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Computer Vision and Art

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As a scientific researcher interested in computer vision and art, I have spent the last seven years working with David Hockney, an artist of whom a respected source writes that "his drawings and etchings are amongst the deftest of this century; posterity may well acclaim him the greatest of modern portraitists."[1] Together, Hockney and I have proposed and provided supporting evidence for a hypothesis, controversial in the art history world, that optical projections were used as aids in making paintings as early as c. 1425.

In David Stork's recent three-part series, he uses our findings as a sounding board for discussing his own research on computer vision and art. Briefly, his premise is that his research shows there are alternatives to our optical projection hypothesis that explain the data just as well.

In this article I show serious errors with Stork's research described in his three-part series. I also clarify the hypothesis that Hockney and I actually have proposed.

Some background

Since the early 1960s, Hockney's skilled eye has repeatedly focused on certain features within some of the best-known paintings of European art whose level of detail seemed exceptional. His interest eventually blossomed into the full-scale investigation described in his book.[2] Based on his visual observations, Hockney hypothesizes that certain painters began using optical projections as aids starting early in the Renaissance, affecting long-held understandings of the relatively sudden emergence of realism c. 1425.

In the course of his investigation, Hockney assembled color photocopies of approximately 500 paintings on one long wall of his studio. When I first saw this wall I noted that his organizational scheme was distinctly scientific, with the images organized both chronologically and geographically (for example, northern Europe was on the upper wall and southern Europe was on the lower).

I recognized a number of features in those paintings that appeared "optical" (for example, more distant portions of a feature becoming blurred, as in the depth-of-field effect seen in many photographs) so, in parallel with the completion of his book, Hockney and I began looking for possible scientific evidence within the images to support our hypothesis. We found a wealth of such evidence, indicating that we can accurately calculate specific types of errors in otherwise realistic paintings, because they were made with the aid of images projected by a lens or a concave mirror.[3-7] For example, measurements on a variety of features in a painting that includes a complex Oriental carpet are in agreement to within ±0.5 percent with calculations from geometrical optics. These calculations are derived from the hypothesis that a lens had to be refocused twice because of the shallow depth of field of projected images at the relatively high magnification of 0.56×.[3,4,7]

Although Hockney and I have presented detailed mathematical evidence supporting this optical hypothesis, many art historians criticize our claims and accuse us of denigrating artists' talent. We might have anticipated this response, given that our findings involve Old Masters no less revered than van Eyck, Caravaggio, and Holbein the Younger.

David Stork et al.[8-10] challenged our findings

Editor's Note

We routinely rely on art to understand science, but science is also used to better understand art. When David Hockney wrote in his book *Secret Knowledge* that he had "rediscovered" secret methods of the great painters, asserting that "from the early 15th century many Western artists used optics—by which I mean mirrors and lenses (or a combination of the two)—to create living projections," he sparked a debate that would motivate new lines of inquiry and research in a multitude of disciplines including art history, optics, image analysis, and more. Charles Falco later claimed he had proven Hockney's findings scientifically. In the last three "Artful Media" articles, David Stork presented applications of computer imaging for analyzing paintings, some of which challenge those claims. In this article, Falco defends his original findings.

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and offered alternate explanations. However, they based four of their central arguments on misconceptions of what we proposed, a fifth on erroneous data, and a sixth ignores relevant contradictory evidence.

Tracing

An example of a contradiction between what Hockney and I are espousing versus what Stork interprets is the following: in one instance, Stork and Johnson write, *"Indeed, Hockney proposes that Georges de la Tour traced projected images during the execution of his dramatic nocturne paintings."*[9] This statement reflects a fundamental misunderstanding of how Hockney proposes an artist would work with projected images.

Even though an image is on the surface in front of him, the artist, unlike a piece of photographic film, is free to use artistic judgment to trace portions of it exactly as projected, alter other portions to balance various aspects of the overall composition, and ignore yet other parts of that projected image entirely. Consequently, because the artist intimately involves his hand and mind in the creation process, we do not subscribe to the misconception that any of these paintings is a composite of slavish tracings.

Talent

Stork also states that *"Inherent in Hockney's claim is that van Eyck, and by implication other realist artists, could not paint a chandelier in good perspective without optical aids."*[8] Something I should note before responding to this fully is that van Eyck's *The Arnolfini Portrait* includes a highly realistic image of a dog identifiable as a Bichon. Since a small dog would not have remained motionless long enough for van Eyck to capture details from its projected image, we can be reasonably certain that its image was made without the aid of an optical projection. That a given artist *could* paint realistically without a tool does not prove that he did not use that tool.

Stork also offers an irrelevant and unreasonable comparison of a large painting of a less ornate chandelier created specifically by Nicholas Williams for Stork's purposes as evidence that an artist can achieve similar accuracy without optics.[8] Contemporary artists are familiar with the laws of geometric perspective and have been influenced by having seen the optical perspective of countless photographs, whereas van Eyck worked before the laws of perspective had been developed.

Furthermore, Stork fails to mention the size of Williams' large painting. An artist can produce a large, accurate painting easier than a tiny one. Van Eyck's chandelier is so small (approximately 12 × 17 cm) the palm of a cupped hand can cover it, yet so detailed that it maintains its structure even on close inspection when enlarged to fill two pages (pp. 82-83) of Hockney's book.[2]

Complicated optics

"*Why would van Eyck build the most complicated optical system of its day just to mark a few points*?" Stork asks.[8] Far from being complicated, van Eyck could have easily replaced the pinhole in a camera obscura with a simple lens. Even if the lens were of quite low quality it would produce a brighter image along with identifiable limitations of geometrical optics such as a calculable reduction of the depth of field of the projected image.

None of the optical features we've identified in paintings as early as c. 1425 requires anything more complicated than one lens from 2-diopter reading spectacles, or a simple 5-cm diameter, with 50-cm focal length, concave metal mirror. (All of these figures are approximate).

Documentations clearly show people used both types of optics at least 100 years prior to the time of van Eyck.[6] Indeed, in his 1434 *van der Paele Altarpiece,* van Eyck shows someone holding a pair of spectacles. Just one lens (with an approximately 50-cm focal length) of those spectacles could have produced every feature that we have shown to be based on an optical projection.[6]

Perfect symmetry

Stork shows that the image of the chandelier in the painting *The Arnolfini Portrait* doesn't accurately represent a perfectly symmetrical chandelier. In his words,

> … the image is inconsistent with the claim that a symmetric chandelier was traced under a projection … The inherent difference between these perspective-aligned arms—roughly 8 cm in Arnolfini's room (using the scale noted elsewhere)—seems quite large indeed.[8]

Stork has misstated our claim. We previously showed that the painting of the chandelier deviates from perfect symmetry, consistent with what should be expected for a handmade object.[4,7] Note, though, that the differences are small in absolute magnitude; the largest difference between the main arc of any of the six arms, and any of the six candle holders, of a perfectly symmetrical, perspective-corrected chandelier overlaid onto the

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actual painting is only approximately 2 mm. However, Stork argues that because the painting doesn't represent a perfectly symmetrical object, van Eyck must have drawn it with the naked eye.

Inaccurately, Stork assumes that a handmade 15th-century chandelier of about one meter in diameter would have been perfectly symmetrical. Even modern, machine-made chandeliers can exhibit deviations from ideal symmetry just as large without appearing visually defective to the naked eye. Indeed, we published evidence of this by analyzing photographs of modern chandeliers for sale in today's shops.[4]

Use of erroneous evidence

Stork uses incorrect data in his analysis of George de la Tour's *Christ in the Carpenter's Shop* (1645).[9,11] In one of his papers,[11] Figure 1 includes five lines he has drawn between points on the subjects and what he says are the corresponding points on their shadows, all of which converge to the candle with high accuracy. From this convergence to a single point Stork concludes, *"We have shown compelling evidence that the illumination within 'Christ in the Carpenter's Studio' is due to the single candle held by Christ, and that source alone."*[11]

One of Stork's lines connects a data point on the kink of the boy's knee to what should be the corresponding kink in the shadow, but the shadow has no kink. The line from the left rear of the block is incorrect as well; the line extrapolated from the actual data is significantly below the candle.

I find it puzzling indeed that Stork's incorrect data should agree so well with his (desired) conclusion that the candle is the sole light source. Interestingly, although 40 percent of the data on Figure 1 in his subsequent paper[9] are now in different locations, Stork again claims it supports his conclusion.

Most problematically, Stork and Johnson's computer analysis scheme[9] treats the de la Tour painting as if it were a photograph. Since their scheme is intrinsically two dimensional, it is incapable of determining whether there are multiple light sources at different depths in an image (for example, at approximately the same x, y of the 2D image, but at a different z). Despite this, they still conclude there's a single light source.

Also, their analysis is visibly inconsistent with the actual painting. According to their occluding contour analysis, the light source's position is no lower than the height of the boy's collar and no higher than his lower lip. However, the boy's stomach is lighter than his collar, even though it's twice as far away from where their analysis finds the light source to be, and thus should be one-fourth as bright.

Selective omission of relevant evidence

Hockney and I argued that van Eyck based his painting *Portrait of Cardinal Albergati* (c. 1435) on optical projections of the smaller drawing of the Cardinal.[5,7] We found that the painting consists of three regions, each of which is an accurate copy of the corresponding portion of the drawing, with these regions separated from each other by displacements of approximately 4 to 5 mm in nonorthogonal directions. These features are consistent with a 15th-century lens or concave mirror providing only a limited area of fidelity to work with, requiring van Eyck to piece together the overall enlargement from separate projections.

Stork and Duarte argue instead that van Eyck produced the roughly 40 percent enlargement by using a proportional divider, offering as evidence that a contemporary artist was able to produce such an enlargement.[10] However, we're neither surprised that an artist could, nor do we find it relevant that an artist is able to, enlarge an entire drawing this way.

Stork and Duarte have simply *ignored* the data that point to the use of optics—the existence of three separate, displaced regions making up the painting—rather than a single, enlarged image. Figure 3 of their work[10] accounts for only one of the three regions, finding high accuracy within that region, just as Hockney and I had previously published[5,7] (and which we also found for the two other regions that Stork and Duarte ignore).

Stork and Duarte write about *"the dramatic discovery of tiny pinprick holes in the silverpoint that indicated mechanical (not optical) methods were used."*[10] However, they offer no explanation for how these few holes actually account for the relevant features of the painting.

Indeed, the researchers who discovered the holes state quite the opposite, that their existence "*offers no explanation for the greater width of the face as it appears in the painting*."[12] In the same paper those researchers describe how the silverpoint drawing was in unknown hands until 1841, and that "*a fully abraded section has been retouched … a semicircular tear has been mended by attaching a new piece of paper…* [*and*] *a reddish-brown print of a finger … probably dates from a later period*."[12] In other words, anyone during the past 572 years could have made those few pinprick holes. Most importantly, the positions of the holes offer no explanation for the differences between the silverpoint and the painting. The optics hypothesis, however, accurately accounts for these differences.

Artists and scientists have the same job—to come to an understanding of some aspect of the world around us and find ways to convey that understanding to others.

Conclusions

Stork et al. have offered alternative explanations for the features in several paintings that Hockney and I identified as having optically based components. However, in each case the conclusions are flawed (the interested reader can find a more detailed discussion at http://www.optics.Arizona.edu/ssd/Storkdataerrors.htm).

In many ways, artists and scientists have the same job—to come to an understanding of some aspect of the world around us and find ways to convey that understanding to others. As our discoveries show, artists such as van Eyck early in the Renaissance found that lenses were useful tools for their work, so we should not be surprised they employed them. We can derive a lesson from this that applies today; computer scientists who learn how artists actually work (and vice versa) have much to gain from their insights and approach to visual information.[13] **MM**

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