MCSL
MUNSELL COLOR SCIENCE LAB

2009 Annual Report

R·I·T

Cover: Ben Darling demonstrating the latest advances in tangible displays. In addition to high color accuracy, objects rendered on the display appear to properly interact with the overhead illumination when the display is moved within the viewing booth. The objective is to produce an interactive display that cannot be visually distinguished from real three-dimensional objects.

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Munsell Color Science Laboratory

Rochester Institute of Technology's Munsell Color Science Laboratory (MCSL) was established in 1983 through a gift from the Munsell Color Foundation, Inc. Since then, MCSL faculty, staff and graduate students have 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.

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

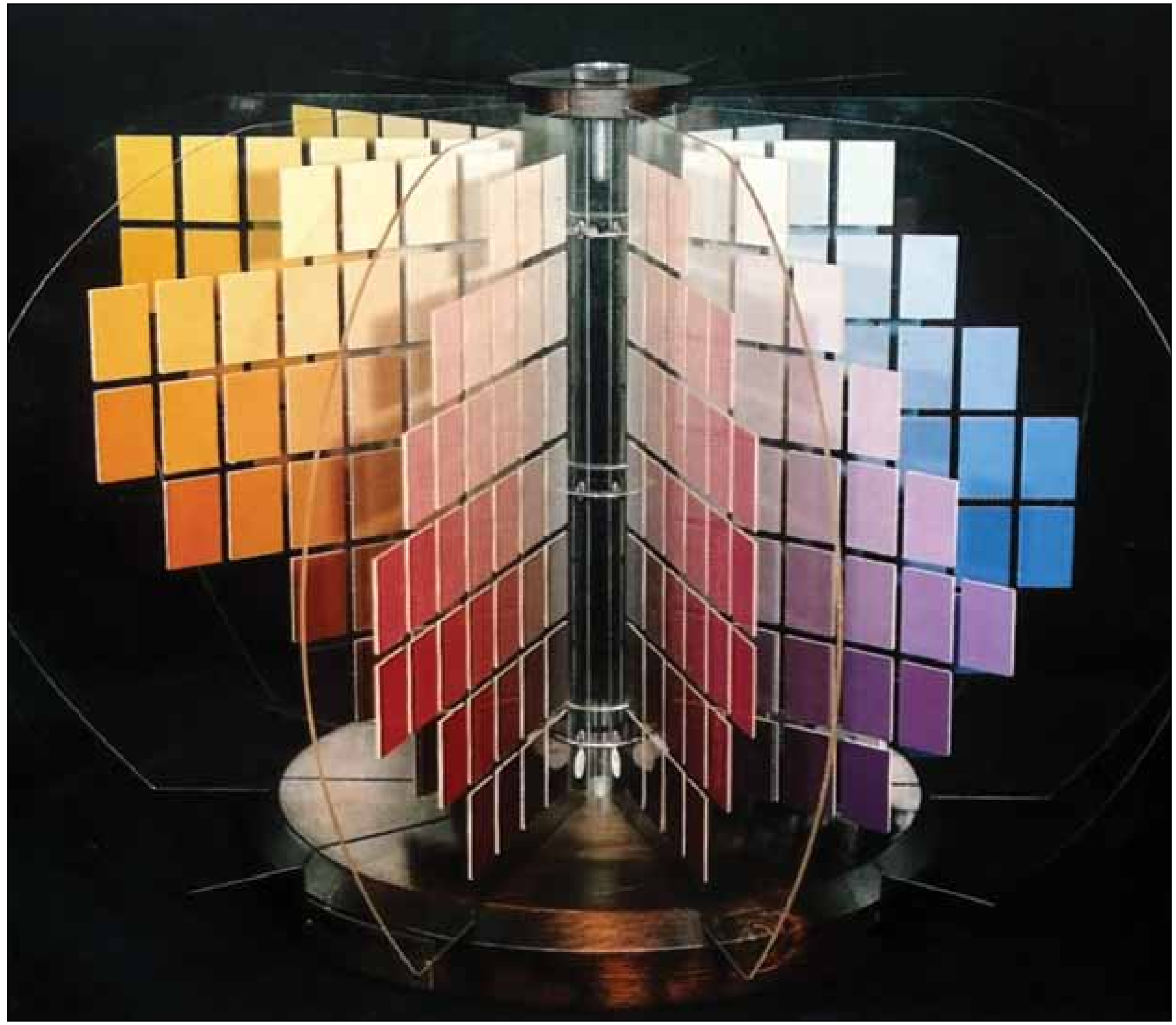
(1) To provide undergraduate and graduate education in color science,

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



The Munsell Color Tree. The perceptual distances between adjacent samples are uniform. Materials do not uniformly or completely sample perceptual color space.

Munsell Color Science Laboratory Supporters

The following lists those that have contributed to our research and education programs through grants, contracts, and gifts during 2009. Thank you for your support and generosity!

The Andrew W. Mellon Foundation

Apple Computer Inc.

Avian Technologies LLC

Canon Inc.

Eastman Kodak

Entertainment Experience LLC

Felix Schoeller, Jr. Digital Imaging

Scot Fernandez

Gamblin Artists Colors Co.

Hallmark Cards Inc.

Hewlett Packard Company

Andrew and Maureen Juenger

Microsoft Corporation

Museum of Modern Art (MoMA), New York

National Science Foundation (NSF)

NCS Colour

New York State Foundation for Science, Technology and Innovation (NYSTAR/CEIS)

ONYX Graphics

Philips Solid State Lighting

Photo Research Inc.

Sherwin-Williams

Sony Corporation

Toppan Printing Co., Ltd.

X-Rite Inc.

Huan Zeng

Endowments and Long-Term Commitments:

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

Director's Note

2009 was another exciting and outstanding year. The big excitement was a celebration of our 25th anniversary with a one-day conference and open house as part of the Inter-Society Color Council Annual Meeting. Invited speakers included Robert W. G. Hunt, Nathan Moroney, Calvin S. McCamy, Rolf G. Kuehni, Joy Luke, Alan R. Robertson, Mark S. Rea, and our own Jim Ferwerda and Mark Fairchild. As you see by the list of speakers, my conference goal was to look back and into the future of color science; my goal was realized well beyond my expectations. There were many old and new friends of MCSL in attendance and a fitting way to celebrate our silver anniversary.

During 2009, we made some significant changes in our facilities. We no longer have an immersive display lab. Research labs are now Co-Innovation (for small video conference meetings), Spectral Color Reproduction (end-to-end multi-spectral capture and seven-ink inkjet printing), 3D Imaging (laser scanning, HDR display, computer graphics rendering), Spectral Imaging (MCSL Imaging Goniospectrometer), Color Measurement, and Display and Perception (Novel displays, ISO print evaluation). These labs reflect our growing activities in understanding appearance, which includes both color and geometry. We are realizing Richard S. Hunter's passion for color and appearance and ways to measure both.

Longtime member of MCSL, Mitch Rosen, has joined the RIT Center for Student Innovation. Although no longer associated with MCSL, Mitch remains on the Color Science faculty.

I am very enthusiastic about the expansion of MCSL research to include 3D image capture, rendering, and display, particularly in support of appearance research led by Jim Ferwerda. Jim has been active taking on undergraduate and graduate students, grant writing, and teaching a new seminar course on material appearance.

We have also made a commitment to expand our measurement research and services. Previously, Dave Wyble has been collaborating with Danny Rich and the ASTM to better define and quantify spectrophotometric precision and accuracy. During 2009, Dave has become the MCSL liaison with NIST and he has just finished an intercomparison of imaging and non-imaging instruments that measure BRDF. This research is necessary as the MCSL Imaging Goniospectrometer comes online. Dave has also been looking at economical ways to continue having fluorescence measurement capabilities as our Labsphere BFC 450 is now on life support.

We continue our commitment to imaging, archiving, and reproducing cultural heritage. Our system is capable of capturing spectral and geometric properties of artwork. Renewed funding from the Andrew W. Mellon Foundation will result in a practical implementation that will be tested at the Museum of Modern Art sometime during the next two years. We also continue a close collegial relationship with Dr. Franziska Frey, McGhee Professor in the School of Print Media, whose research is also supported by the Andrew W. Mellon Foundation and is focused on print quality for artwork reproduction.

Last year, we made a commitment to increase our outreach activities as a recruiting tool for our graduate programs in color science and to develop new relationships with industry. Mark Fairchild was a panel discussant at the IS&T Color Imaging Conference. Jim Ferwerda gave keynote or invited presentations at the Vision Society of Japan Annual Meeting, NTT Research, National Institute for Physiological Sciences (Japan), Chiba University, Stanford HDR Imaging Symposium, Picture Coding Society of Japan Annual Meeting, and Proctor & Gamble Imaging Community of Practice Symposium. I gave keynote or invited presentations at the American Institute of Conservation, the International Association of Colour, North Carolina State University, and Princeton University.

Our students continue to thrive. We had four graduates this year: Mahnaz Mohammad and Rodney Heckaman, Ph.D. Imaging Science; Shizhe Shen, M.S. Color Science; and Erin Fredericks, M.S. Imaging Science. There are 16 full or part-time graduates doing research with MCSL. Benjamin Darling, Ph.D. student in Color Science received two awards this year: best poster at the first RIT Graduate Research Symposium and the MERL best paper at the IS&T Color Imaging Conference.

Details about these and our other activities are contained in this annual report. As always, our education and research programs would not be nearly as effective without the support of our sponsors, RIT, and our friends and supporters, worldwide. Thank you so much!

Roy S. Berns

Richard S. Hunter Professor in Color Science, Appearance, and Technology

Director, Munsell Color Science Laboratory

February 2010

The MCSL group gathered after an early autumn 2009 research meeting.

2009 Honors & Awards

Ben Darling receiving the 2009 MERL Award from IS&T Executive Director Suzanne Grinnan. The MERL Award is given to the author of teh best student presentation at the IS&T/SID Color Imaging Conference and is determined by a vote of the conference participants. Ben received the award for his dissertaion work on tangible displays. Congratulations Ben!

Roy Berns , with wife Susan Stanger, after receiving the 2009 ISCC Godlove Award. The Godlove Award is the most prestigious award bestowed by the Inter-Society Color Council and honors long-term contributions in the field of color. Everyone at MCSL is happy to join in congratulating Roy for this well-deserved honor.

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 1-2 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 and climate 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.

MCSL Summer Short Course: Essentials of Color Science

Every June, MCSL presents this course for people interested in color measurement, specification, control, reproduction, or use. The lectures are designed to form a coherent course that introduces the fundamental concepts of color science, describes various applications, and introduces cutting-edge research areas in color science.

Details can be found at: **www.mcsl.rit.edu/outreach/courses.php** or call +1-585-475-7189.

The Essentials of Color Science Lectures

Color Perception and Appearance

The Visual System

Basic Colorimetery: Tristimulus Values

Basic Colorimetry: CIELAB

Spectrophotometry and Spectroradiometry

Color Differences Equations and Tolerances

Interactive Spectrophotometry

Digital Color Imaging Systems

Instrumental-Based Color Matching

Color Management Systems

Psychophysics and Applications

Color Appearance Models

Spectral Imaging

Realistic Image Synthesis

Image Appearance Models

Visiting researcher Koichi Takase enjoying the sights with MCSL students Dan Zhang, Marissa Haddock, and Max Derhak during a break at the Color Imaging Conference in Albuquerque.

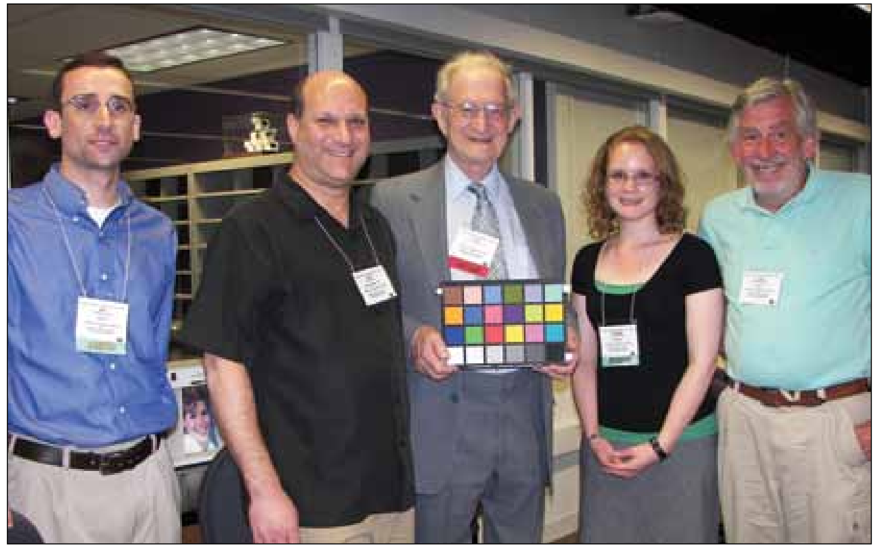
Graduate Education in Color Science

RIT offers the only M.S. and Ph.D. programs in Color Science in the country. Imaging Science students can also concentrate in color imaging, performing research in MCSL. 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.

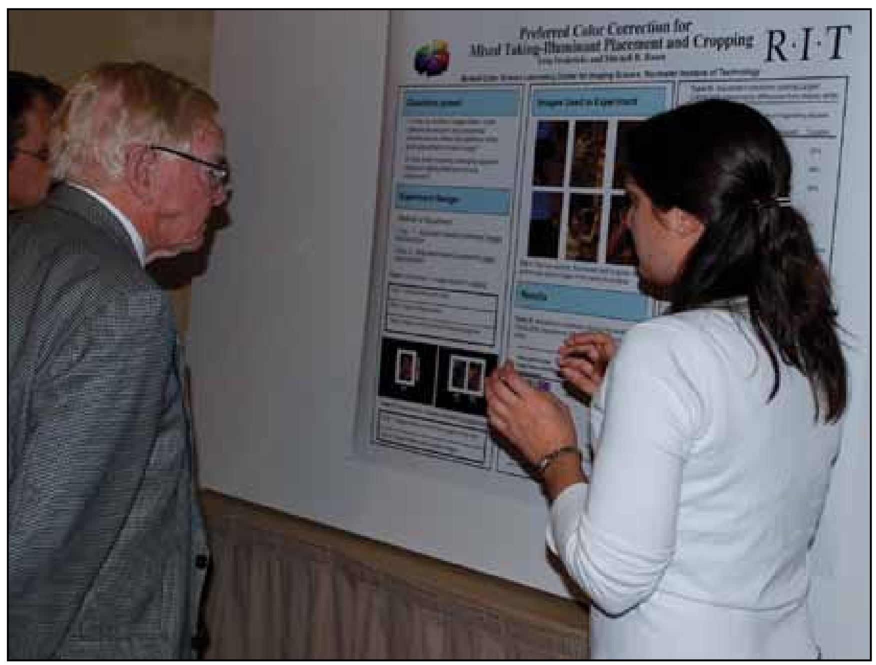
Color Science graduates are in high demand and have accepted industrial and academic positions in a variety of areas including basic and applied research, digital imaging and cinema, color instrumentation, and material appearance.

Students complete their degrees through programs in the Chester F. Carlson Center for Imaging Science within RIT's College of Science. These include the M.S. and Ph.D. programs in Color Science and Imaging Science. In addition, undergraduate students in Imaging Science and other programs occasionally complete research projects or obtain other work experience in the field of color science.

Prof. Mark D. Fairchild is the Graduate Coordinator for the Color Science programs. Feel free to contact him at **mdf@cis.rit.edu**. or see **www.cis.rit.edu**, for more information on our academic opportunities.



MCSL students and alumni celebrating the Munsell ColorChecker Chart with its inventor at the MCSL 25th Anniversary Symposium in June, 2009. From left to right: Ben Darling, Ken Fleisher, Cal McCamy (holding his chart), Marissa Haddock, Rod Heckaman.



Recent Imaging Science M.S. graduate Erin Fredericks discusses her poster presentation with Professor Robert W.G. Hunt at the 2009 Color Imaging Conference.

Current Students, Visiting Researchers, and Alumni

Key:
BS: Bachelor of Science
CS: Color Science
IE: Industrial Engineering
IPT: Imaging and Photo Technology
IS: Imaging Science
MS: Master of Science
PhD: Doctor of Philosophy

MCSL Current Students

Justin Ashbaugh, MS, CS
Juliet Bernstein, BS, IS
Jacqueline Caci, BS, IPT
Ping-Hsu (Jones) Chen, PhD, CS
Benjamin Darling, PhD, CS
Maxim Derhak, PhD, CS
Susan Farnand, PhD, CS
Brian Gamm, MS, CS
Mark Giglio, BS, IS
John Grim, MS, CS
Marissa Haddock, MS, CS
Bingxin Hou, MS, IS
Jun (Chris) Jiang, PhD, CS
Suparna Kalghatgi, MS, IE
Hao Li, MS, CS
David Long, PhD, CS
Stefan Luka, MS, CS
Ann Nunziatta, BS, IS
Jonathan Phillips, PhD, CS
James Proper, PhD, IS
Nannette Salvaggio, MS, CS
Lawrence Taplin, PhD, CS
Mark Updegraff, MS, CS
Hung-Hsin Wu, MS, IS
Dan Zhang, MS, CS

Visiting Researchers

Jens Stenger, Harvard Art Museum
Koichi Takase, Toppan Printing Co.
Philipp Urban, Hamburg University

Graduate Alumni

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 Okumara, 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

2001
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, IS
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

Collaborative Research

MCSL is recognized around the world as a prominent source of leading-edge, interdisciplinary research in color science. MCSL students, faculty, and staff produce scores of journal papers, conference presentations, book chapters, and invited presentations each year (not to mention the occasional text book). Much of this research is done in close cooperation with industrial, government, institutional, or other sponsors. Please see **www.mcsl.rit.edu/about/sponsors.php** to learn about our current and past sponsors.

Recent MCSL research can be generally categorized into five theme areas:

Color & Appearance Measurement, Modeling, and Representation;

Image-Appearance Capture, Modeling, Rendering, and Display;

Color Science for Cultural Heritage;

Spectral Color Reproduction; and

Three-Dimensional Imaging and Realistic Image Synthesis.

A review of the publications list will provide an overview of the range of recent research results. The highlight stories provide a little more insight into some current and planned projects and activities. As always, much more information on past and current research and publications can be found by visiting **www.mcsl.rit.edu**.

There are many opportunities for new collaborative research projects in support of our mission of providing our students with relevant research topics and the best possible educational experience. Please let us know if your organization is interested in learning more about how to collaborate with MCSL.

This rendered HDR image of the National Route 66 Museum is part of the HDR Photographic Survey. The digital color data from these HDR images were used to update the classic work of Jones and Condit done with black and white silver halide photographic images.

Jones and Condit Redux

In 1941 Jones and Condit published a seminal paper in photographic science that examined the luminance distributions in a variety of scenes. Their data were used (and continue to be) to help define the necessary dynamic range and exposure characteristics for photographic imaging systems. In 2007, Mark Fairchild completed the HDR Photographic Survey in which he collected a variety of images along with colorimetric and appearance data about the scenes. These images, encoded in extremely high dynamic ranges, included the same sorts of data that Jones and Condit collected, but in high dynamic range and color. In 2009, Rod Heckaman took each and every pixel in the HDR Photographic Survey and analyzed the luminance and color gamuts of the images to provide a modern revisit to the Jones and Condit work. He found the mean dynamic range to by similar to the original work (about 2 log units) but the HDR survey included images with log dynamic ranges nearing 6 (1,000,000:1). The chromaticity gamuts generally did not significantly exceed those of typical modern display technologies.

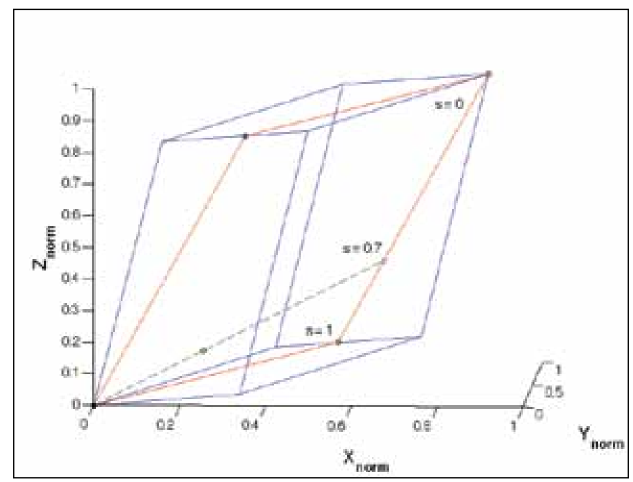
Artist Material Database

Justin Ashbauch, M.S. student in Color Science, developed an artist material database for the Mellon Foundation sponsored project, Improving Artwork Reproduction Through 3D-Spectral Capture and Computer Graphics Rendering. In consultation with Professor Mark D. Gottsegen, now with AMIEN, 600 samples were prepared sampling the five dimensions of medium, substrate, color, application technique, and overcoat. All the samples were measured using a BYK-mac and the MCSL Imaging Goniospectrometer. This image and material database is available online at **art-si.org** .

Colorimetric Image Splitting for High-Dynamic-Range Displays

High dynamic range (HDR) displays are currently being developed that enable the photometrically accurate presentation of scenes with luminance contrast exceeding 100,000:1. The high contrast ratio of these displays is achieved through a dual plane design where light is modulated in two stages. In the first stage, an image is formed by a spatially addressable LED backlight. In the second stage, an LCD front panel optically modulates the backlight image, producing a final image with increased dynamic range. Associated with this design is an inherent image processing problem: In order to produce a final target image, intermediate images must be calculated for each display layer. The process of generating these images is known as image splitting. Prior research on HDR image splitting has focused on maximizing luminance contrast and minimizing parallax errors between the two planes. Stefan Luka (Color Science M.S. candidate) and Associate Professor James Ferwerda have developed a colorimetric model for image splitting in dual plane HDR displays. The model maximizes gamut utilization while minimizing quantization errors, producing displayed HDR images with deeper, more saturated colors.

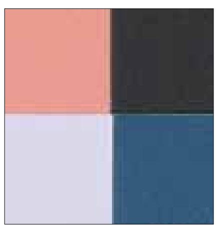
Prototype dual modulator HDR display with high dynamic range content.

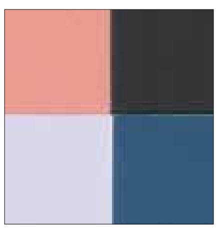


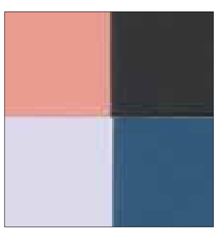
HDR display gamut in normalized XYZ coordinates. The red boundary is the plane containing the target XYZ, maximum white, and minimum black. The dashed line runs through the target XYZ and the point of intersection, s, controls the transition from square root to linear backlight modulation.

Assessment of Noise Reduction Techniques for End-to-End Spectral Color Reproduction Systems

Marissa Haddock, M.S. student in Color Science, spent her summer at MCSL using our spectral imaging system including multispectral camera and multi-ink inkjet printer. When we first starting using this system in 2008, we found that image noise, when propagated through a spectral workflow, could result in appreciable spectral and color errors and low image quality, particularly in dark passages. She looked at two approaches, high-dynamic range (HDR) imaging using three different exposure times and noise-reduction software, specifically PictureCode's Noise Ninja, optimized for each sequential color filter. Both approaches were effective, reducing spatial variance nearly 50% when evaluating spectral and CIELAB images of the Color Checker and a target of 100 paint drawdowns. Research is still ongoing to combine both approaches and to study the impact when printing.







Qualitative comparison of noise reduction techniques for paint drawdowns: Top– uncorrected, Center – Noise Ninja, and Bottom– HDR.

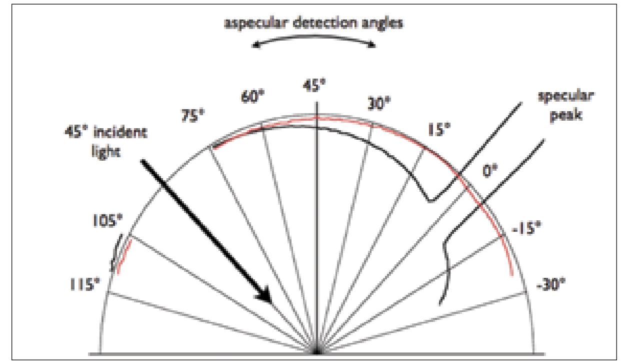
Effect of Scene Content on the Perceptibility of Differential Gloss

Differential gloss is the term used to describe the condition where areas of a printed image, especially adjacent areas, appear to reflect light in different ways giving these areas distinctly different gloss appearance. This phenomenon is quite common in dry toner electrophotographic imaging and some ink jet imaging technologies where the first surface reflection properties of the toner or ink and the substrate can be markedly different. Also, high density areas composed of multiple layers of toner can have substantially different specular reflection properties than low density areas composed of a sparse layer of toner through which areas of substrate remain visible. Differential gloss, while well known, is difficult to quantify in a meaningful way. One of the tasks undertaken by an international standards group involved with developing standards for office printers was to develop an image quality scale for the visual attribute of differential gloss. In an attempt to do this, Susan Farnand completed experiments using prints of three scenes made on equipment exhibiting a range of differential gloss behavior. The prints were visually scaled by observers in several locations across the United States. To make comparative objective measurements, prints of the patch target developed by the W1.1 Committee on Perceptual Measurement of Gloss were also made. However, the experimentation showed that the rankings made by the observers were scene dependent, indicating that the single number provided by measuring gloss differences on a patch target would be insufficient to describe the differential gloss perceived in complex images. Further experimentation was undertaken to examine the effect of scene content on the perceptibility of differential gloss. Two experiments were conducted in which observers were asked to judge the relative perceptibility of a variety of complex scenes using the triplet comparison method. The results of this study indicate that gloss differences are more perceptible when they are central to the scene, are separated by well-defined edges, and of a feature size something greater than about a half centimeter but less than about 10 centimeters. The experiment also provided evidence that the presence of a human face can increase the perceptibility of differential gloss.

Measurement Services of MCSL

MCSL maintains a state-of-the-art color measurement laboratory, both as a research facility and to support other research projects. Our instrumentation covers the typical color measurement needs, such as reflectance factor, gloss, spectral radiance, and more. Additionally, we can measure spectral reflectance factor as a function of incident and detection angles (goniospectrophotometry). The lab is also fortunate to have a large inventory of optical equipment, such as light sources, monochromators, and detectors that can be assembled into a wide range of customized measurement systems.

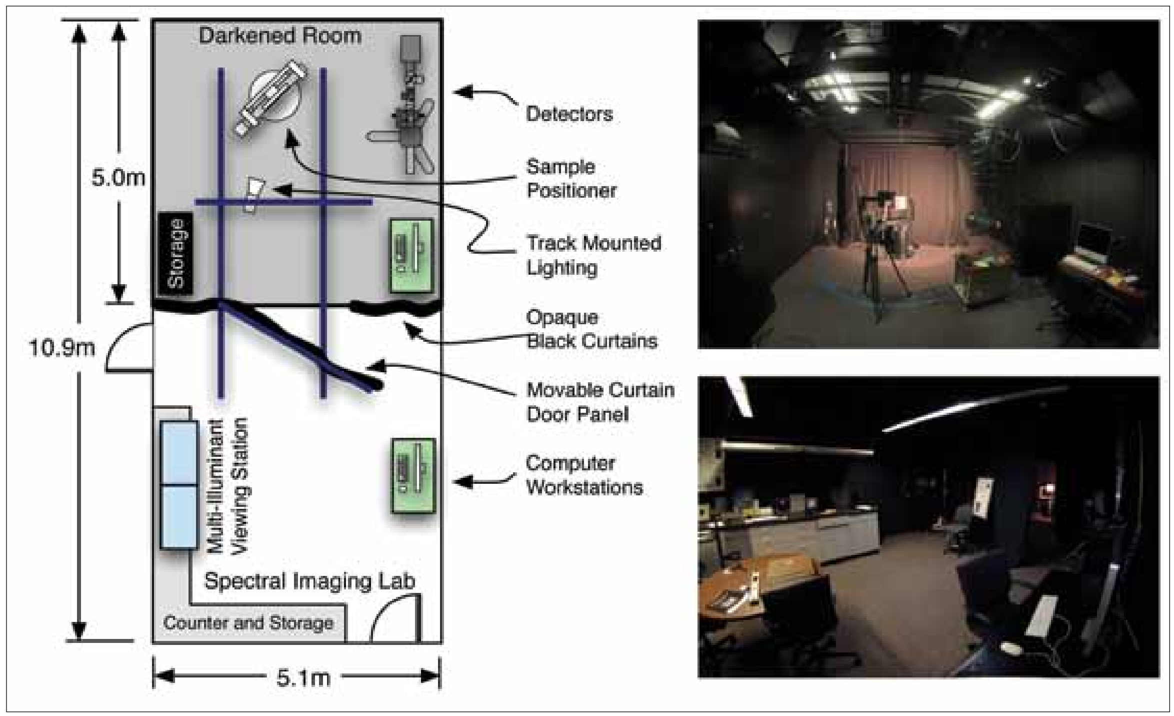
We also provide contract measurement services for external customers, an important funding source for maintaining our measurement capabilities. Such funding allows for periodic maintenance and service of instrumentation that might not be required for any specific research project. Additionally, these funds allow laboratory personnel to maintain a presence in the color measurement community. Dave Wyble, Staff Color Scientist, is responsible for the maintenance of the measurement facilities, performs the measurement services and keeps active in color measurement research.



Reflectance factor of Japanese opal (black line) and PTFE (red line) for 45° incident light, varying detection angle.

Imaging Goniospectrometer System

The Spectral Imaging Laboratory has been configured to accommodate the completed Imaging Goniospectrometer System. The system is made up of a computer controlled 3-axis positioner used to rotate the orientation of samples, ceiling track and floor mounted lighting, and a variety of detectors. The system is used to capture spectral images with the MCSL/Sinar multispectral camera, RGB images with a Canon 5D camera, and spectral radiance measurements with a Konica/Minolta CS-2000 spectroradiometer from different viewing and illumination angles. Data captured for a wide variety of artists materials are being used to build a BRDF database that will aid in building new parametric models of these materials appearance and improve the accuracy of computer graphics based renderings in novel lighting environment. This research will lead to the development of a practical imaging system for museum photographers to capture and more faithfully reproduce the experience of interactively viewing artwork. Research, supported by the Andrew W. Mellon Foundation, is being conducted by Professors Roy Berns and Jim Ferwerda, Scientist Lawrence Taplin, and students Benjamin Darling and Justin Ashbaugh.



Floor plan (left) of Spectral Imaging Laboratory showing division of room with opaque curtain wall into darkened half for Imaging Goniospectrometer and area for viewing reproductions under various types of illumination.

Benchmarking Art Image Interchange Cycles: Image Quality Experimentation

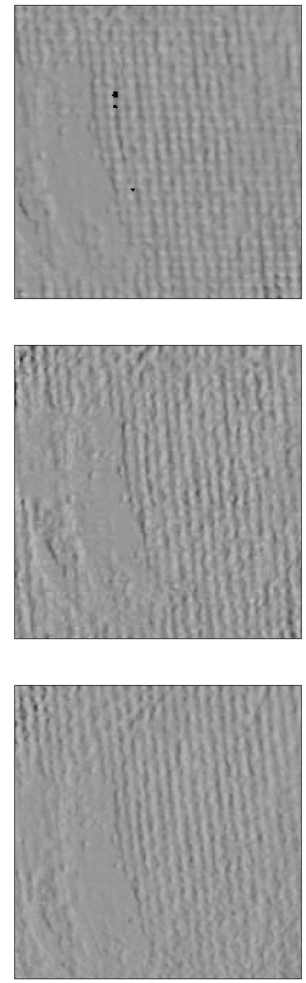
A project, supported by the Andrew W. Mellon Foundation, is currently underway to evaluate current practices in fine art image reproduction, determine the image quality generally achievable, and establish a suggested framework for art image interchange. Toward this end, the team of scientist Susan Farnand, Professor Franziska Frey, and students Jun Jiang, and Suyog Pradhan are conducting experiments in which a set of objective targets and pieces of artwork in various media are being imaged by participating museums. In the first part of this experiment, print files and guide prints were delivered to the Rochester Institute of Technology where prints were made and used as stimuli in psychometric testing to generate scales of image quality. The experimental results of this initial testing indicated that the ISO 12467 workflow generally resulted in reasonable reproductions, that the image content impacted the highest ranked reproduction, that viewing conditions impacted the rank order of the reproductions, and that the visual adjustments made to match guide prints on press generally yielded little benefit. Further testing is underway involving a larger number of institutions using a selection of the artwork and targets used in the first part of the experiment along with new watercolor and acrylic paintings and an additional test target. The results of this experiment will be among the inputs used to construct a conceptual framework of the various types of imaging taking place in cultural institutions at present. Based on this framework, an image processing tool that incorporates appearance models that are adequate for the various working environments in cultural heritage institutions will be developed. This project and its results will be presented at the Current Practices in Fine Art Reproduction symposium at RIT June 16-18, 2010. For details, please see **http://artimaging.rit.edu/**.

Helping Sony Make TV Viewing Better

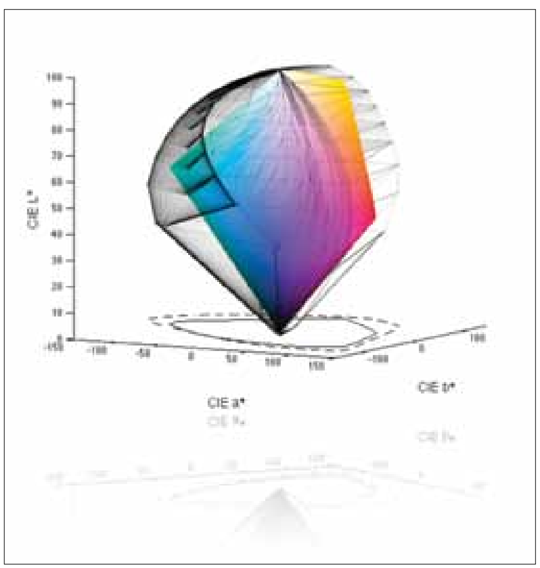
Rod Heckaman and Mark Fairchild, working with several students over the years completed a major 3-year collaboration with Sony. The project examined the use of new television technologies that allow for significantly wider color gamuts. The main thrust of the project was to examine how to enhance the colorfulness of legacy video content, encoded for smaller gamuts, such that viewers would both enjoy the experience and feel like they were getting the most out of their modern television technology. A large number of algorithms were tested and visual experiments completed. The results were published in several journal and conference papers and showed how viewers prefer only the most colorful image elements to be "enhanced." It was a wonderful experience working with Sony and we look forward to seeing our results incorporated in forthcoming televisions and other technologies.

Estimating Surface Normals Using a DLP Projector

Dr. Koichi Takase from Toppan Printing was a visiting scientist during 2009 performing 3D imaging research using the MCSL Imaging Goniospectrometer. Koichi was interested in comparing collimated tungsten light with light generated with a DLP projector when estimating surface normal maps using photometric stereo methods. If comparable, the DLP could alternately display structured and uniform light, enabling the characterization of an object's, shape, surface normal, and BRDF. The technique was most successful when the projector was defocused.



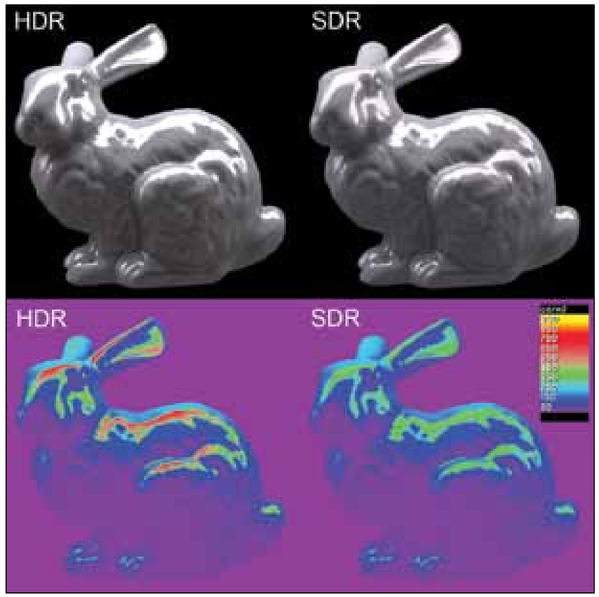
Estimated surface normals of a section of the lemon. Top: Tungsten light source. Middle: DLP projector in focus. Bottom: DLP projector out of focus.



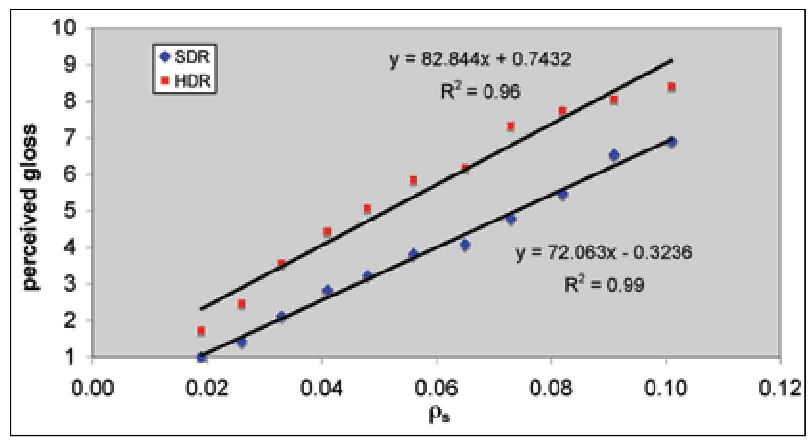
A three-dimensional plot of the gamut of MacAdam's optimal colors (wireframe) and the G0 gamut based on Evans' concept of brilliance and the boundary of zero gray content. These gamuts were used as guides in developing algorithms to expand image data into larger gamuts.

Effects of Dynamic Range on Apparent Surface Gloss

Jonathan Phillips (Color Science Ph.D. student), Stefan Luka (Color Science M.S. candidate) and Professor James Ferwerda have conducted a series of experiments to investigate the effects of image dynamic range on apparent surface gloss. Using a high dynamic range display, they presented high dynamic range (HDR) and standard dynamic range (tone mapped, SDR) renderings of glossy objects in pairs and asked subjects to choose the glossier object. They analyzed the results of the experiments using Thurstonian scaling, and derived common scales of perceived gloss for the objects depicted in both the HDR and SDR images. To investigate the effects of geometric complexity, they used both simple and complex objects. To investigate the effects of environmental illumination, we used both a simple area light source and a captured, real-world illumination map. Our findings are 1) that limiting image dynamic range does change the apparent gloss of surfaces depicted in the images, and that objects shown in SDR images are perceived to have lower gloss than objects shown in HDR images; 2) that gloss differences are less discriminable in SDR images than in HDR images; and 3) that surface geometry and environmental illumination modulate these effects.



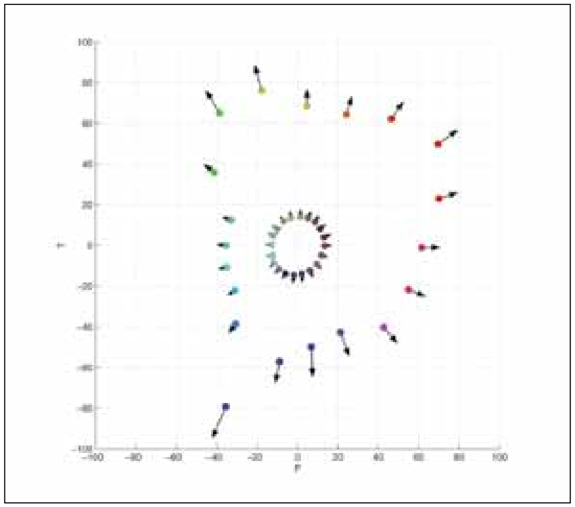
High dynamic range (HDR) and standard dynamic range (SDR) images of a bunny object. The image pair on the top looks similar in limited dynamic range prints, but would appear different on a high dynamic range display that could reproduce the full luminance range in the HDR image (see the false color image pair on the bottom).



Scaling results for bunny/Uffizi scene. ρ_s is the specular energy of the surface material. Perceived gloss increases with this specular energy, and the HDR images always appear glossier than the corresponding SDR images. This indicates a role for absolute reflection intensity in gloss perception, and raises issues with the fidelity of SDR representations of glossy surfaces.

New Chroma Difference Visual Dataset

Bingxin Hou, in partial fulfillment for her M.S. in Imaging Science, has performed a new color-difference experiment focusing on chroma differences. Owing to its excellent hue linearity, IPT was used as the reference color space. Twenty hues at two different chromas were sampled using the largest chroma achievable for an LCD. Fifty observers took part in the experiment where the neutral anchor pair had a CIELAB ΔE^*_{ab} of 2.24. The standard error was 4.3% in units of ΔE^*_{ab}, equivalent to a STRESS of about 4; this is the lowest uncertainty of any RIT color- difference experiment. These data have been combined with the RIT-DuPont, Qiao, et al., and Montag and Berns data forming a new dataset, RIT-Com. Preliminary formula development indicates that the chroma sensitivity function should be enlarged from 1 + 0.045C*ab to 1+ $0.06C^*_{ab}$.



T50 values plotted as vectors. The lengths increase with the color center's chroma. sRGB was used for color coding.

Lightness/Brightness Scaling and Differences

There is a long history of color difference and appearance scaling psychophysics at MCSL. This is currently being carried on by Ping Hsu (Jones) Chen in collaboration with Professors Mark Fairchild and Roy Berns. Jones is focusing on collecting very precise and accurate lightness difference data along the CIELAB L* axis to be used by Roy to improve color difference equations. His data will also extend to lightness values greater than L*=100, which are important for geometrically-complex materials, scene highlights, and illumination sources. Those data, together with some theoretical vision science, are being used by Mark to create a new CIELAB-like color space that will be capable of describing the appearance of high-dynamic-range scenes and images in a more meaningful way. Stay tuned for more!

This high-dynamic-range calibration scene illustrates the questions encountered in the scaling of lightness and lightness differences across complex viewing environments. For example, the black patch on the ColorChecker to the right has a luminance fifteen times higher than the white patch on the chart to the left. Local adaptation modeling perception of this scene handles this paradox. The directly-viewed lamp also illustrates the need for lightness scales with values exceeding diffuse white.

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