Program of Color Science / Munsell Color Science Laboratory

Annual Report 2019

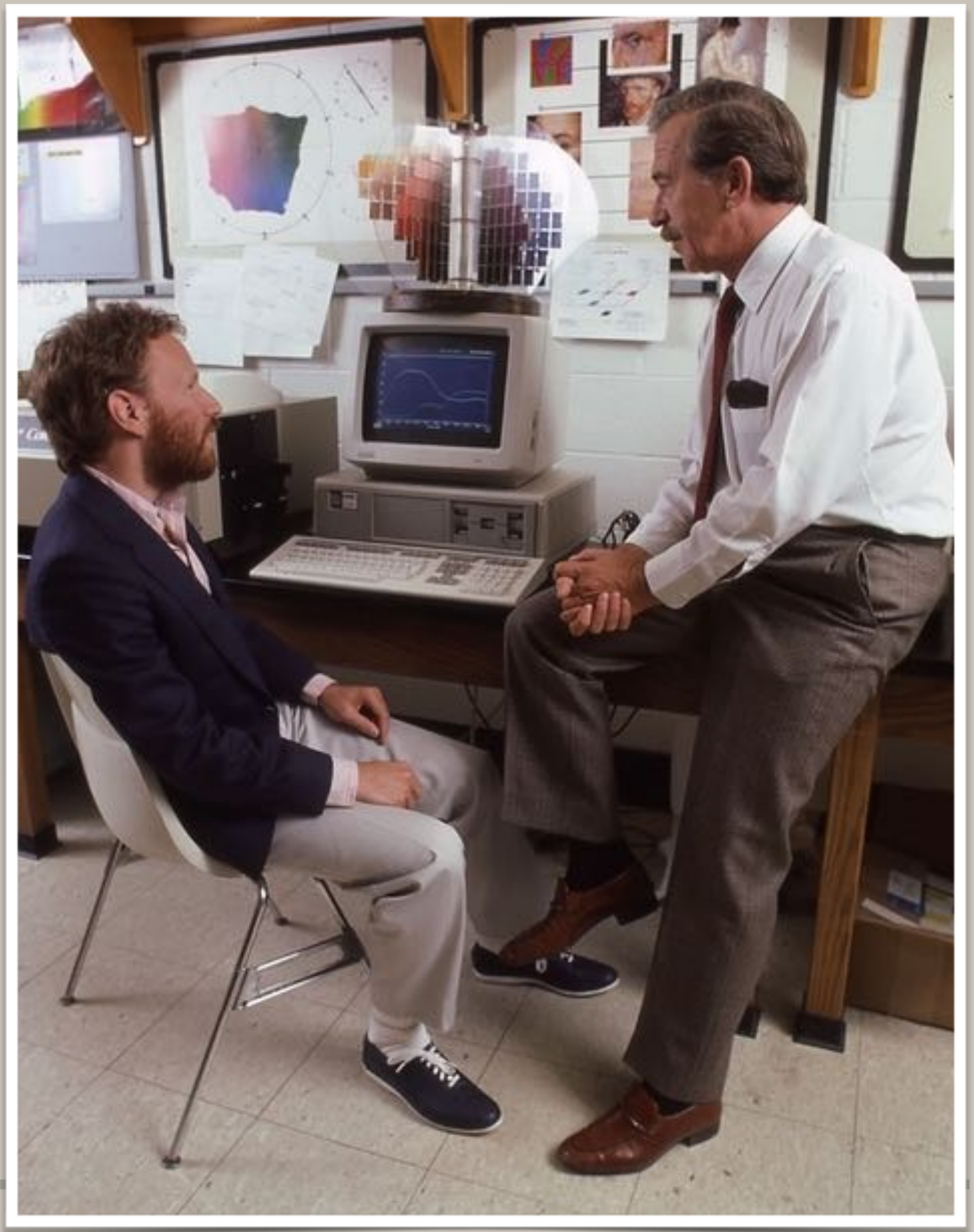
DIRECTOR'S REFLECTIONS: Ready for the Roarin' Twenties

As we move from the twenty-teens to the twenty-twenties, I am happy to report that the Program of Color Science and Munsell Color Science Laboratory are stronger than ever and poised for an exciting future. One measure of that is that we are set to bring in our largest class of entering Ph.D. students ever in the Fall of 2020. The coming years will not just be a time of growth, but a time of transition to a new generation of faculty. Roy Berns will be retiring at the end of the 2019-20 academic year after a truly amazing career full of accomplishments, not the least of which is that he was the principal author of the proposals for both our extremely successful Color Science graduate programs (M.S. in 1986 and Ph.D. in 2007). Roy has spent 36 years at RIT, most as the R.S. Hunter Professor of Color Science, Appearance, and Technology, as well as serving as MCSL director twice. He built on Franc Grum's legacy to set the course for color science at RIT for three decades and certainly well into the future. (Some retirement thoughts from Roy can be found on the second following page.)

Looking forward, we are in the midst of a faculty search where we expect to hire up to two new assistant professors. These new faculty will work with our existing faculty to form the next decades of Color Science education and research at RIT. We will also be transitioning to new leadership as I have announced my intention to step down from my administrative duties (Head of Integrated Sciences, Director of PoCS/MCSL) at the end of the 2021-22 academic year after transitioning those roles carefully to existing faculty. The twenties will be roarin' indeed!

Within the lab, our strong and steady growth and diversification based on our 2013 strategic planning and curriculum redesign have continued unabated. Four outstanding new Ph.D. students joined the program. We had two graduations in 2019, Nargess Hassani (Ph.D.) and Gaurav Sheth (M.S.) and we look to be graduating as many as seven new Ph.D.s in the coming year. Some highlights of the year 2019 include:

~Dr. Elena Fedorovskaya joined MCSL as a Research Professor.
~Dr. Farnand received the IS&T Senior Membership Award.
~Prof. Yoichi Miyaki and Pres. Ryuichiro Yoshie visited from Tokyo Polytechnic University's International Center for Color Science and Art.
~Dr. Fairchild will make a return visit to Tokyo for an invited lecture in March
~Prof. Mike Webster visited from University Nevada-Reno to deliver a COS Distinguished Lecture and tour the lab.
~An NSF ADVANCE grant to grow and reinforce research networks focussed on women and minority researchers commended.
~We hosted our first ADVANCE visit Katie Tregillus from University of Minnesota. Several more are planned.
~Dr. Murdoch was an invited speaker at the CIE-OSA-IS&T Workshop on New Directions in Colorimetry, Color Vision, and Color Appearance.



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DIRECTOR'S REFLECTIONS: Continued

~Dr. Murdoch also convened the CIC 27 Workshop on Chromatic Adaptation and Lighting.
~Dr. Farnand gave an invited presentation at the Transactions Imaging/Art/Science: Image Quality, Content and Aesthetics conference in London.
~All have been busy with the new faculty search.
~New minors commenced in Applied Cognitive Neuroscience and Art of Science / Science of Art.
~The Program of Color Science had a cross-over with RIT's Glass Program on a semester-long Chromascapes course.

As always, the students, staff, and faculty of PoCS/MCSL are deeply indebted to those who sponsor our education and research through gifts and grants. We thank our 2019 donors and sponsors:
~EIZO, Scot Fernandez, Hallmark, Hewlett Packard, HunterLab, LG, Mellon Foundation, NHK, Samsung, Huan Zeng and several internal RIT programs.

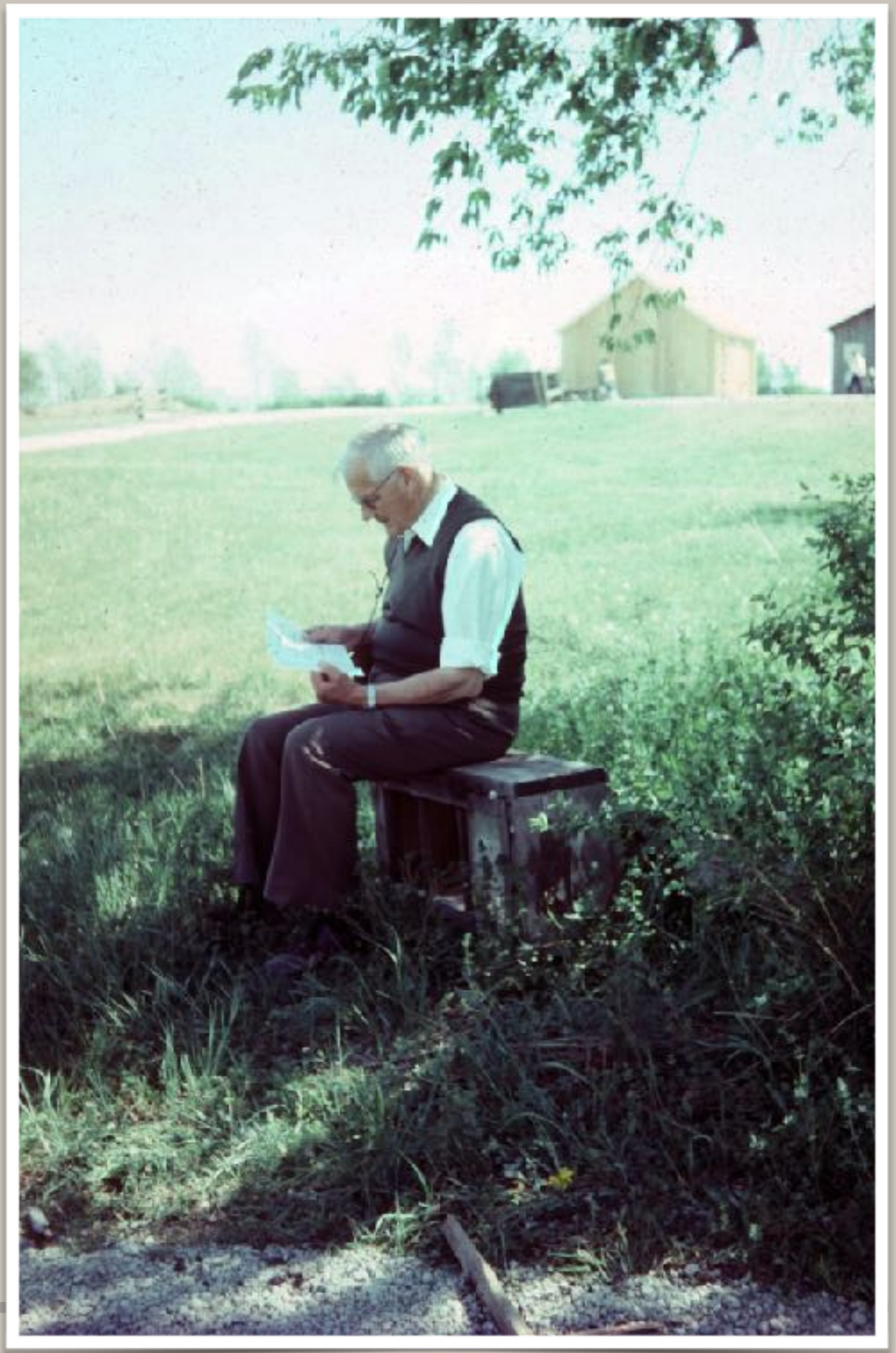
Please read through this report for more information on our current students and research projects. As Newton said, "the rays, to speak properly, are not coloured." As such PoCS/MCSL is no simple physical entity (like a photon), but is a living system that includes the building, the facilities, the people, and most importantly the ideas within and between those people and the rest of the world (a human perception).

I leave you with two historical pictures. One is Roy Berns with Franc Grum in MCSL circa 1984 in Gannett Hall (I was in the room when it happened!) and the other is a picture of David Wright during one of his visits to RIT and Rochester (also circa 1984) that was left with the lab by our good friend and advisor Milt Pearson before he passed away. All have been great inspirations to many in the lab and around the color science world.

We all wish you all the best for another bright and colorful year as we continue to thrive at RIT's unique intersection of technology, art, and design.

Sincerely,

Mark Fairchild
Founding Head, Integrated Sciences Academy, College of Science
Professor and Director, Program of Color Science / Munsell Color Science Laboratory



THOUGHTS FROM ROY: Making a Difference

I joined MCSL in time for its inauguration February, 1984. By Friday at the end of the day, the ribbon had been cut, the open house was over, the talks were finished, and Franc Grum, MCSL's first director, was pouring us bourbon in his office. We toasted the future. He then toasted my dissertation and said, "I know everyone who gets a Ph.D. wants to continue their research forever and ever. However, beginning on Monday, we have real work to do." Deriving a theoretical, color-constant Munsell Book of Color took a back seat to developing the first graduate degree in color science in the U.S., something Franc did not get to see because of his untimely death at the end of 1985. My first industrial-sponsored research was comparing printing and photographic spectral models in predicting the color of electrophotographic copies, completely unrelated to my dissertation.

Thirty-six years later, MCSL is a world leader in color science education, research, and outreach. If the images on your cell phone have acceptable color, if a poster matches your favorite painting, if the bodywork repair matches the rest of the car, our graduates deserve a lot of the credit. When asked to explain color science, I proudly show my cell phone. Today, we have a doctoral degree program in color science. Our books and publications are widely cited. Our graduates remain in high demand in industry. MCSL's future is secure, thanks to Mark's leadership and our energetic junior faculty.

I will be retiring this coming May. Thank you to the trustees of the Munsell Foundation and Richard and Elizabeth Hunter for endowing a laboratory and professorship in color science at RIT. The concept of a "center of excellence in color science" was spearheaded by Milton Pearson. Heartfelt thanks to my dedicated students, knowledgeable visiting industrial scientists, brilliant post-doctoral fellows, outstanding research staff, mentoring colleagues, generous sponsors, affirming administrators, supportive administrative staff, and loving family. I have had an incredible career because of the part each of you played.

Fondly,
Roy

STUDENTS & GRADUATE ALUMNI

Visiting Researchers

Saeedeh Abasi, Amirkabir University of Technology

Kensuke Fukumoto, Chiba University

MCSL Current Students

Rema Amawi, PhD, CS
Anku, PhD, CS
Ben Bodner, MS, CS
Katherine Carpenter, PhD, CS
Dara Dimoff, PhD, CS
Tucker Downs, PhD, CS
Luke Hellwig, PhD, CS
Fu Jiang, PhD, CS
Olivia Kuzio, PhD, CS
Jenibel Paray, PhD, CS
Yongmin Park, PhD, CS
Adi Robinson, PhD, CS
Matt Ronnenberg, PhD, CS
Che Shen, PhD, CS
MingMing Wang, PhD, IS
Hao Xie, PhD, CS
Yue Yuan, PhD, CS
Lili Zhang, PhD, CS

Alumni

2019
Nargess Hassani, PhD, CS
Gaurav Sheth, MS, CS

2017
Brittany Cox, PhD, CS
Morteza Maali Amiri, MS, CS
Chris Thorstenson, MS, CS

2016
Yixuan Wang, MS, CS
Joel Witwer, MS, CS

2015
Yuta Asano, PhD, CS
Maxim Derhak, PhD, CS
Jennifer Kruschwitz, PhD, CS
David Long, PhD, CS
Ashley Penna, MS, IS

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

STUDENTS & GRADUATE ALUMNI

Even More Alumni

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 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

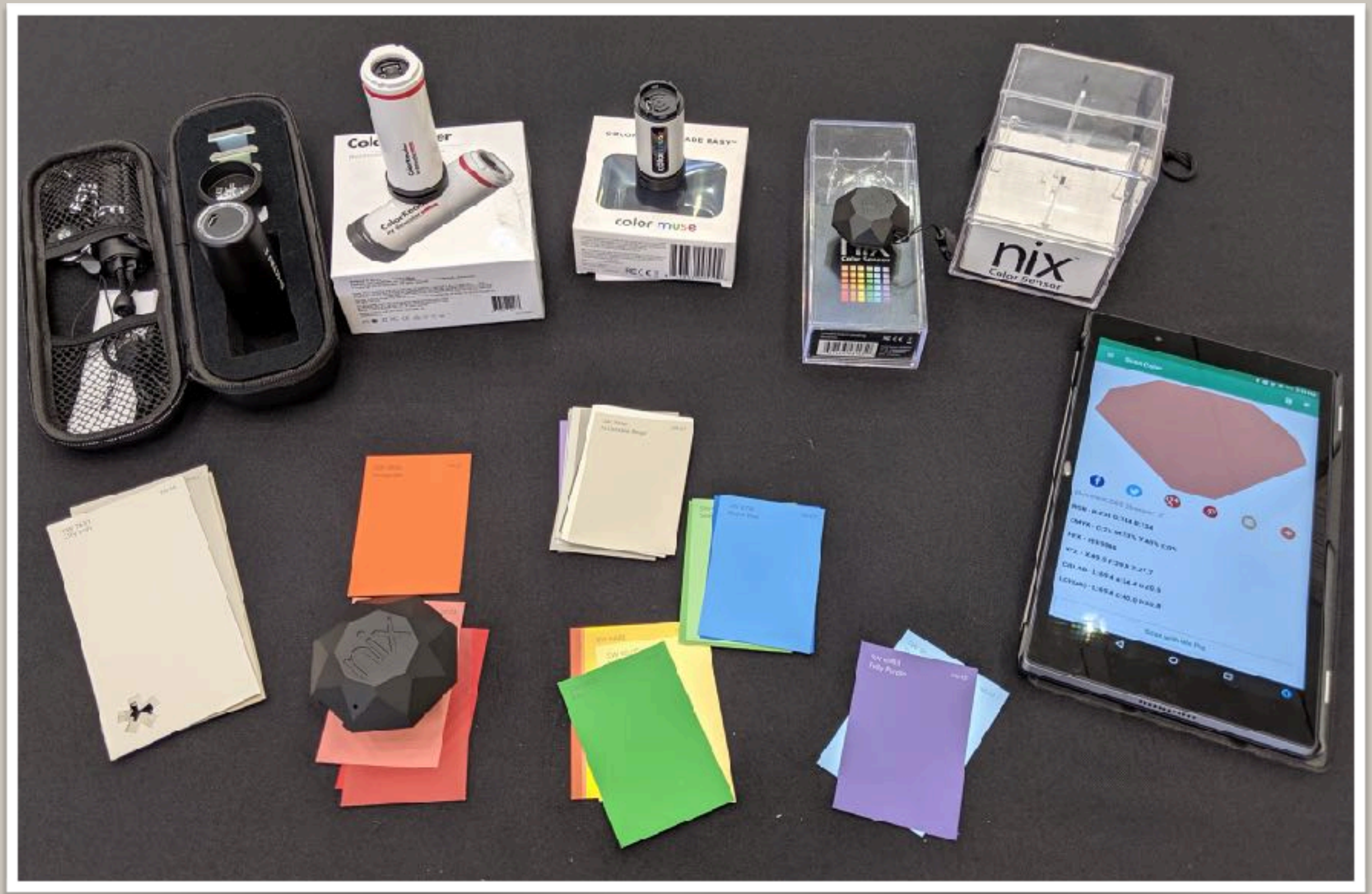
1989
Mitch Miller, MS, IS
Kelvin Peterson, MS, IS
Lisa Reniff, MS, CS

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

1986
Mark Fairchild, MS, IS

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

RESEARCH HIGHLIGHT: Low-Cost Colorimeters & Online Education



What started as a search for online technology to help remote color science students get some of the in-laboratory experience that local students receive led us to an interesting new category of low-cost colorimeters. Similar inexpensive, Bluetooth-connected color measurement devices are made by several large and small instrument makers, and they combine with a smartphone or tablet for control, display, and connectivity. Via a Provost's Learning Innovation Grant, Michael, Susan and PhD candidate Lili Zhang obtained and tested several of these devices, and the results show decent performance for the cost – not only for remote students, but also for other cost-sensitive applications! They especially excel in finding matches in commercial paint-chip databases, but also give real data. Shown in the photo are some of the colorimeters and color samples used; a paper summarizing the results is in preparation.

Michael J. Murdoch, Susan Farnand, Lili Zhang

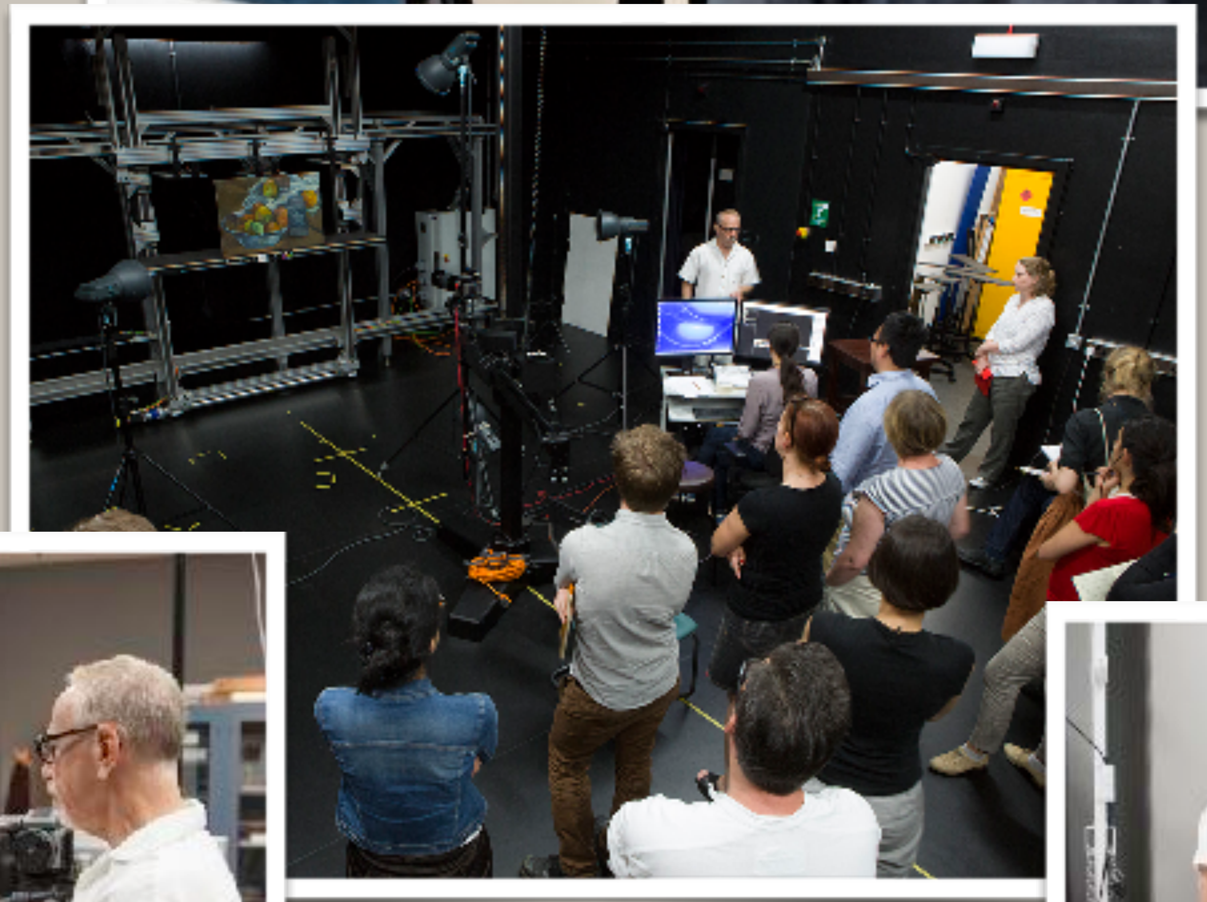
RESEARCH HIGHLIGHT: Human Perception While Driving

The interest in autonomous vehicles is rapidly expanding in the auto industry. Although it has successfully gained more attention from the public, expectations for the accuracy, flexibility and applicability for these driving systems are high. To address such requirements and concerns, the sensor-perception based approach requires a huge amount of training data to evolve and adapt, which takes actual driving mileage. However, on-road tests are restricted by safety requirements. Accumulated mileage may not be sufficient for the autonomous reaction training in diverse and dangerous driving situations. A Virtual Reality driving simulation platform with incorporated eye-tracking is a promising path to provide perceptually-based human driving decisions for assisting in autonomous systems development. To quantify the realism of the platform, we compared the results of a driving simulation test with an existing on-road test. If the test results such as speed control are reasonably correlated, the simulation platform may be a reliable approach for research.

Tunnel scene created in Unity®, based on a real tunnel in Oslo, Norway. This scene was displayed in an experiment evaluating the constructed simulator.

Mingming Wang and Susan Farnand

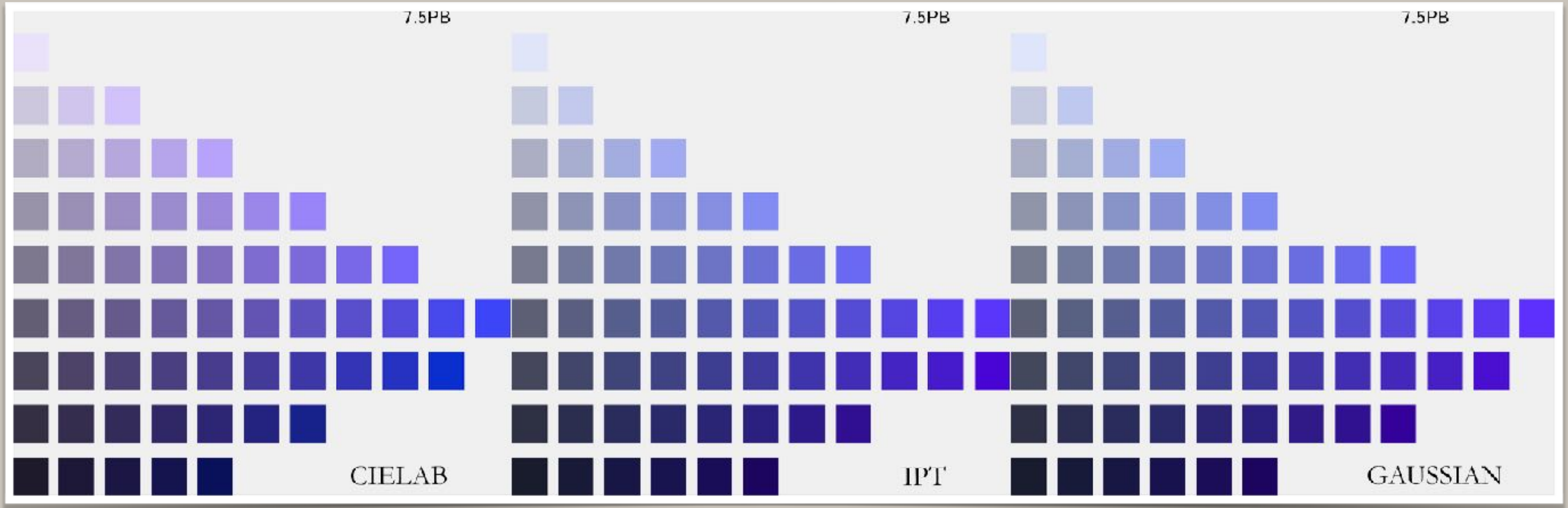
RESEARCH HIGHLIGHT: Mellon Foundation Workshops



The Andrew W. Mellon Foundation has been funding Roy's research for nearly 20 years. The last grant was completed in August. It supported Roy presenting workshops and short courses at the Rijksmuseum, Getty Center, Smithsonian Museum Conservation Institute, the National Gallery London, the Museum of Modern Art New York, and in MCSL. There were 147 total participants from 97 institutions. Here are some photographs.

Roy S. Berns

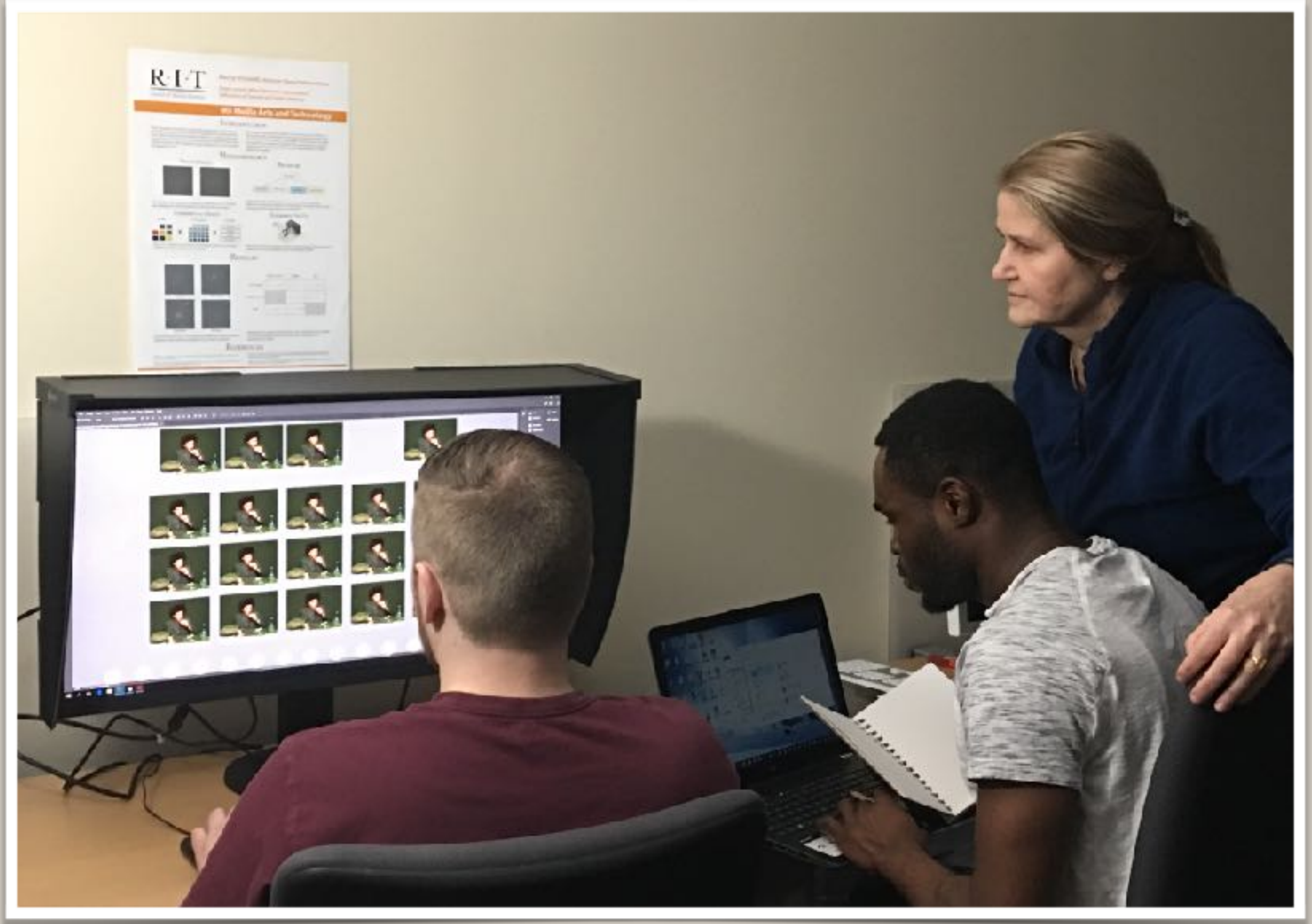
RESEARCH HIGHLIGHT: Theoretical Constant Hue Space



The most well-tested, and best performing, color space for prediction of lines of constant hue has been the IPT space developed by MCSL alumnus Fritz Ebner as part of his Ph.D. dissertation. (It also serves as the basis for the ICtCp space used in the Dolby Vision and ITU B.2100 standards for high-dynamic-range television. In our Modeling Visual Perception course, we discussed a paper by Mike Webster and colleagues on the perception of hue that suggested that the visual system might have evolved to produce constant hue perceptions for increasingly broadening Gaussian spectral profiles of a given peak wavelength. Ph.D. student Luke Hellwig picked up on that theory and wondered if it would produce predictions of constant hue better than IPT and with a theoretical underpinning. Luke's analysis became a very successful second-year project including psychophysical testing. Ultimately he showed that the Gaussian concept performed similarly to IPT, but at least there is now some theoretical background to the empirical IPT space. The work will be submitted to a journal shortly.

Luke Hellwig, Mark Fairchild

RESEARCH HIGHLIGHT: Defining Consistent Color Appearance for Print Images



RIT scientists and industry experts are working on a research project within the CIE Technical Committee TC8-16 "Consistency of Colour Appearance within a Single Reproduction Medium". This committee was established to study how to enable reproductions of the same source images that have consistent color appearance (CCA) using hard copy or soft copy proofing environments. We define CCA as the degree of visual consistency or shared visual appearance of a set of images viewed simultaneously despite noticeable perceptual differences between them. In printing, it can be affected by paper substrates, inks, viewing environments, printing devices and printing parameters, e.g. color balance or color gamut. The goal of this project is to determine factors that control CCA and build a model to quantify it, so CCA can be achieved despite varying conditions of color reproduction, which is important for brand owners, printing industry, as well as display manufactures.

Elena Fedorovskaya, Robert Chung

RESEARCH HIGHLIGHT: Color and Material Appearance in Augmented Reality

Finalizing her PhD, which she successfully defended in June, 2019, Dr. Nargess Hassani proposed a model of color appearance in augmented reality (AR) which depends on the colors of real-world background and virtual AR foreground, as well as the visual complexity of rendered AR objects. The model involves a non-physical addition of the background and foreground stimuli which mimics the human visual system's interpretation of transparent stimuli. This model will be useful in future work on many aspects of perception in AR, and it will evolve with more experimental data. A journal manuscript is in preparation.

Nargess Hassani, Michael J. Murdoch

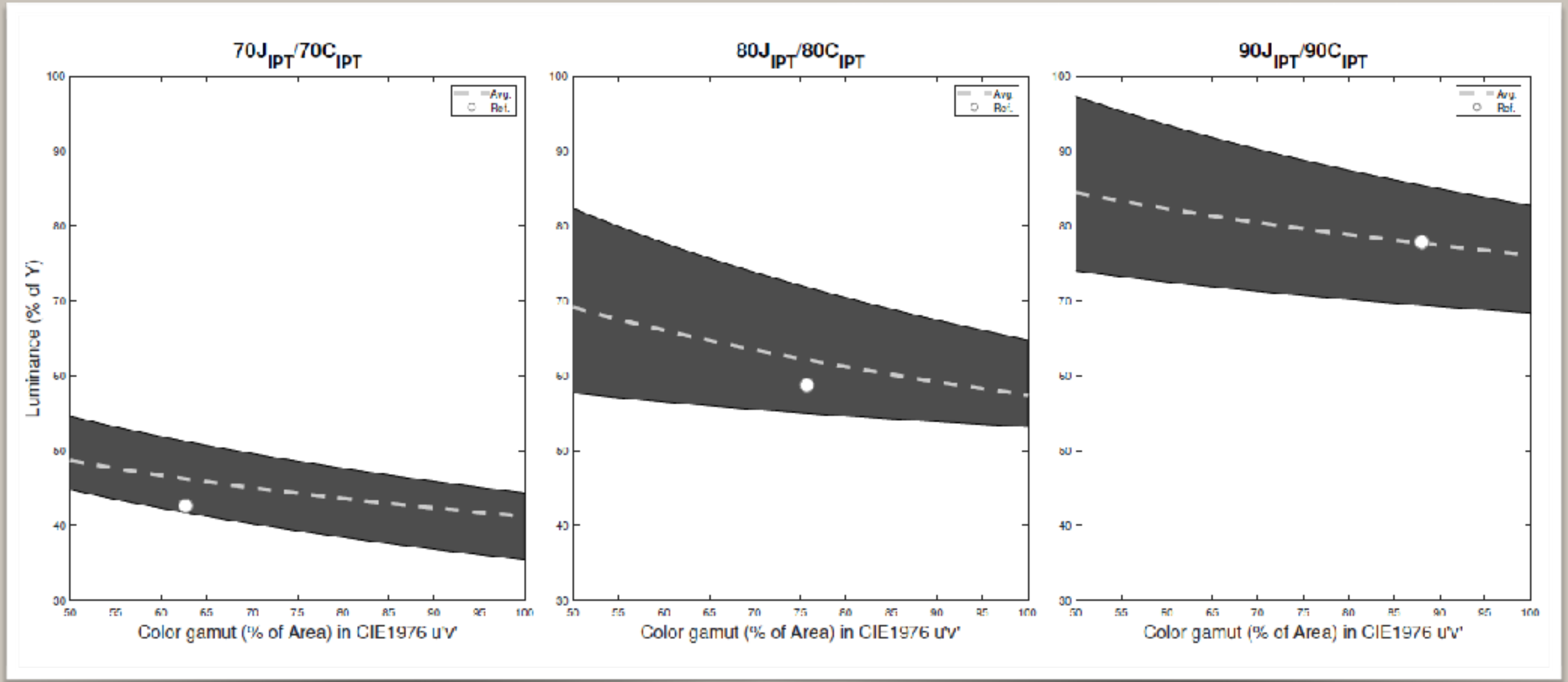
RESEARCH HIGHLIGHT: Appearance Scales

Color space is an interesting concept, but perhaps fundamentally flawed. For example, no single color space can be designed that is uniform for both near-threshold color differences and overall appearance scales. Perhaps the search is based on the flawed concept that the three-to-five dimensions of color experience should fit into some form of three-dimensional (often Euclidean) space. Instead, like other perceptual modalities, it might be more useful to describe color appearance as independent single dimensions of brightness, lightness, saturation, colorfulness, and hue? Mark published an initial formulation of this a few years ago and is currently working with Hao Xie on a dissertation to more carefully and completely specify a system of color appearance modeling based on independent dimensions, rather than a space. Such a system will also allow more flexible, and generally applicable, methods for color differences and tolerances.

Hao Xie, Mark Fairchild

RESEARCH HIGHLIGHT: Image Quality: Peak Luminance vs. Chromaticity Gamut

When designing a display device, its peak luminance and color gamut are important factors that affect its manufacturing cost and image quality. This research has quantified an image quality trade-off between peak luminance and chromaticity gamut. Defining this relationship in terms of equivalent image quality will be helpful for the display industry to select and design physical specifications of display devices. For example, the model would help find an optimal combination of peak luminance and chromaticity gamut, maintaining image quality while lowering production cost and/or power usage. A psychophysical experiment was performed using various natural images including skin tone, sky, food, and so on, to find peak luminance levels resulting in equivalent image quality for varied chromaticity gamuts. Based on the experimental result, simple models taking two-color appearance attributes representing the physical specification of a display device, chroma and lightness, and image statistics extracted from input images as parameters were proposed. This work was submitted for journal publication is currently under review.



The plots show peak luminance versus chromaticity gamut, with shaded regions indicating equivalent image quality relative to the reference conditions, white dots.

Yongmin Park, Michael J. Murdoch

RESEARCH HIGHLIGHT: HyAB Color Differences

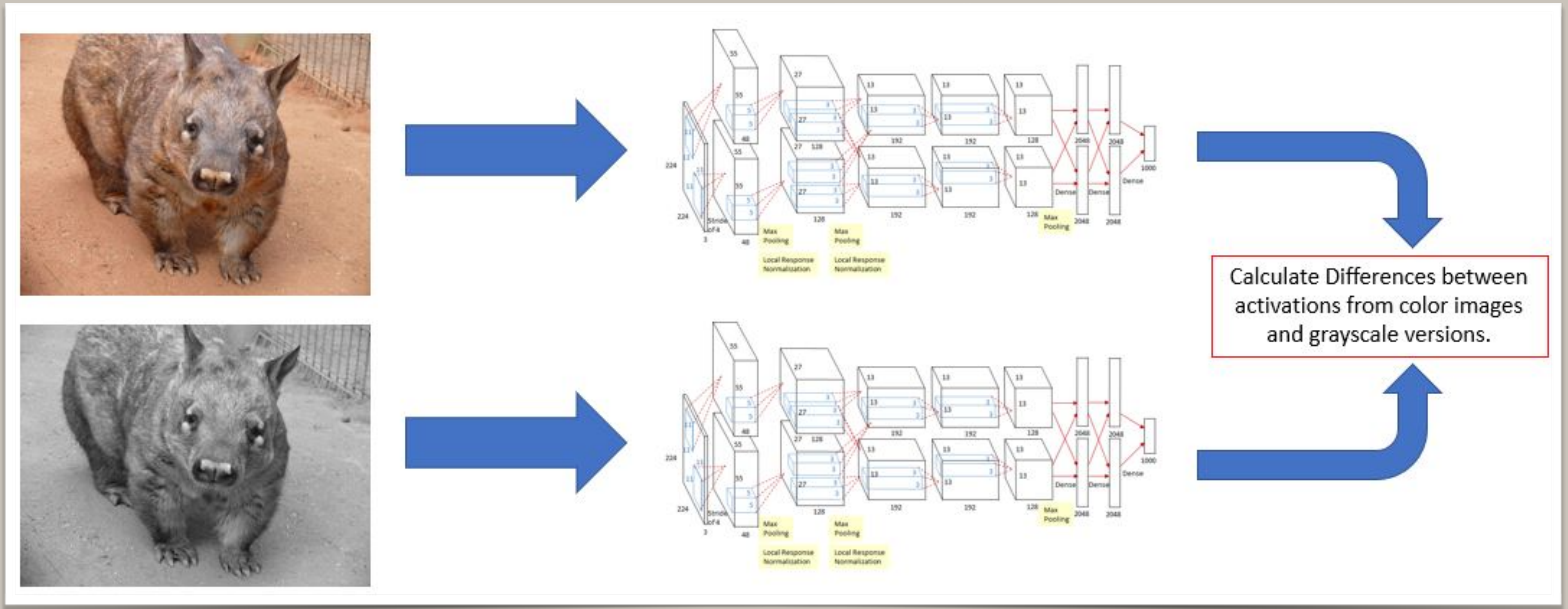
	Pair number	L*	a*	b*	CIELAB	CIEDE2000	Color presentation
Stimulus A	Pair 1	60	−15	6.5	39.28	28.35	
		60	11.5	−22.5			
	Pair 2	60	−15	6.5	40.80	29.74	
		71	11.5	−22.5			

Saeedeh Abasi spent half of 2019 as a visiting student from the Textile Engineering Department of the Amirkabir University of Tehran in Iran. She was very productive and completed several experiments on the perception of large color differences with an eye toward application in image segmentation and classification. Her results, already published in Color Research and Application, showed that Euclidean color difference metrics do not apply well to the scaling of very large color differences. Instead, she proposed a hybrid formula, called HyAB, that uses a Euclidean summation of the differences in a* and b* combined with a city-block summation of the L* dimension. This formulation gives large lightness differences a primary effect on overall color difference and seems to well match human perception of large differences and enable better color image segmentation. Additional publications are forthcoming.

Saeedeh Abasi, Mark Fairchild

RESEARCH HIGHLIGHT: Color Differences Using Deep Neural Networks

The appearance of a three-dimensional object is dependent upon several visual attributes including color, texture, and gloss as well as shape. Each of these attributes have been studied at length independently but a functional model that can describe the complex interactions between each attribute has not yet been developed. One approach to modelling these kinds of appearance interactions is by utilizing neural networks. The dramatic improvement of computing power in recent years allows neural networks to process large image sets in relatively short periods of time. To accomplish this, color sensitive neurons in existing neural networks will be identified and used as the input to a comparative network. Comparisons between images varying in multiple appearance attributes will be used to build a model of object appearance. This research is sponsored by HP.



Schematic of black & white and color images being compared through the AlexNet convolutional neural network to identify color sensitive neurons

Matt Ronnenberg, Susan Farnand

AlexNet: A. Krizhevsky, I. Sutskever, and G. E. Hinton. Imagenet classification with deep convolutional neural networks. In Advances in neural information processing systems, pp. 1097–1105, 2012.
Image from: J. Deng, W. Dong, R. Socher, L.-J. Li, K. Li, and L. Fei-Fei. Imagenet: A large-scale hierarchical image database. In 2009 IEEE conference on computer vision and pattern recognition, pages 248–255. IEEE, 2009.

RESEARCH HIGHLIGHT: Total Appearance of Paintings

Photogrammetry has been added to our total appearance imaging of paintings. Olivia Kuzio, PhD student, used Agisoft Metashape Professional Edition to estimate a height map from 16 images and register diffuse, normal, and height maps, shown on the left for a target painted by Roy. The right image did not use a height map and assumed the surface was planar. The center image used directional lighting. This work was presented by Olivia at the American Institute of Conservation's Annual Meeting.

Olivia Kuzio, Roy S. Berns

Normal and Height Maps

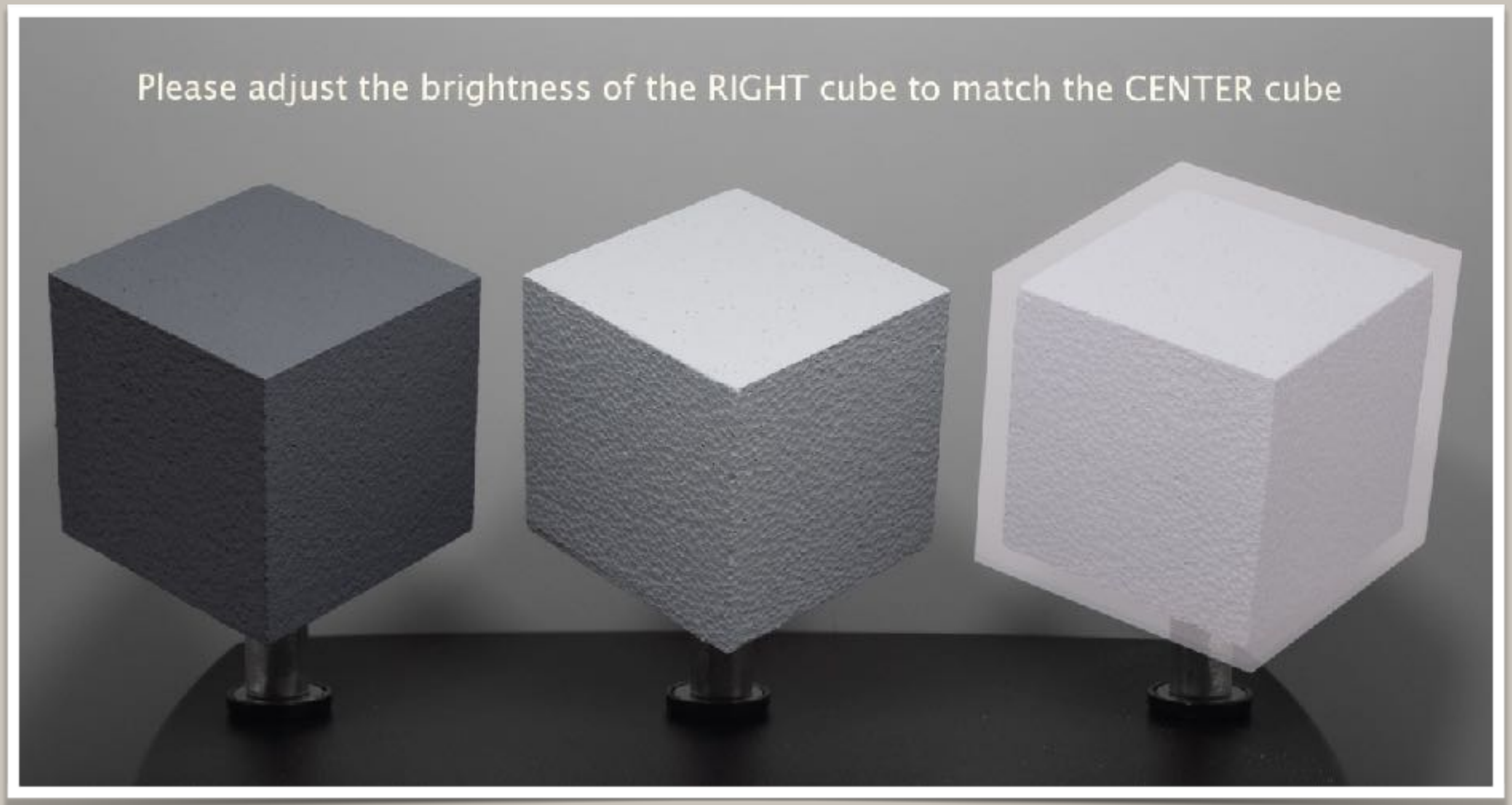
Real Lighting

Normal Map

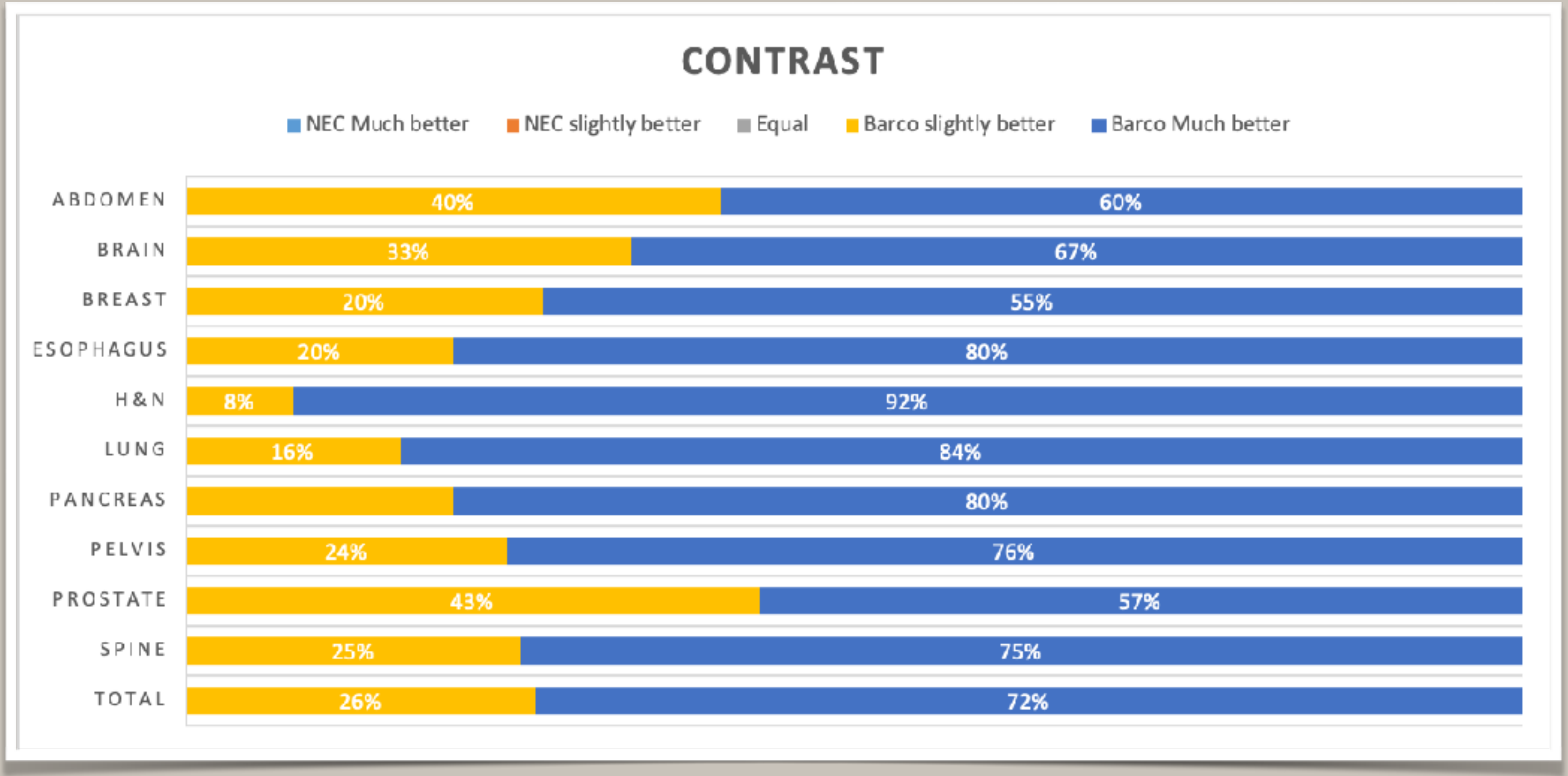
RESEARCH HIGHLIGHT: Lightness Manipulation with AR Overlays

A new experiment examined the perception of transparent augmented reality (AR) overlays on the perceived lightness of real-world physical objects. Extending work begun in 2018 with Imaging Science undergraduate student Sara Leary, the results showed clear dependence on overlay size and alignment, as well as background object reflectance. If AR overlays are tightly-aligned with the real-world objects, brightness matches are equal to luminance matches. However, AR overlays larger than the objects require higher physical luminance to appear the same brightness. This is perhaps similar to the concept of veiling luminance, which is that people can ignore, to some extent, a uniform veil when evaluating real-world objects. A paper describing the experiment and findings is in preparation.

Michael J. Murdoch



RESEARCH HIGHLIGHT: Perception in Medical Displays



Adi Robinson is a part-time Ph.D. student and employee of Rochester General Hospital (part of the Rochester Regional Health system that is RIT's healthcare partner). While he recently has moved to a new position, he continues to work on the completion of his Ph.D. dissertation on the perception of radiological images by various healthcare workers and has shown that those computing the dosimetry for radiation treatments (e.g. Adi's work as a medical physicist) can benefit from use of high-quality medical displays, usually reserved for the radiologists, and provide improved medical care. These results have been recently published in the medical journal, *Medical Dosimetry*.

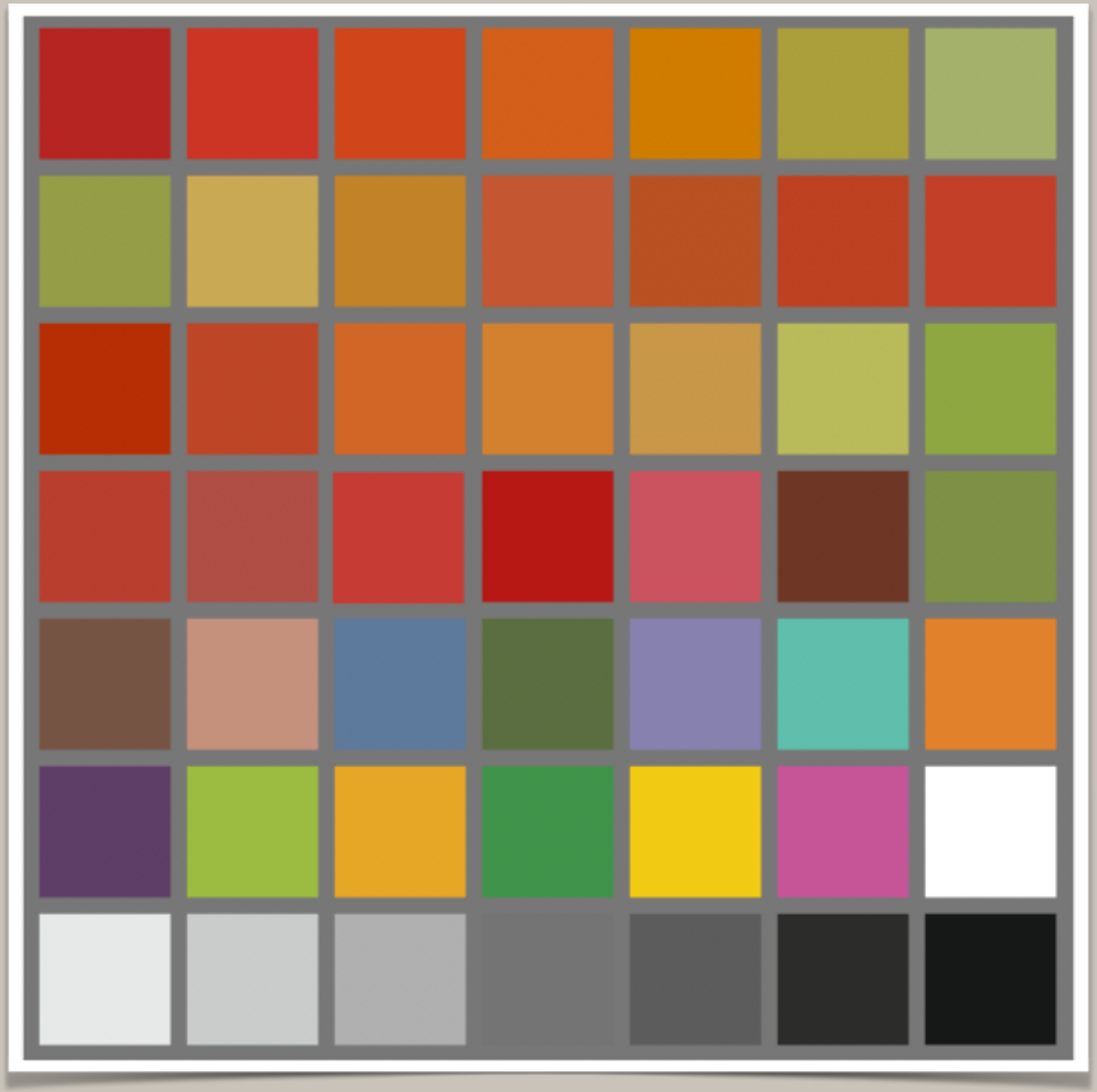
Adi Robinson, Mark Fairchild

RESEARCH HIGHLIGHT: Use of Smartphones to Determine Crop Ripeness

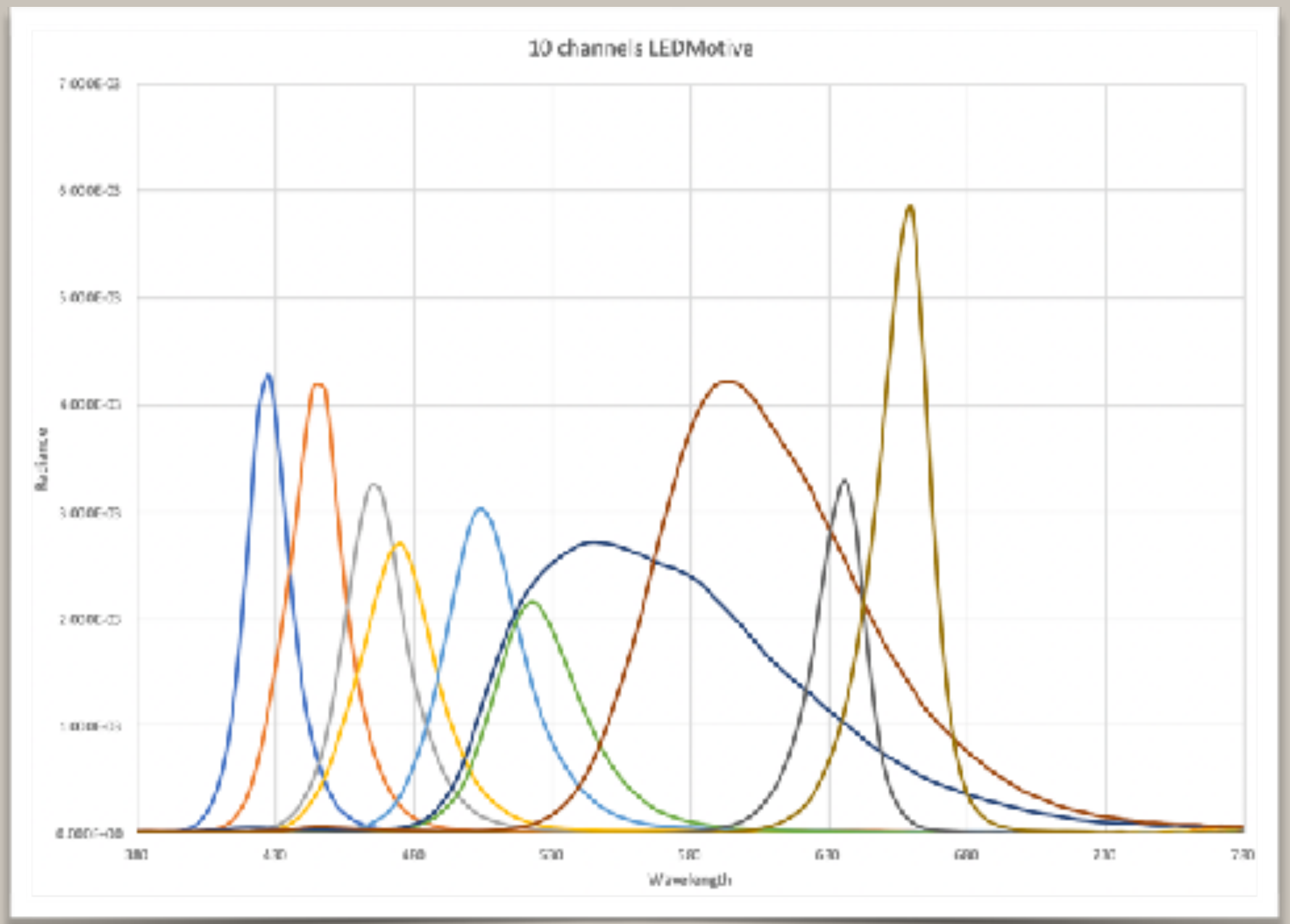
Color quality assessment provides insight into user preference and can be put to use to improve the cameras and display pipelines. The memory color of important content like human skin, food, grass and sky drives perceived color quality. Experiments were conducted to assess the impact of texture on memory color preference. In the first experiment, observers were asked to adjust patches to their memory of grass, sky, beach sand, green peppers, and skin colors. Each color was represented by four different patches, one uniform, one with a sandstone texture, one with a burlap texture and one containing real image content. In cases where the artificially generated textures closely resembled the real image content, particularly for the sky stimulus which resembled a uniform patch, participants were able to adjust the samples more consistently to their memory color. To understand the relation between memory color and the color quality preference for camera images, a second experiment was performed with five different color quality images per object. The results for color image rendering preference were image content dependent.

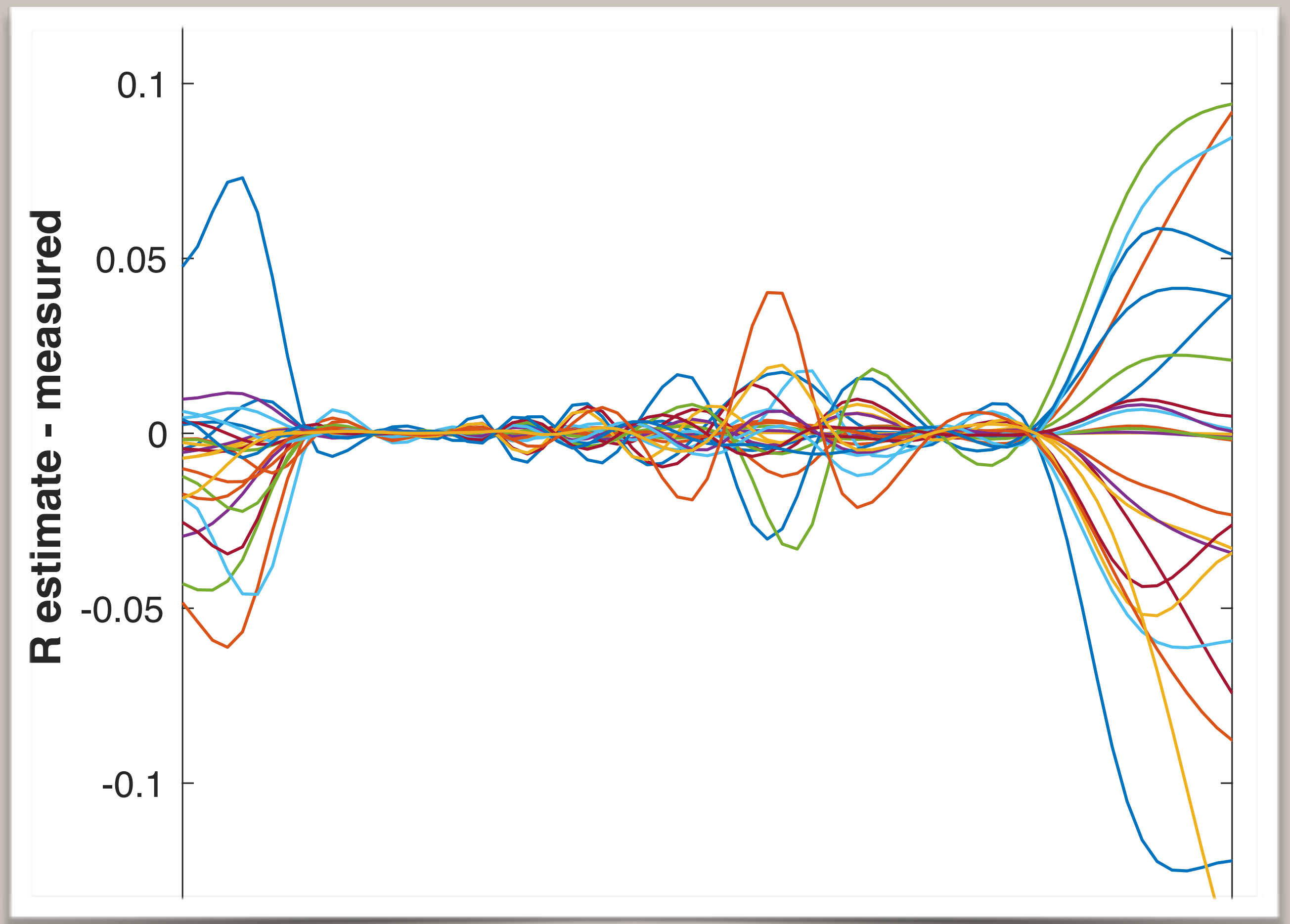
Illustration of the proposed tomato calibration target.

Katherine Carpenter, Susan Farnand



RESEARCH HIGHLIGHT: Multi-LED Sources for Multispectral Imaging





Jenibel Paray, MS student, and Roy have been evaluating a tunable multi-LED source by LEDMotive for multispectral imaging. Multiple linear regression was used to transform camera signals to spectral reflectance factor. Spectral differences between measured and camera estimates are shown for the Artist Paint Target.

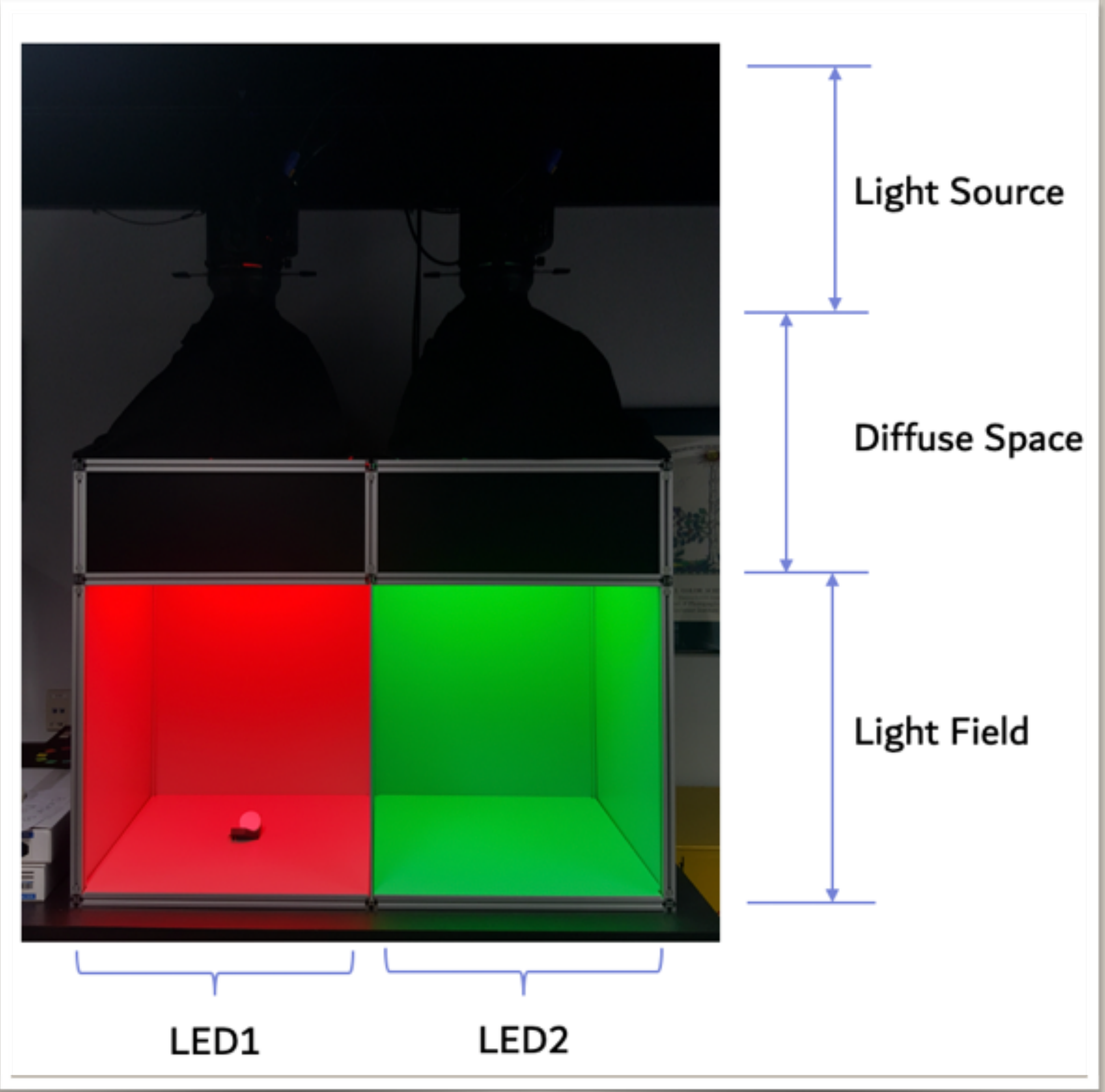
Jenibel Paray, Roy S. Berns

RESEARCH HIGHLIGHT: Influence of Color on Drug Efficacy

People respond to different colors in different ways. You may very well be aware of this effect in terms of your environment, your clothing preferences, and even your food. But what about when it comes to taking medication? The purpose of this study is to understand the effects of pill color on human perception, disposition, and eventual behavior, and the basis on which color association is developed. Participants do not ingest medication. Rather, the study looks at how people perceive the effects of pills, based on specific colors. Given the large number of intended participants, the study will be launched across RIT global campuses in a phased approach through an on-site, interactive survey. Furthermore, participant responses will be subdivided by age brackets, gender, ethnic background, educational level, and pill usage frequency. The emerging patterns will help relate the color association to demographics, thereby helping pharmaceutical companies and medical practitioners better manufacture and prescribe drugs, thus maximizing the beneficial effects of medicine in pill form on patients overall. The survey was launched in Rochester in January, 2020, and will soon be launched in Dubai, where Rema Amawi is based.

Rema Amawi, Michael J. Murdoch

RESEARCH HIGHLIGHT: Observer Metamerism Light Booth



A two-part light booth has been constructed based on ETC seven-channel LED illumination systems, one for each side of the booth. The systems, with seven "primaries" allow various colors to be produced with a large number of possible metamers. For example, a D65 color can be produced that most closely approximates the D65 spectral specification or it can be produced with as few as two primaries to make a maximally-metqmeric stimulus. Yue Yuan has completed the construction of the booth as part of her second-year project and will be examining the use of metameric matches on the two sides for various color matching functions in order to create an observer calibrator. This will allow us to approximate individual color matching functions for various applications.

Yue Yaun, Mark Fairchild, Mike Murdoch

RESEARCH HIGHLIGHT: Effect of Texture on Memory Color and Quality

Color quality assessment provides insight into user preference and can be put to use to improve the cameras and display pipelines. The memory color of important content like human skin, food, grass and sky drives perceived color quality. Experiments were conducted to assess the impact of texture on memory color preference. In the first experiment, observers were asked to adjust patches to their memory of grass, sky, beach sand, green peppers, and skin colors. Each color was represented by four different patches, one uniform, one with a sandstone texture, one with a burlap texture and one containing real image content. In cases where the artificially generated textures closely resembled the real image content, particularly for the sky stimulus which resembled a uniform patch, participants were able to adjust the samples more consistently to their memory color. To understand the relation between memory color and the color quality preference for camera images, a second experiment was performed with five different color quality images per object. The results for color image rendering preference were image content dependent. This work is supported by a gift from Qualcomm.

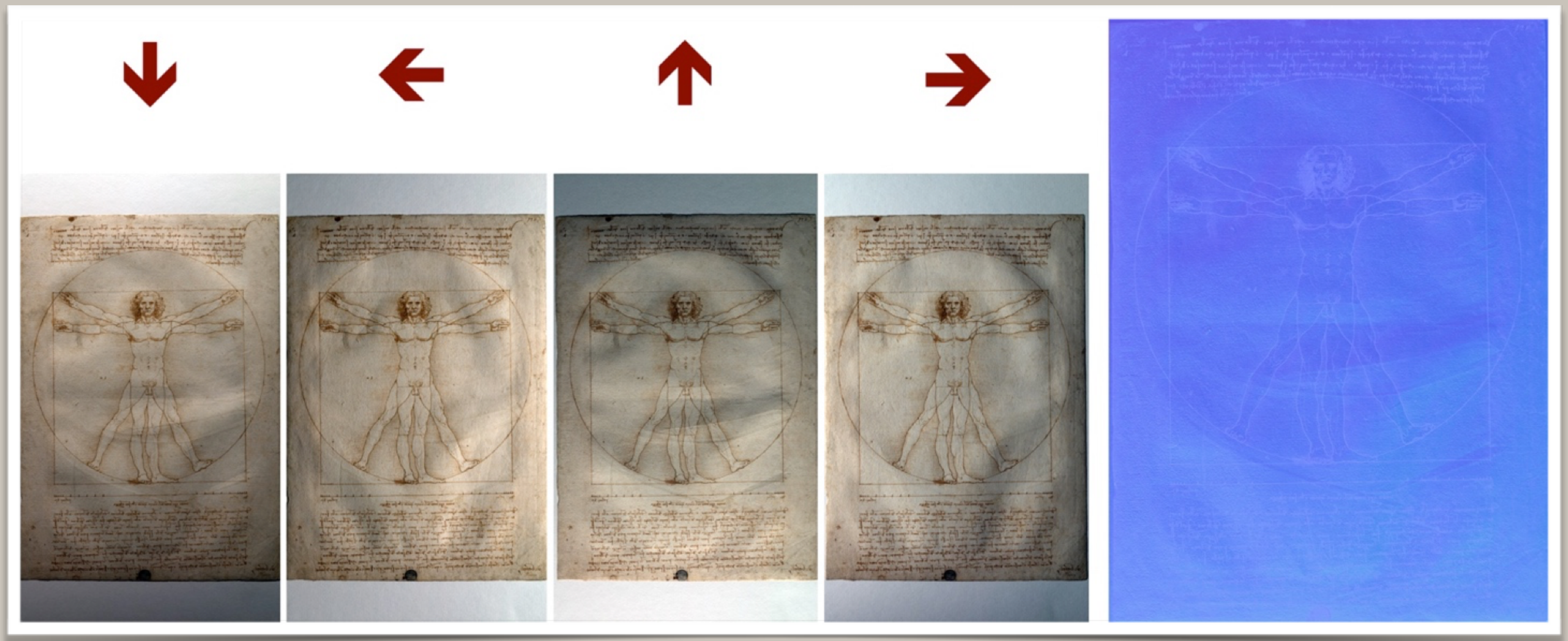
Photo is an observer participating in the experiment during ImagineRIT. The experimental setup includes a black backing to limit stray light. In the experiment, observers were shown 2 familiar object patches side by side where the observer picks the one they prefer based on color quality

Anku, Susan Farnand

RESEARCH HIGHLIGHT: Four-Light Imaging

Our four-light imaging technique was used by researchers at the Università di Bologna when Leonardo da Vinci's Vitruvian Man (and other drawings) was imaged to characterize its total appearance.

Roy S. Berns



Collected Images

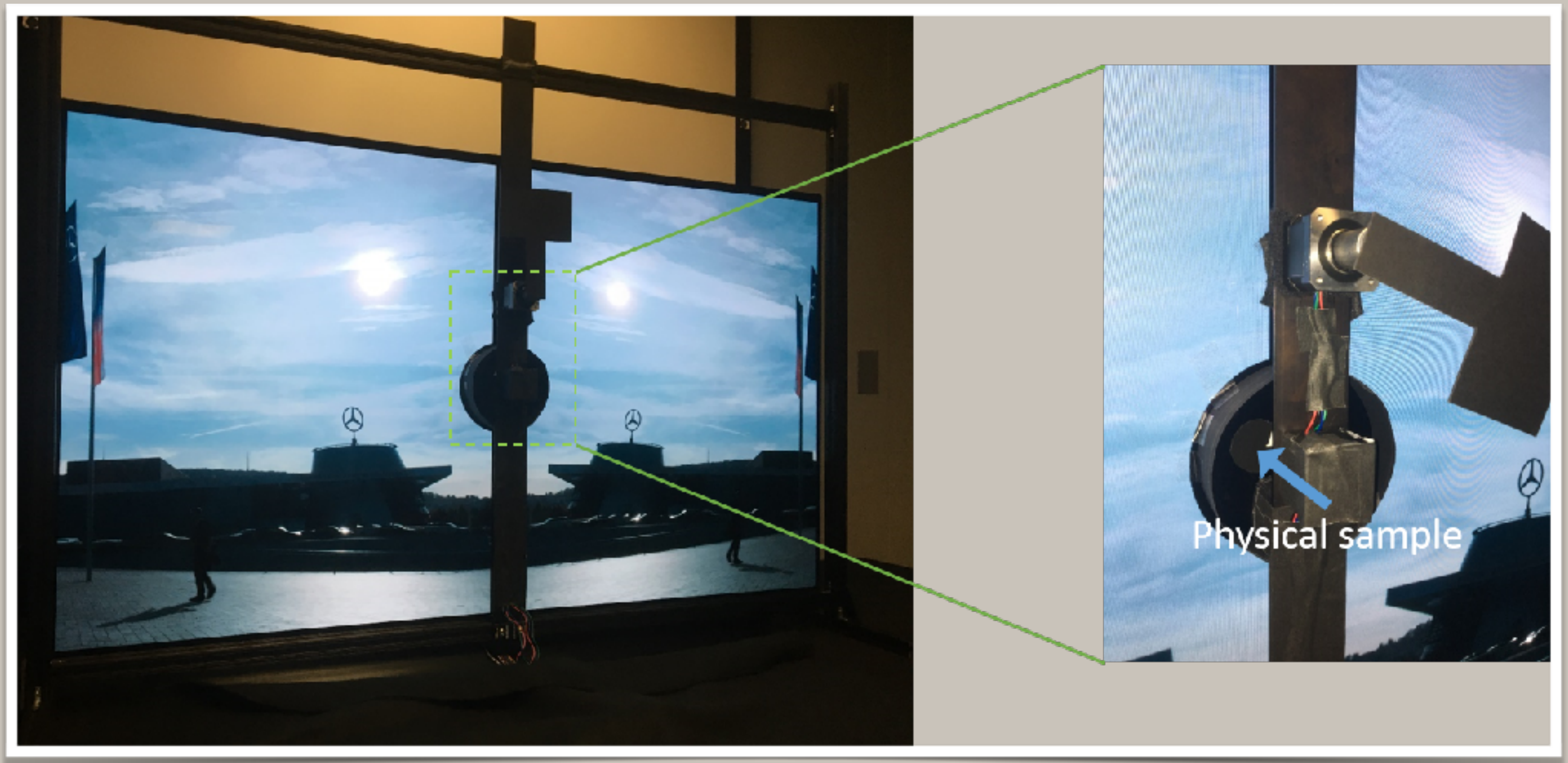
Computed Surface-Normal Map

Close-Up of Rendered Result

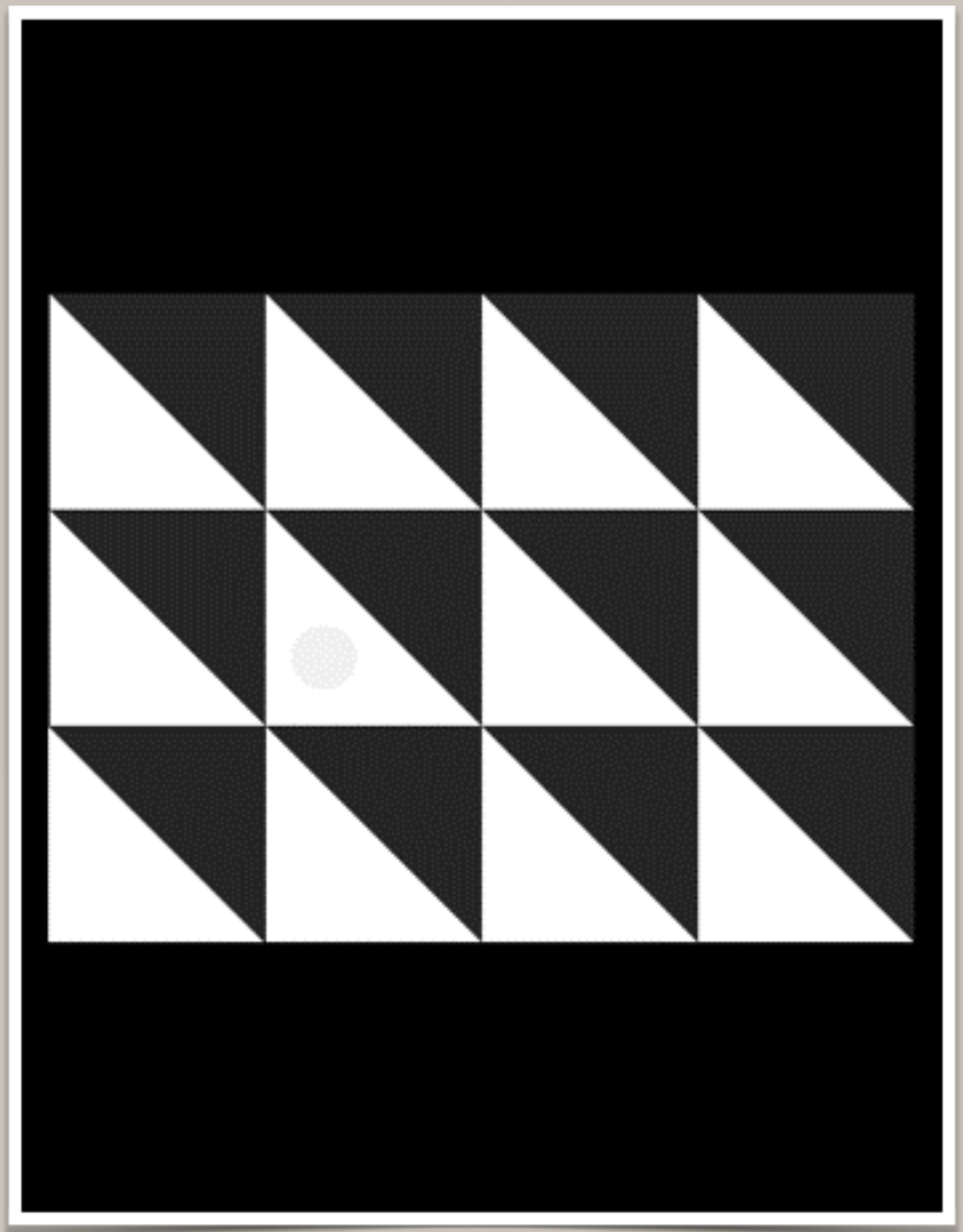
RESEARCH HIGHLIGHT: OLED Black Level

HDR OLED TVs are well-known for their ability to create deep, pure blacks. In this project, the perceptual quality of blacks are being examined, including visual comparisons between the OLED black and a super-dark 1% reflectance sample. In addition to the OLED itself, the experiment involves servo motors, moving panels, and light sensors, carefully shielded from stray light by black paper baffles in an almost-perfectly dark room (seeing the zoom-in image on the right). Different images and patterns were displayed on the OLED TV in the experiment as the background images, and the effects of luminance and glare were studied. The results help explain the lower limits of luminance discrimination and will be helpful in selecting a practical minimal black level in future displays. This project is sponsored by LG Electronics.

Fu Jiang, Michael J. Murdoch, Susan Farnand

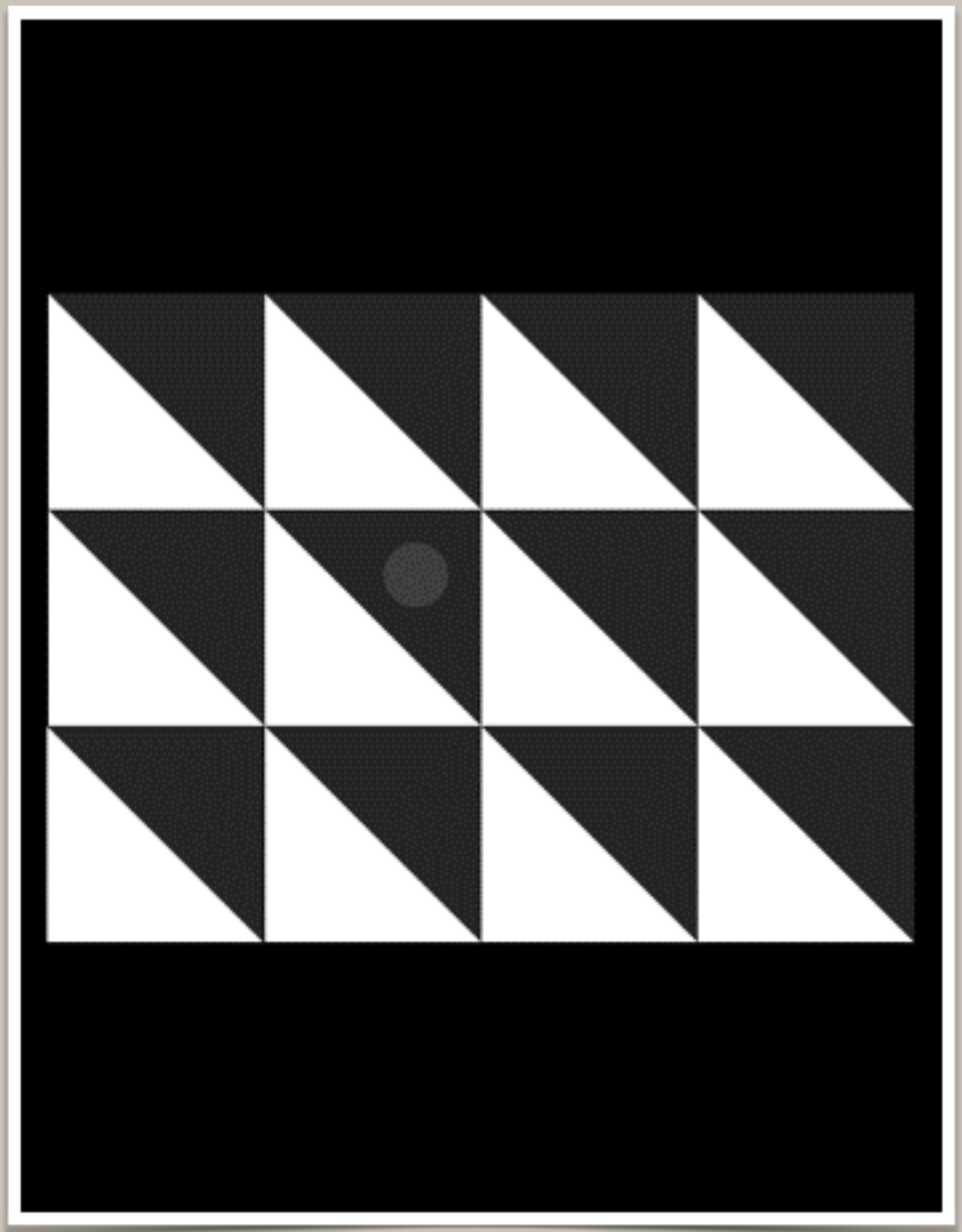


RESEARCH HIGHLIGHT: Luminance Dynamic Range Perception



Mark has been studying high-dynamic-range (HDR) image capture, display, and perception since the late 1990s and now truly capable HDR displays are available commercially to both professionals (reference displays) and consumers (e.g. backlight modulated LCDs and OLED televisions) along with the standards to drive them (e.g. Dolby Vision, HDR10). Fu Jiang is completing a dissertation on the measurement and specification of HDR display gamuts, including perceived color gamuts. With displays that can now exceed human luminance dynamic range capabilities (for some spatiotemporal configurations), we are now examining the limits of dynamic range perception as a function of display pattern to help understand just how much information needs to be encoded.

Fu Jiang, Mark Fairchild



RESEARCH HIGHLIGHT: Observer Metamerism Across Commercial Displays

A project evaluating observer metamerism on commercial displays was completed in two parts. First, based on the dissertations of MCSL alumni, Dr. Yuta Asano and Dr. David Long, in-depth simulations were conducted to evaluate the optimal representative color matching functions (CMFs) for a group of known CMFs. These simulations, which used a multidimensional scaling approach to better describe the display relations in terms of OM potentials, revealed dependencies of color/image contents and color conversion on top of display primaries. Second, a psychophysical experiment was conducted in which observers were asked to compare the color mismatches among three displays. The psychophysical results show promising correlations with a proposed OM metric. Given that the displays used in the experiment were commercial sRGB displays, our findings indicate the existence of OM even in non-WCG displays and help validate Asano's observer model. Graduate student, Hao Xie, presented the simulation work as a poster presentation at the SID 2019 conference. A journal article summarizing the entire project is in press at JOSA-A. The project was sponsored by Samsung.

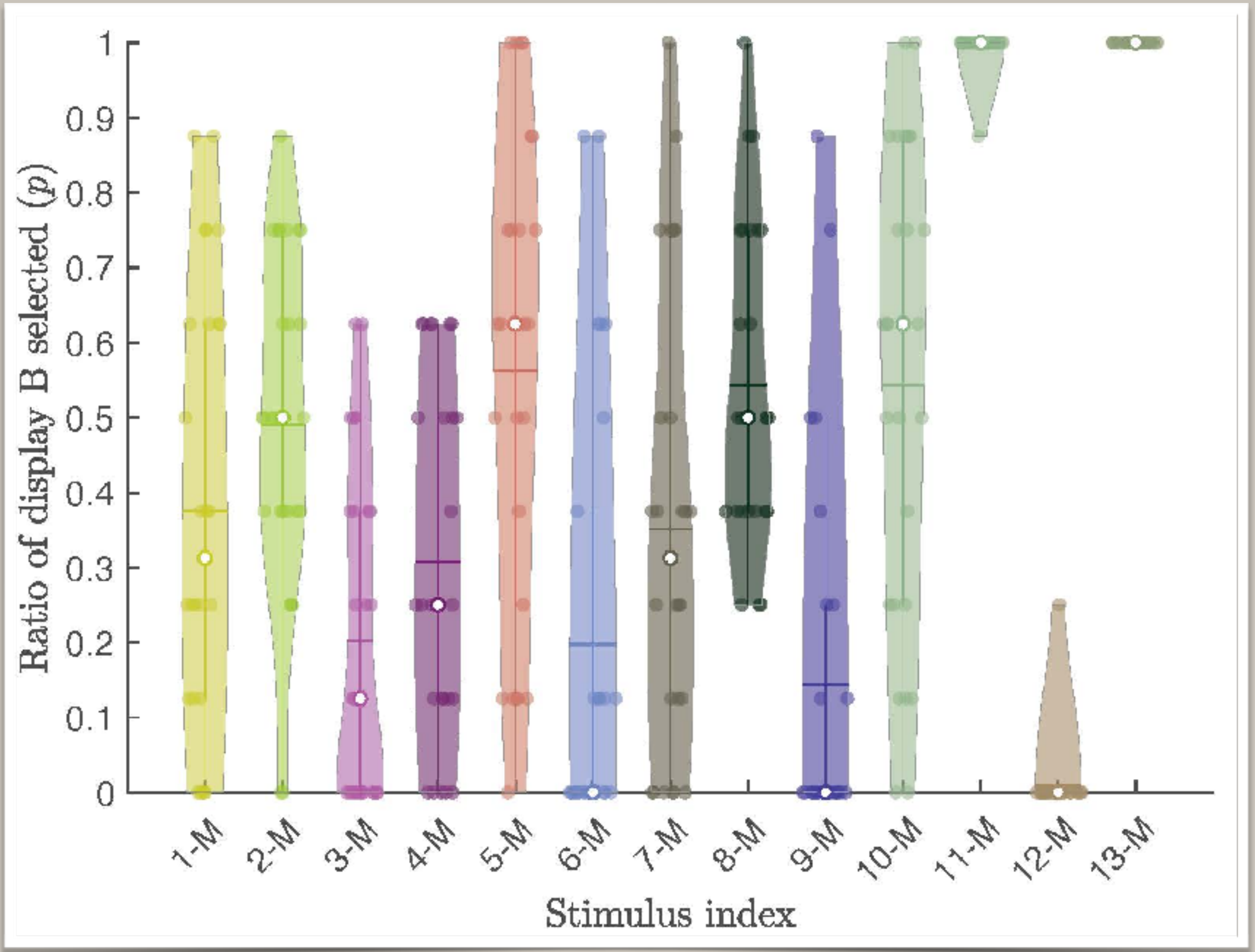
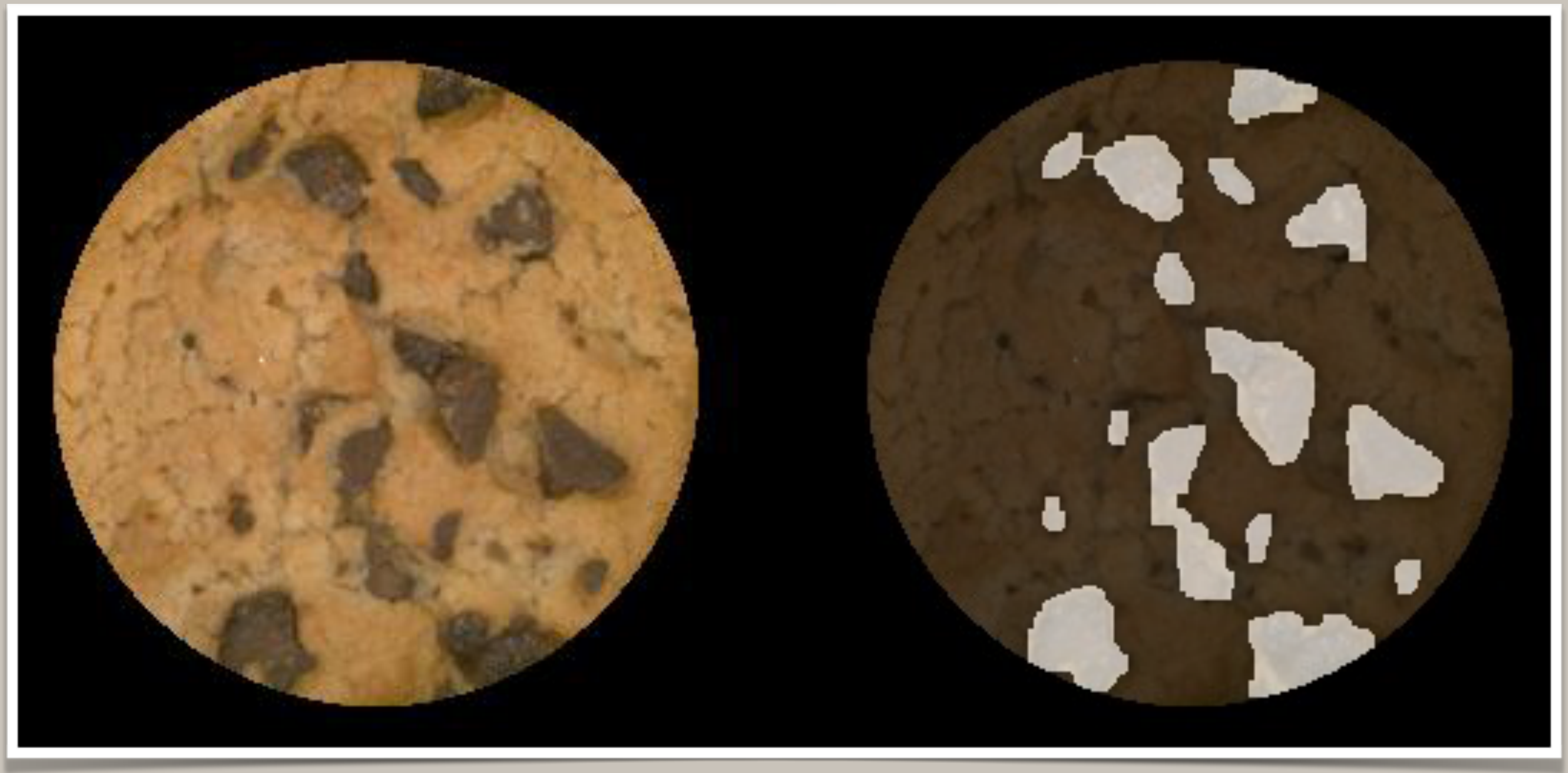


Figure shows violin plots of the proportion of times that one of the test displays was selected over the other. Each violin represents the observer distribution of p for each test stimulus, one observer as one dot. The violin colors approximate the color presented on the reference display. The mean and median are shown as horizontal line segments and white dots, respectively.

Hao Xie, Michael Murdoch, Susan Farnand

RESEARCH HIGHLIGHT: Spectral Characterization of Non-Isotropic Materials



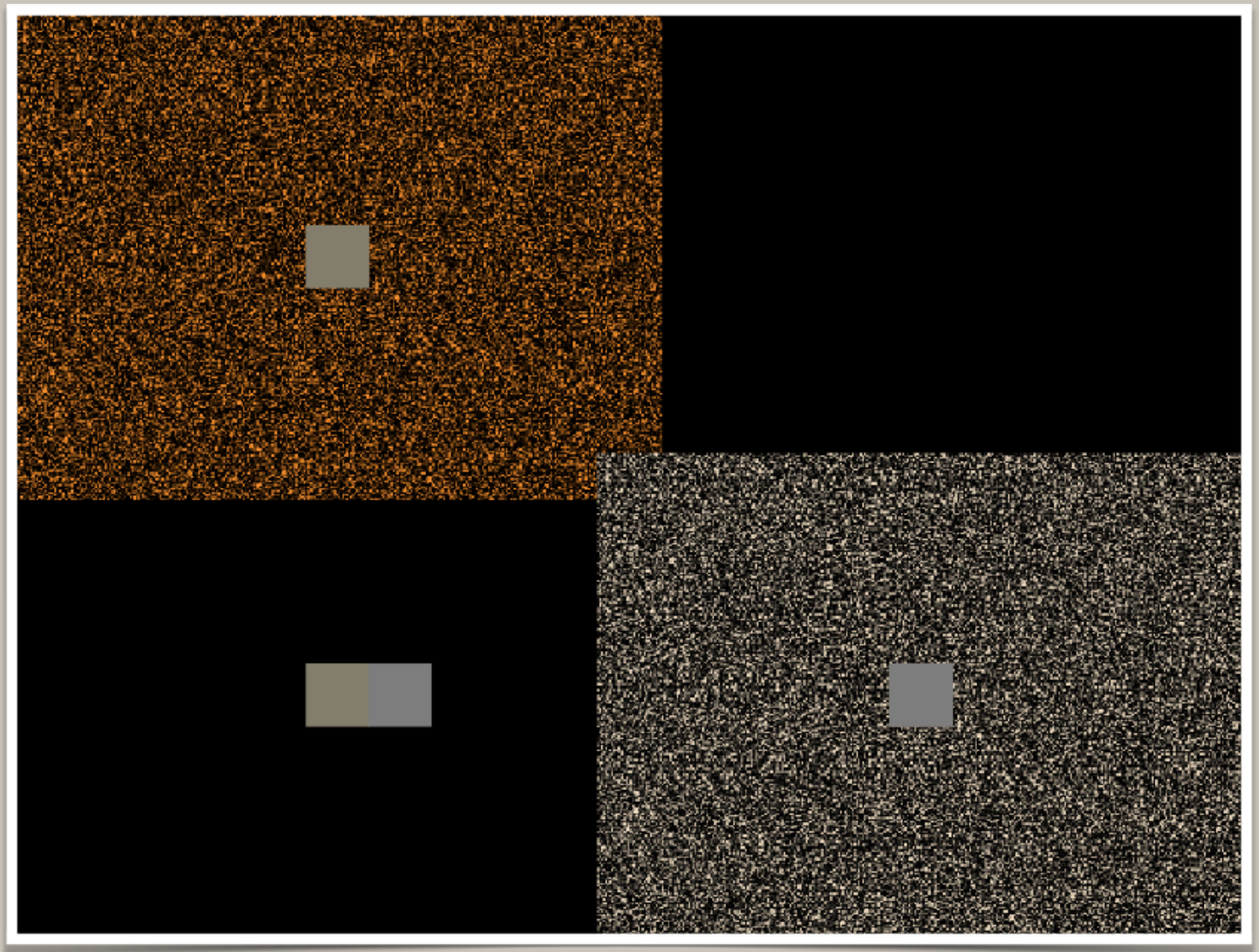
An exciting new project sponsored by HunterLab was begun near the end of 2018. The objective of the project is to discover and develop novel measurement modalities with prototype laboratory instruments using a combination of spectral measurement and RGB image data. This device could allow for improved measurement of objects with multiple distinct regions (like chocolate chip cookies!). When inhomogeneous objects are measured using traditional spectrophotometers, the resulting spectral reflectance measurement is a spatial average of the entire measurement aperture. Combining spectral measurements with pixel-by-pixel colorimetric information for such objects could allow us to infer characteristics of each distinct region.

Luke Hellwig, Lili Zhang, Michael J. Murdoch

RESEARCH HIGHLIGHT: Chromatic Adaptation Reversibility

Corresponding colors are normally thought of as being symmetric. In other words, if a match under illumination 2 is made to a color under illumination 1, it is accepted that the original color under illumination 1 will be a match to that result under illumination 2. Which viewing condition is the reference, and which the match, should not matter. Some more recent results, with greater precision, suggest that this might not strictly be the case. Mark is revisiting his research of the late 1980s to derive very precise corresponding-colors data across two adaptation directions and for a limited number of observers to test the hypothesis that chromatic adaptation is reversible. Experiments will involve memory matching to achromatic stimuli and unique hues of constrained luminance and chroma on various backgrounds. If matches are not symmetric/reversible, a whole new class of chromatic adaptation models will be required.

Mark Fairchild



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X. Kong, M. J. Murdoch, I. Vogels, D. Sekulovski, and I. Heynderickx, Perceived speed of changing color in chroma and hue directions in CIELAB, Journal of the Optical Society of America, A 36(6) pp.1022-1032 (2019).

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N.Hassani, Modeling Color Appearance in Augmented Reality, PhD Dissertation, May 2019.

G. Sheth, Subjective Image Quality Assessment of Digitally Printed Images, MS Thesis, December 2019.

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M.D. Fairchild, What sets the state of chromatic adaptation?, OSA Fall Vision Meeting, Washington, D.C., Journal of Vision 19, in press (2019).

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S.P. Farnand, Invited Presentation: Evaluating colour quality of smartphone images, Transactions Imaging/Art/Science: Image Quality, Content and Aesthetics, University of Westminster, London (2019).

M. J. Murdoch, Invited Paper: Dynamic Color Control in Multiprimary LED Lighting Systems, in SID Symposium Digest of Technical Papers. San Jose, CA: SID (2019).

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S.P. Farnand, Adaptation, in Encyclopedia of Color Science and Technology, Shamey, R., Springer Publishing Company, Incorporated (2019).

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Other Publications

M.D. Fairchild, Curious Kids: How do my eyes adjust to the dark and how long does it take?, The Conversation, Oct. 3, (2019). <https://theconversation.com/curious-kids-how-do-my-eyes-adjust-to-the-dark-and-how-long-does-it-take-124044>

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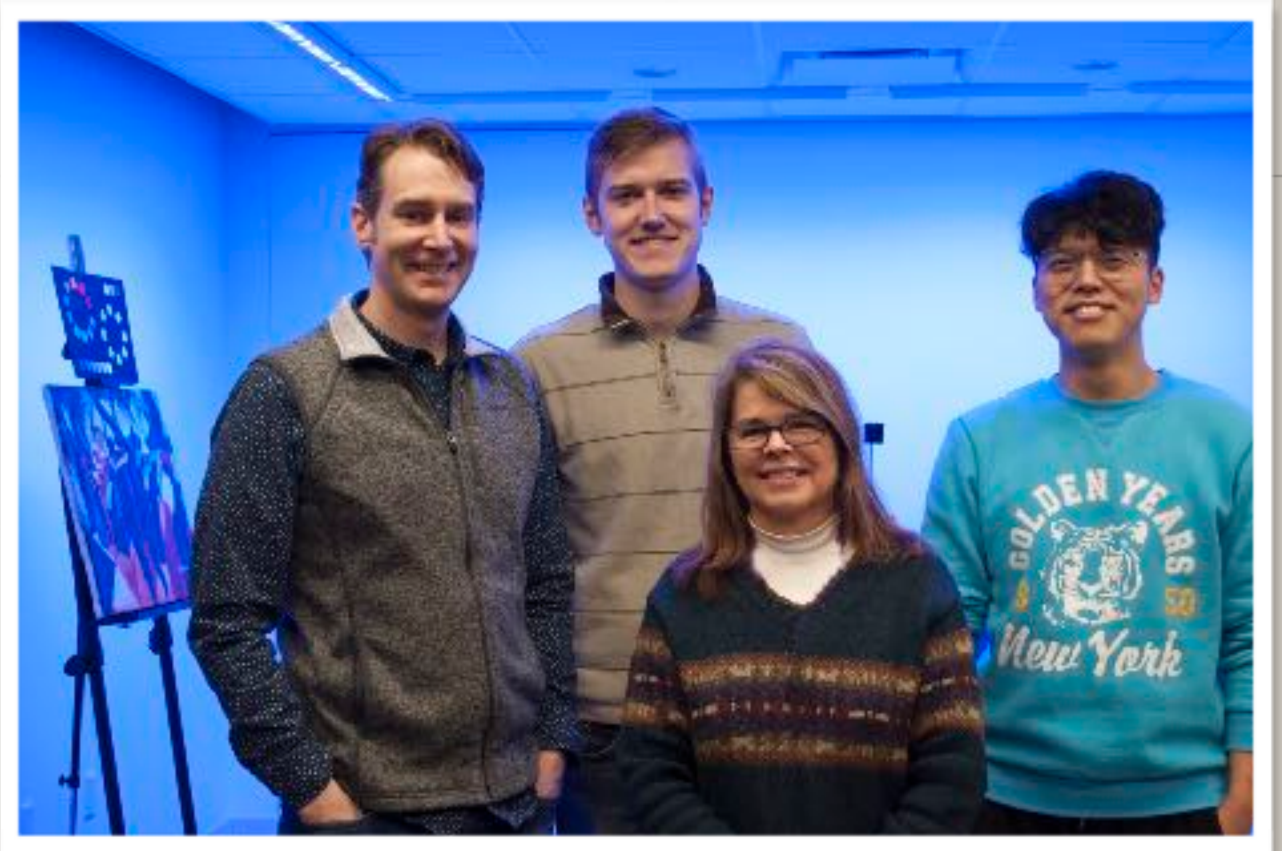

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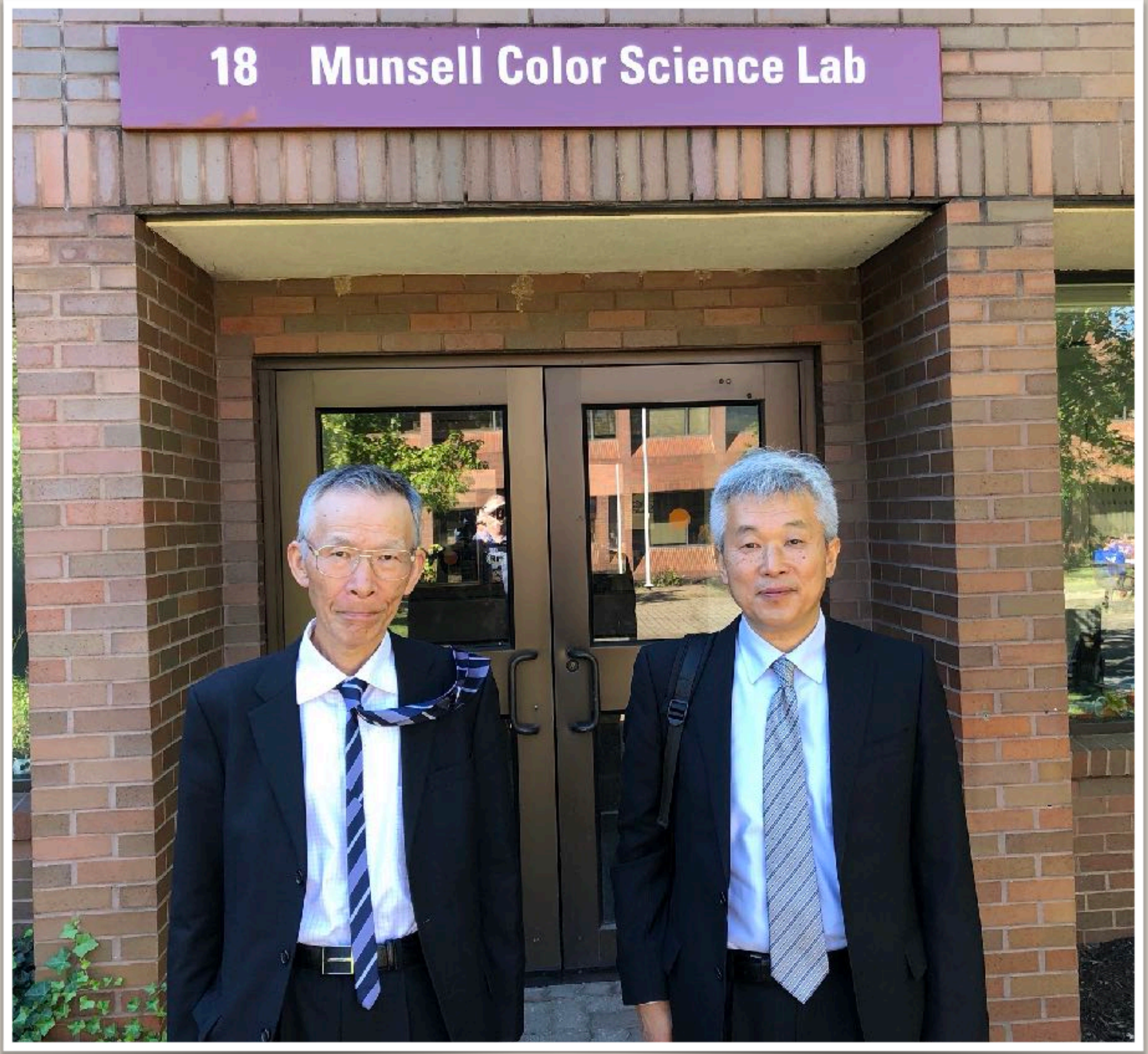
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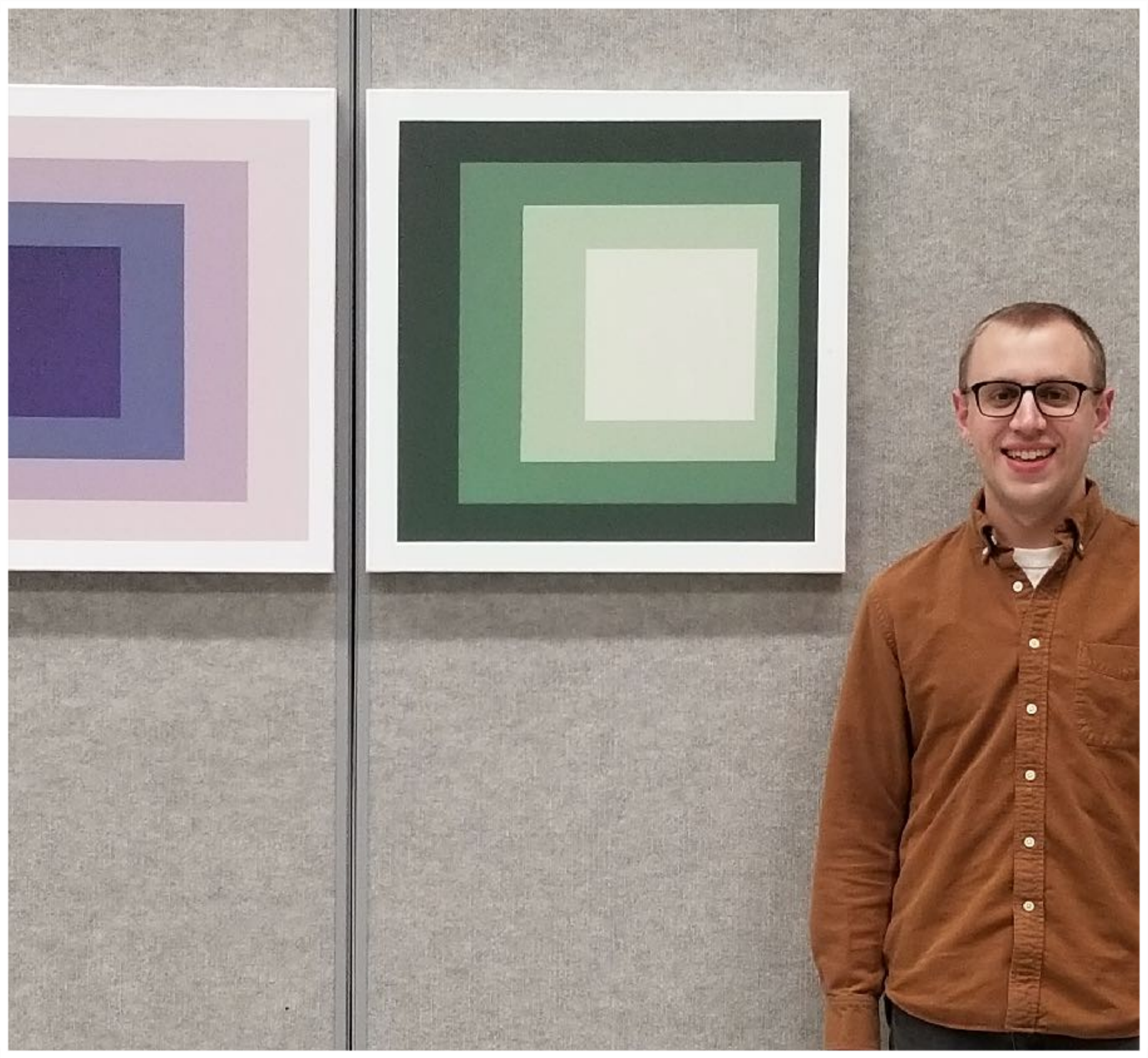
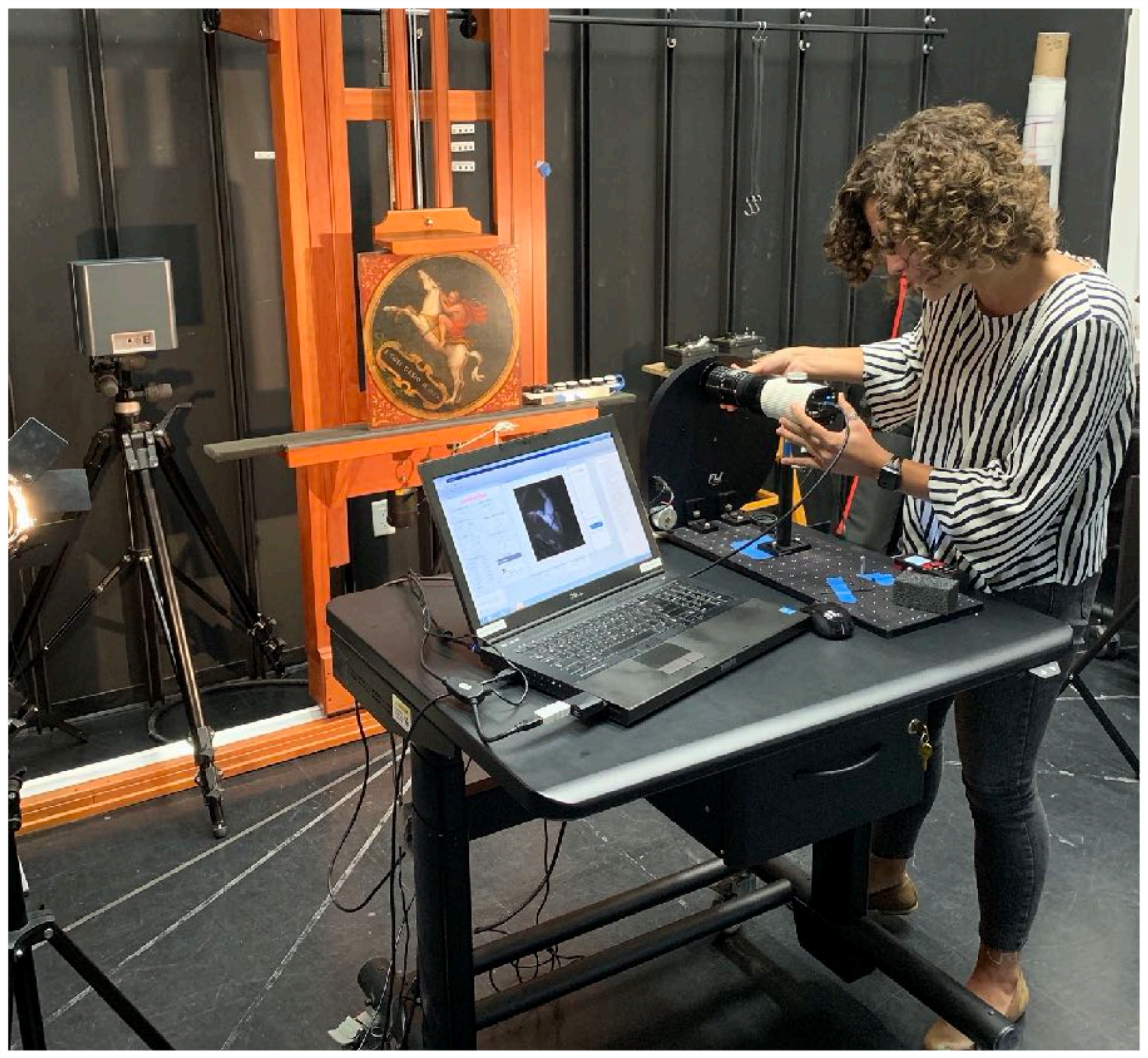
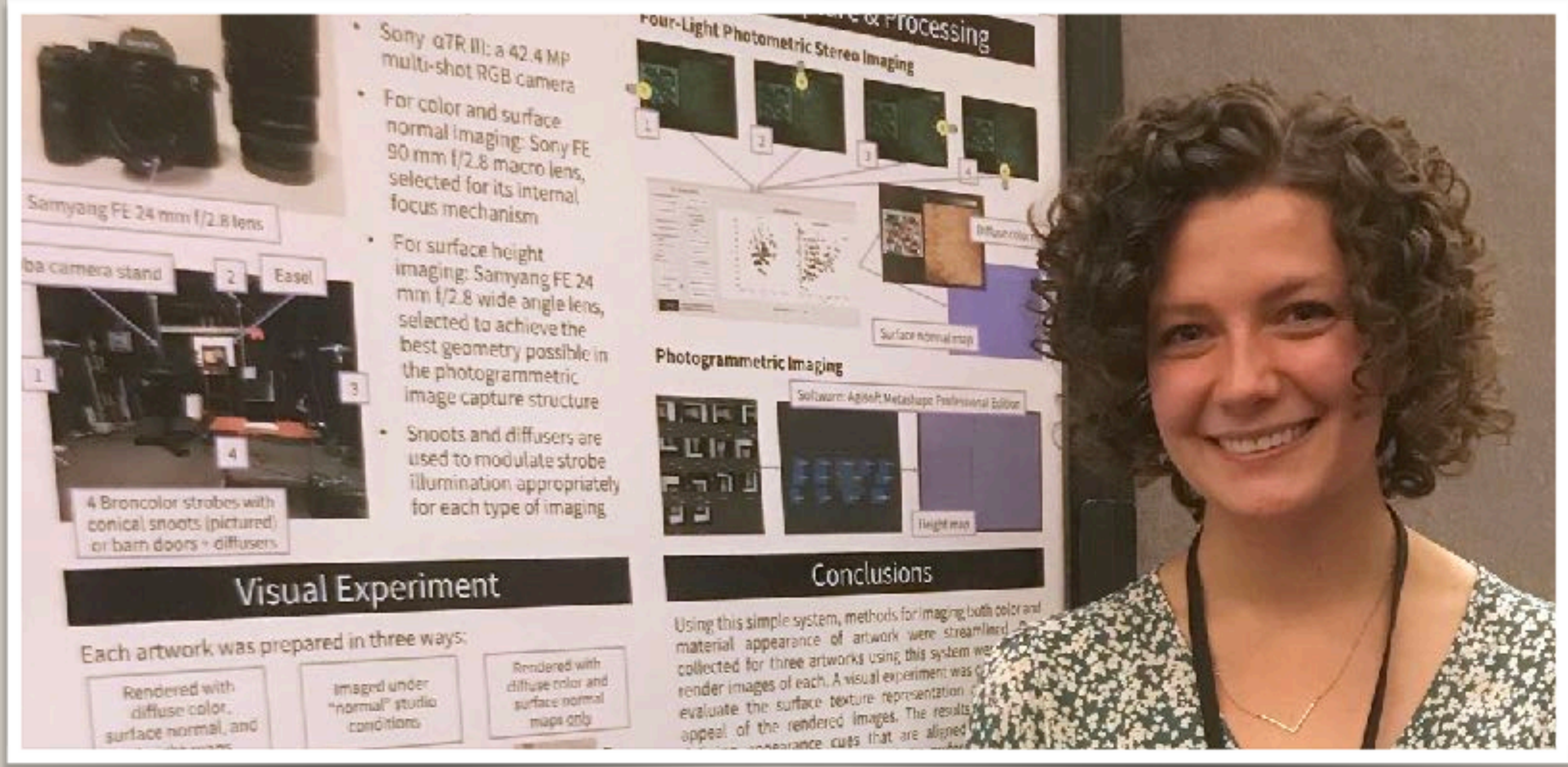
SpectraScan


TO
NEVADA
125 YEARS OF

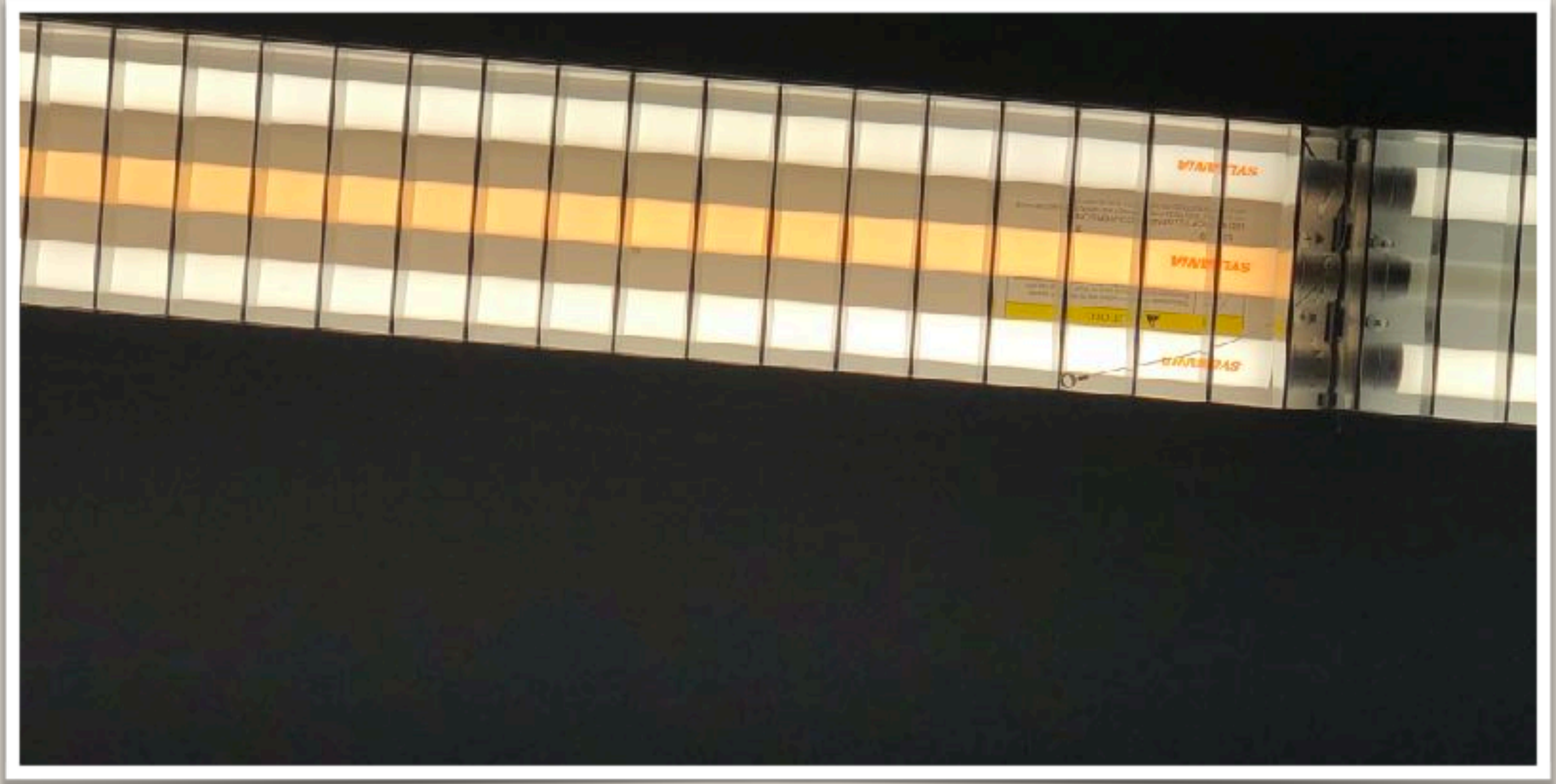
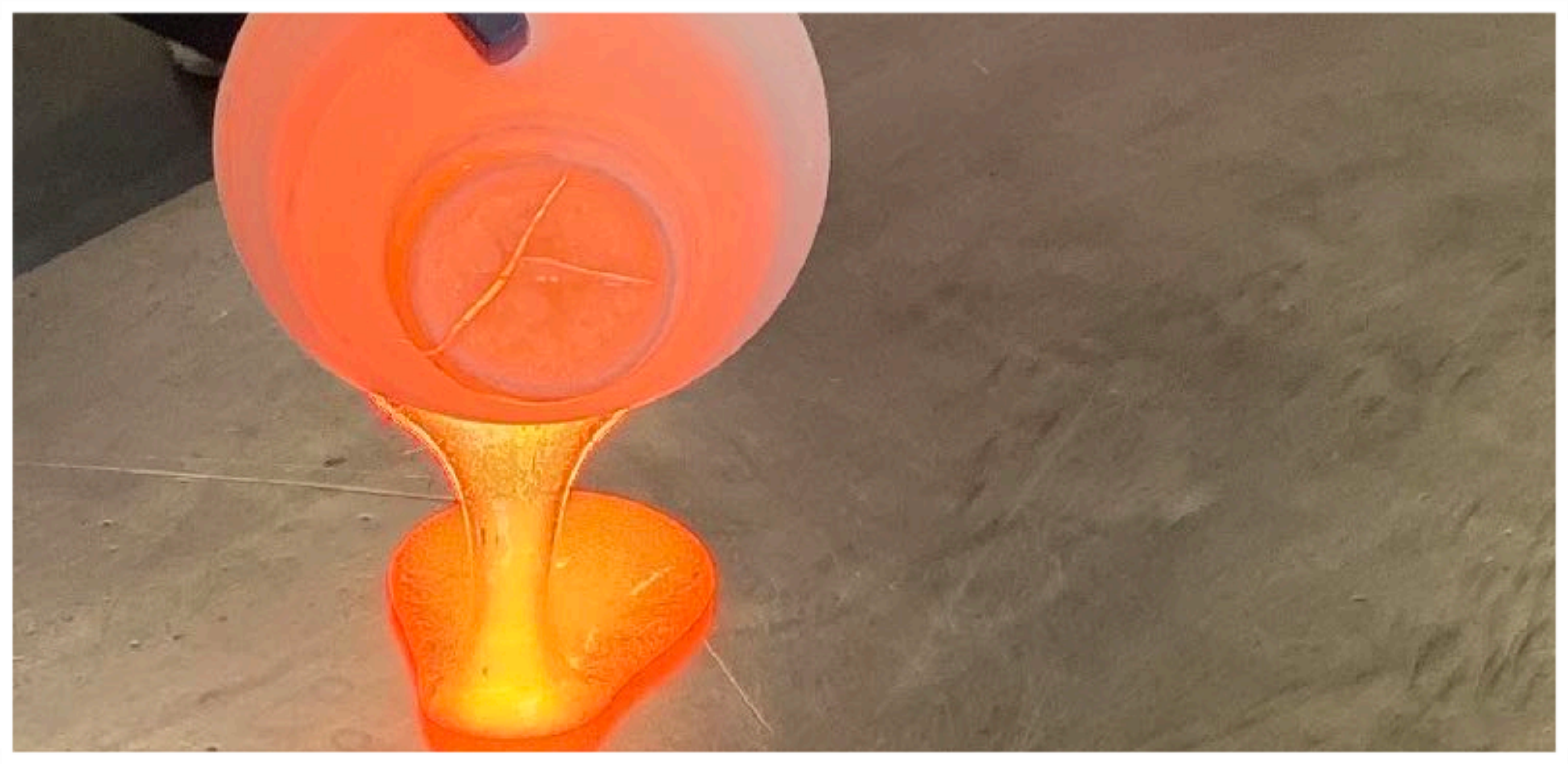





Absorbing species in Beer
Where does "beer color" come from?
The bulk comes from the grains from which the beer is made.
Grains can be pale, dark, or in between, based on length and temperature profile of kilning process
Grain color ratings are based on laboratory mash
• Grain and water amounts, temperature, time specified


Sony α7R III: a 42.4 MP multi-shot RGB camera
For color and surface normal imaging: Sony FE 90 mm f/2.8 macro lens, selected for its internal focus mechanism
For surface height imaging: Samyang FE 24 mm f/2.8 wide angle lens, selected to achieve the best geometry possible in the photogrammetric image capture structure
Snoots and diffusers are used to modulate strobe illumination appropriately for each type of imaging
Samyang FE 24 mm f/2.8 lens
Easel
4 Broncolor strobes with conical snoots (pictured) or barn doors + diffusers
Four-Light Photometric Stereo Imaging
Photogrammetric Imaging
Visual Experiment
Each artwork was prepared in three ways:
Rendered with diffuse color,
Imaged under "normal" studio conditions
Rendered with diffuse color and surface normal maps only
Conclusions


USW
Screen Left - Top
Full Raster: 8064 x 3456
Each Quadrant: 4032 x 1728 with 5px border
USW
Screen Right - Top
USW
Screen Left - Bottom
Full Raster: 8064 x 3456
USW
Screen Right - Bott
RIT | MAGIC Spell Studios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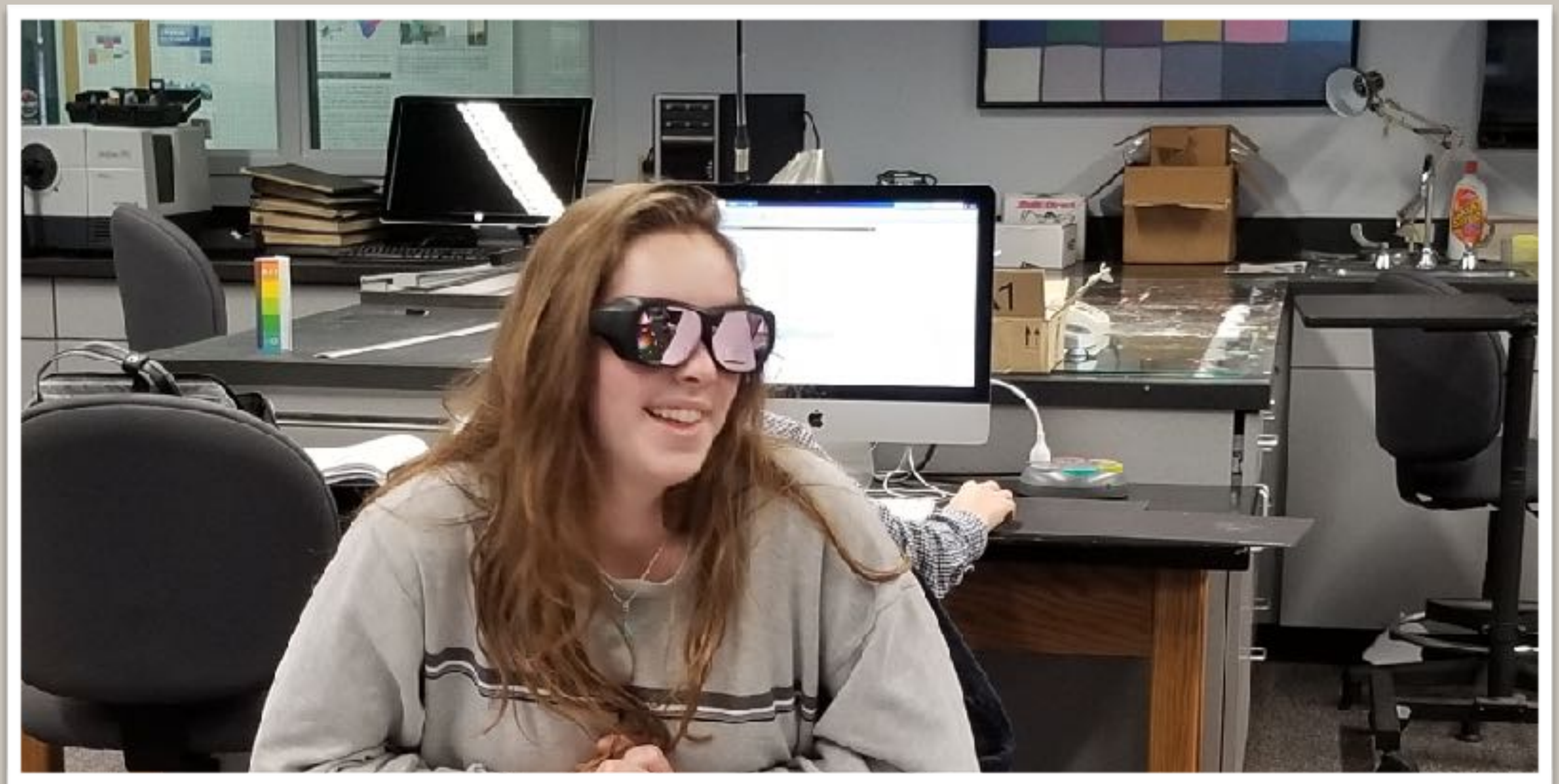

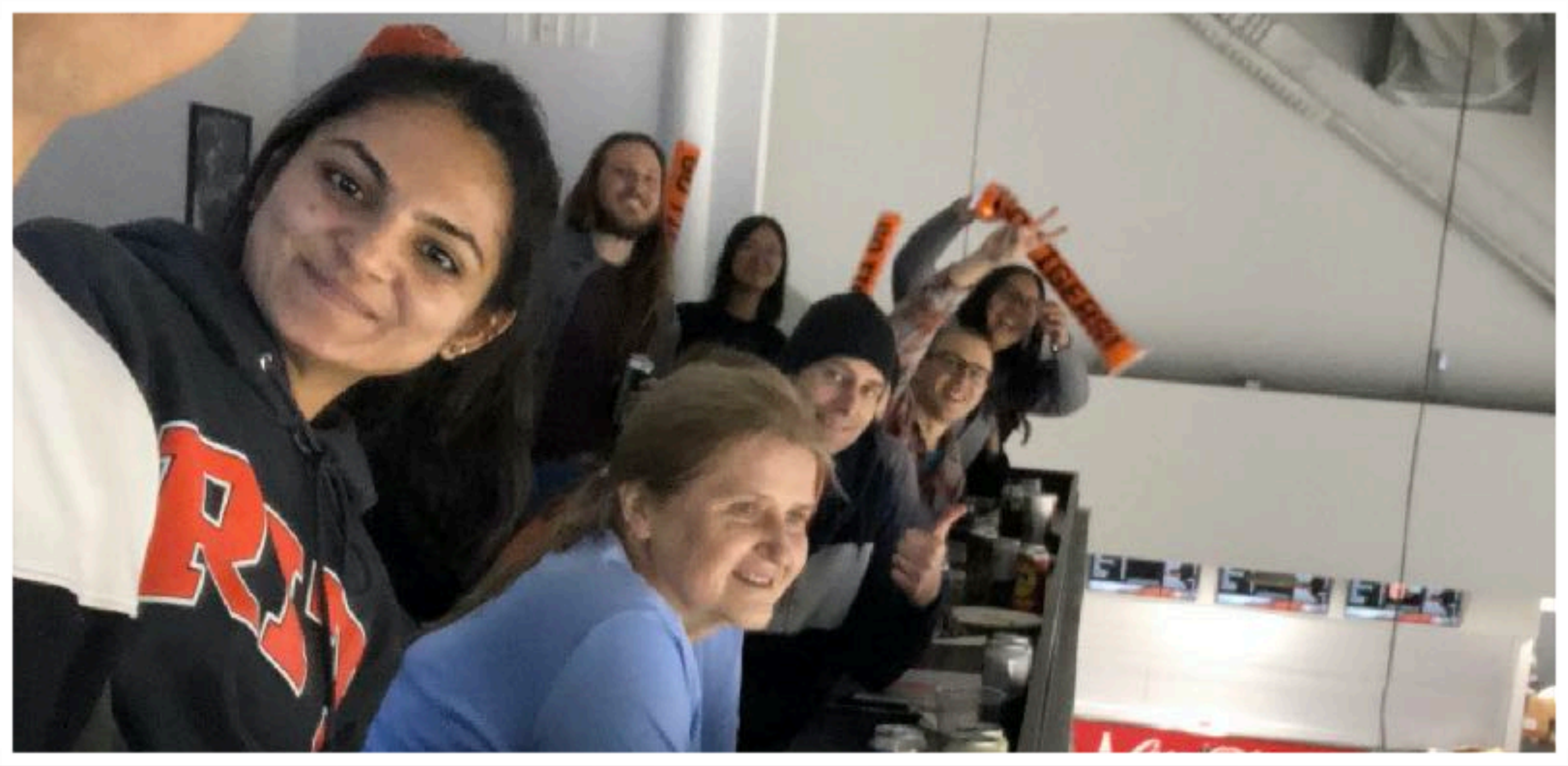

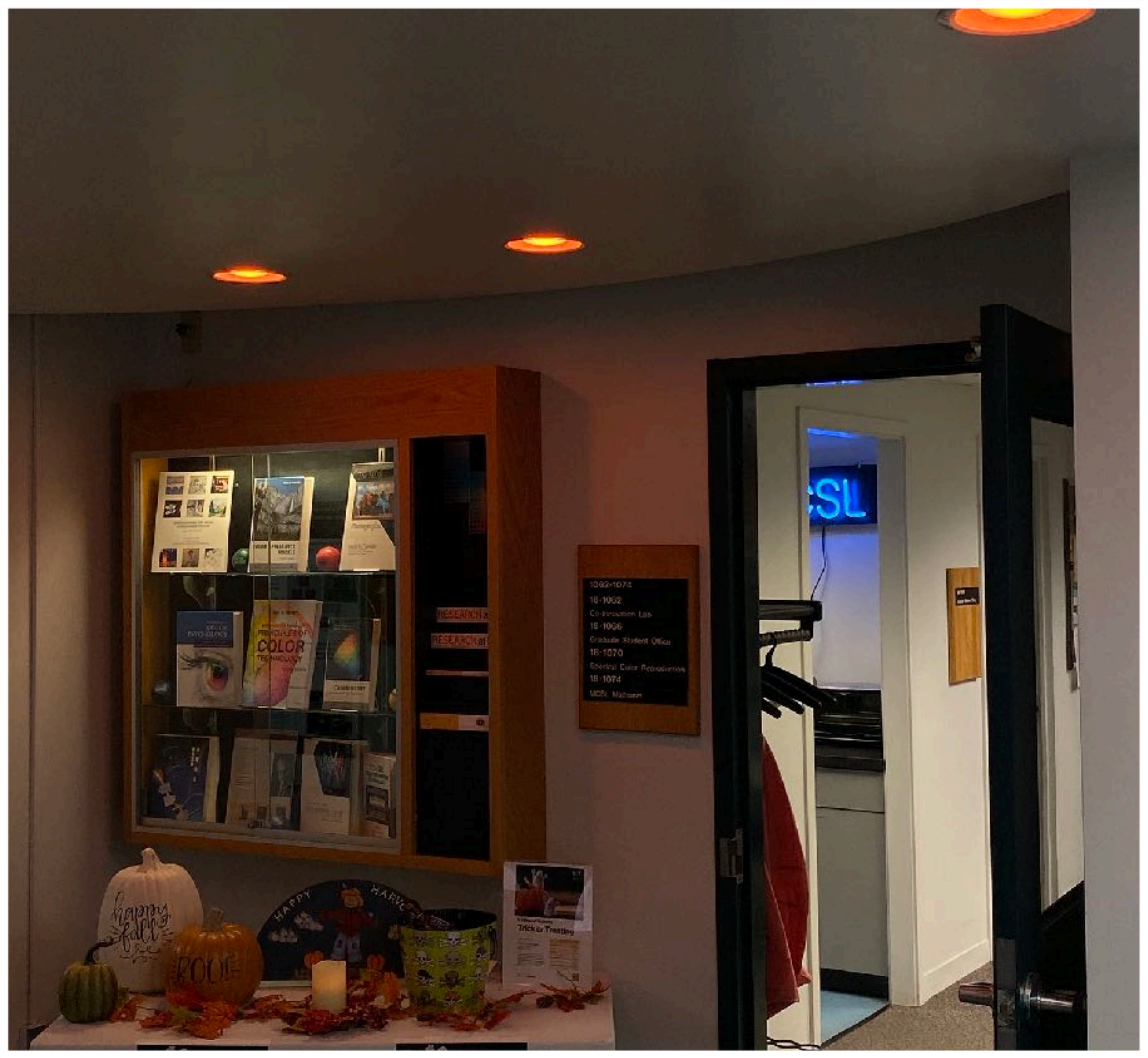
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COLOR


STOP


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