# *Program of Color Science / Munsell Color Science Laboratory*

## Annual Report 2015

# *DIRECTOR'S REFLECTIONS:* The Yin and The Yang

In Taoist traditions, yin and yang represent two halves that together make a whole. The concept stresses the importance of contrast in life and is well illustrated by many analogies. It has long fascinated me that these analogies move effortlessly into the realm of vision and color science. After all, our visual perceptions are nothing more than perceptions of contrast — yin compared with yang. In color science we only need to look so far as Hering's opponent-colors theory where light-dark, yellow-blue, and red-green are contrasted with each other to produce our full range of color perceptions. These concepts follow us today in the light-dark, reddish-greenish, and yellowish-bluish dimensions of modern mathematical color spaces such as CIELAB and CIECAM02. Other examples from color science can be found in lighting, colorant formulation, adaptation, visual physiology, measurement, and modeling. Ponder those and be challenged to think of others. We at PoCS/MCSL also find the yin and the yang in our academic activities where various trade-offs must be made such as facilities-budget, grants-research, students-resources, work-family, study-sleep, journal-conference, and the age-old time-time. We have all been working hard on those contrasts to create an optimal environment for color science education and research within the realities of our resources. We think we are coming close that optimal state, but will always perceive, and act upon, possibilities to improve. The state of our program and laboratory is very strong and we see a bright future. Please enjoy some details within this report. I most sincerely and deeply thank all of our supporters, both within RIT and externally, who have made this sustained success possible.

Some highlights of the past year include:

~ We admitted our four new graduate students from a very strong applicant pool.
~ Preliminary indications are that we will have a larger incoming class for Fall 2016.
~ We graduated 5 newly-minted Ph.D.s at the May, 2015 commencement ceremonies.
~ Dr. Michael Murdoch, formerly of Philips Research in Eindhoven and Eastman Kodak, joined our faculty in July 2015.
~ Dr. Shengyan Cai joined us as a Visiting Scholar from Tianjin University of Science and Technology in China.
~ Dr. Roy Berns hosted a wonderful MCSL alumni reunion in Los Gatos during a trip to California.
~ Many of our students exhibited a strange fascination with the mantis shrimp.
~ And we expect to continue building our faculty over the next 2-3 years.

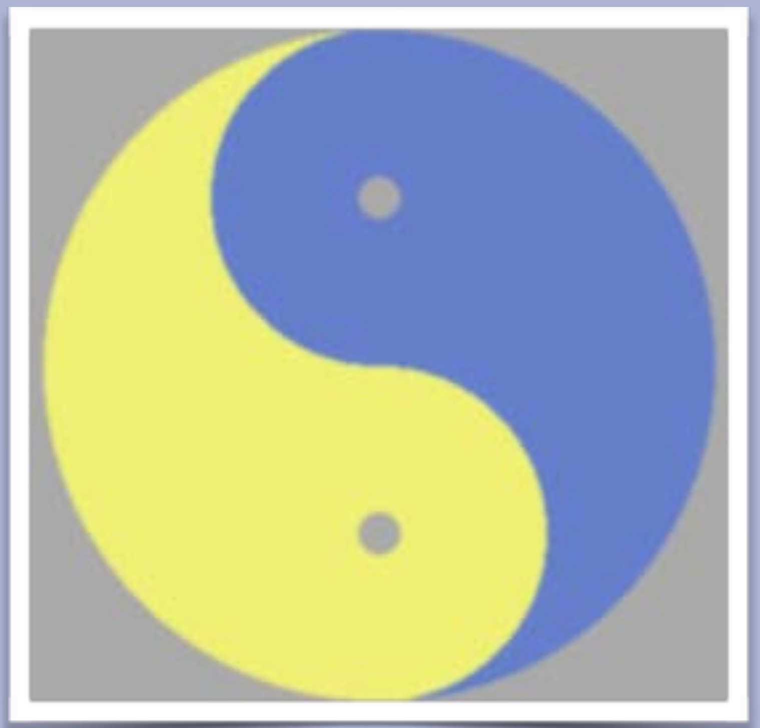
As always, we thank all those who have provided financial and in-kind support over the year including a special note of appreciation to Scot Fernandez of Hallmark, a 2003 alumnus of the lab, and current member of our Board of Counselors, who has personally supported our activities with donations each and every year since he graduated, 13 straight years. Thank you, Scot! I also appreciate the commitment of our PoCS/MCSL Board of Counselors: Ellen Carter, Scot Fernandez, Francisco Imai, Tom Lianza, M. Ronnier Luo, and Ricardo Motta.

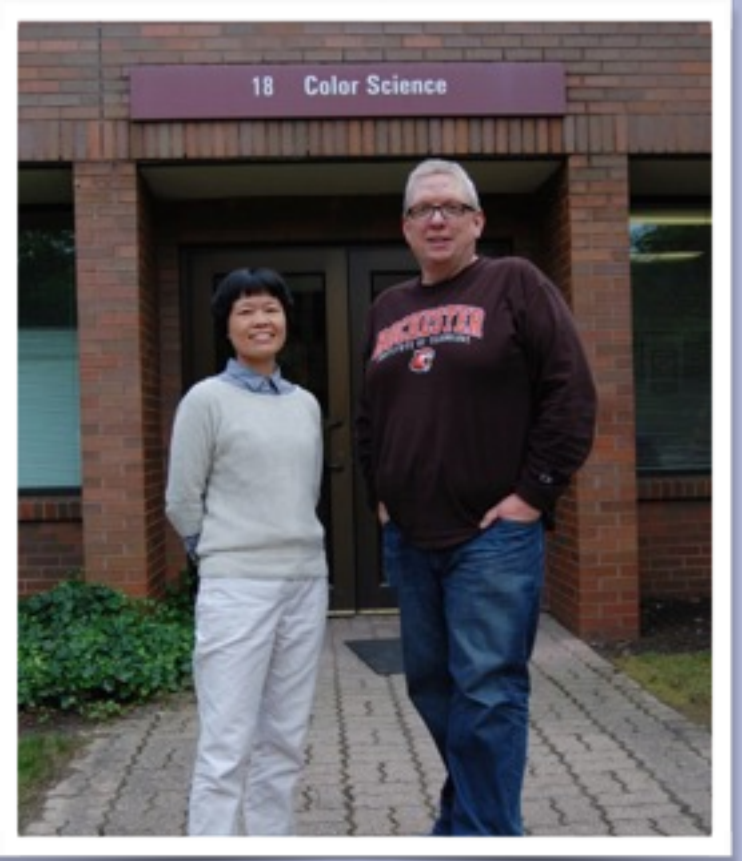
In this report you can find lists of our students and alumni, brief research highlights from ongoing projects, a list of publications over the last year, and a directory of our people. We have kept it brief and visual out of respect for you. There is much more information about PoCS/MCSL on our website and we invite you to explore <*mcsl.rit.edu*>.

Thank you to everyone who has supported the lab and our students in various ways over the years. Please enjoy this report and let me know if you have any comments, suggestions, or questions. Stay tuned for our continuing mission…

Sincerely,

Mark Fairchild
Associate Dean of Research and Graduate Education, College of Science
Professor and Director, Program of Color Science / Munsell Color Science Laboratory





# STUDENTS & ALUMNI

***Current Students***
Ben Bodner, PhD, CS
Katherine Carpenter, PhD, CS
Akshay Chandorkar MS, CS
Brittany Cox, PhD, CS
Nargess Hassani, PhD, CS
Morteza Maali Amiri, PhD, CS
Ashley Penna, MS, IS
Gaurav Sheth, PhD, CS
Chris Thorstenson, PhD, CS
Yixuan Wang, PhD, CS
Joel Witwer, MS, CS

***Alumni***

2015
Yuta Asano, PhD, CS
Maxim Derhak, PhD, CS
Jennifer Kruschwitz, PhD, CS
David Long, PhD, CS

2014
Farhad Abed, PhD, CS
Stephen Dolph, MS, IS
Adria Fores Herranz, PhD, CS

2013
Justin Ashbaugh, MS, CS
Lin Chen, MS, CS
Benjamin Darling, PhD, CS
Susan Farnand, PhD, CS
Jun (Chris) Jiang, PhD, CS

2012
Ping-Hsu (Jones) Chen, MS, CS
Simon Muehlemann, MS, PM

2011
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
Joseph Slomka, 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 Suorsa, 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 Johnson, 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

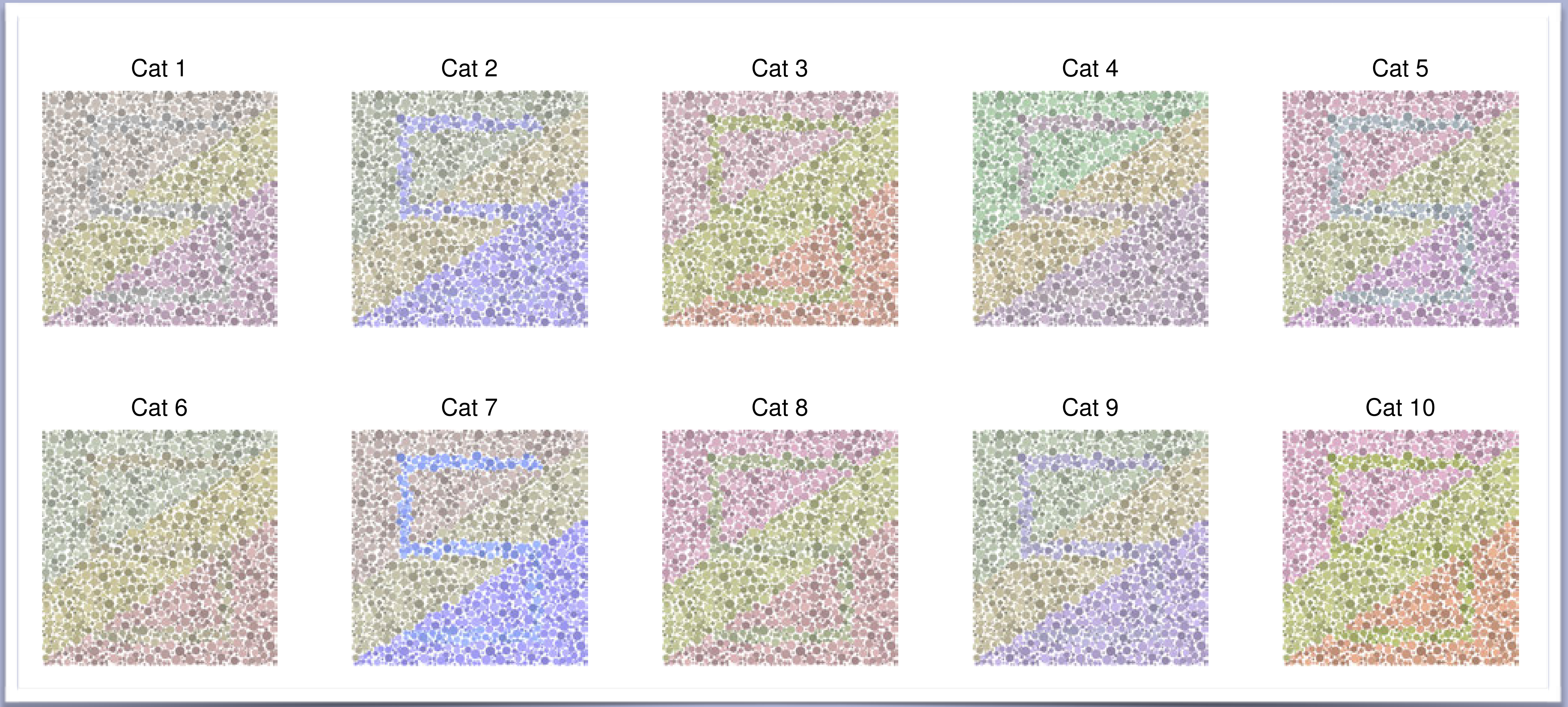

1989
Mitch Miller, MS, IS
Kelvin Peterson, MS, IS
Lisa Reniff, MS, CS

1987
Denis Daoust, MS, IS
Wayne Farrell, MS, IS

1986
Mark Fairchild, MS, IS

*Key:*
CS: Color Science
IE: Industrial Engineering
IS: Imaging Science
MS: Master of Science
PhD: Doctor of Philosophy
PM: Print Media

# *RESEARCH HIGHLIGHT:* A Simple Vision Test for Categorical Observers



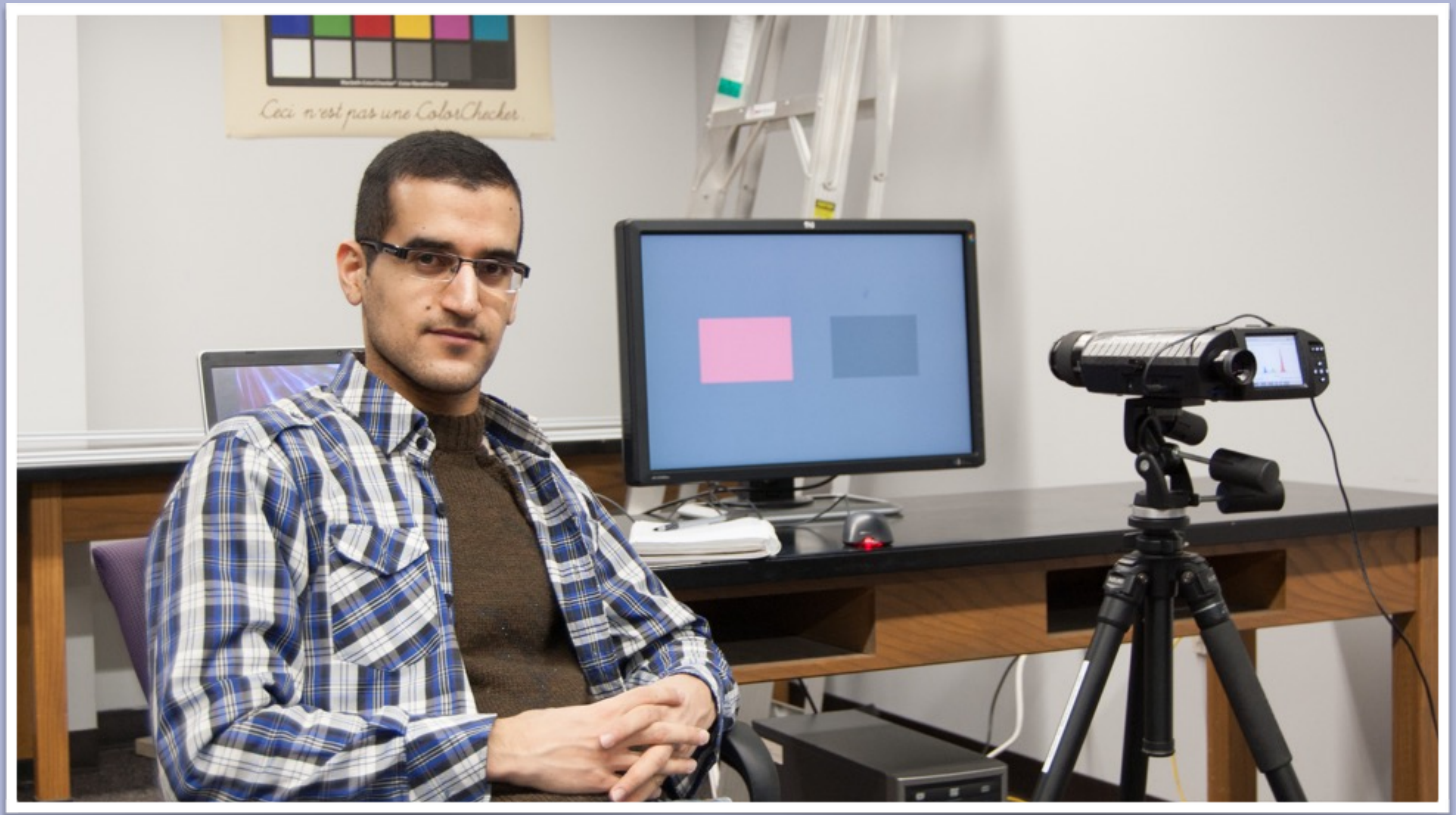

Individual variations in color matching functions (essentially individual differences in color vision) have been a hot research topic in the lab in recent years. Yuta Asano completed his Ph.D. dissertation on the measurement and modeling of such differences. Along the way, he completed a statistical cluster analysis of a large population of simulated human observers and derived ten clusters, or categories, that well described the population. Realizing that these ten categories described ten different color vision systems, he thought it might be possible to build the equivalent of pseudoisochromatic plates to sort observers into their category. Although a spectrally addressable printer is required, this simulation shows a plate where the number 5 is fully visible to observers in category 5, but not to other observers. Note all have "normal" color vision.

*Yuta Asano, Mark Fairchild*

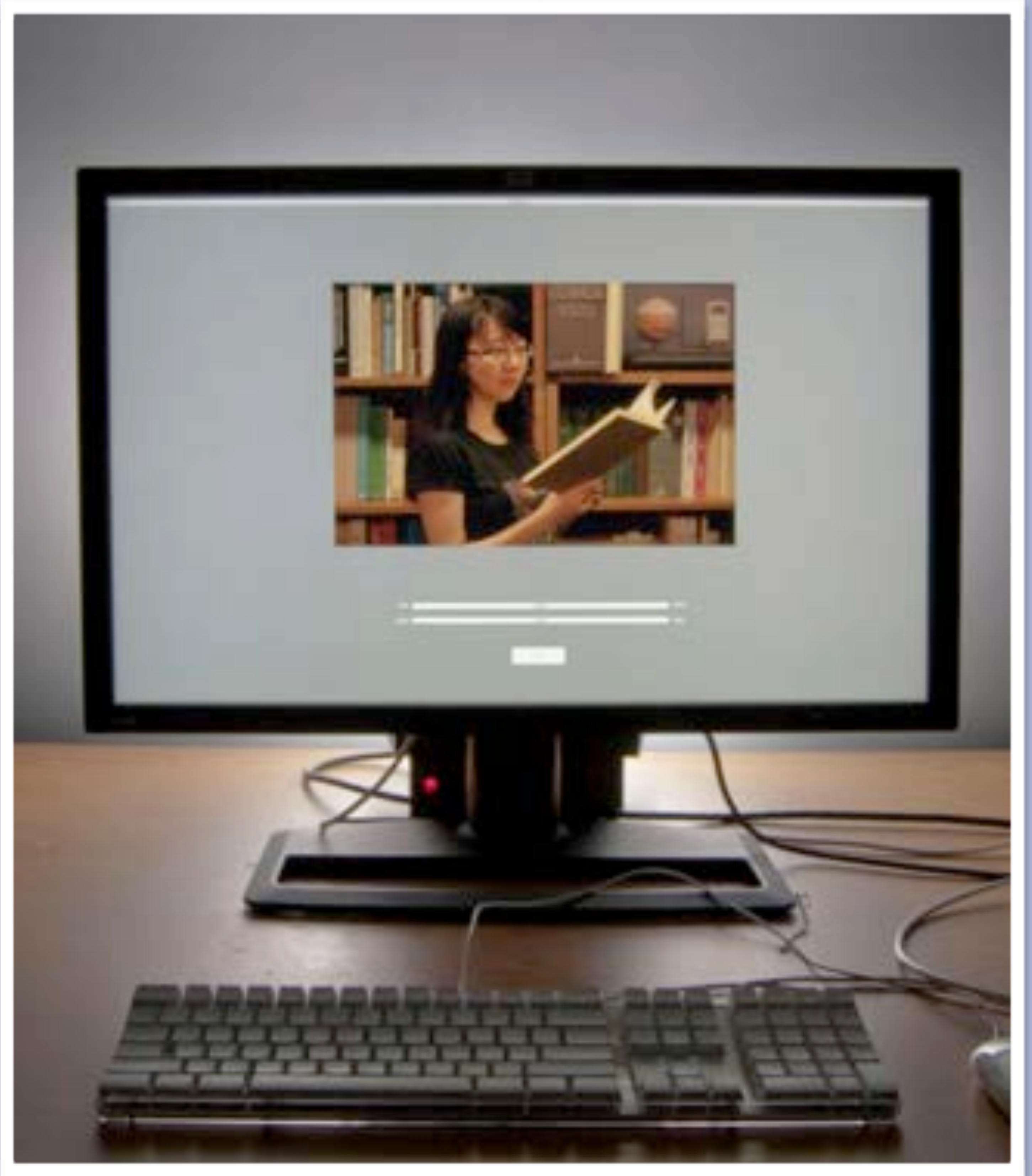
# *RESEARCH HIGHLIGHT:* Scaling Temporal Color Differences

Making first steps in a new research area for MCSL, initial experiments were designed to measure visual sensitivity to temporal color differences, meaning colors changing over time. A pilot experiment was conducted using a display, showing that observers were able to reliably scale the speed of a chromatic patch changing in hue against an achromatic patch changing in lightness. Experiments using both displays and LED lights will continue into 2016, the results of which will help inform the design of dynamic lighting systems and more.

*Morteza Maali Amiri, Michael J. Murdoch*



# *RESEARCH HIGHLIGHT:* Effect of Capture Illumination on Preferred White Point



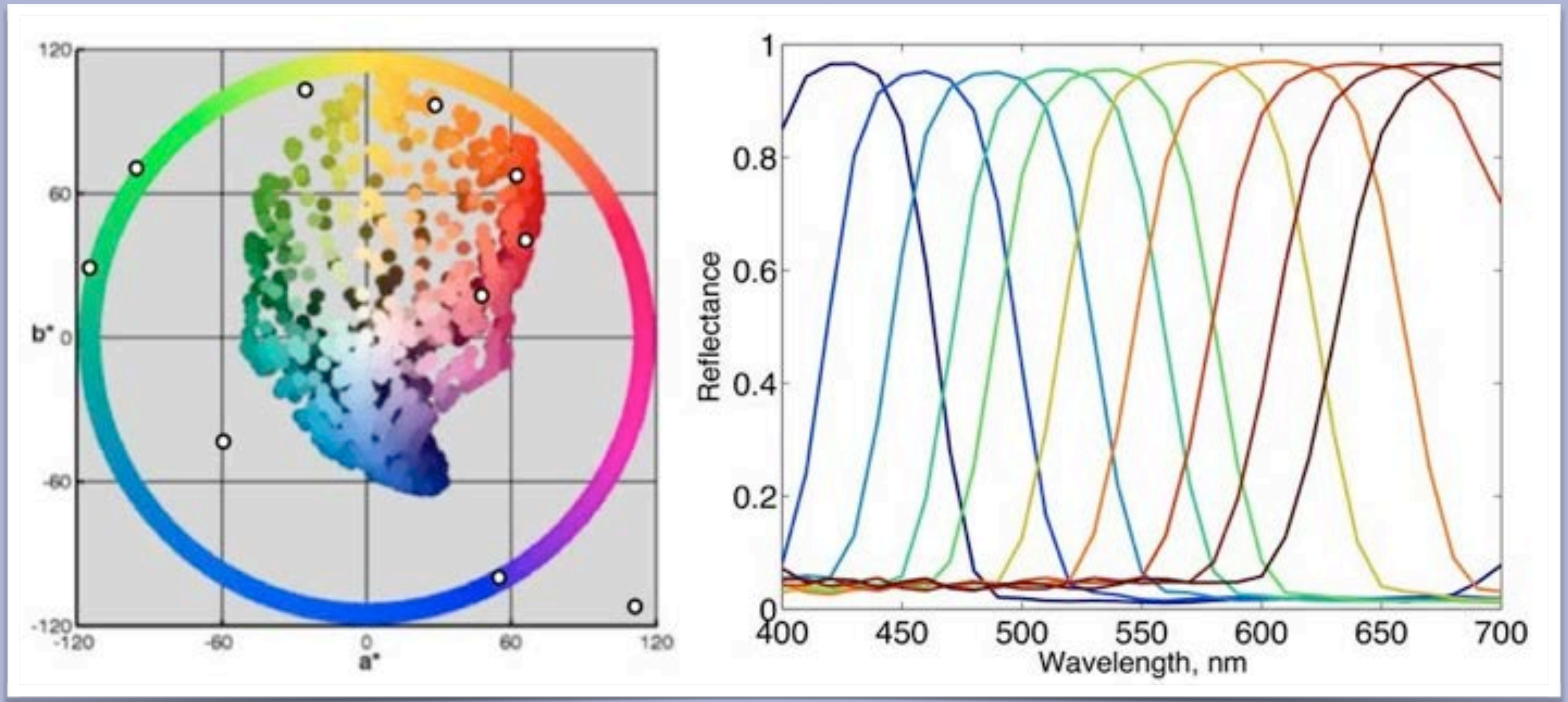
Cell phone camera manufacturers use a variety of illuminant estimation methods to automatically white balance images, which potentially produce visibly different results. This study was undertaken to estimate the aim white point for various capture light sources. Five scenes were captured under eight light sources. A Method of Adjustment experiment in which observers were asked to adjust the redness-greenness and yellowness-blueness was conducted to determine the average preferred white-point and variation in preference between observers. The results indicate that preferred white balance reflects the incomplete nature of chromatic adaptation in human vision. Preferred white balance had a direct dependency on the color of scene illumination even with no obvious cues. The variation between observers was considerable, possibly due to the relatively small number (20) of observers. Future experiments are planned that will involve a larger pool of observers. Also planned is a paired comparison experiment, using images white balanced within the range determined in the first experiment, in which observers will be asked to select the image that looks more natural. It is expected that the perception of what is natural will be more consistent than the perception of what is optimally balanced, and that most people will agree that images that look natural have a reasonable appearance.

*Ben Bodner, Yixuan Wang, Susan Farnand*

# *RESEARCH HIGHLIGHT:* Specialized Color Targets for Reflectance Reconstruction

The left figure is a CIELAB plot projected onto the a*b* plane. The outside circle represents chroma of 100, and the inside colored points represent the color gamut of typical varnished artist paints. The ten white circles symbolize the ten color block mirror (or narrow notch mirror) whose reflectance spectra are plotted on the right hand figure. Each spectral corresponds to an optical interference coating that combines both metal and dielectric layers in its design. These ten color block mirrors can be used to create the ideal color target for imaging systems.

*Jennifer D.T. Kruschwitz, Roy S. Berns*



# *RESEARCH HIGHLIGHT:* Validating Observer Metamerism Models

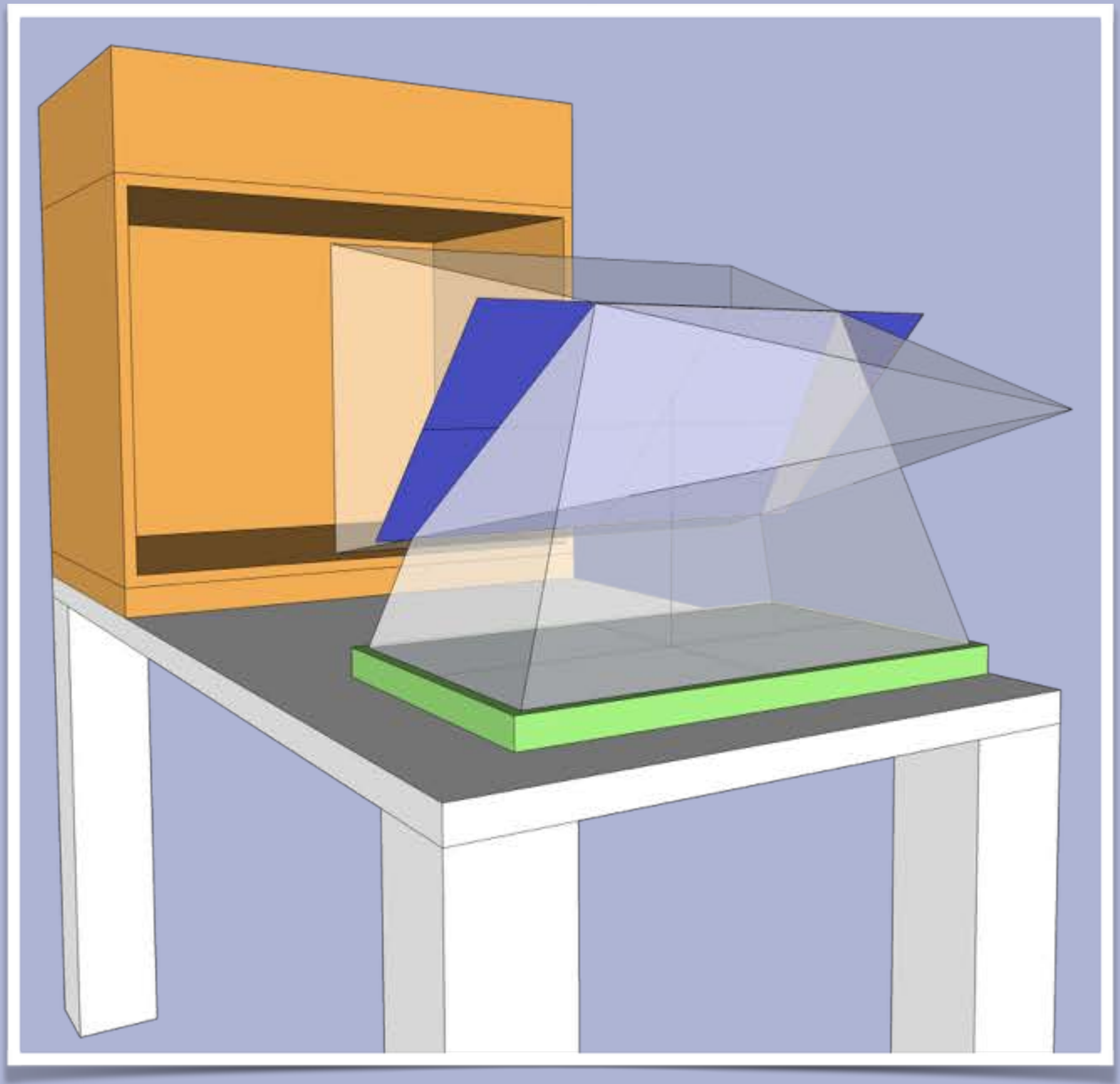
We have confirmed models of observer metamerism derived from the work of former MCSL student, Abjhit Sarkar, and collaborators are predictive of observer preference for color matching in mixed-spectra forced-choice comparisons. Experiments also revealed that concerns of observer color-matching variability induced from emerging television and cinema color gamut standards are significant. New systems based on 3-channel monochromatic color primaries serve to exacerbate differences in color perception amongst color-normal observers. Systems designed under these definitions are likely to deliver greatly exaggerated inconsistency of experience amongst cinema audiences. To correct for this concern, an intentionally engineered multiprimary display encompassing deliberate primary spectral design was proven through observer studies to enhance available color gamut and minimize observer metamerism in an optimized multispectral color management scheme. These techniques will enable film and television producers to generate enhanced ranges and saturation of reproduced colors with maximum consistency of perception.

*David Long, Mark Fairchild*

# *RESEARCH HIGHLIGHT:* Color and Material Appearance in Mixed Reality

A literature review and system simulations have kicked off a new study of the perception of color and material appearance in mixed reality. Mixed or augmented reality, in which a head-mounted or other display overlays synthetic images on a viewer's ordinary view of the world, offers immense potential for entertainment, design, education, commerce, and more. As new technologies enable more possibilities, many questions arise about visual perception and adaptation in mixed reality. This research project has begun by surveying what is already known in this field and by building a spectral model of the physical overlay of images on a background, identifying important system parameters. A simulation device involving a half-mirror and a high-resolution display has been designed for initial experiments.

*Nargess Hassani, Michael J. Murdoch*



# *RESEARCH HIGHLIGHT:* Enhancing Art Appreciation using Gaze Guidance

Many people experience difficulty in understanding and relating to artwork. They assume that the artwork should speak to them, and are frustrated when they find that it does not. They assume that the only way to understand the art piece is to learn a great deal of tedious detail about its history and the artist. Absence of interest and the inability to appreciate the arts cut people off from cultural heritage treasures and the inspiration and self-knowledge that they offer.

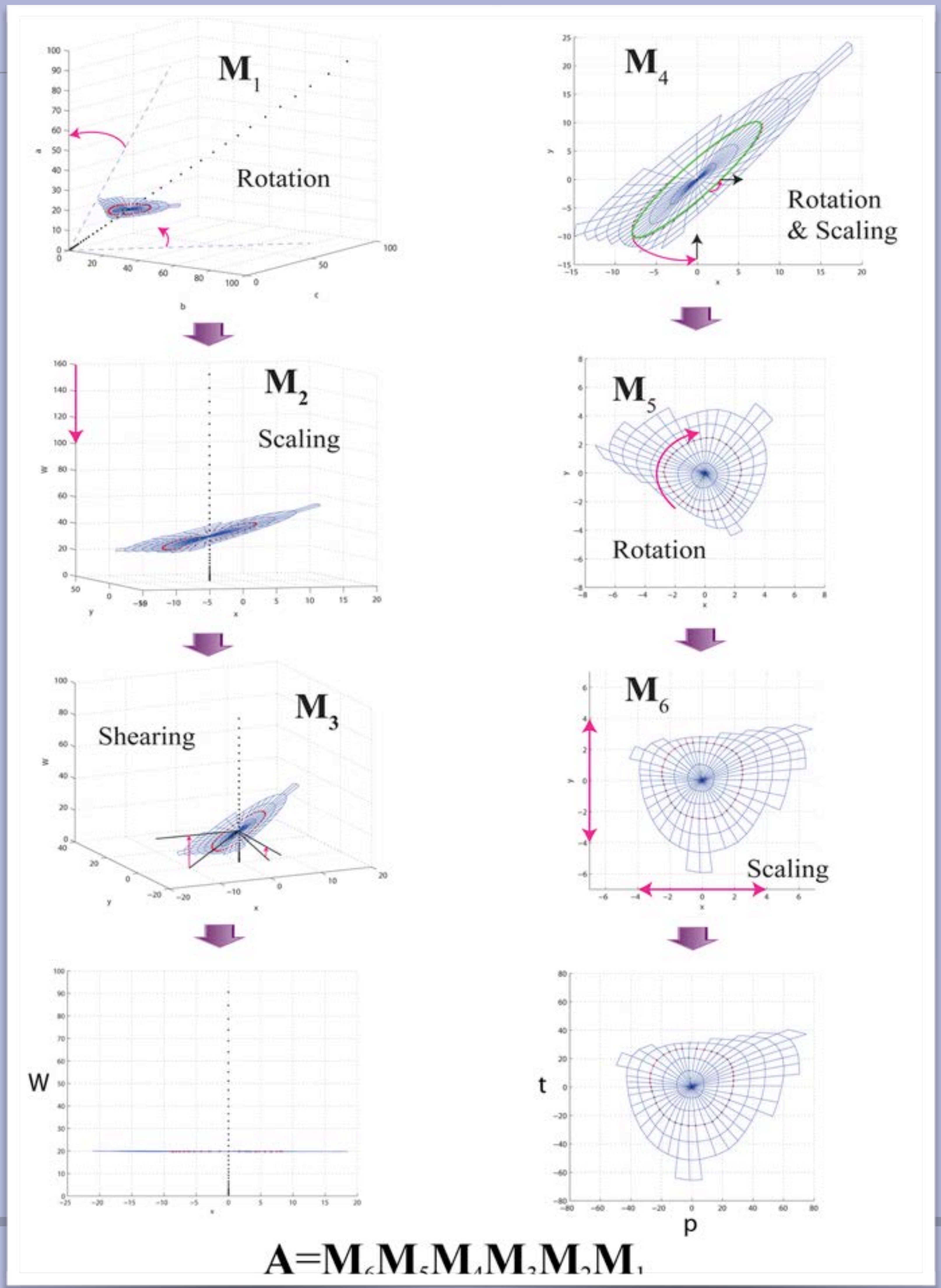
Tools for facilitating art appreciation for a larger community are needed to address this problem. Toward this end, a project was initiated to identify viewing behavior characteristics fundamental for understanding and appreciating artwork and using this knowledge to develop viewing guidance technology to enhance the aesthetic experience of museum visitors. One initial experiment conducted for this project was to evaluate the effect of task on gaze patterns when looking at art images. In this eye-tracking experiment, conducted by Imaging Science high school interns, Jason Menezes and John Wikiera, the observers were divided into two groups, one that was told that they would be describing the images following the experiment and one that was asked to simply look at the images. The results indicated that the group receiving more instruction spent more time viewing images and taking a survey about them than the group who free-viewed the images. This group also rated the images higher, possibly indicating an increased appreciation of the artwork.

*Elena Fedorovskaya, Susan Farnand*

# *RESEARCH HIGHLIGHT:* Spectrally Based Material Color Equivalency

This research represents an alternative way of defining color measurement that has well defined relationships with existing colorimetry. A transformation from sensor excitations is defined using a series of linear geometric transformations (depicted in figure) to minimize differences between observer and illuminant conditions resulting in a color coordinate system (Wpt or "waypoint") that provides a material color equivalency representation. A Material Adjustment Transform (MAT) can be formed using a pair of Wpt normalization matrices to predict material color in similar fashion to a Chromatic Adaptation Transform (CAT) that predicts corresponding color. Wpt coordinates can be converted to uniform WLab coordinates with differences that are not statistically different from ΔE00. WLab variations of object/observer/illuminant allow for various metrics of color comparisons to be established. Lastly, spectral reflectance estimation and manipulation is made possible using a linear relationship between Wpt and spectral reflectance. This freely available dissertation can be found at (http://scholarworks.rit.edu/theses/8789/).

*Maxim Derhak, Roy S. Berns*



# *RESEARCH HIGHLIGHT:* Increased Precision Corresponding-Colors Experiments

It is entirely feasible that individual color matching functions could be used in conjunction with individual chromatic adaptation transforms to produce substantially better models of color appearance. While we can now measure individual color matching functions quite easily, there are no data available with the precision required to assess individual differences in chromatic adaptation, and therefore corresponding colors. Shengyan Cai, a visiting scholar in the lab, and Mark are designing and running an experiment aimed at obtaining corresponding-colors data with precision an order of magnitude better than previously reported. Preliminary results are very promising.

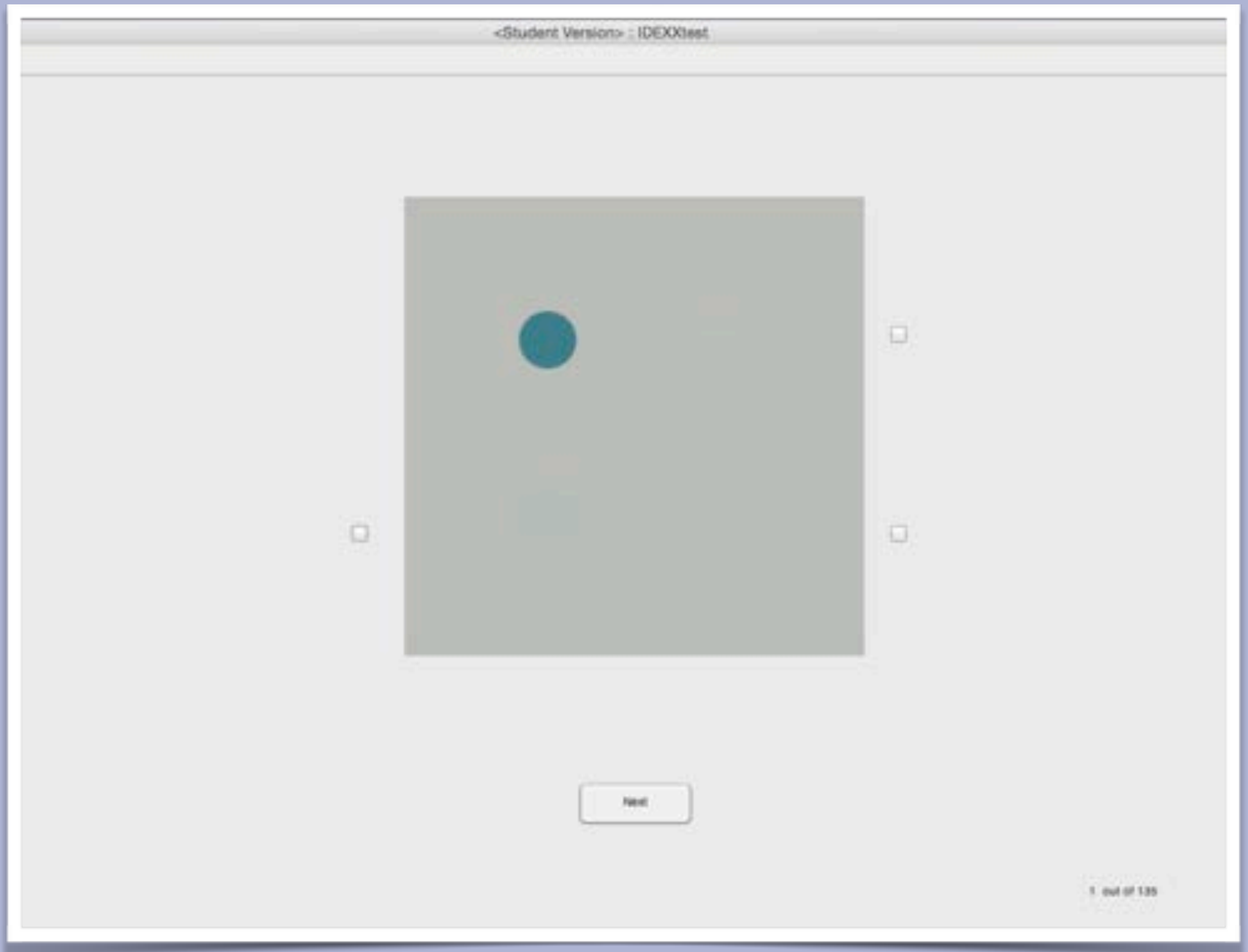
*Shengyan Cai, Mark Fairchild*

# *RESEARCH HIGHLIGHT:* MCSL ColorLights Installation

Adding some color to the MCSL environment in celebration of the "International Year of Light," a dynamic LED light installation was built in the window between the Color Hall hallway and the "blue room." Controlled by a network-connected Raspberry Pi computer, 360 RGB LED elements light up the window and provide an eye-catching, ever-changing light show. Not just for entertainment, the moving blocks of color exhibit how additive color works as they cross over each other and add in different combinations. Passers-by often comment positively on the installation, and some stop to watch. With the hardware in place, future interactive demos and student projects will enable a variety of visual and interactive effects. Come by and take a look!

*Michael J. Murdoch*

# *RESEARCH HIGHLIGHT:* Color Discrimination Veterinary Test Devices




Idexx Laboratories produces disposable indicator devices, similar to human pregnancy tests, for veterinary testing. These devices have a result window that includes three indicator spots and a reference spot. Idexx developed an instrument that automatically interprets the results of these devices, however, the measured results do not consistently match the visual results. Experiments were conducted to determine the visual threshold of a positive spot for this device. The test images in the experiments, conducted on a Dell UltraSharp 24 Ultra HD Monitor and on the Idexx device, the comprised four spot spaces, Figure X. The reference spot, upper left corner, was always present. The twenty observers participating in the experiment were asked to detect test spots having six color difference levels relative to the background. The results yielded an average spot perceptibility threshold of 1.27 (DE00), which was a higher than expected from past results. The analyses were done assuming that the location and number of test spots present do not impact their detectability. Further analysis showed that, while the effect of location was negligible, the number of spots present in the test image might affect detectability.

In completed phase of the study, the detectability threshold was determined for smooth circular spots on noise-free backgrounds. In the next phase of this research, the threshold for more realistic non-circular spots on non-uniform backgrounds will be determined.

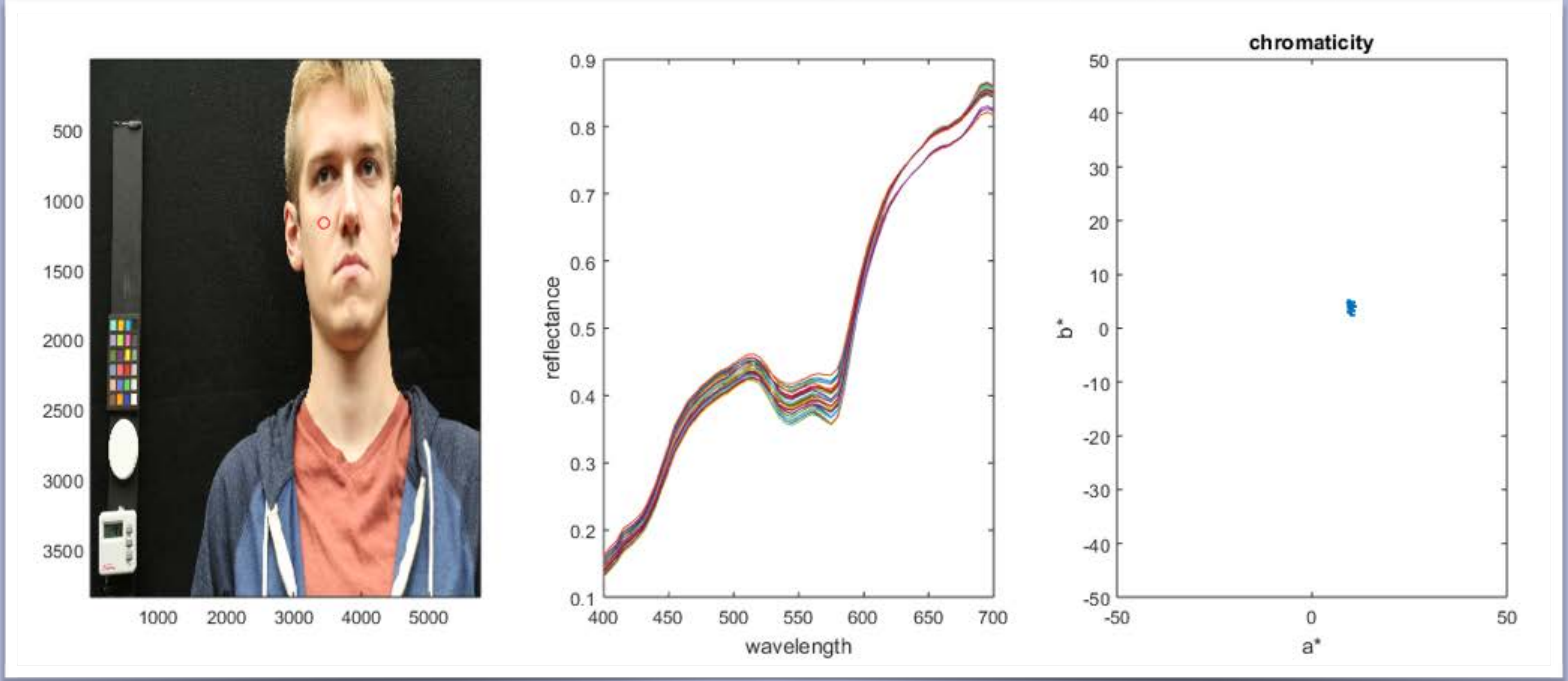
*Nargess Hassani, Susan Farnand*

# *RESEARCH HIGHLIGHT:* Imaging Artwork for Computer Graphics Rendering

The Dual-RGB and Four Lights Simplified techniques were used to image Vincent van Gogh's The Bedroom at the Art Institute of Chicago (ARTIC), resulting in spectral and colorimetric diffuse images and a surface normal image. The diffuse image was altered to visualize the painting's possible appearance when executed by Van Gogh. (It is well documented that the bluish red lake pigments among were highly susceptible to light fading.) The two diffuse images and the surface normal map were used to generate renderings of the painting with mostly diffuse lighting that still accentuated some texture, using commercial rendering software. Visualization credit: Roy S. Berns and Brittany D. Cox (Rochester Institute of Technology); Kelly Keegan and Inge Fiedler (The Art Institute of Chicago); Federica Pozzi (Guggenheim Museum); Maarten van Bommel (Netherlands Institute for Cultural Heritage).

*Brittany D. Cox, Roy S. Berns*

# *RESEARCH HIGHLIGHT:* Remote Estimation of Skin Reflectance




Skin spectral reflectance, and color, are useful indicators of psychological and physiological processes. However, the accurate measurement of spectral reflectance typically requires specialized hardware. The current project aims to estimate skin spectral reflectance, color, and physiological parameters using a commercial off-the-shelf digital camera and temporal change in these parameters through video capture.

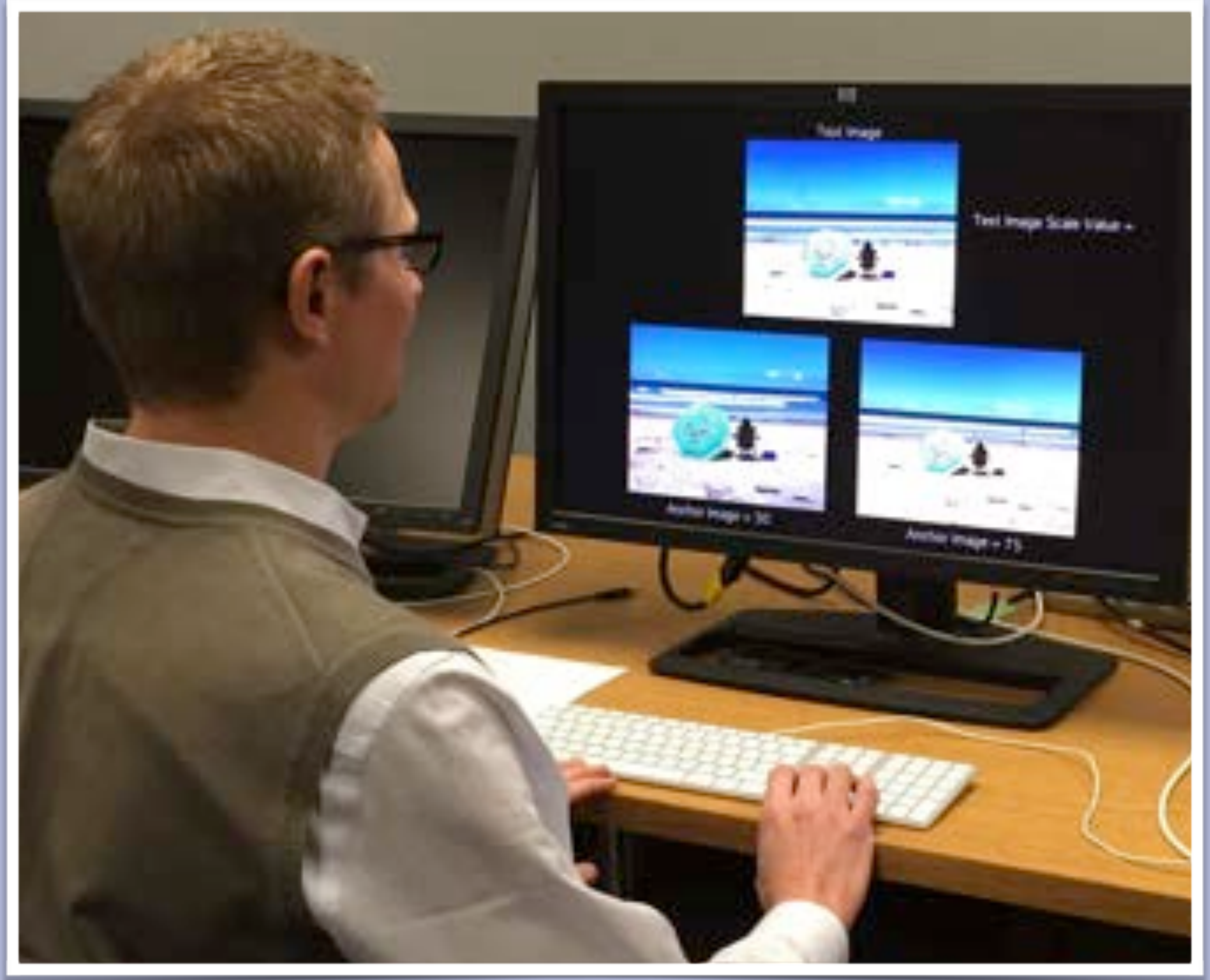
*Chris Thorstenson, Mark Fairchild*

# *RESEARCH HIGHLIGHT:* Perceptual Image Quality Assessment of Smartphone Cameras

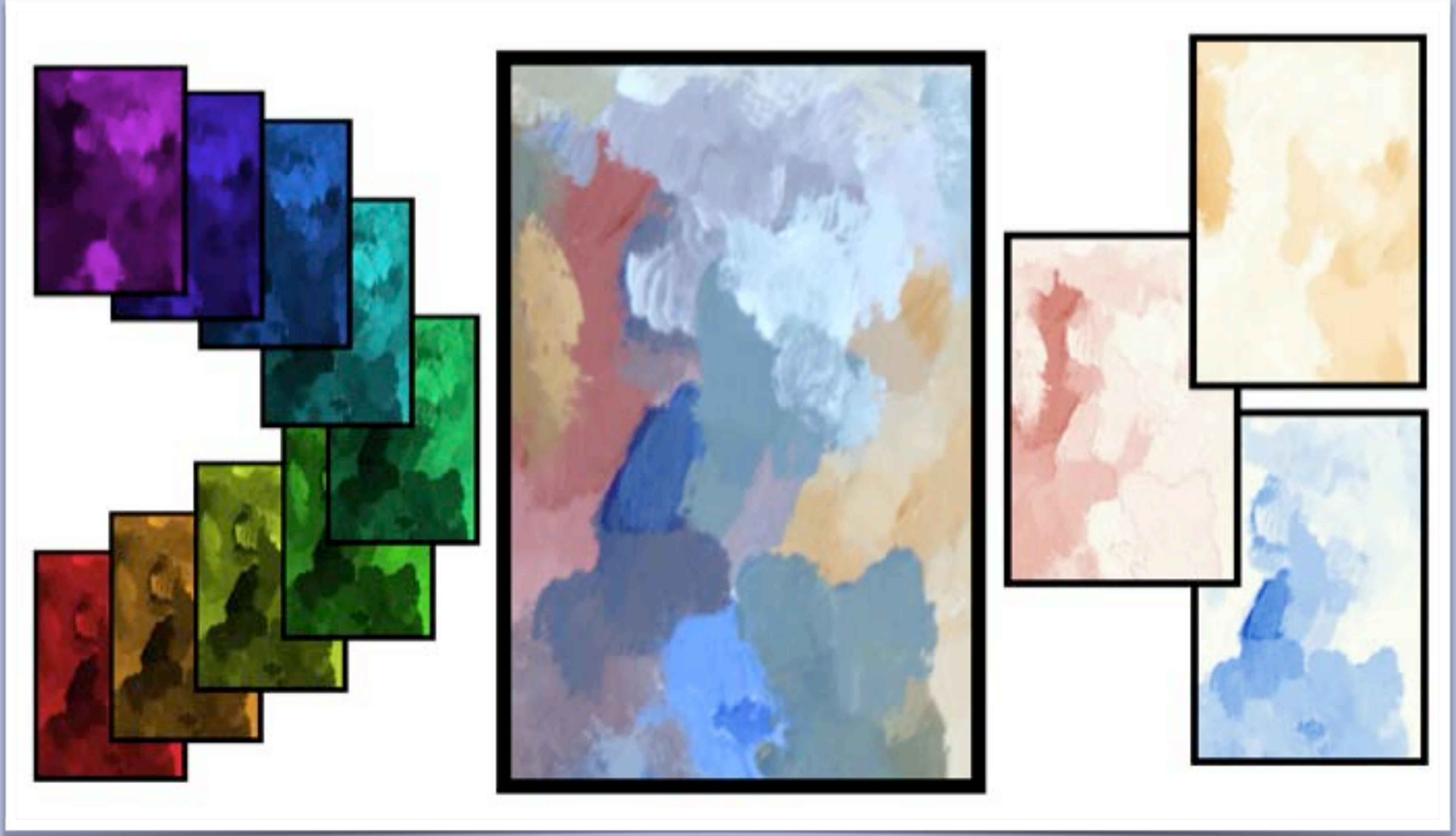
Having a methodology for assessing smartphone camera image quality is advantageous for both those who design and develop cameras and those who use them. Camera engineers need to quickly and reliably assess the impact of the system decisions they make. Smartphone customers who have access to quantitative image quality information can make more informed decisions between products. The objective of this research project was to develop a procedure for evaluating pictorial image quality for smartphone camera. The image characteristics evaluated included tone, color, sharpness and uniformity. In each test, observers rated the test images for overall quality and then for a specific image quality characteristic using an anchored scaling experimental protocol.

The results indicated high correlations between the individual characteristics and overall quality and between visual results and objective measurements for sharpness and image uniformity. The analyses also indicated that a two-step process in which devices are first sorted into categories of higher and lower quality then further sorted within these categories may be advantageous for predicting perceptual quality.

*Susan Farnand*



# *RESEARCH HIGHLIGHT:* Estimating Paint Concentrations using iccMAX



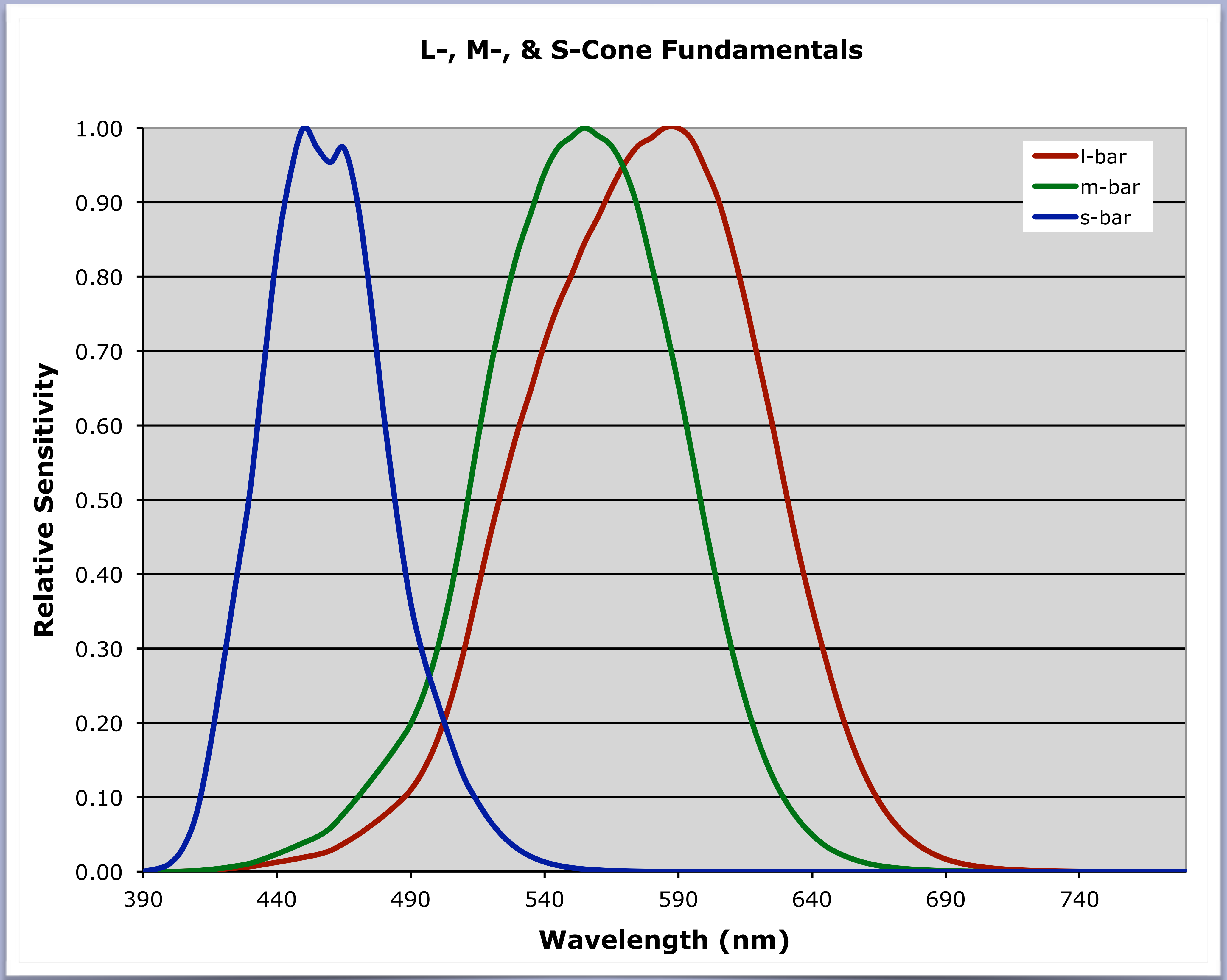
Color profiles in the new iccMAX color management system can include complex linear operations that convert image data between spectral, colorimetric, and material spaces. This research focuses on implementing iccMAX in a spectral imaging workflow designed for artwork. iccMAX profiles will be programmed to calculate the concentrations of component paints from spectral images of paintings using Kubelka-Munk theory. Artists and archivists could use these tools with any iccMAX compatible software to analyze the colorant makeup of artwork. These profiles could also be used to digitally encode paintings as concentration images, allowing for accurate reconstruction of spectral images without storing spectral data. The image shows a painting (center) broken down into spectral components (left) and paint components (right).

*Ben Bodner, Roy S. Berns*

# *RESEARCH HIGHLIGHT:* Computational Analysis of Individualized CATs

Mark has been working on a computational project to simulate multiple observer color matching functions using the CIE 2006 model and their impact on predicted corresponding colors using a simple von Kries model. The results suggest that it is indeed possible to obtain corresponding colors data with the precision necessary to distinguish the effects of small changes in color matching functions. These results will be used to guide future corresponding colors experiments and the development of improved chromatic adaptation and color appearance models. The accompanying plot shows the interesting color matching functions predicted for a one-degree field size and an 80 year old observer.

*Mark Fairchild*



# *RESEARCH HIGHLIGHT:* Evaluating Perceived Differences in Printed Patterns

In order to maintain, control, and enhance printed pattern quality, it is essential to understand which differences in the patterns are important to the overall perceived print pattern similarity. Since people are the ultimate judges of quality, the most accurate way to assess print quality is using subjective evaluation. In this study, an anchored scaling evaluation method was used to evaluate the visual difference in printed patterns and compare these perceived differences to physically measurable differences.

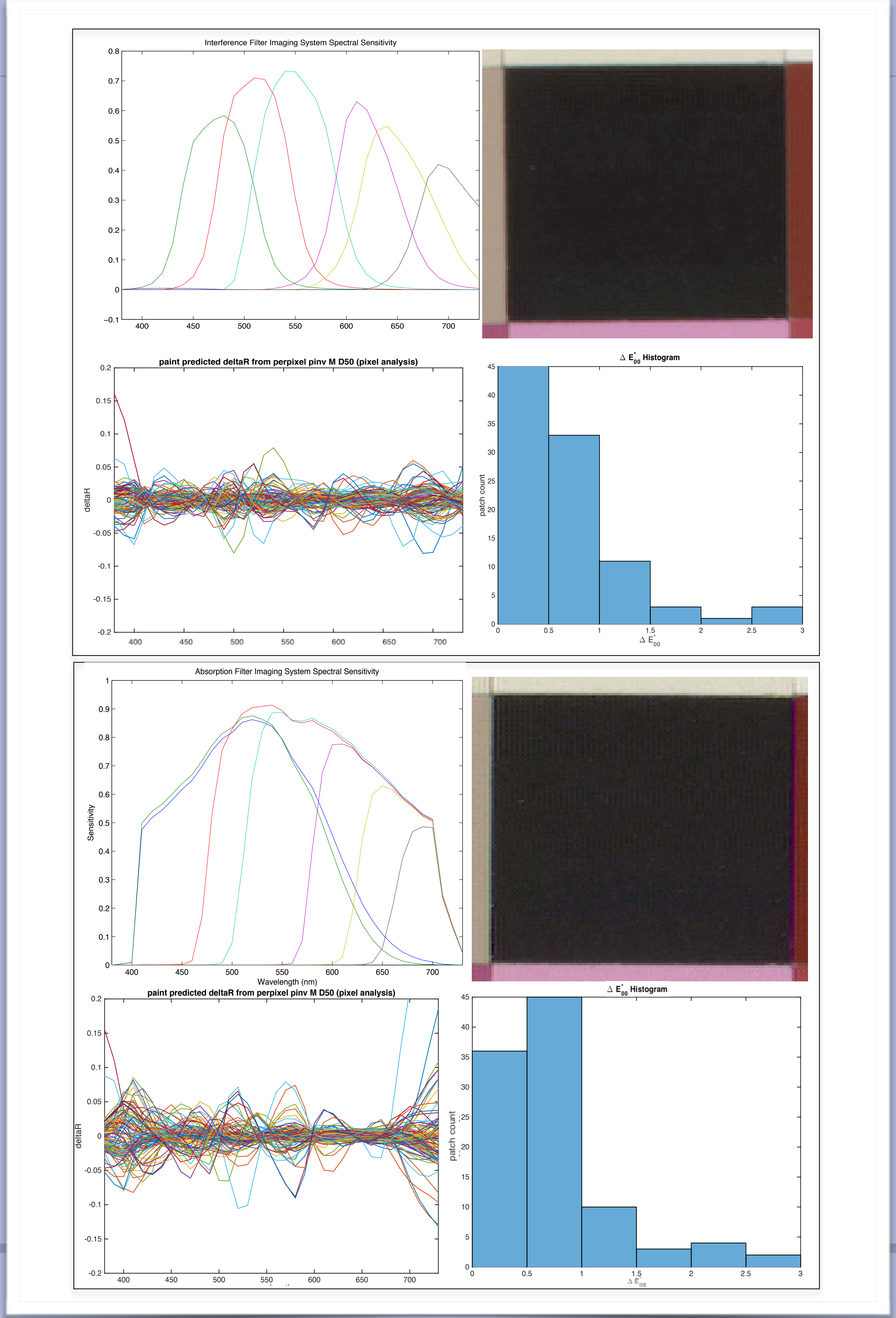
In the experiment, two pairs of print patterns were selected as the anchor pairs. One pair perceived as being similar in a pilot study was designated as the high quality pair and was given an arbitrary rating of 80. Another pair having clearly visible differences in their printed patterns was considered a poor quality pair and was given a rating of 35. Each of 25 participating observers were requested to rate the 64 test pairs relative to the two anchor pairs in terms of their visible differences. The results indicate that the most noticeable differences between print pattern pairs were global characteristics, such as color uniformity, rather than image details. Work continues on relating the perceived differences to physically measurable differences.

*Ritu Bassnet, Susan Farnand, Jeff Pelz*

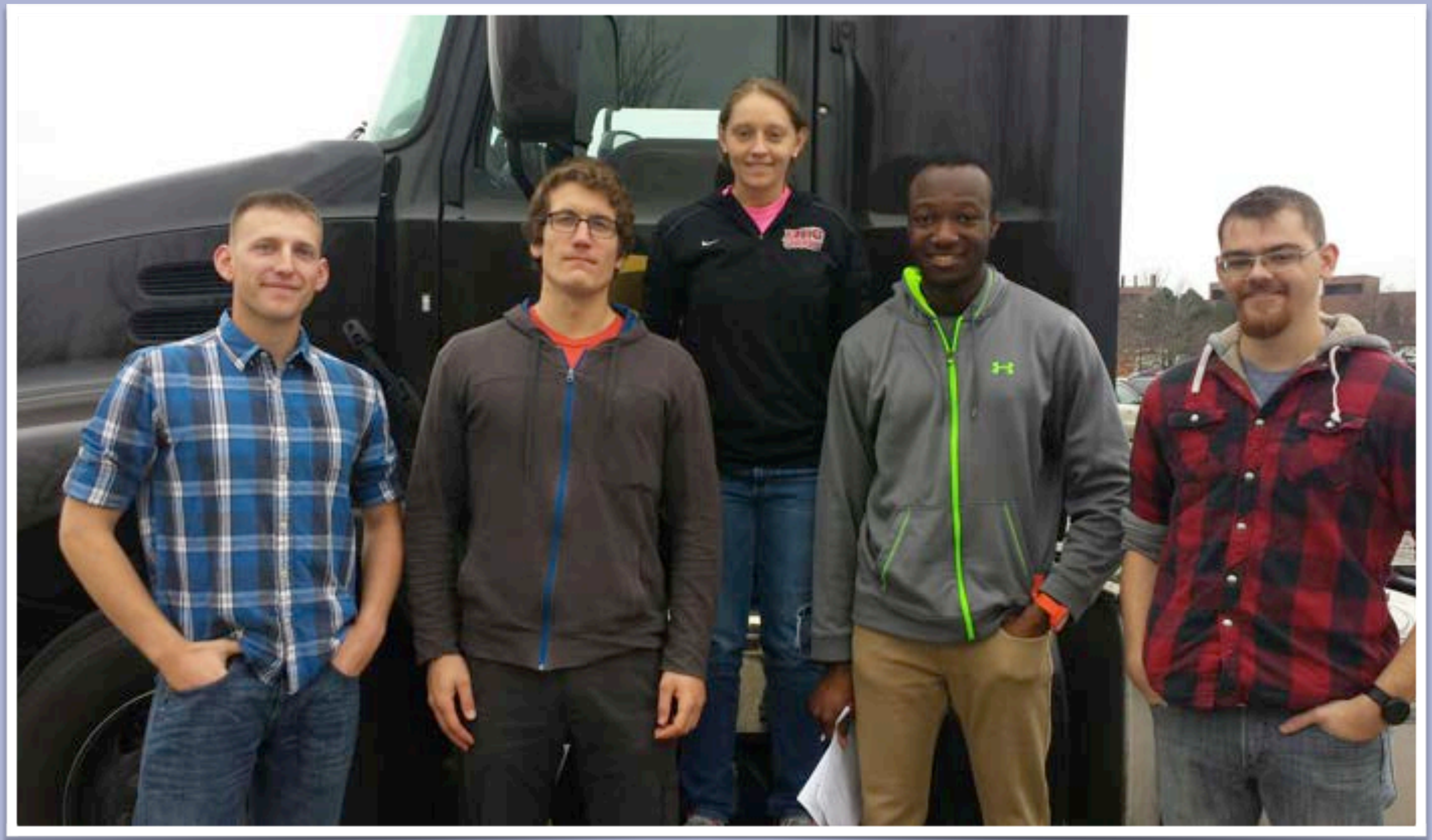
# *RESEARCH HIGHLIGHT:* A Multispectral Camera Considering Image Quality

This research is to develop a filter-wheel multi-spectral imaging system with high spectral and colorimetric reproduction accuracy and high image quality. The sensor is a Canon 5D Mark III DSLR without its color filter array (CFA) and NIR filter. Two sets of filters were evaluated: 80nm bandwidth interference filters spaced approximately every 50nm between 400 and 700nm, and four long-pass and one blue-green absorption filters and the green interference filter (approximating V$\lambda$), both plotted incorporating the sensor's spectral sensitivity. Using an X-Rite Digital ColorChecker SG as training data, linear transforms were developed to estimate spectral reflectance factor. A target of artist paints was used for validation, the results also plotted. Images of its black sample reveal image noise and the quality of removing the CFA. The performance was spectral reflectance RMSE of 0.014 and 0.022, average CIEDE2000 of 0.7 and 0.7, and average image noise of 1.2 and 3.3 CIEDE2000, respectively for the interference and absorption filters.

*Yixuan Wang, Roy Berns*



# *RESEARCH HIGHLIGHT:* Innovative Interdisciplinary Education



Susan Farnand is one of the professors and researchers who received a Provost's Innovative Interdisciplinary Education grant for developing rewarding senior capstone experiences. This work was borne out of the Multi-disciplinary Senior Design program in the Kate Gleason College of Engineering. The MSD projects typically include Senior engineers from Mechanical, Electrical, Industrial & Systems, and Computer Engineering disciplines. As part of this grant several of these teams will be expanded to include students from programs such as Business and Industrial Design.

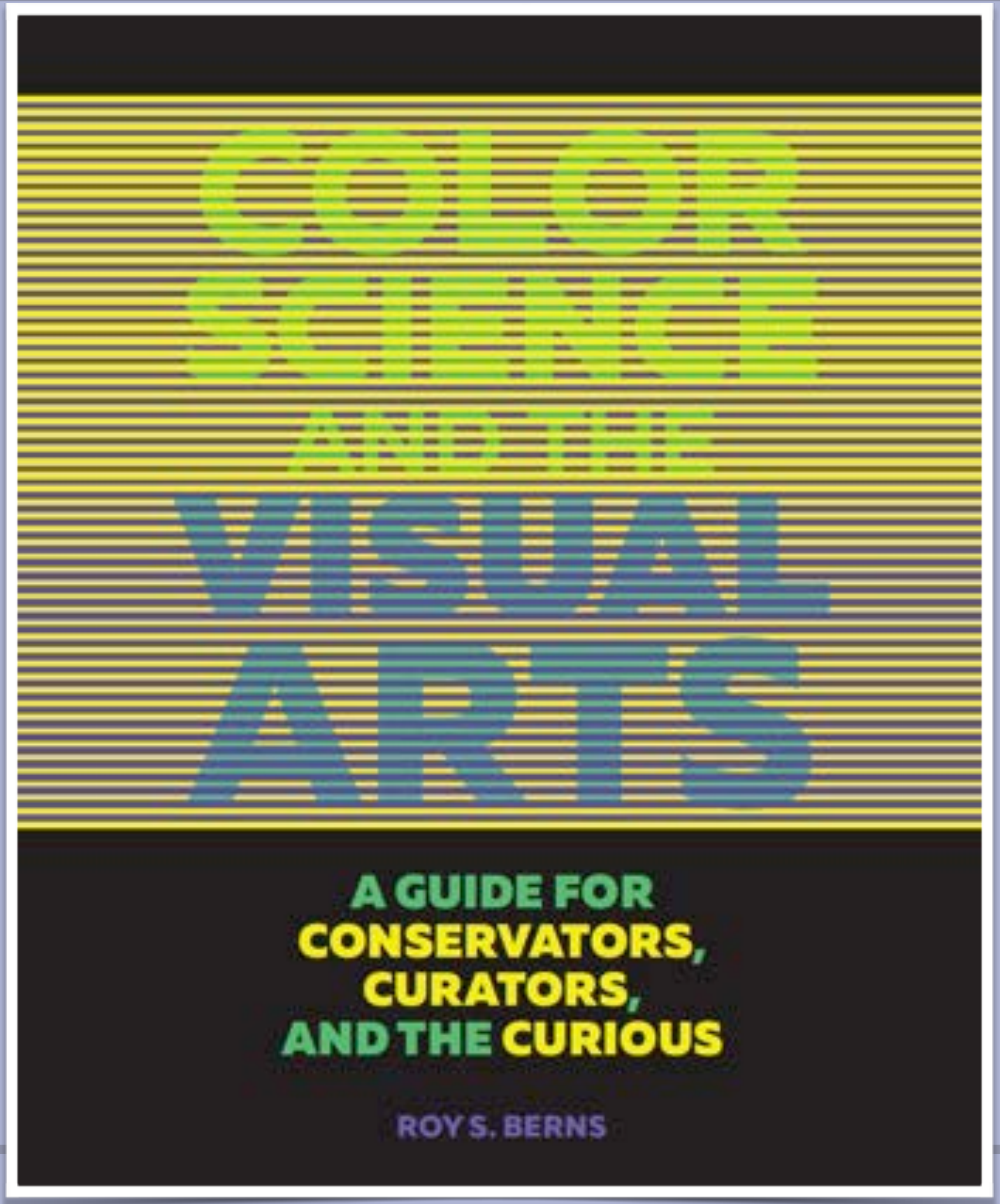
*Elizabeth DeBartolo, Sarah Brownell, Susan Farnand, Shal Khazanchi, Leslie Moore, Stan Rickel, Wade Robison*

# *RESEARCH HIGHLIGHT:* Workflows for the Reproduction of Painted Artwork

This research focuses on increasing the color accuracy of printed reproductions viewed under different sources. Printed reproductions traditionally follow a color management workflow that uses a CIE Illuminant D50 white point. By utilizing color transformation tools such as other illuminants, color adaptation transforms, and material adaptation transforms, a reproduction may result in a better representation of how the painting appeared under gallery lighting, typically incandescent. Six different workflows have been evaluated with a psychophysical memory matching paired-comparison experiment where observers first looked at a painting under gallery incandescent and compared printed reproductions under fluorescent "D50". Each sector represents one of the six workflows. Although the color changes are subtle, results indicate these differences are statistically significant.

*Joel Witwer, Roy S. Berns*

# *RESEARCH HIGHLIGHT:* Color Science and the Visual Arts



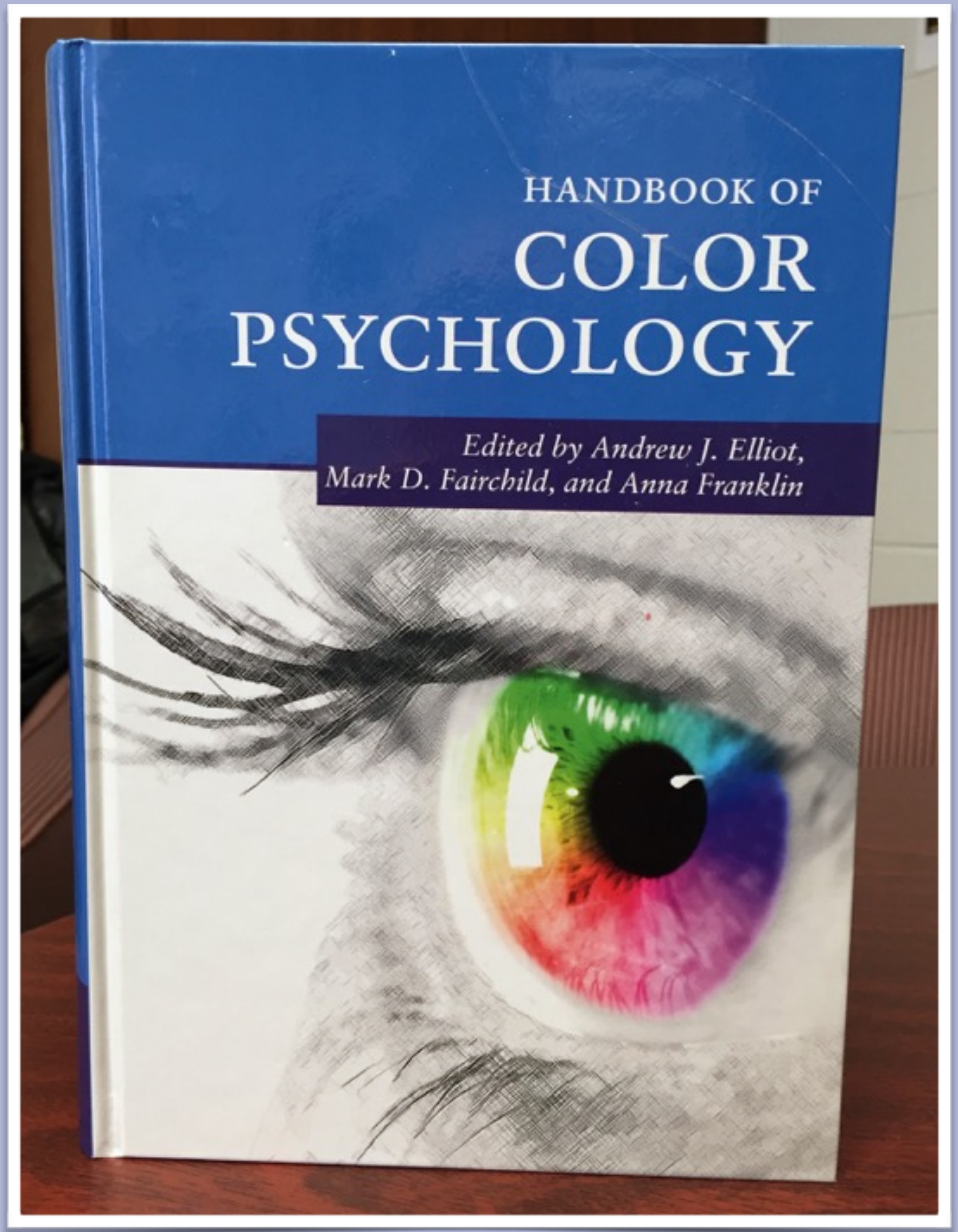

Cover of Roy's new book, Color Science and the Visual Arts: A Guide for Conservators, Curators, and the Curious, to be published by the Getty Conservation Institute in June 2016. The cover is based on Monnier, P., and S. K. Shevell. 2003. "Large Shifts in Color Appearance from Patterned Chromatic Backgrounds." Nature Neuroscience 6: 801–2. "Color Science and the" and "Visual Arts" have the same green color.

*Roy S. Berns*

# *RESEARCH HIGHLIGHT:* Handbook of Color Psychology

Mark had the distinct pleasure of working with Prof. Andrew Elliot from the Department of Psychology at the University of Rochester and Prof. Anna Franklin of the School of Psychology at the University of Sussex on the edited *Handbook of Color Psychology* that was just published by Cambridge University Press. It is a fascinating book that covers all aspects of color perception and psychology from colorimetry, to visual physiology, to development and aging, to color categories, to color symbolism, to color preferences, biological effects, and psychological effects. The authors include many of the most distinguished, qualified, and insightful experts spanning the domains of color science. Please check it out.

*Mark Fairchild*



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Y. Asano, M.D. Fairchild, L. Blondé and P. Morvan, Color matching experiment for highlighting inter-observer variability, Color Research and Application, in press / early view DOI: 10.1002/col.21975 (2015).

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R.S. Berns, B.D. Cox and F.M. Abed, Wavelength-dependent spatial correction and spectral calibration of a liquid crystal tunable filter system, Applied Optics, 54 3687-3693 (2015).

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A. Elliott, M.D. Fairchild, and A. Franklin, Eds. Handbook of Color Psychology, Cambridge University Press, Cambridge, UK (2015).

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M.D. Fairchild, Seeing, adapting to, and reproducing the appearance of nature, Virtual Journal for Biomedical Optics 10, Issue 3, republication (2015).

M.D. Fairchild and R.L. Heckaman, Measuring observer metamerism: The Nimeroff approach, Color Research and Application, in press / early view DOI: 10.1002/col.21954 (2015).

M. Melgosa, L. Gomez-Robledo, M.I. Sure and M.D. Fairchild, What can we learn from a dress with ambiguous colors?, Color Research and Application 40, 525-529 (2015).

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Y. Asano, M.D. Fairchild, and L. Blondé, Spectral pseudoisochormatic images: Vision test for color-normal observers, AIC2015 / MCS 2015, Tokyo (2015).

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B.D. Cox and R.S. Berns, Imaging artwork in a studio environment for computer graphics rendering, IS&T/SPIE Electronic Imaging 939803-939803 (2015).

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M.D. Fairchild, Gustav Theodor Fechner, in the Encyclopedia of Color Science & Technology, in press (2015).

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M.D. Fairchild, Joseph William Lovibond, in the Encyclopedia of Color Science & Technology, in press (2015).

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M.D. Fairchild, Metameric Blacks: A Color Curious Column, ISCC News #445 - 472 (2010-2015).

M.D. Fairchild, Stanley Smith Stevens, in the Encyclopedia of Color Science & Technology, in press (2015).

M.D. Fairchild and Y. Asano, Custom color matching functions: Extending the CIE 2006 model, The 10th Biennual Joint CNC/CIE and CIE/USA Technical Conference, Toronto, Abstract 1 (2015).

A. Forés Herranz, M.D. Fairchild and I Tastl, An abridged goniometer for material appearance measurements, SPIE/IS&T Electronic Imaging Conference, San Francisco, Volume 9398, 93980G (2015).

D.L. Long and M.D. Fairchild, Observer metamerism models and multiprimary display systems, SMPTE Annual Technical Conference, Hollywood (2015).

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J. Witwer and R.S. Berns, Increasing the versatility of digitizations through post-camera flat-fielding, IS&T Archiving Conference 110-113 (2015).

# 2015 PUBLICATIONS

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Y. Asano, Individual Colorimetric Observers for Personalized Color Imaging, Rochester Institute of Technology dissertation, 2015.

M.W. Derhak, Spectrally Based Material Color Equivalency: Modeling and Manipulation, Rochester Institute of Technology dissertation, 2015.

J.D.T. Kruschwitz, Specialized Color Targets for Spectral Reflectance Reconstruction of Magnified Images, Rochester Institute of Technology dissertation, 2015.

***Patent Application***

J. Kruschwitz and R.S. Berns, Spectral Target for Macroscopic and Microscopic Reflectance Imaging, U.S. patent applied for: U.S. Serial No. 14/933,839, on November 5, 2015.

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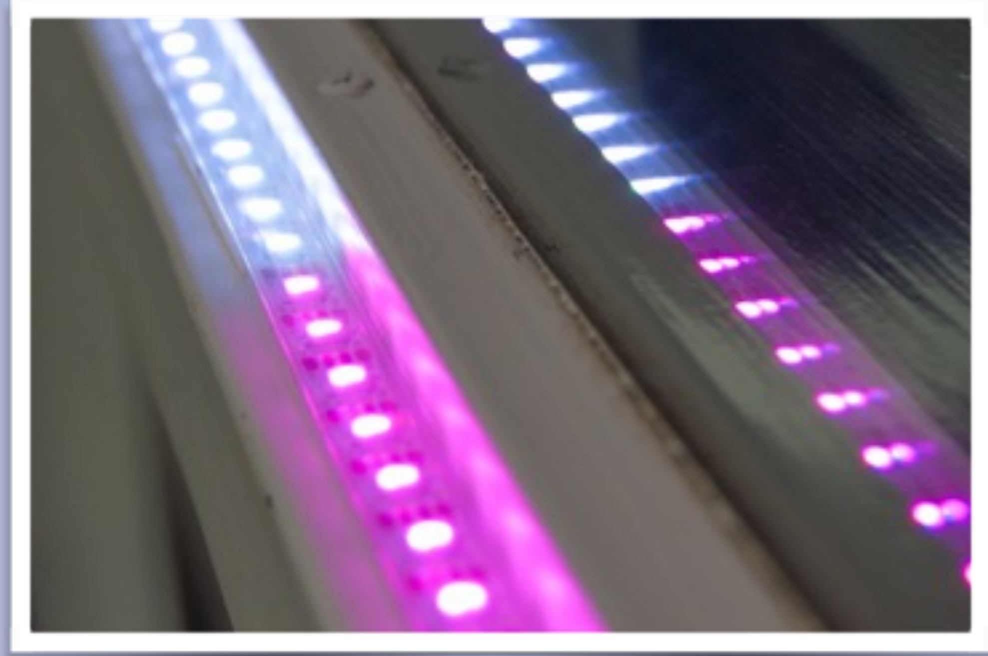

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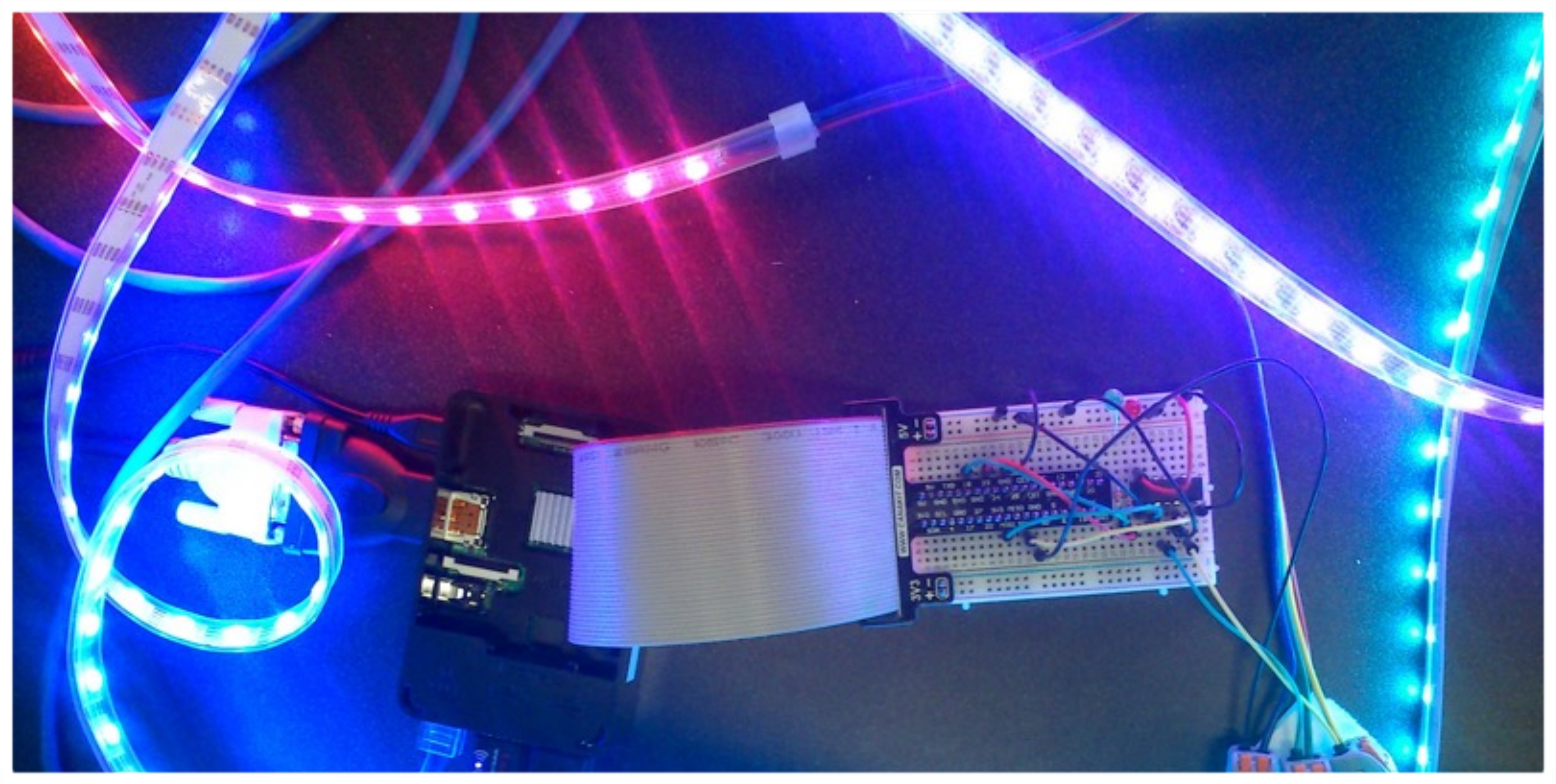


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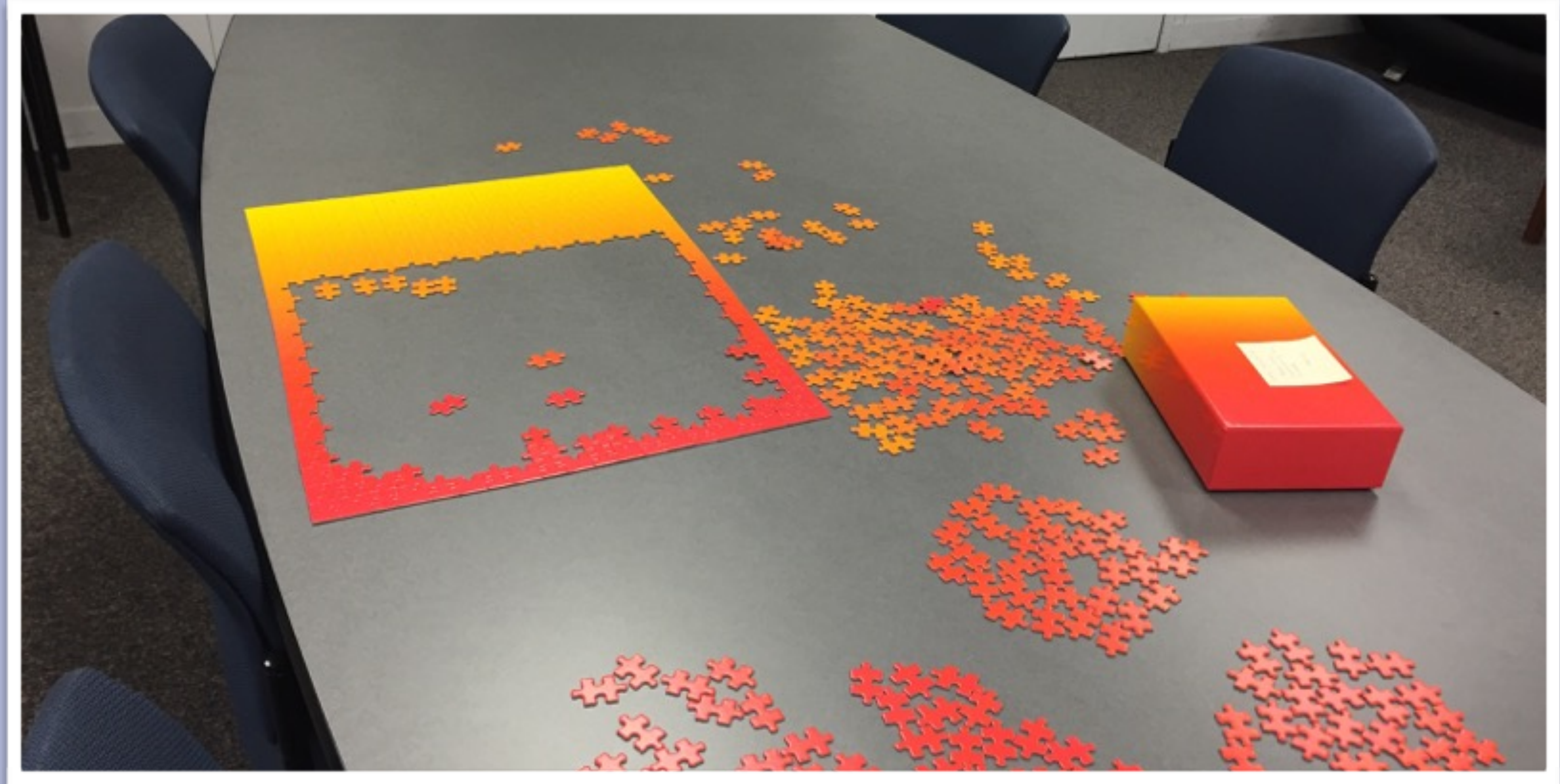
Dr. Mark Fairchild, Adviser
[ CHEERS AND APPLAUSE ]




GUESS


18 Color Science


Measurement
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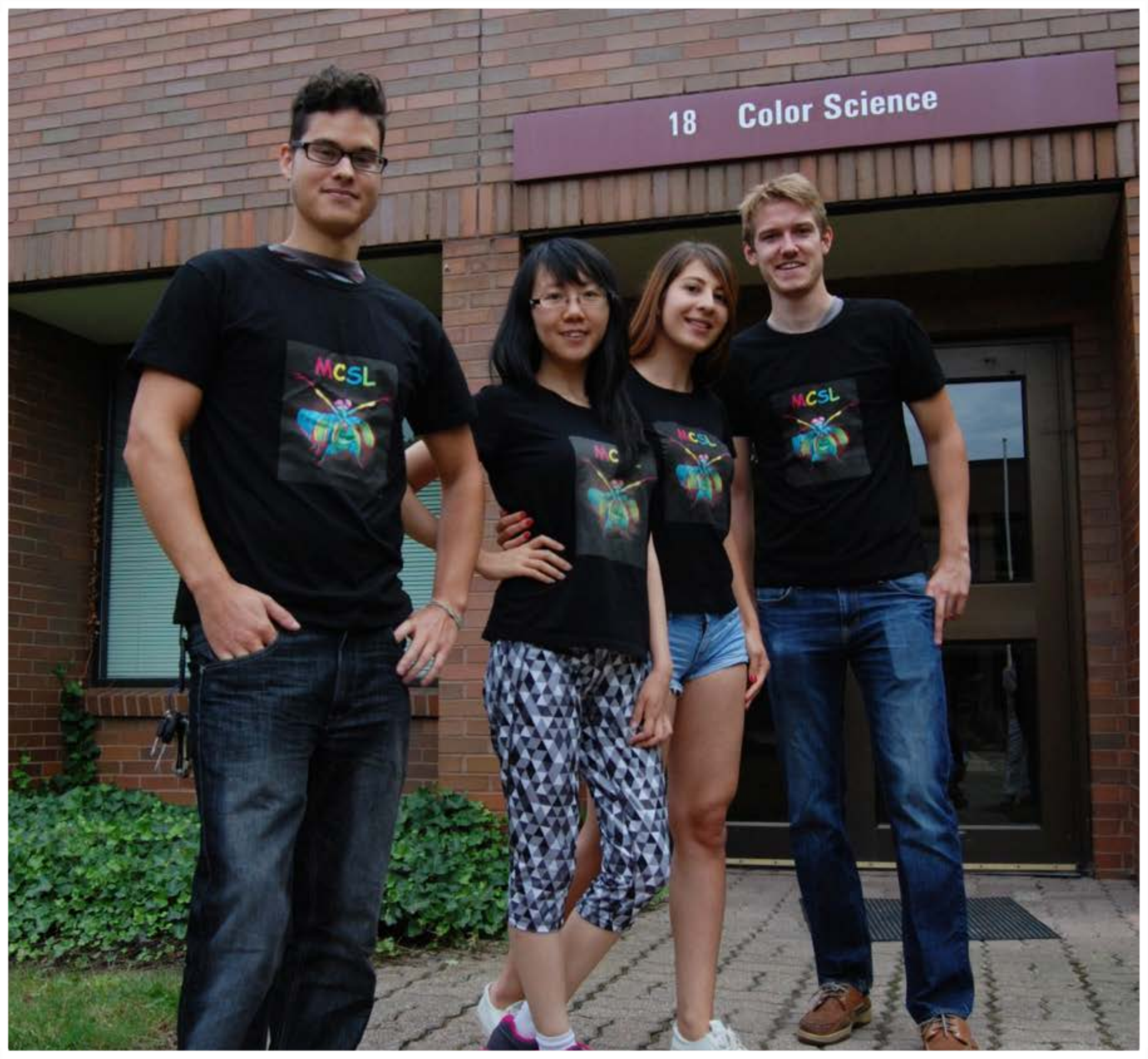
18 Color Science
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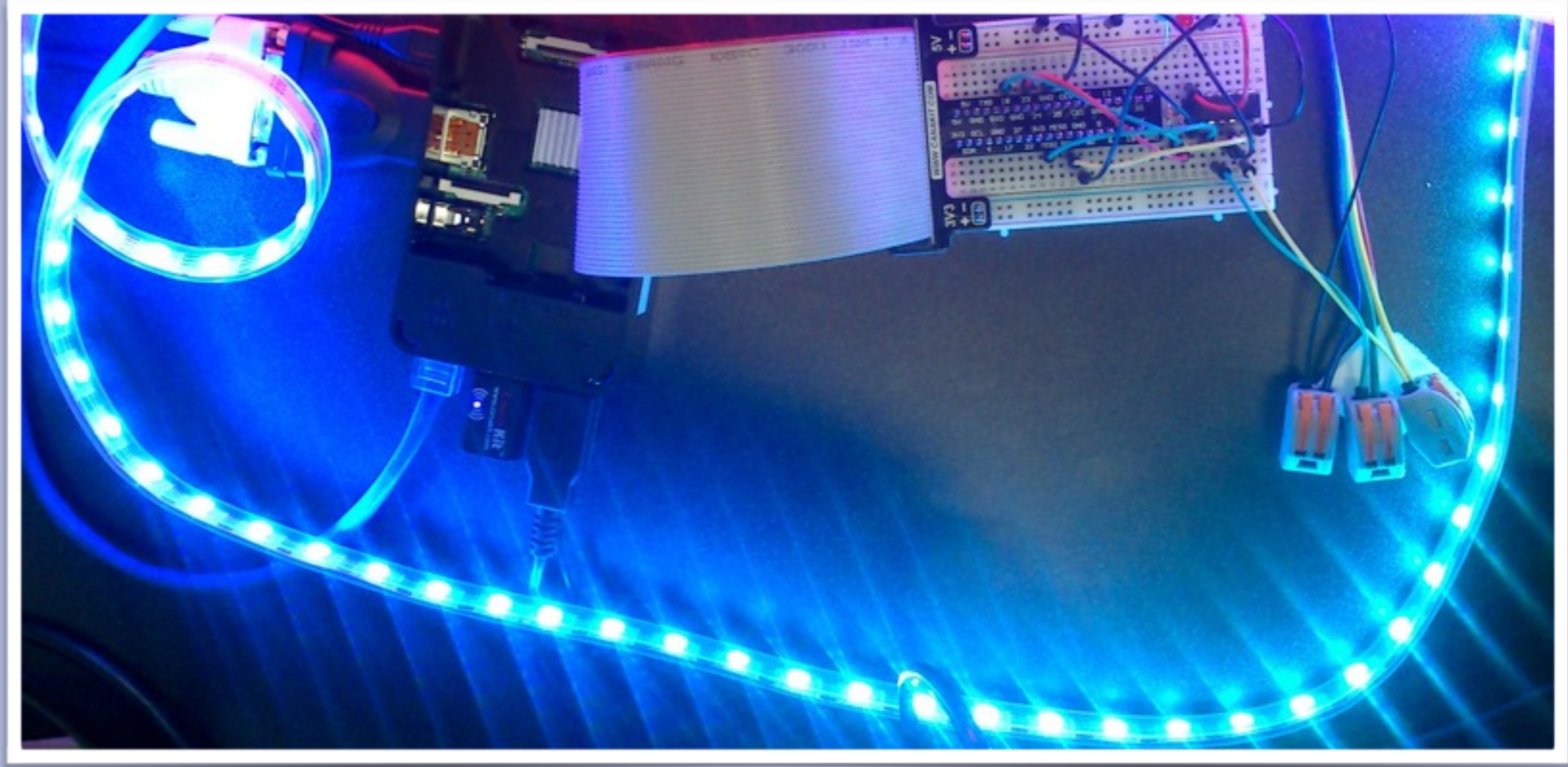

# RIT
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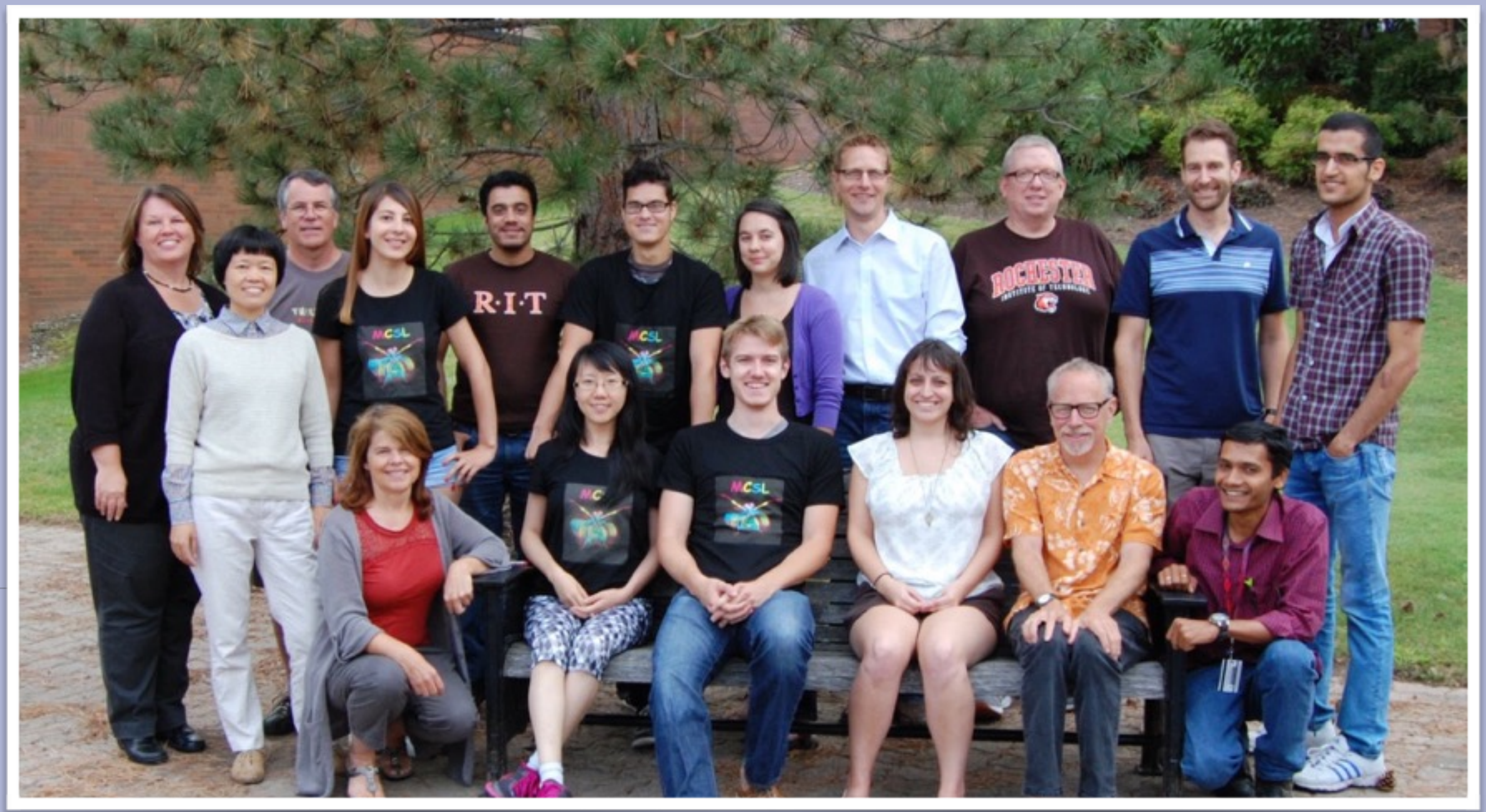

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