Fidelity analysis of mechanically aided copying/enlarging of Jan van Eyck's *Portrait of Niccolò Albergati*

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Abstract

The contemporary artist David Hockney has hypothesized that some early Renaissance painters secretly projected optical images onto their supports (canvas, paper, oak panel, …), directly traced these projections, and then filled in the tracings with paint [1]. Hockney has presented somewhat impressionistic image evidence for this claim, but he and thin-film physicist Charles Falco also point to perspective anomalies, to the fidelity of passages in certain paintings, and to historical documents in search of support for this direct tracing claim [2].

Key visual evidence adduced in support of this tracing claim is a pair of portraits by Jan van Eyck of Cardinal Niccolò Albergati—a small informal silverpoint study of 1431 and a slightly larger formal work in oil on panel of 1432. The contours in these two works bear striking resemblance in shape (after being appropriately scaled) and there are at least two "relative shifts" —passages that co-align well after a spatial shift of one of the images [2]. This evidence has led the theory's proponents to claim that van Eyck copied the silverpoint by means of an optical projector, or epidiascope, the relative shifts due to him accidentally *bumping* the setup during the copying.

Previous tests of the tracing theory for these works considered four candidate methods van Eyck might have used to copied and enlarged the image in the silverpoint study: unaided ("by eye"), mechanical, grid, and the optical projection method itself [3]. Based on the full evidence, including the recent discovery of tiny pinprick holes in the silverpoint, re-enactments, material culture and optical knowledge in the early 15th century, the mechanical method was judged most plausible and optical method the least plausible [3].

However, this earlier work did not adequately test whether a trained artist could "re-enact" the copying by mechanical methods: "Although we have not explicitly verified that high fidelities can be achieved through the use of a *Reductionszirkel* (or compass, protractor and ruler), there are no significant challenges in this regard" [3]. Our work here seeks to complete the test of the direct tracing claim. As we shall see, a talented realist artist can indeed achieve fidelity comparable to that found in van Eyck's works, a result that re-affirms the earlier conclusion that when copying and enlarging the silverpoint image, it is more likely that van Eyck used a well-known, simple, *mechanical* method than a then unknown, secret and complicated *optical* method.

Introduction

In seeking to explain the rise in realism of the "new art" of early Renaissance Europe, David Hockney proposed that some painters of that time secretly employed optical devices and their projections as aids when painting [1,2]. Historians of optics and art stress the fact that there is no documentary evidence from artists, scientists, patrons, or instrument makers from that time showing that anyone had even seen an image projected onto a screen by concave mirror or converging lens [4] (the first step in the Hockney procedure), let alone trace over such an image or create any specific artworks by such means. Hockney and Falco have tried to explain this lack of documentary evidence by stating that artists were protecting "trade secrets" or "secret knowledge," but expert historians point out that artisans of the time freely announced their methods as a means of attracting both patrons and apprentices [5]. One historian, after reviewing the textual record with specific attention to evidence for the tracing theory, concluded: "With regard to the Hockney-Falco thesis the silence of this considerable body of texts on the concave mirror projection method is deafening. Written by well-informed contemporaries who were keenly interested in the relationship between the mirror and painting and eager to impart any 'secret knowledge' to willing listeners, it seems inconceivable that they would not have described a method that according to Hockney and Falco revolutionized the art of their time" [6].

In the absence of persuasive documentary support, most of the debate has been confined to the early Renaissance paintings themselves as primary evidence, studied using methods from pattern recognition and computer image analysis, our approach here.

 

Figure 1: *Jan van Eyck, L: "Portrait of Cardinal Albergati," silverpoint, 21.2 x 18.0 cm (1431), Kupferstich-Kabinett, Dresden; R: "Portrait of Cardinal Niccolò Albergati," oil on wood, 34.1 x 27.3 cm (1432), Kunsthistorisches Museum, Vienna.*

In Sect. *I* we sketch the projection tracing theory, then in Sect. *II* we review previous analysis of the Albergati portraits. In Sect. *III* we then describe image processing and a principled computational method for comparing form based on the Chamfer distance. In Sect. IV we apply these methods to determine the fidelities of modern "re-enactments" by mechanical methods and by unaided free drawing, which we compare to that in the van Eyck oil work. In Sect. V we mention briefly the key matter of burden of proof in the debate and summarize our conclusions.

I. The projection tracing theory

Hockney's tracing theory states that some European painters as early as 1420 employed optical devices to project real inverted images of a scene or part of a scene onto a canvas or other support (canvas, oak panel, etc.). According to the theory, artists would then either trace in pencil the image contours and then commit paint to the support, or perhaps even paint directly, though it is well-known that it is extremely difficult to paint directly under optical projection. The earliest presentations of the theory of painting practice—or *praxis*—strongly favored the use of concave mirrors over converging lenses; such mirrors can indeed project a real image much as can a converging lens [7]. Proponents touted the mirror in part because images it produces images have the same left-right symmetry as the scene being imaged while a converging lens produces images that are reversed left-to-right. Moreover, proponents favored the concave mirror because they felt that historians of art are less familiar with the optical properties of such mirrors, and thus such scholars might have overlooked Renaissance textual evidence supporting the projection use of mirrors in art.

In most of his early presentations, Hockney felt that such tracing methods were key to the rise in realism in European painting around 1420. More recently, however, he seems to have retreated from that claim, feeling that such artists may have merely *seen* and been indirectly *influenced* by the sight of projected images [8]. Given the absence of contemporaneous documentary evidence to support the claim that anyone in the early Renaissance saw an image of an illuminated object projected onto a screen by mirror or lens, this alternate theory seems not only implausible, but difficult (if not impossible) to test satisfactorily. After all, none of the technical analyses of fidelity, perspective, color, shading, illumination, and so on bear directly upon this theory of artistic *influence*.

Here we focus, then, on the claim of direct painting *praxis* in the van Eyck works, and leave the question of the indirect *influence* to art historians.

II. The projection tracing theory and the Albergati portraits

Figure 1 shows the van Eyck works in question: portraits of the Italian Cardinal Niccolò Albergati. At the left is an informal silverpoint study, widely thought to have been executed from life within a three-day period in 1431 when Albergati was visiting Bruges. This study bears handwritten notes about a number of matters, for instance the colors of the garment and of the subject's irises. At the right is a more formal work in oil on panel, executed the following year and surely based on the silverpoint study. The question is thus: *how, precisely, was this copy made?*

Previous work on that question considered four candidate methods [3]:

- Mechanical aid (*Reductionszirkel* or reducing compass)
- Grid construction
- Free drawing without drawing aids ("eyeballing," in Hockney's terminology)
- Optical projections via a mirror-based *epidiascope*

That previous study proceeded as follows. It supposed that van Eyck used the mechanical aid (specifically a *Reductionszirkel* or reducing compass), and then reasoned what visual evidence would or would not be found in the works. Then this supporting evidence was sought in the works themselves. Likewise, it was next assumed that a grid construction was used, supporting evidence sought, and so forth for each of the remaining candidate methods. After all four methods were tested in this way, they were ranked according to plausibility. Here we mention just some of the evidence that bears on two of the methods.

If van Eyck had used a mechanical method, such as the well-known *Reductionszirkel* or reducing compass, we might expect to find tiny pinprick holes in the silverpoint study, left by the sharp tips of this mechanical device. Note that this mechanical device need not leave such holes if the artist only *gently* touches the device to the silverpoint—that is, without pricking the surface. Thus an artist can use such a mechanical device to make a large number of measurements on the images yet leave few or even no pinprick holes.

Yet just such pinprick holes were later discovered in the silverpoint through microscopic analysis by Ketelsen and his team of art historians and physicists [9]. (These scholars concluded that van Eyck indeed employed mechanical reproduction.) These distinctive pinprick holes strongly support the mechanical explanation and provide no support whatsoever to the optical projection theory.

The exploration of the grid construction asked, analogously: *if van Eyck had used a grid, what visual evidence might we find?* It is clear that artists can copy and enlarge an image to very high fidelity by means of a grid. The secondary evidence considered, thus, were the "relative shifts" found in van Eyck's works. First the digital image of the oil work was scaled to match that of the silverpoint and overlapped for maximum correspondence (as judged by eye). This led to good correspondence on the chin nose and outer contour of the face. However, the ear and shoulder regions did not then align well. Then, one of the images was shifted horizontally so as to get maximum correspondence on the remaining portion of the images. Note that this candidate shift was chosen to be *horizontal*, as might arise if the artist was guided by a grid. The shift distance for maximum correspondence found in this way was among all *candidate horizontal* shift distances.

Even after the images had been offset by such an optimum horizontal shift, there was a remaining mismatched area (at the top of Albergati's ear). Hence a second, *vertical*, shift was introduced, again as might arise if the artist was guided by a grid.

It was discovered that the two optimal shift distances, defined in this way, were in the ratio of nearly 2:1, as if van Eyck deliberately (or accidentally) shifted the images by *two* grid squares horizontally then *one* grid square vertically. This result, then, gave mild, but not conclusive, support for the hypothesis that van Eyck used a grid. Note that given a different candidate copying method, with more degrees of freedom (permitting shifts along directions other than horizontal and vertical), a slightly superior quality of image match can be found.

Similar analyses of "eyeballing" and the optical tracing method were described in the original paper. In light of the full evidence, it was concluded that the mechanical reproduction method was the most plausible and the optical tracing method the least plausible.

Nevertheless, as mentioned in that earlier study, future work was to include verifying that van Eyck could have achieved the observed image fidelity using such mechanical methods. One way to shed light on that question is to have a talented realist artist "re-enact" the copying using mechanical aids and measure the fidelity of the copy so produced. That is our approach here.

Next we discuss the image processing needed, then the principled method for quantifying image match, and finally the results.

III. Edge detection, fidelity, and Chamfer metric

According to Hockney's tracing theory, artists would trace contours of optical images, and later apply paint without the projected image present. As such, it is only the fidelity of the *contours* of the portraits that concern us. To isolate the contours from shaded, modelled works, we applied standard derivative-based edge detection, line-thinning and thresholding operators common in the computer vision and image processing communities [10]. There are generally free parameters describing spatial properties and threshold levels in such algorithms and thus for each image we adjusted the parameters semi-automatically so as to yield contours whose position matched the contours found in the original works. In some cases, a single set of parameters could not yield a well defined contour throughout the entire image. The silverpoint, for instance, is quite noisy (cf. Fig. 1), and hence required careful selection of parameters. For several images we added a few contour pixels by hand so as to ensure the contours closely represented those in the original works, a technique that helped ensure the accuracy of our final analyses.

Figure 2 shows the result of edge detection, line-thinning and thresholding on the van Eyck oil portrait—its binary *edge map*.

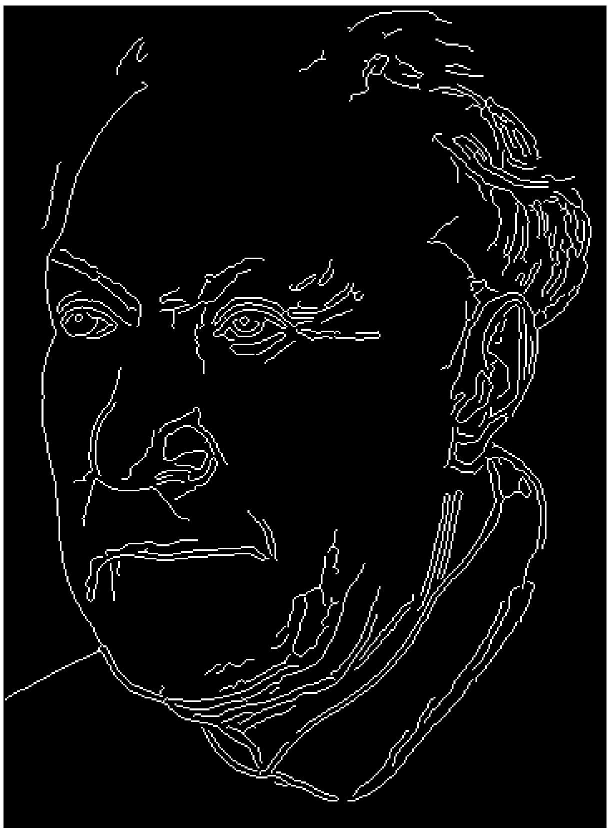

Figure 2: *The binary edge map from the van Eyck oil portrait obtained by semi-automatic application of edge detection, line-thinning and thresholding algorithms.*

Given high-quality edge maps, as just described, the question then becomes how to measure the fidelity between them. To compute the fidelity between two images we first perform the affine transformations of uniform scaling (i.e., same magnification in vertical and horizontal directions) and shifting of the images for maximum overlap, all as judged by eye. Even after these operations, the images differ. We then used the Chamfer distance to quantify this residual difference between two aligned images.

The Chamfer distance between two curves or sets of pixels, C_1 and C_2, is computed as follows. For each pixel in C_1 we compute the spatial distance to the nearest point on C_2. Then we sum all these (non-negative) distances and then divide this total length by the total number of pixels in C_1. The Chamfer distance is thus the average distance from a pixel in C_1 to its nearest pixel in C_2.

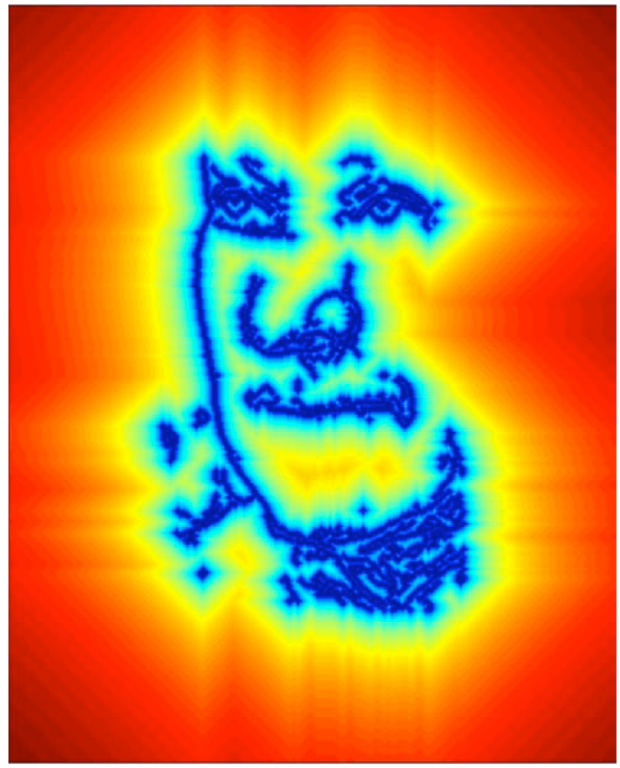

Figure 3: *The distance transform, based on Chamfer metric, applied to a subset of lines corresponding to a single "exposure" within the silverpoint study, i.e., the passage well aligned between the van Eyck portraits.*

This Chamfer distance computation can be illustrated by the *distance transform*. The distance transform of a curve (or set of points) C assigns to every pixel in an area the distance of that pixel to the nearest pixel in C. Figure 3 shows the distance transform applied to a subset of the full edge map of the silverpoint study. Each point is colored by its distance to the nearest point on the edge map: blue for short distances, red for large distances.

V. "Re-enactments" and results

Three professional artists copied and enlarged in pencil (by roughly 40%) a print of the Albergati silverpoint, striving to make as faithful (high fidelity) copy as possible. One artist (PvdW) worked without aids, and two artists (TS and RvdW) used a reducing compass. Figures 4 and 5 show two of the resulting drawings.

Figure 4: *A copy of the Albergati silverpoint executed by a professional artist (RvdW) using a reducing compass. The number and location of pinprick holes is consistent with those found in the Albergati portrait.*

The copy works were scanned and reduced uniformly in software to have the same scale (so the pixel resolutions were the same). We were very careful to ensure that the overall minification was the same in the horizontal and the vertical directions.

We also cropped the images to restrict comparisons to the region of Albergati's eyes, nose, chin and cheek at the left—the region of a single "exposure" found in the van Eyck works [2].

V. RESULTS

Table 1 lists the Chamfer distances, as defined above, between different works and the silverpoint study original.

copy work	Chamfer distance
van Eyck oil (JvE)	5.6304
unaided (PvdW)	7.6476
mechanical (RvdW)	3.8507
mechanical (TS)	4.5356

Table 1: *The average pixel distance between different copies and the van Eyck silverpoint computed on the region of the primary "exposure" (cf. Fig. 3).*

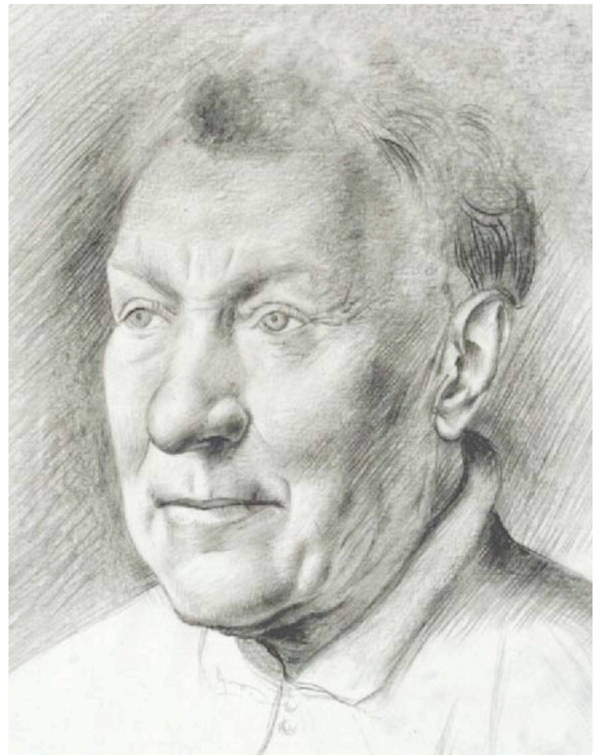

Figure 4: *A copy of the Albergati silverpoint executed by a professional artist (PvdW) entirely by eye, that is, with nothing more than a straightedge for judging angles.*

Our results show that talented artists using mechanical aids can indeed achieve fidelities that are comparable—in fact superior (smaller Chamfer distance)—to that found in van Eyck's oil copy. Our results strongly suggest further, but cannot prove, that van Eyck might have achieved his fidelity entirely "by eye."

Although future work could include estimating the precision of these Chamfer distance estimations, sensitivity to parameters of edge detection, and statistical significance of the difference between the fidelities, our current results seem more than sufficient to reject claims that van Eyck needed to use an optical projector to attain the fidelity shown in his oil copy.

Conclusions

In light of the full range of evidence and earlier analyses of the Albergati copying method, and particularly the discovery of distinctive pinprick holes, it would seem unlikely that van Eyck used an optical projector. The burden of proof lies squarely on the shoulders of the revisionists Hockney and Falco. For them to justify their highly public claims that they have "proven" that early Renaissance artists traced optical projections, they would have to show for this work, at minimum, that the fidelities required the use of optics. It is hard to know how they might succeed in this requirement [11].

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Biographies

Dr. David G. Stork is Chief Scientist of Ricoh Innovations and currently Visiting Lecturer at Stanford University. He studied art history at Wellesley College and received his degrees in physics from M.I.T. and U. Maryland. He has held academic positions at Wellesley College, Swarthmore College, Clark U., Boston U., Stanford U. and was Artist-in-Residence through the New York State Council of the Arts. His five books include *Seeing the Light* and *Pattern Classification* (2[nd] ed.). He was one of four scientists invited to comment on Hockney's theory at the 2001 *Art and Optics* Symposium.

Mr. Marco F. Duarte is a graduate student in Electrical and Computer Engineering at Rice University. He holds a BS in Computer Engineering and an MS in Electrical Engineering from the University of Wisconsin-Madison. His current research interests include pattern recognition and digital signal processing, such as fast algorithms for image reconstruction, as well as distributed architectures for compressive imaging.

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Keywords

Jan van Eyck, Hockney tracing theory, Chamfer distance, *Reductionszirkel*, reducing compass, Renaissance art