Were optical projections used in early Renaissance painting? A geometric image analysis of Jan van Eyck's "Arnolfini portrait" and Robert Campin's "Mérode Altarpiece"

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Abstract

It has recently been claimed that some painters in the early Renaissance employed optical devices, specifically concave mirrors, to project images onto their canvas or other support (paper, oak panel, etc.) which they then traced or painted over. In this way, according to the theory, artists achieved their newfound heightened realism. We apply geometric image analysis to the parts of two paintings specifically adduced as evidence supporting this bold theory: the splendid, meticulous chandelier in Jan van Eyck's "Portrait of Arnolfini and his wife," and the trellis in the right panel of Robert Campin's "Mérode Altarpiece." It has further been claimed that this trellis is the earliest surviving image captured using the projection of any optical device—a claim that, if correct, would have profound import for the histories of art, science and optical technology.

Our analyses show that the Arnolfini chandelier fails standard tests of perspective coherence that would indicate an optical projection. Or more specifically, for the physical Arnolfini chandelier to be consistent with an optical projection, that chandelier would have to be implausibly irregular, as judged in comparison to surviving chandeliers and candelabras from the same 15th-century European schools. We find that had Campin painted the trellis using projections, he would have performed an extraordinarily precise and complex procedure using the most sophisticated optical system of his day (for which there is no documentary evidence), a conclusion supported by an attempted "re-enactment." We provide a far more simple, parsimonious and plausible explanation, which we demonstrate by a simple experiment. Our analyses lead us to reject the optical projection theory for these paintings, a conclusion that comports with the vast scholarly consensus on Renaissance working methods and the lack of documentary evidence for optical projections onto a screen.

Introduction

In seeking to explain an apparent increase in realism in European art around 1420, the contemporary painter David Hockney recently proposed that some Renaissance painters employed optical devices to project images onto their supports (paper, oak panel, etc.), which they then traced or painted over [1,2]. Thin-film physicist Charles Falco later provided technical support to Hockney. They adduce as evidence a number of paintings and features—apparent "blur," perspective changes, and so on. Two important such exhibits are portions of Jan van Eyck's "Portrait of Arnolfini and his wife" (1434) and Robert Campin's "Mérode Altarpiece" (c. 1425-8). Here we apply geometric image analysis to these paintings to test the claims that projections were used in their creation.

The Arnolfini double portrait is an ideal test case for the Hockney theory, in part because the painting has been the focus of extensive scholarship and analysis [3]. Moreover, the painting is rich in optical information relevant to the theory, as we shall see. Hockney and Falco have referred to the painting in virtually every public lecture, magazine article, television interview, radio interview, website, and in Hockney's BBC documentary; clearly they feel it provides strong evidence in support of the theory. If the Hockney theory should fail in this central exhibit, then surely the theory would come under strong doubt. Falco recently claimed the "Mérode Altarpiece" was the earliest example of an image captured using a projection [4], an extremely important result, if true.

We begin in Sect. *I* with a cursory description of Hockney's projection theory. In Sect. *II* we apply geometric analyses to the Arnolfini chandelier and in Sect. *III* rebut possible objections to our results. In Sect. *IV* we turn to the optical claims associated with the trellis in the right panel of the "Mérode Altarpiece" and then in Sect. *V* we provide a far simpler alternate explanation for its creation and end with a few remarks.

I. Optical Projection Theory

Briefly stated, Hockney's projection theory posits that some painters as early as 1420 employed optical devices in the creation of their works. More specifically, Hockney claims they used a primitive *camera obscura* where the focusing was performed by a concave mirror. (He supposes that much later, around 1600, glass lenses were used instead of mirrors.) The artist would project a real inverted image of a very brightly lit scene or part of the scene onto the shadowed support and either trace the image contours or perhaps even paint directly [1,2], though Hockney himself admits it is quite difficult to paint under optical projections. Because noone, including the theory's proponents, has been able to provide plausible corroboratory documentary evidence for such artistic praxis, most of the debate has focused on optical and image analysis, taking the paintings themselves as primary evidence.

II. The Arnolfini chandelier, projection hypothesis and perspective analyses

Hockney has claimed repeatedly that the chandelier or *lichtkroon* (Dutch, "light crown") in the Arnolfini portrait must have been drawn under optical projection [1]. Reporter Leslie Stahl: "Hockney points to van Eyck's 'The Arnolfini Wedding.' He used to wonder how did the painter do that chandelier?" [Hockney]: "That chandelier *is in perfect perspective*. So how was it drawn?" [Stahl]: "He now thinks with a concave mirror and a pencil" [CBS, "60 minutes" 12/1/2002, emphasis in the original, cf. 1]. We now address this claim by perspective analysis of the chandelier. If the chandelier "is in perfect perspective," then a concave mirror might conceivably have been used since its projected image on the oak panel support would be in proper perspective [5]; if the image exhibits poor perspective, it is unlikely a projection was used.

Figure 1 shows a bird's eye view or plan of the Arnolfini chandelier, each of its six arms numbered for reference [6]. For the moment we assume that the chandelier has hexagonal symmetry, a matter to which we shall return. Consider points p_1, p_2, etc., on arm 1 and corresponding points q_1, q_2, etc., on arm 6. Such points refer to the tips of decorative structures or "crockets," crossing points above the arm, the top of the cruciform structure above, and so forth, as we shall see in Fig. 2. Consider the line defined by two corresponding three-dimensional points, called the "*join* of p_1 and q_1" and denoted $\langle p_1,q_1 \rangle$ [5]. This line is horizontal, i.e., parallel to the floor in Arnolfini's room; it is also perpendicular to the vertical plane bisecting arms 1 and 6. Likewise, $\langle p_2,q_2 \rangle$ is horizontal (though possibly at a different elevation than $\langle p_1,q_1 \rangle$) and perpendicular to the same vertical plane bisecting arms 1 and 6. These properties hold for *all* such three-dimensional lines $\langle p_k,q_k \rangle$ and thus all these lines are parallel in the space of Arnolfini's room, or formally

$$\langle p_1,q_1 \rangle \parallel \langle p_2,q_2 \rangle \parallel \ldots \parallel \langle p_k,q_k \rangle \qquad \text{(Eq. 1)}$$

We denote the optical projection of each point p_i onto the two-dimensional image plane by the upper case P_i. Under a homographic perspective transformation arising from the purported concave mirror projection onto the support, these lines should meet at a vanishing point at the elevation of the optical system [5], that is,

$$\langle P_1,Q_1 \rangle \cap \langle P_2,Q_2 \rangle \cap \ldots \cap \langle P_k,Q_k \rangle = VP_{16}. \qquad \text{(Eq. 2)}$$

where VP_{16} is the vanishing point associated with this construction for arms 1 and 6. In short, the lines $\langle P_i,Q_i \rangle$ should all intersect at a vanishing point. Figure 2 tests and refutes this prediction of the Hockney projection theory, assuming the chandelier is symmetric.

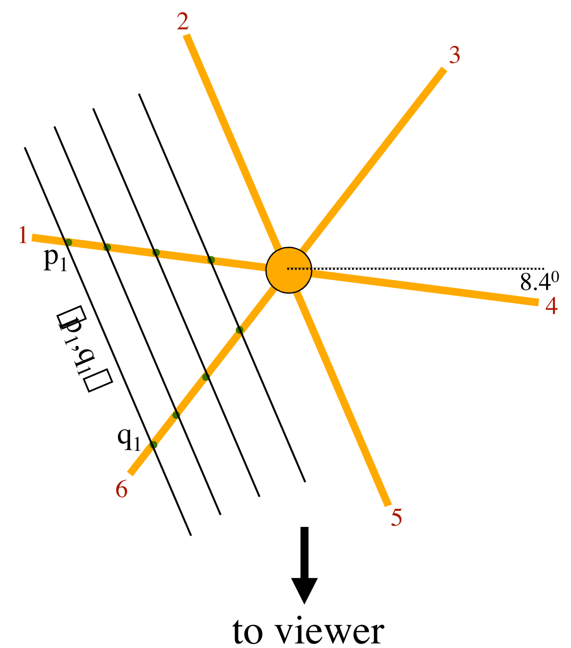

Figure 1: A plan of the Arnolfini chandelier. Corresponding points on any pair of arms e.g., p_1 and q_1 on arms 1 and 6, respectively, define a line $\langle p_1,q_1 \rangle$ which is parallel to the floor and perpendicular to the vertical plane bisecting those two arms. For symmetric chandelier, such lines are mutually parallel in space. The projection of these lines would meet at a vanishing point on a horizon line at the height of the projection mirror, lower than the chandelier. (The projected lengths of arms 5 and 6 imply the chandelier was rotated 8.4°, presumably set by van Eyck to better reveal its ornate structure.)

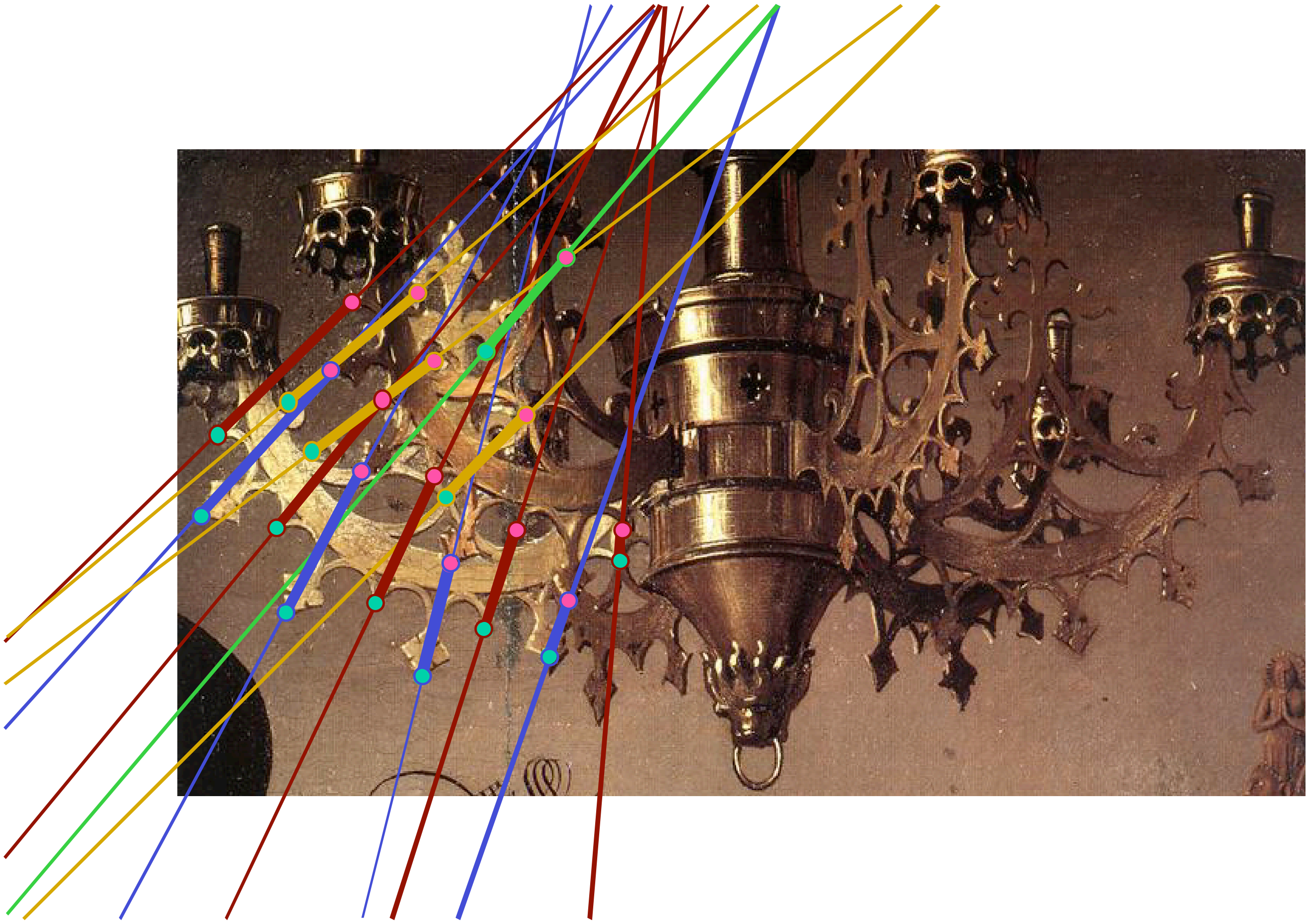

Figure 2: Jan van Eyck, "Portrait of Arnolfini and his wife" (1434) detail approx. 9.1 x 16.0 cm, oil on panel © National Gallery London. Projections of points on arm 1, P_i, and on arm 6, Q_i, arise from lines which are horizontal and mutually parallel in the space of Arnolfini's room. Assuming a symmetric chandelier, a projection from a concave mirror onto the oak support would force all these lines to meet at a vanishing point at the elevation of the optical imaging mirror, beneath the chandelier. In fact, however, the lines deviate haphazardly and give no indication of a vanishing point—below the chandelier or indeed at any elevation.

While not shown here, similar perspective tests for each of the $\binom{6}{2} = 15$ pairs of arms also reveal a generally haphazard pattern of line directions and a lack of clear vanishing point, as the patient reader can demonstrate using a straightedge and Fig. 2. Likewise the chandelier fails other tests, including those based on cross-ratios of projected distances [5].

III. Anticipating and rebutting alternate explanations

We can anticipate and rebut a number of alternate explanations of the results of our perspective analyses. First, one might claim that the chandelier lacks hexagonal symmetry or otherwise deviates from an "ideal" shape. To address that objection, we must first determine the magnitude of the deviation of the physical chandelier that would be consistent with a projection. Figure 3 shows black perspective lines from the best fit "vanishing point" associated with arms 1 and 6. We assume arm 1 is the "gold standard" for comparison and ask how far crockets and other structures on arm 6 would have to move to lie on their perspective lines, and hence be consistent with a projection. This is a measure of the manufacturing error consistent with a projection. These deviations, shown in thick white lines, are very large indeed—as much as 8 cm in the space of Arnolfini's room.

Are such large deviations to be expected in a 15th-century chandelier in Bruges? Or equivalently, are such large deviations consistent with contemporary craftsmanship and surviving metalwork (known as dinanderie)? The answer is clear: No.

While some 15th-century dinanderie used rivets and solder for attaching whole arms, the crockets and decorative structures were instead cast as part of the arms themselves, as scholars of the period know [7], and close inspection of surviving chandeliers confirms [8,9]. As such, we would not expect significant variation in the shapes of the arms. We confirmed this by performing a perspective test on a known projection (i.e., photograph, taken as part of our research) of an early 15th-century chandelier in the Barley Hall Museum, UK, also from Bruges, containing similar crockets. The equivalent deviation was roughly 1 mm, 1/80th the maximum deviation implied for the Arnolfini chandelier. We tested four chandeliers and two candelabras from the photographic database of the Institut royal du patrimonie artistique in Bruxelles, and found the maximum deviation to be less than 1/10 that implied by the Arnolfini results, and in most cases was much smaller.

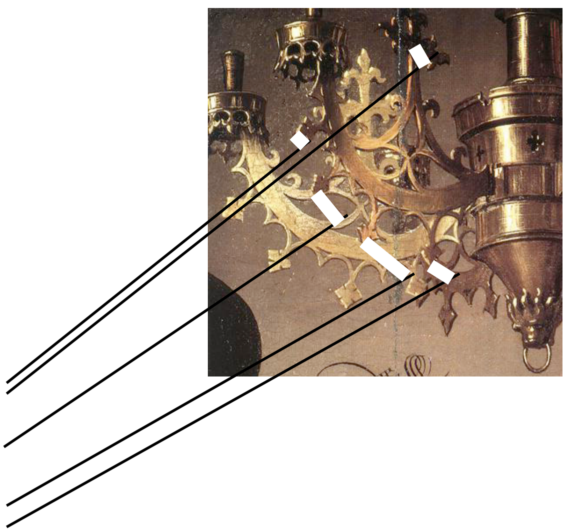

Figure 3: The black perspective lines pass through the best-fit vanishing point to the lower left (not shown) associated with arms 1 and 6. The white bars show the large manufacturing "errors" for structures on arm 6 demanded if an optical projection had been used. © National Gallery London.

In short, on historical and image analysis grounds, we find no justification for any claim that the large deviations in the Arnolfini chandelier demanded by the projection theory were in fact due to poor craftsmanship.

Second, one might claim that the purported optical system was somehow improperly set up. For instance, if the concave mirror or the support or both were tipped, it would indeed be possible to create a mild anamorphism. (In just such a way architectural photographers use perspective control or "PC" lenses and tip their film planes in order to eliminate convergence of vertical lines in photographs of tall buildings [10, page 116].) However the colinearity of all $\binom{6}{2} = 15$ vanishing points VP_{ij}, for $i,j = 1,\ldots,6$ and $i \neq j$ (along a horizon line) is preserved under a homography as would arise from such an "improper" optical setup [5]. Because vanishing points, if any, in the Arnolfini chandelier are in fact *not* colinear, we can reject this objection.

Finally, one might claim that van Eyck refocused or reoriented his concave mirror as he traced the image of the chandelier, moving the mirror forward and backward, possibly tipping it and the support; Hockney and Falco have made such a claim for Lorenzo Lotto's "Husband and wife" (1523) [2]. The perspective inconsistencies occur even for pairs of corresponding points spanning a range of depths of less than an estimated 5 cm, such as the pair of trefoils on arm 5 and on arm 6 closest to the viewer—well within the depth of field of any conceivable candidate concave mirror.

IV. The Mérode trellis and the projection hypothesis

"Mérode Altarpiece" by the Master of the Flémalle, generally identified as Robert Campin [11], reveals an extraordinary number of perspective inconsistencies, as are visible in Fig. 4. It is unlikely that Campin was using techniques of Brunelleschi's geometrical perspective, which by that time had not even arrived in the north from Italy. It is extraordinarily unlikely, too, that he was using optical projections as numerous local patches of the painting have wildly inconsistent perspective, whereas under optical projection they would be consistent.

Falco [4] draws our attention to the change in "perspective lines" associated with the bench trellis in the right panel, reproduced in Fig. 5. We assume, as must Falco, that the trellis in Campin's studio is planar. How then to account for this break in "perspective lines"? Falco argues that Campin painted the trellis by tracing the image projected by a concave mirror. Since a concave mirror has a limited depth of field [10], Falco argues that Campin painted the front of the trellis under projection, then moved the mirror in order to refocus on its rear portion. In doing so, the resulting perspective lines would be altered, as we find. To corroborate this claim, Falco points to the right-hand edge of Joseph's work table, claiming that its slight deviation at the depth of Joseph's head shows that the table too experienced a concomitant break arising from the purported refocusing [4].

Falco's identification of a "break" in the table edge is curious indeed. Even the most cursory examination in Fig. 4 shows that any such "break" is due to occlusion by Joseph's right elbow, not an inherent break in the edge itself. As such, the table edge provides no evidence to support the claim that Campin refocused a concave mirror.

The optical projection would have posed quite a challenge to Campin. Leaving aside the difficulties in finding a suitable mirror and learning that one could project an image onto a screen in the apparent absence of

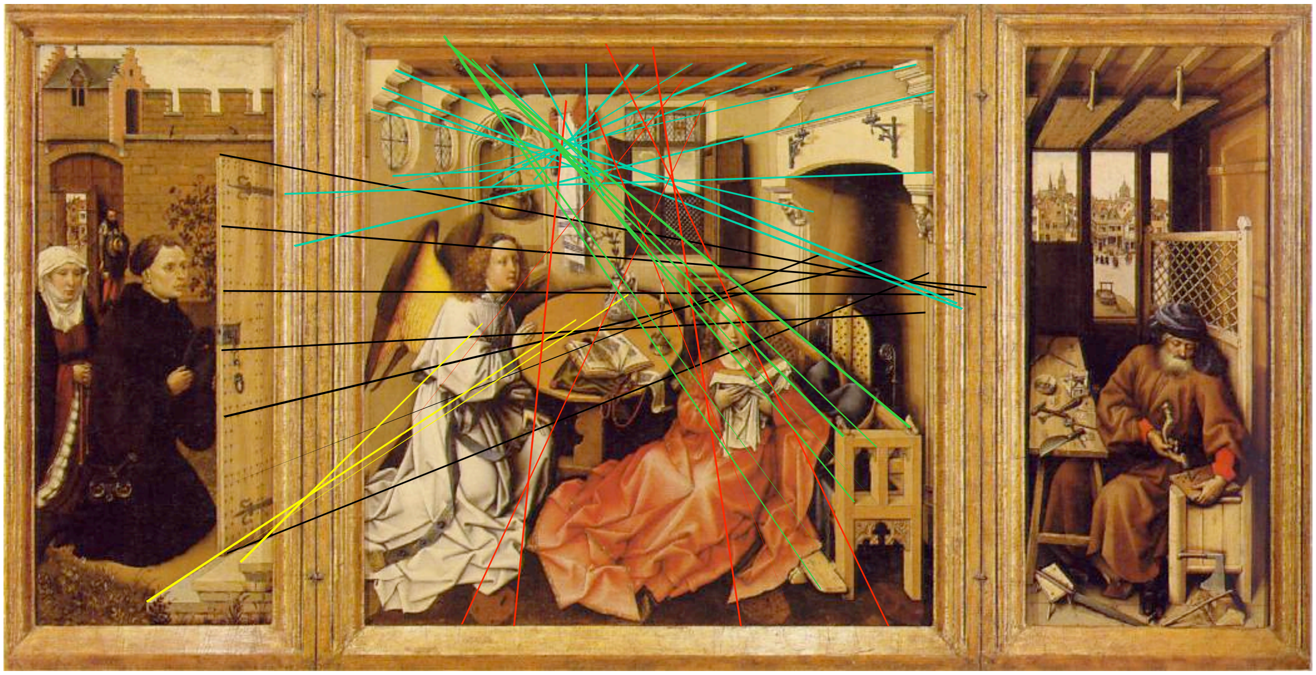

Figure 4: Master of the Flémalle (Robert Campin), "Mérode Altarpiece" (c. 1425-8) Oil on panel; 64.1 x 63.2 cm (central), 64.5 x 27.3 cm (each wing). Were the painting in proper perspective each set of lines of the same color (e.g., red for the floor tiles or yellow for the door steps or black from the line of door nails) would meet at a vanishing point. Moreover, many such sets (floor, ceiling beams, circular windows, etc.), would share the same vanishing point. In fact, however, the perspective is chaotic, haphazard and incoherent. © The Cloisters Collection, Metropolitan Museum of Art.

texts or manuals, the first problem Campin would have encountered is that the projected image would have been very dim. The dimensionless ratio of the illuminance of a portion of a scene to that of its projected image is

$$R = \Box A/f^2 \cos^4 \Box, \qquad \text{(Eq. 3)}$$

where A is the facial area of the concave mirror, f its focal length, □ the associated angle with respect to the mirror's principle axis and □ the reflectivity of the mirror surface ($0 \leq \Box \leq 1$). Putative mirrors inferred by Hockney, Falco, and others yield $R \sim 1/500$ to $1/1000$; thus in general direct sunlight would be needed as the illumination [12]. There is little if any corroborating visual evidence that direct sunlight was the illuminant in the indoor scene depicted in Fig. 4, such as strong, sharp directionally consistent shadows or chromatic scatter between adjacent surfaces [10]. In fact, the evidence such as the multiple shadows cast by the bench argue quite the opposite, i.e., for *multiple local* sources.

Next, Campin would have needed to solve an extremely tricky geometric problem. Notice that every slat that crosses the "break" in the trellis is in fact perfectly straight. Ensuring such linearity for all slats would have been one of the greatest optical achievements of its day. In order to ensure all slats are straight, both the lens *and* the support must be tipped and moved by very precise amounts. The present author attempted to "re-enact" this procedure with a concave mirror but after nearly an hour of frustrating work out of doors (for direct sunlight illumination [12]), the sketch did not have straight slats. Such precision, we are asked to accept, was achieved by the earliest practitioner to capture an image under projections, using dim, blurry projected images—an artist for whom we have no supporting evidence had any knowledge of projections.

V. An alternate explanation for the break in the trellis

Given the extremely challenging task associated with painting the trellis using optical projections, we naturally wonder whether there might be a simpler procedure. Consider the first problem facing Campin in this regard as he draws the frame for the slats given that Joseph's head obscures much of the lower beam: how to drawn the beam in the background so as to align visually with the beam in the foreground. He may have just judged the position of the line by eye, and if so, succumbed to the well-known Poggendorff illusion [13], shown in Fig. 6. Alternatively he may have used a ruler and merely slipped. These are the kinds of geometric "errors" that pervade "Mérode Altarpiece," and indeed other works from the workshop of Robert Campin, for example "The Virgin and Child in an interior" (c. 1435).

Figure 5: Right panel of Fig. 4 (detail), approx. 15.4 x 12.6 cm. Lines linking the intersection of slats in the foreground converge toward a different point than do such lines in the background. Falco claims this "break" is evidence that Campin refocused a concave mirror.

We assume, then, that Campin has in essence the frame shown at the top of Fig. 7, where the dashed line is the portion obscured by Joseph's head. How is Campin to then draw the slats? It seems plausible that he would merely use a straightedge to draw diagonal lines, much as one would draw a checkerboard. He might have placed fiducial markers around the frame image and connected lines diagonally as shown in the middle parts of Fig. 7 (where the angle in the middle of the lower fame has been exaggerated slightly for clarity). For slats connected to the dashed portion of the frame (i.e., the segment obscured by Joseph's head), Campin needed only to draw the slats approximately parallel—he would not need to connect each slat line to an "obscured" fiducial mark. After this construction, the slats automatically evidence the "break" just as in Fig. 5, as shown at the bottom of Fig. 7.

The procedure illustrated in Fig. 7 is extremely simple, indeed obvious. It seems likely Campin would have found this procedure as a modest alteration of techniques used for millennia and by children today for drawing rectangular patterns such as tiled floors. In fact, as part of our research, this procedure was successfully "re-enacted" by a talented nine-year-old girl using colored markers and straightedge—on her first try. This alternate method relies on the simplest of technology, a straightedge, and is quite insensitive to details of the location of the fiducial points around the frame, as the reader can verify by construction. (If one feels there are *two* breaks in the trellis, that can be easily explained by Campin in essence filling in a third line segment, behind Joseph's head, as shown in Fig. 8.)

This geometrical method trivially explains one of the most salient aspects of the trellis—that the slats are straight. In contrast, the optical projection hypothesis relies on the most sophisticated optical projection system of its day (if indeed projections onto a screen even occurred), and yields straight slats if and only if the mirror and the screen are adjusted extremely precisely. The projection hypothesis demands that this challenging engineering feat was accomplished by an artist… for whom we have no independent evidence had experience with optical devices such as concave mirrors.

Of course we do not claim to have "proven" that the procedure outlined in Fig. 7 was in fact used by Campin; to do so would be extremely irresponsible. Nevertheless we do claim that it is not merely a possible alternative to the optical hypothesis, but in fact a far more plausible one.

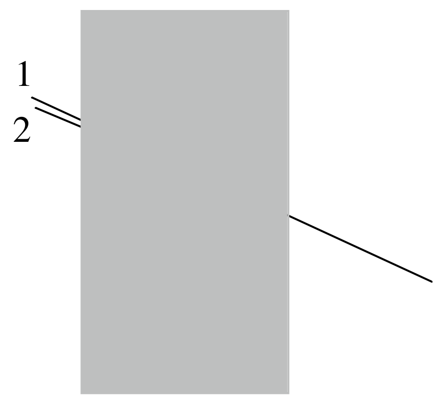

Figure 6: The Poggendorff illusion occurs when a line segment is occluded by an interposed region at an angle. In general subjects perceive the straight-line continuation of the segment on the right to be segment 2 while in fact it is segment 1, as the reader can verify with a straightedge. The angles and distances in segment 2 are the same as those in the lower beam of the trellis in Fig. 5, where St. Joseph's head occludes the lower beam of the frame.

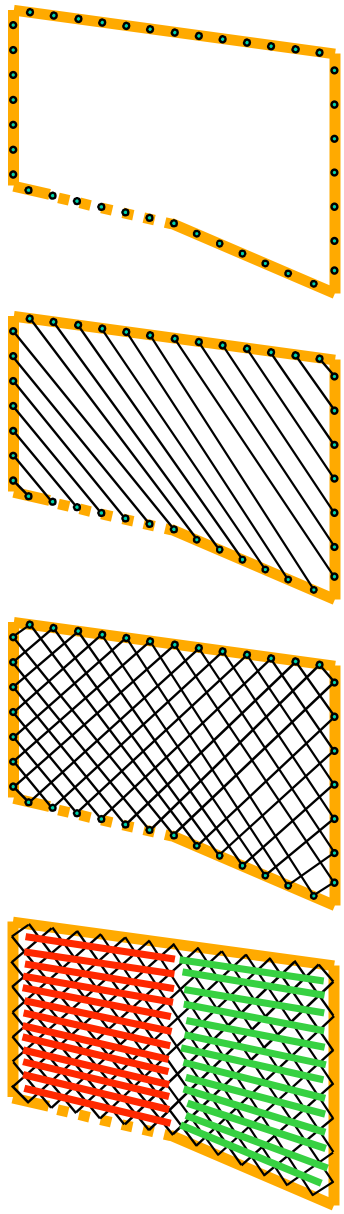

Figure 7: A possible series of steps in the drawing of the Mérode trellis, read top to bottom (see text).

VI. Conclusions

We applied geometric analyses to features in two paintings adduced as evidence for Hockney's theory that some early Renaissance painters employed optical projections. We find that despite the impressive appearance of the splendid Arnolfini chandelier, it fails every relevant perspective test that would indicated it had been created by an optical projection. We find, and verified by "re-enactment," that the technical constraints upon an optical system and its use for creating the Mérode trellis are severe. An almost trivial geometric construction using straightedge can explain all the relevant geometrical features in the painting.

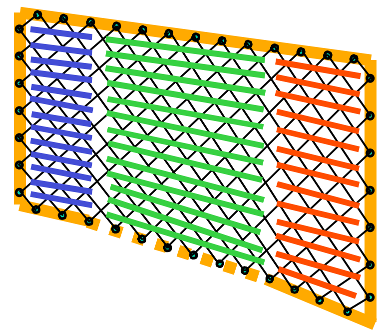

Figure 8: A tri-partite division of the Mérode trellis, with two "perspective breaks."

While our analyses allow us to soundly reject the projection hypothesis, at least as it relates to these two paintings, our technical study nevertheless exposes several essential and broadly applicable points in the debate:

- The science and technology of geometric optics (ray tracing, image formation, depth of field, etc.) taken alone is insufficient to analyze the Hockney theory. For instance, an understanding of perceptual psychology of visual pattern analysis may be needed, such as that related to the Poggendorff illusion [14].
- Even if the optical evidence can be fit with a projection model, that—of course—does not mean that optics were in fact used! There may be other explanations, such as we found and summarized in Fig. 7. In just this way, superb projection "fits" to the visual evidence in Lorenzo Lotto's "Husband and wife" [2] do not mean optics were used [15].
- As a corollary of the previous point, it is manifest that we must explore a number of explanations for the creation of any visual feature before we tentatively conclude whether one is the most plausible. Throughout it is of course essential to look for supporting evidence *as well as* counter-evidence.

The burden of proof lies squarely upon the revisionist proponents of the projection theory. They must first show that more traditional non-optical alternatives are impossible or far less likely than optical ones. After that first step, proponents would have to account for corroborating facts, such as the lack of historical records from contemporary scientists, mirror makers, artists, patrons, etc., that the required optical devices (long-focal-length concave mirrors) existed in the early 15th century, that anyone had even seen an image projected onto a screen, and so on [16]. The theory's proponents have yet to rise to that first basic step.

Our results show how Campin may have used the simplest of artists' tools—a straightedge—and easily drawn the trellis in the "Mérode Altarpiece"; he did not need what would have been the most sophisticated optical device and difficult optical procedure of his day. Furthermore, our results highlight van Eyck's achievement of painting a chandelier so meticulously, so realistically, that one of today's most celebrated artists could proclaim that it "is in perfect perspective," when in fact it is not—all by means of patient talent and oil paint, not concave mirrors and optical projections.

Acknowledgements

My thanks go to Lydia Pigeon for taking a photograph of the Barley Hall chandelier, to Richard Stone (Metropolitan Museum) and Monique de Ruette (Institut royal du patrimonie artistique, Bruxelles) for detailed correspondence on 15th-century metalworking techniques, to Antonio Criminisi (Microcoft Research) for correspondence on perspective analyses, and to the National Gallery London and the Metropolitan Museum of Art for reproduction permissions.

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Biography

Dr. David G. Stork is Chief Scientist of Ricoh Innovations and Consulting Professor of Electrical Engineering and Visiting Lecturer in Art History at Stanford U. He studied art history at Wellesley College and received his degrees in physics from M.I.T. and U. Maryland. He has been on the faculties of Wellesley, Swarthmore College, Clark U., Boston U., Stanford U. where he has taught "Light, color and visual phenomena," "Optics, perspective and Renaissance painting," "Pattern classification," and other courses. He was Artist-in-Residence through the New York State Council of the Arts and his five books include *Seeing the Light: Optics in nature, photography, color, vision and holography* and *Pattern Classification* (2nd ed.). He was one of four scientists invited to comment on Hockney's theory at the 2001 *Art and Optics* Symposium.

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Our analyses show that the Arnolfini chandelier fails standard tests of perspective coherence that would indicate an optical projection. Or more specifically, for the physical Arnolfini chandelier to be consistent with an optical projection, that chandelier would have to be implausibly irregular, as judged in comparison to surviving chandeliers and candelabras from the same 15th-century European schools. We find that had Campin painted the trellis using projections, he would have performed an extraordinarily precise and complex procedure using the most sophisticated optical system of his day (for which there is no documentary evidence), a conclusion supported by an attempted "re-enactment." We provide a far more simple, parsimonious and plausible explanation, which we demonstrate by a simple experiment. Our analyses lead us to reject the optical projection theory for these paintings, a conclusion that comports with the vast scholarly consensus on Renaissance working methods and the lack of documentary evidence for optical projections onto a screen.

Keywords

Concave mirrors, Jan van Eyck, Robert Campin, Hockney theory, Renaissance painting, optical projection, real image