Rochester Institute of Technology

Munsell Color Science Laboratory

Annual Report 2004

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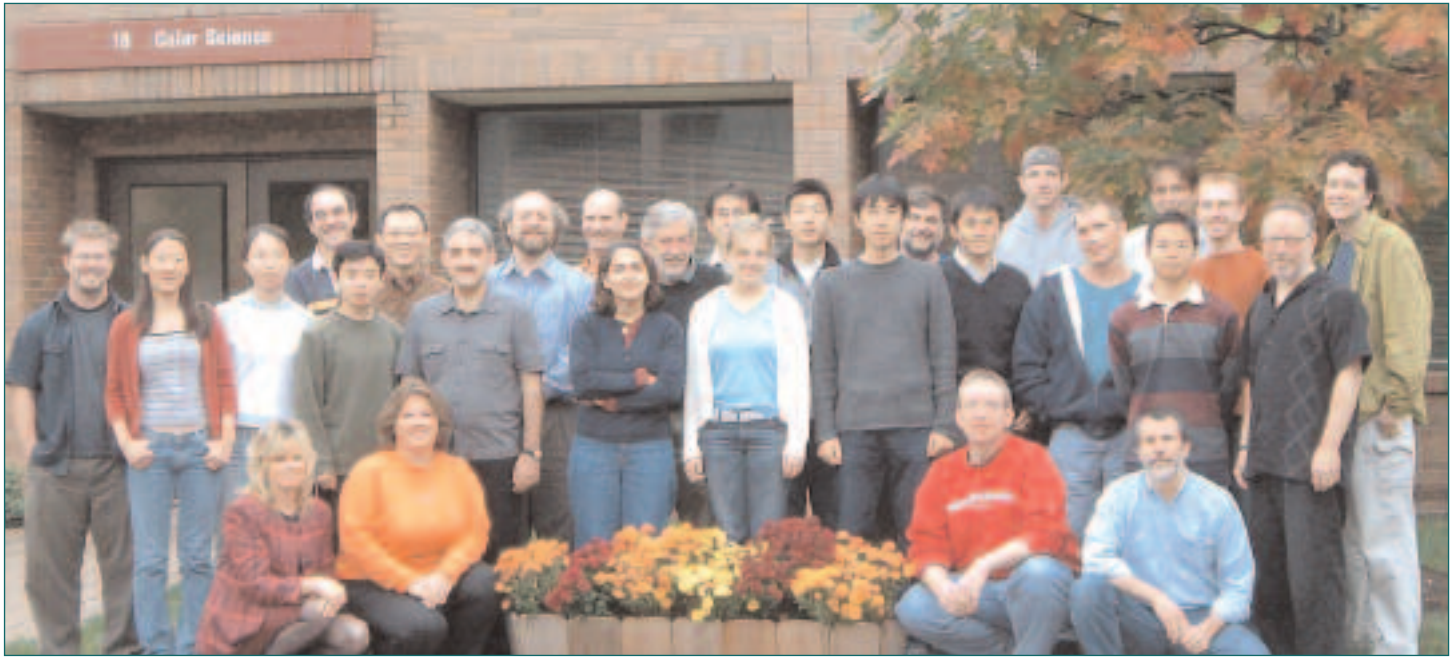


From The MCSL Family

Director's Welcome

Roots are good; as long as they don't get so deep they hold you back. They give you the strength to tear them up and resettle them in a new location. In 2003, the lab tore up its physical roots of the previous 14 years and resettled in the new Color Science Building on the south side of RIT's campus. While the move was completed in 2003, it's safe to say that we didn't get fully settled and finish renovations until early 2004. That was celebrated in May with a wonderful event to mark the dedication of the new *Franc Grum Color Science Learning Center* in honor of our first director (remembering some of those roots). As happens with any move, we were given the opportunity to rediscover some of our past work, instrumentation, and other memories. I was encouraged to make the move by the MCSL staff when several of them said it would be "an adventure". It was, and one I am sure we will all remember fondly as the lab thrives in its wonderful new facilities.

I again thank all of the MCSL alumni and friends who made donations to fund the Grum Learning Center. It is a fantastic facility for teaching and learning and your generosity not only assured that it was well constructed, but that we can maintain that quality for a long time. We enjoy teaching in it every day and had a great time offering our 2004 summer short course (twice due to popular demand) in the new facility. An intended benefit of the move has been exposure. Many RIT students, faculty, and staff pass through our building now and are exposed to the mysteries of color science. This has already helped us recruit new students into our graduate program.

We have also had the privilege to develop a proposal for a Ph.D. program in Color Science during the past year. This program, currently under RIT internal review and aimed at a 2005 start pending approvals, will be an extension of our current Color Science M.S. program and also allows us to get back to our roots. Currently Ph.D. students in the lab are in the Imaging Science program. Our M.S. program has always provided the opportunity for non-imaging research on topics like spectrophotometry, materials, color difference formulas, etc. The new Ph.D. will allow us to continue such research to deeper levels. These were the domains the lab was founded upon as recently recognized by Dupont via new funding for second-year graduate research projects on materials-related topics that was prompted by their review of our Ph.D. program proposal.

We also welcome two new members of the Color Science graduate program faculty as Mitch Rosen and Garrett Johnson moved into Research Assistant Professor positions in the past year. They will play critical roles in expanding our graduate research opportunities.

One of our efforts in dusting off some of those old roots is to return to some of our historical research topics. One example is looking at fundamental limitations of colorimetry imposed by issues of instrumental precision and accuracy, measurement techniques, and color matching functions. We have a few projects and proposals in the works and, as you can see in this annual report, our Color Measurement and Science research theme has been growing.

Of course our natural curiosity forces us to delve into new areas of research as well. One example is the work involved in the American Museums Digital Imaging Benchmarking Conference that we hosted in September, attended by over 100 participants, many of whom had never been exposed to color science, or our work, before. Another example is our taking note of a few interesting visual phenomena, such as adaptation to spatial noise in images and the apparent dependency of visual acuity on image size rather than just visual angle, that have prompted new research projects and significant changes in the way other projects are carried out. All of this is great fun and helping us grow new roots for the future.

It is always nice to see our efforts recognized in various ways such as the publications and presentations detailed in this report, awards such as the Cactus Award for best poster (and the runner up!) at the Color Imaging Conference, selection to give a Xerox Distinguished Lecture, and the various grants, donations, and gifts that allow us to support our students, complete our research and publish the results. Obviously, this is the lifeblood of a laboratory like ours and the students are the vessels that carry that blood and put it to good use. Once again I thank you all, our supporters, our sponsors, our students. You make this all possible and so rewarding. All I need to do is stay out of the way and let you all keep at it.

I'll close with a fascinating quote translated from Chuang Tzu (c. 300 BCE) that I recently read and cannot forget. Give it some thought.

Words exist because of meaning; once you've gotten the meaning, you can forget the words. Where can I find a man who has forgotten words so that I can have a word with him?

Mark D. Fairchild
Xerox Professor of Color Science
Director, Munsell Color Science Laboratory

Munsell Color Science Laboratory

The RIT Munsell Color Science Laboratory (MCSL) was established in 1983 after the the Munsell Color Foundation, Inc. transferred its assets to RIT to create an endowment. Franc Grum was the lab's first Director and the first R.S. Hunter Professor of Color Science, Appearance and Technology. Since then MCSL has been performing internationally-recognized research in color appearance models, image quality, data-visualization, color-tolerance psychophysics, spectral-based image capture, spectral color rendering and computer graphics, archiving and reproduction of artwork, and other areas of color science and color measurement.

Our Objectives

Following the example set by our founders, the guiding objectives of MCSL are …

(1) To provide undergraduate and graduate education in color science,

(2) To carry on applied and fundamental research,

(3) To facilitate spectral, colorimetric, photometric, spatial, and geometric measurements at the state-of-the-art, and

(4) To sustain an essential ingredient for the success of the first three – namely, liaison with industry, academia and government.

The aims and purposes of the Munsell Foundation as stated in its bylaws were "… to further the scientific and practical advancement of color knowledge and, in particular, knowledge relating to standardization, nomenclature and specification of color, and to promote the practical application of these results to color problems arising in science, art, and industry."

Education Is Our Mission

MCSL educates graduate students and industry employees both nationally and internationally. MCSL has been providing high-quality state-of-the-art education and research for over two decades.

M.S. and Ph.D. Degrees

MCSL offers the only M.S. degree program in Color Science in the country. More than 75 alumni currently work in the field world-wide. MCSL graduates are in high demand and have accepted industrial positions in electronic imaging, color instrumentation, colorant formulation and basic and applied research. MCSL students complete Master's and Ph.D. degrees through the programs within the Center for Imaging Science.

Summer School of Industrial Short Courses

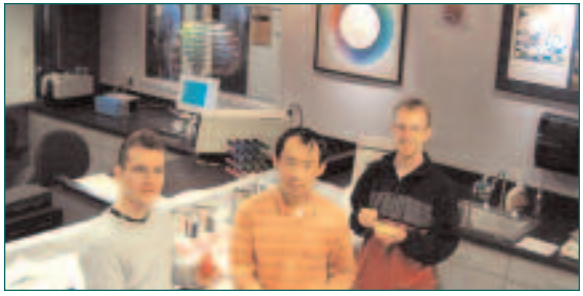
An updated *Essentials of Color Science* will be offered June 7-10, 2005. The MCSL faculty revisited the current program and updated it to continue providing participants with a fundamental understanding of the principles of colorimetry and their application to the production, control and reproduction of color. To learn more or to request a brochure see our web site: *www.mcsl.rit.edu* or call:(585) 475-6783.

Visiting Scientist Program

For more than a decade MCSL has been hosting industrial scientists. These visiting scientists spend 1-2 years in residence at MCSL and work on fundamental research problems of interest to their company and MCSL researchers.

Collaborative Research

Fundamental to our educational mission is collaborative research with industry on important, relevant, and intriguing problems of color science and technology. A list of industrial supporters can be seen at: *www.mcsl.rit.edu/about/sponsors.php*



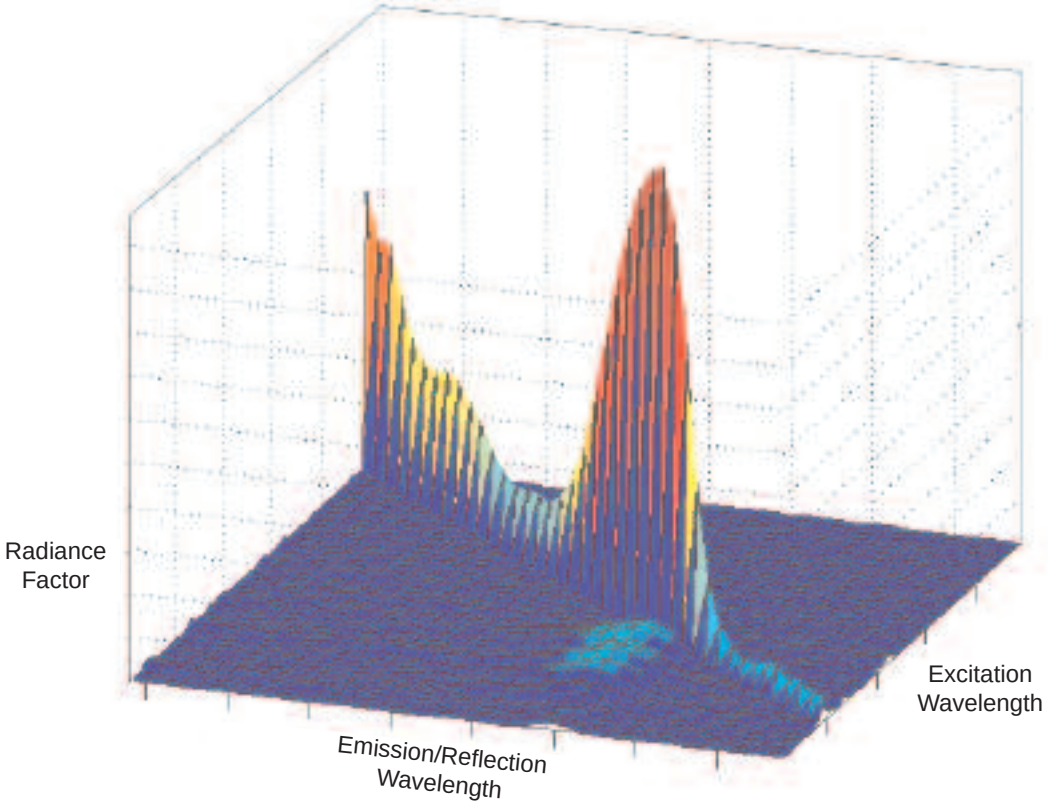
Color Measurement & Science

Color measurement research and application has been a hallmark of MCSL since its inception. There are always opportunities to elevate our various research projects through improvements in measurement techniques. For example, research on cultural heritage archiving and conservation is supported by improved spatial and spectral measurements[2,4,8] and will be further extended to bi-spectral fluorescence colorimetry thanks to a generous equipment donation from Canon Development Americas.

Much of this work is aimed at extending digital camera systems to be spectral imaging devices,[4,7,24,62,63] the work associated with their characterization and calibration for various applications,[40,51] and visual evaluation of the results.[14] On the output side of the imaging chain we have been involved in developing new techniques for the measurement and characterization of displays[13] and projectors.[58,59] Rohit Patil's thesis[47,48] involved creating some new measurement techniques to improve image simulation and display.

Fundamental color science research also provides wonderful support and enhancement of our applied research. This includes ongoing work on color appearance modeling[16,17,43] and psychophysics.[56,61] A natural extension of these interests and technological capabilities has been the emergence of several projects that can be described as computational color science such as an exploration of color constancy in printing systems,[10] an examination of color difference equations,[38] an analysis of uncertainties in psychophysical experiments,[42] and a review of the use of principal component analysis in color technology.[57] A series of theoretical and computational studies has also been continuing through the work of one of our visiting scientists.[33-37]

METACOW: A public-domain, high-resolution, fully-digital, noise-free, metameric, extended-dynamic-range, spectral test target for imaging system analysis and simulation. See: www.mcsl.rit.edu/METACOW/ for more information.



An example, bi-spectral fluorescence measurement from a Labsphere BFC-450 recently donated to MCSL by Canon Development Americas. The instrument will be used in student research on spectral analyses of fluorescent artist pigments and other materials. This sample was a fluorescent magenta.

An illustration of the range of illumination to which our visual system can adapt through the day. This illustrates the challenge of MCSL research on high-dynamic-range (HDR) imaging: to represent this immense range of illumination levels on reproduced images with much smaller luminance ranges.

Image Appearance & Modeling

Image appearance psychophysics and modeling continues to be an area of great interest in the lab. This is illustrated by the revision and publication of the second edition of *Color Appearance Models*,[16] a book chapter,[43] and related review papers.[17,25,26,52] The iCAM extension of color appearance models[18,29] to the spatial and temporal domain continues to be evaluated and improved for various applications, with high-dynamic-range (HDR) imaging being a key interest.[20,21,31,60] Our research continues to explore its application to image quality questions.[28]

Modeling of image quality and appearance has led to a series of psychophysical experiments and improvements in experimental techniques.[19,42] Topics of interest include the reproduction of color preference,[22,56] overall image quality perception,[27,55] the effects of surround on perceived image contrast,[32] computational analyses of appearance effects,[36] and examination of observers' use of various color attributes.[61]

Three students completed their M.S. theses and graduated in 2004. Xiaoyan Song examined the perception of chromatic noise in digital images and its description in various opponent color spaces.[53,54] Her work has already spawned another project on the topic.[30] Sung Ho Park researched the appearance and utility of various techniques for visualizing HDR scientific data and images.[45,46] Rohit Patil developed a 3D simulation tool to allow better soft-proofing of prints by allowing users to manipulate 3D renderings of the prints, complete with simulated noise and gloss properties for various media.[47,48] He also received the *Cactus Award* for best poster presentation at the 2004 Color Imaging Conference in Scottsdale, AZ.

Rohit Patil's Cactus-Award-winning research examined the advantages of performing soft-proofing with 3D renderings of printed images. These images allowed observers to evaluate surface and noise characteristics of prints on soft displays.

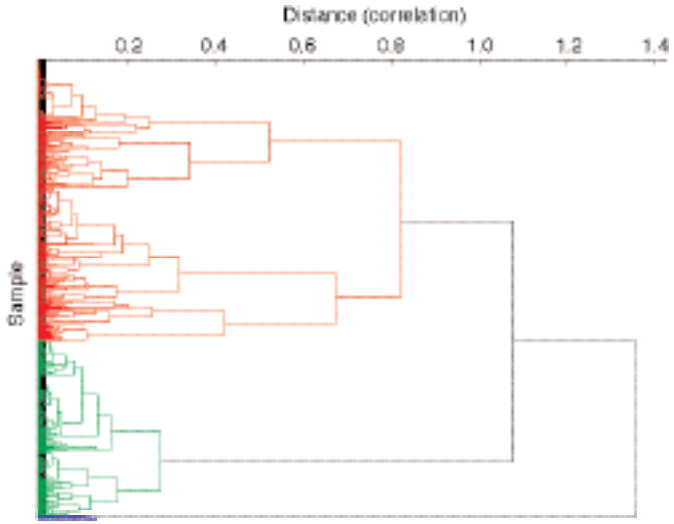
An illustration of noise adaptation through simultaneous contrast. The central area, between Mickey's forehead and the chin of the girl in the blue dress, has the same noise level in each image. However, that area appears noisier when the surround has less noise and vice versa. Ongoing MCSL research will examine this color appearance phenomenon.

Spectral Color Reproduction

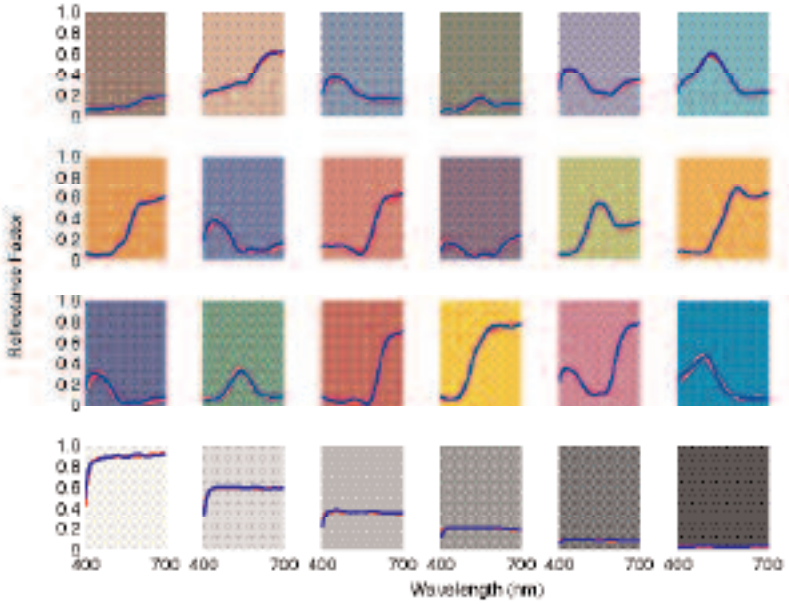
Perhaps inevitably, if you combine interests in spectrophotometry, colorimetry, and image reproduction, researchers will start wondering why image capture systems don't work more like spectrophotometers and image output systems don't work more like colorant formulation systems. This fertile Petri dish in MCSL has grown a significant and continually developing body of research on spectral image reproduction throughout the full imaging process from capture to output. Much of this research has been in support of projects aimed at the archiving and conservation of our cultural heritage described in the next section.[2,4,7,8,9,62,63] (See our web site: *www.art-si.org*).

One area of spectral imaging that is fairly unique to MCSL is our work on spectral printing that includes techniques to improve color constancy in prints,[10] extension of the printed gamut,[11] calibration/characterization techniques,[12,64] and choices of optimal colorants.[39] These projects have provided useful answers to questions regarding what to do with more than four inks in a printer and how to do it.

Of course, no study in color science is complete without psychophysics and that extends to our spectral imaging research as well through experiments on color and spatial image quality for various spectral imaging systems and techniques.[14,55] To add to these capabilities, a high-resolution, noise-free, digital test image was created for imaging system simulation and psychophysical evaluation.[19] Such tools allow us to better examine and develop color management systems and techniques for spectral imaging including a spectral connection space,[15] techniques to estimate spectra from trichromatic digital images,[24] and the development of physical targets for camera characterization.[40]



Dendogram depicting 603 spectra reduced to several characteristic spectra using hierarchical cluster analysis.



Spectral estimation accuracy for the Color Checker using the Sinar 54 and two optimized filters. Blue lines are the estimated spectra; red lines are measured spectra using a contact reflection spectrophotometer.

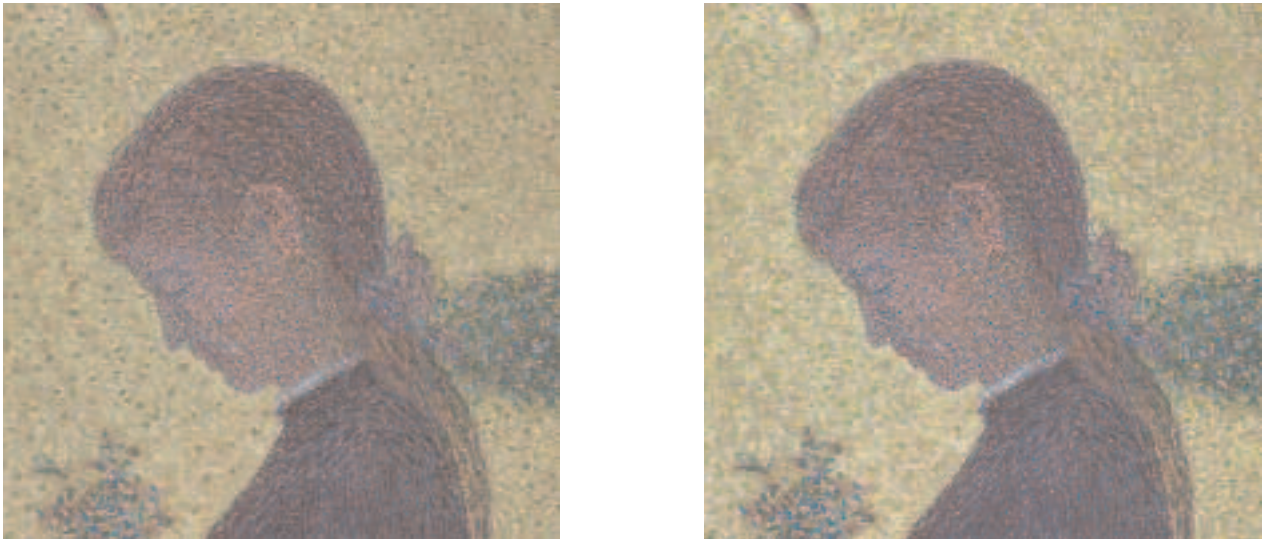
Spectral Color Reproduction Research Group *(Left to right): Pravin Rao, Yoshi Okumura, Shohei Tsutsumi, Mahnaz Mohammadi, Yonghui (Iris) Zhao, Roy Berns, Mitchell Rosen, Yongda Chen, Lawrence Taplin, Dave Wyble and Mahdi Nezamabadi.*

Color Science for Cultural Heritage

MCSL hosted the American Museums Digital Imaging Benchmarking Conference as part of a project sponsored by the Andrew W. Mellon Foundation. Research was completed as both part of the supporting grant to survey practices in museums[23,49,50] as well as presented at the conference itself by several MCSL faculty, staff, students, and alumni. Related work was also carried out as part of Erin (Murphy) Smoyer's M.S. thesis analyzing the performance of imaging systems within various museums.[44]

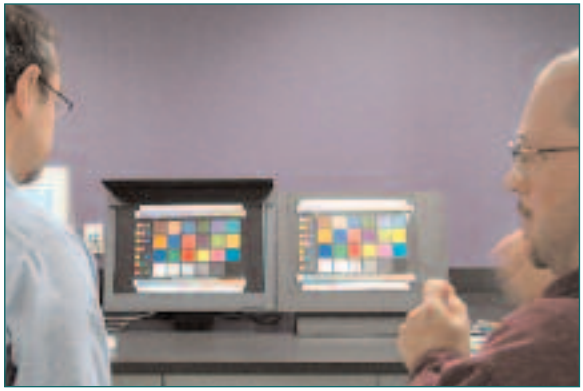
Our research efforts in archiving and conservation of cultural heritage are anchored by significant grants from the Andrew W. Mellon Foundation, the Museum of Modern Art, New York, and the National Gallery of Art, Washington. The major focus of this work is the development of a spectral imaging system and related calibration and characterization techniques that can be deployed and implemented in museum photographic studios to enhance their transition to high-quality digital imaging.[2,4,7,9,40,62,63] Naturally, this research also begets related research on topics such as minimizing metamerism,[6] image quality assessment,[14] and pigment selection.[39] Much of this research has been summarized in a single paper,[8] as well as documented at: *www.art-si.org*.

Exposure of color science techniques to the museum community has resulted in a number of interesting opportunities to work with well-known pieces of art. An example of this has been the careful spectrophotometric and colorimetric analysis of Seurat's *A Sunday on La Grande Jatte – 1884* at the Art Institute of Chicago and its digital restoration.[1,3,5]



*Detail of **A Sunday on La Grande Jatte – 1884** before (left) and after (right) digital rejuvenation. In this painting, the zinz yellow paint used by Seurat darkened considerably turning luminous yellow, green-yellow, and orange pointillist dabs to dark ocher, olive, and brown.*

Color science graduate student, Erin (Murphy) Smoyer, and photographer, Bob Hashimoto, on-site at the Art Institute of Chicago characterizing their imaging system.



Participants at MCSL's American Museums Benchmarking Conference discussing our spectral reproduction demonstration.

Distribution of respondents to the American Museums Digital Imaging Benchmarking Survey. The survey was online for one year. Instructions on obtaining the final report can be found at: ***www.art-si.org***

MCSL Students

Current Graduate Students

Yongda Chen, Ph.D., Imaging Science
Maxim Derhak, M.S., Imaging Science
Kenneth Fleisher, M.S., Color Science
Rodney Heckaman, Ph.D., Imaging Science
Jim Hewitt, M.S., Imaging Science
Jiangtao Kuang, Ph.D., Imaging Science
Justin Laird, M.S., Color Science
Zhaojian Li, M.S., Color Science
Chengmeng Liu, Ph.D., Imaging Science
Mahnaz Mohammadi, Ph.D., Imaging Science
Alistair Neal, M.S., Color Science
Mahdi Nezamabadi, Ph.D., Imaging Science
Yoshio Okumura, M.S., Color Science
Jim Proper, Ph.D., Imaging Science
Pravin Rao, Ph.D., Imaging Science
Michael Surgeary, M.S., Imaging Science
Erin (Murphy) Smoyer, M.S., Color Science
Hongqin Zhang, Ph.D., Imaging Science
Yonghui Zhao, Ph.D., Imaging Science

Visiting Scientists

Paul Kuiper, Océ Technologies
Nobuhito Matsushiro, Oki Data
Shohei Tsutsumi, Canon
Hiroshi Yamaguchi, Fuji Photo

Alumni of Graduate Programs

2004
Rohit Patil, M.S., Color Science
Sung Ho Park, M.S., Color Science
Xiaoyan Song, M.S., Color Science

2003
D. Collin Day, M.S., Color Science
Ellen Day, M.S., Color Science
Scot Fernandez, M.S., Imaging Science
Ed Hattenberger, M.S., Color Science
Steve Jacob, M.S., Imaging Science
Xiaoyun Jiang, Ph.D., Imaging Science
Garrett Johnson, Ph.D., Imaging Science
David Robinson, M.S., Imaging Science
Mitchell Rosen, Ph.D., Imaging Science
Deniz Schildkraut, M.S., Color Science
Qun Sun, Ph.D., Imaging Science

2002
Arturo Aguirre, M.S., Color Science
Jason Babcock, M.S., Color Science
Anthony Calabria, M.S., Color Science
Jennifer Cerniglia Stanek, M.S., Imaging Science
Scot Fernandez, M.S., Color Science
Shuxue Quan, Ph.D., Imaging Science
Yat-ming Wong, M.S., Imaging Science

2001
Jason Gibson, M.S., Color Science
Alexei Krasnoselsky, M.S., Color Science
Lawrence Taplin, M.S., Color Science
Su Ju Park, M.S., Color Science
Michael Sanchez, M.S., Imaging Science
Barbara Ulreich, M.S. Imaging Science

2000
Sergio Gonzalez, M.S., Color Science
Sharron Henley, M.S., Color Science
Patrick Igoe, M.S., Imaging Science
Susan Lubecki, M.S., Color Science
Richard Suorsa, M.S., Color Science

1999
Gus Braun, Ph.D., Imaging Science
Barbara Grady, M.S., Color Science
Katherine Loj, M.S., Color Science
Jonathan Phillips, M.S., Imaging Science
Mark Reiman, M.S., Color Science
Mark Shaw, M.S., Color Science
Di-Yuan Tzeng, Ph.D., Imaging Science
Joan Zanghi, M.S., Color Science

1998
Scott Bennett, M.S., Color Science
Fritz Ebner, Ph.D., Imaging Science
Garrett Johnson, M.S., Color Science
Naoya Katoh, M.S., Color Science
David Wyble, M.S., Color Science

1997
Peter Burns, Ph.D., Imaging Science
Brian Hawkins, M.S., Color Science
Christopher Hauf, M.S., Color Science
Alex Vaysman, M.S., Imaging Science

1996
Karen Braun, Ph.D., Imaging Science
Cathy Daniels, M.S., Color Science
Yue Qiao, M.S., Imaging Science
Jack Rahill, M.S., Imaging Science
Hae Kyung Shin, M.S., Imaging Science

1995
Richard Alfvin, M.S., Color Science
Seth Ansell, M.S., Color Science
Sue Farnand, M.S., Imaging Science

1994
Audrey Lester, M.S., Color Science
Jason Peterson, M.S., Imaging Science
Debra Seitz Vent, M.S., Imaging Science
James Shyu, M.S., Color Science

1993
Nathan Moroney, M.S., Color Science
Elizabeth Pirrotta, M.S., Color Science
Mitchell Rosen, M.S., Imaging Science

1992
Mark Gorzynski, M.S., Imaging Science
Taek Kim, M.S., Imaging Science
Rich Riffel, M.S., Imaging Science
Brian Rose, M.S., Color Science
Michael Stokes, M.S., Color Science

1991
Yan Liu, M.S., Color Science
Ricardo Motta, M.S., Imaging Science
Amy North, M.S., Color Science
Greg Snyder, M.S., Imaging Science

1989
Mitch Miller, M.S., Imaging Science
Kelvin Peterson, M.S., Imaging Science
Lisa Reniff, M.S., Color Science

1987
Denis Daoust, M.S., Imaging Science
Wayne Farrell, M.S., Imaging Science

1986
Mark Fairchild, M.S., Imaging Science

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2004 MCSL Publications

1. R.S. Berns, "Rejuvenating Seurat's palette using color and imaging science: A simulation," in *R.L. Herbert, Seurat and the Making of La Grande Jatte, Art Institute of Chicago and University of California* Press, 214-227 (2004).

2. R.S. Berns, "Color accurate image archives using spectral imaging," *Proc. National Academy of Sciences*, in press (2005).

3. R.S. Berns, S. Byrns, F. Casadio, I. Fiedler, C. Gallagher, F.H. Imai, A. Newman, M. Rosen, and L.A. Taplin, "Rejuvenating the appearance of Seurat's A Sunday on La Grande Jatte – 1884 using color and imaging science techniques – a simulation," *Proc. 10th Congress of the International Colour Association*, in press (2005).

4. R.S. Berns, L.A. Taplin, M. Nezamabadi, Y. Zhao, and Y. Okumura, "High-accuracy digital imaging of cultural heritage without visual editing," *Proc. IS&T Second Image Archiving Conference,* in press (2005).

5. R.S. Berns, F. Casadio, and I. Fiedler, "Rejuvenating the appearance of Seurat's La Grande Jatte using color and imaging science techniques – a simulation," *Proc. 14th Triennial Meeting The Hague, ICOM Committee for Conservation,* in press (2005).

6. R.S. Berns, M. Mohammadi, M. Nezamabadi, and L.A. Taplin, "A retouching palette that minimizes metamerism," *Proc. 14th Triennial Meeting The Hague, ICOM Committee for Conservation,* in press (2005).

7. R.S. Berns, L.A. Taplin, M. Nezamabadi, and M. Mohammadi, "Spectral imaging using a commercial color-filter array digital camera," *Proc. 14th Triennial Meeting The Hague, ICOM Committee for Conservation*, in press (2005).

8. R.S. Berns, "Publications Related to Art Spectral Imaging," *MCSL Technical Report*, December (2004).

9. R.S. Berns, L.A. Taplin, M. Nezamabadi, and Y. Zhao, "Modifications of a Sinarback 54 digital camera for spectral and high-accuracy colorimetric imaging: simulations and experiments," *MCSL Technical Report*, June (2004).

10. Y. Chen, R. S. Berns, L.A. Taplin, "Exploring the color constancy of prints," *Proc. 10th Congress of the International Colour Association*, in press (2005).

11. Y. Chen, R.S. Berns, and L.A. Taplin, "Extending printing color gamut by optimizing the spectral reflectance of inks," *Proc. IS&T/SID 12th Color Imaging Conference*, 163-169 (2004).

12. Y. Chen, R.S. Berns, and L.A. Taplin, "Six color printer characterization using an optimized cellular Yule-Nielsen spectral Neugebauer model," *Journal of Imaging Science & Technology*, in press (2005).

13. E.A. Day, L.A. Taplin, and R.S. Berns, "Colorimetric characterization of a computer-controlled liquid crystal display," *Color Res. Appl.* **29**, 365-373 (2004).

14. E.A. Day, R.S. Berns, L.A. Taplin, and F.H. Imai, "A psychophysical experiment evaluating the color and spatial-image quality of several multi-spectral image capture techniques," *Journal of Imaging Science & Technology* **48**, 99-110 (2004).

15. M.W. Derhak and M.R. Rosen, "Spectral colorimetry using LabPQR – an interim connection space," *Proc. of 12th Color Imaging Conference,* pp. 246-250 (2004).

16. M.D. Fairchild, "Color Appearance Models, Second Edition" *Wiley-IS&T Series in Imaging Science and Technology*, Chichester, UK (2005).

17. M.D. Fairchild, "Color appearance modeling: Splicing color science and practical applications," OSA Fall Vision Meeting, Rochester, *Journal of Vision* **4:11**, 26 (2004).

18. M.D. Fairchild and G.M. Johnson, "The iCAM framework for image appearance, differences, and quality," *Journal of Electronic Imaging* **13**, 126-138 (2004).

19. M.D. Fairchild and G.M. Johnson, "METACOW: A public-domain, high-resolution, fully-digital, noise-free, metameric, extended-dynamic-range, spectral test target for imaging system analysis and simulation," *IS&T/SID 12th Color Imaging Conference*, Scottsdale, 239-245 (2004).

20. M.D. Fairchild, G.M. Johnson, J. Kuang, and H. Yamaguchi, "Image appearance modeling and high-dynamic-range image rendering," *MCSL Technical Report*, (2004).

21. M.D. Fairchild, G.M. Johnson, J. Kuang, and H. Yamaguchi, "Image appearance modeling and high-dynamic-range image rendering," *SIGGRAPH 1st Symposium on Applied Perception in Graphics and Visualization,* Los Angeles, 171 (2004).

22. S. Fernandez, M.D. Fairchild and K. Braun, "Analysis of observer and cultural variability while generating preferred color reproductions of pictorial images," *Journal of Imaging Science & Technology,* in press (2005).

23. F. Frey and M.R. Rosen, "Direct digital capture: RIT american museums survey on digital imaging for direct capture of artwork," *Proc. of Museums and the Web,* in press (2005).

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References by Research Theme

(1) Color Meaasurement and Science
2, 4, 7, 8, 10, 13, 14, 16, 17, 24, 33-38, 40-43, 47, 48, 51, 56-59, 61-63

(2) Image Appearance and Quality
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(3) Spectral Color Reproduction
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(4) Color Science for Cultural Heritage
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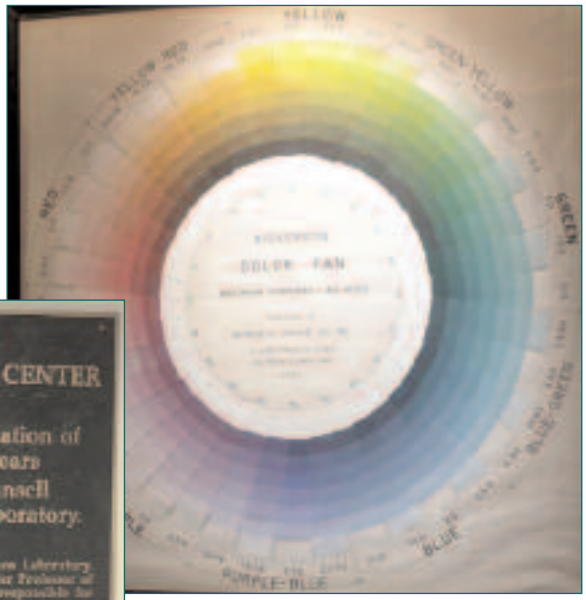

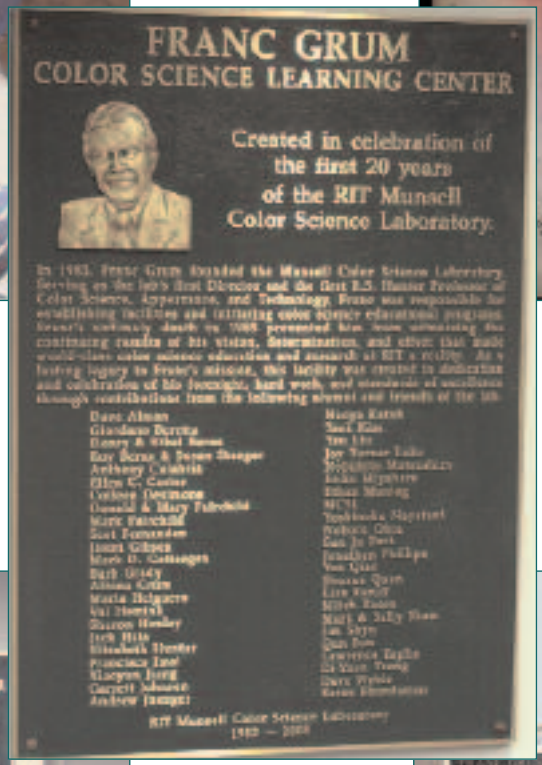

Franc Grum's daughter, Peg Bodine and his wife, Albina, attended the dedication and opening of the Franc Grum Color Science Learning Center.

Justin Laird was awarded the 2004 Franc Grum Memorial Scholarship.

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