PoCS/MCSL

Program of Color Science

Munsell Color Science Laboratory

Annual Report 2021

Rochester Institute of Technology

College of Science

DIRECTOR'S REFLECTIONS: Wilderness of Mirrors

My titular phrase has many attributions, but appears to have originated in *Gerontion* by T.S. Eliot. Somehow both the phrase and the poem seem appropriate summaries of our second full year of operation in a global pandemic and my last as Director of PoCS/MCSL. We in the lab have aspired to fulfill our founding objectives from the Munsell Color Foundation and maintain our creativity and contributions in research and education. We all hope 2022 will afford us some return to the positive aspects of our prior normalcy.

The students, staff, and faculty of PoCS/MCSL were happy to return to classes and research together in the lab for the Fall 2021 semester. While face coverings and other appropriate procedures were the norm, we were able to gather for some good times together outdoors. As an entity, the lab carried on valiantly and we participated in many online conference presentations, symposia, and other professional events. Our reduced need for travel expenses allowed us to register more students and faculty for a wider range of events; at least one instance of the glass being half full. There have been many lessons that could make the field better and more efficient in years to come.

Within the lab, we have maintained our strong and steady growth and diversification based on our 2013 strategic planning and curriculum redesign. Four outstanding new Ph.D. students and two new M.S. students joined the program. With the largest group in over a decade, we had seven graduations in 2021, Fu Jiang (Ph.D.), Yongmin Park (Ph.D.), Anku (Ph.D.), Katie Carpenter (Ph.D.), Adi Robinson (Ph.D.) Yue Yuan(M.S.), and Ben Bodner (M.S.) and we have several students on deck to be graduating soon. Some highlights of the year 2021 include:

~Dr. Christopher Thorstenson joined PoCS/MCSL as an Assistant Professor in August 2021.
~Dr. Mekides Abebe joins PoCS/MCSL as the R.S. Hunter Visiting Assistant Professor of Color Science, Appearance, & Technology in January 2022.
~Dr. Murdoch was awarded tenure and promoted to Associate Professor effective August 2021.
~Dr. Fairchild was honored with the 2021 Godlove Award from the Inter-Society Color Council.
~Dr. Fairchild also received the 2021 Otto Schade Prize from the Society for Information Display.
~Ph.D. Candidate, Hao Xie, received the overall best paper award at the 29th IS&T Color & Imaging Conference.
~Che Shen was also voted as a runner up for the best student paper at the same conference.

continues ..

DIRECTOR'S REFLECTIONS: Continued

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 2021 donors and sponsors:

~Anonymous, Apple, Avian Rochester, Val & Len Hemink, Andreas Kraushaar, LGE, Meta, Muster-Schmidt Verlag, NSF, Samsung, David Wyble, Huan Zeng and several internal RIT programs.

Sadly, the PoCS/MCSL family and the color science community lost a valued member in 2021 with the untimely and unexpected passing of Tongbo Chen. Tongbo was a post-doc in MCSL from 2010-2012 and most recently worked at Apple. We were all surprised and saddened at the news. In the accompanying image, Tongbo is pictured with Roy Berns and David Wyble during his time at MCSL.

Please read through this report for more information on our current students and research projects. We hope they bring some clarity to today's wilderness of mirrors and provide some insight into the ecosystem that is PoCS/MCSL.

On a personal note, this is my final annual report as Director of the Munsell Color Science Laboratory. It has been an honor and privilege, as well as a huge part of my journey for decades, but it is time to move on to new and different adventures. I am happily stepping down from all my administrative duties at the end of the 21-22 academic year in a transition I planned for some time. I will be on sabbatical for 22-23 and finish a book on the colors of leaves and the Munsell system (e.g., see cover image). After that, I will return to campus part-time for three years focusing on teaching and research until my full retirement in 2026. As we transition, I am heartened to find the lab and program in the amazing and very capable guidance of our next generation of outstanding faculty. Mike Murdoch will be taking over as the next MCSL Director and Susan Farnand will become the Color Science Ph.D. Program Director. It will be great working with both of them and I know our students and research programs have a strong future. I look forward to reading next year's annual report from a different viewing direction. It has been an amazing journey and I thank you all.

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

Nulli secundus!

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

MCSL Current Students

Saeedeh Abasi, PhD, CS
Rema Amawi, PhD, CS
Gabrielle Brogle, MS, CS
Dara Dimoff, PhD, CS
Tucker Downs, PhD, CS
Luke Hellwig, PhD, CS
Leah Humenuck, PhD, CS
Olivia Kuzio, PhD, CS
Minyao Li, PhD, CS
Zilong Li, PhD, CS
Likhitha Nagahanumaiah, PhD, CS
Eddie Pei, PhD, CS
Che Shen, PhD, CS
Yuan Tian, PhD, CS
Ming Ming Wang, PhD, IS
Abby Weymouth, MS, CS
Fernando Voltolini De Azambuja, MS, CS
Hao Xie, PhD, CS
Lili Zhang, PhD, CS

Visiting Researchers

Emilie Robert, ISAE-SUPAERO

"Alumni"

2021
Anku, PhD, CS
Ben Bodner, MS, CS
Katherine Carpenter, PhD, CS
Fu Jiang, PhD, CS
Yongmin Park, PhD, CS
Emilie Robert, VS
Adi Robinson, PhD, CS
Yue Yuan, MS, CS

2020
Katie Albus, VR
Siyuan Chen, VR
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

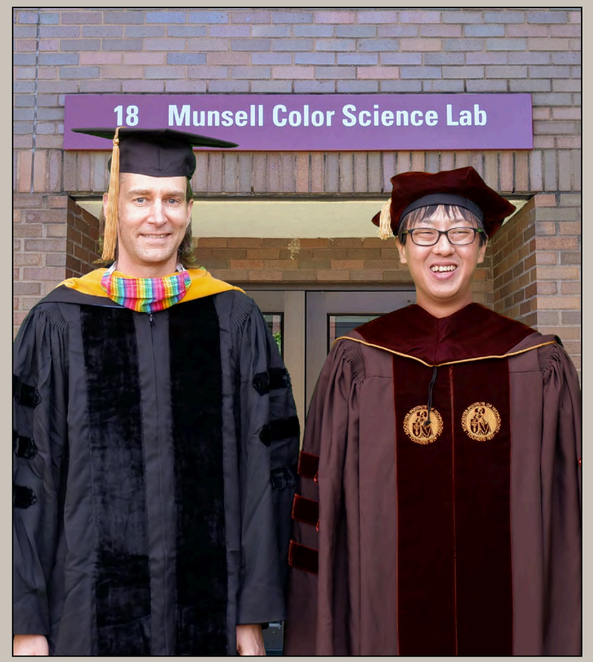
2014
Farhad Abed, PhD, CS
Stephen Dolph, MS, IS
Timo Eckhard, VR
Adrià Forés Herranz, PhD, CS

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

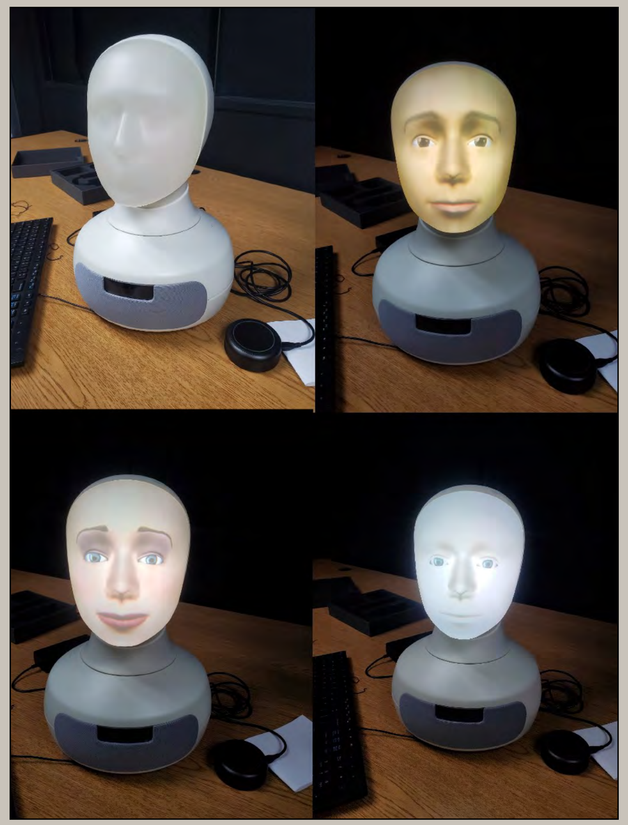
1989
Mitch Miller, MS, IS
Kelvin Peterson, MS, IS
Lisa Reniff, MS, CS

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: Facial Appearance in Social Robots



We are beginning work to evaluate the perceptual factors involved in the appearance and evaluation of artificial social agents, including social robots. This work will address questions critical toward developing social robots that can effectively communicate and interact with humans. For instance, what factors contribute to realistic appearance of artificial skin? How might realistic appearance distract from preferred appearance? In what ways can we augment robots' ability to express social information, like emotion? We recently acquired a social robot capable of rendering complex facial features to a back-projected face-like display (pictured). Some topics of this work will include:

-Investigating properties that contribute to rendering realistic skin appearance in social robots

-Understanding preferred feature characteristics within customized user-generated robot avatars

-Perception and evaluation of social cues (*e.g.*, blushing, emotion) from social robots

Chris Thorstenson

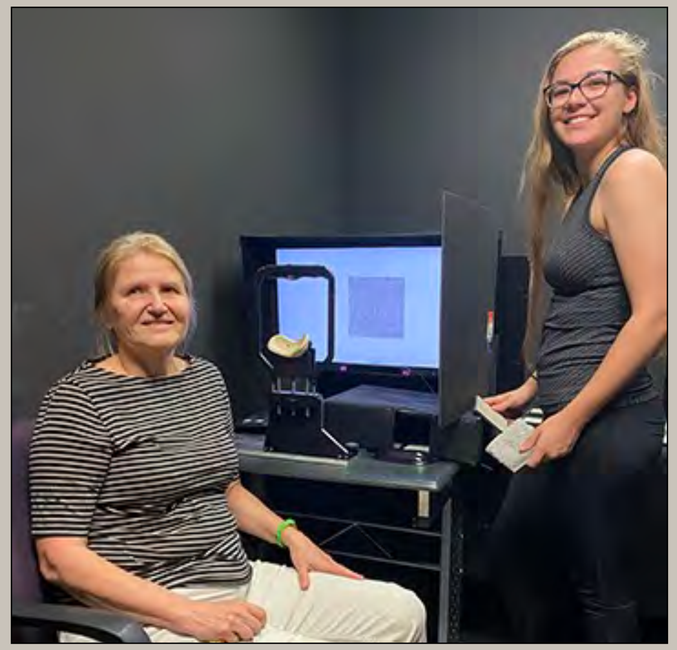
RESEARCH HIGHLIGHT: Preferred White Balance for Different Skin Tones

White balance can be challenging when a scene is illuminated by multiple color light sources. A studio was designed and built that included multiple LED light sources that were capable of producing a range of correlated color temperatures (CCTs) with high color fidelity. These lights were used to illuminate test scenes. A four Alternative Forced Choice experiment was performed to evaluate the white balance appearance preference for images containing a model in the foreground and target objects in the background. The results show that when the background is warm, the skin tone dominated observers' decisions and when the background is cool the preference shifts to scenes with the same foreground and background CCTs. The familiarity in the background scene did not show a significant effect.

Photo shows the Image capture setup featuring separate foreground and background lighting. Models of a range of skin tones sat in the chair in the foreground.

Anku, Susan Farnand

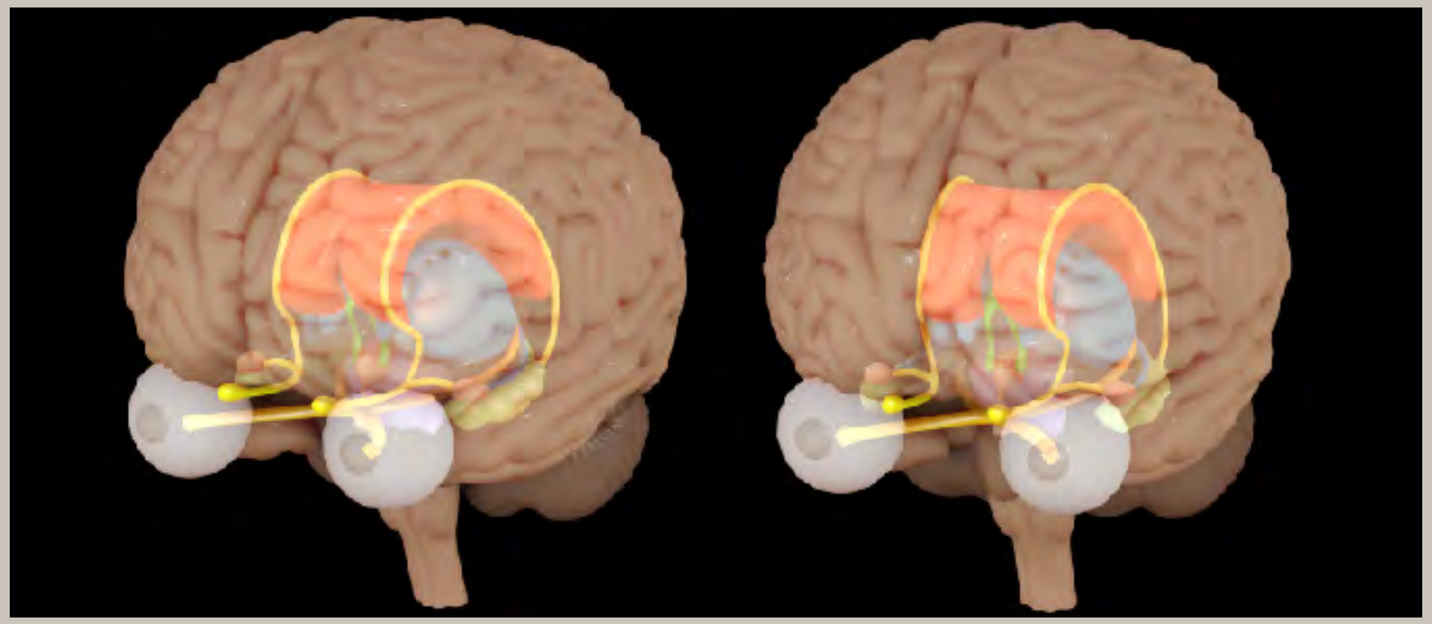
RESEARCH HIGHLIGHT: Center for Applied Neuroscience



Elena Fedorovskaya and Susan Farnand ran a project funded by the COS Dean that aims to establish a Multidisciplinary Center for Applied Neuroscience. The Center activities build upon existing expertise and excellence in Color Science, Imaging Science, Life Sciences and Mathematical Modeling in the College of Science as well as in other colleges, such as COLA and NTID. The research team included several students: Minyao Li, a first-year color science PhD student and several undergraduate students: Lily Gaffney - a fellow of Emerson Summer Undergraduate Research Program; and Elise Guth and Kavya Phadke -participants of the Inclusive Excellence Summer Research Experience. The team conducted a study on multisensory interaction between visual and tactile information in semi-immersive environments. In the experiment, participants touched textured objects that varied along previously reported dimensions for texture perception - "hard -soft" and "rough-smooth, while simultaneously looking at the photographic reproductions of the same objects, randomly presented on the screen of the high-resolution monitor. Differences in response time, gaze patterns, and rate of correctness were observed between congruent and incongruent stimuli conditions. The research will expand toward using virtual and augmented reality systems and will include registration of brain activity via wearable EEG recording device. The results will be important in the development of mixed reality systems.

Elena Fedorovskay, Susan Farnand, Multidisciplinary Student Team

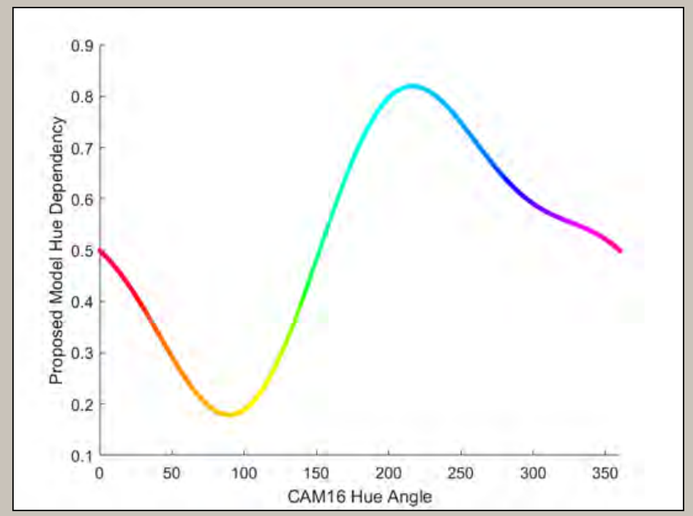
RESEARCH HIGHLIGHT: Exploring Transparency in AR for Neuroscience Education

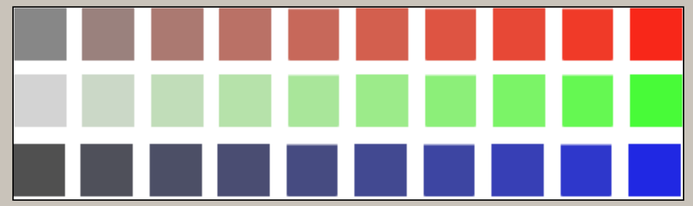


Biomedical Sciences undergraduate Josephine Bensa, of the McNair Scholars LSAMP program, created and tested simulations of 3D AR renderings of the human visual system. In coordination with Susan Farnand's related multi-disciplinary engineering design project, 3D models of the human brain and the components of the visual pathway were selected for study. Graphics renderings were created, and simulations of optical see-through AR resulted in images varying in transparency, following Murdoch's interest in color appearance in AR. This is the first step toward creating an interactive educational AR overlay of visual system information onto the physical model brain constructed by the engineering students, which would in turn become a test application for testing AR rendering parameters. Brave readers may attempt to view the above brain image pair in the cross-eyed stereo method.

Josephine Bensa, Susan Farnand, Michael J. Murdoch

RESEARCH HIGHLIGHT: Improving CAM16





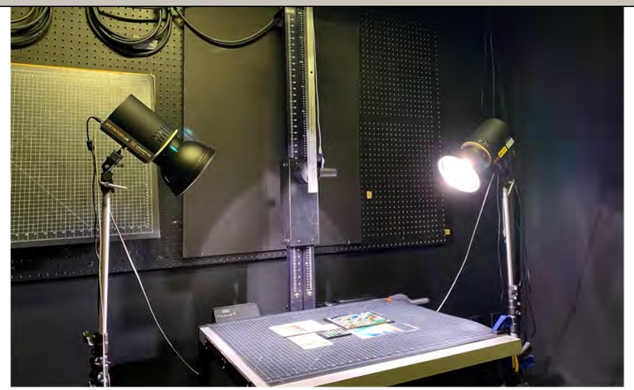
A revision of the CIE color appearance model, CIECAM02, known as CAM16, has been proposed to the CIE as a likely successor. Unfortunately some of the recognized shortcomings of CIECAM02 are not addressed in CAM16. Luke Hellwig, in collaboration with Samsung, has developed improvements to CAM16 that allow it to incorporate the Helmholtz-Kohlrausch effect and correct inconsistencies between the definitions of brightness and lightness as well as making some other adjustments to simplify and improve the model. The newly proposed equations are the subject of two papers submitted to Color Research and Application that should appear in 2022. Further work will include psychophysical evaluation of the new model.

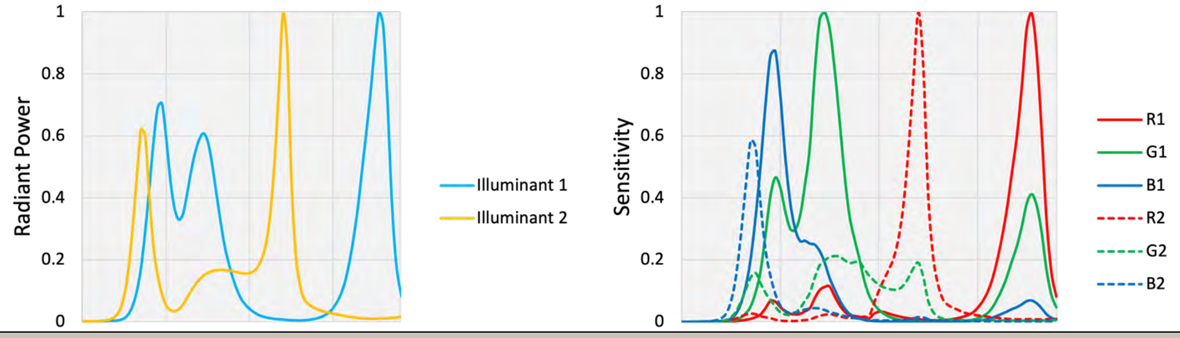
Luke Hellwig, Mark Fairchild

RESEARCH HIGHLIGHT: Practical LED-based Multispectral Imaging

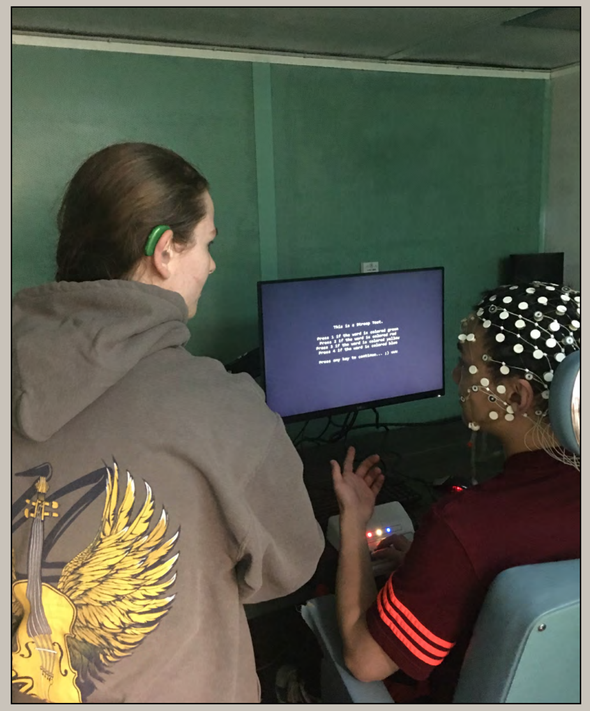
Spectral imaging research in the Studio has focused, in the past year, on the investigation of optimal capture and processing workflows for MSI carried out using narrowband LED sources, in line with the larger goal of developing a practical and affordable strategy for implementing MSI as a routine technique in museum imaging studios. The approach that has been pursued was inspired by the dual-RGB technique developed by Roy Berns, which involved pairing a set of filters with an RGB sensor to turn a three-channel color camera into a five-channel spectral imaging system. Using tunable multichannel LED lights, a pair of illuminants has been optimized for two-light, six-channel spectral capture with a prosumer camera, like those commonly used in museum imaging. This spectral imaging strategy has been shown to enable simple and efficient color accurate rendering of paintings for diverse applications within a museum context, from scholarship, curation, and conservation to gallery lighting design and scientific study. Images show the multispectral capture setup (top) and spectral power curves of the optimized LED light sources (bottom left) and camera spectral sensitivities (bottom right)

Olivia Kuzio, Susan Farnand





RESEARCH HIGHLIGHT: Familial Alzheimer's and Cognitive Performance



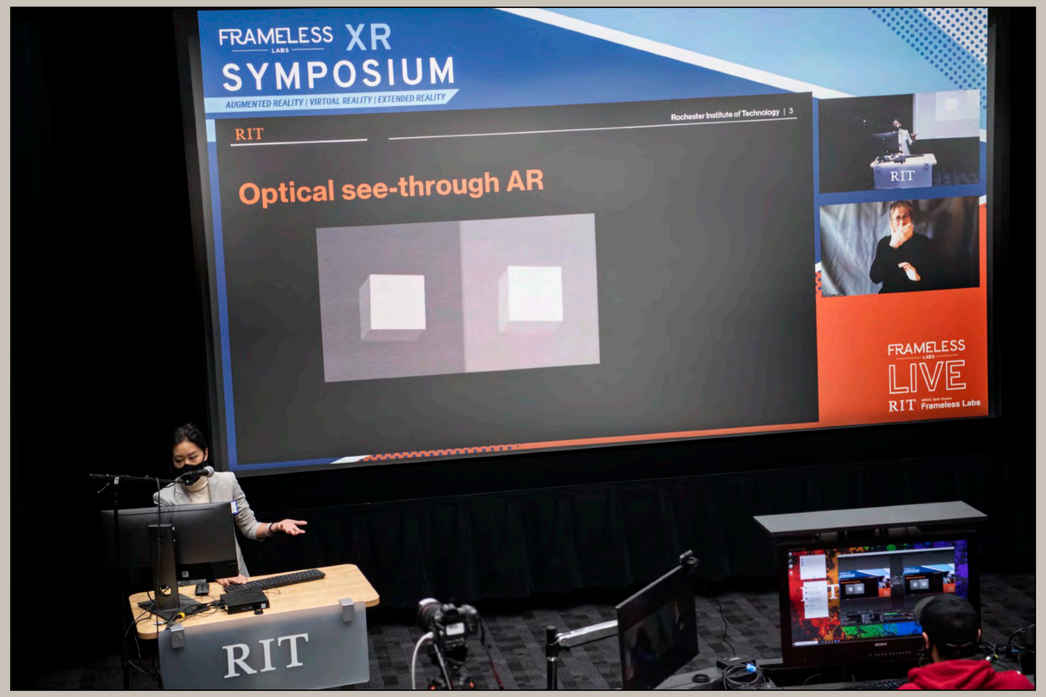
Elena worked with an NTID student Holly Elder on the project entitled Familial Alzheimer's Disease and Cognitive Performance in Young Adults. Holly is a fellow of RISE program, an NIH-funded RIT Research Initiative for Scientific Enhancement Scientists-in-Training Program for Deaf and Hard-of-Hearing Undergraduates. The study aims at investigating potential characteristic markers in cognitive performance and brain activity in asymptomatic young adults who have a family history (F) of Alzheimer's Disease (ALZ) compared to young adults without a family history. They developed research methodology that included performing a paired-associates learning task, single digit modality task and a Stroop task on-line and in the lab where brain signals are recorded using 32-channel EEG system. Data from the 4 participants with a F+ALZ and 4participants without a family history (F-ALZ) indicated a potential difference in performance on these three cognitive tasks. Adults with the F+ALZ show a decreased performance on the PAL and the Stroop Task compared to the F-ALZ individuals. The experiments will continue with more participants and will look at the brain connectivity between different cortical areas.

Holly Elder, Elena Fedorovskaya

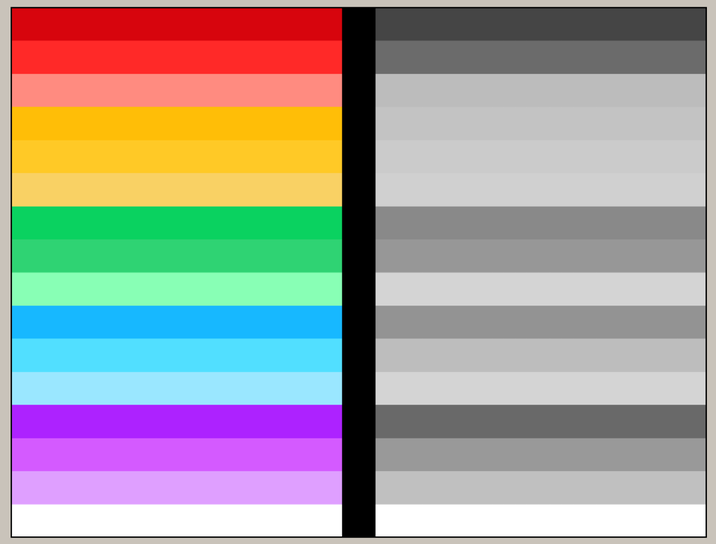
RESEARCH HIGHLIGHT: Brightness in Optical See-Through AR

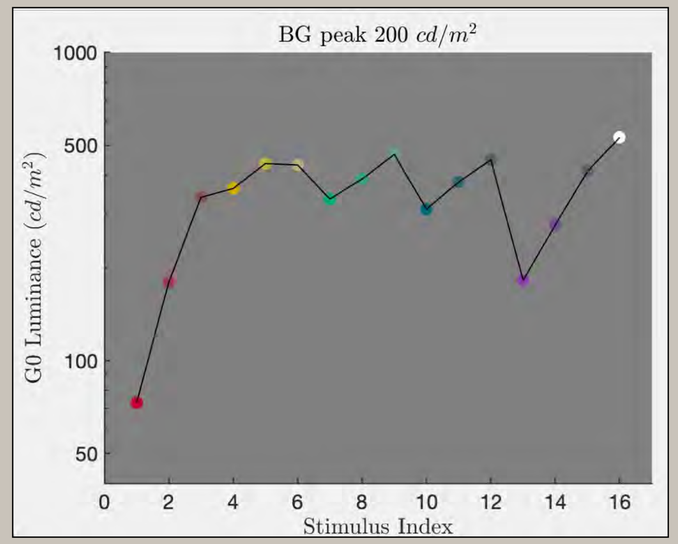
Continuing the research on appearance in optical see-through AR, an extended study aimed to determine how bright to render a 3D AR cube to make it appear reflective diffuse white, rather than an emissive cube. Background condition variations included the background luminance levels, spatial pattern, and luminance contrast. An interactive psychophysical experiment assessed the appropriate luminance level of the cube, providing observers the ability to change the cube material reflectance while rotating its orientation. Both 2D patches and 3D cubes were included to examine the rendering dimensionality effect. The diffuse white threshold helped anchor relative brightness scales resulting from previous studies for seamless connections between the virtual rendering and the real world. The research was presented at the 6th Annual Frameless XR Symposium to AR content creators as a reference for realistic rendering and immersive experiences.

Lili Zhang, Michael J. Murdoch



RESEARCH HIGHLIGHT: Revisiting G0



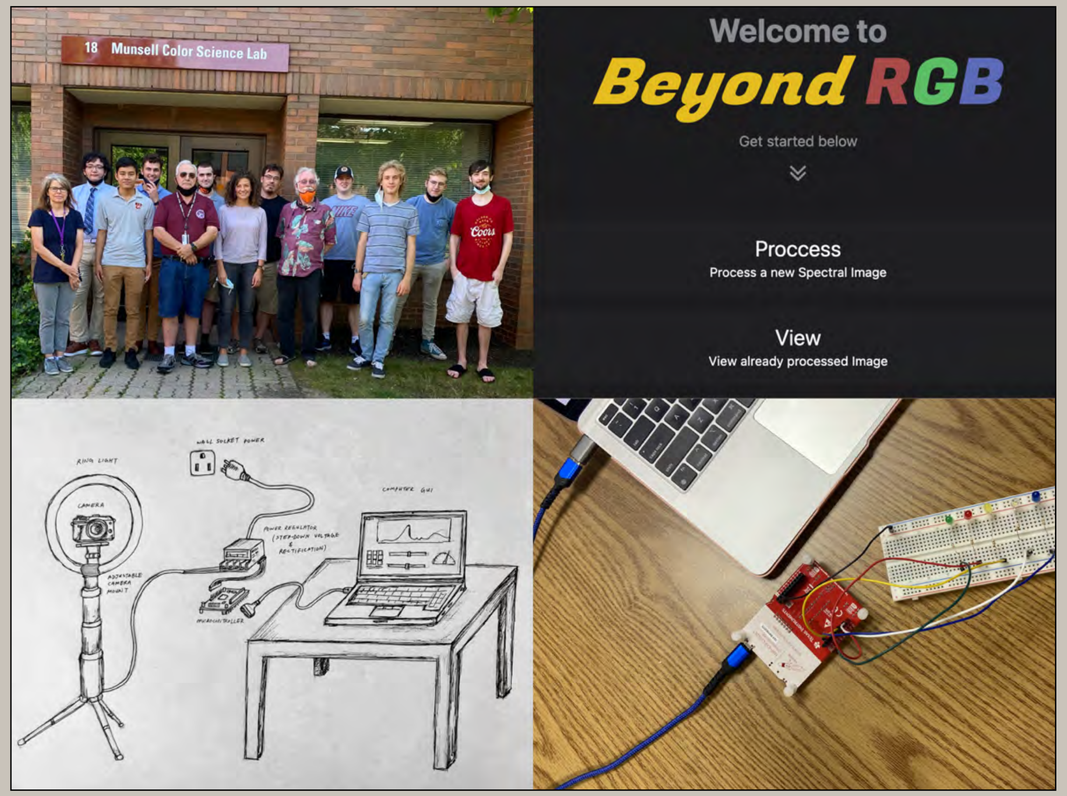


Hao Xie examined the relationship between brightness and colorfulness in a series of psychophysical experiments that illustrated that a new definition of lightness relative to the zero-grayness luminance for the same chromaticity (referred to as G0 by Ralph Evans) can inherently account for the Helmholtz-Kohlrausch effect (the fact that perceived brightness of a stimulus depends on both the stimulus luminance and its chromaticity). The results suggest a new way to model color appearance that will be further developed in future works including an examination of perceived saturation scales. Hao's paper at the 29th Color and Imaging Conference was honored with the Best Paper Award for the conference.

Hao Xie, Mark Fairchild

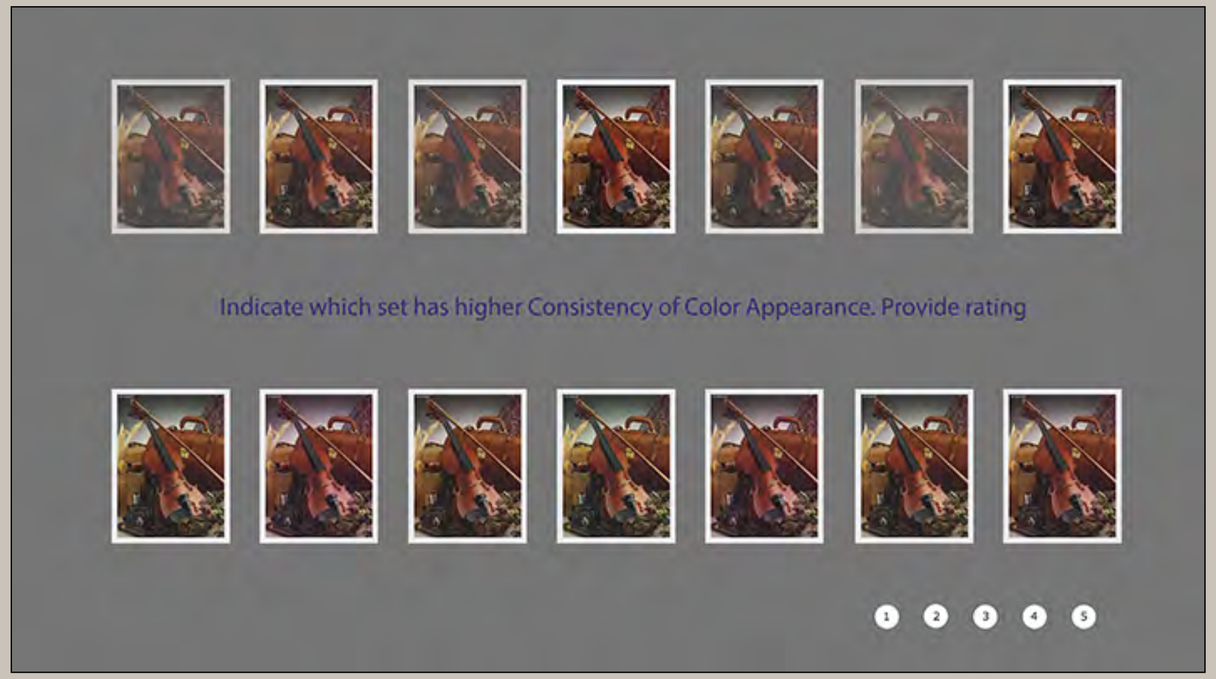
RESEARCH HIGHLIGHT: Tools for Museum Studio Spectral Imaging

Building on the recent spectral imaging research progress are parallel efforts to promote the two-light imaging strategy by developing hardware and software solutions to facilitate its use in practice. For the 2021-2022 academic year, we are working with two RIT undergraduate senior design teams to create these deliverables. The first is a team of software engineering students who are writing an open-source software application with a user-friendly graphical user interface for intuitively processing and interactively inspecting spectral image data. This work will culminate in the availability of an accessible computational tool for photographers to utilize for color quality-focused spectral imaging. The second is a multidisciplinary team of electrical and mechanical engineering students who are constructing a prototype six-channel LED ring light. The prototype will serve as proof-of-concept for an inexpensive, portable spectral lighting fixture that could be easily integrated into a studio imaging workflow. Upon completion, we will work with photographers and conservators from regional institutions to pilot test the software and lighting systems within their studios. These tests will provide the opportunity to engage in spectral imaging education and outreach, promote the methods and tools that have been developed, gather an understanding of how users will interact with them in practice, and inform both short term improvements and areas for broader future research and updates. Clockwise from top left: the Software and Engineering design teams, the welcome screen for the software application, a protoboard, and a sketch of the prototype lighting system



Olivia Kuzio, Susan Farnand

RESEARCH HIGHLIGHT: Consistency of Colour Appearance



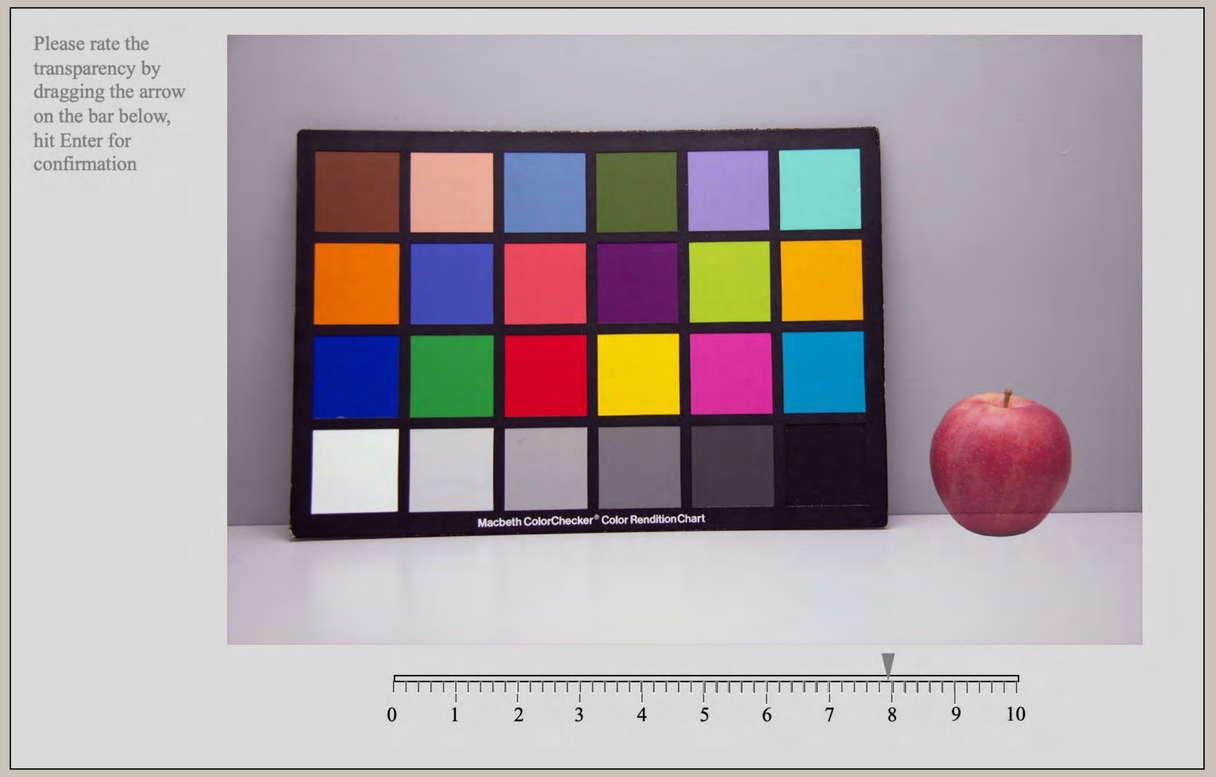
Elena Fedorovskaya continues to be involved in activities of the CIE TC 8-16 "Consistency of Colour Appearance within a Single Reproduction Medium". The goal of this technical committee is to study and report on sets of reproductions of the same source image that have a consistent color appearance and are most similar to a reference reproduction, including recommending assessment methods that measure the similarity of reproductions of an image with different color gamuts, for printed images on substrates with approximately similar characteristics in a fixed viewing environment. The RIT team previously conducted a series of experiments using hard copy images that were printed by varying gamut, tonality and gray balance using controlled printing conditions. The current efforts switched to using soft copy proofing to study the influence of observers' expertise and expectations, as well as the presentation arrangement when a set of more than two mages is evaluated for the consistency of color appearance. The experiments were resumed after delays caused by the COVID pandemic and will be completed in 2022.

Elena Fedorovskaya

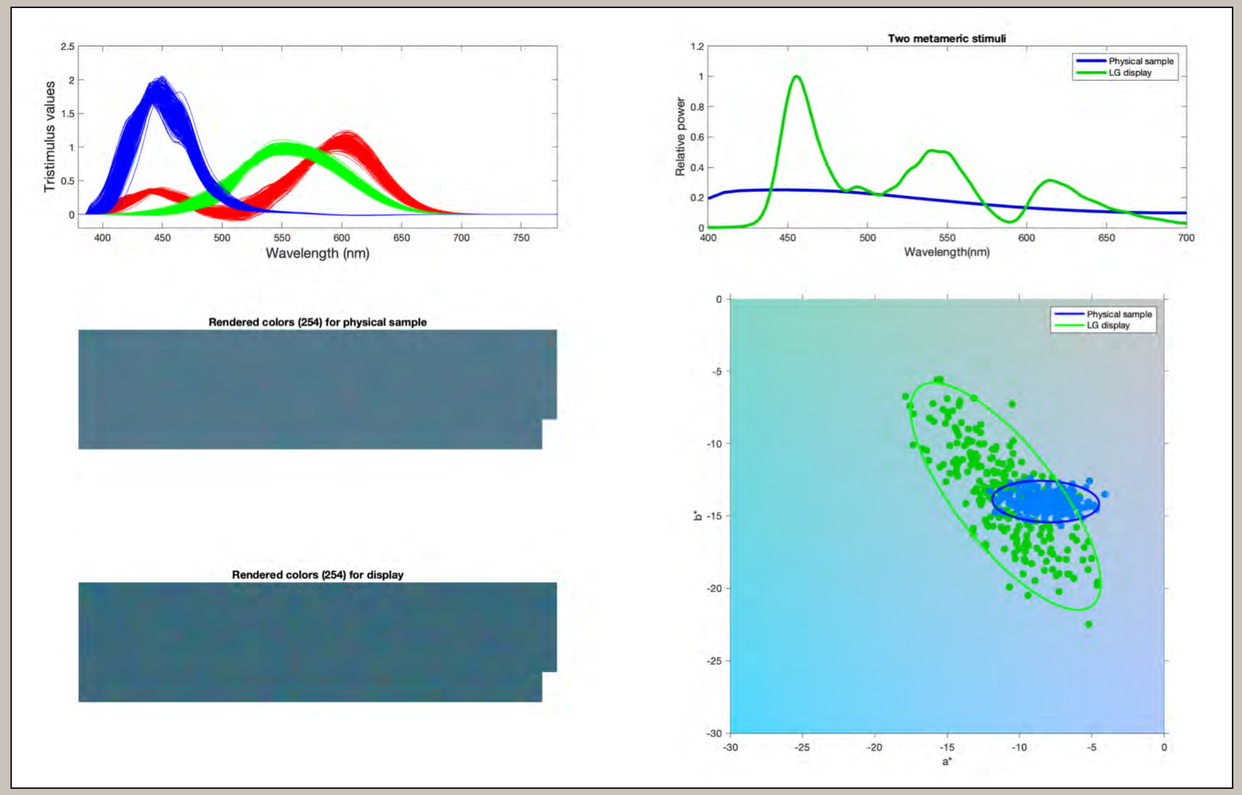
RESEARCH HIGHLIGHT: Perceived Realness in Augmented Reality

What display and rendering factors affect how real a virtual object looks in optical see-through AR? This project aims to study perceived realness, for example of the rendered apple shown, varying image processing and graphics rendering parameters. It will also address preference for gamma for rendered objects in AR environment. The experiment will utilize the MCSL AR setup with an optically transparent display, which that has been used for experiments on color appearance, brightness, and transparency.

Zilong Li & Michael J. Murdoch



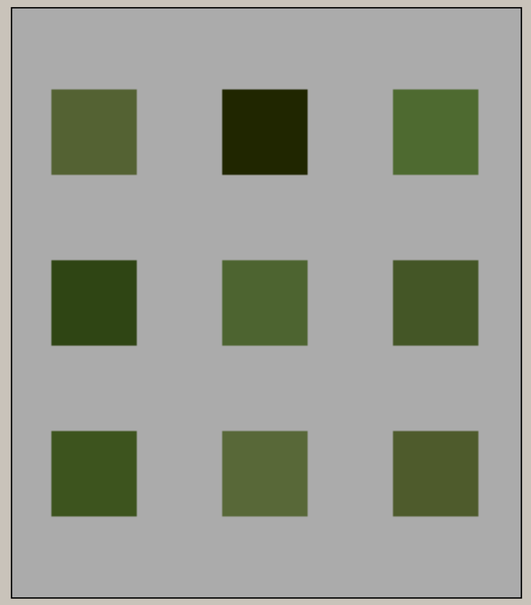
RESEARCH HIGHLIGHT: Metrics for Display Observer Metamerism



In collaboration with LG Electronics, Che Shen has been exploring the possibility of specifying the potential for observer metamerism in display systems without explicit comparison to a second, reference, display. Psychophysical experiments were completed in which observers selected unique hues on various displays to determine if the variability due to observer metamerism could be separated from individual variability in the hues themselves. While the result was negative, the analyses provided guidance on new methods for specifying observer metamerism that are being provided to the display community and are part of a journal paper under preparation.

Che Shen, Mark Fairchild

RESEARCH HIGHLIGHT: Perceived representative image color



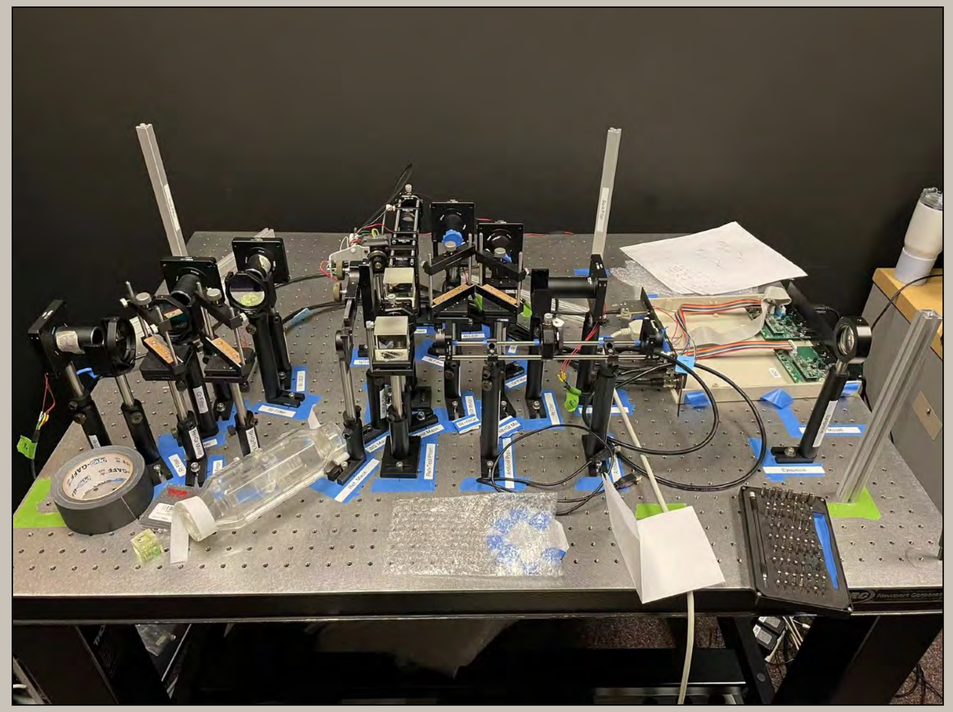
In 2020, an online experiment was created to assess how participants determine the representative color of an image. Images of tomatoes, grass, sky, and skin were included to evaluate a range of image content. Participants are asked to make a choice of which color best represented the overall image from an array of nine choices. The images included full images, cropped versions to remove the background, down-sampled versions of the cropped images and scrambled versions of down-sampled images to compare choices at differing levels of context. In 2021, evaluation of the initial experiment results suggested that observer selections were roughly evenly split between selecting an average color and a more saturated or chromatic color and that the context effect on these tendencies was minimal. It was also apparent that the array configuration led to over-emphasis of the central patch in the color array. Further testing with additional images, including a wide range of skin tones, is planned. The images for this work, including arrays eliminating the central patch, as well as an updated experimental interface were developed. Illustrated are an example image and accompanying array of possible representative color choices

Dara Dimoff, Susan Farnand

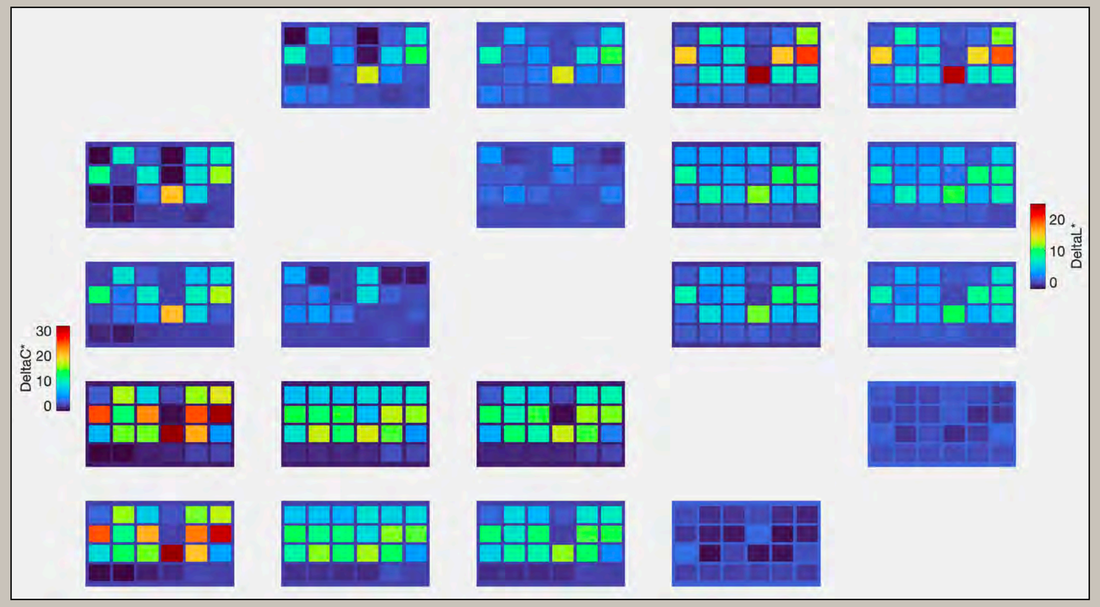
RESEARCH HIGHLIGHT: Trichromator

In the summer of 2021, we received a gift in pieces from Apple: a trichromator designed and built by Prof Stockman from University College London. The trichromator is an instrument that is designed for measuring the color matching function of human observers. The rebuild is still in progress and delayed by component issues, but once complete, individual color matching functions can be measured for observers and we can potentially build up a MCSL observer database.

Zilong Li, Mark Fairchild, Michael J. Murdoch



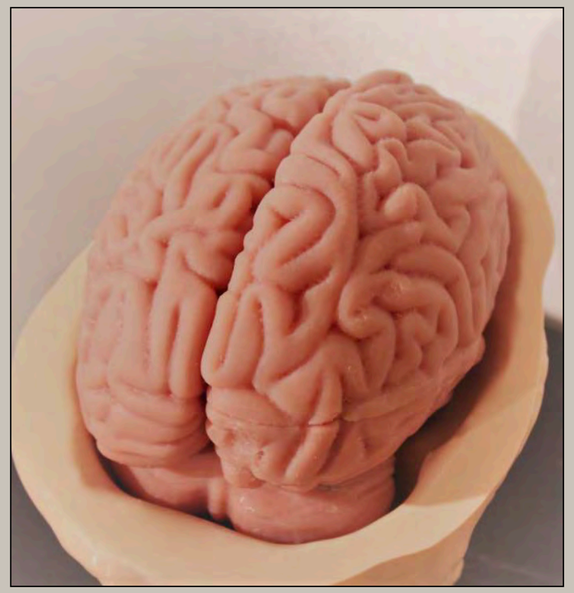
RESEARCH HIGHLIGHT: Perceived Color Gamut Volume



In another collaboration with LG Electronics, Hao Xie has performed a psychophysical and computational assessment of perceived color gamut volume in high-dynamic-range displays using typical images. The main goal is to explore the interaction between the gamut of typical images and the available gamuts of various display technologies. This is of particular interest in the comparison of RGBW displays (which get their added luminance range from a fourth, white, primary, but lack bright saturated colors) with more traditional RGB technologies that have a much larger color gamut volume. The results indicate the importance of image content on the comparison as it is rare for any image to fill a display gamut and illustrate that any shortcomings of RGBW displays are rarely observable with typical images. A journal paper is in preparation.

Hao Xie, Mark Fairchild

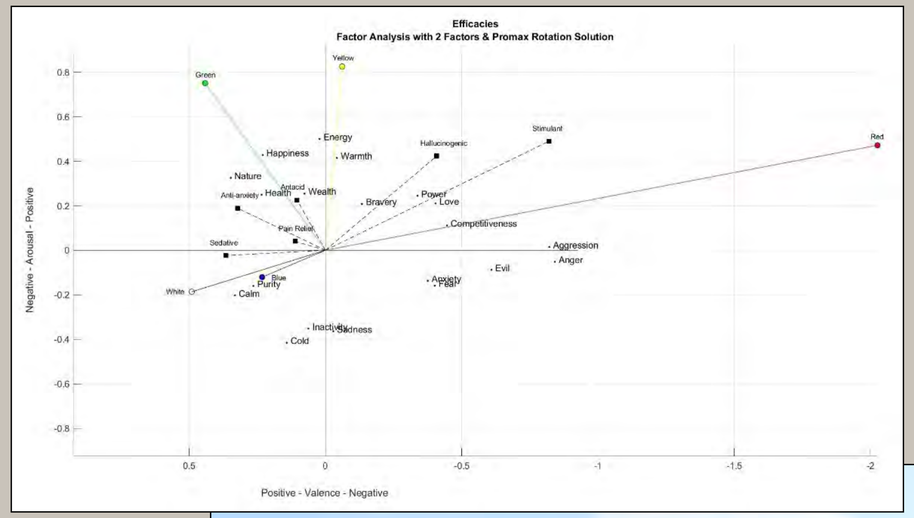
RESEARCH HIGHLIGHT: Dissectible Model Brain



The undergraduate introductory cognitive neuroscience course, CGNS-222, includes content on neural anatomy. When studying brain anatomy, in specific, it is important to learn about the structures of the major parts of human brain and their localizations. An Engineering Multidisciplinary Senior Design project was completed in April that resulted in a skin-tone pigmented, silicone model brain created using 3D-printed molds. It is the size of the average human brain and contains 'dissectible' parts using 3D-printed tools. The cerebrum, cerebellum and brainstem are separable structures in this brain model. The right cerebral hemisphere consists of coronal (transverse) slices of the brain to show main anatomical features of cortical and subcortical structures. The left hemisphere will be used to demonstrate the main structures of the forebrain, midbrain and hindbrain. The Model Brain was used in CGNS-222 course, both during the discussion of gross anatomy of brain structures and throughout the semester in studying of many aspects of cognitive functioning and underlying brain mechanisms. Images show the molded silicone model brain in its 3D-printed stand.

Susan Farnand, Elena Fedorovskaya

RESEARCH HIGHLIGHT: Color in Pharma: Associations and Expected Efficacies



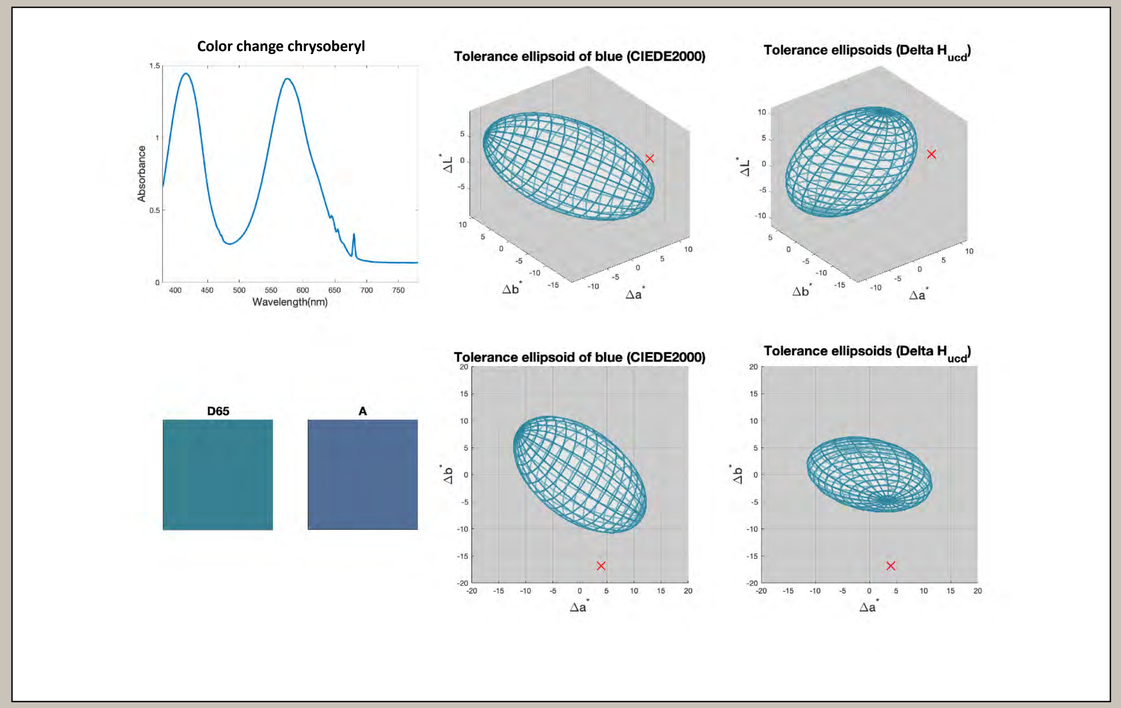
With the cooperation and collaboration of RIT's USA, UAE, Croatia, Kosovo, and China campuses, this project studied the relationship between the colors of pills and their perceived and expected efficacies. The project also looked at the influence of demographics on participants' color choices, as well as the reasoning behind these choices and the color associations exhibited. The strongest and most consistent color associations were those of white with pain relief and red with stimulant efficacies; other efficacies had more dependence on demographic factors. The plot above shows a factor analysis relating the survey participants' color associations with a range of emotion concepts, which reveal factors similar to valence and arousal. The aim of the study is to provide color guidelines to pharmaceutical companies and medical practitioners, to better manufacture and prescribe drugs, increase compliance rates, and thus maximize the effects of the pills on patients overall.

Rema Amawi, Michael J. Murdoch

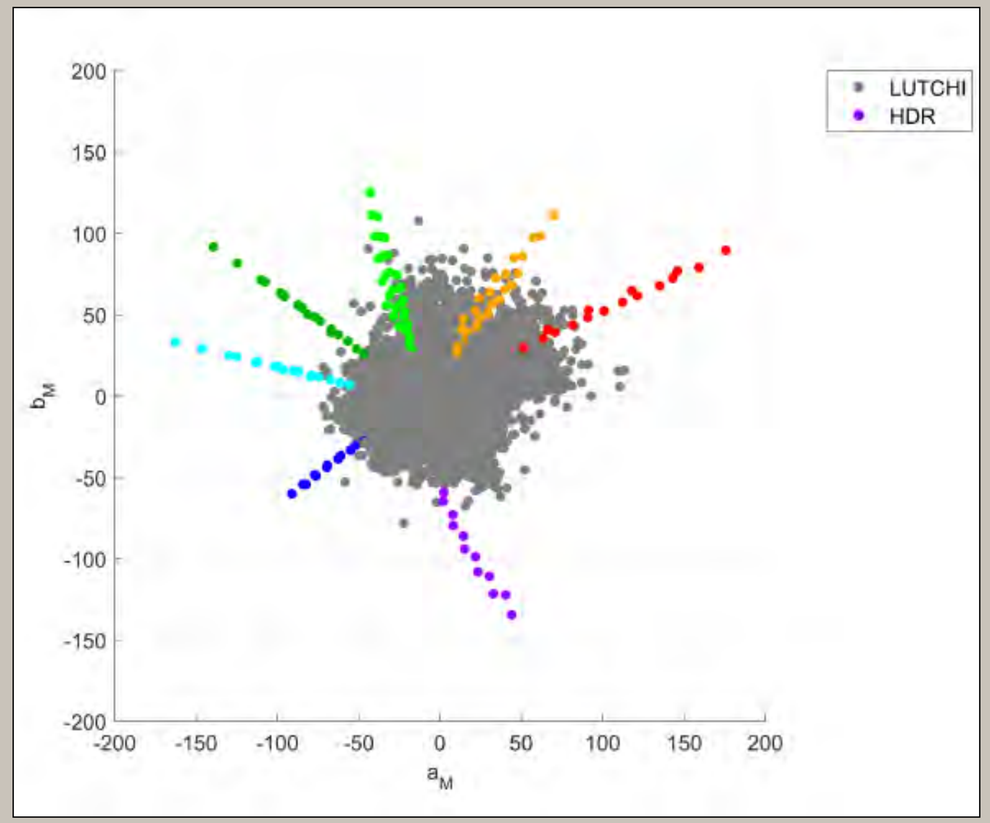
RESEARCH HIGHLIGHT: Tolerances on Color Inconstancy/Change

Color inconstancy refers to significant changes in the perceived color of an object across two or more different lighting conditions, such as daylight and incandescent light. This research focusses on defining the threshold of color inconstancy between generated D65 and A illumination through a psychophysical experiment. Although modern color appearance models provide equations to calculate the degree of adaptation, a neutral grey match experiment was completed to produce a more accurate D values for the experimental viewing conditions. Like setting an instrumental color tolerance experiment, a second, sorting, experiment was used to define the threshold of color inconstancy. This threshold is the color shift, expressed in color difference terms, required for observers to notice a color change across changes in illumination. In addition, the tolerance ellipsoid for each Munsell principal hue group was also established.

Che Shen, Mark Fairchild



RESEARCH HIGHLIGHT: Colorfulness Scaling in HDR



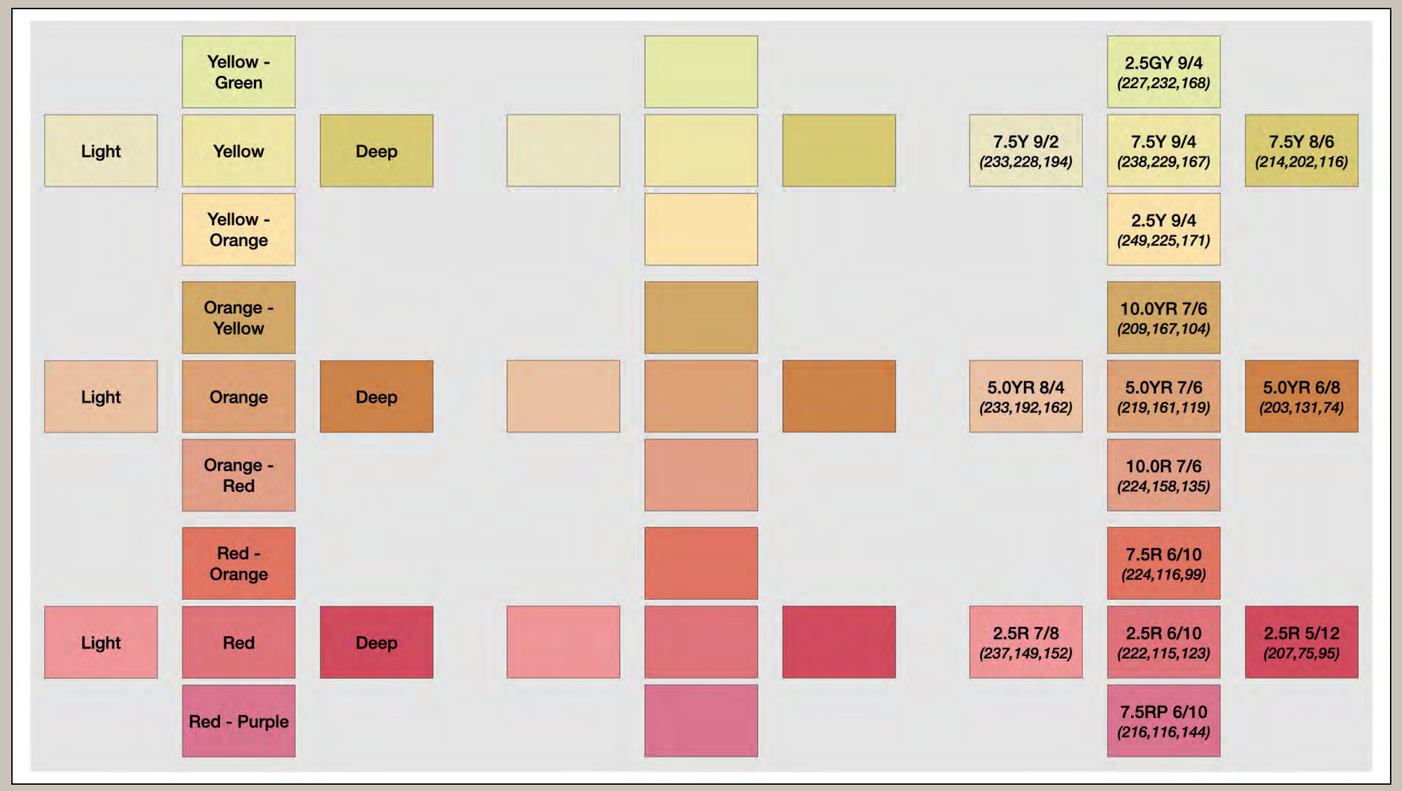
Using a 3-pixel HDR multi-primary display, a psychophysical experiment was carried out to derive relative colorfulness scales of extremely saturated colors with high luminance levels. For the experiment, a new set of color stimuli named MCSL-HDR was generated, which is much saturated than the existing LUTCHI dataset. The experiment revealed that previous CAMs, such as CIECAM02, CAM16 and CIELAB show a typical agreement with the measurements for the highly saturated colors. However, the CAMs tend to overestimate the perceived colorfulness of the less saturated colors in the new dataset and they overestimate the extremely highly saturated colors. It turned out that a power function-based empirical method improves the performance of the previous CAMs' predictors. However, future studies are required to verify the method further with larger numbers of stimuli.

Yongmin Park, Michael J. Murdoch

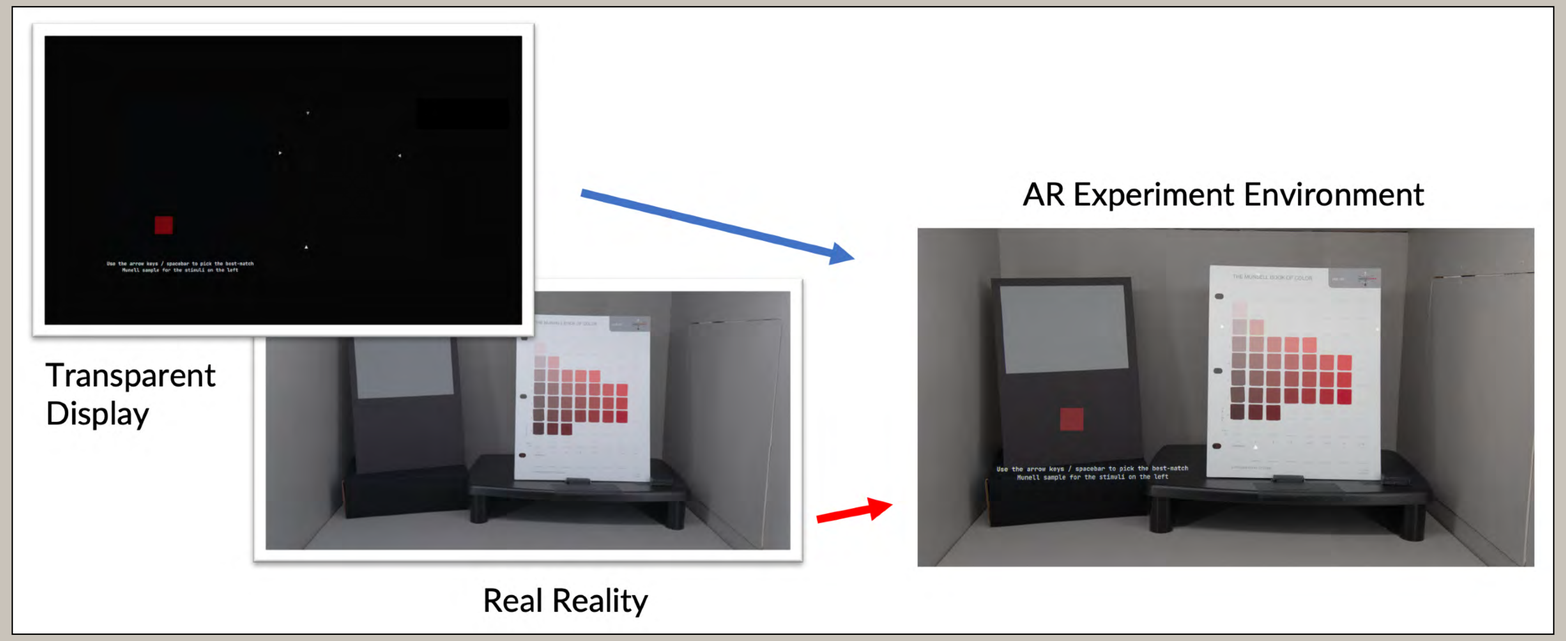
RESEARCH HIGHLIGHT: Wine Color Specification

Mark has been exploring the combination of color science and enology for several years now. His recent efforts have culminated in the development of a color chart explicitly designed for the visual color assessment of wines as a part of more comprehensive hedonistic or analytical tasting systems. The chart is based on visual, colorimetric, and in situ evaluations of existent wine color and the techniques for its assessment in wine sensory evaluation. The system is specified in Munsell coordinates and corresponding sRGB values. Its derivation and use is described and a photographic system for measurement-based implementation of the system is introduced. This work was presented at the 2021 AIC Congress (held online from Milan) and followed up with a paper that will appear in the AIC 2021 special issue of *Color Research and Application*.

Mark Fairchild



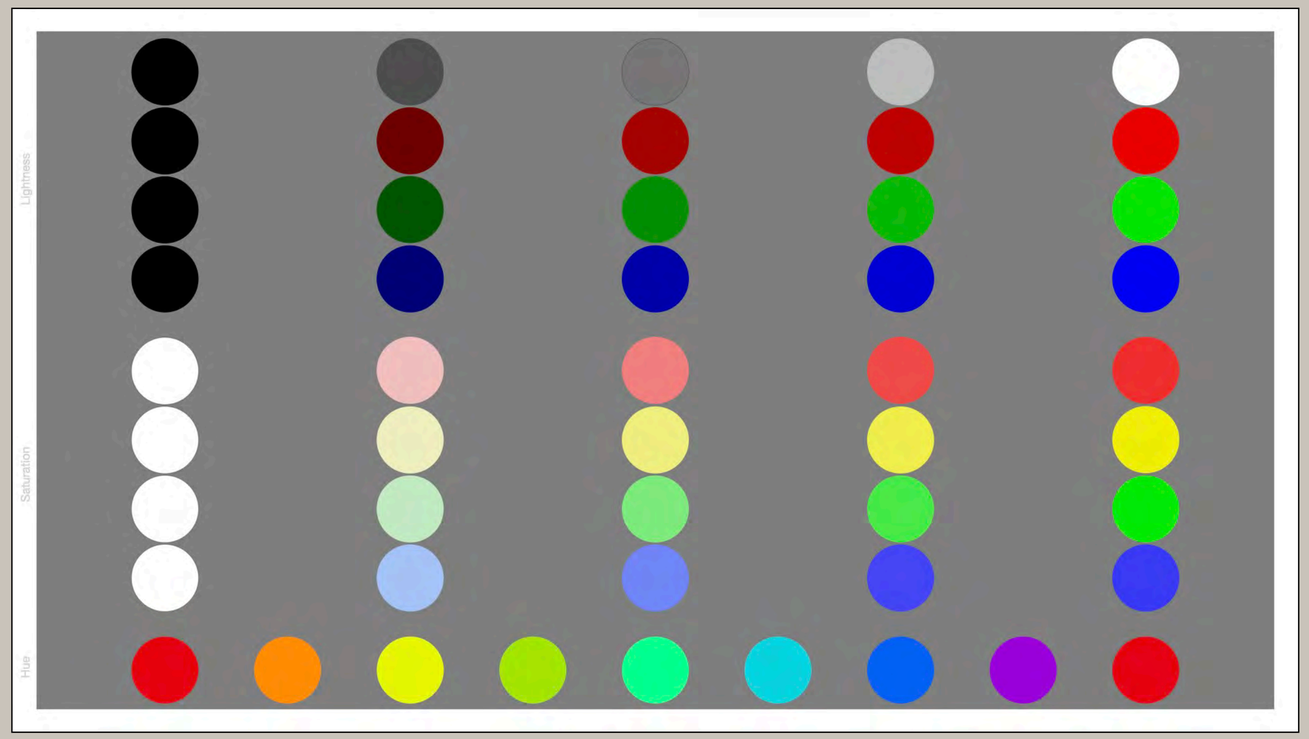
RESEARCH HIGHLIGHT: Color Scissioning in Optical See-Though AR



Ongoing research into color appearance models for augmented reality contexts examined the effectiveness of the foreground-background blending model previously published by Hassani and Murdoch with more diverse stimuli. The most recent experiment asked observers to choose a best match to a transparent AR stimulus from the color samples on pages of Munsell colors. Results showed that the blending model may be useful as an exploratory parameter space for these types of stimuli, but that a general solution to appearance in AR remains elusive. Observations show that perceptual effects, including the separation of foreground and background known as scissioning, require further research, and may connect with other known effects that are not fully accounted for in contemporary appearance models. This research was presented at the 29th Color and Imaging Conference.

Tucker Downs, Michael J. Murdoch

RESEARCH HIGHLIGHT: Color Chart for Appearance Scaling



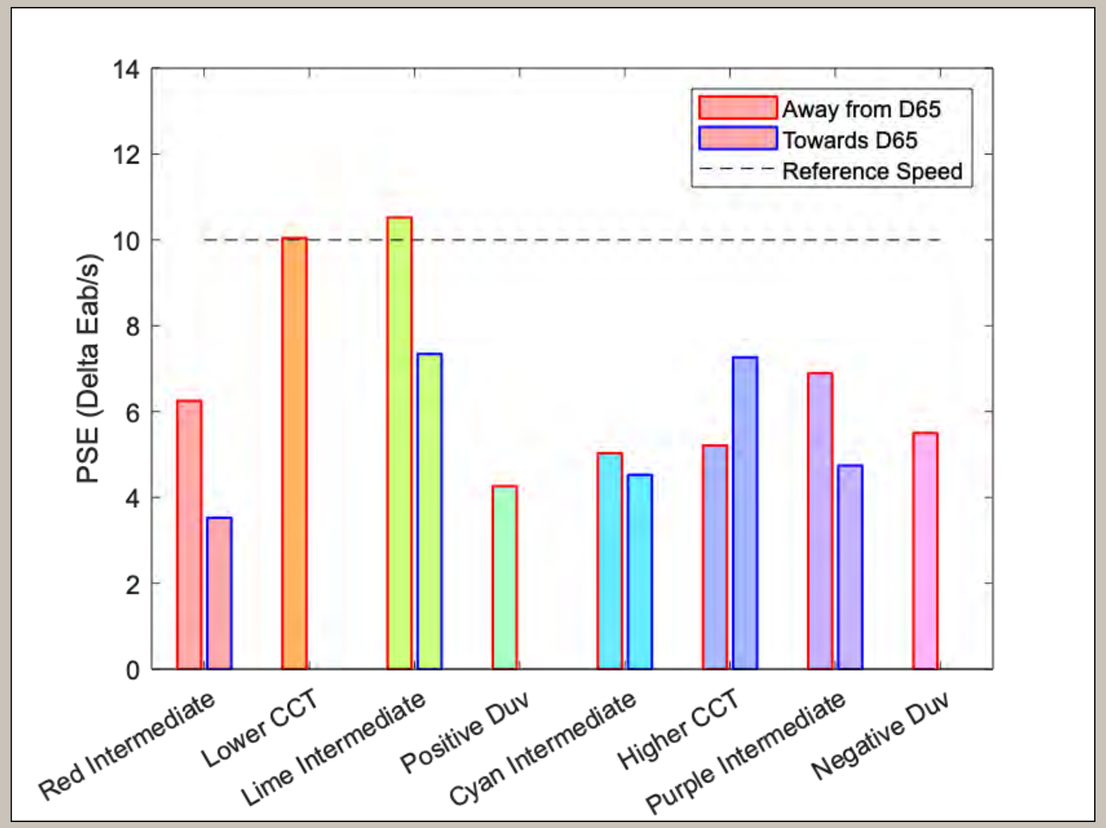
A digital color appearance test chart, akin to a ColorChecker® Chart for human perception, was developed and evaluated both perceptually and computationally. The chart allows an observer to adjust the appearance of a limited number of color patches to allow a quick evaluation of perceived brightness, colorfulness, lightness, saturation, and hue on a display. The resulting data can then be used to compared observed results with the predictions of various color appearance models. Analyses in this paper highlight some known shortcomings of CIELAB, CIECAM02, and CAM16. Differences between CIECAM02 and CAM16 are also highlighted. This paper does not provide new psychophysical data for model testing, it simply describes a technique to generate such data and a computational comparison of models.

Mark Fairchild

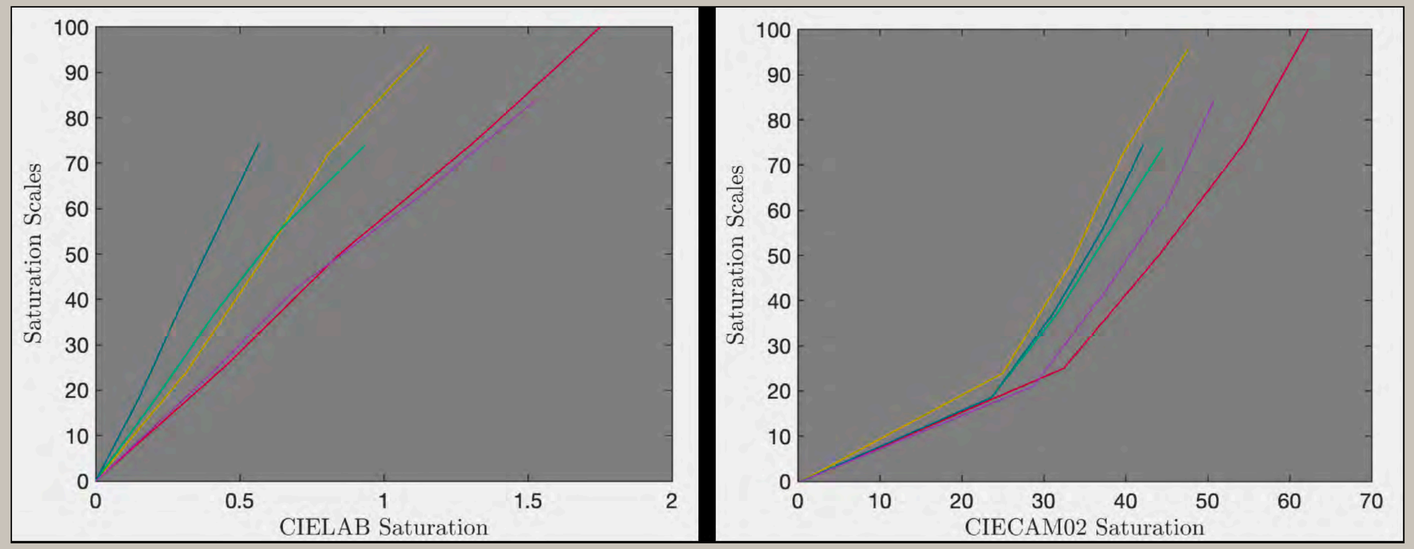
RESEARCH HIGHLIGHT: Perceived Speed of Dynamic Lighting Transitions

Dynamic lighting is an integral part of our experience of illumination, both in daylight and increasingly in artificial lighting. However, little research has been done on the perception of the speed of illumination changes. This work examined unidirectional transitions between neutral illumination and eight different hues, including transitions along the daylight locus. The chromaticity of D65 was the starting point of half of the stimuli and the endpoint of the other half. The experiment was designed to determine the perceived speed of the transitions relative to a reference transition from D65 to warm daylight. Analysis of the preliminary data verifies the temporal nonuniformity of CIELAB, with hue dependencies similar to those seen in previous work. Additionally, transitions ending in neutral were overall perceived as faster than those beginning with neutral, though behavior may be different along the daylight locus.

Abby Weymouth, Michael J. Murdoch



RESEARCH HIGHLIGHT: Saturation Scaling



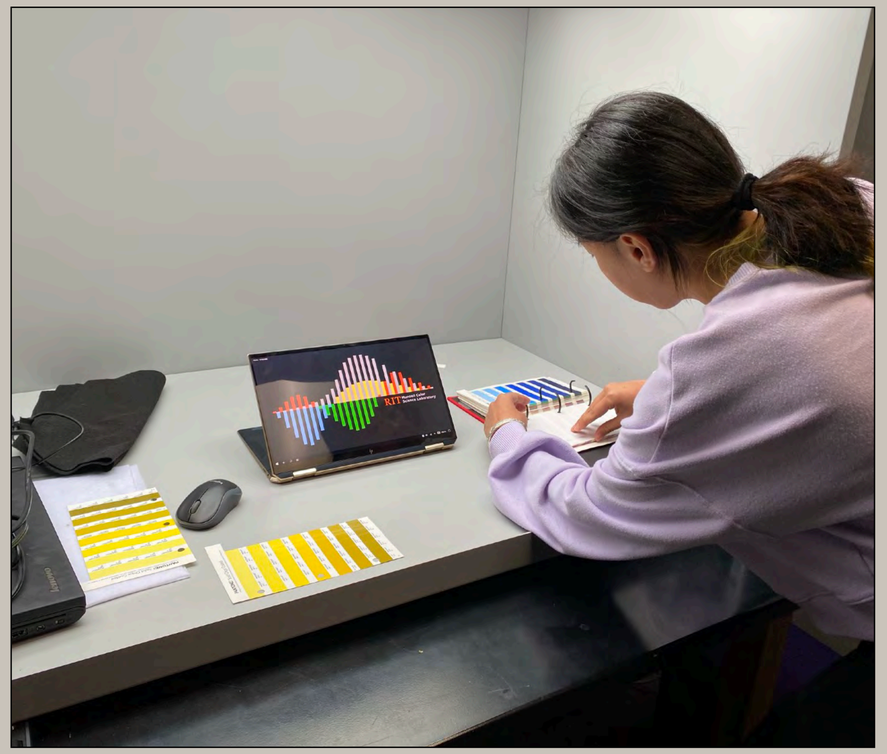
Saturation is defined as the colorfulness of a stimulus relative to its brightness. It is perhaps the most fundamental of the dimensions describing chromatic appearance (colorfulness, chroma, and saturation). It is also often neglected in color appearance models in deference to chroma for relative appearance and colorfulness for absolute appearance. Despite its fundamental importance, scales of perceived saturation are seldom studied. The only accepted psychophysical relationship for saturation is that constant chromaticity (and therefore constant excitation purity) is considered constant perceived saturation. Hao Xie is looking to create perceived saturation scales via partition scaling in order to better understand the psychophysics of saturation and create improved appearance scale models that might give saturation a more prominent role.

Hao Xie, Mark Fairchild

LAB HIGHLIGHT: MCSL T-shirt

MCSL members are now sporting our own lab swag T-shirt! A swag idea, formed from students' casual chat, evolved into an MCSL-themed design brainstorm. More than a dozen fascinating designs from students and faculty were shared and collaboratively tweaked, culminating in a final vote. The winning design is a simple yet meaningful illustration for all MCSL members: opponent chromatic and luminosity spectral response curves. The collaborative effort became a lab project led by winning designer Lili Zhang, featuring color matching, sourcing, final production, and even modeling and photo shooting. Don't forget to get one if you stop by the lab! Find more related images in the "candids" section that follows.

Lili Zhang



2021 PUBLICATIONS

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Anku, A., & Farnand, S. P., Preferred white balance for applications using virtual backgrounds. Color Research & Application (2021).

T. Canham, D.L. Long, M.D. Fairchild and M. Bertalmio,, Physiologically personalized color management for motion picture workflows, SMPTE Motion Imaging Journal 131, in press(2022).

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C. Shen, A. Palke, Z. Sun and M.D. Fairchild, How to calculate color from spectra of uniaxial gemstones, Gems & Gemology 57, 36-45 (2021).

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Tager, A., Kirchner, E., and Fedorovskaya, E., Computational evidence of first extensive usage of violet in the 1860s. Color Research and Application, v. 46, 5, pp. 961-977 (2021).

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S. Abasi, M.A. Tehran and M.D. Fairchild, Color difference metric for stimuli with large color difference, 12th INTEC Conference, Iran (2021).

Anku, A., and Farnand, S. P., White Balance preference under multiple light sources. In Color and Imaging Conference (Vol. 2021, No. 29, pp. 193-196). Society for Imaging Science and Technology (2021).

Carpenter, K and Farnand, S.P., Determination of the Representative Color of a Smartphone Image, International Colour Association (AIC) Gruppo del Colore Conference (2021).

T. Downs & M. J. Murdoch. Color Layer Scissioning in See-Through Augmented Reality, in 29th Color & Imaging Conference (online): IS&T (2021).

M.D. Fairchild, A digital test chart for visual assessment of color appearance scales, IS&T 29th Color and Imaging Conference, ONLINE, 160-165(2021).

M.D. Fairchild, System for visual assessment of wine color, Proceedings of the International Colour Association (AIC) Conference 2021, Milan, 1047-1052(2021).

Jiang, F., Bodner, B., Farnand, S. P., & Murdoch, M. J., 34-3: Visual Sensitivity to "Perfect" Black. In SID Symposium Digest of Technical Papers (Vol. 52, No. 1, pp. 458-461) (2021).

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Kuzio, O. R. and Farnand, S.P., LED-based versus Filter-based Multispectral Imaging Methods for Museum Studio Photography, International Colour Association (AIC) Gruppo del Colore Conference (2021).

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C. Shen and M.D. Fairchild, The threshold of color inconstancy, IS&T 29th Color and Imaging Conference, ONLINE, 374-380(2021).

C. Shen, A. Palke, Z. Sun and M.D. Fairchild, How to calculate color from spectra of uniaxial gemstones, Geological Society of America CONNECTS 2021, Portland, Paper 107-9 (2021).

D.R. Wyble, Spectral Imaging Method for Transmissive Media, IS&T Archiving ONLINE, 51-54 (2021) .

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L. Zhang & M. J. Murdoch. Perceived Transparency in Optical See-Through Augmented Reality. in 2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR): IEEE (2021).

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2021 PUBLICATIONS

Theses & Dissertations

Anku, Preferred Rendering of Memory Colors, Ph.D. Dissertation, December 2021

K.Carpenter, Assessing the Use of Smartphones and Color Science in Agriculture, Ph.D. Dissertation, December 2021

F.Jiang, High Dynamic Range (HDR) Display Perception, Ph.D. Dissertation, March 2021

Y.Park, Modeling Perceptual Trade-offs for Designing HDR Displays, Ph.D. Dissertation, September 2021

A.Robinson, Medical Grade Displays in Radiation Oncology, Ph.D. Dissertation, May 2021

Presentations & Invited Talks

Albus, K., Dimoff, D., Farnand, S. P., Determining the Representative Color of a Multicolored Image. Rochester Institute of Technology Undergraduate Research Symposium, https://www.youtube.com/watch?v=ZXgiRBDOcl4&t=13s, (2020).

Kuzio, O., & Farnand, S., Practical LED-based Multispectral Imaging of Cultural Heritage Materials, meeting of the American Institute for Conservation and Foundation for Advancement in Conservation (2021).

M.D. Fairchild, Why is color?, FOGRA Color Management Café, FOGRA Webinar, Munich (2021).

M.D. Fairchild, Individual differences and the color science of images, IS&T 29th Color and Imaging Conference, ONLINE, invited (2021).

M.D. Fairchild, Spatial color appearance models and image difference models (iCAM and the like), VIPLab Webinar Series, University of Valencia (2021).

M.D. Fairchild, The art of color science: Individual differences, Proceedings of 2nd International Symposium for Color Science and Art, Tokyo Polytechnic University, Japan (2021).

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Three RIT-MCSL recipients of the ISCC Godlove Award:
Franc Grum (1985), Roy Berns (2009), Mark Fairchild (2021).

Program of Color Science Extended Faculty

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Joe Geigel, Computer Science
Andy Herbert, Psychology
David Long, Motion Picture Science

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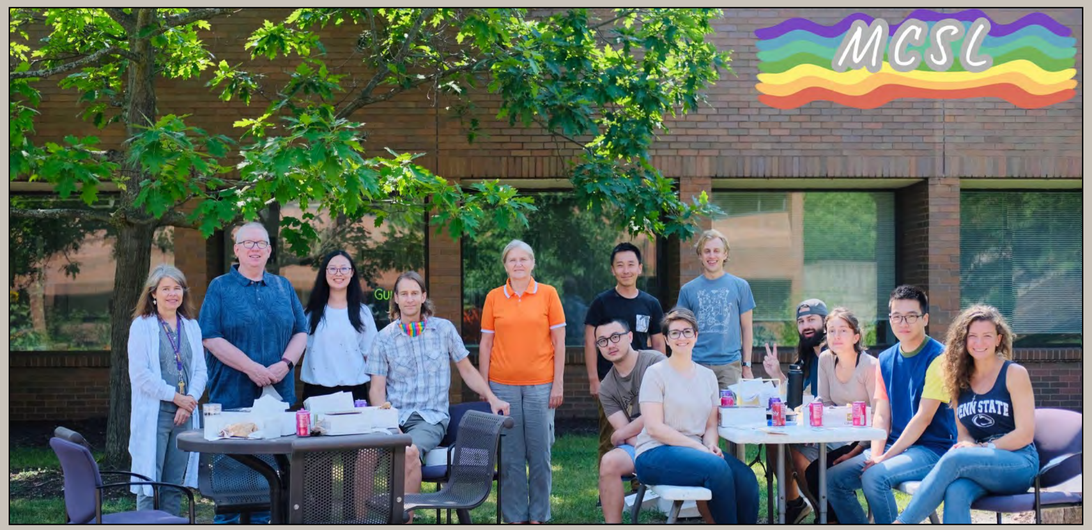
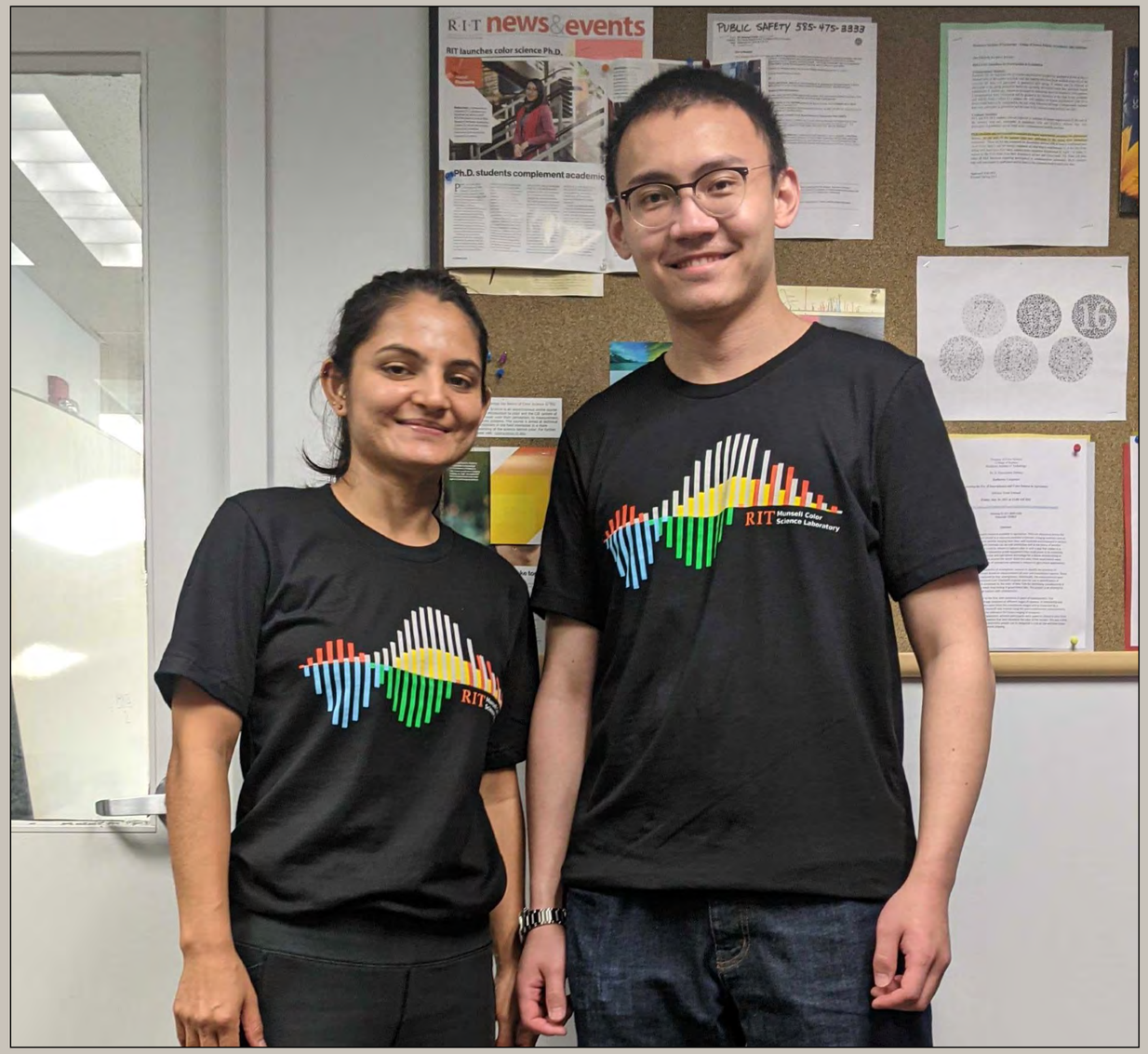

MCSL


Che Shen (RIT Student)
Stephanie Livingston-Heywood
Mark Fairchild
Zilong Li (RIT Student)
Dara Dimoff
Michael Murdoch
Garreth Tigwell
Chris Thorstenson
Abby Weymouth
Gabrielle Brogle (RIT Student)
Minyao Li (RIT Student)
leahhumenuck
Olivia Kuzio (RIT Student)
Hao Xie (he/him)
Eddie Pei (RIT Student)
Susan Farnand
Elena Fedorovskaya
Yuan Tian
Tucker Downs (RIT Student)
Luke Hellwig (RIT Student)


RIT news&events
RIT launches color science Ph.D.
Ph.D. students complement academic
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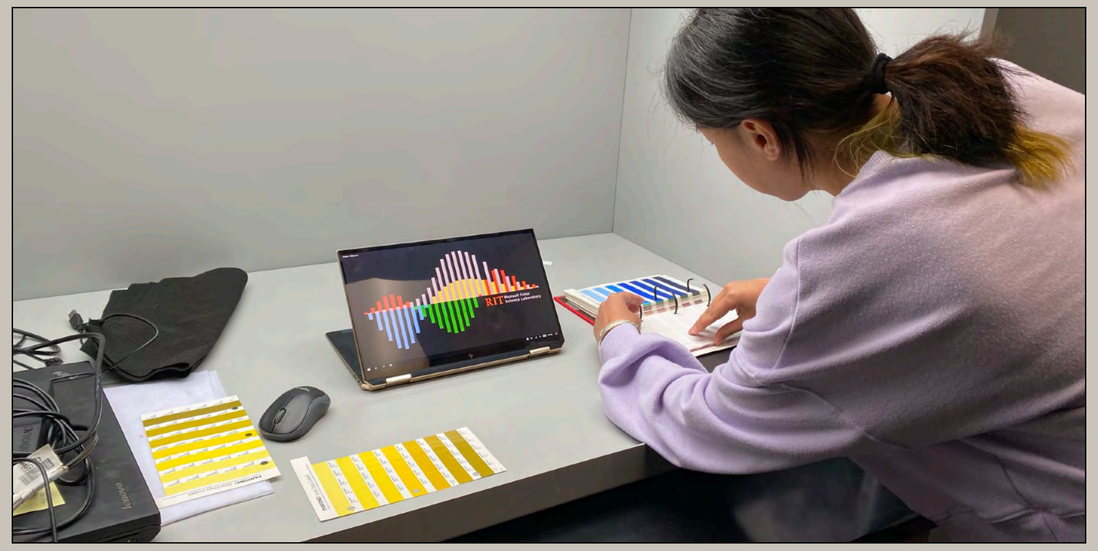
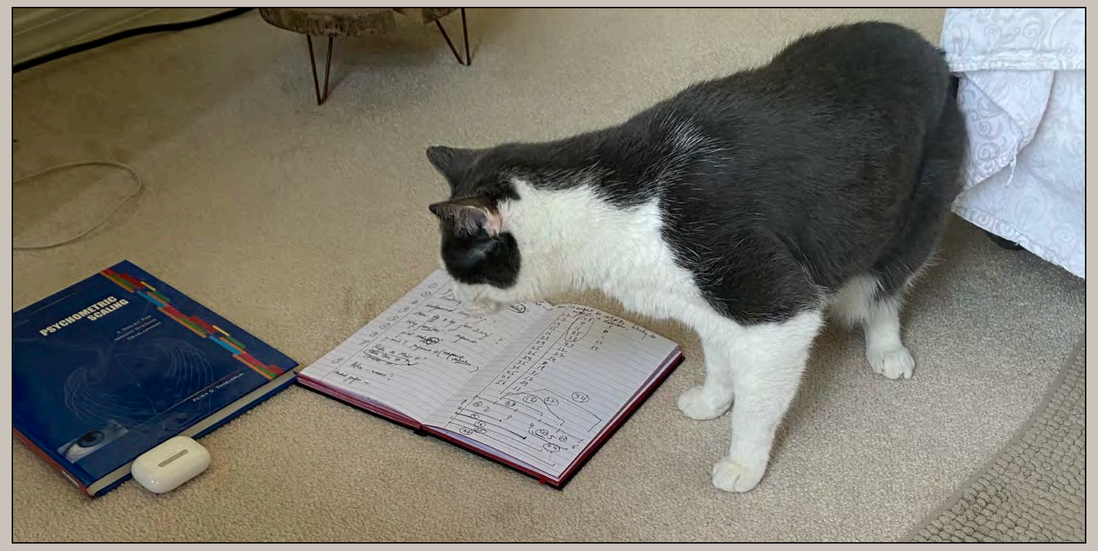
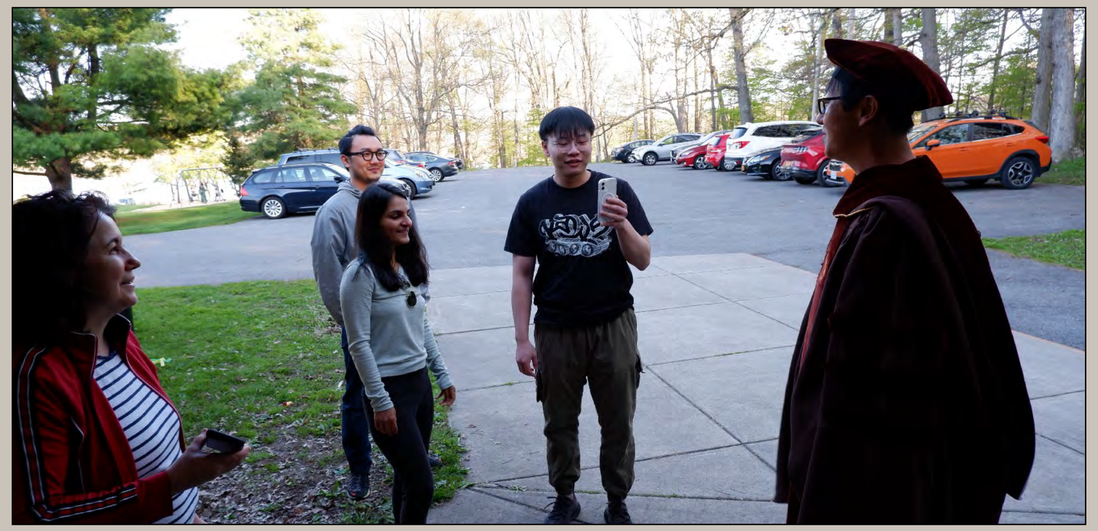

RIT Munsell Color Science Laboratory


Under Slab


Key Questions
1. What is the most basic characteristic of color?
2. How is brightness different from lightness?
3. How is chroma different from saturation and colorfulness?
4. What are the limits of hue, lightness, chroma?
5. What characteristics are valuable in a color picker?
6. Why are unique hues significant?
7. What color is a tennis ball?


PSYCHOMETRIC SCALING


KAFE

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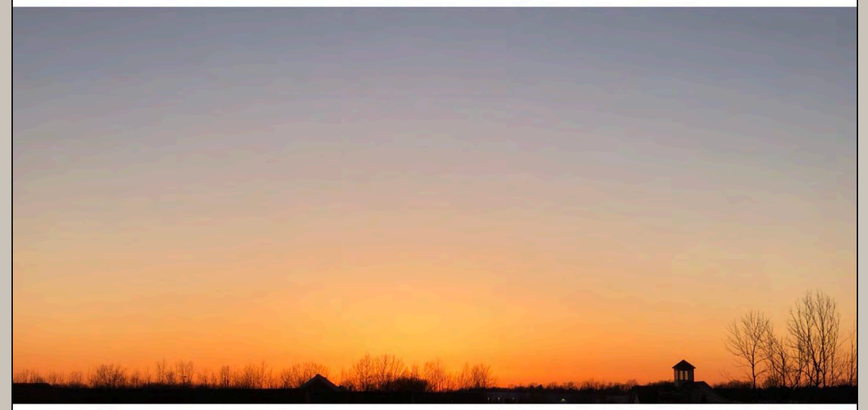
MAGIC

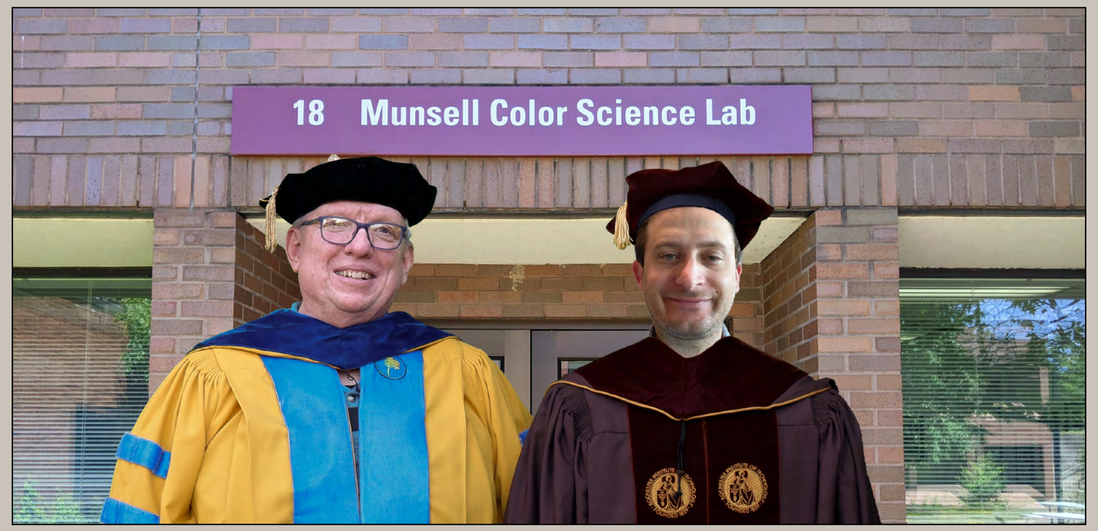


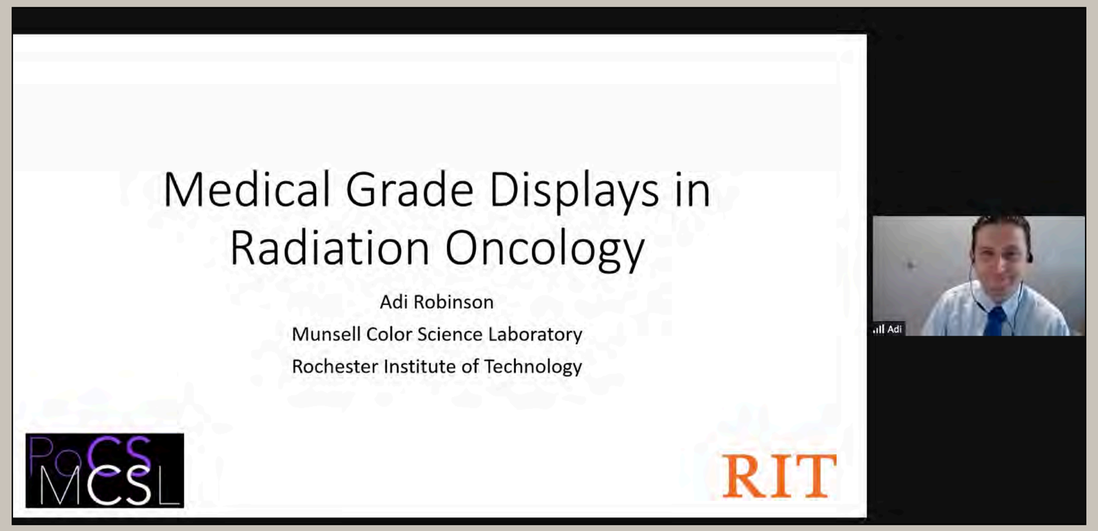

ONE PIECE WANOKUNI

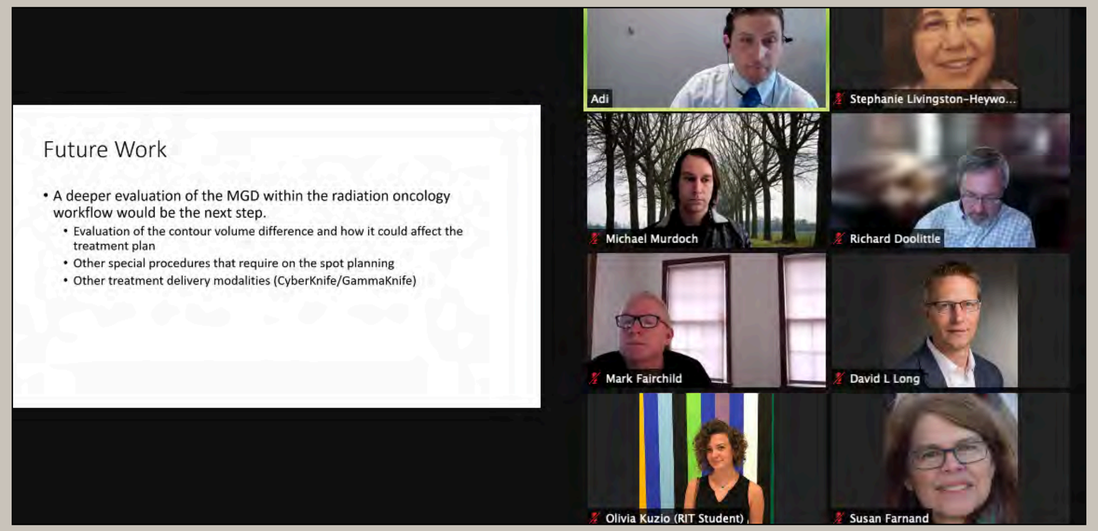

CIC28
BEST INTERACTIVE PAPER

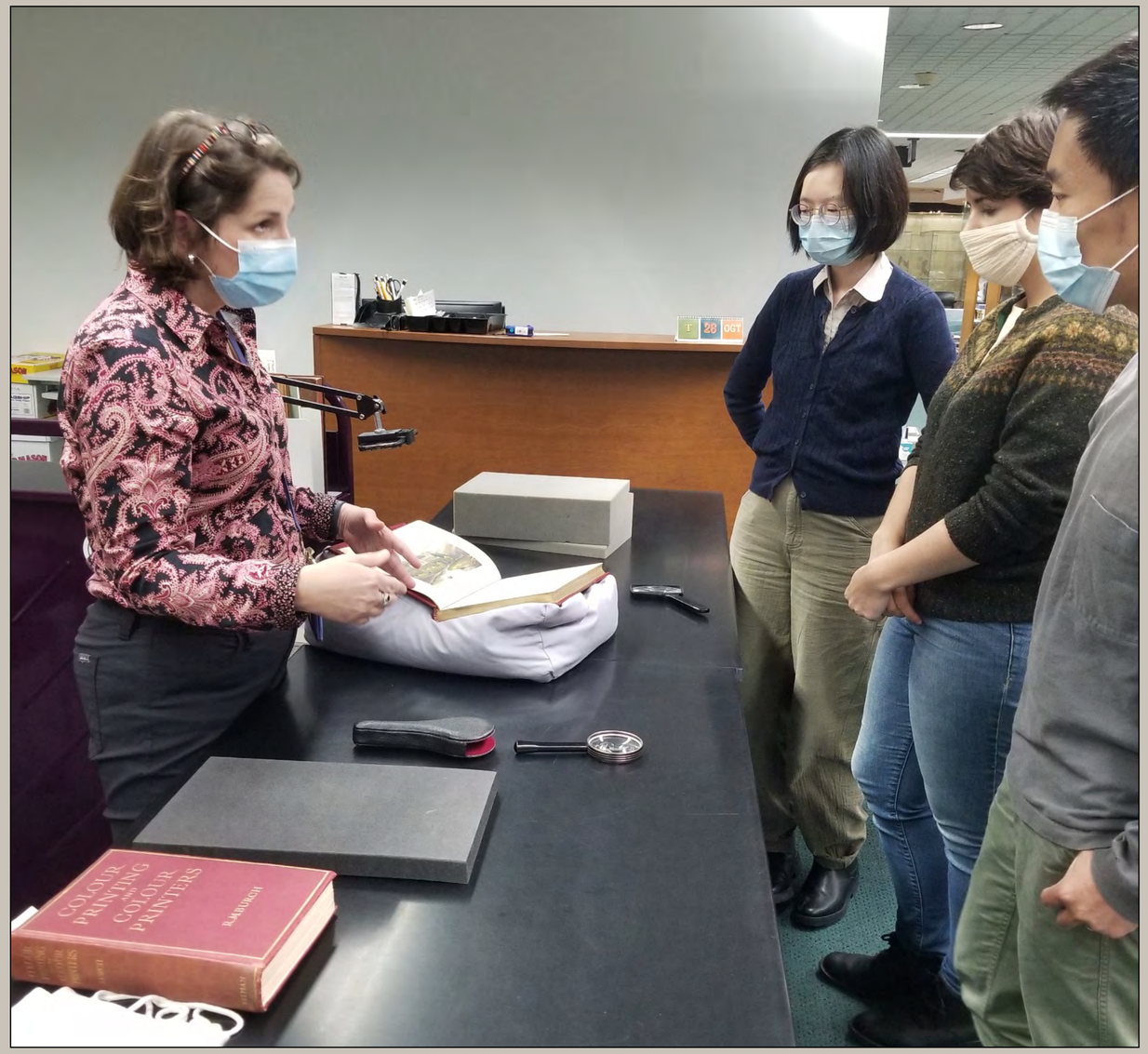

RIT
PoCS
MCSL
HDR Display Perception
Fu Jiang
FU JIANG (RIT Student)

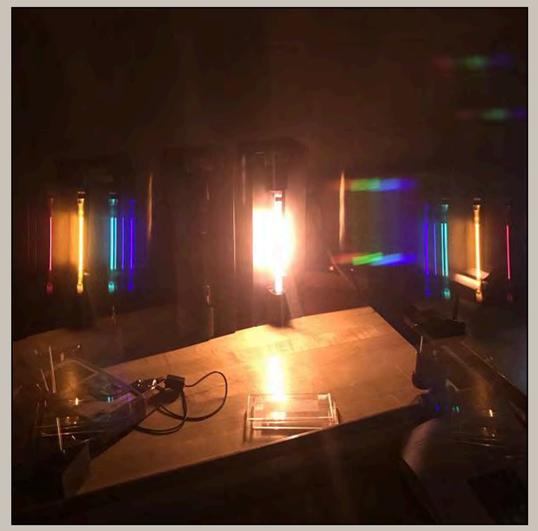

18 Munsell Color Science Lab


18 Munsell Color Science Lab


Medical Grade Displays in Radiation Oncology
Adi Robinson
Munsell Color Science Laboratory
Rochester Institute of Technology
PoCS
MCSL
RIT
Adi


Future Work
• A deeper evaluation of the MGD within the radiation oncology workflow would be the next step.
• Evaluation of the contour volume difference and how it could affect the treatment plan
• Other special procedures that require on the spot planning
• Other treatment delivery modalities (CyberKnife/GammaKnife)
Adi
Stephanie Livingston-Heywo...
Michael Murdoch
Richard Doolittle
Mark Fairchild
David L Long
Olivia Kuzio (RIT Student)
Susan Farnand

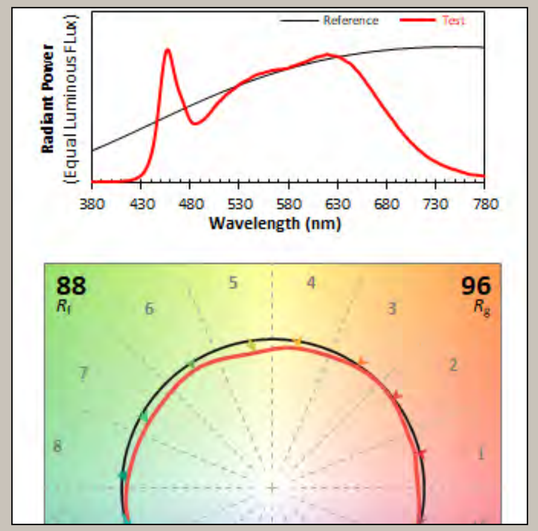

COLOUR PRINTING & COLOUR PRINTERS
BLAIRBURGH



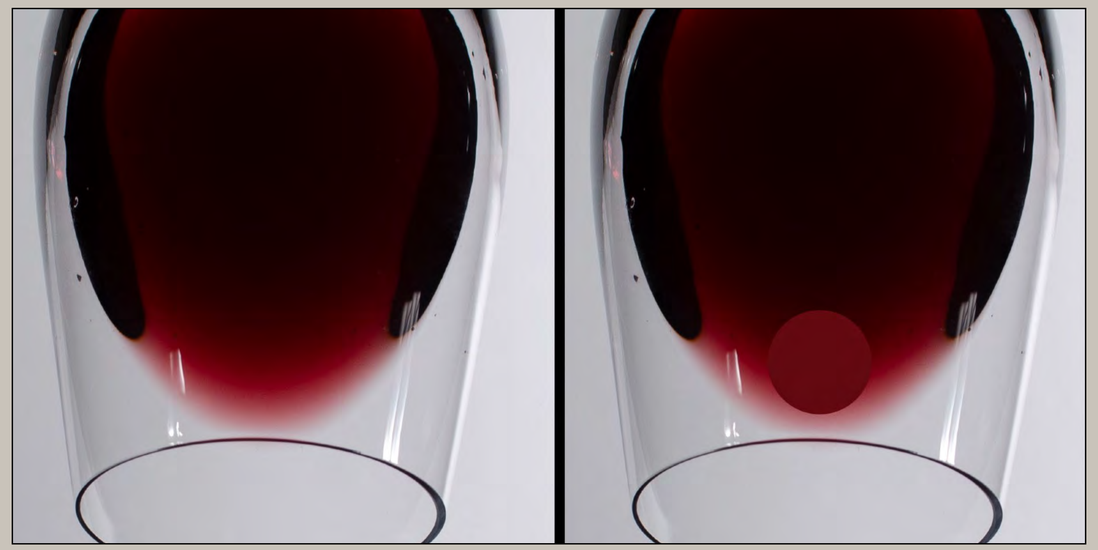

COLOR CORRECT
BaseLight
Color Correction
Suite
71-2160


18 Munsell Color Science La


18 Munsell Colo


Reference
Test
Radiant Power
(Equal Luminous FLux)
380 430 480 530 580 630 680 730 780
Wavelength (nm)
88
R_f
96
R_g
1 2 3 4 5 6 7 8


R·I·T
RIT FoodShare Center
113 Kimball Drive




MILAN
14th AIC Congress 2021
System for Visual Assessment of Wine Color
Mark D. Fairchild
AIC 2021 14th Congress
MARK FAIRCHILD
AIC
MCSL

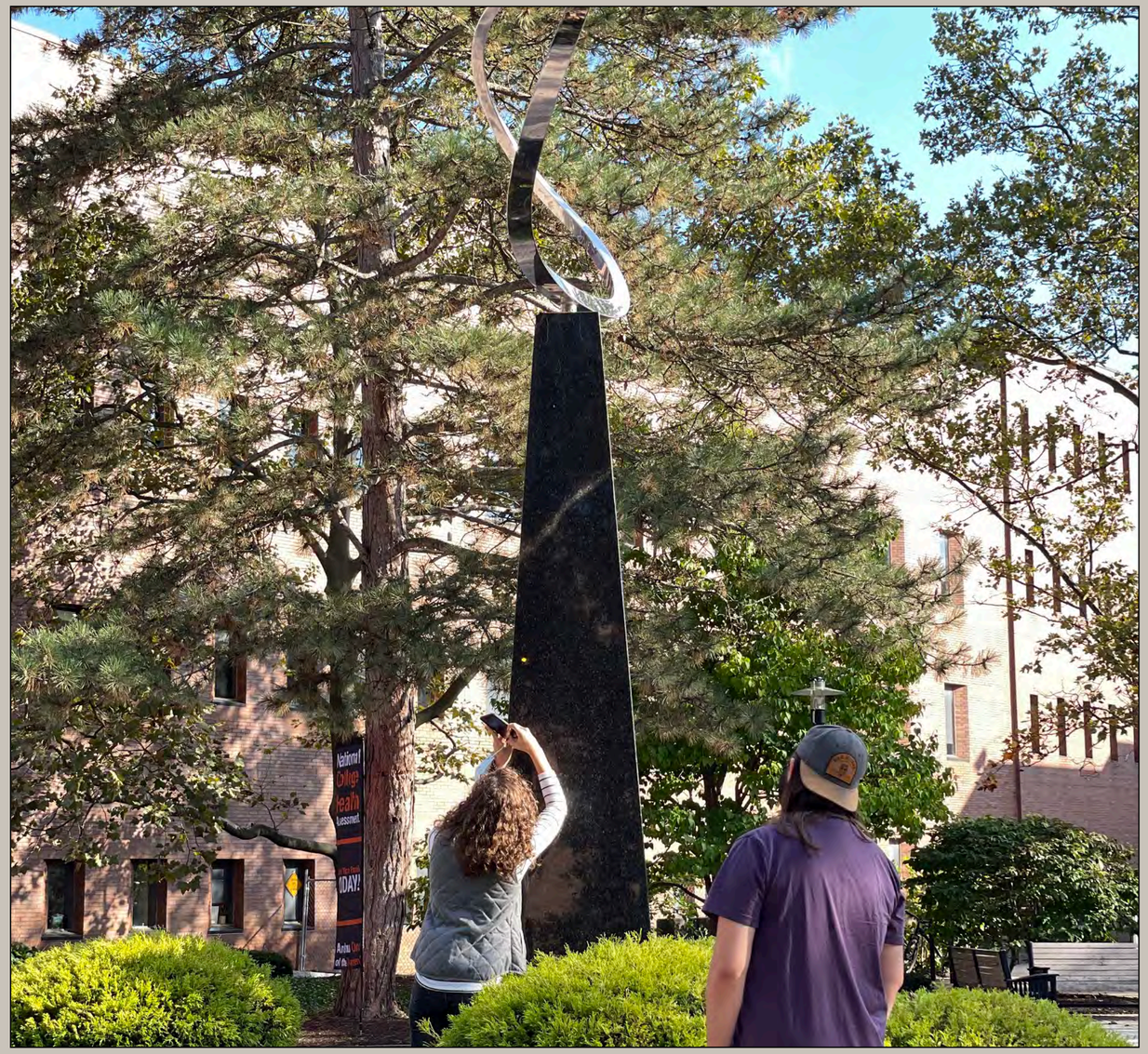

ROY S. BERNS
Billmeyer and Saltzman's
PRINCIPLES OF
COLOR
TECHNOLOGY
FOURTH EDITION
WILEY


For the Rays to speak properly are
not coloured. In them there is nothing
else than a certain power of sensation
to stir up a sensation of this or that colour.
Catering
Catering
Catering


GET
EXCITED


How to Calculate
Color from Spectra of
Uniaxial Gemstones
GIA
RIT
MCSI


Please
Wear Mask
At All Times
Stop The Spread



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