

The Arnolfini Portrait in 3d

Creating Virtual World of a Painting with Inconsistent Perspective

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Abstract

We report on creating a 3d virtual reconstruction of the scene shown in "The Arnolfini Portrait" by Jan van Eyck. This early Renaissance painting, if painted faithfully, should confirm to one-point perspective, however it has several vanishing points instead of one. Hence our 3d reconstruction had to be based on some, from an art historian's point of view plausible assumptions on choosing a unique vanishing point and measures of certain items in the scene. We compare our approach to similar reconstructions by others. Using professional modeling and image processing computer tools, we created a 3d reconstruction of the geometry of the interior, the textures and the lighting. A perspective view of this model is compared to the original painting, showing high fidelity, but at the same time also large local mismatches due to the inconsistent handling of parallel lines in the original painting, as well as some differences in the reflected image in the mirror. A reconstruction such as ours provides new details of the original scene for scholars, is useful for art historians to find out more about the way the painting was created, and could be used as an installation for exploration in museums or other learning environments by the general public.

Categories and Subject Descriptors (according to ACM CCS): 1.3.3 [Computer Graphics]: 3d modeling, cultural heritage

1. Introduction

In this paper we discuss a 3d reconstruction of a painting with incorrect linear perspective by Jan van Eyck. Our aim was to create a rendering of a view best matching the painting. First we introduce the painting, and explain the principle and discovery of using linear perspective for paintings. In Section 2 we discuss related works. In Section 3 we account on how the geometry, the textures and the lighting were reconstructed. We also compare the appropriate view of the scene to the original painting, and elaborate on the difference between the images in the painted and reconstructed mirrors. Finally, we outline possible applications a reconstruction such as ours.

The Arnolfini Portrait – also called *The Arnolfini Wedding* or *The Portrait of Giovanni Arnolfini and his Wife* – is a 1434 painting of the Early Netherlandish painter Jan van Eyck. The painting is on public display in the National Gallery in London, and presented on the web [11, 12]. It is one of the first and prime examples of oil painting, a technique reinvented since classical times. The portrait depicts wealthy Italian

merchant Giovanni di Nicolao Arnolfini, and his wife in what is presumably a reception room – or as Erwin Panofsky claimed [8], a nuptial room – in their home in the Flemish city of Brugge. Lavishly decorated with expensive furniture and small curiosities, the scene was meant to demonstrate the material affluence of the Arnolfini's. The painting is an illustrious masterpiece of Western Art from the early Renaissance, especially in terms of originality and complexity. It articulates the space, presence, individuality and psychological depth (many details have a deep, symbolical meaning) of the scene extremely well, unlike anything produced earlier. The depicted scene looks very realistic – lively through excellent use of the luminous colors provided by oil paint and suggesting the real spatial arrangement. Van Eyck probably painted it 'by the eye', a novel approach to painting in his days. He deficiently (and unknowingly) applied *one-point linear perspective* – the discovery of which allowed for the development of naturalistic painting at the beginning of the Renaissance, thereby further digressing from the stylized figures of medieval art. Though the painting very convincingly suggests depth, it is flawed in terms of its global geometric consistency. The painting does

not, by all means, adhere perfectly to the rules of linear perspective.

1.2 Linear perspective in the Renaissance

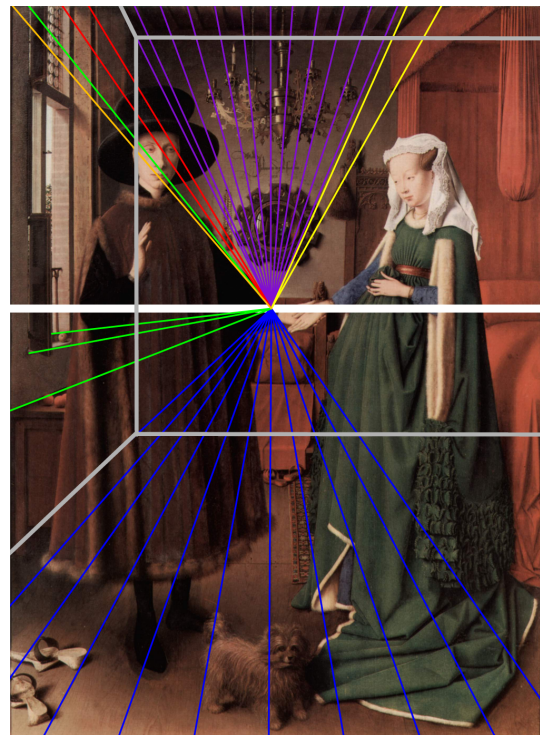
Linear perspective is a mapping of the 3d world to a plane – being the canvas of the painter, or a computer screen. The image of each visible point in the real world is created by drawing a line from it to the center of projection – the eye of the painter, or the *viewing position* or *vantage point* – and marking the intersection of this line with the plane. According to biographer Giorgio Vasari (1511–1574), it was the Florentine architect Filippo Brunelleschi (1337–1446) who first demonstrated and laid down the rules of perspective, some ten years before Van Eyck made his painting [10]. Later, perspective was discussed in texts on painting methods by Leone Battista Alberti (1404–1472), Piero della Francesca (1410–1492) and Albrecht Dürer (1471–1528). The latter also made woodcuts demonstrating how painters should use different equipments to create perspective images [7]. The intuitive observations of these artists were followed by a systematical, analytical description by Girard Desargues (1591–1661), which gave rise to the up to date relevant field of *projective geometry*.

The major characteristic of linear perspective is that (2d) images of (3d) parallel lines converge to a single point, called the *vanishing point*. Lines parallel to the canvas or image plane, however, do not meet in a real point but in infinity, thus images of these, and only these lines remain parallel. The *horizon* is a line on the canvas at the height of the eye of the painter, parallel to the ground, on which the projections of lines parallel to the ground, but not to the canvas, come together. It is therefore a collection of vanishing points, each corresponding to a certain direction. Often there are three major, perpendicular directions in a scene, and painters frequently set their canvas parallel to the 'horizontal' and 'vertical' directions. Hence they need to construct only one vanishing point for the third direction, that is, for the *orthogonals* – such paintings adhere to *one-point perspective*. If two directions, corresponding to edges of the rectangular forms in the real scene, intersect canvas, two vanishing points are to be constructed – in this case we speak of *two-point perspective* paintings.

Van Eyck was probably unaware of the discovery of perspective in Italy during his whole life, as his paintings lack a steady structure for converging lines.



a



b

Figure 1. (a) *The Arnolfini Portrait* with its main orthogonals and vanishing points superimposed. (b) *The Arnolfini Portrait* with corrected orthogonals, their (single) vanishing point and the horizon superimposed.

The Arnolfini Portrait has about a dozen of individual vanishing points for its orthogonals, scattered around the central region of the canvas – most of which being less prominent, as they involve details of single objects. The painting maintains geometric consistency only at a local level, even though it clearly makes an effort to be as true to nature as possible.

2. Related work

Jan van Eyck's pictorial constructions have been the subject of scholarly exchanges ever since the beginning of the last century. Erwin Panofsky, who is known for his iconological interpretation of the hidden symbolism of the portrait, was the first to raise interest in its spatial geometry. Considering linear perspective, he believed the painting harbored four vanishing points [8]. The most recent hypothesis by David Carleton in [1] suggests that a so-called "elliptical perspective" forms the structural basis of The Arnolfini Portrait. Herein the painting is regarded to have two vanishing *areas*, centered at the two foci of a vertically placed ellipse, each accounting for two of the four vanishing points Panofsky observed (the upper and lower ones). The local consistency in the painting also recently gave rise to heated discussion of a hypothesis by David Hockney, which holds that objects were added one after another in separate settings, by the help of an optical projection device – for a summary see [9].

Criminisi, Kemp, and Zisserman have explored the merits of computer vision techniques for the virtual reconstruction of old paintings for perspectival analysis [3]. They have used algorithms for the automated process of creating faithful, interactive 3d representations straight from the surface of a painting [4], dealing with pattern completion to fill in hidden areas, and allowing for new views of a scene to be generated. Judicious application of their reconstruction techniques requires a painting to be perspectively sound, i.e. adhere well to the rules of one- or two-point (in case of Renaissance art) linear perspective. They confirm that The Arnolfini Portrait does not qualify to be subjected their rigorous computational reconstruction methods because of its "lack of global geometric consistency." Regardless, they attest the painting "maintains a striking visual coherence".

Criminisi, Kemp and Kang have in [5] investigated the optical properties of the centrally placed convex mirror. While assuming the mirror has perfect spherical curvature, they proposed algorithms for 'rectifying' the distorted image in the mirror, mathematically 'warping' it to normal projection, consequently presenting a clear view of scene from the other side of the room. In assessment of the warped

version of the mirror image, they concluded Van Eyck's original rendering had some minor faults (if correct linear perspective was intended), notably concerning the curvature of the first vertical side of the first window, the first horizontal edge of the side table beneath it, and the bottom edge of the gown worn by 'Ms. Arnolfini.' They corrected these details manually in the transformed image by means of "off the-shelf image-editing software", while leaving the global geometry/perspective unharmed, and then 'inverse warped' the transformed and altered image to its natural 'optically distorted' condition, thus gaining an 'optically corrected version' of Van Eyck's convex mirror image. They suggested the rectified image may be used for the purpose "of three-dimensional reconstruction as well as measuring accurate dimensions of objects and people."

3. The spatial geometry of the painting

In 'virtualizing' the painting the algorithmic methods of [3] would have a great deal of advantages over traditional 3d modeling tools. However, these methods require the painting to strictly obey the rules of linear perspective. The Arnolfini Portrait does not meet this requirement by a considerable margin. Criminisi et al. have in [3] very accurately computed a few of the painting's main vanishing points by fitting straight lines to edges. They have convincingly shown the painting to be 'consistently inconsistent' when it comes to global geometry – Carleton's claim of an elliptical perspective seems to be unfounded.

Figure 1a shows the key orthogonals, extracted from the painting using ordinary image-editing software, projected onto the painting. Because of its evidently inconsistent perspective, we were destined to reconstruct the painting 'by hand' with the help of commercial 3d modeling software. For this purpose, the depicted scene had to be analyzed carefully in order to make plausible assumptions on basic measurements, and select an appropriate viewpoint.

3.1 Setting the frame for one-point perspective

For the purpose of virtually reconstructing the scene, the perspectival structure needs to be examined, chiefly to determine the principal geometrically coherent section to be used as a basis. In order for this to have the same two-dimensional position and size in the virtual image as in the painting, a *viewpoint* is to be decided, determining the vertical position of the horizon, and, more importantly, the single new vanishing point on it where all the orthogonals meet.

On swift observation of Figure 1a, it is clear the geometrically coherent floor lines and the intersecting back wall plane should be focused on; a rectified image of the painting will resemble it the most if these structures are left in their exact two-dimensional position. Figure 1b illustrates what the correct spatial geometry would then be like. The superimposed lines are the framework for the virtual reconstruction.

3.2 Determining the size and position of objects

The construction of an accurate three-dimensional computer model of the scene – and an eventual rendering thereof, bearing a close resemblance to the original painting – requires the comparative size and distances of scene elements to be known. In this section, for convenience, *life* measurements are determined. They are given only for key elements, for the rest is established mostly in the perspective view of the modeling program used, with the aid of figure 1b as a background image.

The absence of any clear structure of which depth is known precisely (via proportion), made *uniquely* recovering the depth of the original scene impossible. Therefore, all measurements are ultimately based on a few rudimentary *assumptions*.

Height of the man in the door opening. The 'rectified' convex mirror image from [4] is used in figure 2 to determine the approximate height and breadth of the room, and presents a clue on its length. Because the construction of the back wall in the mirror is parallel to the image plane chances are its depiction is fairly accurate. The person standing in the door opening – presumably being Van Eyck himself – can reliably serve as a reference object to determining the absolute size of this wall, and thus the breadth and length of the room (granted it is rectangular). If he's assumed to be averagely tall for a West-European male of high social status, in medieval times, his height would probably be around 1.75 m. Note that the exact height is not of importance, as height is used as a reference to derive further *relative* measurements.

We deemed the constellation of the mirror image – even though it's a small detail – more reliable a source in determining the room's height than either the bench or the window with regard to the (much less clearly defined) back wall visible in the *main part* of the painting. Moreover, breadth is, at all, unrecoverable by any other means than the mirror image.



Figure 2. (a) The image in the convex mirror in *The Arnolfini Portrait*, as originally painted by Van Eyck. (b) The mirror image corrected for spherical distortion (created by Criminisi et al. [5]) with room edges and the silhouette of the individual in the door opening superimposed, so measurements could be taken.

Length of the room. Judging from the mirror image, the total length of the room is probably 5 to 6 m. Accuracy is not of utmost importance here, because it's not relevant to the point of determining the position and size of key elements in the scene.

Breadth of the windows. Both of the windows in the room (as seen in the mirror image) seem to be identical in size. They lend an air of elegance and they must have been rather tall and slim, almost reaching the ceiling and probably around 1 m in breadth. This last measurement was deduced taking into account the height of the window, which could be expressed in terms of the individual's height in the mirror image. The breadth of the windows was (mainly) used to calculate the approximate 'depth size' of many scene elements, as well as their distance from the back wall.

We were hesitant to use the bed's length for this purpose, given its ill defined boundaries and the large deviation in bed size in the 15th Century.

A chair behind the bed hangings. Careful examination of the canvas area just next to the lady reveals that the richly decorated panel against the back wall is in fact part of a chair – below, a small portion of an arm-rest is visible. Therefore, against to what plain vision might lead one to believe, there probably needs to be some 0.5 m of space between the bed hangings and the back wall. The chair looks as if it faces the image plane at a slight angle, say 10 degrees.

Position of the chandelier. The chandelier is assumed to be neatly centered on the window with respect to its 'orthogonal' (depth) position.

Using the above set of assumptions, the following crude dimensions (in meters) of main elements in the scene have been established. All seem plausible.

- Entire room – L x B x H: 5.5x3.5x2.9
- Door opening – B x H: 1.2x2
- Door opening – Distance window-side wall: 1
- Bed – Length: 1.7
- Bed – Breadth: 1.6
- Both windows – B x H: 1x2.1
- Both windows – Distance between: 1.5
- Window near back wall – Distance back wall: 0.9
- Side table/cabinet beneath window – Height: 0.65
- Convex mirror – Diameter (glass part): 0.35
- Convex mirror – Sphere diameter: 0.45
- Bench beneath mirror – Height: 1.15
- Chair next to mirror – Height: 2.10
- Chair next to mirror – Dist. window-side wall: 1.5

The mirror. The "Sphere diameter" of the convex mirror signifies its bulginess. Its value could be obtained upon determining the diameter of the mirror using the mirror protrusion formula from [5], $P = r_{\text{disk}}/r$ (in which P is the protrusion factor of the mirror, r_{disk} the radius of the mirror, and r the radius of the sphere from which the mirror was cut). In [5] P was calculated to be 0,78.

3.3 Modelling and rendering the scene

With the obtained geometrical data a complete three-dimensional computer model of the painted scene was built. In this section, the entire practical reconstruction process is described, and, more importantly, resulting imagery is compared with the original painting.

The software used in this part of the reconstruction mainly comprised Autodesk's 3ds Max 9 (abbr. Max) and Adobe's Photoshop CS2. Basically, these software packages were used for, respectively, (i) constructing the three-dimensional shapes of scene objects, *mapping* textures to the surfaces of these shapes, creating basic textures, illuminating the scene, and *rendering* images of the scene, and, (ii) creating more elaborate textures to be applied to the surfaces of shapes. Chronologically, the following key steps were taken in the reconstruction process.

Building the basic structure. First, the acquired geometrical data, presented in the previous section, was entered into Max. It formed a basic referential structure of the scene.

Determining camera parameters. Next, in order to properly contrast generated images of the virtual scene with the original painting, the camera position and parameters in Max were determined such that most of the groundwork – in any case the floor, the back wall and parts of the window – perfectly matched its painted counterpart with regard to its (2d) position; setting an image of the painting (figure 1b) to the background of Max's perspective view facilitated this. The camera was positioned near the entrance of the room, faced the ground plane at a six degrees angle, and was equipped with a 43,456 mm (focal length) lens, translating to a horizontal field-of-view of 45 degrees.

Adding further scene elements. With the foundational shape and the main viewpoint of the scene established, shapes of all other objects could be added. The background image was heavily relied on in modeling them.



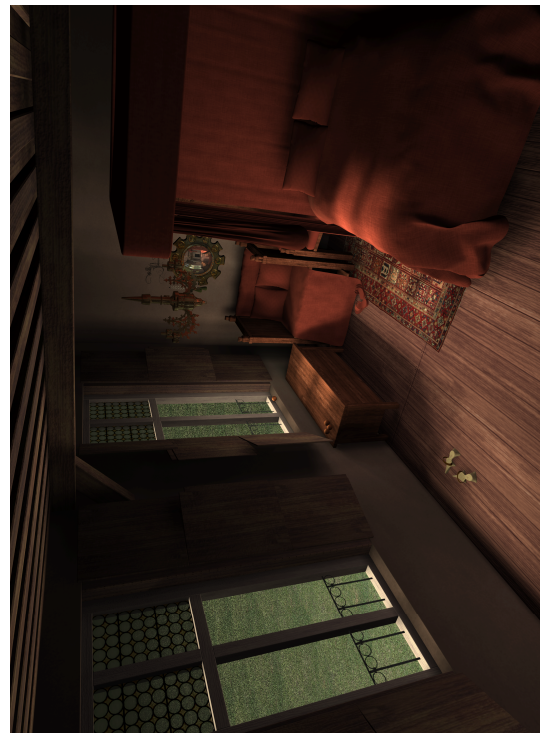
a



b



c



d

Figure 3. (a) *The Arnolfini Portrait*, as painted by Van Eyck. (b) The virtual reconstruction of the painted interior. (c) Projection of the painting's contours onto the virtual reconstruction. (d) The reconstructed room from another viewpoint (and rotated 90 degrees).

Creating and applying materials. Textures and other optical properties were subsequently assigned to surfaces of all shapes in the scene. Photoshop was used to create textures akin to those made by Van Eyck. Most of the textures are color adjusted versions of ones obtained from internet sources, while others have been specially made by the author; still others were generated with the use of Max.

Lighting the scene. A number of point source lights of medium intensity were placed in both windows openings, "fill lighting" the room. A fairly strong target spot casting soft shadows was added at a distance outside, simulating weak (or indirect) sunshine. The area on the floor and the bed lit by this spot was further accentuated, or simulated to produce indirect light, by placing near it a few low intensity point lights.

Rendering images of the scene. Finally, images of the entire scene could be rendered with the camera settings explained earlier. A cyclic process of rendering the scene and making careful adjustments to scene geometry, material properties and lighting was gone through, to achieve the result shown in figure 3.

3.4 Comparing the reconstruction to the original

Figure 3b is the final high-resolution rendering of the three-dimensional scene model best matching the original painting. It is taken from a position close to Van Eyck's vantage point in the scene. The image, and up-close section of the mirror, were compared to their painted counterparts. Figure 3c illustrates how well we managed to adhere to Van Eyck's original composition, while maintaining correct perspective geometry.

When projecting the contours of the painting onto the reconstructed image, with regard of contours a considerably large *projection error* is noticeable in the uppermost parts of the resulting composite. This was inevitable because in resolving the inconsistency of the painting's perspective we relied on the geometrically accurate lower half.

3.5 Reconstruction of the mirror

The convex mirror in The Arnolfini Portrait has long been subject of extensive studying [5]. However, it is only now that a faithful three-dimensional reconstruction can be used to analyze the accuracy of the image painted in it. Clearly, the original mirror image in figure 4a differs significantly from the reconstructed mirror image in figure 4b. The main problems with the latter are (i) its too small central region – with its back wall seemingly too far away – and (ii) the undesirable visibility of (certain things in) its peripheral region. We deem the discrepancy between both images too large to be the result of (slightly) inaccurate room measurements. Also, we reliably modeled the mirror's bulginess in the reconstruction, assuming the mirror was cut from a perfect (glass blown) sphere and using the mirror protrusion value, $P = 0,78$, as computed in [5].

Both issues remain unresolved in this paper – and need further investigation – but as of yet we have thought of two possible explanations. One, invalidating some of the conclusions in [5] with regard to the *actual scene*, is a larger sphere from which the mirror was cut, or a mirror shape other than spherical.



Figure 4. (a) The original convex mirror in The Arnolfini Portrait. (b) The convex mirror in the three-dimensional reconstruction.

We were able to get a better, but still far from perfect, coincidence by increasing the mirror sphere diameter to about 0,7 meter – the same value Stork presented in [9]. Another possible explanation for the mismatch between the painted and reconstructed mirrored scenes could be that Van Eyck departed from optical accuracy for aesthetic reasons. Such a possibility was suggested in [5] in relationship with the side table and the woman's gown. The painter may also have wanted to emphasize certain parts of the mirror image for enhanced symbolism. He could have brought more to the front the back wall where he is standing, by leaving out peripheral parts of the image, thereby making his appearance more noticeable.

Finally, we emphasize that the choice of the bulginess of the mirror has no effect on the room's height and breadth measurements we determined from the mirror image.

4. Conclusion

In this paper we reconstructed the space depicted in The Arnolfini Portrait and created of it a correct linear perspective view closely resembling the original. As the painting did not adhere to linear perspective, the automated computational methods from [3] could not be applied. Instead, traditional 3d modeling tools were used to recreate the interior of the painting. The floor and back wall were focused on in getting optimal coincidence. With help of the convex mirror, rudimentary assumptions on reference measurements, and subsequently crude dimensions of main elements in the scene, were determined. All shapes in the painting (part of the interior) were modeled, textures were designed and added to the shapes, lighting designed and, lastly, the whole scene was rendered. More images of the full reconstruction and mirror variants can be seen at [13].

There are different benefits and potential applications of our work. The three-dimensional representation provides insight into the spatial structure of the painting; it may help art-historians find clues to unanswered questions about the site, the objects, and the process of painting. In our case, moreover, it is interesting to see how different the painting would look if painted in correct perspective.

The interactive exploration of a 3d virtual model allows people with a casual interest in paintings to experience the power of perspective in this beautiful work of art more vividly. It may also raise the attention of the young, who have grown accustomed to realistic 3d computer imagery in cinema and video games.

A reconstruction such as ours could also be used as a scene in an on-site or remote learning environment, extended with interactive capability (to 'interrogate' or 'use' objects, e.g. to see how one would sleep in the bed, sit on the chair) and by adding 3d characters who may talk and move around.

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