Computer graphics for the analysis of realist master art: Current methods and future challenges

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***Abstract*—We review the recent application of computer graphics to problems in the history and interpretation of master artworks. Carefully constructed computer graphics models of tableaus in paintings allow scholars to explore "what if" scenarios concerning lighting, geometry, placement of subjects, physical properties (such as color and reflectance characteristics), and more. A special application of computer graphics is to dewarp images depicted in spherical mirrors, such as appear in works from the northern Renaissance, thus revealing new views into artists' studios. We present a number of methodological recommendations to help ensure the results of such studies are valid. We describe some successes of these new techniques and conclude by discussing several outstanding problems and future directions for the use of computer graphics in the analysis of realist art.**

I. INTRODUCTION

In the past several years, scholars trained in computer science and art history have applied computer graphics to an ever widening range of questions in the history and interpretation of paintings and drawings. These new methods allow the scholars to explore "what if" scenarios in lighting, geometry and physical properties (such as reflectance properties of depicted surfaces), to better understand the artists' working methods and artistic intent. These methods, strongly guided by established art historical knowledge and context, support new interpretations of works and shed new light on artists' studio practice; they may, after continued refinement and extension, become more common tools in art historical research.

We begin in Sect. II by providing several methodological recommendations for creating and using computer graphics models when addressing questions in the history of art. Next, in Sect. III, we review some examples of research using these methods. We conclude in Sect. IV with some future directions and challenges.

II. METHODOLOGICAL RECOMMENDATIONS

As we shall illustrate in Sect. III, all research in this field must start with a clear understanding of both the art historical question at hand and the power and limitations of computer graphics methods for addressing these problems. We must, moreover, recognize that even the most ardent realist artists rarely if ever strive for "photographic accuracy" or photographic mimesis (save, perhaps, for photorealists such as Richard Estes, Robert Bechtle, Ralph Goings, Glennray Tutor, Malcolm Morley, and others). Rather, paintings are constructed objects, where the realist artist may alter the size, geometry, perspective, lighting, color, and so forth for expressive ends, even if such ends include "enhancing" the effect of realism. A computer graphics model—which implements and is based on a physical (or photographic) model of the world—thus can reveal such variations or "inconsistencies" in the painting due to an artist's expressive purposes, or even an artist's outright mistakes or oversights.

Reconstructing or inferring a three-dimensional scene based on a single two-dimensional projection (such as a photograph or an accurate realist painting) is formally "ill posed." That is, there is an infinite variety of three-dimensional scenes that project to yield any given two-dimensional image. As such, one must impose prior knowledge and constraints when creating a computer graphics model or *tableau virtuel*, from a painting. To this end, there are some *uncalibrated* methods for inferring geometry and perspective which have been used to reconstruct and study art, including Masaccio's *Trinity* and Jan Vermeer's *The music lesson* and Hendrik van Steenwick's *St. Jerome*.[1] Often, though, the constraints involve physics, for instance that objects are supported by a floor rather than floating in the air, that a still pendulum hangs vertically, and so on. Occlusion is a very strong constraint about the spatial order, that is, which objects are closer to the viewer than others. Prior knowledge about sizes, such as a typical person or objects such as bed can be incorporated as well. Lighting provides a surprisingly strong constraint upon three-dimensional models: two different models that yield the same geometric projection will nevertheless yield rather different (shaded) images under plausible lighting conditions. In practice, modelers start with generic figures and objects, place and light them incorporating these constraints, then rotate and view the tableau from different directions, comparing the rendering with the painting in question, constantly refining the model until it is adequate for the art historical questions at hand. The goal is not to make a three-dimensional artwork, of course, but instead to capture the relevant features so as to answer the art historical questions.

We stress, though, that even when all constraints have been incorporated into the *tableau virtuel* there is no guarantee the model is highly accurate. What is most important is that any deviations from an underlying model to be random—introducing statistical *variance* rather than systematic *bias* in the matter in question.[3] A good way to reduce the effects of such uncertainties is to use a two-alternative forced choice methodology. That is, the scholar creates two models, differing solely in the one variable of interest, such as the size of a given object or the radius of curvature of a depicted convex mirror or the position of an illuminant. Just such a two-alternative methodology was used by Stork and Furuich when they found the location of the illuminant in Georges de la Tour's *Christ in the carpenter's studio* based on the visual evidence in the tableau, as we shall see below.

III. EXAMPLES

Below are summaries of recent art historical research that has exploited computer graphics models.

- Johnson, Stork, Biswas and Furuichi built a computer graphics model of Jan Vermeer's *Girl with a pearl earring*, then adjusted the direction of illumination from a single, fairly distant virtual source until the rendered girl appeared as similar to the actual painting as possible.[5] This match is somewhat subjective and based on a number of visual cues such as cast shadows, highlights on her eyes and the pearl, the pattern of light on different areas, and so on. Nevertheless, it is reasonable to assume that any deviations from some "ideal" estimate were not biased to place the light source "too high" or "too low." The excellent agreement in the illumination directions emerging from these different estimates very strongly implies that Vermeer worked from an actual figure in his studio rather than from memory or strongly from his imagination.
- Stork and Furuichi built a model of Georges de la Tour's *Christ in the carpenter's studio*,[15] and Stork explored a model of Caravaggio's *Calling of St. Matthew*,[12] to infer the location of the illuminant within the models. In both these cases, the experimenters could adjust the location of virtual illuminants until the rendered image matched the corresponding painting as closely as possible. In this way, these scholars could answer questions about studio practice, concluding, for example, by rebutting the claim that de la Tour secretly traced optically projected images.[4]
- Stork and Furuichi built a model of the tableau in Diego Velàxquez's *Las meninas*, including the viewer's space in front of the tableau.[16] Here the central question involved the reflections of the king and queen in the plane mirror depicted on the rear wall: Are these reflected images consistent with the location of the viewer (in the position defined by the painting's perspective)? In other words, are we the viewers in the position of the king and queen seeing themselves in the plane mirror? These scholars explored the view into the *tableau virtuel* from a range of positions and concluded that the answer to that question is *no*: instead, the viewer is seeing the hidden side of the depicted large canvas being worked on by Velàxquez. Unlike traditional art historical methods,[7] computer graphics allowed these scholars to easily create the hidden painting within the painting consistent with the reflected image.
- Savarese and his colleagues investigated the claim that Hans Memling added the convex mirror in the left panel of the *Virgin and Child and Maarten van Nieuwenhove* diptych after the original composition, that is, when the figures of the Virgin, Child and donor were no longer in place.[6] To this end, they modeled the tableau with a simplified, planar, image of the Virgin, an approximation that was acceptable because they studied merely the silhouette of the figures reflected in the convex mirror. This work was the computer graphics version of the computational dewarping of mirror distortions in art pioneered by Criminisi and his colleagues.[2]
- Stork compared the image of a symmetric computer graphics model of the famous chandelier or *lichtkroon*, (Dutch: "light crown") in Jan van Eyck's *Portrait of Giovanni (?) Arnolfini and his wife* (1434) with the actual image in the painting.[9], [8], [10], [11] In this way he proved that the image in the actual painting deviated significantly from being "in perfect perspective," as had been claimed by others.[4] This model further supported the broad rejection of the claim that the chandelier had been secretly traced under an optical projection.

IV. CONCLUSIONS AND FUTURE DIRECTIONS

These methods should become more familiar to the art community, expanding and supplanting less powerful analytic methods, such as simple perspective constructions with ruler and pencil. The general use of computer graphics and and modeling of artworks should continue to be tested, and its results reviewed by art scholars. Ultimately, the software tools should become easy enough for art scholars to use with the aid of computer scientists.

There are a number of works, such as Parmigianino's *Self portrait in a convex mirror*, that could be analyzed by these methods to reveal geometric inaccuracies and better understand the artistic choices made by the artist. Likewise, computer models of the reflectance properties of surfaces depicted in Vermeer's intimate interiors, such as *The milkmaid*, may shed light on his studio practice and claims that he traced images projected in a camera obscura.

Such research in computer graphics in the study of art is part of a broader research program of applying methods from computer vision and image analysis that is leading to powerful new techniques that shedding new light on art and art praxis.[13], [14]

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