PoCS/MCSL

Program of Color Science

Munsell Color Science Laboratory

Annual Report 2020

Rochester Institute of Technology

College of Science

DIRECTOR'S REFLECTIONS: Year of Wonders 2020-21

My title is taken from a website of the UK National Trust entitled *Year of Wonders 1665-1667* <*https://www.nationaltrust.org.uk/woolsthorpe-manor/features/year-of-wonders*> that discusses Isaac Newton's time at Woolsthorpe while escaping Cambridge during the *Great Plague*. During that time, Newton completed his famous experiments on the colors of the spectrum in his bedchamber *(image at right ©National Trust)* and also happened to have that proverbial apple fall on his head as well as making major advances in the definition of calculus. Newton stated that *"For in those days I was in the prime of my age for invention & minded Mathematics & Philosophy more than at any time since."* We, in PoCS/MCSL have used Newton's time and productivity during a global pandemic to inspire us to creative new heights in research and education during our "quarantine" from the COVID-19 pandemic this past year.

Despite the trying times world-wide the students, staff, and faculty of PoCS/MCSL more than stood up to the challenge. We redesigned the lab for extreme social distancing under RIT's very successful COVID safety plans, we developed new ways to communicate and hold our important meetings (including qualifying and candidacy exams and dissertation defenses) and we participated strongly in international conferences, seminars, and symposia as both organizers and contributors. We learned much this year that will make the field better and more efficient in years to come.

It is with truly mixed emotions that I must report that Valerie Hemink has decided to retire from RIT as of early 2021. Val has been a key part of the lab for two decades and we will all miss her greatly, while at the same time wishing her well with her family in retirement. THANK YOU, VAL!

Stephanie Livingston-Heywood is now joining us as the PoCS/MCSL Sr. Staff Assistant and we are all very much looking forward to having her as part of the team. WELCOME, STEPH!

And, of course, Roy Berns completed the move to retirement early in 2020 after a long and very distinguished career at RIT. Please see the 2019 annual report for more details and a message from Roy.

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 2020, Matt Ronnenberg (Ph.D.) and Jenibel Paray (M.S.) and we have several students on deck to be graduating soon. Some highlights of the year 2020 include:

continues ..

DIRECTOR'S REFLECTIONS: Continued

~Dr. Christopher Thorstenson will join PoCS/MCSL as an Assistant Professor in August 2021.
~Dr. Mekides Abebe will join PoCS/MCSL as the R.S. Hunter Visiting Assistant Professor of Color Science, Appearance, & Technology in August 2021.
~Dr. Fairchild received the 2020 RIT Trustees Scholarship Award
~Dr. Murdoch gave an invited presentation "Color and Brightness in Optical See-Through Augmented Reality Display Systems," at International Display Week (IDW 2020), Japan
~Dr. Fairchild's HPCG paper with NVIDIA received a best paper award
~Dr. Farnand received unrestricted gifts from Apple and HP to support her research

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:
~Anonymous, Apple, Avian Rochester, BabelColor, Arthur Elzy, Scot Fernandez, Hewlett Packard, HunterLab, LG, Mellon Foundation, NSF, 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, but is a living system. As a special note we have extended our "alumni" list this year to include our many visiting researchers who have been a integral part of the lab since the beginning. They are listed under the year they completed their visits.

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

STUDENTS, VISITORS, & GRADUATE ALUMNI

Visiting Researchers

Katie Albus, Michigan State U.
Siyuan Chen, The Hong Kong Polytechnic 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
Minyao Li, PhD, CS
Zilong Li, PhD, CS
Yongmin Park, PhD, CS
Adi Robinson, PhD, CS
Che Shen, PhD, CS
Yuan Tian, PhD, CS
Ming Ming Wang, PhD, IS
Abby Weymouth, MS, CS
Hao Xie, PhD, CS
Yue Yuan, MS, CS
Lili Zhang, PhD, CS

"Alumni"

2020
Jenibel Paray, MS, CS
Matt Ronnenberg, PhD, CS

2019
Saeedeh Abasi, VR
Nargess Hassani, PhD, CS
Gaurav Sheth, MS, CS

2018
Kensuke Fukumoto, VR
Rik Spieringhs, VR

2017
Brittany Cox, PhD, CS
Kensuke Fukumoto VR
Xiangzhen Kong, VR
Morteza Maali Amiri, MS, CS
Samuel Morillas Gómez, VR
Chris Thorstenson, MS, CS

2016
Yixuan Wang, MS, CS
Francis Wild, VR
Joel Witwer, MS, CS

2015
Yuta Asano, PhD, CS
Yiheng Cai, VR
Shengyan Cai, VR
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
Timo Eckhard, VR
Adrià Forés Herranz, PhD, CS

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

2012
Ping-Hsu (Jones) Chen, MS, CS
Carrie Houston, BS, IS
Kenichiro Masaoka, VR
Simon Muehlemann, MS
Weiping Yang, VR

2011
Anthony Blatner, MS, CE
Yiheng Cai, VR
Jie Feng, VR
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

VISITORS & GRADUATE ALUMNI — 2000s

2009
Erin Fredericks, MS, IS
Rodney Heckaman, PhD, IS
Koichi Iino, VR
Mahnaz Mohammadi, PhD, IS
Shizhe Shen, MS, CS

2008
Farnaz Agahyan, VR
Lina Carenas, VR
Stacey Casella, MS, CS
Ying Chen, MS, CS
Iichiro Katayama, VR
Hideyasu Kuniba, VR
Nobuhito Matsushiro, VR
Mahdi Nezamabadi, PhD, IS
Abhijit Sarkar, MS, CS
Philipp Urban, VR
Yang Xue, MS, IS
Hongqin (Cathy) Zhang, PhD, IS
Yonghui (Iris) Zhao, PhD, IS

2007
Kenneth Fleisher, MS, CS
Rafael Huertas, VR
Andreas Kraushaar, VR
Jiangtao (Willy) Kuang, PhD, IS
Manuel Melgosa, VR

2006
Yongda Chen, PhD, IS
Yu-Kuo Cheng, VR
Timothy Hattenberger, MS, IS
Zhaojian (Li) Li, MS, CS
Rafael Nicolas, VR
Joseph Stellbrink, MS, CS
Shohei Tsustumi, VR
Xiaoxia Wan, VR

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
Hiroshi Yamaguchi, VR

2004
Takayuki Hasegawa, VR
Andreas Kraushaar, VR
Paul Kuiper, VR
Takayuki Ogasahara, VR
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
Masao Inui, VR
Edward Hattenberger, MS, CS
Steve Jacob, MS, IS
Xiaoyun (Willie) Jiang, PhD, IS
Garrett Johnson, PhD, IS
Kiyotaka Nakabayashi, VR
David Robinson, MS, IS
Mitchell Rosen, PhD, IS
Deniz Schildkraut, MS, CS
Hisao Shirasawa, VR
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
Jae Chul Shin, VR
Yat-ming Wong, MS, IS

2001
Hirokazu Kasahara, VR
Alexei Krasnoselsky, MS, CS
Sun Ju Park, MS, CS
Michael Sanchez, MS, IS
Lawrence Taplin, MS, CS
Barbara Ulreich, MS, IS

2000
Yoshihito Azuma, VR
Sergio Gonzalez, MS, CS
Sharon Henley, MS, CS
Patrick Igoe, MS, IS
Susan Lubecki, MS, CS
Richard Suorsa, MS, CS

VISITORS & GRADUATE ALUMNI —1980s & 1990s

1999
Gus Braun, PhD, IS
Barbara Grady, MS, CS
Akihiro Ito, VR
Katherine Loj, MS, CS
Jonathan Phillips, MS, CS
Mark Reiman, MS, CS
Mark Shaw, MS, CS
Masayoshi Shimuzu, VR
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
Hideto Motomura, VR
Katsuya Itoh, VR
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
Koichi Iino, VR
Tsuneo Kusunoki, VR
Yue Qiao, MS, IS
Hae Kyung Shin, MS, IS
Kazuhiko Takemura, VR

1995
Richard Alfvin, MS, CS
Seth Ansell, MS, CS
Susan Farnand, MS, IS
Bong Sun Lee, VR
Atsushi Suzuki, VR

1994
Heui-Keun Choh, VR
Taek Kim, MS, IS
Audrey Lester, MS, CS
Jason Peterson, MS, IS
Debra Seitz Vent, MS, IS
James Shyu, MS, CS
Toru Tanaka, VR
Hiorshi Uno, VR

1993
Toru Hoshino, VR
Nathan Moroney, MS, CS
Elizabeth Pirrotta, MS, CS
Mitchell Rosen, MS, IS

1992
Mark Gorzynski, MS, IS
Taek Gyu Kim, VR
Rich Riffel, MS, IS
Brian Rose, MS, CS
Hiorshi Uno, VR

1991
Po-Chieh Hung, VR
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

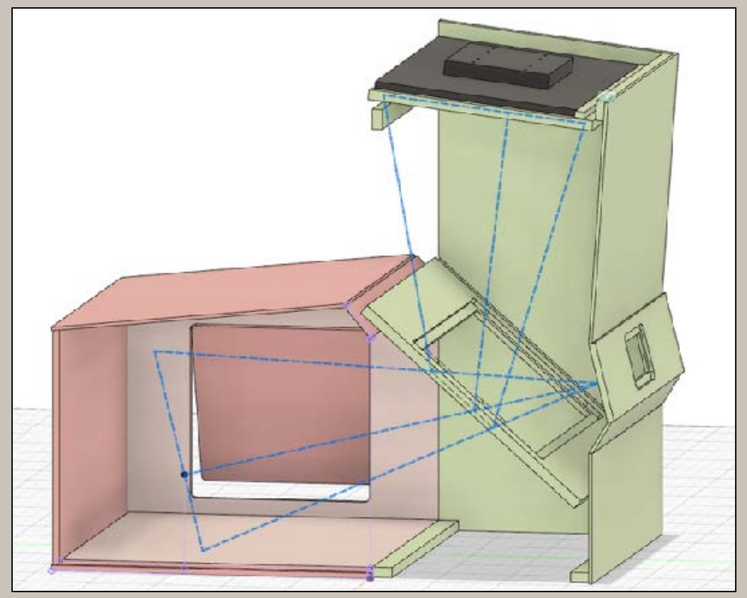
Key:
BS: Bachelor of Science
CS: Color Science
IE: Industrial Engineering
EE: Electrical Engineering
IPT: Imaging and Photo Technology
IS: Imaging Science
MS: Master of Science
PhD: Doctor of Philosophy
PM: Print Media
VR: Visiting Researcher

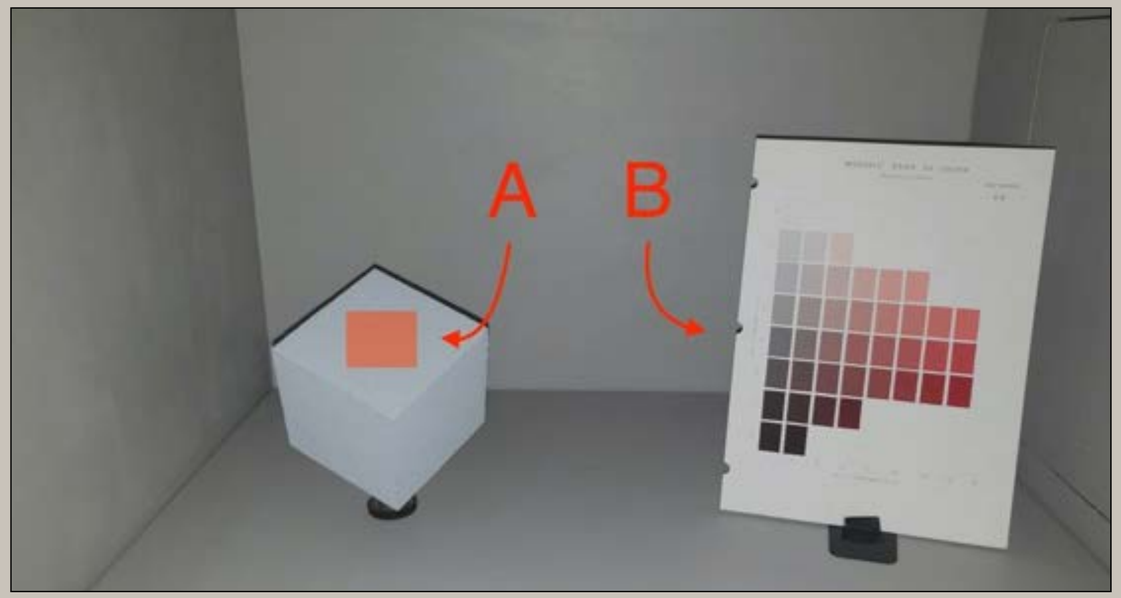
RESEARCH HIGHLIGHT: Appearance Differences of Color 3D Printed Objects

The appearance of complex three-dimensional objects is dependent upon several visual attributes such as color, texture or gloss. This project aimed to evaluate appearance differences of Color 3D printed objects that varied in both color and texture. A direct scaling psychophysical experiment was used to quantify differences in visual appearance. The color 3D objects used in this experiment were printed with a color 3D printer that can inherently add texture to prints, depending on the printing angle. In the end it was found that this inherent texture does have some effect on object appearance, but that this effect is minimal relative to color difference and can be accurately modeled using data collected with existing color measurement devices.

Matt Ronnenberg, Susan Farnand

RESEARCH HIGHLIGHT: NSF-Funded AR Color Perception Research

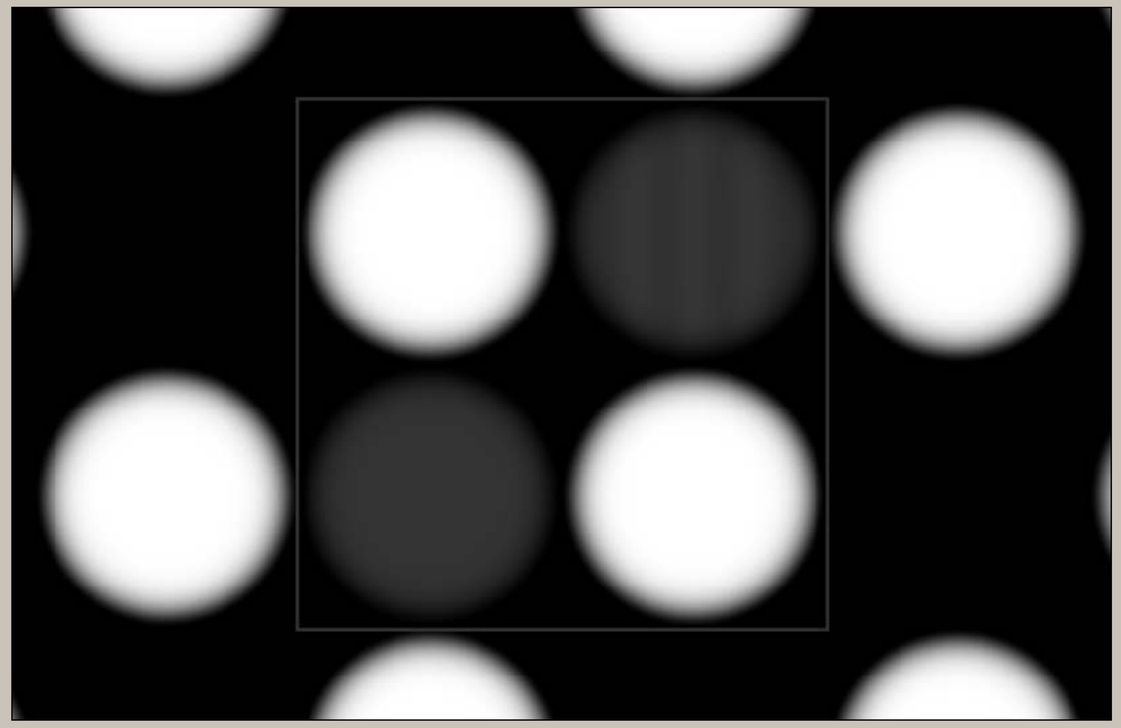




Murdoch's NSF CAREER research grant, "Computational Model of Perceived Color and Appearance in Augmented Reality" began in September, 2020, with an investigation of color correspondence between virtual AR stimuli and real-world color samples. A new AR display system for the lab has been designed and built, including a multiprimary LED light booth, beamsplitter, and high-brightness display (see diagram). A psychophysical experiment is currently being set up to scale the value and chroma of AR virtual samples (A, in the photo) using physical Munsell book pages (B). This project is funded by National Science Foundation Award 1942755.

Tucker Downs, Michael J. Murdoch

RESEARCH HIGHLIGHT: Simultaneous Perceptual Dynamic Range



As the final experiment in his dissertation, Fu has been studying the human capability to perceive simultaneous dynamic range (when both bright and dark areas are viewed at the same time in a single scene). This image shows a stimulus in which the luminance of the dark patches with a 10 percent contrast grating superimposed are lowered until the grating can no longer be perceived. This provides a metric of the range between bright and dark areas that can be viewed while still allowing contrast to be perceived in the dark regions. Of course, the result is dependent on the size of the bright and dark patches in an interesting way. In general the results show that dynamic range greater than 1000:1 is wasted on humans within in a single scene. However, when given time to adapt from bright to dark scenes (or vice versa) greater dynamic range can be useful.

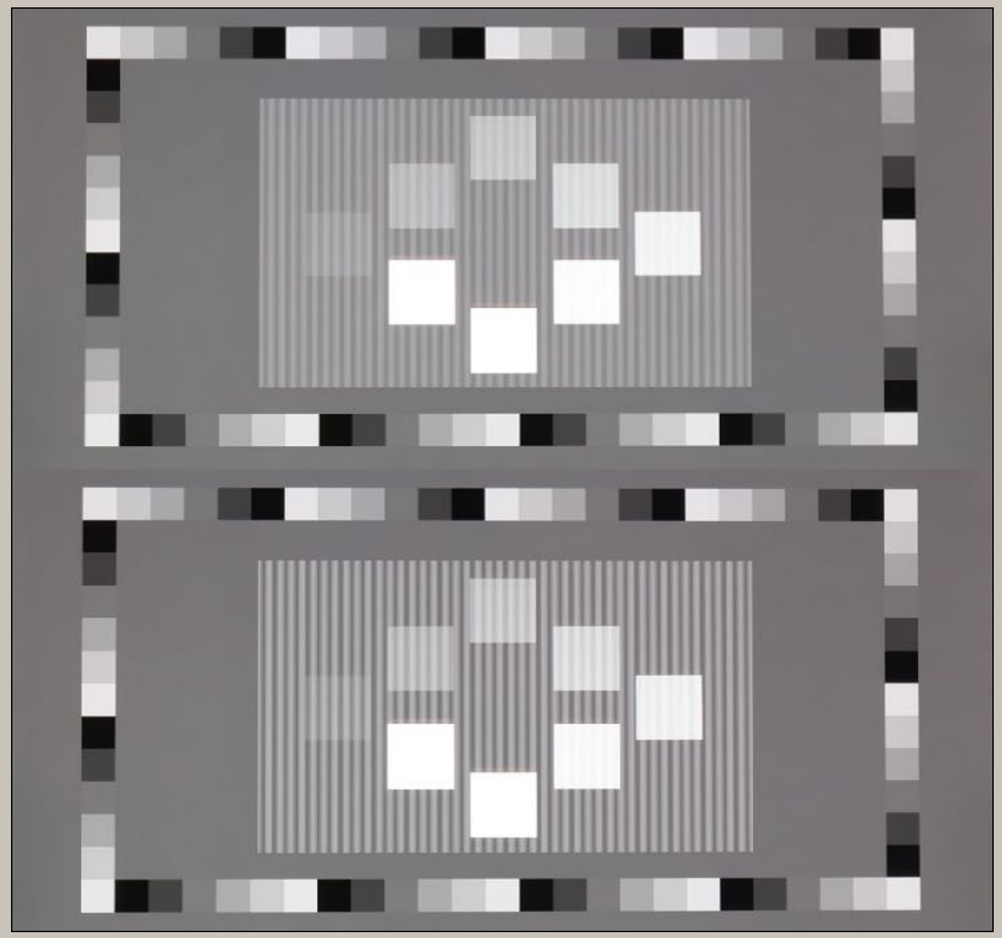
Fu Jiang, Mark Fairchild

RESEARCH HIGHLIGHT: Preferred White Balance for Virtual Backgrounds

Under the current COVID19 global pandemic, most of the world is operating online, which has increased the importance of better understanding the perceived color quality of video conference calls. We performed two experiments to evaluate the white balance appearance preference for images simulating a scene from a video conference call where a person is using a virtual background. The experiments were designed to assess the preference of white balance appearance for images containing a foreground subject with different skin tones, and different background scenes, with five different color temperatures. The main finding of these experiments was content dependency - preference varied based on the foreground subject skin tone and background scene.

Anku, Susan Farnand

RESEARCH HIGHLIGHT: Transparency in Optical See-Through AR



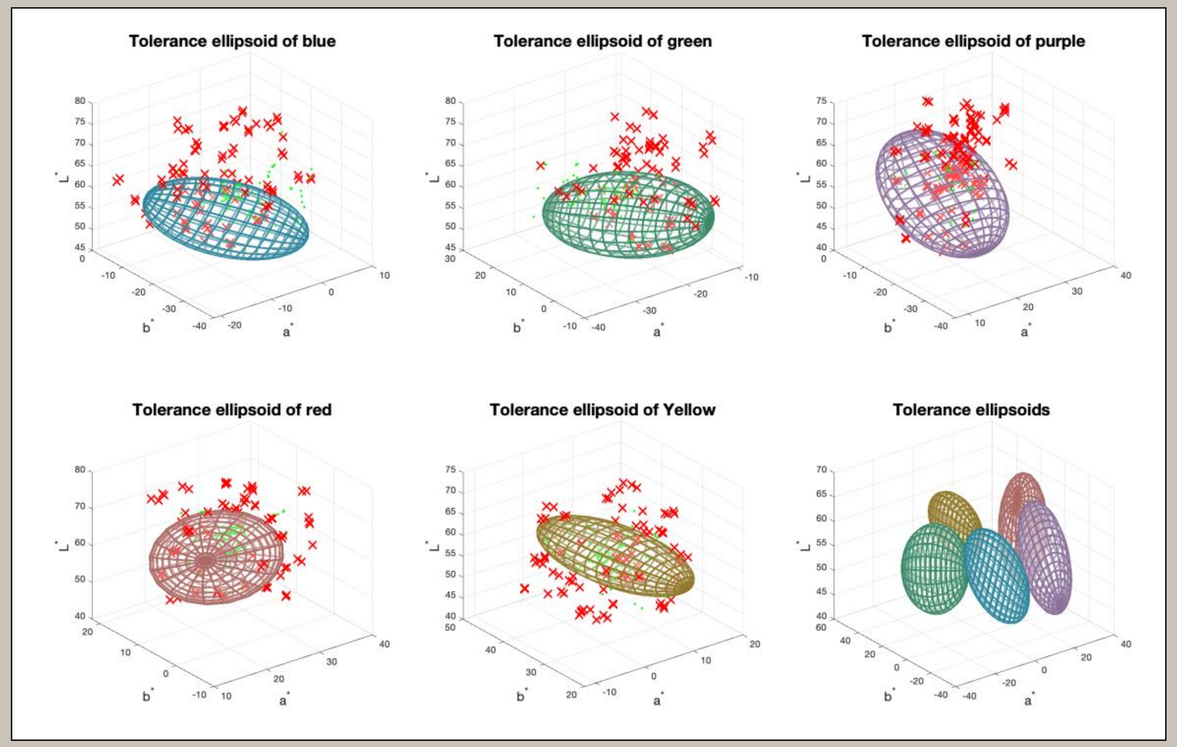
Future AR interactive experiences require exceptional color quality. However, because AR content is shown on optically transparent displays to overlay the real world behind, color and transparency perception seems to differ from what is known about subtractive filters or graphical simulation. This research project aims to quantify the perceived transparency in optical see-through AR with ultra-high luminance displays in our AR systems. A new psychophysical experiment procedure was designed for the pandemic time, with minimum human interaction while running the experiment. Observers were given a self-guided tutorial, then were asked to scale perceived transparency of AR overlay stimuli on various backgrounds. The results will supplement color appearance models with another perceptual dimension.

Lili Zhang, Michael J. Murdoch

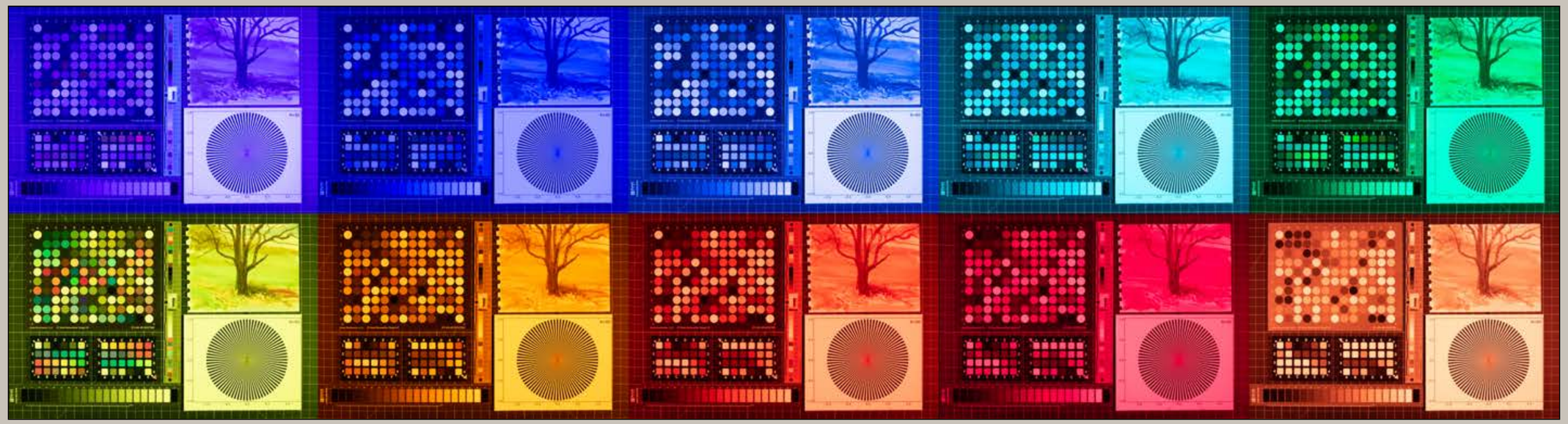
RESEARCH HIGHLIGHT: Quantifying Color Inconstancy

Che Shen undertook a psychophysical study of the tolerances on color inconstancy as his 2nd-year research project. The experiment looked at the precision with which observers could select the same reflectance samples after a change in illumination color. By finding the populations of colors that observers would select as matches, tolerances on the accuracy and precision of color inconstancy (and yet another example showing that color constancy does not exist!) Could be obtained. The accompanying figure illustrates such tolerances as optimized to CIE DE2000 ellipsoids. Of note is that the ellipses are so large that they support the hypothesis that color inconstancy tolerances are so large that color stimuli must cross categorical color boundaries before observers will reliably notice they have changed with changes in illumination color.

Che Shen, Mark Fairchild



RESEARCH HIGHLIGHT: LED-based Multispectral Imaging for Cultural Heritage



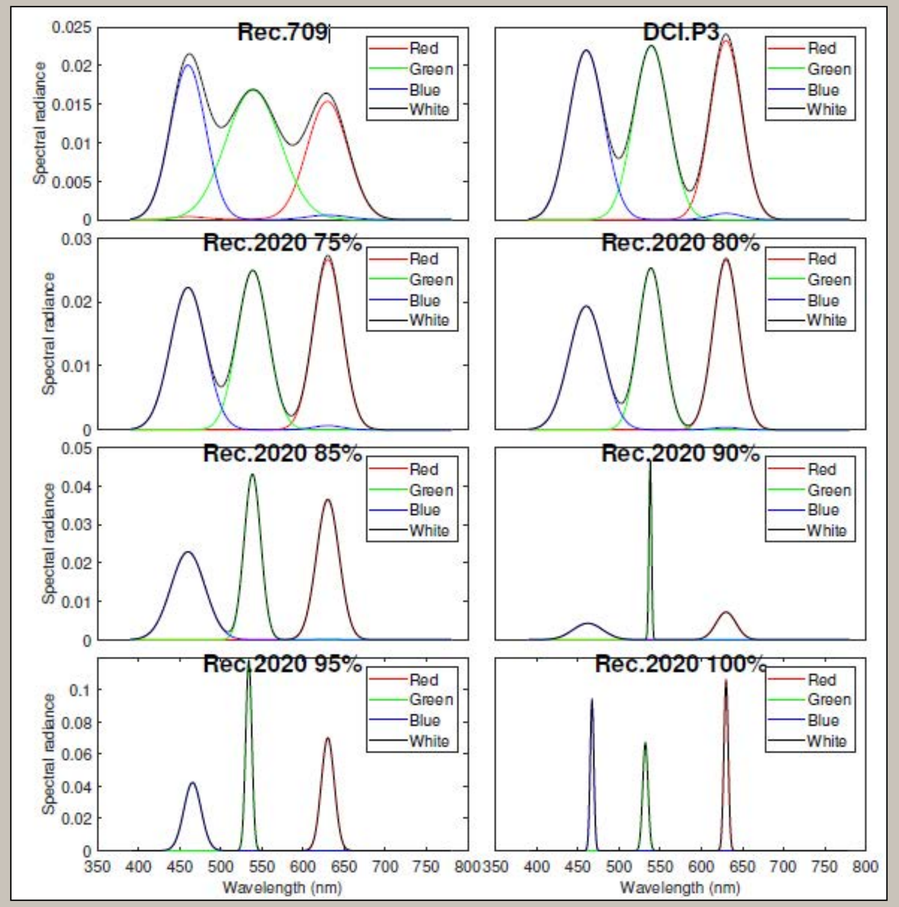
Multispectral imaging (MSI) is a powerful tool for documenting cultural heritage materials. In this research, MSI refers to the capture of 6-to-10 images within select wavebands spanning the visible spectrum. The collection of several more channels than that of conventional 3-channel RGB capture, coupled with computational image processing techniques, enables improved color reproduction. This is particularly advantageous for digitizing print media created using processes that do not render properly in RGB reproductions. Furthermore, the multispectral image set can be used to estimate a reflectance spectrum at every pixel of the image, which is useful for characterizing different materials across an object's surface. Current research is investigating optimal capture and processing workflows for MSI carried out using narrowband LED sources, in line with the larger goal of developing a practical and affordable strategy for implementing MSI as a routine technique in museum imaging studios. Figure is a set of test targets captured using a 10-channel LED system, illustrating the narrowband illumination of each channel.

Olivia Kuzio, Susan Farnand

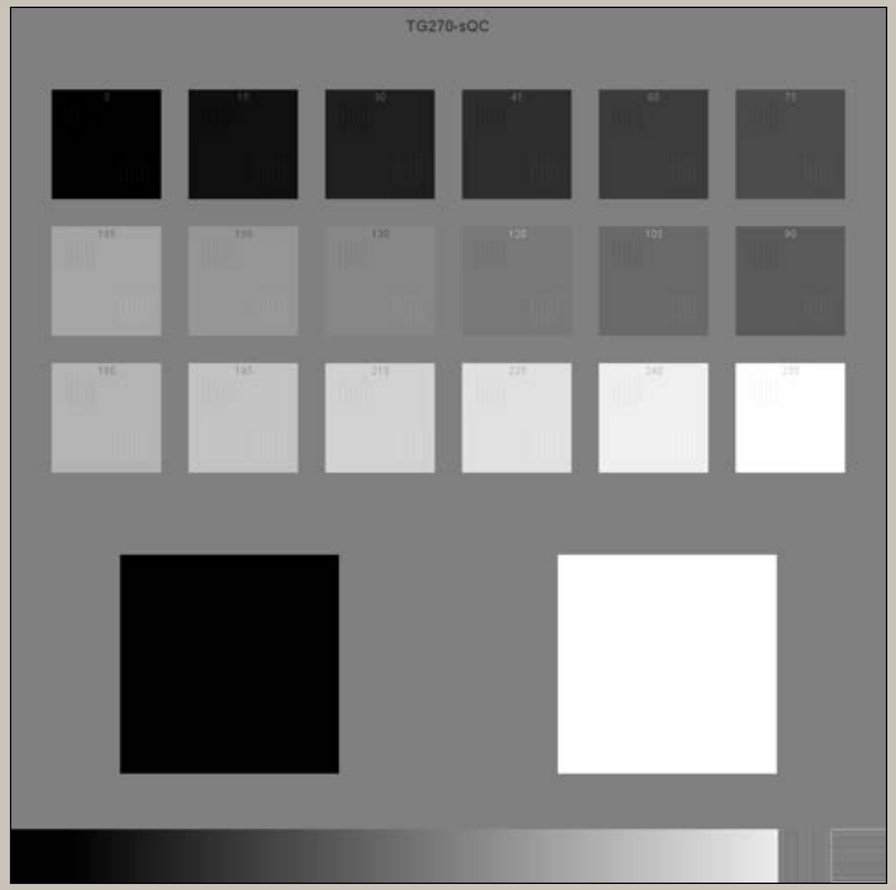
RESEARCH HIGHLIGHT: HDR Display Color Gamut & Observer Metamerism

Because human color vision differs slightly from person to person, the phenomenon of Observer Metamerism occurs, in which a color match for an individual observer does not hold for other observers. This phenomenon is potentially a serious issue in HDR displays because it is known that narrow-band primaries can worsen Observer Metamerism. Addressing the relationship between magnitude of observer metamerism and the bandwidth of display primaries, observer simulations were performed, and an efficient metric to evaluate observer metamerism between HDR displays was defined. The results will be helpful for the design of future HDR displays. Part of the work was presented at the 28th Color & Imaging Conference, and a full manuscript was recently submitted for journal publication.

Yongmin Park, Michael J. Murdoch



RESEARCH HIGHLIGHT: Display Image Quality in Medical Imaging



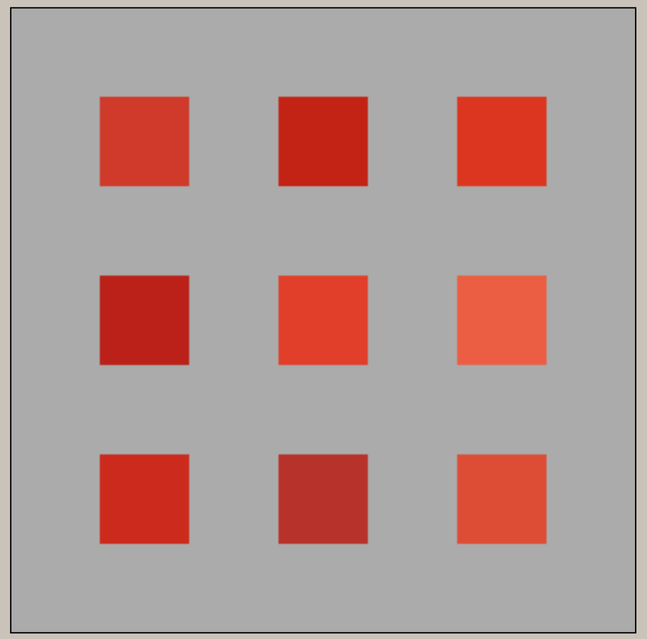
As part of Adi Robinson's dissertation, he is exploring the importance of using high-quality displays in various medical applications and situations. Part of that work has been the study of observer contrast sensitivity at various gray levels for commercial computer displays versus high-quality medical displays. Results are suggesting that more medical workers should have the benefit of high-quality medical displays since important determinations might be in error on commercial computer displays.

Adi Robinson, Mark Fairchild

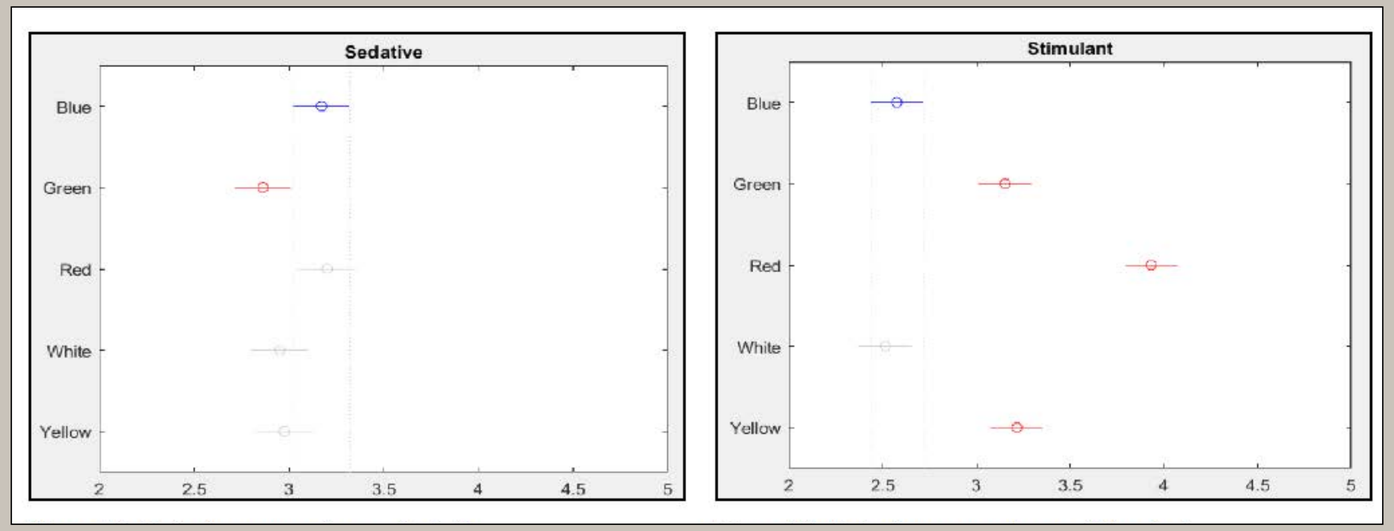
RESEARCH HIGHLIGHT: Perceived Representative Image Color

An online experiment was created to assess how participants determine the representative color of an image, particularly tomatoes. Images of grass, sky, and skin were also included to serve as a check if the participants used the same approaches for tomatoes as with these subjects. Previous studies indicate that observers often use a saturated color. Participants are asked to make a choice of which color best represented the overall image from an array of nine choices. The images included full images in context, cropped versions of the full images to remove the background, 768x768, 64x64, and 16x16 pixel down-sampled versions of the cropped images and scrambled versions of the 16x16 down-sampled images to compare choices at different levels of context. Development of the experiment comprised a summer undergraduate research project, details of which were presented at the virtual RIT Undergraduate Research Symposium: https://www.youtube.com/watch?v=ZXgiRBDOcI4&t=13s

Katherine Carpenter, Katie Albus, Dara Dimoff, and Susan Farnand



RESEARCH HIGHLIGHT: Influence of Color on Drug Efficacy



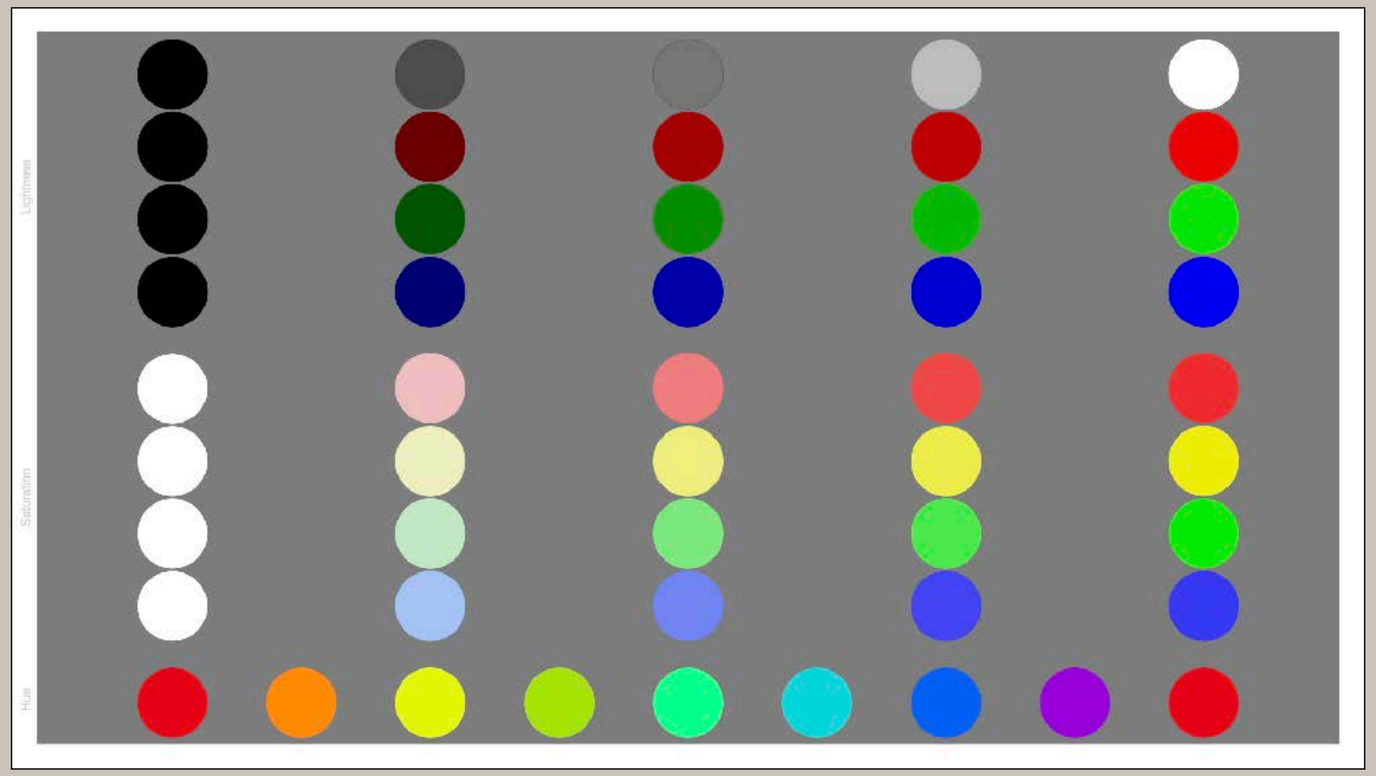
In January 2020, a study was launched across RIT's Rochester and Dubai campuses to understand the effects pill colors have on a wide variety of people, and the basis on which color association is developed. Participants did not take medication, but rather logged their perceptions of the effects of pills based on color, and further accounted for different age brackets, gender, ethnic backgrounds, educational levels, and pill usage frequency. A second phase of the study – an online interactive survey – was launched in October 2020 across RIT's Rochester, Dubai, Croatia, and Kosovo campuses. That data is currently being analyzed to identify commonalities across a more diverse pool of participants' demographics.

Rema Amawi, Michael J. Murdoch

RESEARCH HIGHLIGHT: Color Appearance Scales

We are beginning work to examine individual color scales with a detailed study of lightness, brightness, and brilliance as a function of saturation and luminance (as can be produced on new HDR displays). The work will be ultimately used to define new color appearance scales as a part of an improved system of colorimetry. The figure shows part of a test pattern that Mark separately developed to directly scale appearance. This particular target has been used to scale lightness, saturation, and hue (separate targets used for colorfulness and brightness) and will be the subject of a future paper.

Hao Xie, Mark Fairchild



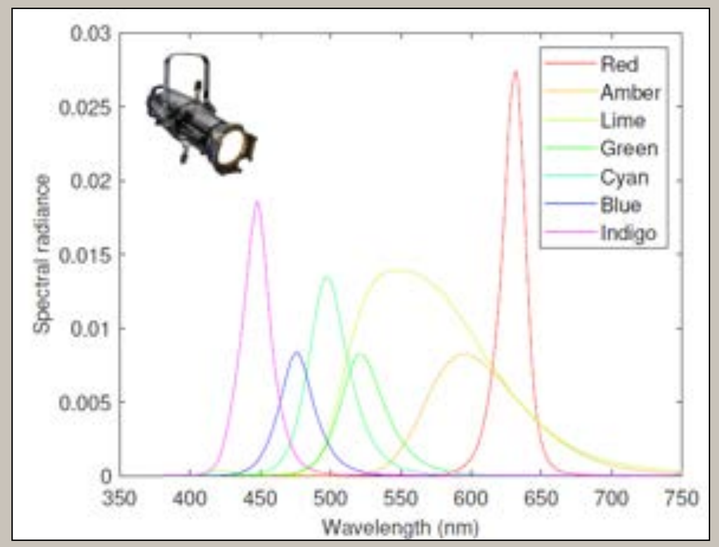
RESEARCH HIGHLIGHT: Neural Network Appearance Modeling of 3D Printed Objects

Convolutional neural networks (CNNs) are powerful tools with applications in just about any current field of research. In this work a siamese CNN was developed using transfer learning from AlexNet to compare images and predict appearance differences. Information from color sensitive neurons in AlexNet was pulled and used to train a siamese CNN. Images of color 3D printed objects were simulated by starting with uniform patches and applying texture in Adobe Photoshop®. The applied texture was visually comparable to what some color 3D printers might apply to a print due to the technology and material used in the printing process. A model was developed that accurately predicted sCIELAB differences between images using information from only the color sensitive neurons.

Images are patches used to train and test the siamese CNN. Canvas and sandstone textures were applied to the uniform patch, on the left, in Adobe Photoshop® to create the other two patches. The starting color remained the same but texture varied.

Matt Ronnenberg, Susan Farnand

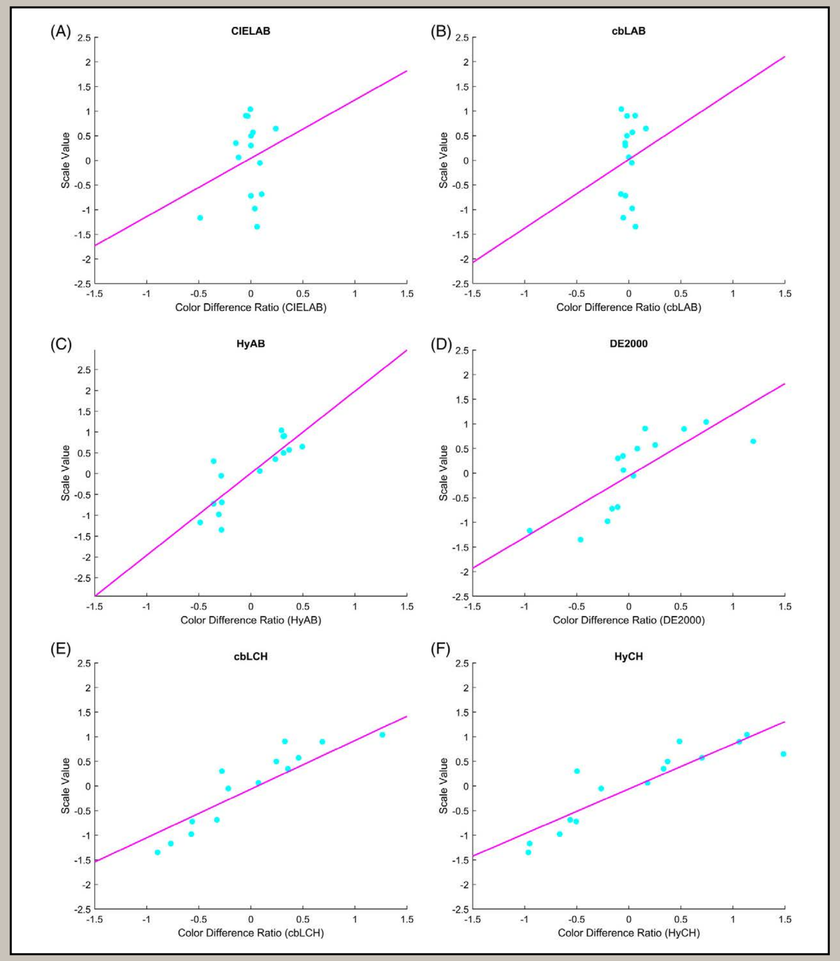
RESEARCH HIGHLIGHT: 3-pixel HDR Multiprimary Display, aka Bisection Box



In preparation for a variety of experiments addressing chroma scaling, brightness matching, and the Helmholtz-Kohlrausch effect, a new apparatus has been constructed. Based on an initial idea of a 3-stimulus multiprimary LED system for the sake of partition scaling, aka bisection experiments, it was named the "Bisection Box." Far more capable that just bisection, however, it will be first used for direct scaling experiments to derive a colorfulness scale for highly chromatic colors, which will help display and lighting industries who design and develop advanced display and multi-channel lighting systems. The box uses three highly-capable 7-primary Source Four LED fixtures on loan from ETC Lighting, and it sits inside the Dynamic Visual Adaptation Lab, whose existing LED lighting system provides controllable ambient surround lighting.

Tucker Downs, Yongmin Park, Michael J. Murdoch

RESEARCH HIGHLIGHT: Measuring Large Color Differences



Saeedeh's work on visual scaling and mathematical modeling of large color differences was published in 2020. Her HyAB and HyCH models proved very useful for large color differences. They included Euclidean summation of hue and chroma differences with a city-block summation of lightness difference. The figure shows performance for one of her experiments in comparison with traditional color difference metrics and a full city-block CIELAB metric (cbLCH and cbLAB). The HyAB metric has been successfully applied in image segmentation algorithms and in a new image quality metric developed by NVIDIA.

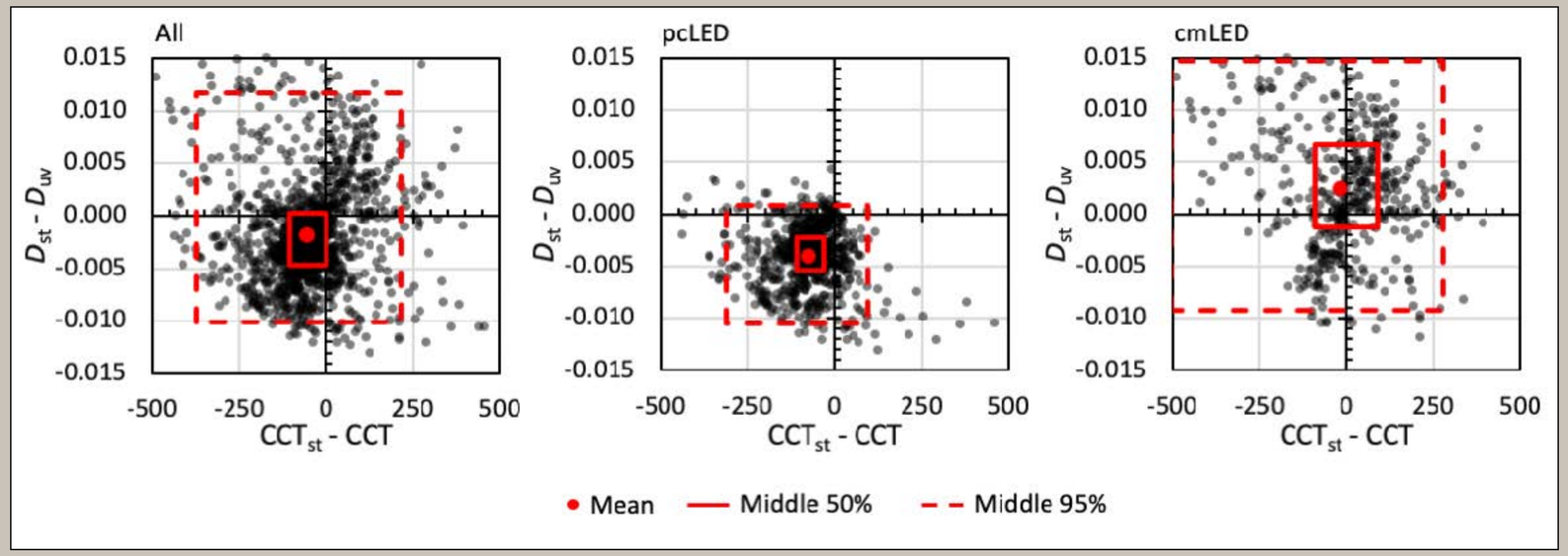
Saeedeh Abassi, Mark Fairchild

RESEARCH HIGHLIGHT: Preferred White Balance for Different Skin Tones

Color quality is a priority for the smartphone and camera industries. Computational photography techniques, used to enhance images making them more pleasing to viewers, have become a major differentiating factor between manufacturers. One major focus area for these techniques regards white balance. The aim of this research is to study preferred white balance settings for images where the foreground, containing a person, is illuminated by a different correlated color temperature (CCT) than the background. People of different skin tones will serve as foreground subjects. The two different CCT illuminants will have combinations covering a range of color temperature pairs. This design setup is meant to mimic real-world scenarios such as a person standing under a tree on a bright blue day where the color temperatures of the sky and the light on the person's face are very different. Perceptual testing is planned to assess preferred color rendition for these images.

Anku, Susan Farnand

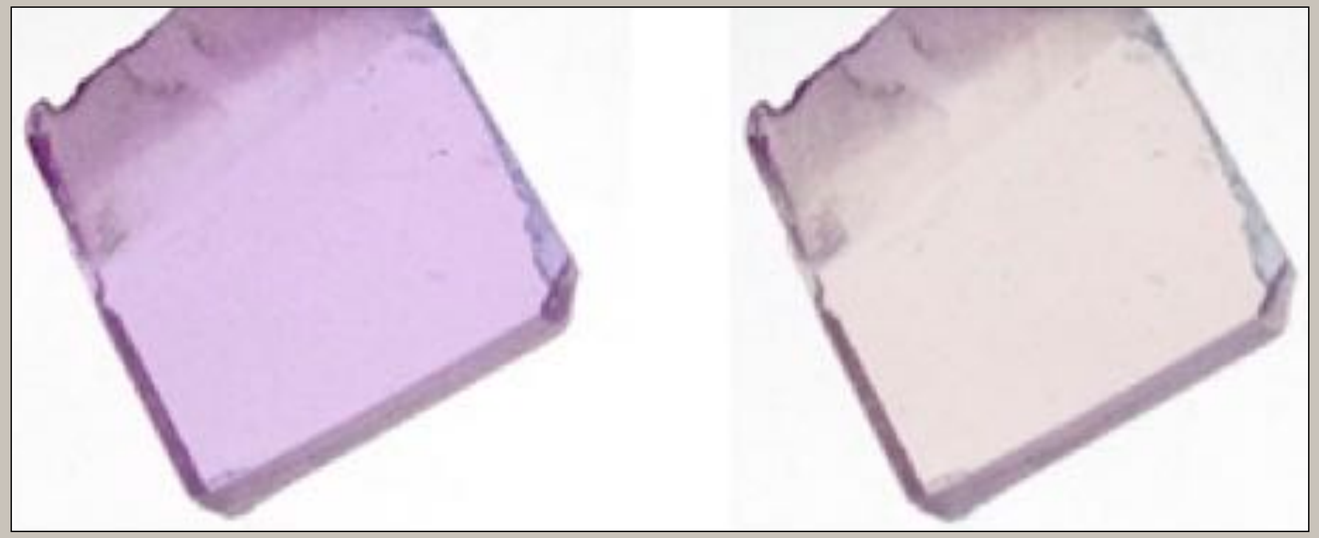
RESEARCH HIGHLIGHT: Updating Colorimetry for Lighting Applications



With an international group of color and lighting experts, a detailed recommendation was made to adopt the 2015 10-degree cone fundamental-based CMFs for colorimetric characterization of light sources, including using the 1976 u'v' UCS chromaticity formula and updating the definitions of CCT and Duv accordingly. Computational modeling was used to assess how this proposed change would affect existing phosphor-converted LEDs, color-mixed LEDs, and traditional light sources (changes in CCT and Duv are illustrated). The update provides chromaticity values more closely related to the population average sensitivity, and exposes inconsistencies arising from the use of CIE 1931 CMFs. An overview was presented at the IES Annual Conference, and a journal manuscript is in preparation.

Michael J. Murdoch, IES Color Committee

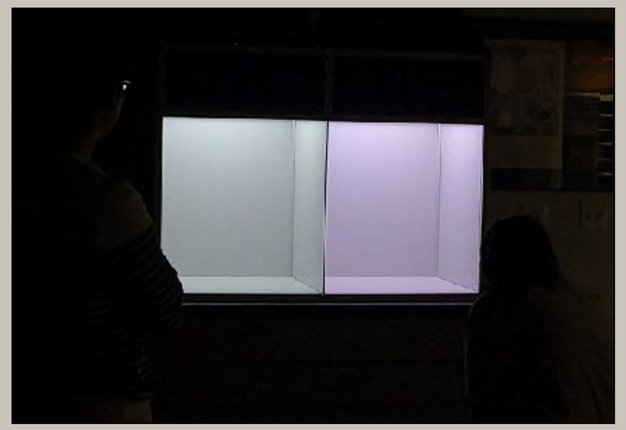
RESEARCH HIGHLIGHT: Colorimetry of Uniaxial Gemstones

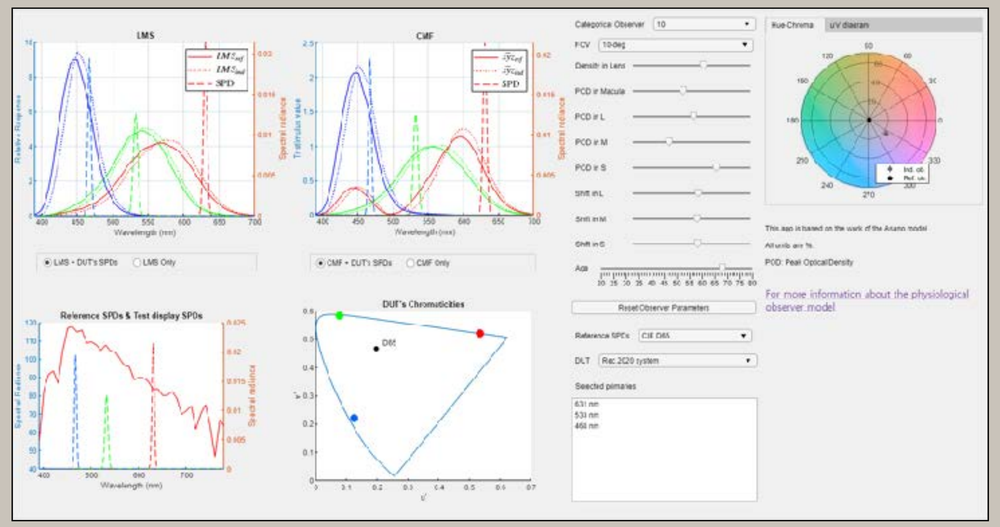


Color is the most important quality for colored stones and is widely discussed and studied by gemologists. Understanding the color characteristics of a gemstone can provide a scientific basis to guide its cutting. This study uses visible spectroscopy to determine the unpolarized spectra of a uniaxial material from the polarized o-ray and e-ray spectra in order to predict the color of a uniaxial gemstone when viewed in any direction. The accompanying image shows a synthetic ruby under the polarized lighting (Left: electric vector perpendicular to the optic axis (o-ray). Right: electric vector parallel to the optic axis (e-ray)). This work will appear in an early 2021 paper in the GIA journal *Gems & Gemology*.

Che Shen, Mark Fairchild

RESEARCH HIGHLIGHT: Pinkish-Greenish [mis]matches of Neutral





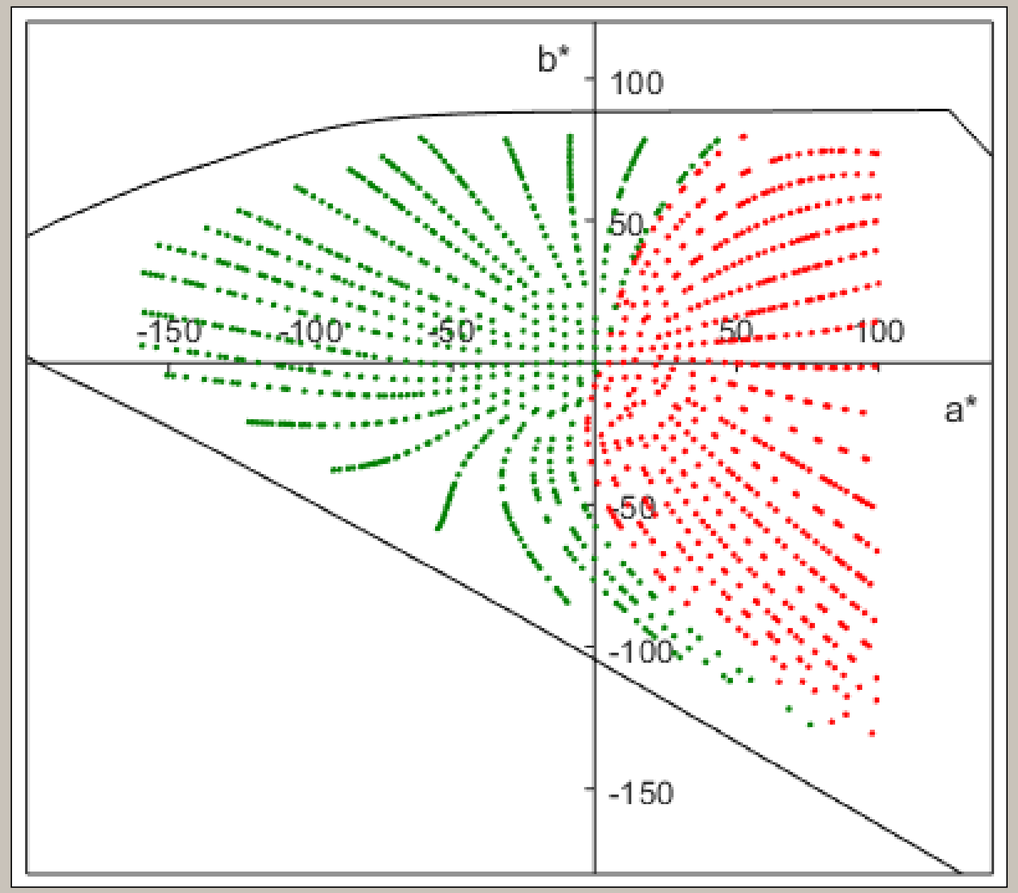
It has been anecdotally observed that metamers prepared for the study of Observer Metamerism often appear either greenish or pinkish when imperfectly matched. In the photo shown, the two light booths meant to match in color (neutral or white) for a specific observer do not match in color for the camera. Typically, the color mismatches appear pinkish or greenish, but rarely bluish or yellowish, both to cameras and people. Investigations were made using simulations, which showed that the occurrence of pinkish and greenish was due to both the color matching functions and the spectral primaries of the LEDs; results were presented at the 28th Color & Imaging Conference. A demo simulation tool may be found via the QR code or this URL: http://www.rit-mcsl.org/Research/WhyNeutralsVaryFromPinkToGreen/

Yongmin Park, Michael J. Murdoch, Mark Fairchild

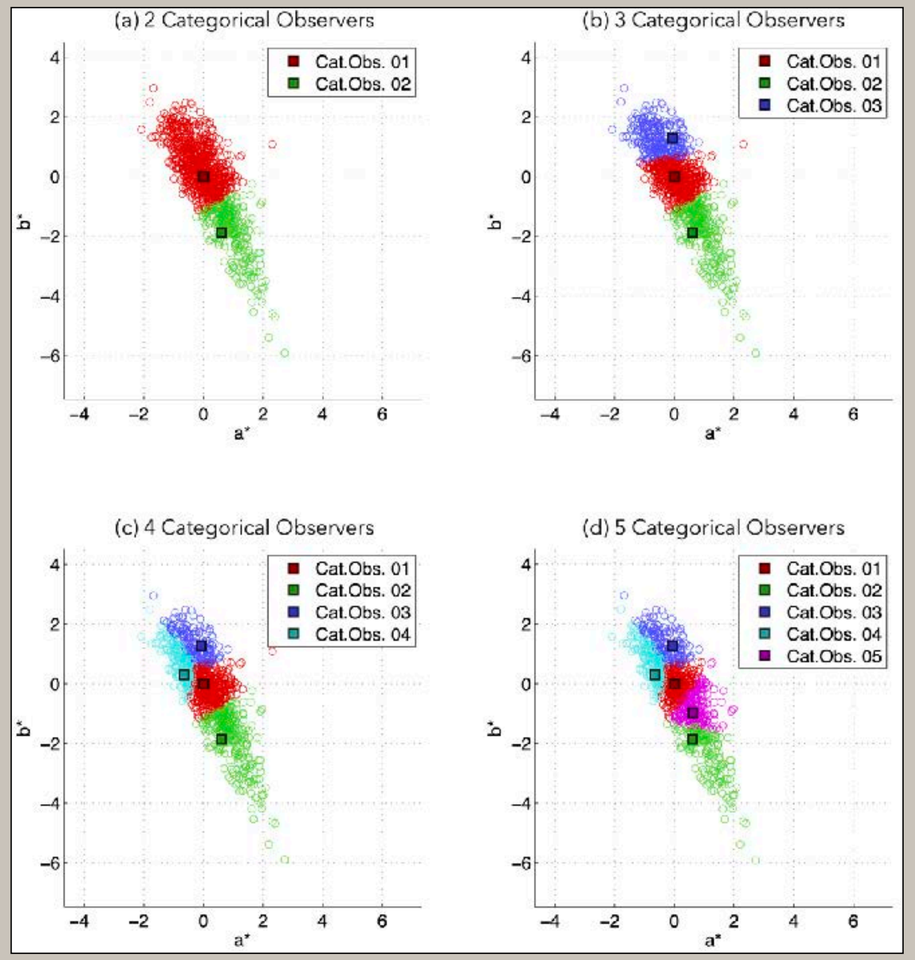
RESEARCH HIGHLIGHT: Hue Uniformity From Physics?

Luke's hue uniformity work was published in the Journal of Perceptual Imaging and presented at CIC28 in 2020. The work involved deriving a theoretical uniform hue space in which constant hue was defined using Gaussian spectra. Spectra with a fixed peak wavelength and varying width were defined as proposed constant perceived hue. The psychophysical evaluation of the proposed space showed it performed as well as the empirical IPT space, but not significantly better. Thus, the work helped to set some theoretical groundwork for the improved performance that has been found in IPT.

Luke Hellwig, Mark Fairchild



RESEARCH HIGHLIGHT: Categorical Color Observers



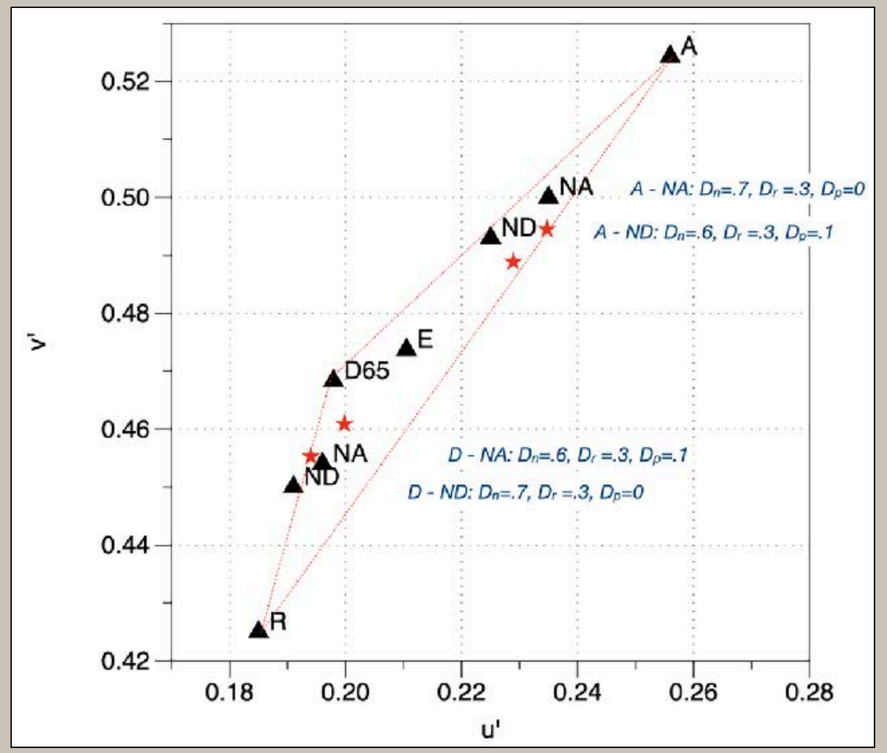
While Yuta graduated with his Ph.D. several years ago, we found that one chapter of his dissertation was often referenced but had never been published. Mark made sure that chapter was finally published in 2020. The paper details a system of categorical observers that can be used for personalized colorimetry. The results show great promise as a step toward an improved system of colorimetry. The accompanying figure shows the cluster analysis on metameric matches made by 1000 simulated observers that was used to determine optimal categorical observers.

Yuta Asano, Mark Fairchild

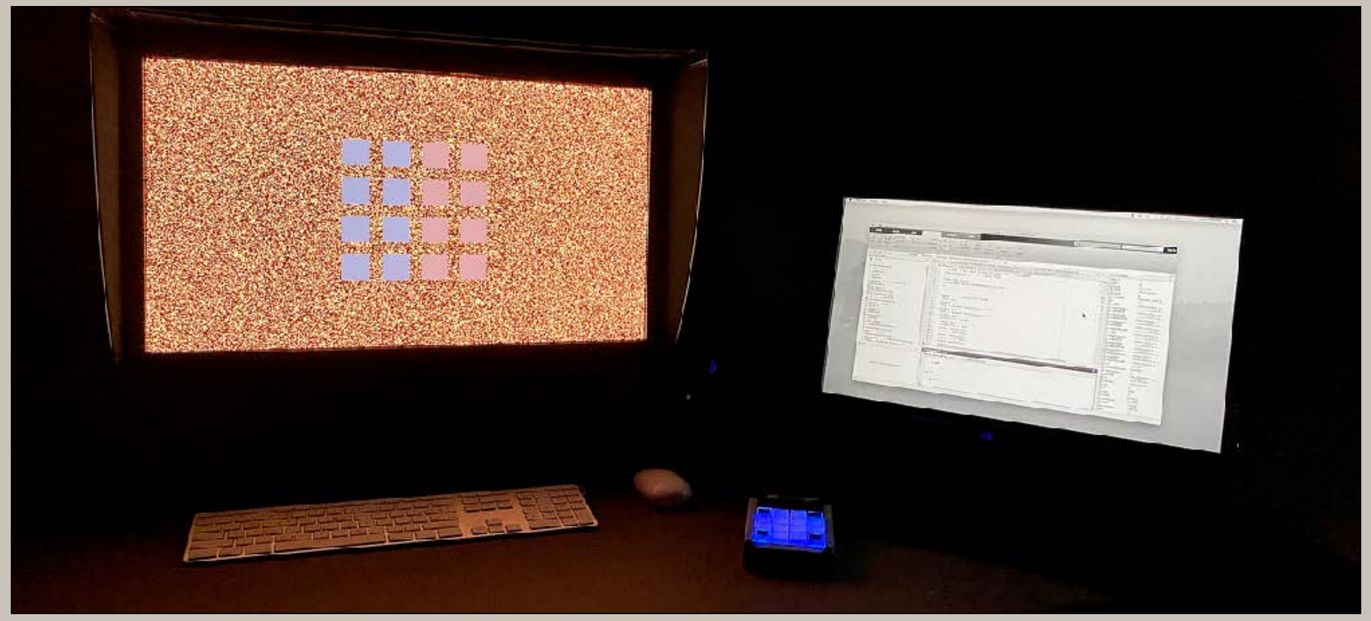
RESEARCH HIGHLIGHT: vK20 — A New Look at Degree of Adaptation

Recent data has shown that the process of chromatic adaptation might be asymmetrical, or irreversible, and that this effect might be more than simply a manifestation of the time course of adaptation. A paper presented at CIC28 introduced a simple modification of the von Kries chromatic adaptation transform, referred to as vK20, that can account for the asymmetry in chromatic adaptation through inclusion of previous adapting conditions. Also introduced was a new reference chromaticity (~15000K) for degree of adaptation that seems more physiologically plausible than the commonly used equal-energy (EE) illuminant or CIE illuminant D65.

Mark Fairchild



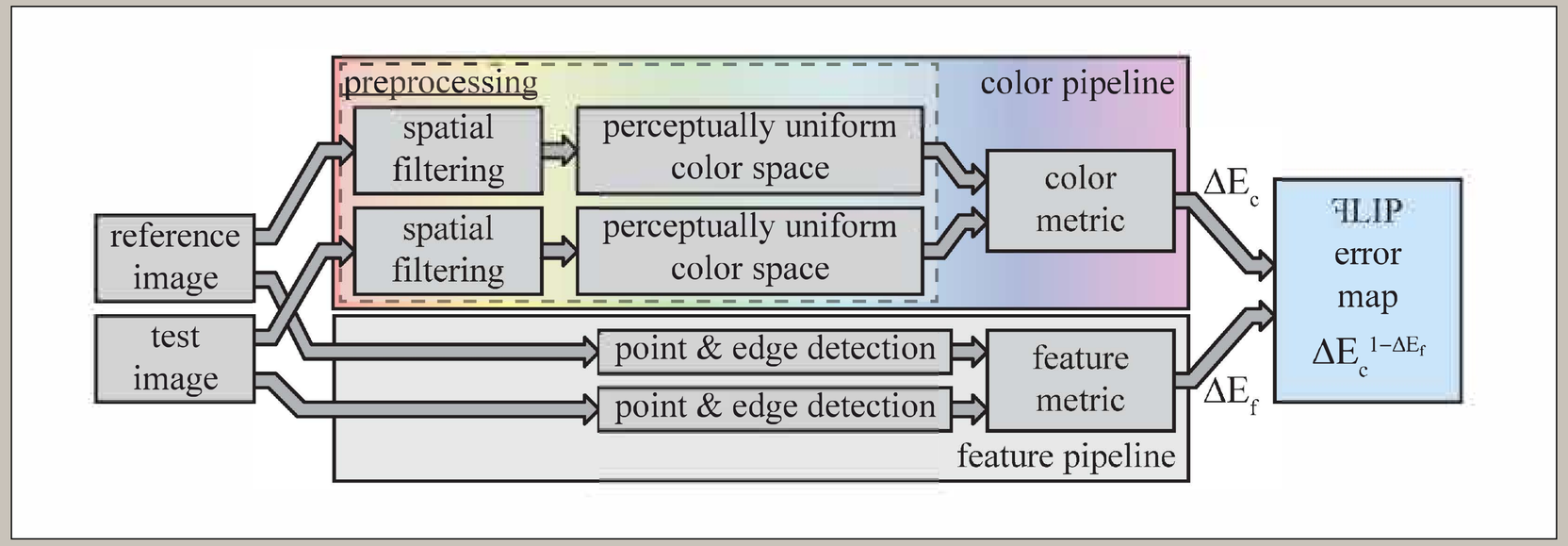
RESEARCH HIGHLIGHT: Reversibility of Chromatic Adaptation



Mark has been carrying out a long-term corresponding-colors experiment to evaluate the reversibility of chromatic adaptation with extremely high precision. The Image shows the experimental setup (in Mark's basement during the pandemic). Stimuli were presented on the calibrated reference display to the right and controlled from the black/white monitor to the left (which was covered during observations). The 16-key keypad (self-luminous in blue) was used to allow observers to choose stimuli from the 4x4 array of stimuli on the experimental display without looking away. The remainder of the room was dark. Results suggest a small lack of reversibility that is statistically significant, but probably not important in most applications.

Mark Fairchild

RESEARCH HIGHLIGHT: A "Random" Image Quality Metric



An innocent email inquiry from NVIDIA regarding past research on image difference metrics (iCAM) and our more recent work on large color differences (HyAB) blossomed into a great collaboration that resulted in a new image difference metric called FLIP that was presented at the 2020 SIGGRAPH/EuroGraphics High Performance Graphics conference and awarded as a runner up best paper. The metric was rigorously tested psychophysically and was designed for situations where observers flip back and forth between two versions of an image that are superimposed on a display. This is different from historical viewing situations and does require a difference model.

Mark Fairchild, NVIDIA Team

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M. Ronnenberg, Evaluating Appearance Differences of Color 3D Printed Objects, PhD Dissertation, December 2020.

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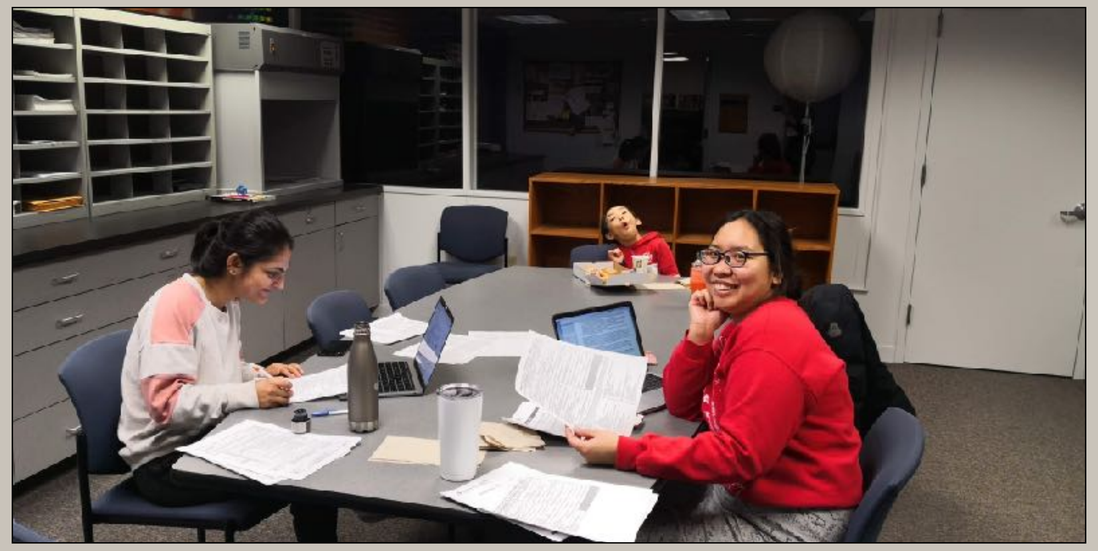
Manfrotto

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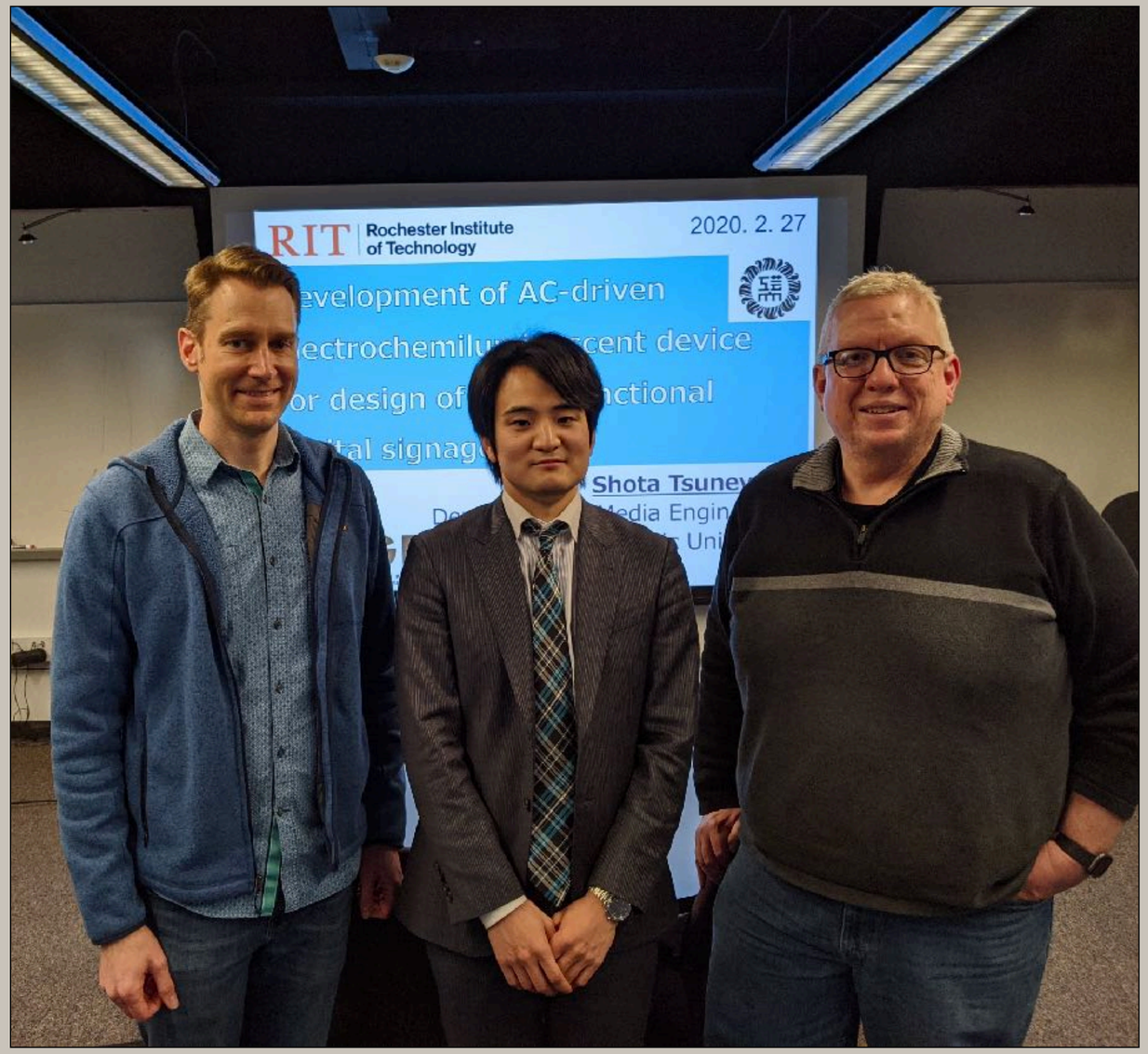
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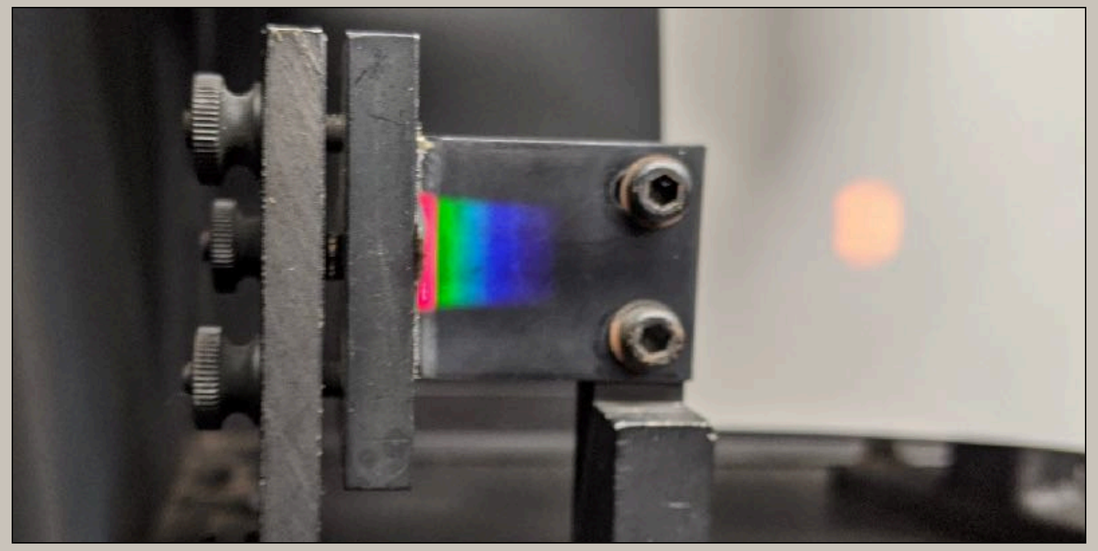

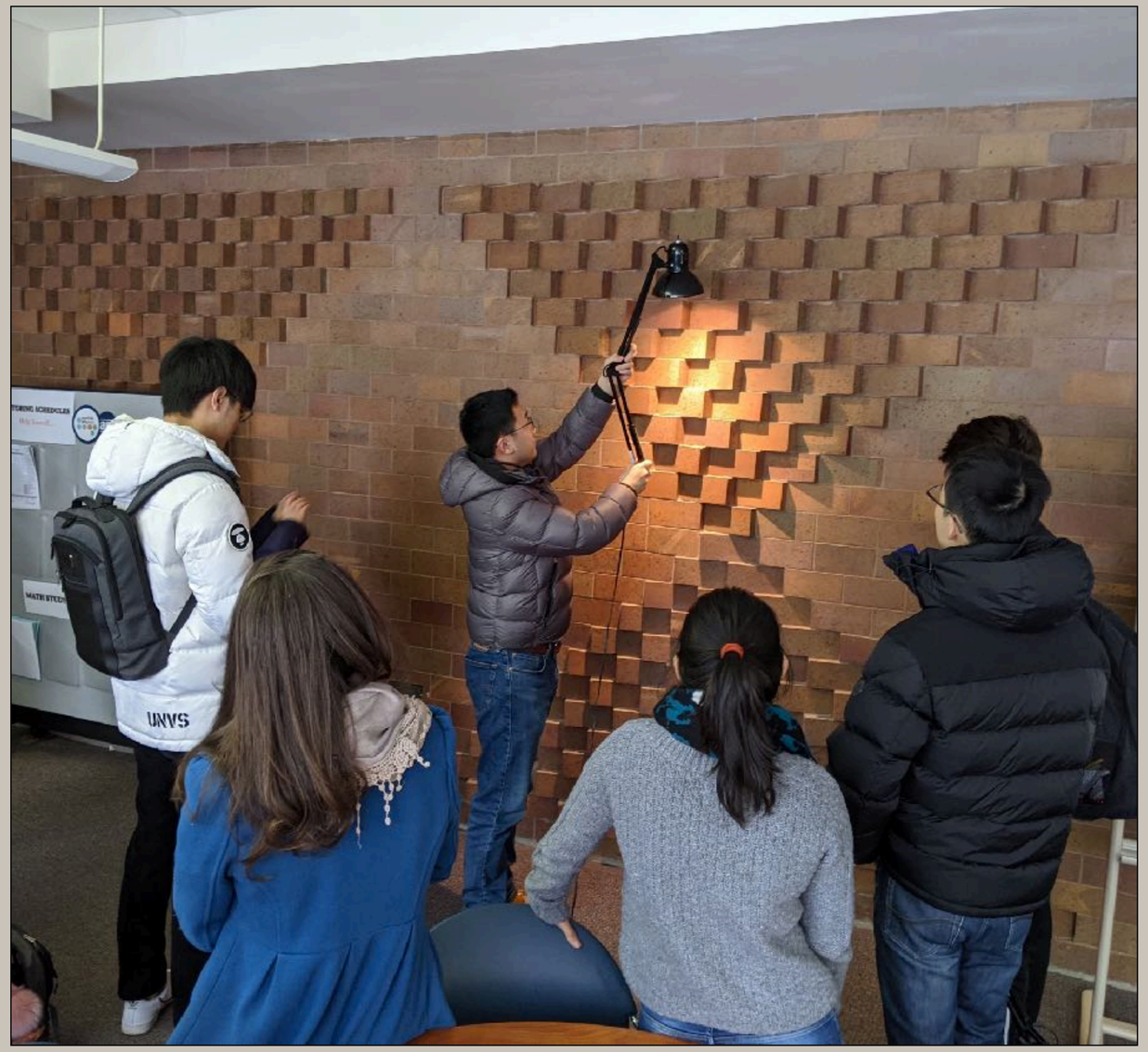

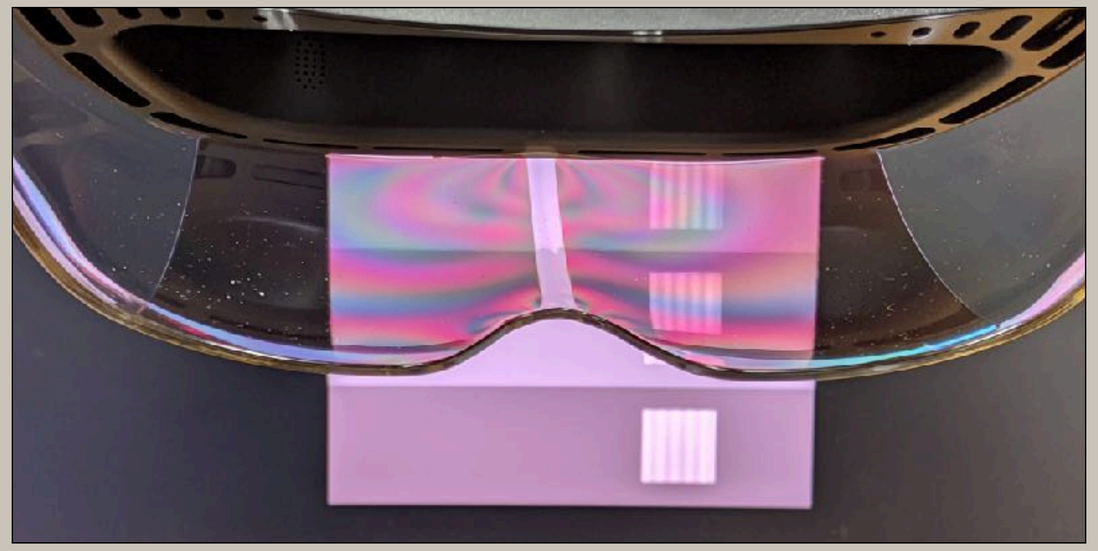

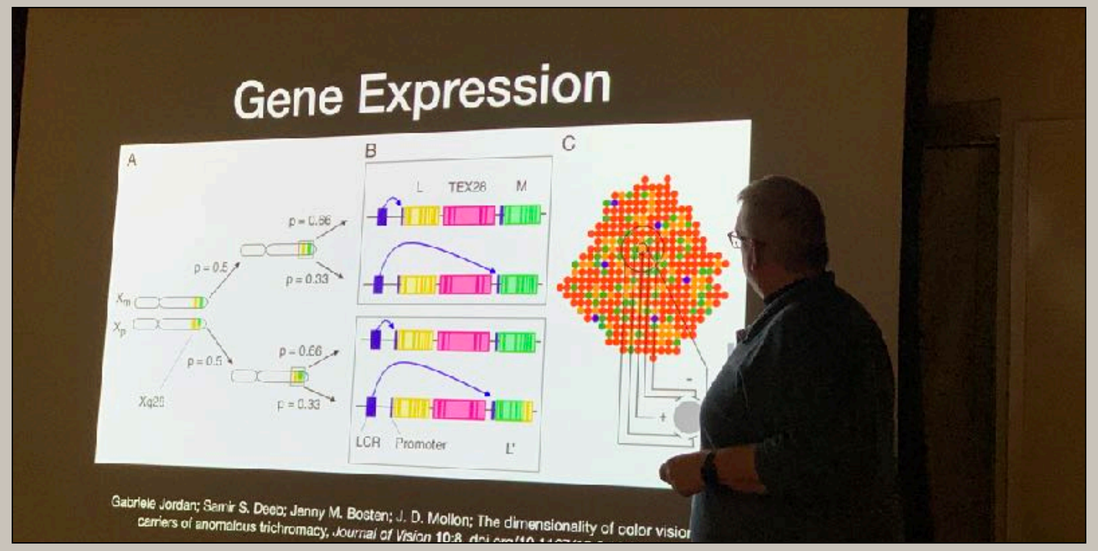
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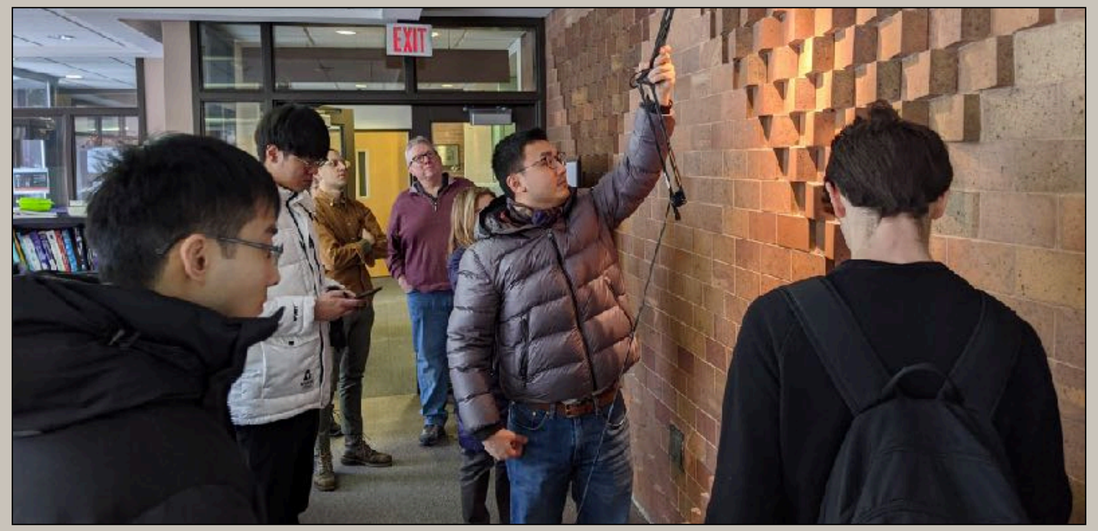
carriers of anomalous trichromacy, Journal of Vision 10:8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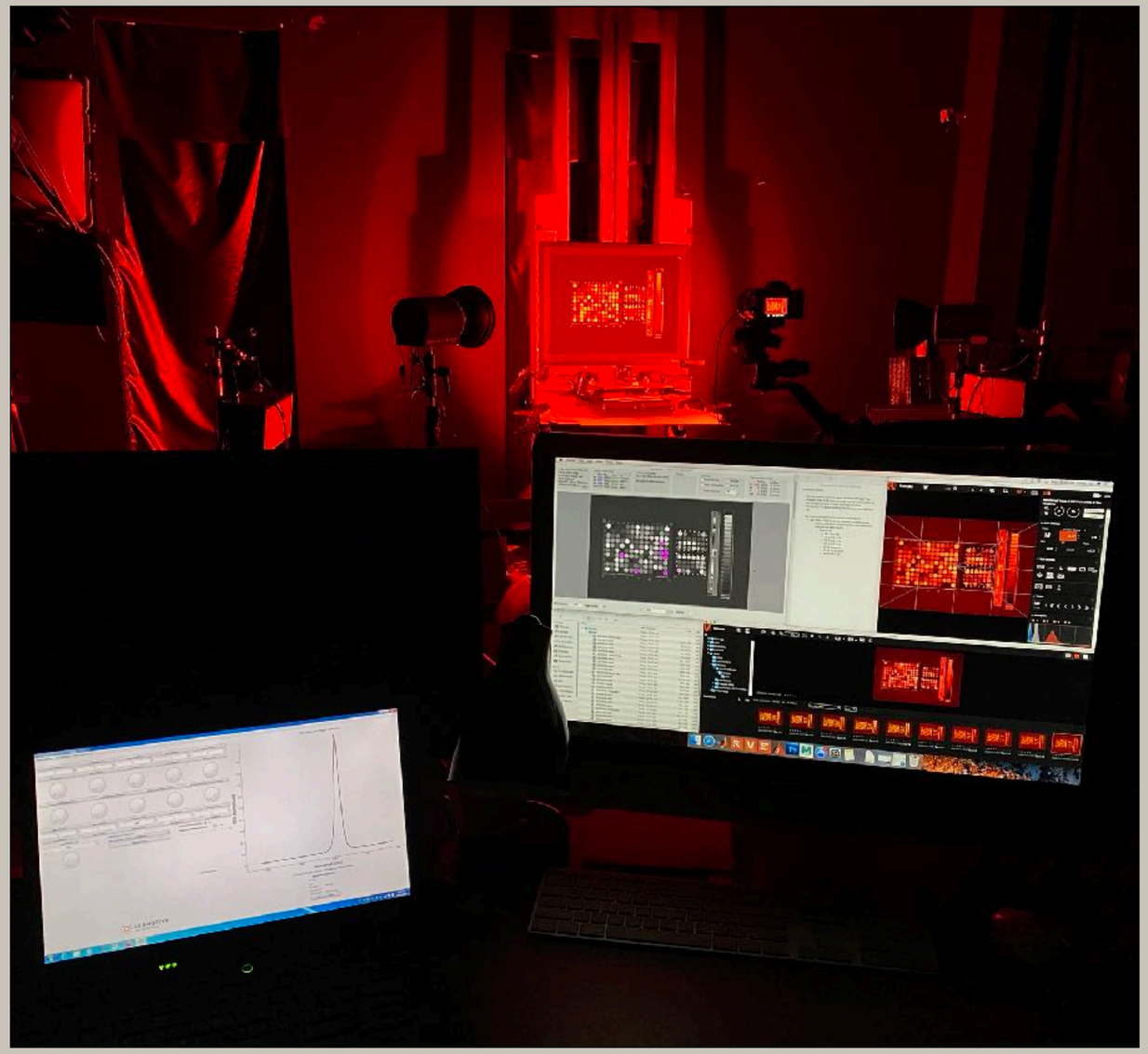

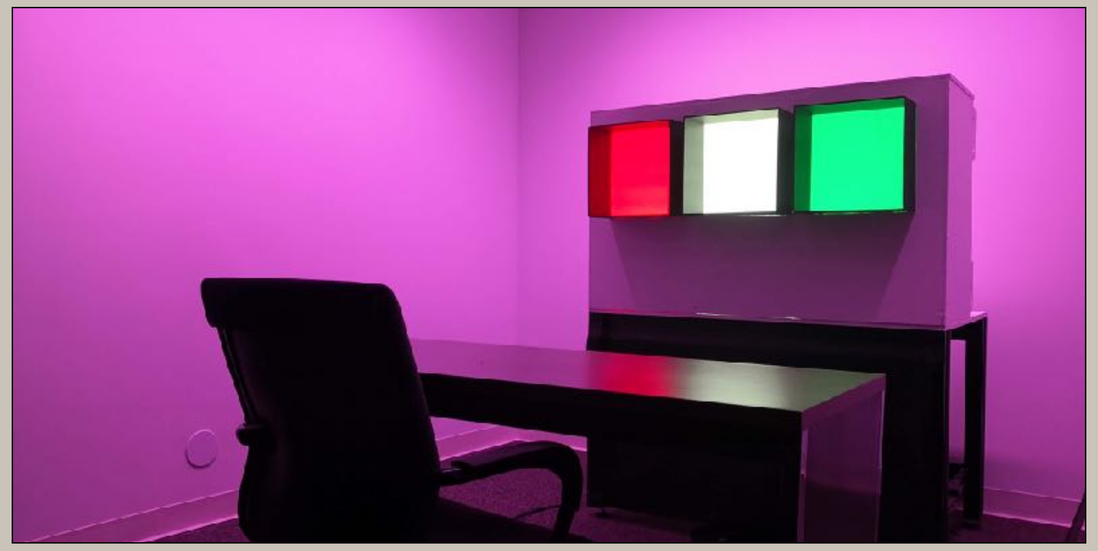


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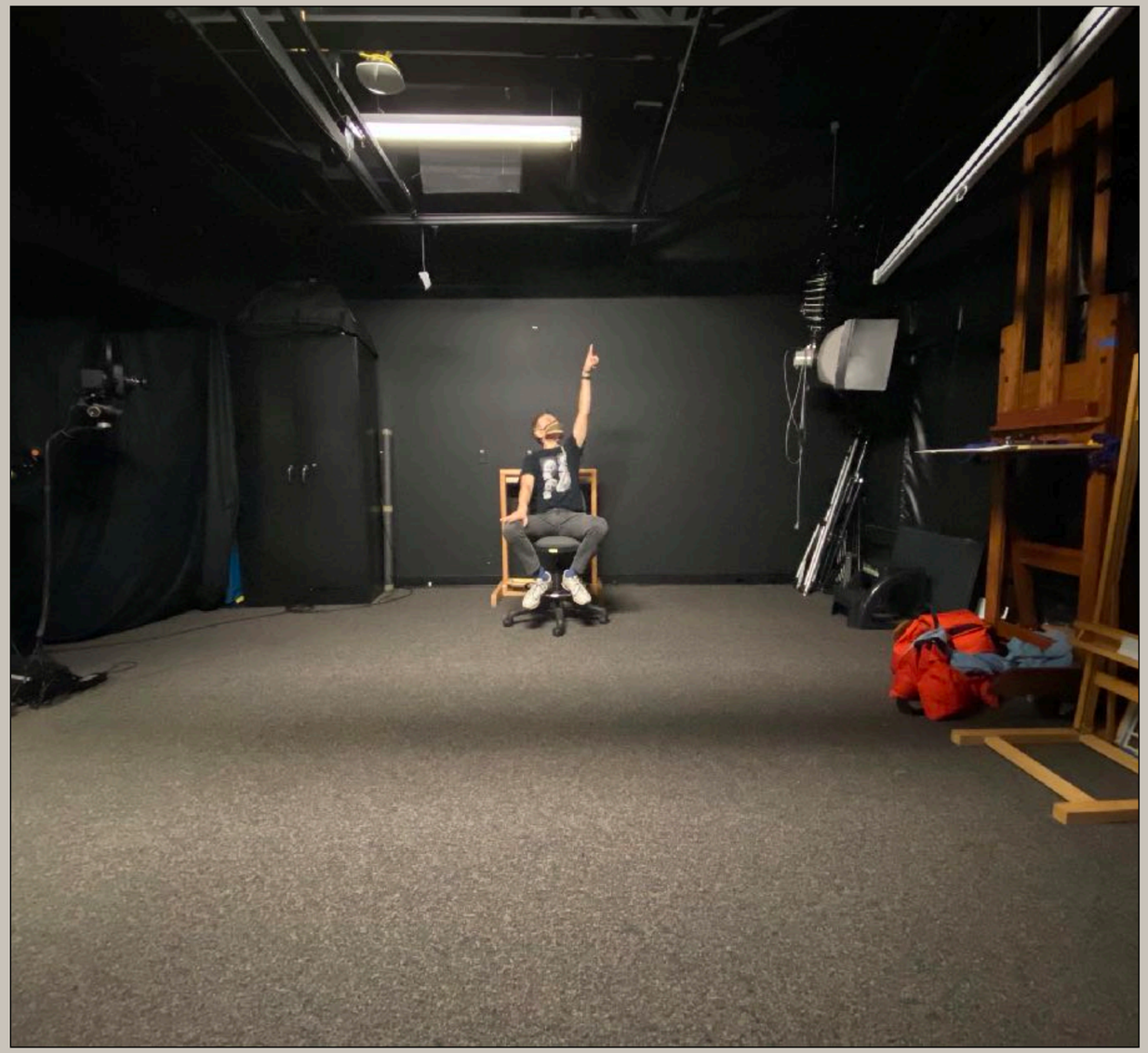

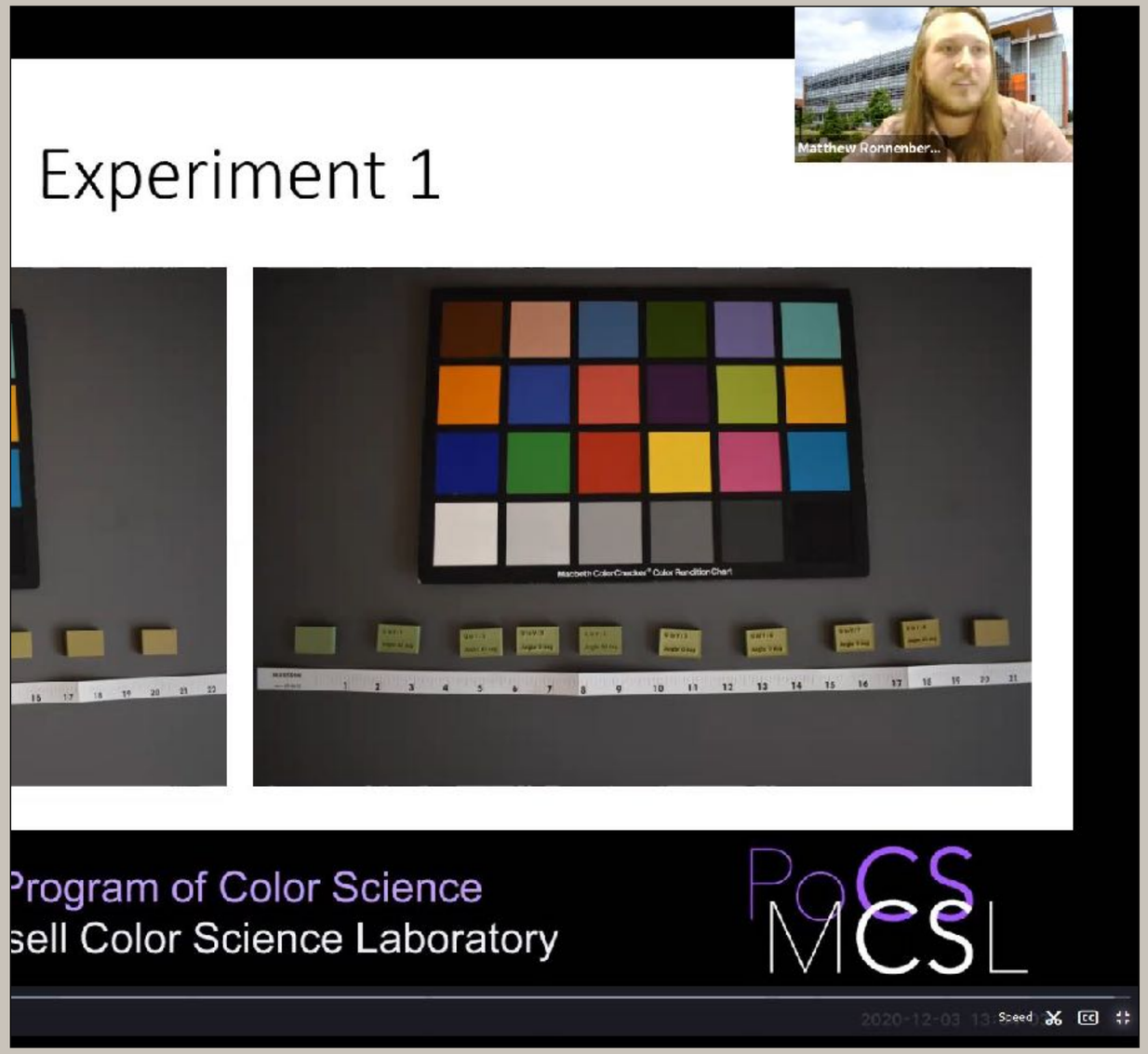
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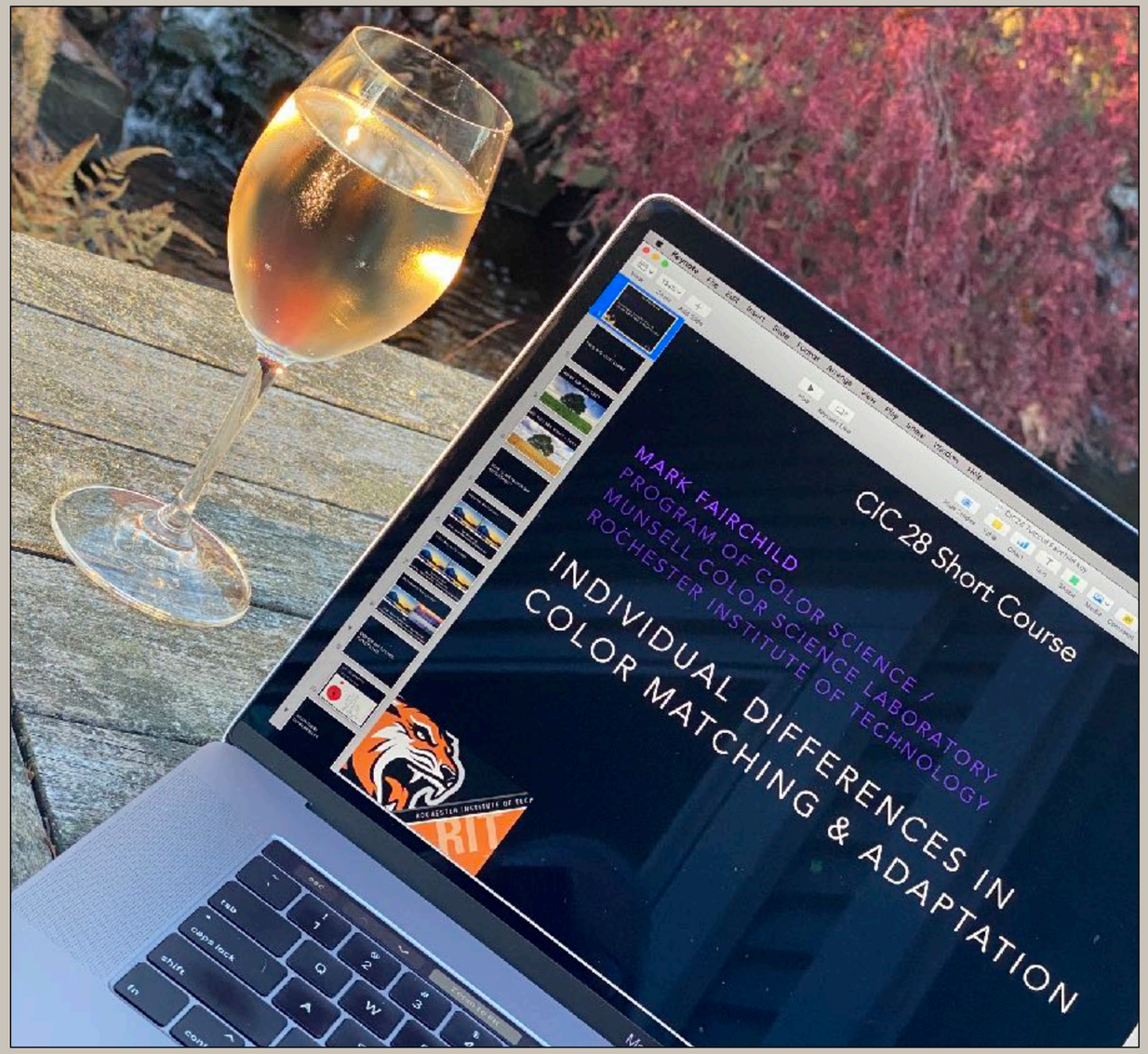
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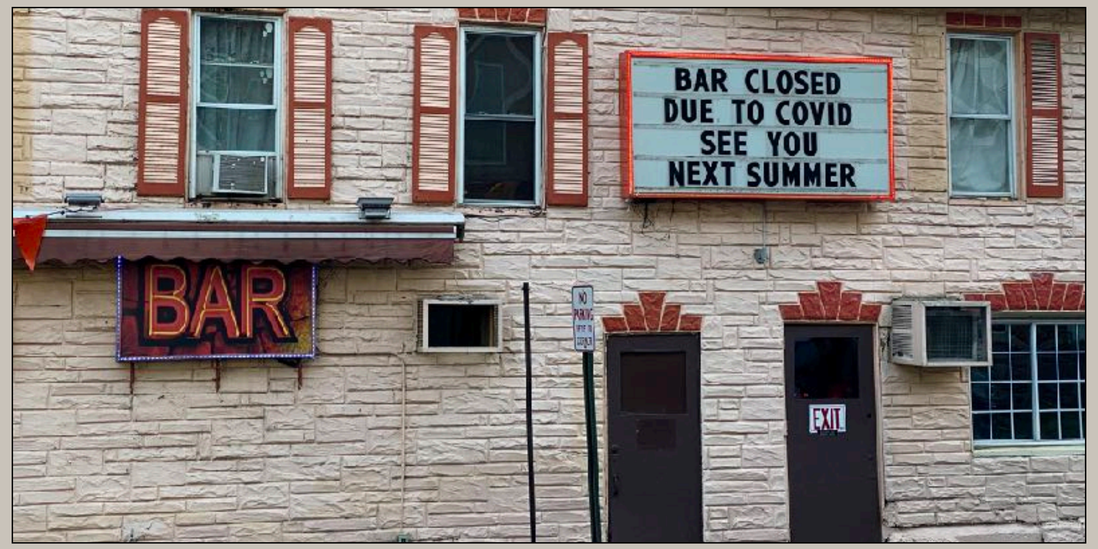
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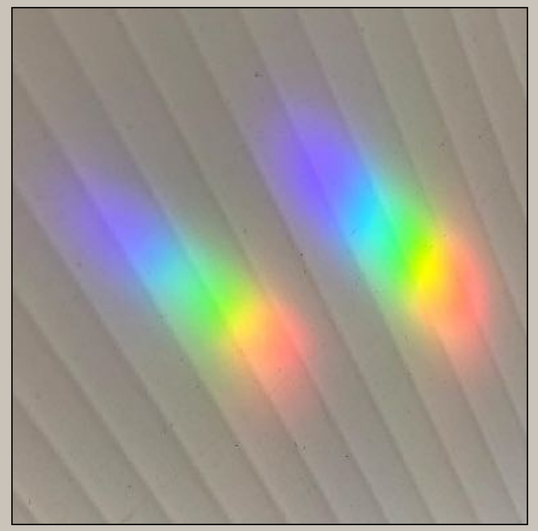

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