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Munsell Color Science Laboratory



Front Row: Roy Berns, Dave Wyble, Jennifer Kruschwitz, Brittany Hensley, Yuta Asano, Farhad Abed, Val Hemink. Middle Row: Susan Farnand, Jun (Chris) Jiang, Dengyu Liu, Rachel Schwen, Jie Feng, Alicia Stillwell, Weiping (Bill) Yang, Rodney Heckaman, Lin Chen, Chao Liu. Back Row: David Long, Jim Ferwerda, Adriá Fores Herranz, Mark Fairchild, Brian Gamm, Jinwei Gu, Ben Darling, Tongbo Chen, Simon Muehlemann, Hao Li.

The Munsell Color Science Laboratory (MCSL) was founded at the Rochester Institute of Technology (RIT) in 1983 through a gift from the Munsell Color Foundation, Inc. The laboratory is part of the Chester F. Carlson Center for Imaging Science in RIT's College of Science. It was created, and continues to operate, with the vision of being the preeminent academic laboratory dedicated to color science education and research and the preferred source of educated color scientists for industry, academia, and government.

The following four objectives guide MCSL faculty, staff, and students in their endeavors to fulfill its vision and mission:

- 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 mission of the Munsell Color Science Laboratory is to advance the science, understanding, and technology of color and appearance through education, research, and outreach.

Munsell Color Science Laboratory Supporters

The following lists those that have contributed to our research and education programs through grants, contracts, and gifts during 2011. Thank you for your support and generosity!

The Andrew W. Mellon Foundation Applied Image Inc. Avian Technologies LLC Bron Imaging Group BYK Gardner Corning **Dolby Laboratories** Eastman Kodak Entertainment Experience LLC Extreme Science and Engineering Discovery Environment Scot Fernandez (with match from Hallmark Cards Inc.) Gamblin Artist Colors Golden Artist Colors, Inc. HP Labs Intel Andy and Maureen Juenger Museum of Modern Art, New York National Science Foundation (NSF) Precision Scale & Balance X-Rite Inc. Xerox Corporation Huan Zeng (with match from the Hewlett-Packard Company)

Endowments and Long-Term Commitments:

Munsell Color Science Laboratory Richard S. Hunter Professorship Xerox Professorship Macbeth-Engel Fellowship Franc Grum Memorial Scholarship Max Saltzman Memorial Scholarship

Director's Note



The Munsell Color Science Laboratory (MCSL) had an active 2011 with new research, coursework, and facilities. As we continue to evolve in measuring material appearance and begin research in computational photography, some space rearrangement was necessary. After much planning, we were a whirlwind of activity at the start of fall quarter. These are the laboratories forming MCSL: object perception, display perception, computational imaging, opto-electronic fabrication, informationdriven imaging, print quality, computational illumination, spectral projection, color measurement, spectral imaging, 3D imaging, spectral color reproduction, high-dynamic-range imaging, and

microscopy.

Our measurement capabilities have never been better. Color Scientist Dave Wyble maintains a close relationship with NIST, Avian Technologies, and instrument manufacturers to insure our spectral measurements are traceable to national standards and that our instruments have the best precision and accuracy possible. We have two linear light source systems that can measure spatially varying surface normal and BRDF using imaging techniques. We have a dome system with colored LED illumination that can estimate surface normal, BRDF, and spectral reflectance factor using a standard RGB camera. We have an X-Rite MA98 portable multi-angle spectrophotometer and a Murakami bench top goniospectrophotometer that measure large area material appearance. For the first time, we used the MA98 in the graduate color-modeling course to estimate BRDF and analyze the effects of applying a clear coat to diffuse surfaces. We revived our spectral imaging system with a new interface for our CRI liquid-crystal tunable filter and a new USB blue-enhanced monochrome sensor.

Several new research projects began during 2011. Xerox Professor Jim Ferwerda won a four-year award from the National Science Foundation to model material appearance. This program also includes Yale University and University of Central Florida. Jim is working with the Corning Corporation studying the impact of surface texture on display performance. Associate Dean Mark Fairchild received a one-year grant from the Intel Corporation to examine techniques for enhancing the color quality of legacy content for viewing on modern television display technology. Assistant Professor Jinwei Gu received a three-year gift from the Xerox Corporation to develop new techniques for high-speed imaging and event detection.

This year was also award laden. Following Professors Noboru Ohta and Mark Fairchild, Jim became the Xerox Professor. This is a three-year appointment providing discretionary funds to enable Jim to explore new avenues of research. An announcement was made that Mark will become an Optical Society of America Fellow during 2012. I received RIT's Board of Trustees Scholarship Award during the spring. This is RIT's top scholarship award recognizing student-centered research. The award was established in 2005. This was the first year that only one award was presented and that the award ceremony included a colloquium.

Our students were recognized for their research accomplishments. Brian Gamm, Color Science Ph.D. student, received the award for the Best Overall Presentation at the 2011 RIT Graduate Research Symposium (photo on page 11). At the Color Imaging Conference in San Jose, Anthony Blatner, Computer Engineering M.S. graduate, received the Cactus Award for the best interactive paper while Ben Darling, Color Science Ph.D. candidate, was the runner up for the MERL Award for best student paper.

Mark Fairchild along with Manuel Melgosa from the University of Granada completed the Spanish translation of "The Color Curiosity Shop." Mark has also signed a contract to write a third edition of "Color Appearance Models." This year, I completed the text for a new color science book for artists and art conservators and have started making the figures, both graphical and image.

Towards the end of 2011, we bid an *au revoir* to Professor Franziska Frey, who has become the Malloy-Rabinowitz Preservation Librarian Head of Preservation and Digital Imaging Services at Harvard Library. Franziska remains an extended faculty member in the Center for Imaging Science and will continue to participate in several of our museum-oriented research projects. Although this is a tremendous opportunity for Franziska, we will miss her.

I invite you to read our annual report where you can find a summary of our activities and accomplishments during 2011. As always, our education and research programs would not be nearly as effective without the support of our sponsors, RIT, and our friends, worldwide. Thank you so much!

Roy S. Berns Richard S. Hunter Professor in Color Science, Appearance, and Technology Director, Munsell Color Science Laboratory January 2012

Graduate Education in Color Science

RIT offers the only M.S. and Ph.D. programs in Color Science in the country. Color Science graduates are in high demand and have accepted industrial and academic positions in a variety of areas including basic and applied research, digital imaging and cinema, color instrumentation, and material appearance. Worldwide, more than 100 MCSL alumni are working diligently to advance the field. Many of them are recognized leaders making significant contributions to the advancement of color science and technology. Xerox Professor Jim Ferwerda is the Graduate Program Director for the Color Science programs. Feel free to contact him at ferwerda@cis.rit.edu and see cis.rit.edu/mcsl or cis.rit.edu for more information on our academic opportunities.

Students doing research in MCSL are not only Color Science students. During 2011, majors included Imaging Science, Computer Engineering, Industrial Engineering, and Print Media.



Color Science graduate students (from left to right) Lin Chen, Rachel Schwen, Alicia Stillwell, and Jennifer Kruschwitz enjoying the MCSL fall potluck dinner.



Color Science Ph.D. student Jun (Chris) Jiang is doing research on recovering multi-spectral images from measurements taken at two different times under natural daylight.

Industrial Education

MCSL Visiting Scientist Program

For nearly two decades, MCSL has been hosting industrial scientists and engineers for extended periods. These visiting scientists spend between six months and two years in residence at MCSL and work on fundamental research problems of interest to their employer and MCSL researchers. They also have time to participate in formal MCSL course offerings if they so desire and to experience the culture of Rochester and the entire United States. Feel free to contact any member of the MCSL faculty or staff for more information on becoming an MCSL visiting scientist.

During 2011, we hosted two Visiting Professors from Yunnan Normal University, Dr. Jie Feng and Dr. Weiping (Bill) Yang, both with interests in spectral imaging. Dr. Yiheng Cai from Beijing University of Technology completed a one-year residency in April. During the fall, Kenichiro Masaoka from NHK Science & Technology Research Laboratories, Japan arrived for a six-month residency as a Visiting Scientist where he'll be working with Professors Mark Fairchild and Roy Berns.

MCSL Summer Short Courses

Every June, MCSL presents industry-oriented short courses for people interested in traditional color technology, color imaging, and instrumental-based color matching.

Details can be found on our web page or call +1-585-475-7189

In 2011 we presented two short courses. The first, **The Essentials of Color Science**, was a two-day course taught by MCSL faculty and staff. The course had eight lectures and an early-evening open laboratory and icebreaker. These were the 2011 lectures:

Understanding Color Color Vision CIE Color Spaces Color Measurement Setting Color Tolerances Beyond Color: Gloss and Texture Color and Illumination Color Imaging

Following **The Essentials of Color Science**, Professor Roy Berns presented the oneday course **Instrumental-Based Color Matching**. This course used two-constant Kubelka-Munk turbid media theory as the optical model and included hands-on work using an opaque acrylic dispersion artist paint system. An Excel file was given out that was used to build the colorant optical database, perform spectral and colorimetric matching, and batch correction. These were the 2011 lectures:

Optical Models for Reflecting Materials Colorant Database Development and Evaluation Spectral and Colorimetric Matching Algorithms Matching Evaluation and Batch Correction

Students from Instrumental-Based Color Matching receiving some pointers from Professor Roy Berns.

Here is a listing of some of the places our short-course participants hailed from!

Academy of Art University Americhem Barbieri Electronic snc Boeing CBC/Radio Corning Incorporated Department of the Treasury - BEP Dolby Cananda **DuPont Building Innovations** Getty Conservation Institute Hewlett-Packard Lexmark International Inc. 3M Qualcomm, Inc. **Rust-Oleum Corporation** Sabic Innovative Plastics Samsung Mobile Display Toshiba

Current Students, Visiting Scientists, and Alumni

Key:

BS: Bachelor of Science CS: Color Science CE: Computer Engineering IE: Industrial Engineering EE: Electrical Engineering IPT: Imaging and Photo Technology IS: Imaging Science MS: Master of Science PhD: Doctor of Philosophy PM: Print Media

MCSL Current Students

Farhad Abed, PhD, CS Justin Ashbaugh, MS, CS Yuta Asano, PhD, CS Maggie Castle, BS, IS Huaijin (George) Chen, BS, IS Lin Chen, MS, CS Ping-Hsu (Jones) Chen, MS, CS Benjamin Darling, PhD, CS Maxim Derhak, PhD, CS Kevin Dickey, BS, IS Susan Farnand, PhD, CS Adriá Fores Herranz, PhD, CS Brian Gamm, PhD, CS Brittany Hensley, PhD, CS Carrie Houston, BS, IS Jun (Chris) Jiang, PhD, CS Jennifer Kruschwitz, PhD, CS Hao Li, MS, CS Chao Liu, PhD, IS Dengyu Liu, PhD, IS David Long, PhD, CS Simon Muehlemann, MS, PM Jonathan Phillips, PhD, CS Nannette Salvaggio, MS, CS Rachel Schwen, PhD, CS Alicia Stillwell, MS, CS Santosh Suresh, PhD, IS

Visiting Scientists

Yiheng Cai, Beijing University of Technology Jie Feng, Yunnan Normal University Kenichiro Masaoka, NHK Science & Technology Research Laboratories Weiping Yang, Yunnan Normal University

Alumni

2011

Anthony Blatner, MS, CE Brian Gamm, MS, CS John Grim, MS, CS Marissa Haddock, MS, CS Dan Zhang, MS, CS

2010

Bingxin Hou, MS, IS Suparna Kalghatgi, MS, IE

2009

Erin Fredericks, MS, IS Rodney Heckaman, PhD, IS Mahnaz Mohammadi, PhD, IS Shizhe Shen, MS, CS

2008

Stacey Casella, MS, CS Ying Chen, MS, CS Mahdi Nezamabadi, PhD, IS Abhijit Sarkar, MS, CS Yang Xue, MS, IS Hongqin (Cathy) Zhang, PhD, IS Yonghui (Iris) Zhao, PhD, IS

2007

Kenneth Fleisher, MS, CS Jiangtao (Willy) Kuang, PhD, IS

2006

Yongda Chen, PhD, IS Timothy Hattenberger, MS, IS Zhaojian (Li) Li, MS, CS Joseph Stellbrink, MS, CS

2005

Maxim Derhak, MS, IS Randall Guay, MS, IS Jim Hewitt, MS, IS Justin Laird, MS, CS Erin Murphy Smoyer, MS, CS Yoshio Okumura, MS, CS Michael Surgeary, MS, IS

2004

Rohit Patil, MS, CS Sung Ho Park, MS, CS Xiaoyan (Yan) Song, MS, CS

2003

D. Collin Day, MS, CS Ellen Day, MS, CS Scot Fernandez, MS, IS Edward Hattenberger, MS, CS Steve Jacob, MS, IS Xiaoyun (Willie) Jiang, PhD, IS Garrett Johnson, PhD, IS David Robinson, MS, IS Mitchell Rosen, PhD, IS Deniz Schildkraut, MS, CS Qun (Sam) Sun, PhD, IS

2002

Arturo Aguirre, MS, CS Jason Babcock, MS, CS Anthony Calabria, MS, CS Jen Cerniglia Stanek, MS, IS Scot Fernandez, MS, CS Jason Gibson, MS, CS Shuxue Quan, PhD, IS Yat-ming Wong, MS, IS

200 I

Alexei Krasnoselsky, MS, CS Sun Ju Park, MS, CS Michael Sanchez, MS, IS Lawrence Taplin, MS, CS Barbara Ulreich, MS, IS

2000

Sergio Gonzalez, MS, CS Sharon Henley, MS, CS Patrick Igoe, MS, IS Susan Lubecki, MS, CS Richard Soursa, MS, CS

1999

Gus Braun, PhD, IS Barbara Grady, MS, CS Katherine Loj, MS, CS Jonathan Phillips, MS, CS Mark Reiman, MS, CS Mark Shaw, MS, CS Di-Yuan Tzeng, PhD, IS Joan Zanghi, MS, CS

1998

Scott Bennett, MS, CS Fritz Ebner, PhD, IS Garrett Johsnon, MS, CS Naoya Katoh, MS, CS David Wyble, MS, CS

1997

Peter Burns, PhD, IS Christopher Hauf, MS, CS Brian Hawkins, MS, CS Jack Rahill, MS, IS Alex Vaysman, MS, IS

1996

Karen Braun, PhD, IS Cathy Daniels, MS, CS Yue Qiao, MS, IS Hae Kyung Shin, MS, IS

1995

Richard Alfvin, MS, CS Seth Ansell, MS, CS Susan Farnand, MS, IS

1994

Taek Kim, MS, IS Audrey Lester, MS, CS Jason Peterson, MS, IS Debra Seitz Vent, MS, IS James Shyu, MS, CS

1993

Nathan Moroney, MS, CS Elizabeth Pirrotta, MS, CS Mitchell Rosen, MS, IS**1992** Mark Gorzynski, MS, IS Rich Riffel, MS, IS Brian Rose, MS, CS

1991

Yan Liu, MS, CS Ricardo Motta, MS, IS Amy North, MS, CS Greg Snyder, MS, IS Michael Stokes, MS, CS

1989

Mitch Miller, MS, IS Kelvin Peterson, MS, IS Lisa Reniff, MS, CS

1987

Denis Daoust, MS, IS Wayne Farrell, MS, IS

1986

Mark Fairchild, MS, IS

Brian Gamm, Ph.D. student in Color Science, being awarded the Best Overall Presentation at the 2011 RIT Graduate Research Symposium.

Current Research

Research in MCSL can be organized into these themes:

- I) Colorimetry including metrology, psychophysics, and tolerance formulae modeling,
- 2) Image color-appearance psychophysics and modeling,
- 3) High-dynamic range image capture and display,
- 4) 3-D imaging of paintings including BRDF, surface-normal, and visible-spectral measurements and realistic image synthesis,
- 5) Spectral color reproduction including spectral capture, multi-ink inkjet printing, and spectral color management,
- 6) Art conservation science,
- 7) Museum imaging and lighting,
- 8) Material appearance,
- 9) Computational photography.

The following is a pictorial representation of some of our research. See the Publications section (page 21) for a complete listing of our scholarship during 2011.

First year Imaging Science undergraduate student Margaret Castle spent part of her summer working with Professor Roy Berns developing a new color target to evaluate both camera spectral and colorimetric accuracy and solid-state lighting quality for museum lighting.

Imaging Science first-year undergraduate student Kevin Dickey spent the summer of 2011 working with Assistant Professor Jinwei Gu to implement a portable gloss meter with LEDs, phototransistors, and Arduino boards.

During January and February 2011, Professor Roy Berns returned the Getty Conservation Institute and the J. Paul Getty Museum to conduct new experiments using the multi-filter spectral approach developed at MCSL. The left image was captured with a Better Light 4000, Getty's current camera used for paintings; the middle image used a Sinar prototype multi-filter system with a profile based on direct measurements of the painting; the right image also used the prototype camera, but with a profile based on a ColorChecker Classic. Because the background of this Salai renaissance painting was produced with ultramarine blue and lead white, the Better Light's red channel produced an excessive signal resulting in a purplish color.

TangiPaint is a digital painting application developed by Computer Engineering M.S. graduate Anthony Blatner, Professor James Ferwerda, Color Science Ph.D. candidate Benjamin Darling, and Professor Reynold Bailey. Using fingers on the iPad users can lay down strokes of thick, three-dimensional paint on a simulated canvas. They can then tilt the device to see the gloss and relief or "impasto" of the simulated surface, and modify it until they get the appearance they desire. A variety of paints and substrates are available and new ones can be created or imported. The tangiPaint system represents a first step toward developing digital art media that look and behave like real materials.

Color Scientist Dave Wyble and Assistant Professor Jinwei Gu worked with fifth-year mechanical engineering students to build a computer-controlled LED-based dome illumination system. The system will be used in Professor Gu's research on appearance capture and material classification. Top photograph from left to right: Dave Wyble, Jinwei Gu, Nicholas Liotta, Alexander Usachev, Azamat Boranbayev, Sigitas Rimkus, and Michael Miranda.

Staff Scientist and Color Science Ph.D. candidate Susan Farnand is exploring the techniques used in the psychophysical assessment of color image quality together with Professor Mark Fairchild. One initial goal is to explore the numbers of areas within an image that observers attend to when making an image quality judgment. Ultimately the goal will be to develop guidelines for the design and selection of representative image content in visual experiments. The above images represent three different crops of an image that are being assessed to determine the numbers and relationships between important areas.

Color Science Ph.D. candidate Benjamin Darling, Professor James Ferwerda, Postdoctoral Fellow Dr. Tongbo Chen, and Professor Roy Berns have developed a six-channel multispectral framework for capturing illumination maps and incorporating them into a real-time rendering pipeline. The benefits of the system are illustrated in this figure where teapots were assigned metameric spectral reflectance curves where the teapots match under tungsten illumination and mismatch under daylight. The back of each teapot is lit by daylight and the front is lit by a tungsten lamp. With standard three-channel RGB rendering (top), a color mismatch between the two teapots, expected for daylight, is still present for the tungsten lamp. With the six-channel workflow (bottom) the color difference is there for the side facing daylight, and the correct metameric match is seen for the side facing the tungsten lamp.

Dr. Tongbo Chen, Postdoctoral Fellow, and Professor Roy Berns have been improving software for use by conservation scientists when analyzing spectral images. Here is a partial screenshot of the subroutine "SpectralAnalyzer" that shows the estimated spectrum for any image position. Input to the system is a six-channel TIFF image using the MCSL spectral imaging approach. This image was captured and processed using a system under development between MCSL and Sinar.

Professor Mark Fairchild and Postdoctoral Fellow Dr. Rod Heckaman are working to implement the concept of independent color appearance scales described in a presentation at the November ISCC meeting on color spaces. The implementation will use constant hue derived from hue angle in the IPT model. The above chart explores the differences in defining saturation along lines of constant dominant wavelength in the CIE u'v' diagram (straight lines) or by line segments of constant IPT hue angle. Such saturation metrics will not only represent one of the derived appearance scales, but they will also serve as an index into a definition of zero-gray-content luminance levels needed to create a definition of high-dynamic-range lightness-brightness.

During July, Professor Roy Berns and Post-Doctoral Fellow Dr. Tongbo Chen (top left) traveled to the Museum of Modern Art in New York to test a new system for imaging the color and appearance of paintings. The system used a linear light source traveling across the painting in 2mm intervals in both horizontal (top right) and vertical directions. From these hundreds of images, spatially varying BRDF, surface normal, and spectral reflectance factor was calculated. In this example, the Jackson Pollock painting <u>Shimmering Substance</u> (30 1/8" x 24 1/4") was measured. The bottom left image is the diffuse colors of a portion of the painting. The bottom right image is the normal map and spatially varying surface appearance.

Spectral radiance functions of the Brightside DR37P HDR display at maximum luminance (3000 cd/m²).

Retinal irradiance of the HDR in terms of display "white" and display "blue light".

High Dynamic Range (HDR) displays have great potential for vision testing because they allow the presentation of images that accurately reproduce the wide variations in luminance we experience in the real world. However one concern about vision testing with HDR displays is evidence that exposure to intense short-wavelength light can damage the eyes of people with retinal disease (the "blue light hazard"). Xerox Professor James Ferwerda has conducted a radiometric analysis of an HDR display with respect to international phototoxicity guidelines. The findings have important implications for the use of HDR displays in vision research and the design of future HDR displays.

Ejemplo del icono de páginas

Professor Mark Fairchild published the online version of The Color Curiosity Shop in 2010 (whyiscolor.org) and two hardcopy editions in 2011. Over the past year, he has been working on a Spanish version of the resource with Professor Manuel Melgosa of the University of Granada. The translation work is complete and an initial hard-copy Spanish edition is expected sometime in 2012. (Later on there will be a Spanish website and a free PDF download.) This figure shows the resource map and example icon.

David Long, Chair of RIT's Motion Picture Science B.S. Program and part-time Color Science Ph.D. student is working on a dissertation with Professor Mark Fairchild. The dissertation will examine the potential for, and implementation of, spectral imaging techniques in the motion picture industry with an eye toward understanding observer metamerism effects. The figure above, from work presented at the 19th Color Imaging Conference, shows optimal spectral approximations of a ColorChecker Chart illuminated by D65 when reproduced by two standard video projectors filtered in an attempt to create six spectrally-independent channels. This is one approximation of what might be possible to implement in motion picture exhibition.

One limitation of our multi-filter approach to spectral imaging has been apparent image mis-registration and noise. Professor Roy Berns and post-doctoral fellow Dr. Tongbo Chen developed new algorithms to reduce these artifacts. Top image: 2006 processing; middle image: single image without processing (benchmark); bottom image: 2011 processing.

Rachel Schwen, Color Science Ph.D. student, and Professor Roy Berns have been extending Roy's computational research in designing white light LEDs for museum lighting. Rachel has amassed spectral data for most currently available LEDs. She has been evaluating three-light combinations that can match the color rendering properties of a 3000K blackbody, illuminant D50, and illuminant D65. She has also selected combinations that can either decrease (top row of plots) or increase (bottom row of plots) chroma without appreciable hue shifts, shown in this example for 3000K. The left plots are the source spectra. The middle plots are the colorimetric shifts from the MCSL spectral target's maximum chroma samples shown in a Euclidean color-difference IPT space. The right plots are renderings where the top triangle is the appearance for a 3000K reference and the bottom triangle is the test source.

Professor Roy Berns made spectral measurements on René Magritte's <u>The False Mirror</u> in the conservation studio at the Museum of Modern Art, New York to evaluate changes before and after varnish removal during conservation treatment (left). Using our linear light source (see page 17), the surface roughness was measured (right). The lighter area on the left side of the painting identifies the region where varnish was removed.

2011 Publications

Books

I. Fairchild, M.D., The Color Curiosity Shop, MDF Publications, Honeoye Falls, NY, USA (2011)

Refereed Journal Articles

- 2. Berns, R.S., Designing white LED lighting for the display of art: A feasibility study, Color Research and Application, 36, pp. 324-334 (2011)
- 3. Farnand, S.P., Effect of Scene Content on the Perceptibility of Differential Gloss, Journal of Imaging Science & Technology, 54, 3, pp. 30505-1–30505-13 (2011)
- 4. Heckaman, R.L.; Fairchild, M.D., Brighter, more colorful colors and darker, deeper colors based on a theme of brilliance, Color Research and Application, 36, pp. 255-265 (2011)
- 5. Shen, S.; Berns, R.S., Color difference formula performance for several datasets of small color differences based on visual uncertainty, Color Research and Application, 36, pp. 118-126 (2011)
- 6. Urban, P.; Berns, R.S., Paramer mismatch-based spectral gamut mapping, IEEE Transactions on Image Processing, 20, pp. 1599-1610 (2011)

Reviewed Conference Proceedings

- Abed, F.M.; Berns, R.S., Using ICC profiles for spectral estimation and lighting evaluation, Proceedings IS&T/SID 19th Color Imaging Conference, San Jose, CA, pp. 52-57 (2011)
- 8. Berns, R.S.; Abed, F.M., Photoshop as a tool for museum lighting design using apriori colorant optical data, Proceedings International Colour Association Midterm Meeting, Zurich, Switzerland, pp. 78-81 (2011)
- 9. Berns, R.S.; Haddock, M.I., A Color Target for Lighting and Camera Evaluation, Proc. 16th Triennial Meeting Lisbon, ICOM Committee for Conservation, Lisbon, Portugal, Paper 1601-1–1601-9 (2011)
- Blatner, A.M.; Ferwerda, J.A.; Darling, B.A.; Bailey, R.J., TangiPaint: a tangible digital painting system, Proceedings IS&T/SID 19th Color Imaging Conference, San Jose, CA, pp. 102-107 (2011)

- 11. Darling, B.A.; Ferwerda, J.A.; Chen, T.; Berns, R.S., Real-time multi-spectral rendering with complex illumination, Proceedings IS&T/SID 19th Color Imaging Conference, San Jose, CA, pp. 345-351 (2011)
- Fairchild, M.D.; Chen, P., Brightness, lightness, and specifying color in highdynamic-range scenes and images, SPIE/IS&T Electronic Imaging Conference, 7867, San Francisco, CA, pp. O-1 – O-14 (2011)
- Farnand, S.P.; Frey, F.S., The Impact of Lighting on Perceived Quality of Fine Art Reproductions, Proceedings of AIC's Conference on the Interaction of Colour and Light, Zurich, Switzerland, pp. 185-188 (2011)
- 14. Farnand, S.P.; Jiang, J.; Frey, F.S., Comparing hardcopy and softcopy results in the study of the impact of workflow on perceived reproduction quality of fine art images, Proceedings of the Image Quality and Systems Performance VII conference at the IS&T/SPIE Electronic Imaging Symposium, San Francisco, CA, pp. 786705-1– 786705-9 (2011)
- Ferwerda, J.A., High dynamic range displays and low vision, Proceedings IS&T/SID 19th Color Imaging Conference, San Jose, CA, pp. 181-185 (2011)
- Gamm, B.M.; Frey, F.S.; Farnand, S.P., An analysis of the factors influencing paper selection for books of reproduced fine art, Proceedings of IS&T's Non-Impact Printing Conference, Minneapolis, MN, pp. 791-796 (2011)
- Gu, J.; Kabayashi, T.; Gupta, M.; Nayar, S., Multiplexed Illumination for Scene Recovery in the Presence of Global Illumination, IEEE Interactional Conference on Computer Vision (ICCV) pp. 691-698 (2011)
- Heckaman, R.L.; Sullivan J., Rendering Digital Cinema and Broadcast TV Content to Wide Gamut Display Media, Proceedings of SID Display Week 2011, pp. 225-228 (2011)
- Hitomi, Y.; Gu, J.; Gupta, M.; Mitsunaga, T.; Nayar, S., Video from a Single Coded Exposure Photograph using a Learned Over-complete Dictionary, IEEE International Conference on Computer Vision (ICCV), pp. 287-294 (2011)
- Jiang, J.; Frey, F.S.; Farnand, S.P., Evaluating the Perceived Quality of Soft-copy Reproductions of Fine Art Images With and Without the Original Present, Proceedings IS&T/SID 19th Color Imaging Conference, San Jose, CA, pp. 276-283 (2011)
- Li, H.; Fairchild, M.D.; Webster, A., Appearance-based primary design for displays, Proceedings IS&T/SID 19th Color Imaging Conference, San Jose, CA, pp. 139-145 (2011)
- Long, D.L.; Fairchild, M.D., Optimizing spectral color reproduction in multiprimary digital projection, Proceedings IS&T/SID 19th Color Imaging Conference, San Jose, CA pp. 290-297 (2011)

Conference and Invited Presentations (No Proceedings)

- 23. Berns, R.S., Beyond the valley of the RGB: spectral imaging, Museum Computer Network, Atlanta, GA, November (2011)
- 24. Berns, R.S., Conservation-Oriented Paint Formulation Software for Inpainting, Getty Conservation Institute, Los Angeles, CA, February (2011)

Staff Scientist and Color Science Ph.D. candidate Susan Farnand giving a presentation at the International Association of Colour Interim meeting held in Zurich, Switzerland.

- 25. Berns, R.S., Panel discussion Workshop on Digitalization Workflow Guidelines, Taiwan e-Learning and Digital Archives Program, Taipei, Taiwan, March (2011)
- 26. Berns, R.S., Plenary paper: Three-Dimensional Multi-Spectral Imaging of Artwork, Taiwan e-Learning and Digital Archives Program, Taipei, Taiwan, March (2011)
- 27. Berns, R.S., The RIT Munsell Color Science Laboratory: An International Resource for Color and Imaging Science Research, Education, and Outreach, Color Associate of Taiwan and CIE-Taiwan, Taipei, Taiwan, March (2011)
- 28. Berns, R.S., Spectral-Based Color Reproduction: An Intersection of Color Science, Imaging Science, and Visual Arts, RIT Scholar Award Colloquium, Rochester, NY, May (2011)
- 29. Berns, R.S., Turning back the ravages of time: Color reconstructions of Seurat and van Gogh paintings and drawings using color and imaging sciences, Museum Computer Network, Museum Computer Network, Taipei, Taiwan, March (2011)
- 30. Berns, R.S., Image Capture Minimizing Visual Editing An Update From The 2005 American Benchmarking Project, Taiwan e-Learning and Digital Archives Program, Taiwan e-Learning and Digital Archives Program, Taipei, Taiwan, March (2011)
- 31. Berns, R.S., The RIT Munsell Color Science Laboratory: An International Resource for Color and Imaging Science Research, Education, and Outreach, Color Associate of Taiwan and CIE-Taiwan, Color Associate of Taiwan and CIE-Taiwan, Taipei, Taiwan, March (2011)
- 32. Fairchild, M.D., Is there really such a thing as color space? Foundations of unidimensional appearance spaces, ISCC, ISCC/IS&T/SID Special Topics Meeting: Revisiting Color Spaces, San Jose, CA, November (2011)
- 33. Ferwerda, J.A., A talk about pictures and stuff. IEEE IVMSP 2011, Workshop on Perception and Visual Signal Analysis, Cornell University, Ithaca, NY, June (2011)
- 34. Ferwerda, J.A., Envisioning the material world. International Symposium on Material Appearance, Giessen, Germany, May (2011)
- 35. Ferwerda, J.A., Envisioning the material world. Inter-society Color Council (ISCC) Annual Meeting, Charlotte, NC, May (2011)
- 36. Ferwerda, J.A., Making pictures of stuff. Eastman Kodak, Rochester, NY, May (2011)

- 37. Ferwerda, J.A., Making pictures of stuff. Hewlett-Packard Laboratories, Palo Alto, CA, November (2011)
- 38. Heckaman, R.L.; Sullivan J., Rendering Digital Cinema and Broadcast TV Content to Wide Gamut Display Media, 18th International Display Workshops (2011)
- 39. Long, D.L.; Fairchild, M.D., Reducing observer metamerism by spectral color reproduction in digital projection, National Association of Broadcasters, Annual Meeting, Las Vegas, NV, April (2011)

Technical Reports

 Frey, F.S.; Farnand, S.P., Benchmarking Art Image Interchange Cycles, prepared for The Andrew W. Mellon Foundation, Rochester Institute of Technology, College of Science, Center for Imaging Science, Munsell Color Science Laboratory, Rochester, New York, June (2011)

Theses

- 41. Blatner, A., TangiPaint: interactive tangible media, M.S. Thesis, Rochester Institute of Technology, College of Engineering, Department of Computer Engineering, Rochester, New York (2011)
- 42. Gamm, B.M., An analysis of the factors influencing paper selection for books of reproduced fine art, M.S. Thesis, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York (2011)
- 43. Haddock, M.I., Prototype software for colorant formulation using Gamblin conservation colors, M.S. Thesis, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York (2011)
- 44. Kalghatgi, S., A multiscale analysis of the touch-up problem, M.S. Thesis, Rochester Institute of Technology, College of Engineering, Department of Industrial Engineering, Rochester, New York (2011). (Best thesis award)
- 45. Zhang, D., Appearance-based image splitting for HDR display systems, M.S. Thesis, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York (2011)

Dan Zhang, (M.S. Color Science 2011) and Bingxin Hou (M.S. Imaging Science 2010) showing school spirit at a hockey game.

Munsell Color Science Laboratory Advisory Board

The MCSL Advisory Board is an advisory group composed of industrial and academic experts in color science and color aesthetics. Their role is to insure that the activities of MCSL are in concert with industrial needs, to evaluate the degree programs in Color Science, to promote funding opportunities, and to provide employment opportunities to Color Science and Imaging Science graduates focused on color-related problems.

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Calvin S. McCamy visiting MCSL. He is holding the X-rite ColorChecker Classic, perhaps Cal's most famous invention.

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