RIT | Rochester Institute of Technology

Program of Color Science
Munsell Color Science Laboratory

Annual Report 2022

From the Director: A New Leaf in a Familiar Book

Greetings! With excitement and humility, I am honored to pen my first introduction to a POCS/MCSL Annual Report. In my first year as Director, I have been lifted up, supported by the growing number of students, faculty, staff, and others who have built this academic organization to its current, thriving, internationally-renowned state. I owe a ton of gratitude to my predecessor, Mark Fairchild, whom I met when I worked at Kodak in the early 2000's, who came to the Netherlands in 2013 as my external PhD committee member, and who hired me at RIT in 2015. I hope to keep MCSL running much like Mark did, maybe making some strategic adjustments but no major changes in direction. Thanks, Mark!

2022 has been an extremely busy year – I have admittedly been overwhelmed at times with the day-to-day responsibilities of leading POCS/MCSL and the Integrated Sciences Academy. I also took my first opportunity for a sabbatical, spending part of the Fall semester in Ghent, Belgium, as a Fulbright Scholar. Back at RIT, I have been working with both the College of Science and College of Liberal Arts to get our new Neuroscience BS program ready to go with new courses, a new teaching lab with EEG suite, and more. First-year neuro undergraduates just arrived for Fall 2023! We look forward to new faculty hires to support Neuroscience and Cognitive Science, and we hope for exciting synergies with Color Science.

I'm finishing this Annual Report much later than I intended, but late is better than never, right? As I write this report about 2022, we're deep into 2023, and we already had our MCSL 40th Anniversary Celebration – it was great, but I'll save the details and photos of that for the 2023 report.

In these pages, I'm proud to highlight the accomplishments of the Lab and our partners, to communicate our interests, and to start new conversations. Please drop me a line if anything you read here catches your attention, if you need information, or if you just want to say hello!

Michael J. Murdoch, PhD
Director, Munsell Color Science Laboratory /
Program of Color Science
Head, Integrated Sciences Academy
michael.murdoch@mail.rit.edu


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Munsell Color Science Lab

Students, Visitors, & Graduate Alumni

Current MCSL Students
Saeedeh Abasi, PhD, CS
Gabrielle Brogle, MS, CS
Dara Dimoff, PhD, CS
Tucker Downs, PhD, CS
Luke Hellwig, PhD, CS
Sofie Herbeck, PhD, CS
Leah Humenuck, PhD, CS
Olivia Kuzio, PhD, CS
Alexis Lazaro, MS, CS
Zilong Li, PhD, CS
Likhitha Nagahanumaiah, PhD, CS
Eddie Pei, PhD, CS
Alireza “Nima” Rabbanifar, MS, CS
Che Shen, PhD, CS
Sahara Smith, MS, CS
Yuan Tian, PhD, CS
Ming Ming Wang, PhD, IS
Fernando Voltolini De Azambuja, MS, CS
Abby Weymouth, PhD, CS
Hao Xie, PhD, CS

Exchange Student
Julia Versteden, MSC, HT

Visiting Researcher
Juan Serra Lluch, Universitat Politècnica de València

2022 Alumni
Rema Amawi, PhD, CS
Abby Weymouth, MS, CS
Lili Zhang, PhD, CS

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

2020 Alumni
Katie Albus, VR
Siyuan Chen, VR
Jenibel Paray, MS, CS
Matthew Ronnenberg, PhD, CS

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

Students, Visitors, & Graduate Alumni

2018 Alumni
Kensuke Fukumoto, VR
Rik Spieringhs, VR

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

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

2015 Alumni
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 Alumni
Farhad Abed, PhD, CS
Stephen Dolph, MS, IS
Timo Eckhard, VR
Adrià Forés Herranz, PhD, CS

2013 Alumni
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 Alumni
Ping-Hsu (Jones) Chen, MS, CS
Carrie Houston, BS, IS
Kenichiro Masaoka, VR
Simon Muehlemann, MS
Weiping Yang, VR

2011 Alumni
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 Alumni
Bingxin Hou, MS, IS
Suparna Kalghatgi, MS, IE

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

2008 Alumni
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 Alumni
Kenneth Fleisher, MS, CS
Rafael Huertas, VR
Andreas Kraushaar, VR
Jiangtao (Willy) Kuang, PhD, IS
Manuel Melgosa, VR

2006 Alumni
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 Alumni
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

Students, Visitors, & Graduate Alumni

2004 Alumni
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 Alumni
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 Alumni
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 Alumni
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 Alumni
Yoshihito Azuma, VR
Sergio Gonzalez, MS, CS
Sharon Henley, MS, CS
Patrick Igoe, MS, IS
Susan Lubecki, MS, CS
Richard Suorsa, MS, CS

1999 Alumni
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 Alumni
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 Alumni
Peter Burns, PhD, IS
Christopher Hauf, MS, CS
Brian Hawkins, MS, CS
Jack Rahill, MS, IS
Alex Vaysman, MS, IS

Students, Visitors, & Graduate Alumni

1996 Alumni
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 Alumni
Richard Alfvin, MS, CS
Seth Ansell, MS, CS
Susan Farnand, MS, IS
Bong Sun Lee, VR
Atsushi Suzuki, VR

1994 Alumni
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 Alumni
Toru Hoshino, VR
Nathan Moroney, MS, CS
Elizabeth Pirrotta, MS, CS
Mitchell Rosen, MS, IS

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

1991 Alumni
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 Alumni
Mitch Miller, MS, IS
Kelvin Peterson, MS, IS
Lisa Reniff, MS, CS

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

1986 Alumni
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

PhD Graduate Rema Amawi served as the College of Science Graduate Delegate and delivered remarks for the COS Commencement Ceremony.

Dr. Amawi is a faculty member at RIT Dubai who completed her PhD mostly remotely:
Color in Pharma: Color Associations and Expected Efficacies

2022 Publications

Book

M.D. Fairchild, Munsell Trees: A Season of Leaves and Colors, RIT Press, Rochester, in press (2023).

Journal papers

R. M. Amawi and M. J. Murdoch. Understanding Color Associations and Their Effects on Expectations of Drugs' Efficacies, *Pharmacy* 10 (82), 2022.

R. M. Amawi and M. J. Murdoch. Effects of pill colors on human perception and expectation of drugs' efficacy, *Color Research and Application* 47(5), pp. 1200—1215, 2022.

T. Canham, D. L. Long, M. D. Fairchild and M. Bertalmio, Physiologically personalized color management for motion picture workflows, *SMPTE Motion Imaging Journal* 131:2, 8-16 (2022).

M.D. Fairchild, Visual and photographic assessment of wine color, *Color Research and Application* 47, early view 10.1002/col.22787 (2022).

L. Hellwig, D. Stolitzka and M.D. Fairchild, Extending CIECAM02 and CAM16 for the Helmholtz-Kohlrausch Effect, *Color Research and Application* 47, 1096-1104, 10.1002/col.22793 (2022).

L. Hellwig and M.D. Fairchild, Brightness, lightness, colorfulness, and chroma in CIECAM02 and CAM16, *Color Research and Application* 47, 1083-1095, 10.1002/col.22792 (2022).

O. R. Kuzio and S. P. Farnand, Toward Practical Spectral Imaging beyond a Laboratory Context. *Heritage*, 5, 4140–4160 (2022)

O. R. Kuzio and S. P. Farnand, Comparing Practical Spectral Imaging Methods for Cultural Heritage Studio Photography. *J. Comput. Cult. Herit.*, 16, 11–1--11–13 (2022)

M. Royer, M. J. Murdoch, K. Smet, L. Whitehead, A. David, K. Houser, T. Esposito, J. Livingston & Y. Ohno, Improved Method for Evaluating and Specifying the Chromaticity of Light Sources, *LEUKOS*, 2022.

C. Shen, R. Wanat, J. J. Yoo, J. Jang and M. D. Fairchild, Measuring display observer metamerism, *The Visual Computer* 38, 3301-3310, 10.1007/s00371-022-02546-7 (2022).

Journal papers continued

N. S. Smith and M. D. Fairchild, Virtual color atlas, *Color Research and Application* 47, 817-826, 10.1002/col.22780 (2022).

C. A. Thorstenson, J. McPhetres, A. D. Pazda, & S. G. Young (2022). The role of facial coloration in emotion disambiguation. *Emotion*, 22(7), 1604-1613.

A. Weymouth & M. J. Murdoch, Speed perception of dynamic lighting around daylight, *Journal of the International Colour Association* 31, pp. 30-39, 2022.

H. Xie and M. D. Fairchild, Representing Color as Multiple Independent Scales: Brightness versus Saturation, *Journal of the Optical Society of America A* 39, in press (2022).

H. Xie and M. D. Fairchild, Deriving and dissecting an equally bright reference boundary, *Optics Express* 30, in press (2022).

H. Xie, R. Wanat and M. D. Fairchild, Perceived color gamut in images: From boundary to difference, *Frontiers in Neuroscience* 16, 907697 doi: 10.3389/fnins.2002.907697(2022).

Y.Yuan, M. J. Murdoch and M. D. Fairchild, A multi-primary lighting system for customized color stimuli, *Color Research and Application* 47, 74-91, 10.1002/col.22695 (2022).

Conference Proceedings & Presentations

R. Amawi & M. J. Murdoch, “Relating Color Associations to Pill Colors and Expected Efficacy” *IS&T 30th Color and Imaging Conference*. Scottsdale, AZ: IS&T, 2022.

D. Dimoff and S. P. Farnand, Representative Color of Skin Tones and Natural Objects. *IS&T 30th Color and Imaging Conference*. Scottsdale, AZ: IS&T, 2022.

T. Downs, O. Kuzio, M. J. Murdoch, "Image Based Measurement of Augmented Reality Displays and Stimuli," in *AIC 2022 Sensing Color*. Toronto (online): AIC, 2022.

Conference Proceedings & Presentations continued

M. D. Fairchild, Reversibility of corresponding colors in sensory chromatic adaptation, *IS&T 30th Color and Imaging Conference*, Scottsdale, 153-158(2022).

E. A. Fedorovskaya, L. Gaffney, M. Li, E. Guth, K. Phadke, S. Farnand, "Multisensory Visuo-Tactile Interaction in Semi-immersive Environments" in *Human Vision and Electronic Imaging Conference*, IS&T, 2022.

L. Hellwig and M. D. Fairchild, Revising CAM16-UCS, *IS&T 30th Color and Imaging Conference*, Scottsdale, A3-A5 (2022).

L. Hellwig and M. D. Fairchild, Chromatic adaptation to heterochromatic illumination, *Optica Fall Vision Meeting*, Rochester, in press (2022).

L. Hellwig, D. Stolitzka and M. D. Fairchild, Why achromatic response is not a good measure of brightness, *IS&T 30th Color and Imaging Conference*, Scottsdale, 1-5 (2022).

L. Hellwig, D. Stolitzka, Y. Yi and M. D. Fairchild, Brightness and vividness of high dynamic range displayed imagery, *SID International Symposium Digest of Technical Papers* 53, 1009-1012 (2022).

O. R. Kuzio and S. P. Farnand, Simulating the Effect of Camera and Lens Choice for Color Accurate Spectral Imaging of Cultural Heritage Materials. in *AIC 2022 Sensing Color*. Toronto (online): AIC, 2022.

O. R. Kuzio and S. P. Farnand, Beyond RGB: A spectral image processing software application for cultural heritage studio photography. In *IS&T Archiving Conference* (Vol. 2022, pp. 95-100), 2022.

Z. Li & M. J. Murdoch, "Improving Naturalness in Transparent Augmented Reality with Image Gamma and Black Level" *IS&T 30th Color and Imaging Conference*. Scottsdale, AZ: IS&T, 2022.

C. Shen and M. D. Fairchild, Weighted geometric mean (WGM) method: A new chromatic adaptation model, *IS&T 30th Color and Imaging Conference*, Scottsdale, 231-235 (2022)

C. Shen and M. D. Fairchild et al., Measuring display observer metamerism, *AIC 2022 Sensing Color*, Toronto, in press (2022).

Conference Proceedings & Presentations continued

C. Shen, A. Palke and M. D. Fairchild, Color origin of color change sapphire, *Geological Society of America CONNECTS 2022*, Denver, Geological Society of America Abstracts with Programs 54(5) ,10.1130/abs/2022AM-377878 (2022).

C. Shen, R. Wanat, J. J. Yoo, J. Jang and M. D. Fairchild, Measuring display observer metamerism, *Computer Graphics International* 2022, Geneva, (2022).

C. A. Thorstenson, "Emotive facial coloration as a context to explore perceptual versus conceptual influences on color-emotion associations" in *Conference of the International Society for Research on Emotion*, Los Angeles, CA: ISRE, 2022.

A. Weymouth & M. J. Murdoch, "Perceived Speed in Transitions between Neutral and Chromatic Illumination," in *AIC 2022 Sensing Color*. Toronto (online): AIC, 2022.

H. Xie and M. D. Fairchild, The Luther Condition for all: Evaluating colorimetric camera design for personalized color imaging, *AIC 2022 Sensing Color*, Toronto, in press (2022).

H. Xie and M. D. Fairchild, Isolating saturation and hue for equally bright colors, *VSS 2022*, St. Pete Beach, Journal of Vision 22, 4108 (2022).

H. Xie and M. D. Fairchild, Representing color as multiple independent scales: Brightness vs. saturation, *IS&T 30th Color and Imaging Conference*, Scottsdale, i (2022).

Presentations & Invited Talks

S. P. Farnand, Color appearance of facial images, *IS&T 30th Color and Imaging Conference*, Scottsdale, 1-5(2022).

M. D. Fairchild, Dimensions and Scales of Color Appearance, *TLC Technology Innovation Conference*, Shenzen, China (2022).

M. D. Fairchild, Color Dualism and Arboreal Transcendentalism, *ISCC Godlove Award Lecture*, ISCC Webinar (2022).

Presentations & Invited Talks continued

M. J. Murdoch, “Keynote: Color in Layers: From Pepper’s Ghost to Augmented Reality,” in *AIC 2022 Sensing Color*. Toronto (online): AIC, 2022.

M. J. Murdoch, “Keynote: Color from Real Reality to Extended Reality," *3rd International Symposium for Color Science and Art*, Tokyo Polytechnic University (Online). Mar 12, 2022.

M. J. Murdoch, “Color Appearance in Augmented Reality Imaging Systems," *IS&T Imaging for XR Workshop and Panel Discussion* (Online). March 4, 2022.

C. A. Thorstenson, “Visual and Social Perception of Color Appearance in Artificial Faces,” *Human Robot Interaction with Furhat Robotics*, (Webinar), March, 2022.

Online Trade Journal

S. P. Farnand and O. R. Kuzio, Two is Better Than One: True color museum imaging using dual illumination, *Designing Lighting* III(2), 2022: https://issuu.com/designinglighting/docs/oct_2022/38

Theses & Dissertations

R. Amawi, *Color in Pharma: Color Associations and Expected Efficacies*, Ph.D. Dissertation, August, 2022.

A. Weymouth, *Perceived Speed in Transitions between Neutral and Chromatic Illumination*, M.S. Thesis, May, 2022.

L. Zhang, *Lightness, Brightness, and Transparency in Optical See-Through Augmented Reality*, Ph.D. Dissertation, March, 2022.

Research Highlight: **Smartphone based HDR and Spectral imaging**

The dynamic range and sensor responses of sample smartphones and DSLR cameras are being measured and evaluated under extended illumination and integration levels. Currently, most HDR acquisition techniques assume the sensor linearity, colorimetry transformation, as well as the effects of glare and noise to remain unchanged, with varying exposure and illumination levels. However, not all the assumptions hold true with most consumer smartphone cameras. This work is validating this issue and investigates the cameras' colorimetry reproduction quality over extended exposure levels. Accordingly, novel and improved HDR acquisition techniques will be proposed and later extended to spectral image acquisition application.

Leah Humenuck and Mekides Assefa Abebe

Research Highlight: **Revision of CAM16-UCS**

Luke Hellwig continued his Ph.D. research on the measurement and modeling of color appearance by extending his revisions of CAM16 (now CIECAM16) to the CAM16-UCS extension that attempts to provide dimensions suitable for a Euclidean color difference metric. Luke's presentation at CIC30 was rewarded with the annual Cactus Award for Best Interactive Presentation. In it, he described the logical inconsistencies he had earlier identified and corrected in CAM16 and their extension to a UCS version. He suggests two types of difference metrics, relative (lightness-chroma-hue) and absolute (brightness-colorfulness-hue) and showed that his improved and simplified model performs as well as the original CAM16-UCS. Luke will be joining a new CIE committee on this topic to share his expertise and encourage improved CIE models in the future.

Luke Hellwig and Mark D. Fairchild

Research Highlight: **3D Printed Substrates for Evaluating Cosmetics**

Cosmetic companies currently evaluate their products on two-dimensional surfaces. To improve on this approach, an Engineering Multidisciplinary Senior Design Team was tasked with creating a series of model faces that mimic the appearance of human skin in terms of texture and color. The client requested at least six different color/texture combinations that they could use as substrates to evaluate cosmetic products and their ingredients. The team successfully produced six model faces using 3D-printed negative and positive molds and materials meant to more closely resemble the compliancy of human skin. The models are pigmented to approximate the Fitzpatrick Skin Tone Scale and incorporate a variety of textures from smooth to aggressively wrinkled.

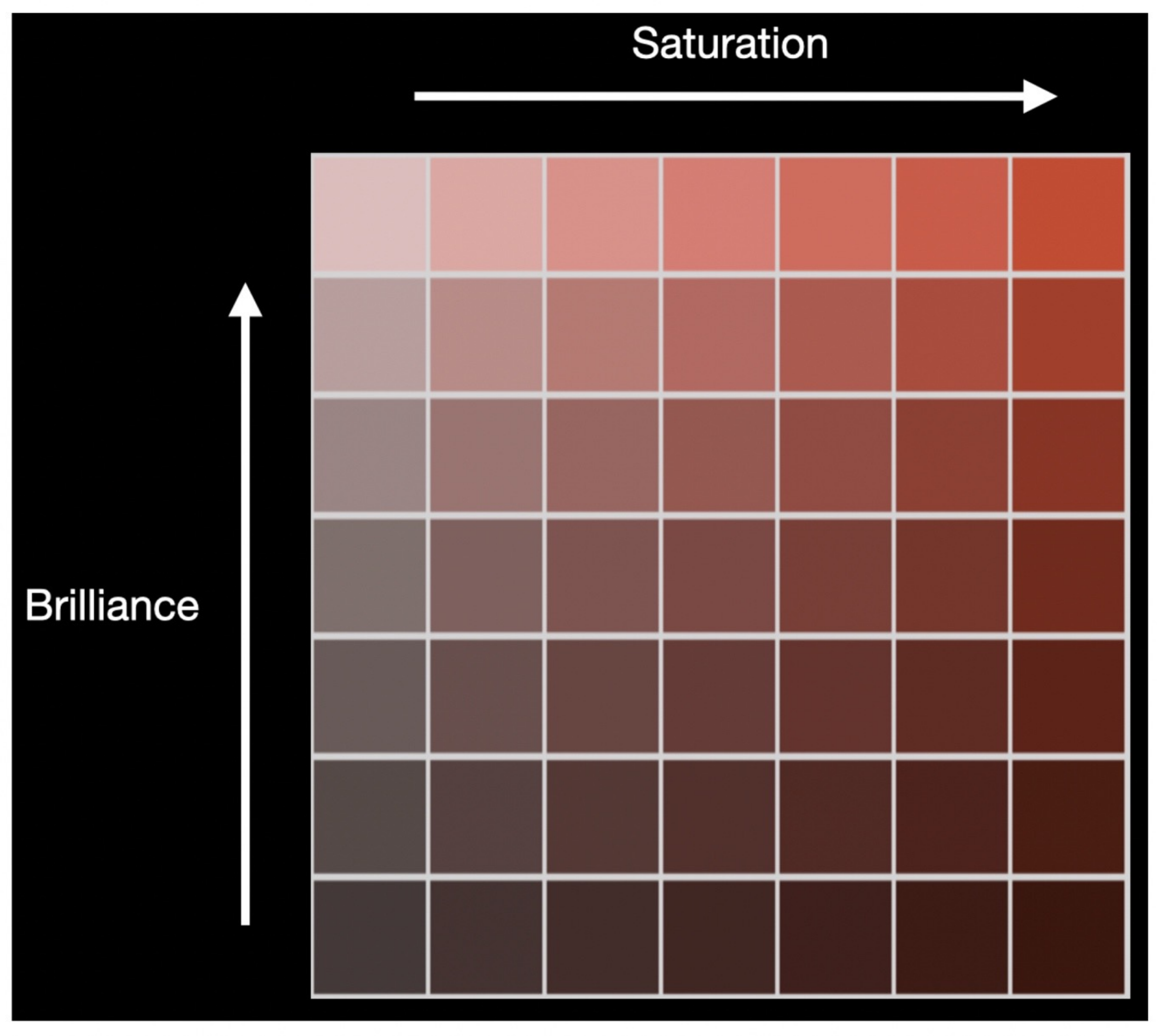
Susan Farnand, Maya Vanderhorst, Hannah Brush, Mathew Marinelli, Olivia Spencer

Molded model faces in tones selected to match the Fitzpatrick scale

Research Highlight: **Saturation Scaling**

Hao Xie has nearly completed his Ph.D. dissertation on fundamental scales of appearance with a focus on brilliance and saturation. Hao's latest work has more closely examined perceived saturation. Two important concepts he has established are that saturation is indeed perceived as independent of brilliance (a term used to incorporate lightness and brightness) and that a physical scale similar to excitation purity is a reasonable predictor of saturation in a complex visual environment with fixed adaptation. The image illustrates some initial visual scaling of brilliance and saturation for a red hue and is similar in concept to the dimensions used in the DIN color system. Combined with Saeedeh's work on new hue scales, this work sets the stage for a new form of color appearance model, based on independent scales of appearance, that Mark has been developing for some time.

Hao Xie and Mark D. Fairchild

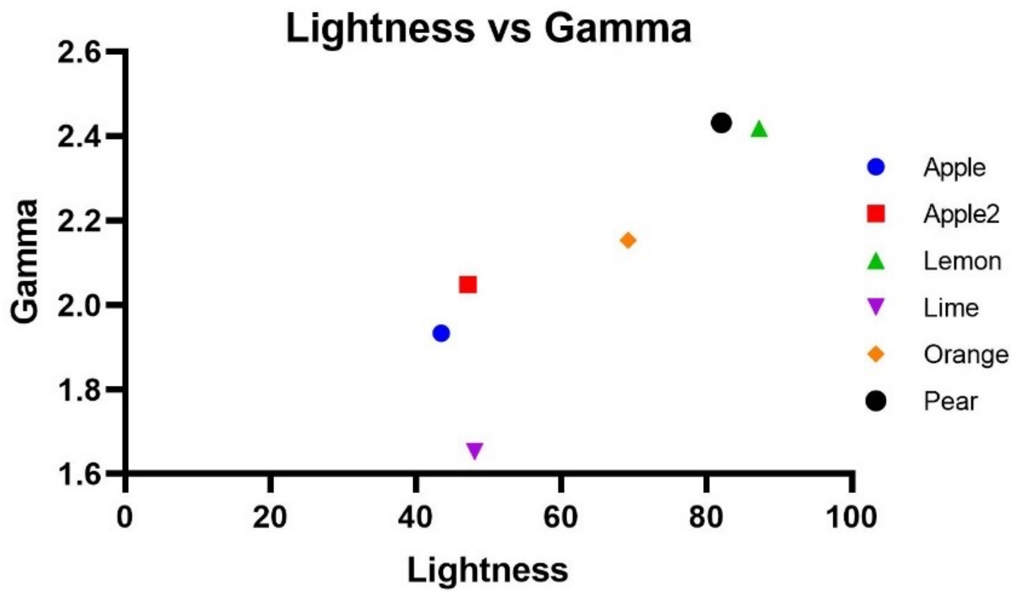


Research Highlight: **Perception of Gloss on Human Faces**

Material properties, such as gloss, can influence how people perceive and characterize an object's color. While it is possible to account for the influence of gloss on color appearance for most objects in general, human faces are a somewhat unique class of object because of their prevalence and importance in people's daily lives. For instance, it is possible that people are better at ignoring highlights and artifacts that result from glossy material on faces, than they are on other kinds of objects, because of high familiarity and expectations about normal face appearance. Further, given the increasing prevalence of artificial social agent generation (e.g., in making avatars, video games, virtual media), it is important to understand how model parameters like gloss influence the perception of artificial faces. Yuan has been working to understand how material spectral roughness influences perceptions of gloss and color appearance on faces. This research can help inform how artificial social agents are generated and displayed in emerging virtual environments

Yuan Tian and Chris Thorstenson

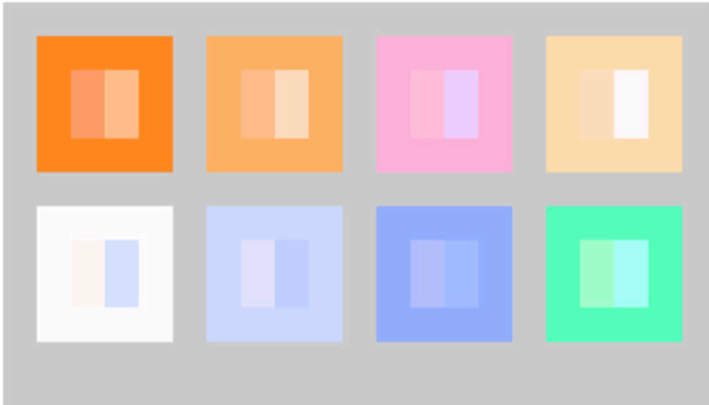
Research Highlight: **Perceived realness of Human face rendering in OST-AR**

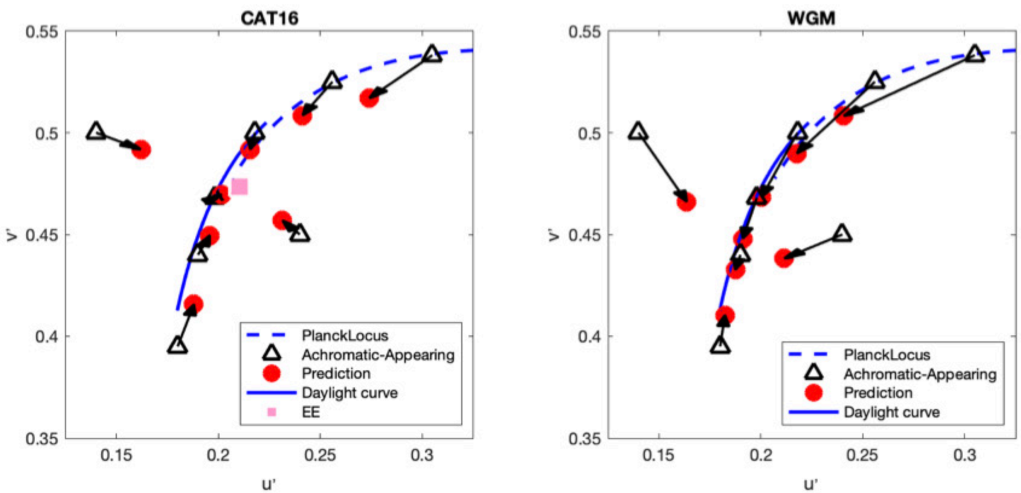


We want to know how to render human faces in optical see-through (OST) AR in a natural way, making the best of the transparent image that can be distorted by the background visible through the transparent display. This project aims to study the relationship between perceived realness and face-rendering color attributes, for example: gamma adjustment and redness and yellowness of facial skin. A previous study about perceived realness in AR revealed a nearly proportional relationship between average lightness and the gamma preference for AR fruit stimuli. The current project will confirm whether the gamma preference in OST-AR for other AR objects is the same as that of AR face rendering. TThis project will utilize the same transparent AR setup that has been used other for AR experiments on color appearances, brightness, transparency, and realness. This work is supported by NSF Grant No. 1942755.

Zilong Li and Michael J. Murdoch

Research Highlight: **Weighted Geometric Mean Chromatic Adaptation Model**

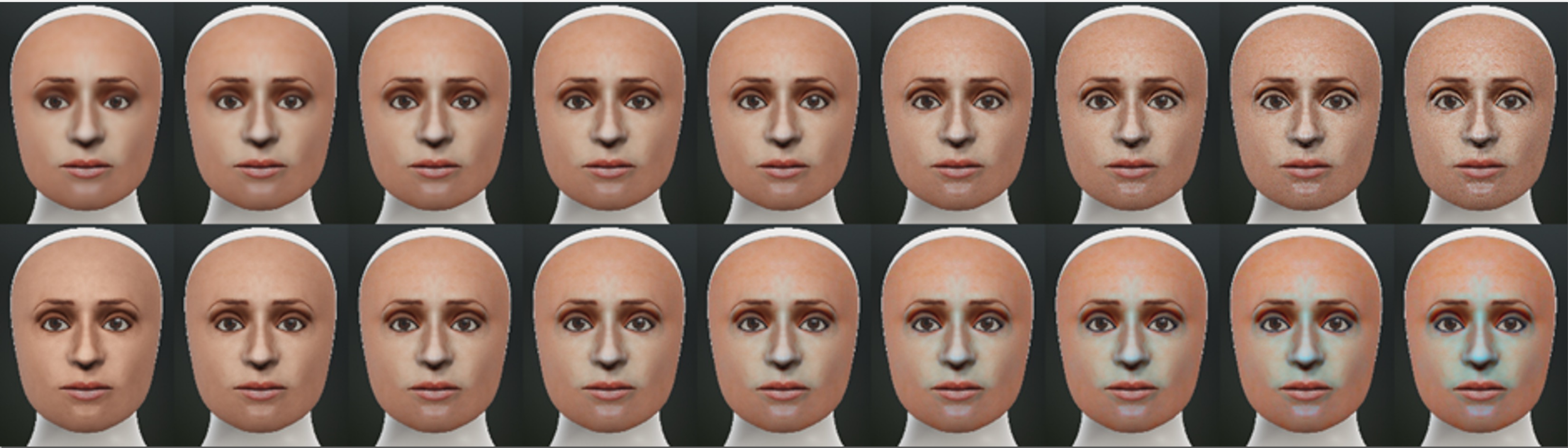




A recent neuroscience paper suggested that the ultimate resting state of neurons after a change in stimulus level can be modeled as the geometric mean of the initial baseline response and the peak response immediately stimulus onset. This made us wonder if the same could apply to predicting the degree of chromatic adaptation. The short answer is yes! If one takes the LMS values of a reference point as the baseline, and the LMS values of an adapting stimulus as the peak response, then the simple geometric mean does directly predict the degree of sensory adaptation. Additionally, it predicts that the adaptation points will follow the Planckian (or Daylight) curve on a chromaticity diagram, as often observed psychophysically, rather than following straight lines as in previous adaptation models. The Weighted Geometric Mean model is part of Che Shen's dissertation and was fist published at CIC30. It is an exciting new model that will become part of future improved appearance models.

Che Shen and Mark D. Fairchild

Research Highlight: **The Influence of Face Appearance on Perceptions of Social Robots**



Social robots are designed to interact with humans in meaningful social ways. Because developers presumably aim to foster engagement and interaction with these robots, they should aim to design their appearance to be approachable, engaging, and enjoyable. A separate goal of many robot models is to also appear realistic or human-like as possible. To investigate how the appearance of robots might influence these important social perceptions, Julia has manipulated the appearance of highly detailed social robot face (Furhat) along two dimensions - skin texture and skin color-heterogeneity - and measured how the varied appearance influenced evaluations of the robot's trustworthiness, realism, and appearance preference. The current work found interesting patterns in how each dimension influenced the perceived trust, realism, and preference based on the robot's appearance, which suggests there are important tradeoffs that need to be considered based on the design goals of robot developers. This work should help to inform important considerations when designing robots that are intended to interact with humans, and help facilitate more meaningful human-robot social interactions.

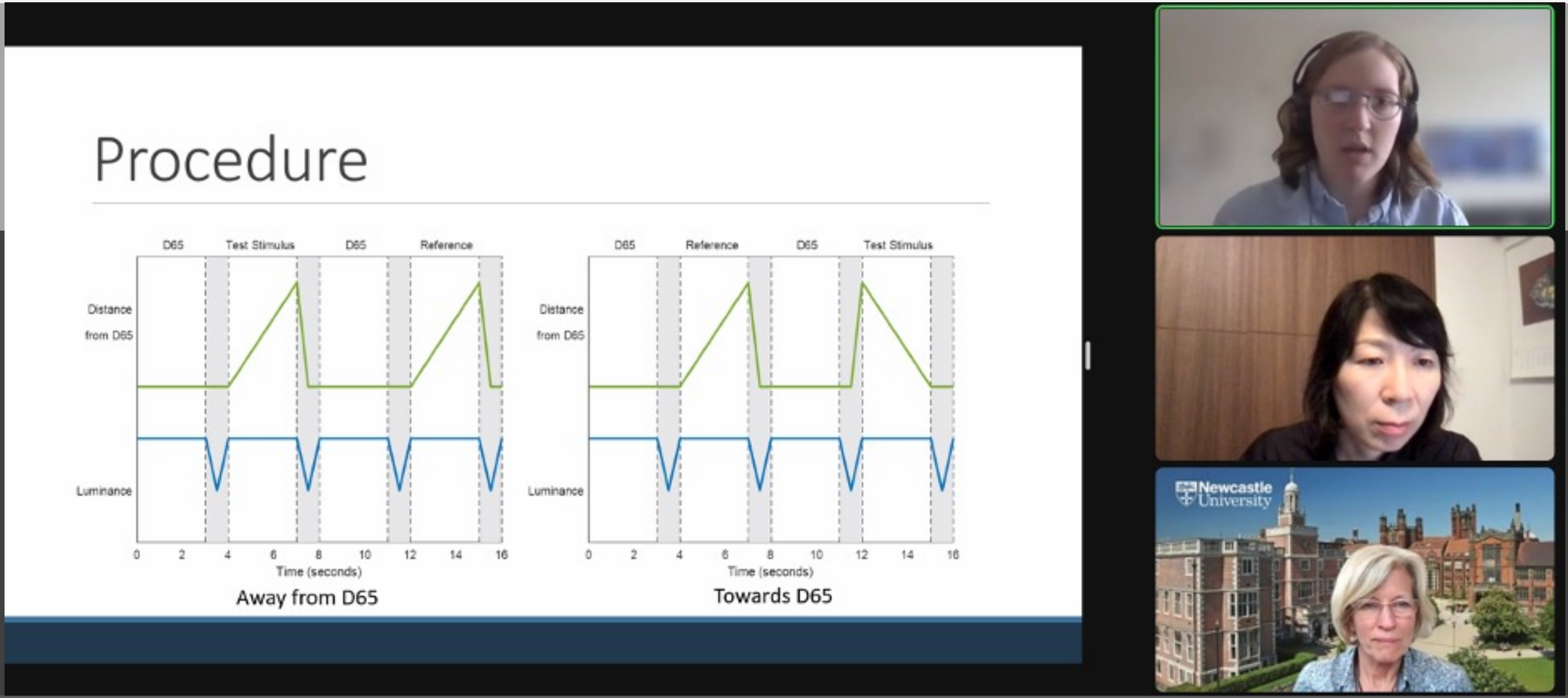
Julia Versteden and Chris Thorstenson

Research Highlight: **Munsell Trees**

Mark is spending the 2022-23 academic year on sabbatical and his main project has been a forthcoming book from RIT Press titled *Munsell Trees: A Season of Leaves and Colors*. In it, Mark tracks the lives of 24 local trees through a photographic technique that features trans-illumination. The book includes collections of leaves by tree across the season, by date across the trees, and simply by pleasantness. In addition the tree leaves are plotted on Munsell coordinates to provide a technical record of tree leaf color across a growing season. Chapters in the book include overviews of Munsell and his system, the lives of trees, the work and inspiration of Henry David Thoreau, and the technical processes of collecting, measuring, and photographing the leaves. An appendix includes full technical details and data. Look for the book in mid- to late- 2023.

Mark D. Fairchild

Research Highlight: **Perceived Speed of Dynamic Lighting Transitions**



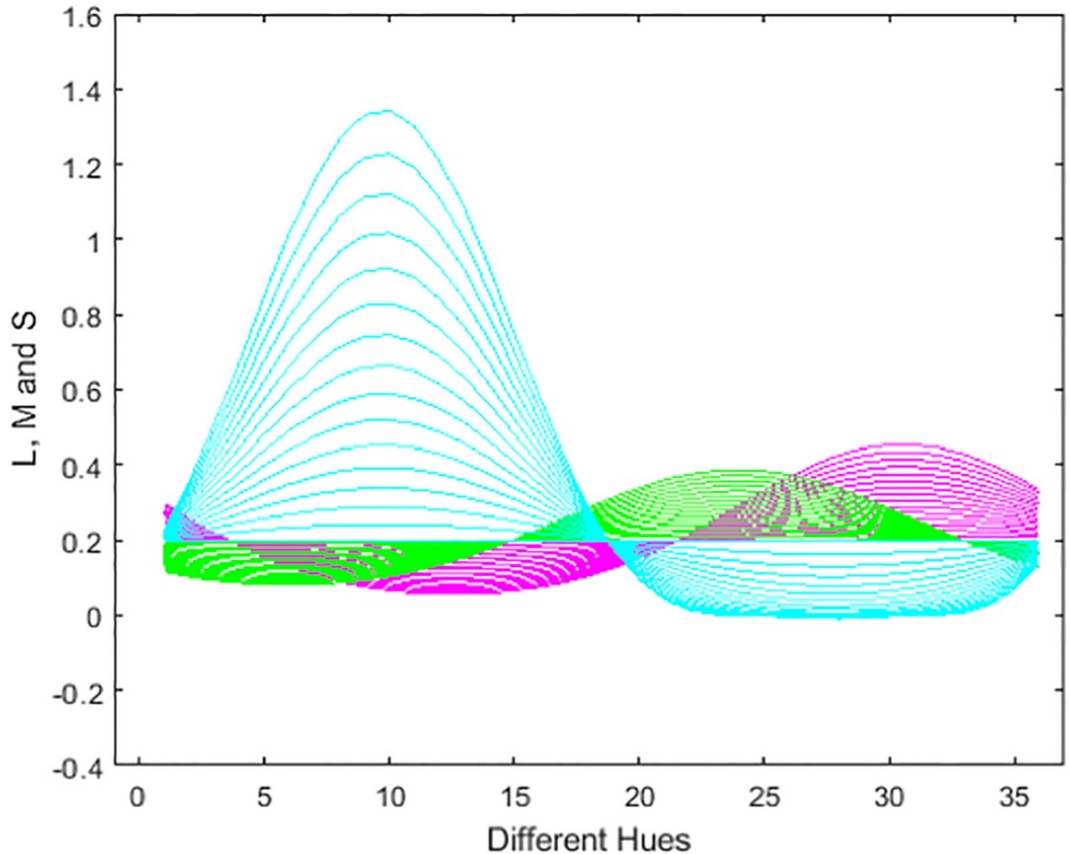
Dynamic lighting is an integral part of our experience of illumination, both in daylight and increasingly in artificial lighting. However, little research has been done on the perception of the speed of illumination changes. This work examined transitions between neutral D65 illumination and eight different hues, including transitions along the daylight locus. The experiment was designed to determine the perceived speed of the transitions relative to reference a transition to warm daylight. Analysis of the transitions away from D65 suggested that changes along the b*/s and (S – (L + M))/s axes in CIELAB and DKL spaces, respectively, contribute less to speed perception than changes along the a*/s and (L – M)/s axes. Thresholds for most transitions towards D65 were not identifiable, perhaps due to adaptation during the transition, and further experimentation on these stimuli showed wide variation with some observers judging the slowest measured speeds as faster than the highest measured speeds. This work was presented virtually at AIC Toronto.

Abby Weymouth and Michael J. Murdoch

Research Highlight: **Hue Scales**

Saeedeh Abasi, a former visiting student at MCSL, has returned to the lab as a Ph.D. student. In her first year back, she has been working with Mark on the development of fundamental hue scales. A paper is in preparation that will be submitted to CR&A soon. She has derived two types of hue scales, one for hue discrimination (that follows the concepts of hue angle and the Munsell system) and a second for hue appearance (that follows the concepts of hue quadrature and the NCS system). Her results show constant hue predictions similar to those of the IPT color space that has served as the benchmark for constant hue predictions for nearly three decades. Additionally her scales are based on physiological underpinnings and start from LMS cone responses to easily allow predictions for individual observers.

Saeedeh Abasi and Mark D. Fairchild



Research Highlight: **Representative Color**

Sample images and their corresponding color palettes – down-sampled at top and full resolution at bottom

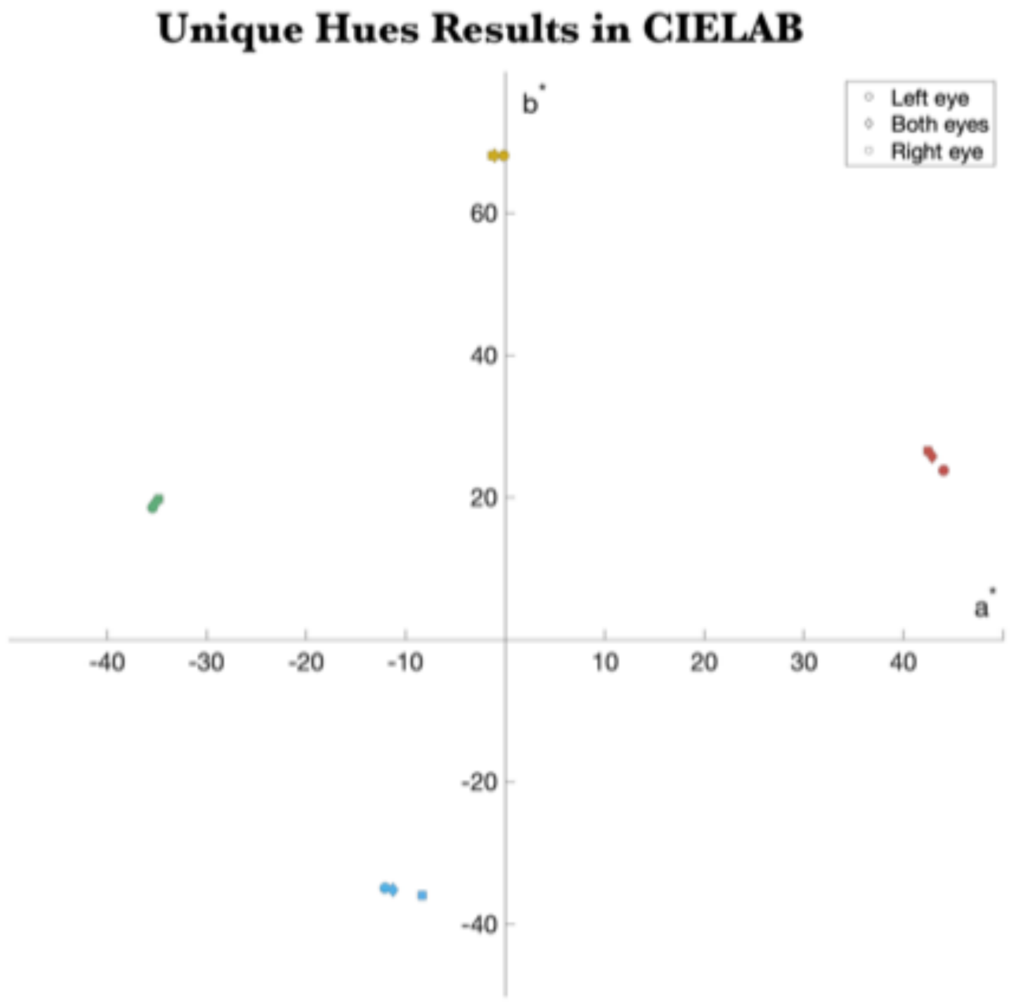
Two experiments were conducted to assess how observers determine the color that best represents a multicolored object. Observers were presented with an image and were next given eight color patches to choose from. To evaluate the importance of context, scrambled versions of the images were presented first, then 16x16 down-sampled versions, then the full resolution versions. Images primarily consisted of human faces with an emphasis on skin tones, but some natural objects such as tomatoes, the sky, and grass were also included. In a previous iteration of these experiments, images of tomatoes were predominantly present, and a bias towards more saturated and chromatic colors was observed. In these experiments, that bias was not present, possibly due to the nature and sensitivity the human eye has to skin tones. The first experiment was conducted on a regular display device, and the second experiment took place in an augmented reality setup. Illustrated is a down-sampled version of one of the face images and its corresponding color choices.

Dara Dimoff and Susan Farnand

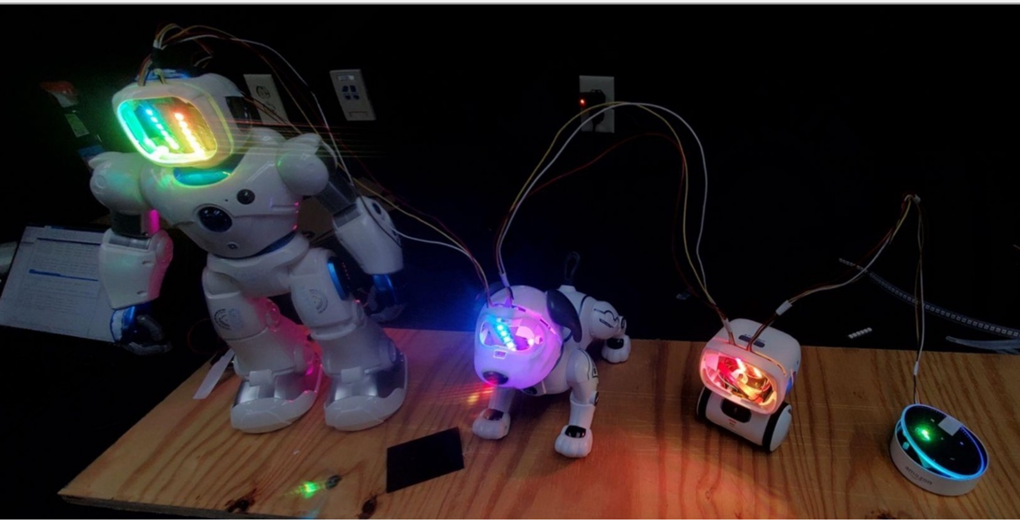
Research Highlight: **A Case study: Individual differences in color perception**

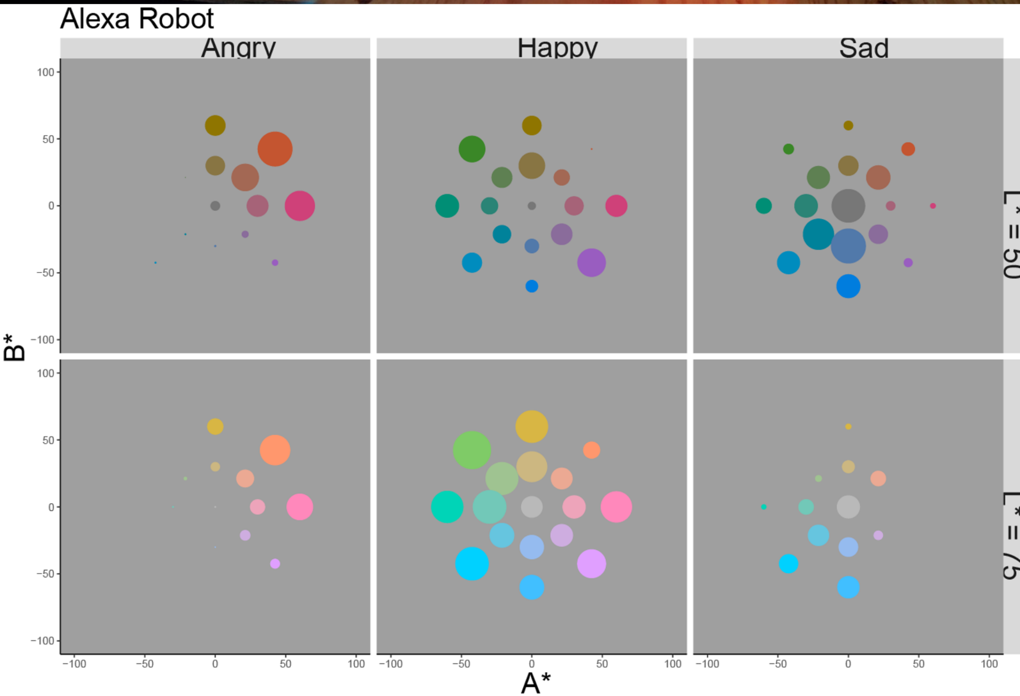
Color vision can vary significantly between people, even for those without color vision deficiencies. These differences arise from optical, neural, and cognitive processes, from factors such as lens density, macular pigment density, peak luminance, and others. This study explored methods to efficiently determine individual differences in color perception. One observer, who, following cataract surgery in one eye, has slightly but perceptibly different color vision between her two eyes, took part in three experiments to compare these differences. The evaluation of color perception difference focused on Unique Hue angles and Color Matching functions. This research took advantage of a unique observer to explore possible methods for evaluating color perception differences.

Eddie Pei and Susan Farnand



Research Highlight: **Using Color for Robot Emotions**

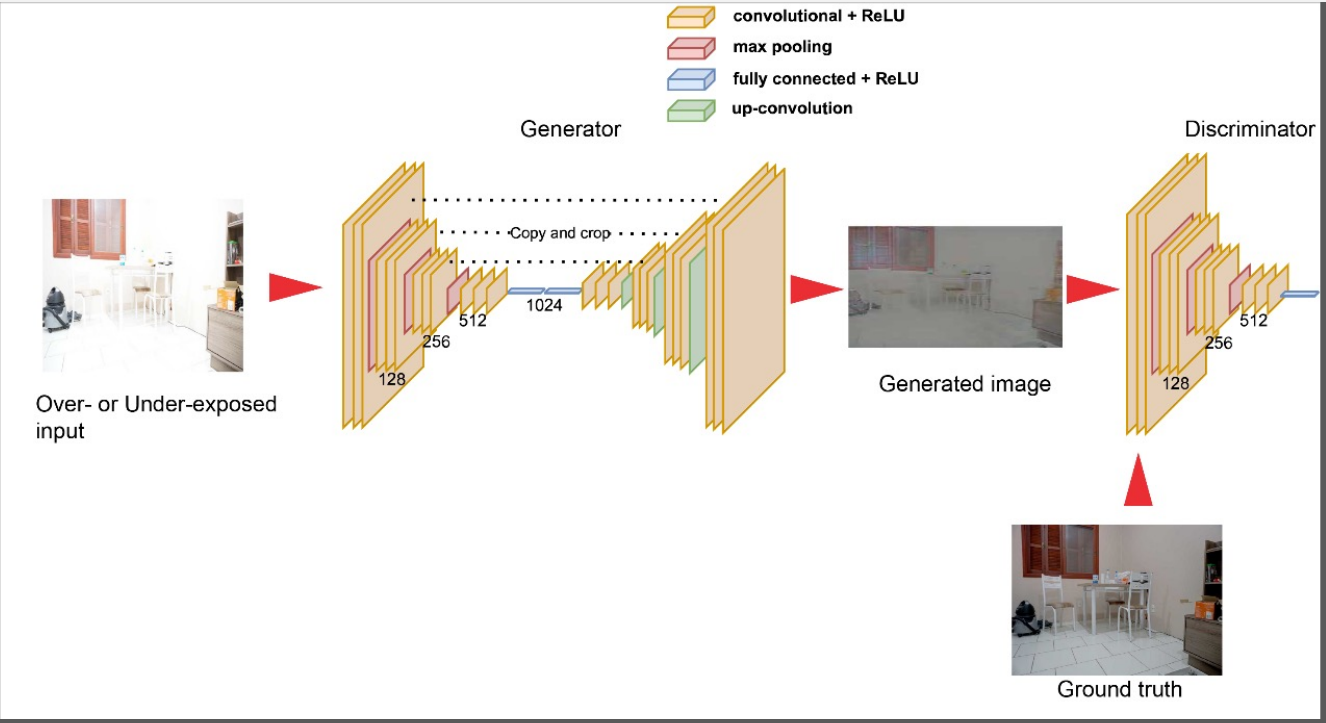




Social robots are robots designed to interact and socialize with humans. One of the most important ways that social robots can interact with humans is to communicate information about emotion - for example telling a user whether it is angry, happy, or sad, based on interactions with its users or environment. There are several ways that a robot can express emotions, but doing so through colored lights is particularly efficient due to color's flexibility (color can be displayed on robots with various sizes and architecture), simplicity (e.g., using inexpensive and simple LED lights), and the existence of robust color-emotion associations that people have already formed. Chris has been working to better understand how color can convey emotions in social robots. This topic is surprisingly complex, because color-emotion associations are based on more than just hue (lightness, chroma, and hue are independently associated with different emotions), and can also vary depending on what the robot initially looks like (e.g., whether it has a human-like face, resembles a pet, or is just a small box). The current work is an initial step of an ongoing project to better understand the nuances of color-emotion associations, artificial social agent perception, and robot social communication.

Chris Thorstenson

Research Highlight: **Over-exposed image reconstruction**



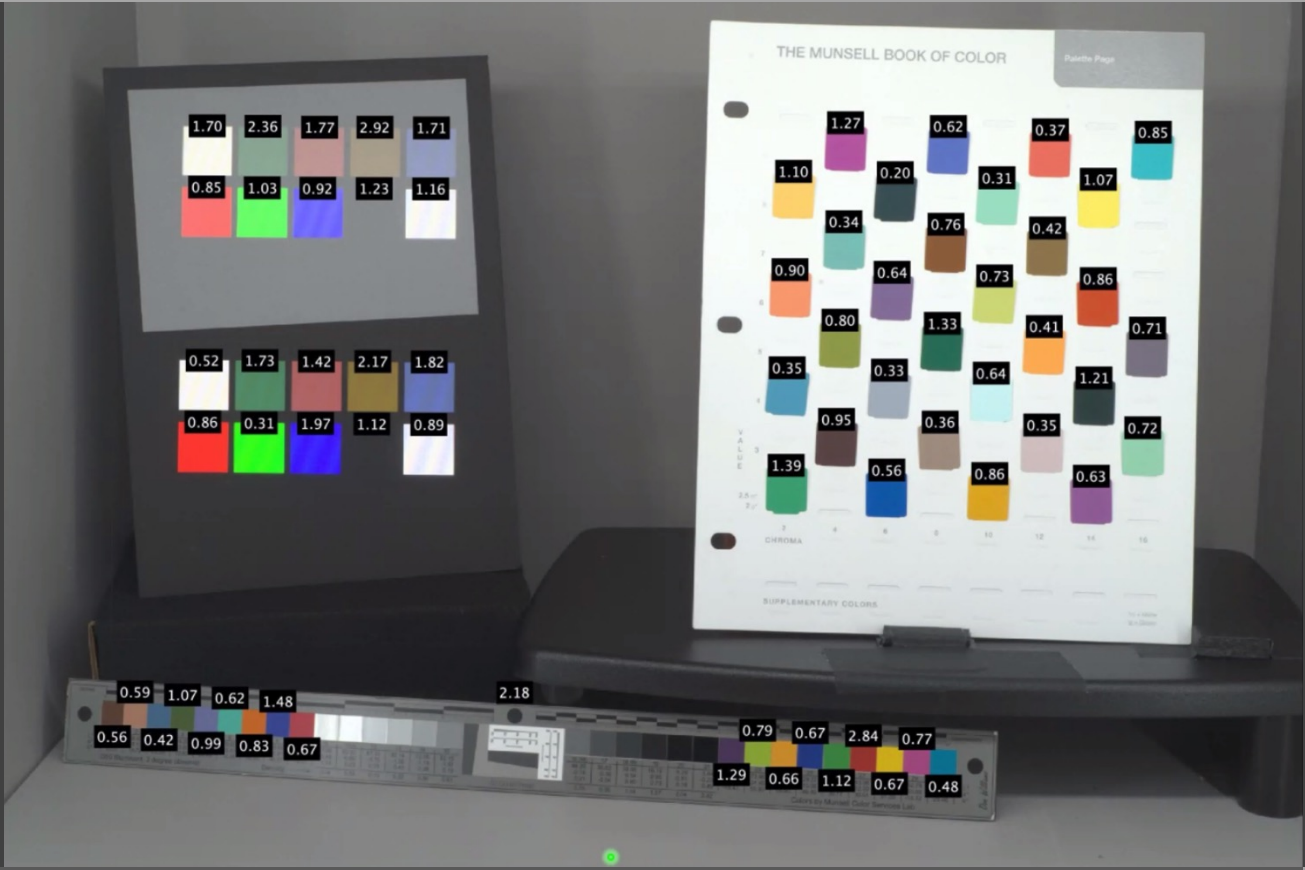
Detail and appearance reconstruction, for under- and over-saturated images, is vital for HDR imaging applications such as tone expansion operators. Various conventional image processing approaches have been followed over the years. In most of the severely under- and over-exposure cases, however, all the color information is entirely lost and more advanced techniques are required to bring back the details. Therefore, with the increasing traction of deep learning (DL) approaches in color imaging, various convolutional neural network (CNN) based DL models have been used for the enhancement and reconstruction of over- and under-exposed images. With most CNN architectures, the reconstructing processes of completely lost details remains challenging. In this work, existing challenges such as insufficient training data and resources, CNN's weak spatial and cross-class representation, and the luck of appearance-based loss functions are being explored. New deep learning architectures based on generative adversarial networks (GANs) and transformer networks are being investigated and tested with promising results.

Mekides Assefa Abebe

Research Highlight: **Image Based Measurement of Augmented Reality Displays and Stimuli**

Perceptual research of see-through augmented reality (AR) displays faces many challenges in the design of display stimulus and viewing conditions for effective psychophysics experiments due to the many known and unknown factors that can affect the appearance of transparent stimuli. The decisions made about the stimulus presentation may be very difficult to document in a simple or intuitive way and very few tools for describing and designing experiments for AR displays exist. This was solved with an imaging technique that borrows inspiration from other multi-capture imaging approaches. Besides the application need in AR, the design of this imaging technique might be applied to many other areas of imaging where only a specific application is required, and color accuracy must be as high as possible. The approach used here, with the particular application factors described, resulted in an imaging system capable of imaging AR stimulus presentations with an accuracy of around 1 ΔE_{00}. This work was presented virtually at AIC Toronto.

Tucker J. Downs, Olivia Kuzio, Michael J. Murdoch

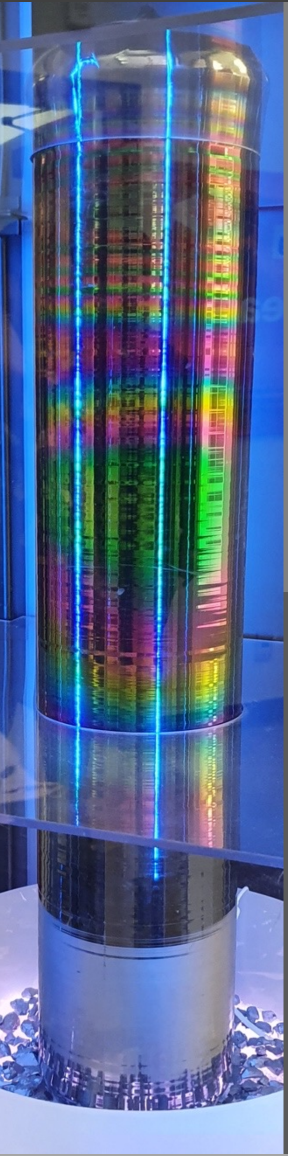


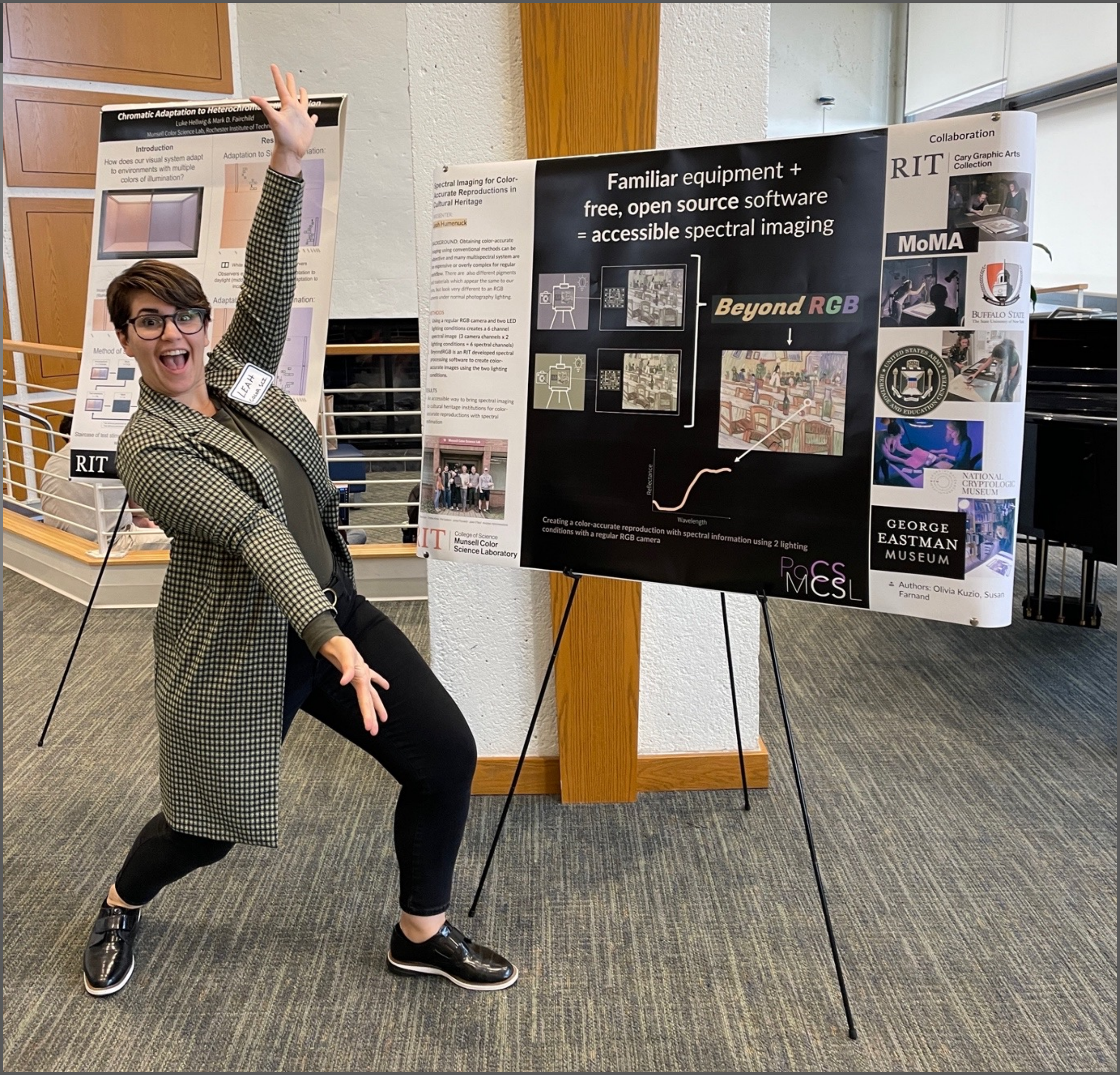
Research Highlight: **Toward Practical Spectral Imaging Beyond a Laboratory Context**

Two years of testing and refining LED-based "two-light imaging" culminated in the realization of a portable, user-friendly multispectral imaging system assembled almost entirely of common photography equipment and supported computationally with custom, open-source image processing software. From the conceptualization of the project, this system had been intended as a tool for outreach and education, and as a means of promoting routine scientific imaging for cultural heritage digitization and photography. Therefore, the final stages of the project involved demonstrating this research and testing the practicality of the system in real studio environments. These efforts were aimed primarily at institutions where advanced imaging technologies are not already found, and where funding and expertise limit access to the expensive, commercial multispectral imaging solutions that are currently available. Testing was carried out in one-day on-site visits to six cooperating institutions of different sizes and collection types in the northeast US, including the Cary Graphic Arts Collection (Rochester, NY), the National Cryptologic Museum (Annapolis Junction, MD), the US Army Heritage and Education Center (Carlisle, PA), the Museum of Modern Art (New York, NY), the Art Conservation Department at SUNY Buffalo (Buffalo, NY), and the George Eastman Museum (Rochester, NY). During these visits, two-light imaging was presented, and the benefit of collecting spectral data using low barrier-to-entry capture and processing methods relative to conventional imaging methods was discussed. Real-time imaging of collections objects was demonstrated at each institution to showcase the current capabilities of the system and to inform ongoing improvements to the setup and processing.

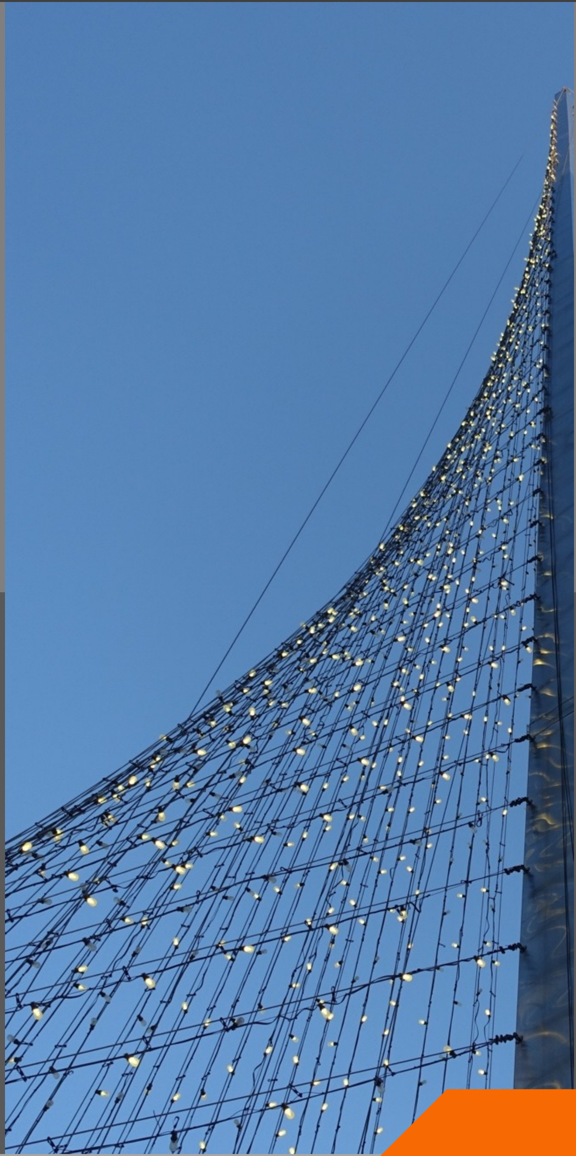
Olivia Kuzio and Susan Farnand


18 Munsell Color Science Lab

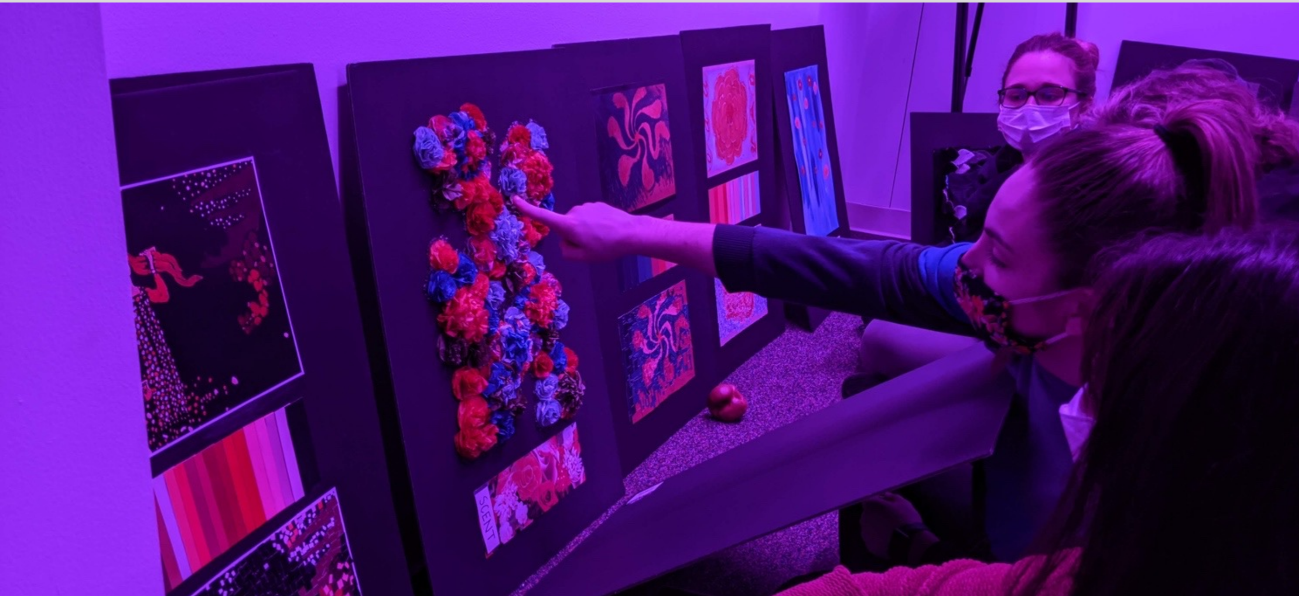


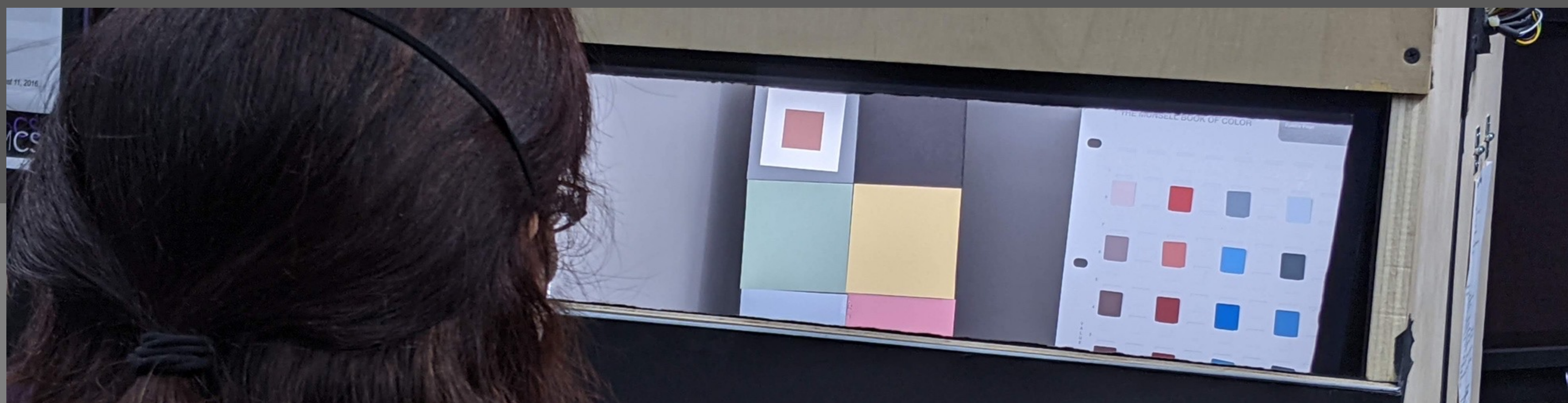


Luke Hellwig & Mark D. Fairchild
Introduction
How does our visual system adapt to environments with multiple colors of illumination?
RIT
LEAH
Familiar equipment + free, open source software = accessible spectral imaging
Beyond RGB
Reflectance
Wavelength
Creating a color-accurate reproduction with spectral information using 2 lighting conditions with a regular RGB camera
College of Science
Munsell Color Science Laboratory
Collaboration
RIT
Cary Graphic Arts Collection
MoMA
Buffalo State
National Cryptologic Museum
George Eastman Museum
Authors: Olivia Kuzio, Susan Farnand




Macbeth ColorChecker® Color Rendition Chart

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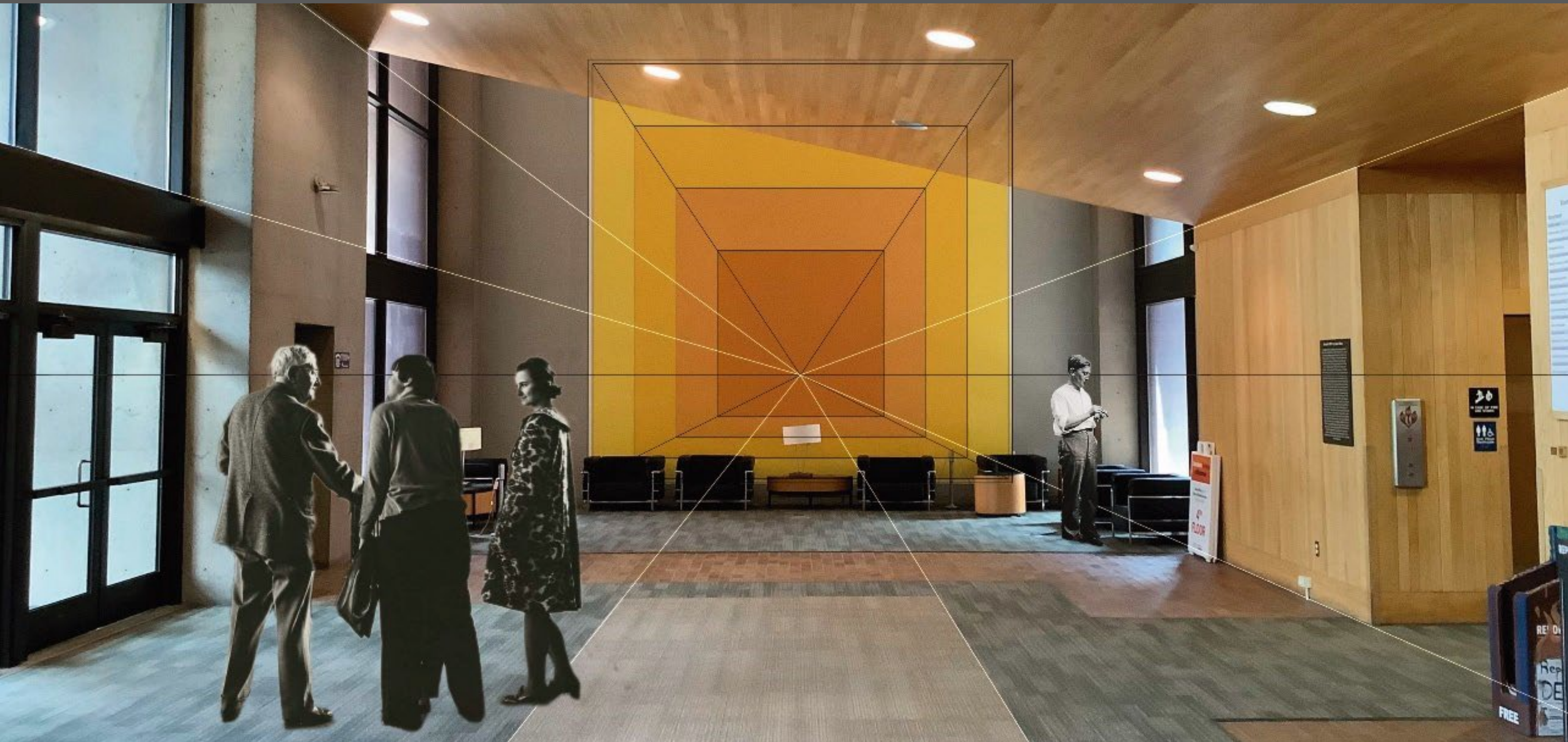
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Scot Fernandez, YRC Worldwide
Francisco Imai, Apple
Tom Lianza, Sequel Color Science
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