P}_{in} = (p^x_{in}, p^y_{in}, p^z_{in})$, changes direction and leaves the glass from a nearby location $\mathcal{P}_{out} = (p^x_{out}, p^y_{out}, p^z_{out})$, in a new unit size direction $\mathcal{V}_{out} = (v^x_{out}, v^y_{out}, v^z_{out})$. One can clearly compute $\mathcal{V}_{out}$ and $\mathcal{P}_{out}$ from $\mathcal{V}_{in}$ and $\mathcal{P}_{in}$, with the aid of the available geometry of the *USG*.

Notwithstanding, this forward ray tracing gives us a crucial hint at looking into the *IRUSG* problem. Without loss of generality, assume that the *USG* is aligned with the XY-plane. With $\mathcal{V}_{in} = (0, 0, -1)$ as before, $\mathcal{V}_{out} = (v^x_{out}, v^y_{out}, v^z_{out})$ gives us essential information as to the rate in which the image is distorted due to the *USG*!

A ray from the viewer's eye, $\mathcal{V}_{in} = (0, 0, -1)$, that hits the *USG* at point $\mathcal{P}_{in}$ will continue to search for the actual color of this pixel at direction $\mathcal{V}_{out} = (v^x_{out}, v^y_{out}, v^z_{out})$, emanating from

$\mathcal{P}_{out}$. $\mathcal{P}_{out}$ is known to be very close to $\mathcal{P}_{in}$ and is a direct function of the thickness of the *USG*. The location of the first object that $\mathcal{V}_{out}$ hits, if any, will be,

$$O = \mathcal{P}_{out} + (v^x_{out}, v^y_{out}, v^z_{out})\mathcal{L},$$

where $\mathcal{L}$ is the length of the path that was traversed in the direction of $\mathcal{V}_{out}$ from $\mathcal{P}_{out}$. In other words, a point $O = (o_x, o_y, o_z)$, on an object $\mathcal{O}$ and behind the *USG*, that is hit by $\mathcal{V}_{out}$, will appear to the viewer through the *USG* at the XY location of,

$$\left(o_x - v^x_{out}\frac{o_z}{v^z_{out}}, o_y - v^y_{out}\frac{o_z}{v^z_{out}} \right),$$

due to the depth relation of $v^z_{out}\mathcal{L} = o_z$. The deviation of the ray inside the *USG* can also be taken into consideration, adding the difference of $(\mathcal{P}_{out} - \mathcal{P}_{in})$.

One conclusion that can be drawn from our model is that if a picture was simply attached behind the *USG* at zero depth, no distortion could occur, a result that everyone can verify via a small experiment. The reason can be found in the lack of XY motion that can be introduced by the *USG* due to a zero depth value o_z.

Assume we know the distance that the object was placed behind the *USG*, or o_z is given, and that this depth is fixed throughout. Then, for each ray in a forward ray tracing process do:

Algorithm 1

Input:
$S(x, y)$, the uniform shower-glass;
$\mathcal{V}_{in} = (0, 0, -1)$, direction of incoming ray from the eye;
$\mathcal{P}_{in} = (p^x_{in}, p^y_{in}, p^z_{in})$, incoming ray-$S$ intersection point;

Output:
(o_x, o_y), XY location where the ray $\mathcal{V}_{out}$ hits the object at depth o_z;

Algorithm:
$\mathcal{P}_{out} \Leftarrow$ emanating location of ray from USG;
$\mathcal{V}_{out} = (v^x_{out}, v^y_{out}, v^z_{out}) \Leftarrow$ emanating direction of ray from USG;
$(o_x, o_y) \Leftarrow \left(p^x_{out} + v^x_{out}\frac{o_z}{v^z_{out}}, p^y_{out} + v^y_{out}\frac{o_z}{v^z_{out}}\right)$;

Algorithm 1 is not required to perform ray-surface intersection tests. The geometry of the *USG* as well as the prescribed o_z depth of the object is all that is necessary. Then, in order to reconstruct the original image and eliminating the affect of the *USG*, one needs to perform the following inverse procedure:

Algorithm 2

```
Input:
𝓘(x,y), 0 ≤ x, y ≤ N, the discrete image
                as seen through the USG;
S(x,y), the uniform shower-glass;

Output:
I(x,y), the reconstructed image;

Algorithm:
𝒱_in ⇐ (0,0,-1);
for x from 0 to N
  for y from 0 to N
    𝒫_in ⇐ (x,y,0);
    (o_x, o_y) ⇐ XY location where we hit
                the object at depth o_z,
                following Algorithm 1;
    I(o_x,o_y) ⇐ 𝓘(x,y);
  end;
end.
```

While it is clearly desired to traverse all the domain of I, it is equally clear we are unable to do so. Given a location (x, y) in $I(x, y)$, we have no efficient way of finding what are the *USG*'s locations that affects it. Hence, and in a search of a practical solution, we are coerced to resort to the traversal of the domain of $\mathcal{I}$, uniformly traversing rays into the *USG*.

In Algorithm 2, the assumption was made that o_z, or the depth of the object behind the *USG*, is not only constant throughout but is also known. It is obvious that o_z is typically neither constant nor available. Nevertheless, in the coming section, Section 3, it will be shown that this depth factor could be searched for and efficiently found, via some simple interactions. We will also present a partial remedy to the inability of traversing I, in Section 3.

3 Results and Extensions

In this section, we are emulating a *USG* using a randomized surface such as the one in Figure 1.

The ideal conditions one can aim for, solving the *IRUSG* problem, are objects that are at a fixed o_z depth. Such an object is essentially a picture. In Figure 2, two pictures were placed behind the *USG* of Figure 1, one at depth of two units and the other at a depth of eight units. The two pictures as seen through the synthetic *USG* are shown in Figure 2 (a). In the sequel, several o_z depths are presumed and the images are reconstructed, following Algorithms 1 and 2. Figure 2 (b) assumes $o_z = 1$.

In Figures 2 (c) and (d), and for the first time, we encounter the expected behavior that this reconstruction is unlikely to be bijective, and further more might be singular. Infinitely

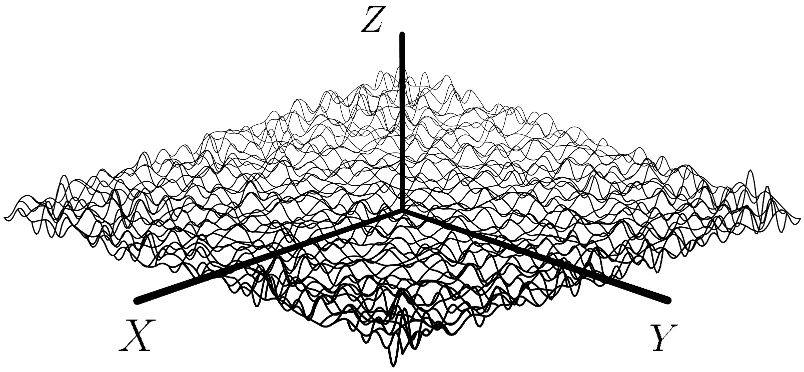


Figure 1: A randomized freeform surface emulating an *USG*. The Z fluctuations of the surface are scaled by the factor of ten. This surface is a piecewise polynomial biquadratic Bspline surface of size forty by forty. The surface was assumed to have an index of refraction of 1.33.

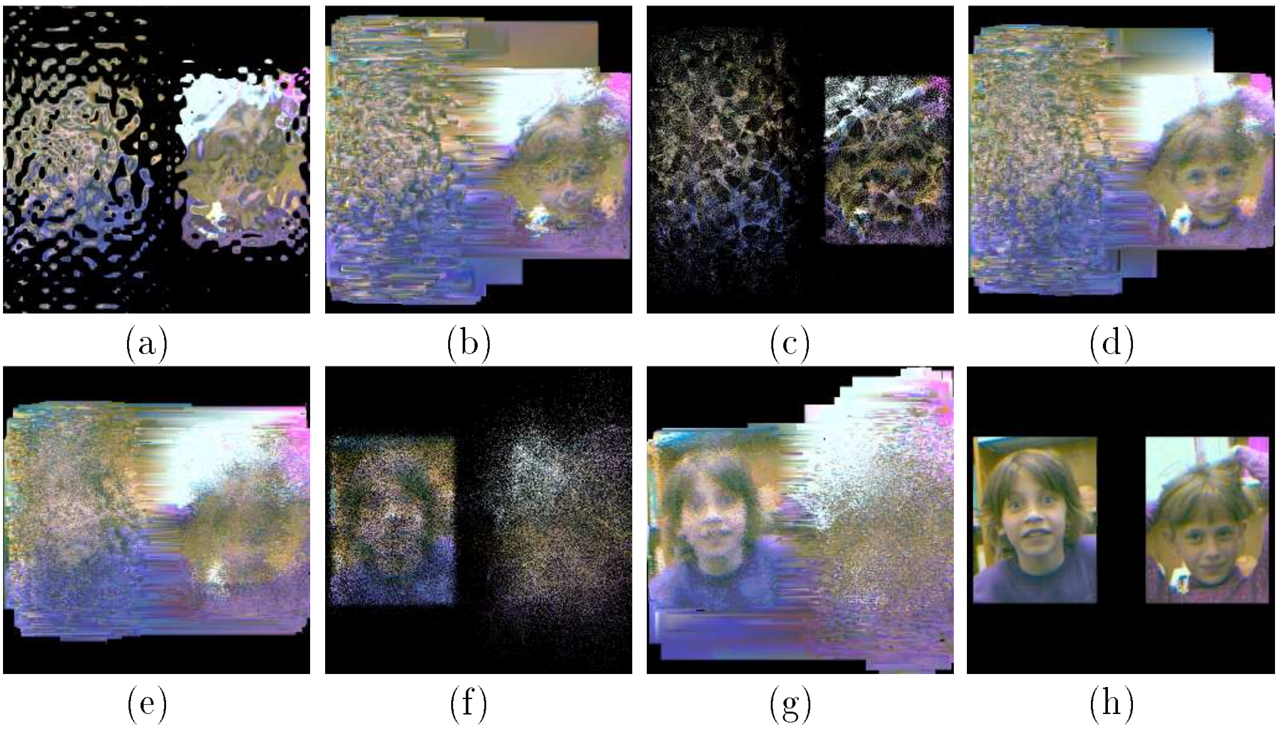
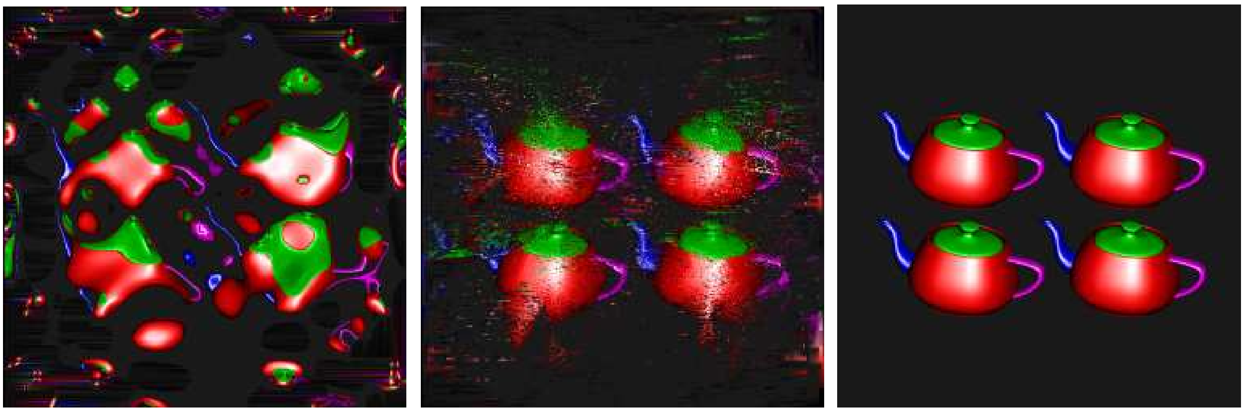
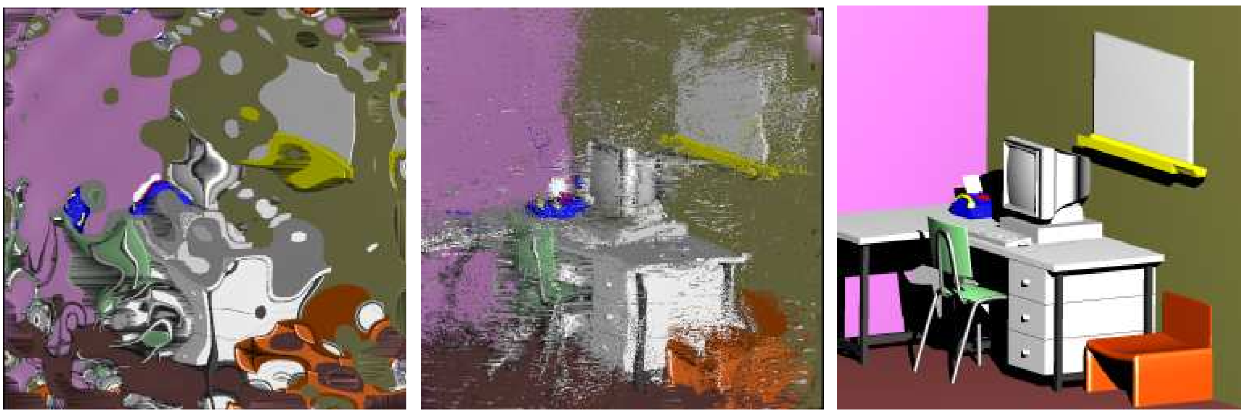


Figure 2: The reconstruction of two pictures at depth of 2 (right) and 8 (left) units behind a shower–glass. (a) shows the original two pictures behind the *USG*. (b) shows the result with the assumption of a depth of $o_z = 1$, with pixel interpolation. (c) and (d) shows the reconstruction result with a depth of $o_z = 2$ without and with pixel interpolation, respectively. (e) shows the result with a depth of $o_z = 4$, with pixel interpolation. (f) and (g) shows the reconstruction result with a depth of $o_z = 8$ without and with pixel interpolation, respectively. Finally, (h) shows the original two pictures with the *USG* removed. Using the rough surface area of the *USG* of Figure 1.



(a) (b) (c)

Figure 3: The reconstruction of a three dimensional scene with four three-space Utah teapots at approximately depth of 8 units. (a) shows the original scene through the *USG*. (b) shows the reconstructed result, assuming depth $o_z = 8$ and (c) shows the original scene once the *USG* has been removed.



(a) (b) (c)

Figure 4: The reconstruction of a three dimensional scene of an office at varying depths from 5 to 8. (a) shows the original scene through the *USG*. (b) shows the reconstructed result, assuming depth $o_z = 6$ once the *USG* is in place and (c) shows the original scene once the *USG* has been removed.

many rays that hits the *USG* might meet at the same location on one of the two pictures seen in the figure, while one of these rays would be sufficient to reconstruct this original location's color. In contrast, other locations on the pictures behind the *USG* might be visited by no ray, out of the discrete set of ray samples. In other words, a uniform sampling of incoming rays, $\mathcal{V}_{in}$ is expected to yield a non uniform sampling of the pictures or objects behind the *USG*, by outgoing rays, $\mathcal{V}_{out}$. This behavior can be observed in Figure 2 (c). The reconstructed pattern of the outgoing rays for the pictures of the two girls is shown, with the assumption of $o_z = 2$, that is the correct depth for the right girl's picture. The ray samples of the right picture in Figure 2 (c) are nicely aligned along the rectangular frame of the right picture, yet the image is difficult to decipher. This lack of uniformity can only be alleviated with the increase of sampling rate, but not resolved. Hence, we also employ a simple yet partial remedy in the form of a linear interpolation of missing pixels, yielding the result that is shown in Figure 2 (d). Figure 2 (e) shows the interpolated result at depth $o_z = 4$ while Figures 2 (f) and 2 (g) again show the discrete sampling and interpolated results at depth $o_z = 8$ which is the proper depth of the left picture. Finally, Figure 2 (h) shows the two pictures with the *USG* completely removed.

The examples shown in Figure 2 and in the other figures in the section, are snapshots of an interactive session where the user can modify the presumed o_z value in real time, and converge very efficiently on the best and proper depth. All the presented examples are recorded at a resolution of 512 by 512 pixels and at that size, several frames per second can be obtained on modern graphics workstations. Quite interestingly, this approach can therefore be used to interactively estimate the distances to the artifacts behind the *USG*.

A common practice in ray tracing is to form a piecewise linear approximation of a general freeform rational surface as a preprocessing stage. While a new method for direct ray tracing of polynomial patches was recently introduced [3], it should be noted that the problem in hand is much simpler. The incoming ray is always parallel to the Z axis. Further, if the *USG* is properly parameterized, then finding the surface parameters of the location of the ray-surface intersection is trivial because the *USG* becomes an explicit patch: $S(p^x_{in}, p^y_{in}) = (p^x_{in}, p^y_{in}, s_z(p^x_{in}, p^y_{in}))$. Therefore, Algorithm 1 is reduced to the simple evaluation of the normal of S at the incoming ray location and the following of Snell's law at that location.

The example shown in Figures 2 is artificial because one assumed a constant o_z value throughout. Placing some three dimensional geometry behind the *USG* is likely to provide less attractive results because one must continue to prescribe one constant o_z depth for the entire scene. Yet, if the artifacts presents only small deviations in their depth, the result can still be significantly improved. Figure 3 portrays four instances of the Utah teapot that is a three dimensional model. Figure 3 (a) shows the scene as it is viewed through the synthetic *USG*. In Figure 3 (b), the reconstructed result is shown, assuming a depth of $o_z = 8$, the correct depth of the centers of the four teapots. Figure 3 (c) shows the scene of the four Utah teapots, with the *USG* completely removed. Clearly, Figure 3 (b) is a significant improvement over Figure 3 (a).

Our third and last example takes the depth variation in the scene to larger extents. Figure 4 considers a scene of an office. Figure 4 (a) shows the scene as it is seen through the synthetic *USG*. In Figure 4 (b), the reconstruction result is shown, assuming a depth of $o_z = 6$ units, the depth of the center of the scene. Figure 4 (c) shows the original scene of the office, with the *USG* completely removed. Due to the large variation in the depth of the scene, the quality of Figure 4 (b) is not as one desires. Yet, details in Figure 4 (b) are far more distinguishable than in Figure 4 (a), focusing at the mid-range depth where the monitor resides on the table.

4 Conclusions

This short paper presents a simple method to reconstruct the original image, given the view through a *USG*. The complete potential of this work is yet to be revealed. Nevertheless, this work also serves as an encouragement to employ computer graphics tools toward the solution of real physical problems.

The necessity to have the exact geometry of the *USG* is probably the greatest hindering factor before one can use this approach, in practice. Yet, one can envision cases were one is able to a-priori sample a *USG*, or alternatively, perform the sampling of the *USG*, later in time.

5 Acknowledgment

This work was supported by the Fund for Promotion of Research at the Technion, Haifa, Israel.

References

[1] J. D. Foley, A. Van Dam, S. K. Feiner, and J. F. Hughes. Computer Graphics, Principles and Practice, second edition. Addison Wesley, 1990.

[2] J. Loos, G. Greiner, and H. P. Seidel. A Variational Approach to Progressive Lens Design. Computer Aided Design, Vol 30, No 8, pp 595-602, July 1998.

[3] T. Nishita, T. W. Sederberg and M. Kakimoto. Ray Tracing Trimmed Rational Surface Patches Computer Graphics, Vol 24, pp 337–345, (SIGGRAPH '90 Proceedings), August 1990.

[4] T. Whitted. An Improved Illumination Model for Shaded Display. Communication of the ACM, 23 (6), pp. 343-349, June 1980.