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Munsell Color Science Laboratory

2007 Annual Report

www.mcsl.rit.edu

Director's Note

Welcome to the 2007 Munsell Color Science Laboratory (MCSL) Annual Report. We've had a very active and fascinating year traveling down our various paths to educate the next generation of color scientists. Our activities would not be possible without the generous support of our research sponsors and other donors. On behalf of all the MCSL students, faculty, and staff, thank you for your support of our activities and confidence in our mission. For those considering donations or project sponsorship, thank you for your interest and I hope we will be able to collaborate in the future to advance the fascinating field of color science.

We work in many different ways to fulfill our mission of education. The following pages briefly describe and document some of our activities and results from the past year along with some highlight stories to communicate a sense of MCSL. We hope you enjoy the report and encourage you to explore our website at <mcsl.rit.edu> to learn more.

Many things happen over the course of a year at MCSL, but two events of 2007 are particularly noteworthy. RIT's new Ph.D. program in Color Science began enrolling students in the fall and we already have 5 students hard at work in that program, which extends well beyond MCSL to include faculty interested in color science from across the campus. Also, Jim Ferwerda from Cornell University joined us as a new faculty member and he is busy teaching his first courses and developing his research program at RIT. These and many other exciting events have us all anxiously looking to what the future will bring to MCSL.

We wish you all the best for a bright and colorful 2008.

Mark D. Fairchild
Director, Munsell Color Science Laboratory

Thank You For Your Support

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Munsell Color Science Laboratory

The RIT Munsell Color Science Laboratory (MCSL) was established in 1983 through a gift from the Munsell Color Foundation, Inc. Since then MCSL faculty, staff and graduate students have been performing internationally-recognized research in color appearance models, image quality, data-visualization, color-tolerance psychophysics, spectral-based image capture, spectral color rendering and computer graphics, archiving and reproduction of artwork, and other areas of color science and color measurement.

Following the example set by our founders, the guiding objectives of MCSL are . . .

(1) To provide undergraduate and graduate education in color science,

(2) To carry on applied and fundamental research,

(3) To facilitate spectral, colorimetric, photometric, spatial, and geometric measurements at the state-of-the-art, and

(4) To sustain an essential ingredient for the success of the first three – namely, liaison with industry, academia and government.

Back Row (standing): Sunghyun Lim, Philipp Urban, Lawrence Taplin, Mark Fairchild, Justin Ashbaugh, Tim Stephany, Mark Updegraff. **Middle Row (standing):** Ichiro Katayama, Stacey Casella, Jonathan Phillips, Dave Wyble, Mitchell Rosen, Stefan Luka, Jim Ferwerda. **Front Row (standing):** Susan Farnand, Erin Fredericks, Roy Berns, Colleen Desimone, Mahnaz Mohammadi, Abhijit Sarkar, Val Hemink. **Front Row (seated/kneeling):** Rod Heckaman, Shizhe Shen, Hideyasu Kuniba.

Graduate Education in Color Science

RIT offers the only M.S. and Ph.D. programs in color science in the country. More than 80 color science alumni currently work in the field world-wide. Many of them are recognized leaders making significant contributions to the advancement of color science and technology.

Color science graduates are in high demand and have accepted industrial and academic positions in a variety of areas including digital imaging, color instrumentation, colorant formulation and basic and applied research.

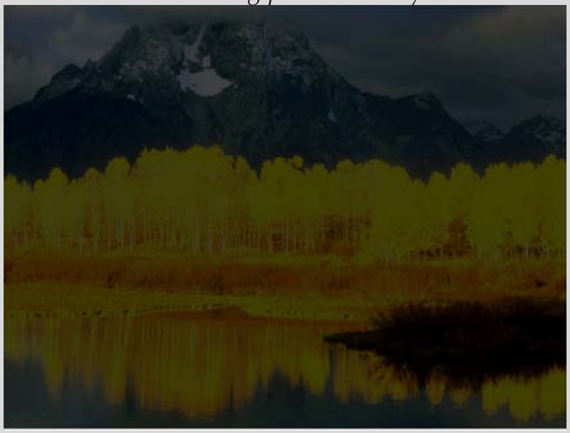
Students complete their degrees through programs in the Chester F. Carlson Center for Imaging Science within RIT's College of Science. These include the M.S. and Ph.D. programs in Color Science and Imaging Science. In addition, undergraduate students in Imaging Science and other programs occasionally complete research projects or obtain other work experience in the field of color science.

See <www.mcsl.rit.edu/education/> for more information on our academic opportunities.

Beyond the Locus of Pure, Spectral Color and the Promise of HDR Display Technology:

In emerging media technologies - particularly High-Dynamic-Range (HDR) displays, much more is possible in achieving brighter and more vibrant colors and a richer visual experience that may even transcend what we see everyday. And while such a perceptual experience is certainly complex, the richness and vibrancy of it is largely and simply made possible by the broad extent of sensitivity of the human visual system and its innate ability to adapt to its surround. By exploiting these powers of adaptation, a methodology was demonstrated both empirically and in a limited set of images using color appearance model, CIECAM02, to expand the perceptual gamut in lightness, chroma, brightness, and colorfulness beyond the MacAdam Limits of pure, spectral colors.

The pair of images below, Grand Tetons, illustrate the effect. A region was chosen as diffuse white – the patch of snow on the mountain, and the image was rendered, in this case, by mapping diffuse white to a white point 25% below the maximum display luminance. In the version on the left, those portions of the image with a luminance above the chosen white point were clipped thus representing the more traditional methodology of rendering the white point to the maximum luminance of the media. On the right, those portions with luminance above the white point - the sunlit trees - were maintained at 100% of the original. This research is being performed by Rod Heckaman (Imaging Science Ph.D. candidate).



Outreach

Outreach is a key educational vehicle for MCSL. In addition to the extensive educational and research resources available for the community at <www.mcsl.rit.edu>, our Summer Short Course and Visiting Scientist Program provide two particularly successful examples of outreach to the color science and technology community.

MCSL Summer Short Course: Essentials of Color Science, June 3-6, 2008

Every June MCSL presents this course for people interested in color measurement, specification, control, reproduction, or use. The lectures are designed to form a coherent course that introduces the fundamental concepts of color science, describes various applications, and introduces cutting-edge research areas in color science. Details can be found at: <www.mcsl.rit.edu/outreach/courses.php> or call +1-585-475-6783.

MCSL Visiting Scientist Program

For nearly two decades MCSL has been hosting industrial scientists and engineers for extended periods. These visiting scientists spend 1-2 years in residence at MCSL and work on fundamental research problems of interest to their employer and MCSL researchers. They also have time to participate in formal MCSL course offerings if they so desire and to experience the culture and climate of Rochester and the entire United States.

Feel free to contact any member of the MCSL faculty or staff for more information on becoming an MCSL visiting scientist or send an email to: *desimone@cis.rit.edu* to inquire.

Mapping the Blues of Vincent van Gogh's *The Starry Night*:

During August, Yonghui (Iris) Zhao (Imaging Science Ph.D. candidate), Philipp Urban (Post-Doc), Lawrence Taplin, and Roy Berns went to the Museum of Modern Art (MoMA) in New York to test the spectral-imaging system they developed for MoMA. One of the targets was The Starry Night, *requested by Roy because of its presumed color palette and surface characteristics (impasto). The image data are being used for both spectral printing (Philipp) and pigment mapping (Iris) research. Contact spectrophotometry indicated that only ultramarine blue was used. Following pigment mapping, it was discovered that van Gogh also used cobalt blue and was very deliberate in both its and ultramarine's usage.*

The Starry Night

Ultramarine Blue

Colbalt Blue

Vincent van Gogh, Dutch, 1853-1890. The Starry Night, Saint Rémy, June 1889. Oil on canvas 29 x 36 1/4" (73.7 x 92.1 cm). The Museum of Modern Art, New York. Acquired through the Lillie P. Bliss Bequest. Digital image © 2007 The Museum of Modern Art.

Collaborative Research

MCSL is recognized around the world as a prominent source of leading-edge, interdisciplinary research in color science. MCSL students, faculty, and staff produce scores of journal papers, conference presentations, book chapters, and invited presentations each year (not to mention the occasional text book). Much of this research is done in close cooperation with industrial, government, institutional, or other sponsors. Please see <www.mcsl.rit.edu/about/sponsors.php> to learn about our current and past sponsors.

Recent MCSL research can be generally categorized into four theme areas: Color Measurement & Science, Image Appearance & Modeling, Spectral Color Reproduction, and Color Science for Cultural Heritage. A review of the publications list on the following pages will provide an overview of the range of recent research results. The highlight stories throughout this annual report provide a little more insight into some current and planned projects and activities. As always, much more information on past and current research and publications can be found by visiting <www.mcsl.rit.edu>.

There are many opportunities for new collaborative research projects in support of our mission of providing our students with relevant research topics and the best possible educational experience. Please let us know if your organization is interested in learning more about how to collaborate with MCSL.

Computer Rendering of Paintings:

Research is ongoing to build a practical imaging system that captures spectral images for specific illumination angles about the painting. These images are used to estimate the painting's bi-directional distribution function using computer-graphics light reflection models. This research is being performed by Ying Chen (Color Science M.S. candidate), Lawrence Taplin, and Roy Berns.

Real Image

Rendered Image

Comparison between a painting imaged with an RGB digital camera and its rendering using the Torrance-Sparrow model and a limited number of illumination angles.

2007 MCSL Publications

1.) R.S. Berns and M. Mohammadi, "Evaluating single- and two-constant Kubelka-Munk turbid media theory for instrumental-based inpainting," *Studies in Conservation*, **52**, 299-314 (2007).

2.) R.S. Berns and M. Mohammadi, "Single-Constant Simplification of Kubelka-Munk Turbid-Media Theory for Paint Systems – a review," *Color Research and Application*, **32**, 201-207 (2007).

3.) R.S. Berns, "Let's call it 'color-gamut rendering'," *Color Research and Application*, **32**, 334-335 (2007).

4.) Y. Chen and R.S. Berns, "Model evaluation for computer graphics renderings of artist paint surfaces," *Proc. IS&T/SID Fifteenth Color Imaging Conference,* 54-59 (2007).

5.) Y. Chen, R.S. Berns, L.A. Taplin and F.H. Imai, "A multi-ink color-separation algorithm improving image quality, *Journal of Imaging Science and Technology*, in press (2007).

6.) M.D. Fairchild, "High, wide, & deep: Displayed image color appearance and perception, *SID International Symposium,* Los Angeles," invited/in press (2008).

Visual Equivalence ~ Towards a New Standard for Image Fidelity:

Efficient, realistic rendering of complex scenes is one of the grand challenges in computer graphics and Ganesh Ramanarayanan, Jim Ferwerda, Bruce Walter, and Kavita Bala have taken on the task. Perceptually based rendering addresses this challenge by taking advantage of the limits of human vision. However existing methods, based on predicting visible image differences, are too conservative because some kinds of image differences do not matter to human observers. Jim Ferwerda and colleagues have recently introduced the concept of visual equivalence, a new standard for image fidelity in graphics. Images are visually equivalent if they convey the same impressions of object appearance, even if they are visibly different. To understand this phenomenon, they conducted a series of experiments that explored how object geometry, material, and illumination interact to provide information about appearance, and characterized how two kinds of transformations on illumination maps (blurring and warping) affected these appearance attributes. They then derived visual equivalence predictors (VEPs) that indicate when images rendered with transformed maps will be visually equivalent to images rendered with reference maps. Finally, they showed how VEPs can be used to improve the efficiency of two computer graphics rendering algorithms: Lightcuts and precomputed radiance transfer. This work represents some promising first steps towards developing perceptual metrics for computer graphics based on higher order aspects of visual coding.

7.) M.D. Fairchild, “Beyond the locus of pure spectral colors,” *SPIE/IS&T Electronic Imaging*, San Jose, invited/in press (2008).

8.) M.D. Fairchild, D.R. Wyble and G.M. Johnson, “Matching image color from different cameras,” SPIE/*IS&T Electronic Imaging*, San Jose, in press (2008).

9.) M.D. Fairchild, “The HDR photographic survey,” *IS&T/SID 15th Color Imaging Conference*, Albuquerque, 233-238 (2007).

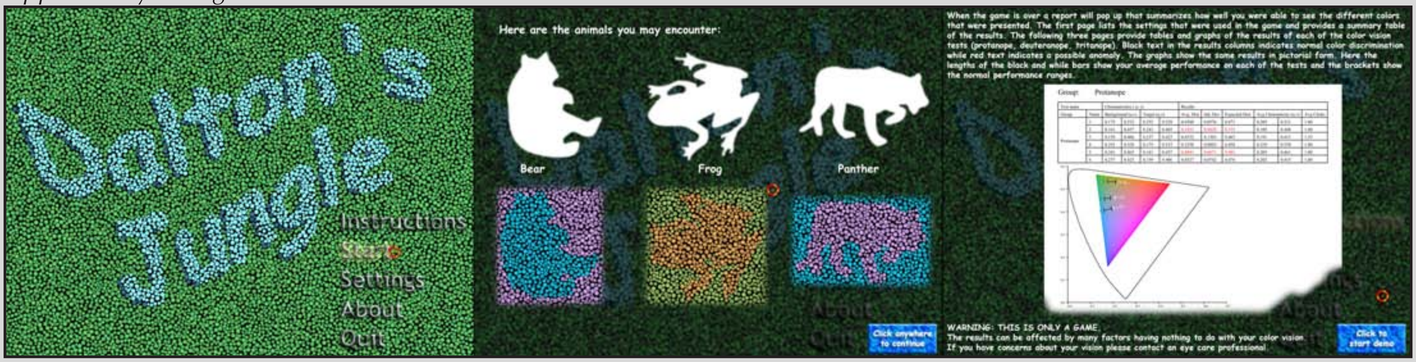
10.) M.D. Fairchild, “The HDR photographic survey,” *IEEE Signal Processing Society Western New York Image Processing Workshop Proceedings*, Rochester, 39-42 (2007).

11.) M.D. Fairchild and D.R Wyble, “Mean observer metamerism and the selection of display primaries,” *IS&T/SID 15th Color Imaging Conference*, Albuquerque, 151-156 (2007).

12.) M.D. Fairchild, “Spectral adaptation,” *Color Research and Application,* **32***,* 100-112 (2007).

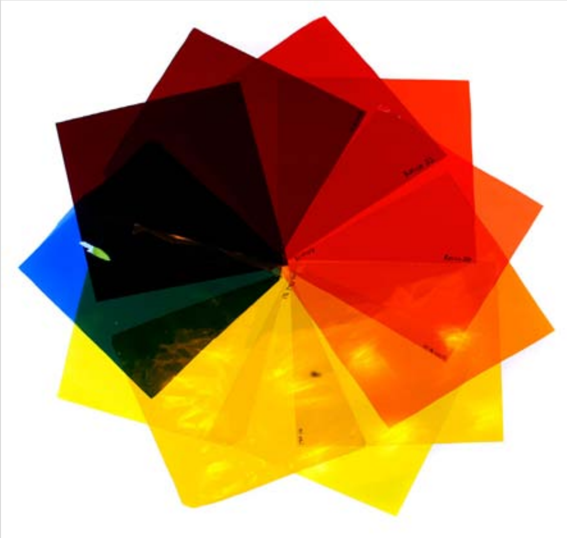
Dalton’s Jungle ~ A Video Game for Testing Children’s Color Vision:

Anomalies of color vision affect approximately ten percent of the male population and a smaller percentage of females. With recent advances in desktop publishing and printing technologies, color is now commonly used in teaching materials in K-12 classrooms. Therefore, it is becoming increasingly important to identify children with color-anomalous vision so appropriate accommodations can be made. Existing tests such as the Ishihara plates and the Farnsworth D-15 test are both expensive to acquire and difficult to administer to the pediatric population. To address these issues Jim Ferwerda and Ang Pet Chean, undergraduate advisee, have developed a PC-based video game called Dalton’s Jungle that can assess color-anomalies in children’s vision. The goal of the game is to find animal patterns that are hidden in images of jungle-like foliage. The colors of both the animals and the foliage are chosen to fall along dichromatic confusion lines in the CIE u,v uniform chromaticity space. In each round of the game, chromaticity differences between the animal and foliage patterns increase over time, allowing direct measurement of discrimination thresholds. Thus the game can assess both the form and degree of color anomalies in vision. Performance is summarized in both tabular and graphical reports. This project provides an example of how game-based methods can be used to develop efficient and effective tools for screening children’s vision. This work was supported by NSF grant IIS-0113310.



13.) M.D. Fairchild, "A color scientist looks at video," *3rd International Workshop on Video Processing and Quality Metrics (VPQM)*, Scottsdale, Invited Paper 1 (2007).

Spectral Fluorescence Estimation Imaging:



In discussing color management and spectral imaging, a question that almost always comes up is how to deal with fluorescent materials. The approach taken in most imaging work at MCSL has been to try to record what a human observer would see if looking at the object under the lighting used for imaging. While it is possible to use the known taking illuminant spectrum to estimate reflectance, it has not been possible to separate reflectance from fluorescent emission and accurately estimate appearance under different lighting. Mahnaz Mohammadi (Imaging Science Ph.D. candidate) has been working on research to separately estimate the excitation, emission and reflectance spectra at each pixel in an imaged scene. The technique she has used is based on an abridged method previously used in spectrophotometry. A set of gel absorption filters are sequentially placed in front of the scene lighting. By observing the filters' effect on total radiance (estimated using our six-band spectral camera) and knowledge gained from a database of known fluorescent materials, the three spectra can be separately estimated. Using the technique it is possible to estimate the appearance of the scene objects under any lighting power distribution and accurately include the effect of fluorescence. This is particularly useful for imaging works on paper with florescent brighteners and modern art that incorporates fluorescent pigments.

14.) M.D. Fairchild and G.M. Johnson, "Measurement and modeling of adaptation to noise in images," *Journal of the Society of Information Display* **15**, 639-647 (2007).

15.) M.D. Fairchild, Ed., "Color," *World Book Encyclopedia*, (2007).

16.) J.A. Ferwerda and B. Rehon, "MagnoFly: game-based screening for dyslexia," *Journal of Vision*, 7(9): 520a, (2007).

17.) T.J. Hattenberger, M.D. Fairchild, G.M. Johnson and C. Salvaggio, "A psychophysical investigation of global illumination algorithms used in augmented reality," *ACM Transactions on Applied Perception*, in press (2008).

18.) R.L. Heckaman, M. Sakurai, M.D. Fairchild, T. Nakatsue and Y. Shimpuku, "The effect of display gamut volume on image preference," *IS&T/SID 15th Color Imaging Conference*, Albuquerque, 201-206 (2007).

Infinite Pixel Liberation Laboratory:

This past year saw the birth of the Infinite Pixel Liberation Laboratory (iPixLab), a new laboratory associated with the Munsell Lab and the Center for Imaging Science. Under the direction of Mitchell Rosen, iPixLab is developing concepts related to liberated media, content that depends upon non-traditional display categories such as immersive, wide-view, transient or environmentally-interactive. The lab explores hardware, software and standards for these new modes of expression. The lab has been successful in creating outlets and infrastructure for faculty and students across the Institute for making wide-view and immersive presentations. Here is a photograph of our student Erin Fredericks (Imaging Science M.S. candidate) in front of a wide-view production she developed in honor of visiting lecturer, Jenna Levin, author of How the Universe Got Its Spots. Erin is in the Auditorium of the College of Science, which several times a week transforms into RIT's largest immersive theater. More modest platforms are popping up in various places around campus. We are currently building one for use in the Color Science Building. Undergraduates, graduate students, faculty, staff and the broader community are all discovering ways to incorporate these new abilities into their visual communication repertoire. Collaborations are brewing across campus with members of various colleges and with the Rochester Museum and Science Center, the Warner School of the University of Rochester, the Children's Zone in Rochester and a number of corporations.

19.) R.L. Heckaman and M.D. Fairchild, "Beyond the locus of pure spectral colors and the promise of high-dynamic-range display technology," *Information Display* **23**:7, 22-27 (2007).

20.) G.M. Johnson and M.D. Fairchild, "Image Appearance Modeling," Ch. 12 in *Colorimetry: Understanding the CIE System*, Wiley, Chichester (2007).

HDR Photographic Survey Website and Awards:

Mark Fairchild spent much of 2007 working on completion of the High-Dynamic-Range Photographic Survey. He spent Spring Quarter traveling the country collecting images and related data and much of the summer processing the images, compiling data and putting the website in place. Over 100 images and related colorimetric and appearance data have been placed in the public domain for researchers at <www.cis.rit.edu/fairchild/HDR.html>.

The HDR survey was the subject of a poster presentation at the IS&T/SID 15th Color Imaging Conference in Albuquerque in November. Mark had a great time sharing his images, and the stories of their capture and creation, with the conference participants and was pleasantly surprised to have the work voted to receive the coveted "Cactus Award" as the best poster presentation of the conference. Images from the HDR survey were also shown at the October awards ceremony of the Royal Photographic Society in London. There Mark was presented with the Davies Medal for his contributions to the digital field of photographic science. The accompanying image illustrates one of the four major trip routes that Mark followed in collecting the images and a visually-rendered interpretation of an HDR image of the Golden Gate Bridge that was captured about 30 minutes after sunset.

21.) N. Katoh, N. Ohta, S. Quan, M.R. Rosen, "System and method for analyzing, optimizing and/or designing spectral sensitivity curves for an imaging device," *US Patent* 2007; **7173657**.

22.) J. Kuang, R.L. Heckaman and M.D. Fairchild, "Evaluation of HDR tone mapping algorithms using a high-dynamic-range display to emulate real scenes," *IS&T/SID 15th Color Imaging Conference*, Albuquerque, 299-303 (2007).

Perceived Color Gamuts:

Mark Fairchild, Rod Heckaman (Imaging Science Ph.D. candidate), and Stacey Casella (Color Science M.S. candidate) are working on research aimed at understanding the perception of images made with new color imaging technologies for capture, processing, and display. In a collaboration with Sony, visual experiments are being completed to better understand how observers react to novel displays for HDTV that are capable of producing a significantly enhanced range of colors, or color gamut. While such display technology is becoming available, the encoded video signals are not intended for such displays and, in many instances, a bigger gamut is not better unless it is utilized appropriately. The collaborative research aims to find the optimal color gamut volume for consumer displays based on observer preference for certain image types and the trade-offs between enhanced color gamut and improved perceptual quality. This work has already resulted in several conference papers on image preference as a function of color gamut volume and on how to quantify perceived colorfulness in displays. The closeness of this collaboration is illustrated by these papers each having multiple authors from both RIT and Sony. Ultimately, this work will be one piece of the puzzle that must be solved to give us all improved television viewing experiences, at least in terms of image quality. The accompanying images illustrate how a difference in color gamut volume might affect the appearance of a colorful scene.

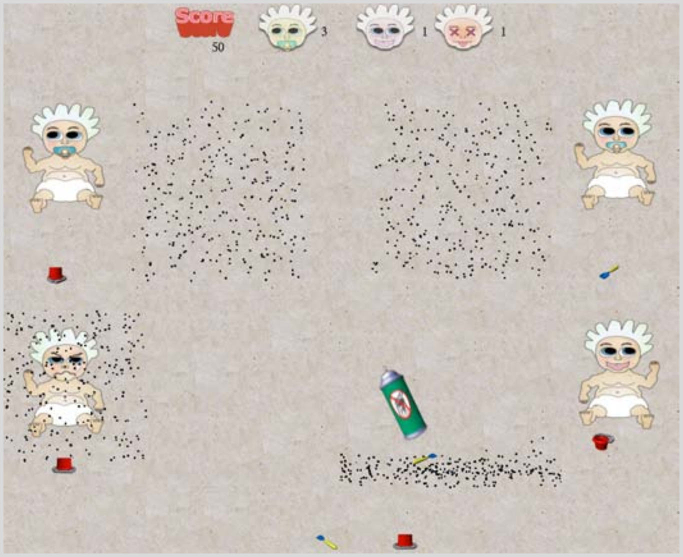
23.) J. Kuang, G.M. Johnson and M.D. Fairchild, “iCAM06: A refined image appearance model for HDR image rendering,” *Journal of Visual Communication and Image Representation* **18**, 406-414 (2007).

24.) J. Kuang and M.D. Fairchild, iCAM06, “HDR, and image appearance,” *IS&T/SID 15th Color Imaging Conference*, Albuquerque, 249-254 (2007).

25.) J. Kuang, H. Yamaguchi, C. Liu, G.M. Johnson and M.D. Fairchild, “Evaluating HDR rendering algorithms,” *ACM Transactions on Applied Perception* **4**, Article 9 (2007).

MagnoFly ~ Game-based Screening for Dyslexia:

Dyslexia is an impairment of reading ability that affects between 5 and 15 percent of the population. Recent research suggests that reduced motion sensitivity in the magnocellular pathways of the visual system may play an important role in some forms of the problem. Screening school age children for this visual correlate of dyslexia could facilitate targeted interventions and minimize learning disabilities, however standard tests of motion perception are time consuming, boring, and difficult to administer. To address this issue Jim Ferwerda and undergraduate advisee Brendan Rehon have developed a computer game called MagnoFly that evaluates a player's magnocellular motion sensitivity. In the game, the player's task is to protect babies from swarms of flies. Initially the swarms move randomly, but over time one swarm moves coherently toward one of the babies. The player gains points by spraying the swarm before it reaches its target, but loses points by spraying randomly. Over the course of the game a background process varies the coherence of swarm motion, and thereby measures the player's motion sensitivity. At the end of the game a report is generated that allows physicians and other specialists to compare individual results with age-based norms to determine if further evaluation for dyslexia might be indicated. This project provides an example of how game-based methods can be used to develop efficient and effective tools for screening children's vision. This work was supported by NSF grant IIS-0113310.



26.) H. Kuniba and R. S. Berns, “Spectral sensitivity optimization of color image sensor considering photon shot noise,” *Proc. SPIE Electronic Imaging Conf*., in press (2007).

27.) Z. Li and R. S. Berns, “Comparison of methods of parameric correction for evaluating metamerism,” *Color Research and Application,* **32**, 293-303 (2007).

28.) C. Liu and M.D. Fairchild, “Re-measuring and modeling perceived image contrast under different levels of surround illumination,” *IS&T/SID 15th Color Imaging Conference*, Albuquerque, 66-70 (2007).

29.) M. Nezamabadi, R. S. Berns and E. D. Montag, An Investigation of the effect of image size on the color appearance of softcopy reproductions using a contrast matching technique, *Proc. SPIE***, Vol. 6493**, 649309 (2007).

30.) S.-H. Park and E.D. Montag, Evaluating tone mapping algorithms for rendering non-pictorial (scientific) high-dynamic-range images, *Journal of Visual Communication and Image Representation*, **18,** No. 5, 415-428 (2007).

31.) S. Quan, N. Katoh, N. Ohta, M.R. Rosen, “Method and System for Optimizing a Selection of Spectral Sensitivities,” *US Patent* 2007; **7236195**.

32.) G. Ramanarayanan, J.A. Ferwerda, B.J. Walter and K. Bala, “Visual Equivalence: towards a new standard for image fidelity,” *ACM Transactions on Graphics. (SIGGRAPH ’07)*, 76, 1-11, (2007).

33.) G. Ramanarayanan, K. Bala and J.A. Ferwerda, “Dimensionality of visual complexity in computer graphics scenes,” *Proceedings SPIE Electronic Imaging ’08 (Human Vision and Electronic Imaging)*, in press (2008).

34.) M. Sakurai , R.L. Heckaman, M.D. Fairchild, T. Nakatsue and Y. Shimpuku, “Relationship between color appearance and color gamut of the display,” *ITE/SID 14th International Display Workshops*, Sapporo, in press (2007).

35.) A. Sarkar, M.D. Fairchild and C. Salvaggio, “Integrated daylight harvesting and occupancy detection using digital imaging,” SPIE/*IS&T Electronic Imaging*, San Jose, in press (2008).

36.) S. Tsutsumi, M.R. Rosen and R.S. Berns, “Spectral color reproduction using an interim connection space-based lookup table,” *Proc. IS&T/SID Fifteenth Color Imaging Conference,* 184-189 (2007).

37.) S. Tsutsumi, M.R. Rosen and R.S. Berns, “Spectral Gamut Mapping using LabPQR,” *Journal of Imaging Science and Technology*, in press (2007).

38.) S. Tsutsumi, M.R. Rosen and R.S. Berns, “Spectral color management using interim connections spaces based on spectral decomposition, *Color Research and Application*, in press (2007).

39.) P. Urban, D. Schleicher, M.R. Rosen, and R.S. Berns, “Embedding non-Euclidean color spaces into Euclidean color spaces with minimal isometric disagreement,” *Journal Optical Society of America: A*, **24**, 1516-1528 (2007).

40.) P. Urban, M.R. Rosen, and R.S. Berns, "Accelerating spectral-based color separation within the Neugebauer hyperplane," *Journal of Electronic Imaging*, 16(4) 043014-1-11 (2007).

41.) P. Urban and M.R. Rosen, "Inverting the Cellular Yule-Nielsen modified Spectral Neugebauer Model," *9th International Symposium on Multispectral Color Science and Application,* 29 – 35, (2007).

42.) P. Urban, M.R. Rosen, and R.S. Berns, "Constructing Euclidean color spaces based on color difference formulas," *Proc. IS&T/SID Fifteenth Color Imaging Conference,* 77-82 (2007).

43.) P. Urban, R.S. Berns, and R.-R. Grigat, "Color correction by considering the distribution of metamers within the mismatch gamut," *Proc. IS&T/SID Fifteenth Color Imaging Conference,* 222-227 (2007).

44.) P. Urban, M.R. Rosen, amd R.S. Berns, "Fast spectral-based separation of multispectral images," *Proc. IS&T/SID Fifteenth Color Imaging Conference,* 178-183 (2007).

45.) D.R. Wyble and D.C. Rich, "Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments. Part I: Repeatability," *Color Research and Application*, **32**,166-175 (2007).

46.) D.R. Wyble and D.C. Rich, "Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments. Part II: Inter-Instrument," *Color Research and Application*, **32**, 176-194 (2007).

47.) D.R. Wyble, "Color Measurement," *The Focal Encyclopedia of Photography*, Fourth Edition, 2007.

48.) D.R. Wyble, Consulting Editor, "Colorworks", *Odyssey Magazine*, December issue, (2007).

49.) D.R. Wyble, "Color by Computer," *Odyssey Magazine*, December issue (2007).

50.) H. Zhang, H. Peng, M.D. Fairchild and E.D. Montag, "Hyperspectral image visualization based on a human visual model," SPIE/*IS&T Electronic Imaging*, San Jose, **6806**, 68060N (2008).

51.) Y. Zhao and R.S. Berns, "An investigation of multispectral imaging for the mapping of pigments in paintings," *Proc. SPIE Electronic Imaging Conf*., in press (2007).

52.) Y. Zhao and R.S. Berns, "Predicting the spectral reflectance factor of translucent paints using Kubelka-Munk turbid media theory: Review and evaluation," *Color Research and Application*, in press (2007).

53.) Y. Zhao and R.S. Berns, "Image-based spectral reflectance reconstruction using the Matrix R method," *Color Research and Application*, **32**, 343-351 (2007).

MCSL Students

Current Graduate Students

Justin Ashbaugh, mc
Stacey (Emery) Casella , mc
Ying Chen, mc
Ben Darling, pc
Susan Farnand, pc
Erin Fredericks, mi
Rodney Heckaman, pi
Sunghyun Lim, pc
Chengmeng Liu, pi
Stefan Luka, mc
Mahnaz Mohammadi, pi
Mahdi Nezamabadi, pi
Jonathan Phillips, pc
Jim Proper, pi
Nannette Salvaggio, mc
Abhijit Sarkar, mc
Shizhe Shen, mc
Lawrence Taplin, pc
Mark Updegraff, mc
Yang Xue, mi
Hongqin Zhang, pi
Yonghui Zhao, pi

Visiting Researchers

Andreas Kraushaar, *FOGRA*
Ichiro Katayama, *Miyagi Univ.*
Hideyasu Kuniba, *Nikon*
Philipp Urban, *Hamburg Univ.*

Alumni of Graduate Programs

2007
Kenneth Fleisher, mc
Jiangtao Kuang, pi

2006
Yongda Chen, pi
Zhaojian Li, mc
Joe Stellbrink, mc

2005
Maxim Derhak, mi
Tim Hattenberger, mi
Jim Hewitt, mi
Justin Laird, mc
Erin Murphy, mc
Yoshio Okumara, mc
Michael Surgeary, mi

2004
Rohit Patil, mc
Sung Ho Park, mc
Xiaoyan Song, mc

2003
D. Collin Day, mc
Ellen Day, mc
Scot Fernandez, mi
Ed Hattenberger, mc
Steve Jacob, mi
Xiaoyun Jiang, pi
Garrett Johnson, pi
David Robinson, mi
Mitchell Rosen, pi
Deniz Schildkraut, mc
Qun Sun, pi

2002
Arturo Aguirre, mc
Jason Babcock, mc
Anthony Calabria, mc
Jen Cerniglia Stanek, mi
Scot Fernandez, mc
Jason Gibson, mc
Shuxue Quan, pi
Yat-ming Wong, mi

2001
Alexei Krasnoselsky, mc
Lawrence Taplin, mc
Sun Ju Park, mc
Michael Sanchez, mi
Barbara Ulreich, mi

2000
Sergio Gonzalez, mc
Sharron Henley, mc
Patrick Igoe, mi
Susan Lubecki, mc
Richard Suorsa, mc

1999
Gus Braun, pi
Barbara Grady, mc
Katherine Loj, mc
Jonathan Phillips, mi
Mark Reiman, mc
Mark Shaw, mc
Di-Yuan Tzeng, pi
Joan Zanghi, mc

1998
Scott Bennett, mc
Fritz Ebner, pi
Garrett Johnson, mc
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David Wyble, mc

1997
Peter Burns, pi
Christopher Hauf, mc
Brian Hawkins, mc
Alex Vaysman, mi

1996
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Yue Qiao, mi
Jack Rahill, mi
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Seth Ansell, mc
Sue Farnand, mi

1994
Audrey Lester, mc
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James Shyu, mc

1993
Nathan Moroney, mc
Elizabeth Pirrotta, mc
Mitchell Rosen, mi

1992
Mark Gorzynski, mi
Taek Kim, mi
Rich Riffel, mi
Brian Rose, mc

1991
Yan Liu, mc
Ricardo Motta, mi
Amy North, mc
Greg Snyder, mi
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MCSL Advisory Board

The MCSL Advisory Board is an advisory group composed of industrial and academic experts in color science and color aesthetics. Their role is to insure that the activities of MCSL are in concert with industrial needs, to evaluate the degree programs in Color Science, to promote funding opportunities, and to provide employment opportunities to Color Science and Imaging Science graduates focused on color-related problems.