From Digital Imaging to Computer Image Analysis of Fine Art

David G. Stork[1,2]

[1] Ricoh Innovations, 2882 Sand Hill Road Suite 115, Menlo Park, CA 94025 USA
artanalyst@gmail.com
www.diatrope.com/stork/FAQs.html
[2] Department of Statistics, Stanford University, Stanford CA 94305 USA

Abstract. An expanding range of techniques from computer vision, pattern recognition, image analysis, and computer graphics are being applied to problems in the history of art. The success of these efforts is enabled by the growing corpus of high-resolution multi-spectral digital images of art (primarily paintings and drawings), sophisticated computer vision methods, and most importantly the engagement of some art scholars who bring questions that may be addressed through computer methods. This paper outlines some general problem areas and opportunities in this new inter-disciplinary research program.

Keywords: Computer vision, image analysis, fine art, art history, perspective analysis, color analysis, authentication.

1 Introduction

Ever since the discovery of x-rays, imaging has been used in the service of art scholarship, generally to reveal invisible, partially obscured, or illegible images. Particularly important in this development is infra-red reflectography, which uses long-wavelength radiation to penetrate layers of paint to reveal underdrawings and *pentimenti* (brush strokes or forms that have been changed or painted over) in paintings. Likewise multi-spectral imaging can reveal properties of paint and media that otherwise elude the unaided human eye. Such techniques have been invaluable for understanding artists' aesthetic decision and working methods and for dating and authenticating works. In these and nearly all other cases, the revealed image is interpreted by art scholars. A great success in this imaging and image processing tradition is the work decoding an important lost text by Archimedes in the *Archimedes palimpsest.*[8,16]

The large number of high-resolution multi-spectral images of art, and the growing body of rigorous techniques from computer vision and computer graphics set the stage for a new era in this interdisciplinary field: true computer analysis, where computer algorithms detect patterns or properties in an image that are too subtle, diffuse or of a type difficult for humans to detect or interpret.

Computer vision—the discipline seeking to make computers "see"—has addressed a wide range of problems in robotics, forensic image analysis, automated

F. Huang and R.-C. Wang (Eds.): ArtsIT 2009, LNICST 30, pp. 1–8, 2010.

inspection, biometrics, security, remote sensing, automated lipreading, optical character recognition, document analysis, and so on. Its many successes include algorithms for object recognition, shape recognition, shape-from-shading, color analysis, lighting analysis, perspective analysis, and many others. Of course, the application of these methods in technical areas depends greatly upon the problem and this is especially true in their application to problems in the history of art. Scholars must be deeply familiar with the strengths and limitations of algorithms and the assumptions underlying their use, but also must bring deep knowledge of artist and the work in question, its cultural context, documentary evidence, and much more. These new computer methods do not *replace* other methods, such as the trained eye of an art historian or connoisseur, but rather extend and refine them.

This brief article seeks to provide an introduction for computer scientists to some of the more important classes of problems from art history that have benefitted—and are likely to continue to benefit—from the application of computer image analysis methods.

1.1 Authentication and Attribution

The technically distinction between *authentication* and *attribution* is that the task of authentication is to determine whether a particular, candidate artist created a given work, whereas the task of attribution is to determine who among a candidate *set* of artists likely created the work. (In some attribution studies, this set of artists might be large.) A subclass of this general problem domain is to determine the number of "hands" in a work, that is, the number of artists contributing to a given work, as was quite common in Renaissance workshops. For example, Andrea del Verrocchio collaborated with his young apprentice Leonardo on *Baptism of Christ* (c. 1472), where Verrocchio painted Christ and St. John and Leonardo painted the angels. Classical art scholarship approaches to such problems rely heavily on careful visual study and informed opinions of experts.

Computer vision methods may contribute to such efforts through the automatic recognition of subtle differences in artists' styles (cf., Sect. 1.2). Of course which aspect of style is relevant depends upon the art work and artists in question. Statistical classifiers based on wavelet decompositions of brush strokes have been applied to identifying the number of hands in Perugino's *Holy family*,[17] and a closely related method has been applied to the authentication of paintings by Vincent van Gogh.[11]

A related approach relies on sophisticated computational methods is the recent work on image-based authentication of Jackson Pollock's drip paintings. (If one determines that a work is not by Pollock, the task of attribution is rarely of interest.) Richard Taylor and his colleagues were intrigued by the prospect that Pollock's drip paintings might exhibit fractal or scale-space properties—visual features not previously considered by the art community and virtually impossible to infer "by eye." This research group introduced a box-counting method for estimating such properties and reported that genuine Pollock paintings revealed a characteristic scale-space signature while fake paintings generally did not.[32]

This method has been criticized on a number of grounds,[13] but recent theoretical and empirical results show that such criticisms may not be warranted.[26,10] In particular, classifiers trained with scale-space features *as well as* other features, may indeed perform better than chance, and thus complement traditional methods for the authentication of such drip paintings.

1.2 Stylometry

Stylometry is the discipline of quantifying artistic style, and has been applied to a range of works and creators in music, literature, dance, and other modes of artistic expression. The particular aspects of style that are relevant depend on the class of art works and the problem at hand, and might involve color, brush stroke, composition and so forth, or even combinations of these properties. Stylometry nearly always exploits pattern recognition and machine learning techniques to infer subtle properties of style.[7] Stylometry underlies much of the work in authentication, but there are other applications as well. For example, one might consider just the color schemes or *palette* of an artist such as Vincent van Gogh as an aspect of his style and track quantitatively the variations in his palette through his career. Indeed, there are three main stages in his career—Netherlands, south of France, and Paris—each with a rather distinct palette. In this way, color stylometry can reveal objectively the effects in van Gogh's paintings of influences such as his response to colorful Japanese Ukiyo-e woodblock prints in Paris around 1886.

1.3 Dating of Works

Most of the technical methods for dating a work, such as a painting, are based on chemical and physical analyses of pigments, supports (canvas, wood panel, paper, parchment, ...) and knowledge of contemporary working methods, for instance preparation of supports, marking tools, and so on. Art historians also consider compositional style, the types of objects or events depicted, the influences of other artists or works whose dates are known, iconography and of course their expert visual analysis of style, brush strokes, colors, techniques, and so on.

A particularly intriguing automated image analysis approach to this problem applies to printed documents, such as maps printed using an intaglio process.[9] Each metal intaglio master plate is cleaned before each major print run, and such cleaning abrades the surface and thus affects the width of printed lines. Statistical models of such degradation, learned from optical scans of printed lines and textures from works of known dates, can then be applied to works of unknown date. Similar problems and opportunities arise in the dating of Japanese woodblock prints, where degradation of marks and lines, including breaks, indicate the wear on block masters and hence provide an estimate of age.

1.4 Predicting the Effects of Conservation Treatment

Cleaning a painting (eg., removing darkened varnish) is a very slow and expensive task; it is not unusual for the full cleaning of a large painting to take several years and cost $1M US or more. Curators, conservators and art scholars face the difficult task of deciding which of their works most deserve such cleaning and often their most important consideration is how the painting will appear after such cleaning—the appearance of colors, details that are revealed, and so on. Digital image processing methods can help predict how a given painting will appear after such cleaning. The methods involve modeling the optical physics of varnish as well as empirical statistical estimation from physical tests and small samples.[2]

1.5 Rejuvenating Faded Works

Some pigments are *fugitive*, that is, they fade over time; thus, some old master paintings we see today are faded versions of what the artist intended. Much as described in Sect. 1.4, one can develop computer models of such fading—based on experimental colorimetric evidence and chemical analysis. One then starts with the painting as it appears today and runs the fading model "backward" in time, to the date of the painting's creation. In this way the algorithms "rejuvenate" the colors, as for example recent research rejuvenating the colors in Georges Seurat's *Un dimanche après-midi à l'Ile de la Grande Jatte* (1884–86).[1]

1.6 Inferring Artists' Working Methods

An important set of problems in art scholarship is to infer artists' studio conditions and working methods. The most direct class of such problems is understanding an artist's marking tools and implements, for instance the nature of paint brushes, pencils, pastel sticks, conte crayons, or other markers. Statistical classifiers have been trained on features extracted direct from the image of lines and marks drawn with different markers, such as the shape of the ends of such lines.[15]

A somewhat less direct approach is used for testing whether an artist used a mechanical aid, such as a *Reductionszirkel* or *reducing compass* or even traced optically projected images. Such image analysis relies on the Chamfer metric or distance transform to measure the fidelity of copies.[22,6] A more sophisticated approach to testing for artists' possible use of projected images is computer ray tracing. Scholars build models the putative projector and then explore matters such as the depth of field, blurriness, and overall brightness that would arise in the artist's studio.[20]

Perspective is one of the richest sources of information in realist paintings. Sophisticated perspectival tests, image metrology and the estimation of perspective transformations have been used to test for artists' use of projected images.[23,22,5] Moreover, algorithms for analyzing lighting in images have been used to infer the position of illuminants in tableaus, and thus test claims about lighting and possible use of optics.[30]

Johnson and his colleagues applied a number of lighting analysis techniques to Jan Vermeer's *Girl with a pearl earring* (c. 1665) in order to infer the primary direction to the illuminant. The excellent agreement among the directions estimated from different sources of visual information (cast shadows, lightness along occluding contours, highlight reflections from the eye, ...) strongly imply

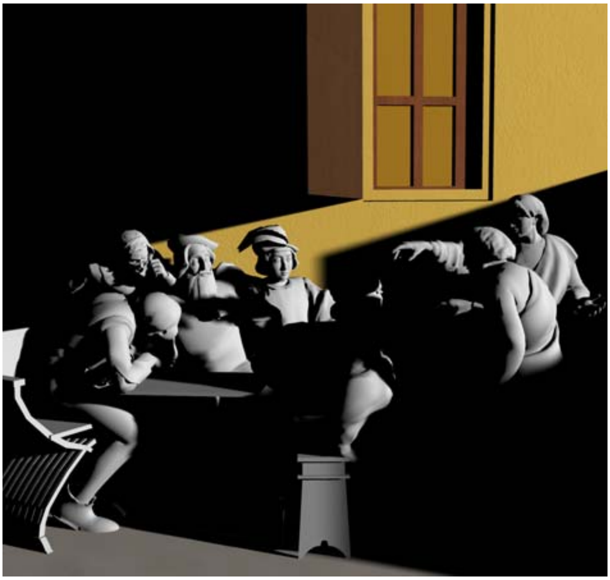

Fig. 1. Computer graphics rendering of Caravaggio's *The calling of St. Matthew* (1599–1600).[25,18] Such detailed computer graphics renderings of tableaus of paintings allow art scholars to visualize the work in new ways and explore hypothetical or "what if" scenarios to infer artists' working methods. For instance, this model can reveal what would have been seen by each of the figures (eg., who sees Christ, who does not). Likewise, one can explore Caravaggio's working methods, for instance the nature of the source of light in this tableau, specifically whether it is local artificial light or instead distance solar illumination. Computer experts and art scholars together thus simulate plausible studio conditions, always aware that artists are not "photographers" and that scholars must be careful to consider both the objective physical image in the studio and the artist's perception and expressive ends. Specifically, this computer graphics model includes detailed models of the reflectance properties of the rear wall, expressed as a bidirectional reflectance distribution function (BRDF) that can be adjusted to best approximate the pattern of lightness found in the painting.

that Vermeer worked from a live model, rather than from his imagination.[12] One can infer the position of the illuminant based on the pattern of light on the rear wall in Caravaggio's *The calling of St. Matthew* (Fig. 1) to determine whether it was distant solar illumination or nearby artificial illumination, a result that has important implications for the question of whether Caravaggio employed optical projections.[14,24]

Some of the most sophisticated algorithms ever applied to the analysis of images in art infer the complex pattern of illumination based on measured lightness along the outer or occluding boundaries of objects. Stork and Johnson used a method based on spherical harmonics to reveal that the lighting on different figures in Garth Herrick's paintings differed significantly, thus showing that Herrick worked under two different lighting conditions. In essence, Herrick "composited" one figure into his painting—a fact difficult to discern by eye.[31]

1.7 Rendering New Views for Visualization

Computer methods can provide new views into art works. Criminisi and his colleagues dewarped the images in spherical mirrors depicted in Renaissance paintings such as Jan van Eyck's *Arnolfini portrait* (1434) and Robert Campin's *Heinrich von Werl and St. John the Baptist* (1438), revealing new views into the respective tableaus.[4] Criminisi also developed uncalibrated methods to reconstruct three-dimensional models from two-dimensional artworks, including Masaccio's *Trinità* (1427–28) and Piero della Francesca's *Flagellazione di Christo* (1455–60).[3] Art scholars can now rotate, zoom in and "fly" through these virtual spaces, study the consistency of the perspective and artists' deviations from geometric accuracy. Smith, Stork and Zhang used multi-view reconstruction to form a three-dimensional model of the tableau in Scott Fraser's *Three way vanitas* based on the images depicted in multiple plane mirrors within the tableau.[21]

Computer graphics models of studios allow scholars to study artists' working methods (cf. Sect. 1.6) and gain insights for new interpretations. For example, Stork and Furuichi built a computer graphics model of Diego Velázquez's *Las meninas* (1656) to determine what was the source of the images reflected in the plane mirror on the rear wall.[29] In this way they confirmed the claim that the source was not the king and queen in position of the viewer, but instead an otherwise hidden portrait on the large canvas depicted within the painting itself.

2 Conclusion

This interdisciplinary research program, while fairly new, has had several successes and a growing number of adherents, among both computer scientists and art scholars.[1] There have been several conferences in major scientific and technical organizations[27,28] and recently interest from traditional art organizations as well.[25,19] Computer scientists interested in contributing to this field should work as closely as possible with art scholars to ensure that their work is grounded in art historical knowledge and addresses questions of interest to the art community.

Acknowledgements

The author would like to thank the Getty Research Institute, Santa Monica, CA, for granting reader's privileges to its superb reference library.

References

1. Berns, R.S.: Rejuvenating Seurat's palette using color and imaging science: A simulation. In: Herbert, R.L. (ed.) Seurat and the making of La Grande Jatte, pp. 214–227. Art Institute of Chicago, Chicago (2004)

[1] www.diatrope.com/stork/FAQs.html

2. Chahine, H., Cupitt, J., Saunders, D., Martinez, K.: Investigation and modelling of color change in paintings during conservation treatment. In: Imaging the past: Electronic imaging and computer graphics in museums and archaeology. Occasional papers of the British Museum, vol. 114, pp. 23–33 (1996)
3. Criminisi, A.: Accurate visual metrology from single and multiple uncalibrated images. ACM Distinguished Dissertation Series. Springer, London (2001)
4. Criminisi, A., Kemp, M., Kang, S.-B.: Reflections of reality in Jan van Eyck and Robert Campin. Historical methods 3(37), 109–121 (2004)
5. Criminisi, A., Stork, D.G.: Did the great masters use optical projections while painting? Perspective comparison of paintings and photographs of Renaissance chandeliers. In: Kittler, J., Petrou, M., Nixon, M.S. (eds.) Proceedings of the 17th International Conference on Pattern Recognition, vol. IV, pp. 645–648 (2004)
6. Duarte, M., Stork, D.G.: Image contour fidelity analysis of mechanically aided enlargements of Jan van Eyck's Portrait of Cardinal Niccolò Albergati. Leonardo 42 (in press, 2010)
7. Duda, R.O., Hart, P.E., Stork, D.G. (eds.): Pattern classification, 2nd edn. John Wiley and Sons, New York (2001)
8. Easton Jr., R.L., Knox, K.T., Christens-Barry, W.A.: Multispectral imaging of the Archimedes palimpsest. In: Proceedings of the 32nd Applied Imagery Pattern Recognition Workshop, AIPR 2003, El Segundo, CA, pp. 111–116. IEEE, Los Alamitos (2003)
9. Blair Hedges, S.: Image analysis of Renaissance copperplate prints. In: Stork, D.G., Coddington, J. (eds.) Computer image analysis in the study of art, Bellingham, WA, vol. 6810, pp. 681009–1–20. IS&T/SPIE (2008)
10. Irfan, M., Stork, D.G.: Multiple visual features for the computer authentication of Jackson Pollock's drip paintings: Beyond box-counting and fractals. In: Niel, K.S., Fofi, D. (eds.) SPIE Electronic Imaging: Machine vision applications II, vol. 7251, pp. 72510Q1–11. SPIE/IS&T, Bellingham (2009)
11. Johnson, C.R., Hendriks, E., Berezhnoy, I.J., Brevdo, E., Hughes, S.M., Daubechies, I., Li, J., Postma, E., Wang, J.Z.: Image processing for artist identification. IEEE Signal Processing magazine 25(4), 37–48 (2008)
12. Johnson, M.K., Stork, D.G., Biswas, S., Furuichi, Y.: Inferring illumination direction estimated from disparate sources in paintings: An investigation into Jan Vermeer's Girl with a pearl earring. In: Stork, D.G., Coddington, J. (eds.) Computer image analysis in the study of art, vol. 6810, pp. 68100I–1–12. SPIE/IS&T, Bellingham (2008)
13. Jones-Smith, K., Mathur, H., Krauss, L.M.: Drip paintings and fractal analysis. Physical Review E 79(046111), 046111–12 (2009)
14. Kale, D., Stork, D.G.: Estimating the position of illuminants in paintings under weak model assumptions: An application to the works of two Baroque masters. In: Rogowitz, B.E., Pappas, T.N. (eds.) Electronic Imaging: Human vision and electronic imaging XIV, vol. 7240, pp. 72401M1–12. SPIE/IS&T, Bellingham (2009)
15. Kammerer, P., Lettner, M., Zolda, E., Sablatnig, R.: Identification of drawing tools by classification of textural and boundary features of strokes. Pattern Recognition Letters 28(6), 710–718 (2007)
16. Knox, K.T.: Enhancement of overwritten text in the Archimedes Palimpset. In: Stork, D.G., Coddington, J. (eds.) Computer image analysis in the study of art, vol. 6810, pp. 681004–1–11. IS&T/SPIE, Bellingham (2008)
17. Lyu, S., Rockmore, D., Farid, H.: A digital technique for art authentication. Proceedings of the National Academy of Sciences 101(49), 17006–17010 (2004)

18. Nagy, G., Stork, D.G.: Inferring Caravaggio's studio lighting and praxis in 'The calling of St. Matthew' by computer graphics modeling. In: Stork, D.G., Coddington, J., Bentkowska-Kafel, A. (eds.) Computer vision and image analysis of art. SPIE/IS&T, Bellingham (2010)
19. Noble, P., Stork, D.G., Meador, S.: Computer image analyses of brick patterns in paintings by Jan van der Heyden (1637–1712). American Institute for Conservation, Paintings specialty group, 20 (2009) (poster abstract)
20. Robinson, M.D., Stork, D.G.: Aberration analysis of the putative projector for Lorenzo Lotto's Husband and wife: Image analysis through computer ray-tracing. In: Stork, D.G., Coddington, J. (eds.) Computer image analysis in the study of art, vol. 6810, pp. 68100H–1–11. SPIE/IS&T, Bellingham (2008)
21. Smith, B., Stork, D.G., Zhang, L.: Three-dimensional reconstruction from multiple reflected views within a realist painting: An application to Scott Fraser's Three way vanitas. In: Angelo Beraldin, J., Cheok, G.S., McCarthy, M., Neuschaefer-Rube, U. (eds.) Electronic imaging: 3D imaging metrology, vol. 7239, pp. 72390U1–10. SPIE/IS&T, Bellingham (2009)
22. David, G.: Stork. Optics and realism in Renaissance art. Scientific American 291(6), 76–84 (2004)
23. Stork, D.G.: Optics and the old masters revisited. Optics and Photonics News 15(3), 30–37 (2004)
24. Stork, D.G.: Locating illumination sources from lighting on planar surfaces in paintings: An application to Georges de la Tour and Caravaggio. In: Optical Society of American Annual Meeting, Rochester, NY. Optical Society of America (2008)
25. Stork, D.G.: New insights into Caravaggio's studio methods: Revelations from computer vision and computer graphics modeling. In: Renaissance Society of American Annual Meeting, Los Angeles, CA, p. 102 (2009) (abstract)
26. Stork, D.G.: Comment on Drip paintings and fractal analysis: Scale-space features in multi-feature classifiers for drip painting authentication. Physical Review E (submitted, 2010)
27. Stork, D.G., Coddington, J. (eds.): Computer image analysis in the study of art, vol. 6810. SPIE/IS&T, Bellingham (2008)
28. Stork, D.G., Coddington, J., Bentkowska-Kafel, A. (eds.): Computer vision and image analysis of art. SPIE/IS&T, Bellingham (forthcoming 2010)
29. Stork, D.G., Furuichi, Y.: Computer graphics synthesis for interring artist studio practice: An application to Diego Velázquez's Las meninas. In: McDowall, I.E., Dolinsky, M. (eds.) Electronic imaging: The engineering reality of virtual reality, vol. 7238, pp. 7238061–7238069. SPIE/IS&T, Bellingham (2009)
30. Stork, D.G., Johnson, M.K.: Estimating the location of illuminants in realist master paintings: Computer image analysis addresses a debate in art history of the Baroque. In: Proceedings of the 18th International Conference on Pattern Recognition, Hong Kong, vol. I, pp. 255–258. IEEE Press, Los Alamitos (2006)
31. Stork, D.G., Johnson, M.K.: Lighting analysis of diffusely illuminated tabeaus in realist paintings: An application to detecting 'compositing' in the portraits of Garth Herrick. In: Delp III, E.J., Dittmann, J., Memon, N.D., Wong, P.W. (eds.) Electronic Imaging: Media forensics and security XI, vol. 7254, pp. 72540L1–8. SPIE/IS&T, Bellingham (2009)
32. Taylor, R.P., Micolich, A.P., Jonas, D.: Fractal analysis of Pollock's drip paintings. Nature 399, 422 (1999)