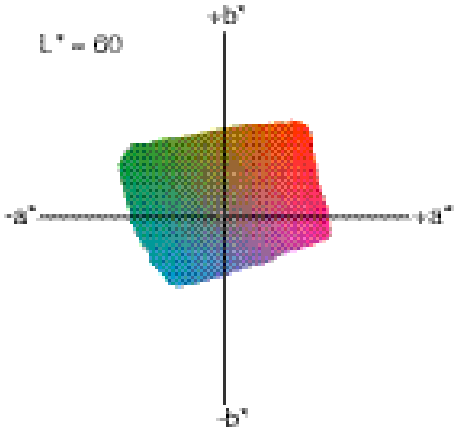
MCSL

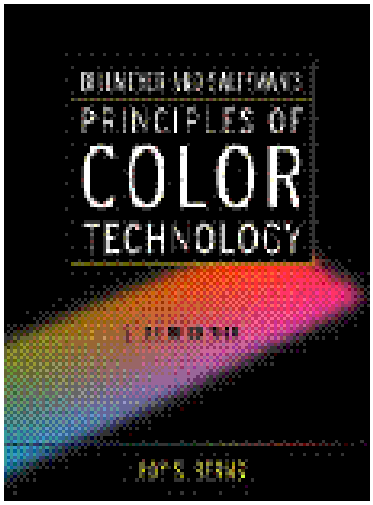
Munsell Color Science Laboratory

2000

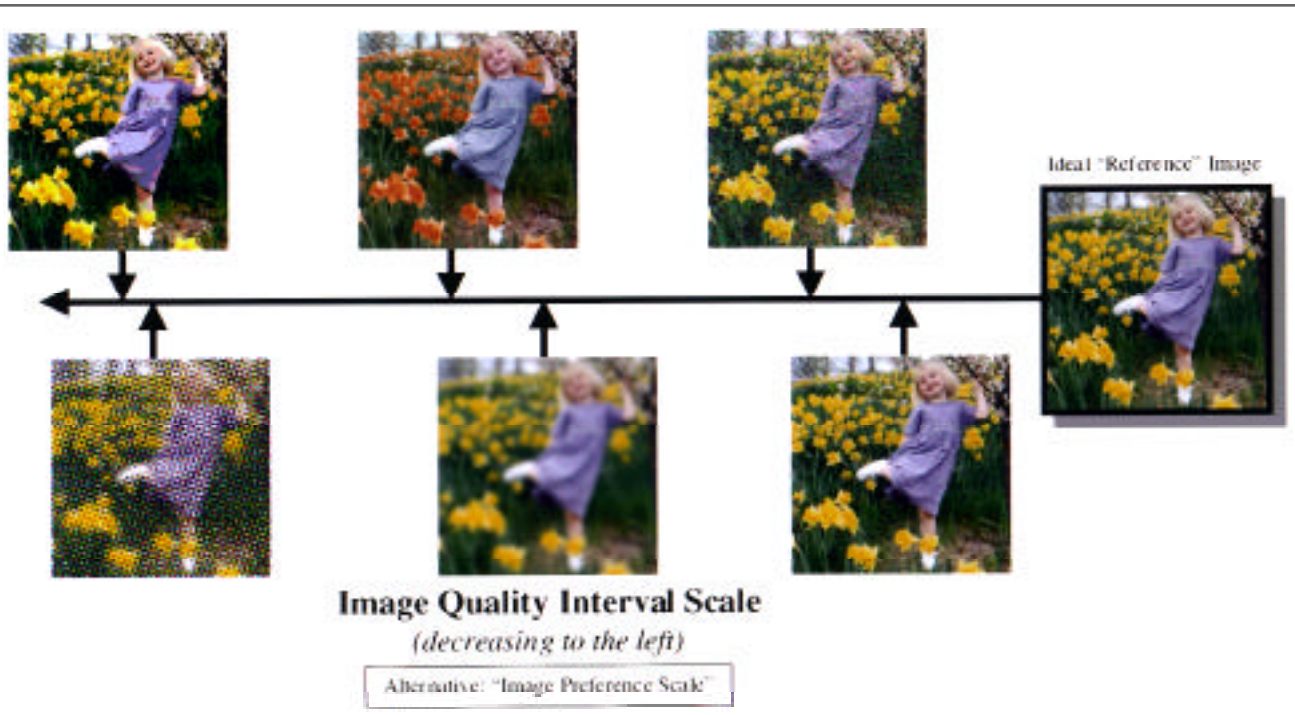
Annual Report

Inside Front Cover



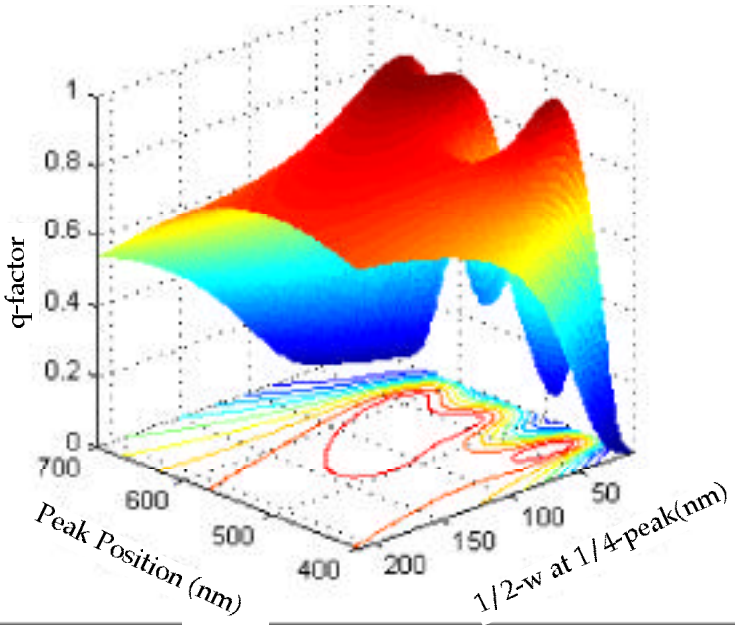


*CIELAB a*b* projection of the color gamut of the inks and paper used to produce* ***Billmeyer and Saltzman's Principles of Color Technology, 3rd edition*** *and its use in the cover design.*

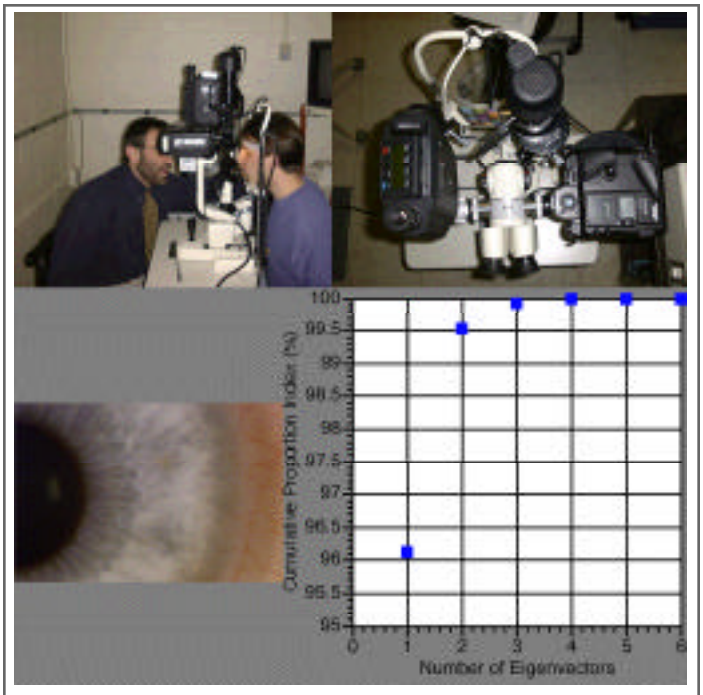


Concept of an interval scale of image quality that might be modeled using a spatially-tuned color difference metric (Pg. 21).

Inside Back Cover



Q-factor is one of a number of color quality factors being evaluated for deriving optimal spectral sensitivities for camera systems. This illustration is from Quan Shuxue's dissertation research. See inside back cover for additional interesting views and discussion from this project (Pg. 19).



Spectral Imaging of the Iris. Clockwise from top: Dr. Bill Fisher helping with image capture; the spectroradiometer and camera mounted on the ophthalmic microscope; eigenvector analysis of iris reflectances; image of iris (Pg. 21).

Munsell Color Science Laboratory
Overview & History

The Munsell Color Science Laboratory (MCSL) was established in 1983 after the dissolution of the Munsell Color Foundation, Inc. The aims and purposes of the Munsell Foundation as stated in its bylaws were "... to further the scientific and practical advancement of color knowledge and, in particular, knowledge relating to standardization, nomenclature and specification of color, and to promote the practical application of these results to color problems arising in science, art, and industry."

The following four basic objectives guide the activities of the Munsell Color Science Laboratory:

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.

Mark D. Fairchild has been Director of the Munsell Color Science Laboratory since 1996.

Richard S. Hunter Professorship

The Richard S. Hunter Professorship in Color Science, Appearance, and Technology was established in 1983 by a gift from Richard and Elizabeth Hunter. They recognized a need for perpetual education and research in this critical area.

Franc Grum was the first Hunter Professor and Director of MCSL from 1983 until his untimely death in 1985. He was a leader in the color science community and well-known for his work in colorimetric standardization and colorimetry of fluorescent materials. Roy S. Berns has been the R.S. Hunter Professor since 1987 and served as Director of MCSL from 1986 until 1996.

Xerox Professorship

The Xerox Professorship in the Center for Imaging Science was established in 1996 by a gift from the Xerox Corporation. Currently, the topical area for this position is Color Imaging Systems.

Noboru Ohta is the first Xerox Professor and has held that position since 1998. In this role he has founded the Color Engineering Laboratory within MCSL.

Who We Are

The Munsell Color Science Laboratory is made up of five faculty, seven staff, and approximately 30 graduate students and visiting scientists. Research in the laboratory falls into the general areas of appearance modeling and psychophysics, fundamental color science, color measurement, image reproduction, and color engineering. MCSLis made up of seven main laboratories devoted to research and education in these areas and housed in R.I.T.'s Chester F. Carlson Center for Imaging Science. Further information can be found throughout this report and by visiting our website at *www.cis.rit.edu/mcsl.*

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Director's Report

Mark D. Fairchild, Director, MCSL (716)457-2784, mdf@cis.rit.edu
Ph.D., Vision Science, University of Rochester, 1990.
M.S., Imaging Science, Rochester Institute of Technology, 1986.
B.S., Imaging Science, Rochester Institute of Technology, 1986.

As we turn our calendars to a new millennium at the beginning of 2001, we look back and realize that MCSL is fast coming upon its 18th birthday. While I was just an undergraduate student at the time, I can still vividly remember that day in 1983 when the lab held its inaugural conference. It is very hard for me to believe that so many years have passed. We are looking forward to an even bigger party in 2001 as Rochester hosts the quadrennial congress of the AIC in June and MCSL hosts the welcome reception for that congress with an open house on the RIT campus. We look forward to welcoming color enthusiasts from around the world to visit our facilities and enjoy western New York for a week. We are also looking forward to July when everyone in the lab will finally be able to take a well-deserved break.

We are fortunate that we have been able to maintain stable funding for our research and educational activities from a variety of industrial and government sources. These funding sources are acknowledged in our research and funding sections later in this report. One unique source of funding warrants special recognition however. RIT has instituted a program entitled First-in-Class aimed at developing certain areas of the University to the level that they are internationally recognized by industry as the premier source for education and research in that area. MCSL plays a key role in this initiative as both a focal point and a model for other laboratories. As part of this program, RIT has made a major investment in the MCSL infrastructure by providing a loan of funds to purchase an SGI Onyx2 graphics supercomputer. These funds will be repaid from the overhead on future grants over the next few years. The system features 8 CPUs, 8 GB of RAM, an InfiniteReality2 graphics subsystem, and over half a terabyte of disk storage. It was installed last spring and has already been used for research on image rendering, spectral image separation for multi-ink printing, visual modeling of sharpness, computation of image difference metrics, and optimization of camera responsivities. Excess CPU cycles are also used by other researchers in the Center for Imaging Science and artists in the computer animation program.

The new MCSL Summer School of Industrial Short Courses was run for the first time in 2000 and was an unqualified success. Attendance was excellent and the courses went better than we could have ever expected. Everyone enjoyed the new, hands-on, laboratory sessions. We will continue that format for our courses in 2001 and have added a new course taught by Noboru Ohta in addition to the courses offered last year. Our distance-learning activities also got underway this past fall. Students can now complete an Imaging Science M.S. (Color Imaging Track) through courses offered via the internet. Ethan Montag kicked off this effort by offering the *Vision and Psychophysics* course on-line this past fall. I am currently developing an on-line *Color Reproduction* course to be offered in the winter of 2001 and other color courses will be coming on-line soon. We are quite excited by this new way of teaching and the ability to reach students who are unable to come to Rochester for extended periods.

2000 saw several positive changes in the faculty and staff of MCSL. After an international search, Ethan Montag was appointed to a tenure-track Assistant Professor position in the Center for Imaging Science. While Ethan's responsibilities and activities won't change too much from his previous Research Assistant Professor position, this is an important appointment for his long-term career and the stability of color science education at RIT. Francisco Imai has also transferred to a new position. After a very successful term as a Post-Doctoral Fellow with the lab, Francisco has now joined our staff as a Senior Color Scientist. In this role, Francisco will continue his research work, develop funding opportunities, interact with labora-

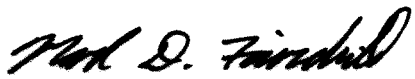
tory supporters and collaborators around the world, and take on some educational roles. Lastly, Colleen Desimone has made a major shift in her career as well. After more than a decade of holding the lab together, producing all our publications, coordinating our summer courses, etc., Colleen has moved into a professional position as the MCSL Outreach Coordinator. In this role, Colleen will be responsible for MCSL publications, recruiting, the summer school, visiting scientists, and other related activities. To cover all those other activities that Colleen used to take care of, we created a new MCSL Staff Assistant position. Val Hemink joined the lab in late 2000 as our new Staff Assistant. Val is no stranger as she worked in the Center several years ago as the student records secretary. We are all happy to welcome Val to the MCSL family and also congratulate Ethan, Francisco, and Colleen on their new roles. Of course, we are also happy to welcome Roy Berns back from his successful sabbatical at the National Gallery of Art. All of these changes in the staff prompted the great office shake-up of 2000. No fewer than six of us somehow decided it would be wise to move our offices. This was particularly interesting since some of us had been in the same space since the building opened in 1989. When the music stopped we were all nicely settled in our new homes and we managed to come up with one more office to house the additional person. I am now in the office behind Val's in rooms 76-3270 and 76-3274. The new surroundings have provided a welcome bit of change for the lab and everyone seems to believe they are more productive in their new offices. Maybe we should all move more often?

As always, students are the lifeblood of the laboratory. And likewise they are continually renewing themselves. During the past year Arturo Aguirre, Sergio Gonzalez, and Sharron Henley, all completed their degrees and moved on to new opportunities. Their places were quickly filled by Jason Babcock, Anthony Calabria, and Ellen Day who joined the lab as new graduate students. We are also fortunate to have a number of visiting scientists with us in the lab. Kiyotaka Nakabayashi from Sony, Hirokazu Kasahara from Epson, Nobuhito Matsushiro from Oki Data spent time with the lab during 2000 and Yoshihiko Azuma completed his visit and returned to Tokyo Institute of Polytechnics.

2000 proved to be another exciting and productive year at MCSLand I'm sure that 2001 will be even better. I invite you to review the pages of this report to get an idea of what has transpired in the past year. Please also visit our web site at *www.cis.rit.edu/mcsl* for further information on last year's activities and current activities. If you find yourself in Rochester, please feel free to come by the lab and see what's happening.

I would now like to turn to some of my personal activities of the past year. My research activities are described on the research page, so I will focus on other things here. I did a fair amount of traveling while participating in conferences such as the ISCC 2nd Panchromatic Conference in Savannah in February, the Color Image Science 2000 Conference in Derby in April, and the 8th Color Imaging Conference in Scottsdale in November. I also made it to Easton, Boise, and San Francisco for various color science activities. (Fortunately my golf clubs accompanied me on several of these trips and I was able to play in Hilton Head, Boise, and Scottsdale.) My course teaching included the graduate courses *Image Rendering* in spring quarter, *Color Measurement Laboratory I* in fall quarter, and *Color Appearance* in winter quarter. I am also in the process of developing a distance-learning *Color Reproduction* course that will be offered for the first time over the internet in the 2001-2002 winter quarter. Development of the distance learning materials has proven to be a most rewarding and enjoyable challenge. I look forward to teaching this course. I also was an instructor in three of the courses (Principles of Color Technology, Vision and Psychophysics, and Color Appearance Models) during the 2000 MCSLSummer School. I will be participating in the same three courses this coming summer. The 2001 MCSL Summer School will take place during the week preceding the AIC Color 01 Congress in Rochester. Those combined with the co-located CIE meetings will make for a busy few weeks around MCSL (and a very quiet July!). Lastly, I taught two tutorials (Colorimetry and Color Appearance Models) at the 8th Color Imaging Conference.

As we move into 2001 looking forward to many new and exciting challenges in MCSL, I sincerely thank everyone involved with making the laboratory a success: our students, our staff, our faculty, and our generous sponsors. May you all have a happy and prosperous year.



Mark . Fairchild, Ph.D.
Director, Munsell Color Science Laboratory
mdf@cis.rit.edu

Richard S. Hunter Professor's Report

Roy S. Berns, Richard S. Hunter Professor, (716)475-2230, berns@cis.rit.edu
Ph.D., Color Science, Rensselaer Polytechnic Institute, 1983.
M.S., Textile Science, University of California at Davis, 1978.
B.S., Textile Science, University of California at Davis, 1976.

It's hard to believe that this time last year, I was writing my report from a cubicle deep within the bowels of the National Gallery of Art. Today, I am looking at a blue sky and snow-covered fields, a usual Rochester scene during January. During 2000, there were to two highlights. The first was the release of *Billmeyer and Saltzman's Principles of Color Technology* in March. I was in my Gallery cubicle evaluating digital camera colorimetric characterization data when the book arrived. I was afraid to open it, wondering about the color printing. To my delight, the color was quite reasonable. One of our graduate students, Mark Reiman, developed ICC-compliant profiles for the book as his graduate project. We are working on an article for *Color Research and Application* describing methods and performance. My greatest fear was a metameric pair, created by matching cyan, magenta, and yellow to a 50% black. Under fluorescent lighting, the pair was clearly a mismatch, but would it match under daylight? I ran to an entrance; it was raining – a perfect D65 kind of day. It matched!

The second highlight was the remainder of my sabbatical at the Gallery. The first quarter of 2000 was spent analyzing the colorimetric accuracy of digital cameras used in many American museums, archives, and libraries. This resulted in a review article about digitizing two-dimensional works of art, to be published in the Journal of Imaging Science and Technology. The second quarter was spent studying the optical properties of painting varnishes. This was a new research topic for me – my main experiment tool was image analysis. This was my first foray into imaging science. Fortunately, I was able to call on my many imaging colleagues for advice including Jon Arney, Peter Engeldrum, and Peter Burns.

Since returning to RIT during June, I have continued to research spectral color reproduction of works of art. We have a strong team of staff, Francisco Imai, Dave Wyble, and Mitch Rosen and students, Lawrence Taplin, JaeChul Shin, Collin Day, and Dan Lerner. Our printing research continues to be supported by DuPont iTechnology. Very soon, we will have our multi-channel visible spectral imaging supported by the Gallery. We hope to develop a prototype system to archive the spectral properties of paintings. We are also having discussions with other industrial sponsors. I am anticipating a long and fruitful research partnership with the Gallery during the next decade.

RIT has encouraged us to look for opportunities to patent intellectual properties. During 2000, I was co-inventor on two patents. The first is with Francisco Imai, "System and method for scene image acquisition and spectral estimation using a wide-band multi-channel image capture." The second is with Masayoshi Shimizu, a recent visiting scientist from Fujitsu, "Method for measuring a lighting condition and an apparatus thereof."

As always, I am very lucky to be associated with the Munsell Color Science Laboratory. My activities would not be possible without the financial support through the Hunter Professorship, industry, and personal contributions from Mrs. Elizabeth Hunter, and intellectual support from my students, colleagues, and staff. Thank you all very much. I would also like to acknowledge my new colleagues from the National Gallery of Art who have been very kind and welcoming.

Xerox Professor's Report

Noboru Ohta, Xerox Professor, (716)475-7061, noboru.ohta@cis.rit.edu
Ph.D., Applied Physics, Tokyo University, 1973.
M.S., Physical Chemistry, Tokyo University, 1968.
B.S., Chemistry, Tokyo University, 1966.

At close of the final year of the 20th century, I am quite happy to report that our laboratory, Color Engineering Laboratory (CEL), is now well organized and is still undergoing vigorous development. I describe below our activities according to the four primary roles I designated at the start of my tenure here at RIT. Our research activities will be described in detail in the research section on page 19.

Education: I opened my spring course again on *Color Reproduction Optimization Methods* for graduate students. Here I taught how to optimize spectral absorption bands of three subtractive color dyes. I introduced two criteria for the optimization: the area of obtainable color gamut and the stability of selective grays. My students implemented the optimization through extensive programming using IDL or MATLAB. I imposed nine to ten homeworks to my students and through these they learned the art of optimization. Arriving finally at the optimal absorption bands, my students found that the numerically derived ones were very close to those currently used in industry. Then they learned two things: the numerical optimization technique is very powerful and effective, and at the same time, the wisdom gotten from many long year's experience is not too bad.

Joint projects between RIT and industry: Relationships with Sony, Fuji Xerox and Epson continued to grow and bear fruit this year. Our ongoing project with Sony, "Optimization of Spectral Sensitivities," has produced a number of exceptional results. We have joined forces with Fuji Xerox to study "Spectral Image Processing." This becomes an important query as multi-channel imaging continues to gain interest in our field. We have also developed a joint research with Epson on the psychological evaluation of color images with the study of "photographic quality" in mind. This latter project is headed by Professor Ethan Montag, and accordingly the detail will be reported by him elsewhere. In addition, we proposed a number of new projects to industrial partners, old and new. Their details will be further elaborated next year. We have now a variety of research activities and in an attempt to fully make the most of them, we will pursue other friendly liaisons with industry. As such, we strive to incubate future projects for our research.

Disseminate our activities outside of RIT: We presented the results of our research to a number academic societies. I also made extensive lectures more than ten times both in the US and in Japan. These are reported in detail in research section of this report. We constantly make such efforts firstly in order to demonstrate our activities and to recruit excellent, ambitious students to our arena. Secondly, this is important in order to have a grasp of needs from industry. Without the proper knowledge for the industrial needs, we cannot appropriately take the helm and skillfully guide our research toward fruitful results.

Faculty and Student Exchange: Among Chiba University, University of Derby, and our Center for Imaging Science, we make up three of the world's most active institutions in academic imaging science. I have cooperated in helping to initiate a program of formal and informal faculty and, now, students exchange. This program may soon grow into joint certificate programs. This year we hosted a visit from Chiba University of Professors Miyake and Tsumura, and their two students, Mr. Ohishi and Mr. Tamura. They delivered three important and interesting lectures. Also according to the exchange program, I delivered two courses at Chiba University in the winter quarter. One was for undergraduate students on "Color Engineering" and the other was for graduate students on "Color Reproduction." We have also begun to involve graduate students in the exchanges. Mr. JaeChul Shin, a Ph.D. candidate at Chiba University, came to RIT and will stay until June 2001. He will attend our courses to learn imaging science and will also be involved in our research on multispectral color imaging systems.

Finally, it goes without saying that all these activities are only possible owing to a variety of support from the MCSL and CIS staff, the financial support from the Xerox Professorship, and a number of corporate sponsors. Taking this opportunity, I would like to heartily thank you all.

Faculty & Staff Activities

Jonathan S. Arney, Associate Professor, (716) 475-7322, jsapci@rit.edu
Ph.D., Chemistry, University of N.C., Chapel Hill, 1975.
B.S., Chemistry, Wake Forest University, 1968.

Most of my activities this past year focused on the undergraduate teaching program in CIS. A new curriculum for the undergraduate degree in Imaging Science is under development, and undergraduate recruiting activities have occupied a lot of time. As a result, most of the research and publishing has been delayed. The change of pace has been fun, with diverse projects ranging from helping undergraduate students mount a video transmitter to a kite, to developing and conducting workshops for high school science teachers. Over the past two years I have been involved in a new undergraduate course sequence in colorimetry and color reproduction. These courses have been extremely successful, especially with the recent publication of Roy's updated version of *Principles of Color Technology*, which has been adopted as the text for the course sequence.

I am still the Faculty Advisor for student chapter of the Society for Imaging Science & Technology. The student organization has been active organizing tours of faculty research labs so students better opportunities to see all the fascinating things going on in CIS. As faculty advisor for the RIT Amateur Radio Club, I have enjoyed working with students to add new digital capabilities to the club radio station. Needless to say, I also have taken the opportunity to combine my interests in radio and in imaging by getting both the imaging students and the radio club members involved in amateur radio television activities.

Although research has taken a back seat to curriculum issues over the past year, several projects have actually gone quite well. The most significant delay has been in finding time to write up all the things that have been going on. Work on the probability model of halftone optics continues to go well and is being combined with new concepts for generating halftones. I am collaborating with Prof. Peter Anderson, a faculty member in the Computer Science department at RIT. Peter has developed some fundamentally new concepts for processing image information and designing halftones. These new algorithms, based on a process he calls “Linear Pixel Shuffling” (LPS), presented at the October IS&T NIP-16 conference. The LPS process has significant potential for controlling spatial properties of halftones such as edge enhancement, noise power, and more. In addition, it may provide significant advantages in the repeatability of colorant delivery in various printing processes. These new algorithms are used to print actual test images, and my students and myself carry out the experimental characterization part of the project.

Professor Yoshihiko Azuma of Tokyo Polytechnical Institute spent the summer with me conducting joint research. He has been exploring new concepts in modeling halftone optics and thought there may be some connection between his halftone theory and our probability model. Prof. Azuma based his work on a principal component analysis (PCA) of reflection spectra at different c, m, and y dot fractions. The results of his work on magenta, for example, indicated the presence of three rather than two color components. In other words, in addition to the magenta spectrum and the paper spectrum, a third spectrum was required to rationalize the magenta component of halftone color reproduction. This same conclusion has been reached by Engeldrum (JIST, 38, 545(1994)), but Prof. Azuma demonstrated he could extract quantitative information about the spectrum of this third color component through PCA. Through our collaboration, we were able to show the third component to be identical to the third component predicted in our probability model (JIST, in press 2001). Our collaboration has been extremely fruitful, and we have two new manuscripts in preparation for submission to JIST on this work.

A somewhat unusual collaboration was started in the Fall of 2000 with Mr. Klaus D. Pollmeier, an Advanced Resident at the International Museum of Photography at Eastman House in Rochester. Mr. Pollmeier and I are developing digital imaging techniques for the analysis and documentation of the surface structure of historic photographic prints. The task is significant from an art historical perspective, and it certainly presents interesting challenges in imaging science. We anticipate a first publication by late spring of 2001.

Presentations:
Peter Anderson, J.S. Arney, and K. Ayer, “Linear Pixel Shuffling (I): New Paradigms for New Printers,” IS&T NIP-16 Conference, pg. 801, Vancouver, BC, October 2000.

J.S. Arney, Peter Anderson, K. Ayer, and P. Mehta, “Linear Pixel Shuffling (II): An Experimental Analysis of Tone and Spatial Characteristics,” IS&T NIP-16 Conference, pg. 807, Vancouver, BC, October 2000.

J.S. Arney, Peter Anderson, K. Ayer, and P. Mehta, “The MTF of Printing Systems,” IS&T NIP-16 Conference, pg. 367, Vancouver, BC, October 2000.

Colleen M. Desimone, MCSL Outreach Coordinator, (716) 475-6783, cmd9553@rit.edu
A.A.S., Business Administration, Rochester Institute of Technology, 1995.

After twelve years of adding new tasks to my list of responsibilities, I am proud to say this November I was promoted to MCSL Outreach Coordinator. Ultimately it was the success and growth of the lab that made this opportunity possible.

When I look back on this past year, I see a blur. That blur was me – literally running up and down stairs, to the copier, to the color printer, and to meetings. While juggling my everyday secretarial responsibilities, I spent a considerable amount of time re-designing the brochure and making preparations for the summer school, designing the AIC 01 congress final circular, managing and designing MCSL's quarterly *ChromaZone* newsletters plus two *Imaging Connection* newsletters. I am proud that I managed to make all my deadlines.

Overall, I am excited to have this new opportunity to focus on larger projects including, but not limited to the development and implementation of promotional activities for academic activities, industrial courses, and visiting scientist programs. As always, it is a pleasure to work with people who are like family.

Valerie Hemink, MCSL Staff Assistant, (716)475-7189, vlhpci@rit.edu

I just began working (part-time) for MCSL at the end of November. This past month has been spent trying to learn some of the things that Colleen did to support the needs of the Lab. I will be taking over many of Colleen's duties as she focuses on her new position as Outreach Coordinator. Although I am new to MCSL, I am not new to RIT. I began working here 9 years ago as a Records Secretary for the Imaging Science program. I moved over to the Gannett building three years later and stayed there for six years working with the Printing and Photography programs. After doing the same job for all those years, I found that it was time to move on to a new challenge and that's what brought me here. I hope my dedication and willingness to learn will prove to be an asset to the Lab.

My husband and I have three wonderful children ages 11, 8, and 5. The two oldest (boys) are football players for the Pop Warner division and our youngest (girl) hopes to be a cheerleader someday. They keep us very busy and we love every minute of it!

Francisco Imai, Sr. Color Scientist, (716)475-7842, imai@rit.edu
Ph.D., Imaging Science, Chiba University, 1997.
M.S., Electronics & Computer Eng., Technological Institute of Aeronautics, Brazil, 1993.
B.E., Electronical Engineering, Technological Institute of Aeronautics, Brazil, 1990.

After working three years as a post-doctoral fellow, I have a new position as a Senior Color Scientist. My main responsibility is research in color science and color imaging and software development. I've been working in the following research areas:

a) End-to-end multispectral reproduction from scene to hardcopy – I have been working in Multi-channel visible spectrum imaging (MVSI) with Roy Berns, Mitch Rosen, Dave Wyble and several students at MCSL. During the first half of the year I worked closely with Dave and DuPont, our sponsor, to extend Di-Yuan Tzeng's thesis on spectral-based printing color separation minimizing metamerism to more practical applications using ink-jet.

b) Comparison of spectrally narrow-band capture versus wide-band with a priori sample analysis for spectral reflectance estimation - I also worked with Mitch Rosen comparing the performance of two different approaches for multi-channel imaging. One of the approaches uses spectrally narrow-band capture and spectral reconstruction using linear transformation that presents robustness to any spectral shape. The other approach uses spectrally wide-band multi-channel imaging with a priori sample analysis for spectral reflectance estimation. This research was presented at the Industrial Associates Meeting in the fall and as a poster at the Color Imaging Conference in Scottsdale. Our poster was awarded the cactus award as best poster during this conference.

c) Spectral reflectance estimation of human iris from digital camera signals – since only colorimetric description of the human eye iris is available in the literature, I worked with Ethan Montag in cooperation with Dr. William Fisher from the Biomedical laboratory in order to sample spectral information from human iris and research a scheme to estimate the spectral reflectance of the human iris from digital counts provided by a digital camera.

Besides research, my current responsibilities also include developing worldwide relationships within the industrial, government, academia and nonprofit sectors to aid in securing significant research funding and work for research cooperation – Regarding building of relationships, it started in February with a visit to Polaroid with Mitch. In April I went to Xerox, Toronto with Prof. Noboru Ohta. On both occasions we presented our MCSL activities. After CIC, I started a tour, first at Sony US Research Labs in San Jose with Naoya Katoh and days later I presented our preliminary research on spectral compression at the Color Forum Japan 2000 in Tokyo. After that, I visited Japan research centers and universities related to my field of research. I attended a seminar at Prof. Miyake's Lab, Chiba University and then visited FujiFilm Ashigara Laboratories, Canon Musashi-Kosugi Laboratories, Nikon Digital Imaging Group at Nishi-Ooi, Sharp research group on liquid crystal displays in Tenri, Nara. In every visit I had opportunity to talk about our research at MCSL and meeting managers and scientists. Finishing the stay in Japan I visited two universities. A small symposium was organized by Prof. Toyooka at first Saitama University on spectral reproduction where I presented. Soon after I traveled to Aichi Province for the following day visit at Toyohashi University of Technology in Toyohashi where I spent a day visiting Prof. Usui and Dr. Nakauchi.

Having a role in the emerging three-way relationship between RIT, the University of Derby and Chiba University - As a cooperation with Chiba University, I made some joint research with Dr. Norimichi Tsumura while he spent 10 months as Visiting Assistant Professor at the University of Rochester. This collaboration resulted in a presentation, on medical vision, "Measurement of skin absolute spectral reflectance image and component its component analysis at the 47th Applied Physics Conference in Japan. Since September I have been working with a visiting student from Chiba University, our pre-doctoral fellow Jae-Chul Shin who has started his research on the noise aspects of digital camera systems.

In my new position I will have more activities in assisting the management of grants and contracts interacting with sponsors, advising graduate students and assisting the faculty in courses and seminars. Finally I would like to thank all the faculty, staff and students who have helped and supported my activities in the MCSL.

Ethan D. Montag, Assistant Professor, (716) 475-5096, edmpci@rit.edu
Ph.D., Experimental Psychology, University of California at San Diego, 1991.
M.S., Experimental Psychology, University of California, at San Diego, 1986.
B.S., Psychology, University of Pennsylvania, 1985.

The major focus of my efforts this past year has been working on the initiative the Center for Imaging Science started last year, as part of RIT's First-in-Class enterprise, to implement the Masters in Imaging Science, with a Color Imaging concentration, as a distance learning program. After many weeks of meetings that brought the Center's faculty together with the staff at the Educational Technology Center, the campus organization that coordinates the distance learning program, and scheduling within the Center, the work began. The development of the courses was a labor-intensive effort that occupied the whole summer. This fall the program kicked off by offering *Linear Image Math I* and my course, *Vision & Psychophysics*. Both courses successfully completed the quarter with a dozen students in the math course and 5 students in mine. We hope to grow on our success in the coming year.

In addition to my DL course, I concurrently taught the local version of *Vision & Psychophysics* and *Color Science Seminar*. I would like to thank Francisco Imai (and welcome him as a staff scientist) for helping me with this course by giving the exemplary presentation at the start of the quarter in *Color Science Seminar*.

As usual the *Color Science Seminar* provided an opportunity for our students to prepare presentations relating to their upcoming thesis work and other diverse areas of color science. Currently I am also co-teaching *Color Perception*, an undergraduate psychology class, with Eriko Miyahara.

This was the first year that I participated in the Munsell Color Science Laboratory Summer School of Industrial Short Courses. The format of the courses was revamped this year with restructured and added courses. With Mark Fairchild, I taught the course on vision and psychophysics. Mark concentrated on the psychophysics while I lectured on the human visual system. As with the other short courses, practical laboratories were used to give hands-on examples of the concepts presented in the lectures. As it is stated elsewhere in this report, one goal of MCSL is to provide education in color science and to liaise with industry. These short courses not only provide such opportunity but also will bring students into the program through interest in the Distance Learning Imaging Science Masters program.

I would like to welcome Roy Berns back from his sabbatical. Although acting as coordinator of the color science program had its rewards, I was happy to return the mantle back to Roy. Thanks to Colleen for helping me with this job.

Late in November, I was happy to accept a position as a member of the tenure-track faculty of the Center for Imaging Science. I would like to thank the faculty and staff of the Lab for their support during the application process. I look forward to continuing my work here in the Center and especially the Munsell Color Science Laboratory in this new position.

Lisa A. Reniff, Color Specialist, larpci@rit.edu
M.S., Color Science, Rochester Institute of Technology, 1989.
B.S., Chemistry, Rochester Institute of Technology, 1986.

This past year I have continued to work on a limited basis, mostly from home (isn't technology wonderful?!). I continue to do support work for our courses, such as preparing presentation materials. Presently I am involved in preparing material for our distance learning *Color Reproduction* course. On the whole, life is good.

Mitchell Rosen, Sr. Color Scientist, (716)475-7691, rosen@cis.rit.edu
M.S., Imaging Science, Rochester Institute of Technology, 1994.
B.S., Computer Science, Tufts, 1984.

This was a very busy and productive year here at the Munsell Lab. As in previous years, my technical energy was mainly focussed on a number of projects involving spectral color reproduction. I continued to investigate methods of narrow bandwidth multi-channel image capture as well as data-efficient system designs and I explored approaches to spectral image processing. Noboru Ohta, as always, has been a great support and collaborator for these researches. Assisting him in his Xerox Chair and Color Engineering Lab activities is a primary and pleasant part of my position. On behalf of Roy Berns, a state-of-the-art image capture system was specified and acquired. Mark Fairchild foresaw the need for a spectral image visualization tool. The ongoing development of this platform, *Spectralizer*, has been a lot of hard and fulfilling work. I expect *Spectralizer* to be useful in my breadboarding of spectral color management approaches. Among the more interesting administrative tasks I undertook was participating in the filing of several patents. Of interest, two patents from my previous position at Polaroid were also granted this year. I enjoyed my interaction with laboratory sponsors, both current and potential. We were successful in bringing in a number of new projects and I'm highly optimistic about several on the horizon. And, it is with pride that I say that we saw a good deal of success in continuing to build closer relationships with a number of our key institutional peer laboratories around the world.

Our new image acquisition system is called the *Hunter Camera* because it was primarily purchased through funds from the Hunter Chair. The *Hunter Camera* consists of a 6 Mega-pixel, 5 MHz cooled Photometrics Quantix camera with a blue-enhanced imaging chip, a Cambridge Research Instruments 10nm bandpass

high-contrast tunable filter (range 400nm to 720nm), a computer controlled filter wheel, and a dual-processor industrial portable computer to accompany the camera into the field. We have also acquired a quarter-terabyte RAID to support the system. Lights and filters are among components still to be purchased. In addition to Roy, funding for portions of the system came from Noboru Ohta, Roger Easton and Mark Fairchild.

The Munsell Lab community afforded many opportunities for collaboration this year. I worked closely with Francisco Imai on a number of projects including spectral image capture and spectral image compression. A paper we co-authored along with Roy Berns won the "Cactus Award" for being voted best poster at the Color Imaging Conference in November. I also had the pleasure of co-authoring conference articles this year with Dave Wyble, Garrett Johnson, Nobuhito Matsushiro, Mark Fairchild, and Noboru Ohta. Dr. Ohta and I had an exciting time helping Shuxue Quan dissect a huge data set he had produced as part of his dissertation work. It is now revealing a universe of amazing details concerning the relationship between the spectral shapes of camera channel sensitivities and expected color quality. I've enjoyed working with Lawrence Taplin who has become an important member of the spectral imaging research team. Through his thesis work he has become point man on our multi-ink spectral hardcopy implementation. All-in-all the past year has seen the lab continue to be a fun and cohesive environment for color imaging research.

Pano Spiliotis, Assistant Color Scientist, (716)475-7188, pano@cis.rit.edu
B.S., Imaging Science, Rochester Institute of Technology, 1999.

This is my second year at MCSL and it seems like I just started. In the past year, I have started my MBA here at RIT and will be completing it in May 2001. I would like to thank the lab with their patience and consideration throughout this process.

We have completed the upgrades of the computer facilities and will be upgrading our instrumentation and other lab equipment in the up coming months. In the past year, I have continued to help the marketing of the Color Science graduate program and I have also joined the undergraduate recruitment team. I am pleased that I can bring my marketing experience to the lab.

Dave Wyble, Color Scientist, (716) 475-7310, wyble@cis.rit.edu
M.S., Color Science, Rochester Institute of Technology, 1998.
B.S., Computer Science, SUNY Brockport, 1992.

Over the past year the focus of the lab as a center of spectral imaging expertise has really taken form. I have continued to participate in the spectral printing part of the imaging chain, now working with Lawrence towards his thesis. The concept of a complete spectral color reproduction system is exciting, and I am very glad to have a role in its development. Where this journey will lead us no one can fully guess, but it will be one of constant questions, problems, and solutions, not to mention frequent successes.

Looking externally, several of us have continued to put significant effort into the upcoming AIC Color 01 congress in Rochester next June. It will be hard to forget the week I spent up to my knees in Final Circulars! It was a lot of tedious work crammed into a few days, but this is an important event, and it was satisfying to know that the information made it out on time. That work is far from over, however, and I think those weeks in June are likely to be the most frustrating and satisfying that I will experience for some time.

Again this year I have the pleasure of teaching the freshmen *Programming for Imaging Science*. I think that experience has helped me get a better picture of the Center as a whole, and I really enjoy this aspect of my work here. For winter quarter 2000, I am also teaching the graduate course, *Computing for Imaging Science*. Graduate students definitely pose a different kind of challenge to the instructor! As for the rest of my job, I continue to be stimulated on a daily basis. For that, I thank all of the faculty, staff, and students in the Munsell Lab and CIS as a whole. The unique environment with its continual learning makes easy to come to work each day.

Visiting Scientists

Hirokazu Kasahara, Visiting Scientist, Epson Research & Development, Japan
Researching with Dr. Noboru Ohta

I have spent one year as visiting scientist in MCSL. It is great pleasure to study and research here. The staff has deep knowledge of color science, vision and psychophysics and the students are very active and eager in their studies. All of the color science courses I attended were full of clearly understandable materials, useful, and appropriate information. In addition to the courses, the discussion with faculty and students is also valuable. I want to thank everyone in MCSL. Only one thing I regret is my poor skill in English. If I were better at English, I could convey my ideas easier. During the rest of my time in MCSL, I will try to exchange views as much as I can.

I would like to touch on my research. I am working on image quality analysis with Dr. Montag and Dr. Ohta. In order to increase the image quality of printing I will construct image quality scales by using psychophysical techniques. Also I will measure physical values of image, e.g. sharpness and graininess, and make clear the relation between psychophysical scales and each physical value.

Kiyotaka Nakabayashi, Visiting Scientist, Sony Corporation, Japan
Researching with Dr. Mark Fairchild

I have spent four months in MCSLas a visiting scientist since the end of August. During this time, I have received a lot of useful information regarding basic and applied color science by participating in classes, having discussion with MCSL faculty, staff, students and colleagues. I would like to thank everyone who has supported my research.

The main focus of my research is concerned with "Lightness Rescaling using Black Point Adaptation". When the images are seen as softcopy on CRT monitor under the ambient light, the chromaticity of the black on the CRT screen is far from the achromatic axis because of the reflection of ambient light on the CRT monitors. If such a CRT monitor is the source device and printer is the destination device, the black of the CRT will be mapped the point which is far from the achromatic axis. However, the black of the CRT does not seem like such chromatic color. To overcome this problem, the black on the CRT screen should be mapped the black on the printer by the lightness rescaling function. I assume that the appropriate black point is located between the black on the CRT screen and the black on the printer; I am going to find the appropriate black point by the visual experiment.

In closing, I would like to thank Dr. Fairchild, Dr. Ohta, Sun Ju Park, Mr. Rosen and Mr. Kasahara for the discussions and advice. In addition, I cannot forget to acknowledge Colleen who gave me the perfect arrangements to visit here. Finally, I would like to thank the faculty, staff, and colleagues of the MCSLand Center for Imaging Science for helping me in my research.

Nobuhito Matsushiro, Visiting Scientist, Oki Data, Japan
Researching with Dr. Noboru Ohta

I am working with Prof. N. Ohta. My research subject is “Mathematical analysis of colorimetric problems based on information theory.” Last year, we have derived mathematical theorems and characteristics about subtractive color mixing problems and metamer spectrum crossing problems. These results will be presented this year. These results will contribute to many color engineering problems in my company.

There are many supreme professors and scientists at MCSL. RIT MCSL is the best place to study about color science in the world.

Graduate Students

Arturo Aguirre, Full-Time, M.S. GRADUATE, Color Science, 2000.
B.S., Chemical Engineering, ITESM Mexico, 1997.
Thesis Topic: Color Printing Modeling

Jason Babcock, Full-Time, M.S., Candidate, Color Science
B.S., Imaging & Photo Technology, Rochester Institute of Technology, 2000.

Anthony Calabria, Full-Time, M.S. Candidate, Color Science
B.S., Imaging Science, Rochester Institute of Technology, 1999.

Ellen A. Day, Full-Time, M.S. Candidate, Color Science
B.S., Imaging & Photo Technology, Rochester Institute of Technology, 2000.

Scot Fernandez, Full-Time, M.S. Candidate, Color Science
B.S., Imaging & Photographic Technology, Rochester Institute of Technology, 1999.
Thesis Topic: Image Color Preference Reproduction

Jason Gibson, Full-Time, M.S. Candidate, Color Science
B.S., Imaging Science, Rochester Institute of Technology, 1994.
Thesis Topic: Color Tolerances on Various Image Displays

Sergio Gonzalez, Full-Time, M.S. GRADUATE, Color Science, 2000.
B.S., Chemical Engineering, ITESM Mexico, 1997.
Thesis Topic: Fluorescence Colorimetry of Printing Materials

Sharron Henley, Full-Time, M.S. GRADUATE, Color Science, 2000.
B.S., Printing & Packaging Technology, West Herts College, England, 1997.
Thesis Topic: Color Appearance in Mixed Adaptation

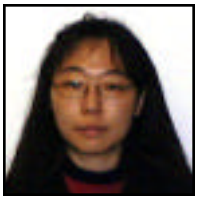
Pat Igoe, Part-Time, M.S. GRADUATE, Imaging Science, 2000.
M.S., Software Development & Management, Rochester Institute of Technology, 1996.
B.S., Computer Science, Rochester Institute of Technology, 1992.
Project Topics: Development and Analysis of Physiologically Based Color-Spaces Providing Uniform Color-Differences

Xiao-Yun (Willie) Jiang, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Optical Engineering, Beijing Institute of Technology, 1996.
B.S., Optical Engineering, Beijing Institute of Technology, 1993.
Thesis Topic: Computational Approaches to Color Vision

Garrett Johnson, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Color Science, Rochester Institute of Technology, 1998.
B.S., Imaging Science, Rochester Institute of Technology, 1996.
Thesis Topic: Measuring and Modeling Image Quality, Spectral Rendering

Alexei Krasnoselsky, Full-Time, M.S. GRADUATE, Color Science 2000.
Ph.D., Chemistry, Institute for Bioorganic Chem., Moscow, Russia, 1990.
Thesis Topic: Effects of Illumination Geometry on the Color Difference Judgements of Textured Color Samples

Susan Lubecki, M.S. GRADUATE, Color Science, 2000.
B.S., Mathematics and Computer Science, University of Notre Dame, 1984.
Project Topic: Verification of ICC Profiles



Sun Ju Park, Full-Time, M.S. Candidate, Color Science
M.S., Software Development & Management, Rochester Institute of Technology, 1997.
Thesis Topic: Black-Point Adaptation in Cross-Media Color Reproduction

Mitchell Rosen, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Imaging Science, Rochester Institute of Technology, 1994.
B.S., Computer Science, Tufts, 1984.
Thesis Topic: Spectral Color Management

Michael Sanchez, Part-Time, M.S. Candidate, Imaging Science
Rochester Institute of Technology, M.S., B.S., Ph.D., Chemical Engineering.
Project Topic: Brightness Perception of Chromatic Video Displays

Deniz Schildraut, Part-Time, M.S. Candidate, Color Science
Ph.D., Analytical Chemistry, University of Oklahoma, Norman 1982.
Project Topic: TBD

Quan Shuxue, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Optical Instrument, Beijing Institute of Technology, 1997.
B.S., Opto-Electronic Technology, Beijing Institute of Technology, 1994.
Thesis Topic: Spectral Sensitivity Optimization for Digital Color Imaging

Qun (Sam) Sun, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Physics, Flordia International University, 1997.
B.S., Electronic & Science Technology, East China Normal University, 1985.
Thesis Topic: Image-Based Spectral Rendering and Spectral Image Quality

Richard Soursa, Part-Time, M.S. GRADUATE, Color Science, 2000.
B.S., Imaging Science, Rochester Institute of Technology, 1987.
Project Topic: Evaluation of Retinex Algorithms

Lawrence Taplin, Full-Time, M.S. Candidate, Color Science
B.S., Computer Science, University of Delaware, 1996.
Thesis Topic: Spectral Modeling of Ink-jet Printer

Picture Not Available

Barbara Ulreich, Part -Time, M.S. Candidate, Imaging Science
B.S., Chemical Engineering, University of Syracuse, 1992.
Project Topic: Spatio-Temporal Analysis of Motion Picture Film Non-uniformities in Projection

JaeChul Shin, Visiting Pre-Doctoral Fellow from Chiba University
M.S., Imaging Science, Chiba University, 2000
Research Interest: Color Reproduction

MCSL Alumni

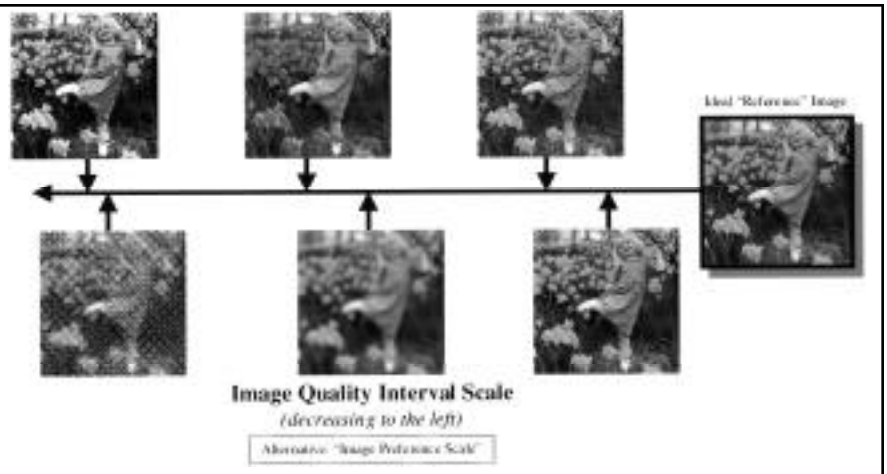
Arturo Aguirre, M.S., Color Science, 2000.
Seth Ansell, M.S., Color Science, 1995.
Richard Alfvin, M.S., Color Science, 1995.
Scott Bennett, M.S., Color Science, 1998.
Gus Braun, Ph.D., Imaging Science, 1999.
Karen Braun, Ph.D., Imaging Science, 1996.
Peter Burns, Ph.D., Imaging Science, 1997.
Cathy Daniels, M.S., Color Science, 1996.
Denis Daoust, M.S., Imaging Science, 1987.
Fritz Ebner, Ph.D., Imaging Science, 1998.
Mark Fairchild, M.S., Imaging Science, 1986.
Sue Farnand, M.S., Imaging Science, 1995.
Wayne Farrell, M.S., Imaging Science, 1987.
Sergio Gonzalez, M.S., Color Science, 2000.
Mark Gorzynski, M.S., Imaging Science, 1992.
Barbara Grady, M.S., Color Science, 1999.
Brian Hawkins, M.S., Color Science, 1997.
Christopher Hauf, M.S., Color Science, 1997.
Sharron Henley, M.S., Color Science, 2000.
Patrick Igoe, M.S., Imaging Science, 2000.
Garrett Johnson, M.S., Color Science, 1998.
Naoya Katoh, M.S., Color Science, 1998.
Taek Kim, M.S., Imaging Science, 1992.
Alexei Krasnoselsky, M.S., Color Science, 2000.
Audrey Lester, M.S., Color Science, 1994.
Yan Liu, M.S., Color Science, 1991.
Katherine Loj, M.S., Color Science, 1999.
Mitch Miller, M.S., Imaging Science, 1989.
Nathan Moroney, M.S., Color Science, 1993.
Ricardo Motta, M.S., Color Science, 1991.
Amy North, M.S., Imaging Science, 1991.
Jonathan Phillips, M.S., Imaging Science, 1999.
Kelvin Peterson, M.S., Imaging Science, 1989.
Jason Peterson, M.S., Imaging Science, 1994.
Elizabeth Pirrotta, M.S., Color Science, 1993.
Yue Qiao, M.S., Imaging Science, 1996.
Jack Rahill, M.S., Imaging Science, 1996.
Mark Reiman, M.S., Color Science, 1999.
Lisa Reniff, M.S., Color Science, 1989.
Rich Riffel, M.S., Imaging Science, 1992.
Brian Rose, M.S., Color Science, 1992.
Mitch Rosen, M.S., Imaging Science, 1993.
Mark Shaw, M.S., Color Science, 1999.
Hae Kyung Shin, M.S., Imaging Science, 1996.
James Shyu, M.S., Color Science, 1994.
Greg Snyder, M.S., Imaging Science, 1991.
Richard Soursa, M.S., Color Science, 2000.
Michael Stokes, M.S., Color Science, 1992.
Debra Seitz Vent, M.S., Imaging Science, 1994.
Di-Yuan Tzeng, Ph.D., Imaging Science, 1999.
Alex Vaysman, M.S., Imaging Science, 1997.
Dave Wyble, M.S., Color Science, 1998.
Joan Zanghi, M.S., Color Science, 1999.

Research - Mark D. Fairchild

Color Appearance and Image Quality

Over the past year, my research has continued to focus on the general theme of color image quality. However, the manifestation of that theme has appeared in a variety of ways that touch upon many aspects of color and imaging science. Overall, I am looking at ways to spectrally measure and specify scenes and images, model the human visual systems spectral, spatial, and cognitive responses to images, and verify this work through psychophysical experimentation. The research of each of the graduate students I am supervising is outlined below with the main research sponsor in parentheses.

Scot Fernandez (Xerox, NYSTAR) is working on an M.S. thesis to psychophysically determine observer preferences for color reproduction of printed pictorial images. Part his work will include collection of multicultural data in cooperation with the University of Derby and Chiba University. Jason Gibson (IBM Watson) performed M.S. thesis research on the perceptibility of color differences in complex images presented on various types of displays (LCD, CRT, and print). Jason presented this work at the 8th Color Imaging Conference and has since moved on to work with Hewlett Packard in Boise. Sergio Gonzalez (Labsphere) completed his M.S. thesis on bi-spectral spectrophotometry of fluorescent printing materials and presented his results at the CORM annual meeting and the Color Imaging Conference. Sergio has since returned to his company in Mexico. Sharron Henley (Canon Research America) completed an M.S. thesis examining chromatic adaptation in mixed illumination while comparing CRT displays with printed stimuli. Her results were presented at the Color Imaging Conference and she is now employed at Canon Research America. Garrett Johnson (Fuji Photo) has continued his Ph.D. dissertation research on the sharpness perception and modeling. Garrett presented some of his work at the 8th Color Imaging Conference. Garrett has also been actively involved in our research on spectral image rendering (Kodak and Pixel Physics). Sun Ju Park (Canon Research America) is currently working on an M.S. thesis on adaptation to the black point in image displays. Qun 'Sam' Sun (Kodak) has completed some preliminary research for his Ph.D. dissertation that will be presented at the SPIE OptoNE and AIC conferences during 2001. He has developed an algorithm for synthesizing spectral images of human portraits from 3- or 6-channel images and is analyzing the application of his approach to various skin types. I am also supervising a part-time student, Michael Sanchez (Xerox), who is working on an M.S. project on the Helmholtz-Kohlrausch effect.



Concept of an interval scale of image quality that might be modeled using a spatially-tuned color difference metric.

I have also been fortunate enough to have some time for personal research. I presented my work on the relationship between the perception of brightness and the contrast of variegated backgrounds at the ISCC 2nd Panchromatic conference in February. I have also just begun work on the design and construction of a digitally-controlled visual colorimeter that will be used for educational purposes as well as research on observer metamerism and transformability of primaries. I hope to have a functioning version of this instrument together before the AIC Congress in June. For more information on my research, publications, presentations, etc. please visit my personal web site at *www.cis.rit.edu/fairchild.*

Publications

M.D. Fairchild, "Human Visual System — Color Visual Processing," *The Encyclopedia of Imaging Science and Technology*, Wiley, New York in press (2001).

M.D. Fairchild, "Modeling Color Appearance, Spatial Vision, and Image Quality," *Color Image Science: Exploiting Digital Media*, Wiley, New York, in press (2001).

M.D. Fairchild, "ARevision of CIECAM97s for Practical Applications," *Color Res. Appl*., in press (2001).

K.M. Braun and M.D. Fairchild, "Psychophysical Generation of Matching Images for Cross-Media Color Reproduction," *Journal of the Society of Information Display* **8**, 33-44 (2000).

G.J. Braun and M.D. Fairchild, "General-Purpose Gamut-Mapping Algorithms: Evaluation of Contrast-Preserving Rescaling Functions for Color Gamut Mapping," *Journal of Imaging Science and Technology* **44**, 343-350 (2000).

C.M. Daniels, E.J. Giorgianni, and M.D. Fairchild, "Method and Apparatus for Achieving Color-Appearance Matching for an Image Viewed in Surrounds of Different Relative Luminances," *United States Patent* 6,046,723, Apr. 4, 2000.

D.R. Wyble and M.D. Fairchild, "Prediction of Munsell Appearance Scales Using Various Color Appearance Models," *Color Res. Appl*., **25,** 132-144 (2000).

D.R. Wyble and R.S. Berns, "ACritical Review of Spectral Models Applied to Binary Color Printing," *Color Res. Appl*., **25**, 4-19 (2000).

Invited Presentations
M.D. Fairchild, "Modeling Color Appearance, Spatial Vision, and Image Quality," Color Image Science 2000, Derby, 1-10 (2000).

M.D. Fairchild, "On the Perception of Brightness and Contrast of Variegated Backgrounds," ISCC 2nd Panchromatic Conference, Savannah, 26 (2000).

Presentations
M.D. Fairchild, "Status of CIE Color Appearance Models," AIC Color 01, Rochester, in press (2001).

M. Shaw and M.D. Fairchild, "Evaluating the CIE 1931 Color Matching Functions," AIC Color 01, Rochester, in press (2001).

M. Sanchez and M.D. Fairchild, "Lightness Appearance Matching Model, and Data, for the Re-Mapping of Chromatic Video Images to their Corresponding NTSC Gray Image Lightness Appearance," AIC Color 01, Rochester, in press (2001).

Q. Sun and M.D. Fairchild, "ANew Procedure for Capturing Spectral Images of Human Portraiture," AIC Color 01, Rochester, in press (2001).

Q. Sun and M.D. Fairchild, "Spectral Imaging for Human Portraiture," SPIE OptoNE and Imaging 2001, in press (2001).

G.M. Johnson and M.D. Fairchild, "Sharpness Rules," IS&T/SID 8th Color Imaging Conference, Scottsdale, 24-30 (2000).

S. Gonzalez and M.D. Fairchild, "Evaluation of Bispectral Spectrophotometry for Accurate Colorimetry of Printing Materials," IS&T/SID 8th Color Imaging Conference, Scottsdale, 39-43 (2000).

M. Rosen, M.D. Fairchild, G.M. Johnson, and D.R. Wyble, "Color Management within a Spectral Image Visualization Tool," IS&T/SID 8th Color Imaging Conference, Scottsdale, 75-80 (2000).

S. Henley and M.D. Fairchild, "Quantifying Mixed Adaptation in Cross-Media Color Reproduction," IS&T/SID 8th Color Imaging Conference, Scottsdale, 305-310 (2000).

J.E. Gibson, M.D. Fairchild, and Steven L. Wright, "Colorimetric Tolerances of Various Digital Image Displays," IS&T/SID 8th Color Imaging Conference, Scottsdale, 295-300 (2000).

N. Matsushiro, N. Ohta. M.Q. Shaw, and M.D. Fairchild, "Optimizing color-matching functions for individual observers using a variation method," IS&T/SID 8th Color Imaging Conference, Scottsdale, 357-360 (2000).

S. Gonzalez and M.D. Fairchild, "Evaluation of bispectral spectrophotometry for accurate colorimetry of printing materials," CORM Annual Meeting, Session IV: Measurements and Uncertainties in Color Measurements, Rochester (2000).

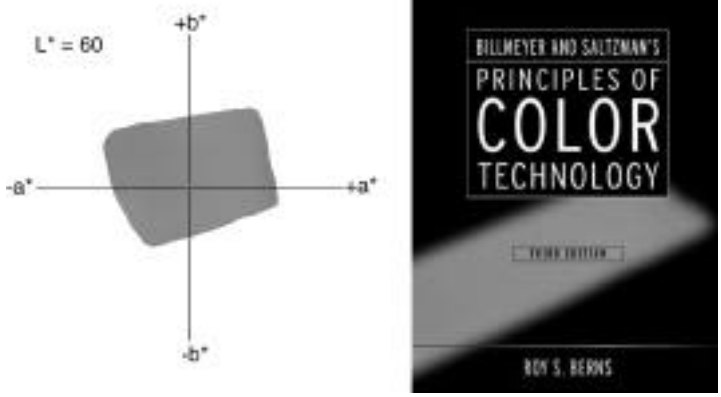
Research - Roy S. Berns

Multi-Spectral Image Acquisition

This year's research has concentrated on documenting and disseminating our research on spectral estimation from multi-illuminant or multi-filter trichromatic image capture. Francisco Imai and I have a patent pending on this technique. Francisco has been very busy writing articles and presenting conference papers, and visiting potential industrial sponsors. I have looked in detail at the spectral estimation accuracy of blue pigments often used by artists.

Spectral Printing Models

Research supported by DuPont iTechnology has been focused on end-to-end spectral color reproduction. This has integrated our multi-spectral image acquisition and spectral printing. We have been using both four- and six-ink ink-jet printing as our output media. This research has been challenging due to large amount of processing required for each pixel. Essentially, we are performing spectral matching using nonlinear optimization for each pixel of an image. We are continuing to look at ways to improve the efficiency of data processing as well as improving spectral accuracy. Papers were presented at the Scottsdale CIC conference.



*CIELAB a*b* projection of the color gamut of the inks and paper used to produce* ***Billmeyer and Saltzman's Principles of Color Technology, 3rd edition*** *and its use in the cover design.*

Color Management

For a number of years, I have been doing research that can be applied to building color profiles. Periodically, I have written overview articles about color management. This last year, I had the opportunity to test ICC-based color management with the publication of *Billmeyer and Saltzman's Principles of Color Technology*. With my graduate student, Mark Reiman, doing most of the work, images of color order systems, the spectrum, a metameric pair, and the book's color gamut were created. We are preparing an article for *Color Research and Application* describing this effort.

Art Conservation Science

While at the National Gallery of Art during my sabbatical, I was involved in two research projects. The first was using instrumental-based spectral color matching for pigment selection for inpainting. I described the technique at the ISCC annual meeting in Charlotte and at the Gallery. A paper was submitted to *Studies in Conservation*. I also have plans to present workshops at the Gallery this spring.

Painting varnishes affect the color and appearance of paintings predominantly by reducing surface roughness. Using slanted-edge MTF image analysis, research was performed to quantify the relationship between a varnish-resin's molecular weight and its ability to smooth a topographically non-uniform paint surface. A paper has been accepted for the PICS2001 conference and a manuscript is in preparation for *Studies in Conservation.* This research has been carried out with E. René de la Rie, head of scientific research at the Gallery. This year, a senior, Collin Day, is continuing to evaluate this technique.

Publications

R.S. Berns, *Billmeyer and Saltzman's Principles of Color Technology*, **3rd ed**., John Wiley & Sons, New York, 2000.

D.R. Wyble and R.S. Berns, "ACritical Review of Spectral Models Applied to Binary Color Printing" *Color Res. Appl.,* **25**, 4-19 (2000).

E.D. Montag and R.S. Berns, "Lightness Dependencies and the Effect of Texture on Suprathreshold Lightness Tolerances," *Color Res. Appl.,* **25**, 241-250 (2000).

F.H. Imai, R.S. Berns, and D.Y. Tzeng, "A Comparative Analysis of Spectral Reflectance Estimated in Various Spaces Using a Trichromatic Camera System," *Imag. Sci. Tech.* **44**, 280-287 (2000).

Invited Presentations

R.S. Berns, "Colorant Selection for Inpainting Using Visible Reflectance Spectrophotometry," Department of Conservation, National Gallery of Art.

R. S. Berns, "An Assessment of Imaging at the National Gallery of Art," Department of Conservation, National Gallery of Art.

Presentations

D.Y. Tzeng and R.S. Berns, "Spectral-Based Six-Color Separation Minimizing Metamerism," Proceedings IS&T/SID Eighth Color Imaging Conference, 342-347 (2000).

F.H. Imai, M.R. Rosen, and R.S. Berns, "Comparison of Spectrally Narrow-Band Capture Versus Wide-Band with a Priori Sample Analysis for Spectral Reflectance Estimation," Proceedings IS&T/SID Eighth Color Imaging Conference, 234-241 (2000).

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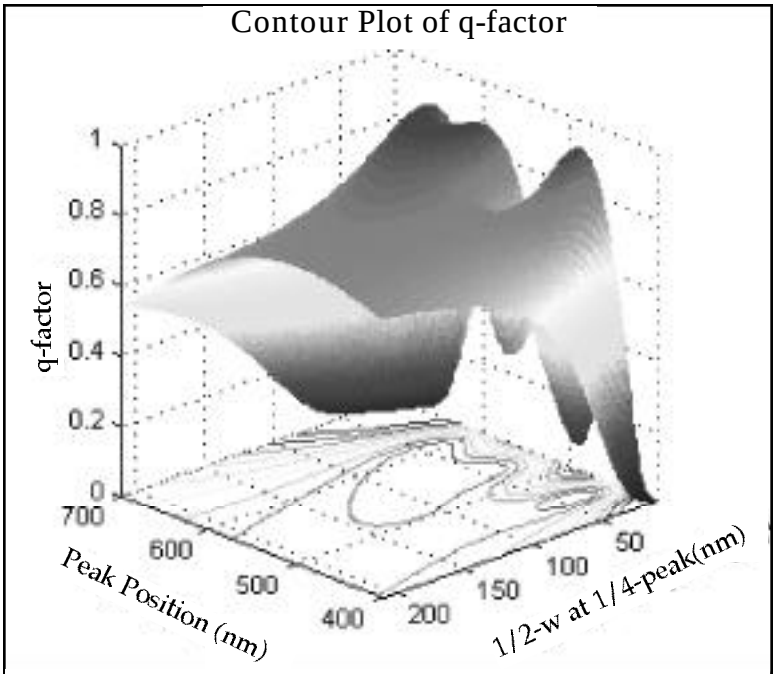
Research - Noboru Ohta

Spectral Color Management and Data-Efficient Imaging Spectrometry

Metamerism is a cumbersome problem in trichromatic color reproduction. In order to overcome this difficulty, topics in multispectral imaging have been under vigorous study and development. Mitchell Rosen is investigating multi-channel image acquisition and spectral image processing as his Ph.D. dissertation. He made some important progress for the image input part and his results have been filed as a basic patent. Progress on spectral color management was presented at the CIC meeting in Scottsdale under the title "Color Management within a Spectral Image Visualization Tool."

Optimization of Spectral Sensitivities of Color Imaging Devices

Quan Shuxue energetically continued the optimization of spectral sensitivities as his Ph.D. dissertation. He used a cubic spline function as a hypothetical standard spectral sensitivity. Then starting from the standard function, he systematically changed the peak wavelength, the width of spectral sensitivities and the amount of skewness in the curve. In the optimization, he used three classes of objective functions as a q-factor, a mu-factor, and a universal measure of goodness (UMG). He discovered that the solution is not unique but that only particular combinations of peak wavelengths, breadths and skewness give the optimal. The optimal ranges were obtained in a nine dimensional space and summarized on a series of two-dimensional graphical displays for simplicity. These results were quite surprising and they were filed as an important basic patent. After filing the patent, he presented three talks as shown below. His work will extend to take into consideration the system noise including that from CCD sensors.



Q-factor is one of a number of color quality factors being evaluated for deriving optimal spectral sensitivities for camera systems. This illustration is from Quan Shuxue's dissertation research. See inside back cover for additional interesting views and discussion from this project.

Estimation of Illuminants Irradiating Object Colors from Their Colorimetric Values

When reproducing color images from conventional or digital cameras properly, the information about the taking illuminant is of vital importance. The camera, however, does generally not record the information of taking illuminant. Xiaoyun Jiang (Willie) is carrying out a study, as her Ph.D. dissertation, to establish a novel algorithm for estimating the taking illuminant. As a first step, she calibrated a high-definition digital camera (Nikon D1) and she prepared a series of samples color images under illuminants of different color temperature. Then her second step was to review already existing algorithms and evaluate them by using her sample images. She planned to present a talk at PICS meeting to be held in Montreal in 2001. Apart from this, she tried to create a novel method. This algorithm was completely different from the existing ones and was very promising. She carried out a mathematical formulation of the algorithm and analyzed its implications.

Physical and Psychological Evaluation of Ink-jet Color Images

Our visiting scientist Hirokazu Kasahara under the leadership of Professor Ethan Montag carried this out. As such, the detail will appear in the report of Professor Montag.

Mathematical Analysis of Colorimetric Problems Using Information Theory
There are a number of problems in color science waiting for a sophisticated mathematical analysis. They are, for example, metamerism, color vision model, or line elements. Dr Nobuhito Matsushiro continued to be very productive in these fields. Particularly he proposed a new idea of "Orthogonal Illuminant" and studied theoretically characteristics of subtractive color mixing and color entropy based on metamers. The term "Orthogonal Illuminant" may be a bit misleading but it represents an illuminant that is most different from a given illuminant. A plethora of his research results were presented to a variety of academic society, as shown below, including PICS, CIC, IST meeting.

Publications
N. Matsushiro, "Ink Media Printer: Development Technology," Chapter 6, Technical Information Association, Japan (Aug).

N. Matsushiro and N. Ohta, "Theoretical Analysis of Characteristics of Subtractive Color Mixing," IEICE Jpn, IE2000-62.

Invited Presentations
N. Ohta, "Basis and Application of Color Engineering," Japan Industrial Engineering Center

N. Ohta, "Principles of Color Reproduction," Color Science Association of Japan

N Ohta, "Optimization of Color Reproduction: Past Results and Future Prospects," Xerox Canada

N. Ohta, "Color Reproduction System: Basis and Optimization," Society of Photographic Science and Technology Japan

N. Ohta, "Basis of Color Reproduction," Chiba Univ Symposium

N. Ohta, "Spectral Sensitivities of Color Reproduction Systems," Color Science Association of Japan

Presentations
S. Quan and N. Ohta, "Evaluating Quality Factors of Hypothetical Spectral Sensitivities," Proceedings of IS&T PICS Conference, 37-42, (2000).

S. Quan and N. Ohta, "Evaluation of Camera Spectral Sensitivities with Quality Factors," Proceedings of Society of Photographic Science and Technology Japan, 111-112, (2000).

S. Quan and N. Ohta, "Optimization of Camera Spectral Sensitivities," IS&T/SID 8th Color Imaging Conference, Scottsdale, 273-278, (2000).

M. Rosen, "Lippmann2000: A Spectral Image Database Under Construction," Multispectral Imaging Symposium, Chiba University.

M. Rosen, "Color Management within a Spectral Image Visualization Tool,"IS&T/SID 8th Color Imaging Conference, Scottsdale, (2000).

F. Imai, M. Rosen, R. Berns, N. Ohta, and N. Matsushiro, "Preliminary Study on Spectral Image Compression," Proceedings of Color Forum Japan, 67-70, (2000).

N. Matsushiro and N. Ohta, "Orthogonal Illuminant Model and Its Applications," IEICE Japan.

N. Matsushiro and N. Ohta, "Orthogonal Illuminate Model and Its Applications," IS&T 16th Non-Impact Printing Conference, (2000).

N. Matsushiro, "Illuminant Conversion by Using Iterative Variation Method," IS&T 16th Non-Impact Printing Conference, (2000).

N. Matsushiro and N. Ohta, "Orthogonal Illuminant Model and Its Application to Counting Metamers," IS&T/SID 8th Color Imaging Conference, Scottsdale, (2000).

N. Matsushiro, N. Ohta and M. Q. Shaw, "Optimizing Color Matching Functions for Individual Observers Using a Variation Method," IS&T/SID 8th Color Imaging Conference, Scottsdale, (2000).

N. Matsushiro and N. Ohta, "Color Entropy Based on Metamer Count and Its Applications," Proceedings of Color Forum Japan (2000).

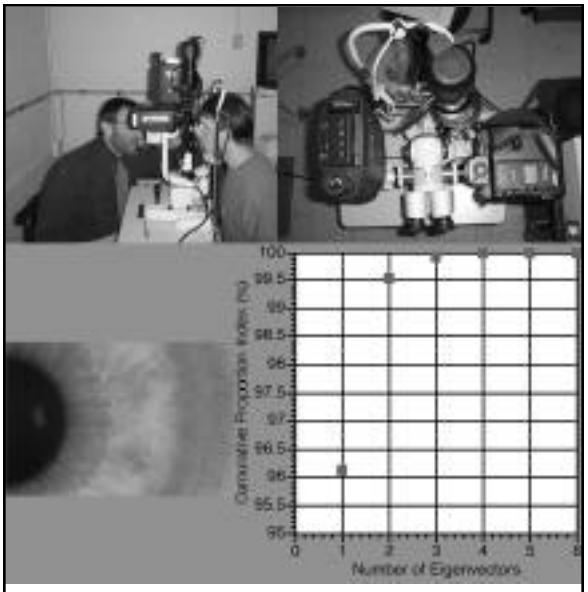
Research - Ethan D. Montag

Below is a summary of the research I have been involved in during the past year. I would also like to mention that during the past year I presented my work on the use of color in visualization at the ISCC Annual meeting in Charlotte. I am still very much interested in this area of research and hope to continue with it in the future.

Spectral Imaging and Rendering

This past year I was the PI on a project that involved spectral imaging and rendering of the human eye. This project was sponsored by Pixel Physics as part of the New York State CAT program. Various members of the laboratory participated in the different aspects of this project.

Francisco Imai worked on spectral imaging of the anterior human eye to obtain spectral images of the iris. The method involved a priori analysis of measurements of the human eye using a spectroradiometer in order to determine whether a small number of basis functions could be used to reconstruct reflectances. This result was used to determine how many channels were necessary for capturing the image using a digital camera.



Spectral Imaging of the Iris. Clockwise from top: Dr. Bill Fisher helping with image capture; the spectroradiometer and camera mounted on the ophthalmic microscope; eigenvector analysis of iris reflectances; image of iris.

Measurements and imaging were done using an ophthalmic microscope that allowed the mounting of a camera and spectroradiometer. Thanks to Bill Fisher at the biomedical photography lab in the School of Photography for allowing us to use the equipment and providing us with help, advise and student eyes. Analysis determined that three channels may be sufficient for reconstructing spectral images.

Garrett Johnson, a Ph.D. student, is working on an aspect of this project that involves extending his previous work on spectral rendering to spectral ray tracing of transparent objects. Dave Wyble is also contributing to this project through his expertise on the output end of the imaging chain.

Industrial Color Tolerance

In addition to publishing our work on the effect of texture on suprathreshold lightness tolerance and the measurement of lightness dependency in lightness tolerance, we completed a couple of new projects that continue the tradition of exploring color tolerance in the lab.

Alexei Krasnoselsky (now at Applied Science Fiction) completed his thesis entitled, Effects of Texture on Color Difference Evaluation of Surface Color. Alexei's thesis dealt with the parametric effect of texture on color difference using simulated textures created from high resolution photographs of textured plastic panels. In the first part of his thesis, he found that subjects were able to accurately match the average lightness of textured patches. In the second part of the thesis, tolerance thresholds were measured using an adaptive psychophysical procedure, for colors varying in hue, chroma, and lightness around five color centers. The results showed that hue tolerances increase in the presence of texture but chroma tolerances showed little effect. His results also confirmed the results found previously that the degree of texture can influence lightness tolerance.

Dave Wilber, a senior majoring in Imaging Science, completed his senior thesis with a project in which he compared two different psychophysical procedures used in determining tolerance thresholds. The Method of Constant Stimuli, a mainstay here at the lab, was compared to a grayscale comparison method that has been used in other laboratories. The findings indicated that although the results of the two methods were comparable within statistical limits, the Method of Constant Stimuli was easier to implement and the analysis was more straightforward (Probit analysis) yielding more reliable data (smaller error). In addition, subjects found this procedure easier to use and completed it more quickly. Dave's effort was rewarded with the Industrial Associates Research Poster Award at the end of the year.

Image Quality

This year I began a project sponsored by Epson Corporation to study image quality. The goal of the research is to use uni- and multidimensional scaling techniques to identify psychological dimensions of image quality and correlate them with physical measurements of images. I am working with Hirokazu Kasahara, a visiting scientist from Epson, on these experiments. Hiro has been working hard making measurements and running subjects while I have been concentrating on the psychophysical analysis of the data.

Publications

E.D. Montag and R.S. Berns, "Lightness Dependencies and the Effect of Texture on Suprathreshold Lightness Tolerance," *Color Res. and Appl.* **25**, 241-249, (2000).

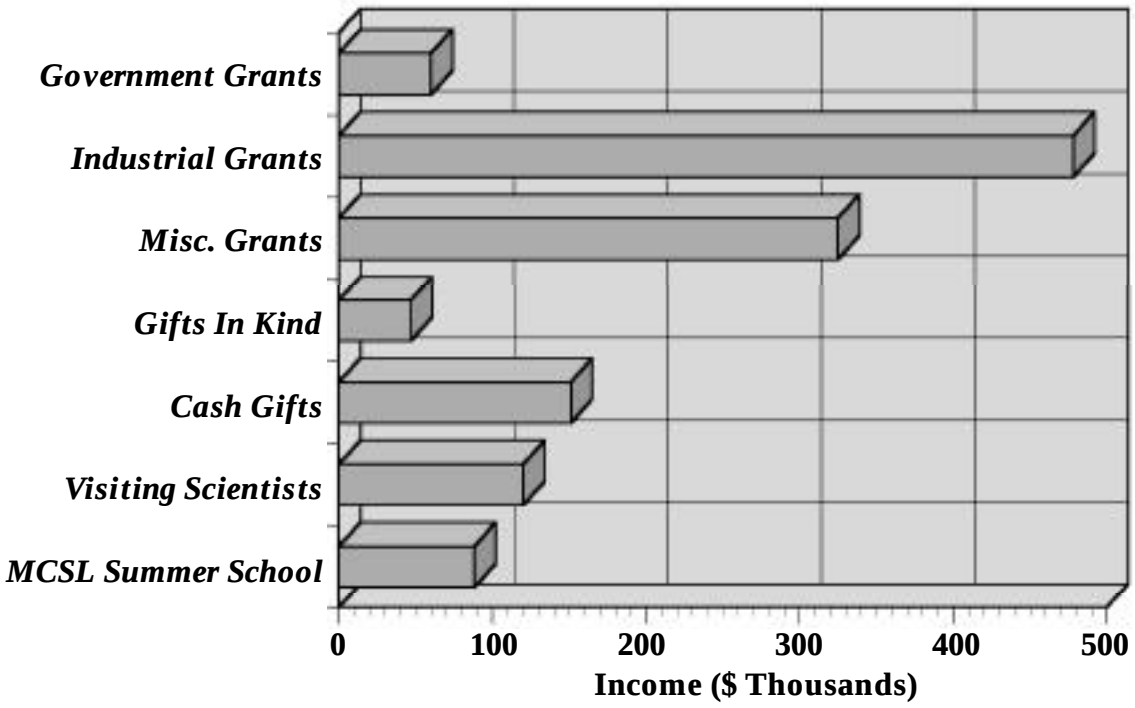
Presentations

E.D. Montag, "The Effect of Encoding Scheme on the Interpretation of Data Maps," ISCC 2nd Panchromatic Conference, Savannah, GA, (2000).

A.L. Krasnoselsky, E.D. Montag, and R.S. Berns, "Effects of Texture on Color Difference Evaluation of Surface Color." ISCC 69th Annual Meeting, Charlotte, NC (2000).

Funding

The total MCSL budget for 2000 was approximately $1.27 million (excluding the Hunter Chair, Xerox Chair, and Munsell Lab endowment income and faculty base salaries provided by RIT). As illustrated in the chart below, 50% of MCSLfunding is from industrial grants and gifts, 5% from government grants, and about 10% from visiting scientists support. The largest expenditures are for student, staff, and faculty salaries and benefits. Sources of grants, gifts, and equipment donations are acknowledged below.



Sources of Support

Gifts, Grants, and Other Donations

Canon Research America, Color Curve Systems, Cyberchrome, DuPont iTechnology, Eastman Kodak, Epson, Fuji Photo Film, Fuji Xerox, Fujitsu Laboratories, Hewlett-Packard, Mrs. Elizabeth Hunter, IBM Watson, Labsphere, Matsushita Research Institute (Panasonic), Nikon, NYSTAR-CAT, NSF-NYS IUCRC, Oki Data, Photo Research, Pixel Physics, PPG, Sony, Xerox.

Color Science M.S. Curriculum

Enrollment in the Color Science M.S. program during 2000 was 12 full-time and 5 part-time students.

Required Courses

Fall (Yr. 1)

1050-701 Vision and Psychophysics	4 Credit Hours
1050-702 Applied Colorimetry	4 Credit Hours
1050-721 Color Measurement Laboratory I	2 Credit Hours

Winter

1050-703 Color Appearance	3 Credit Hours
1050-722 Color Measurement Laboratory II	2 Credit Hours

Spring

1050-813 Color Modeling	4 Credit Hours

Fall (Yr. 2)

1050-801 Color Science Seminar	3 Credit Hours

Many of our students have interests in color imaging. The following is a typical schedule of available courses for full-time students. Other imaging courses are available as electives.

Color Imaging Course Track*

Fall (Yr. 1)

1050-701 Vision and Psychophysics	4 Credit Hours
1050-702 Applied Colorimetry	4 Credit Hours
1050-721 Color Measurement Laboratory I	2 Credit Hours

Winter

1050-703 Color Appearance	3 Credit Hours
1050-722 Color Measurement Laboratory II	2 Credit Hours
1051-726 Computing for Imaging Science	4 Credit Hours
Statistics Elective	3 Credit Hours

Spring

1050-813 Color Modeling	4 Credit Hours
1051-753-01 Color Reproduction: Optimization Methods (Systems)	4 Credit Hours
Statistics Elective	3 Credit Hours

Fall (Yr. 2)

1050-801 Color Science Seminar	3 Credit Hours

* If a student does not want the M.S. degree to concentrate in the color imaging area, other course options are available under advisement.

MCSL Summer School Course Descriptions

Monday June 18	Tuesday June 19	Wednesday June 20	Thursday June 21	Friday June 22	Saturday June 23
Course A Principles of Color Technology		***Course B - New Offering*** Optimization Techniques for Color Reproduction		***Course E*** Color Appearance Models	
		Course C Vision and Psychophysics		***Course F*** Device Profiles for Color Management	
		Course D Instrumental-Based Color Matching		***Course G*** Color Reproduction	

Each course consists of two days of morning lectures followed by afternoon hands-on laboratory experiences, instructed by experienced RIT-MCSL faculty.

Principles of Color Technology, Roy Berns and Mark Fairchild

This course introduces basic colorimetry through derivation of the CIE tristimulus system, color spaces such as CIELAB, and color difference equations including CIE94, CIE2000, and CMC. Instrumentation and methods for evaluating measurement accuracy and precision are introduced. Colorimetry is used in fields as diverse as coatings, textiles, automobiles, plastics, and image reproduction. It is safe to assume that any colored product has undergone some form of colorimetric evaluation in its manufacture or use.

Optimization Techniques for Color Reproduction, Noboru Ohta and Mitch Rosen

High quality color imaging systems such as television, printing and photography require optimal spectral characteristics for each system component. This course introduces the use of numerical optimization for determining these characteristics. Optimization techniques currently employed in the industry are explored through interactive discussions and intensive in-class programming assignments plus one "homework."

Prerequisites: Principles of Color Technology (or equivalent) and strong competency in a favorite scientific programming package such as MATLAB or IDL. *Participants must bring laptop with programming environment already installed.*

Vision and Psychophysics, Ethan Montag and Mark Fairchild

An overview of the structure, function, and performance of the human visual system and a detailed introduction to visual psychophysics are provided. Virtually every color or imaging task produces an object to be viewed and evaluated by human observers. Understanding human vision and psychophysical techniques are essential for measuring human visual response. Psychophysical experiments allow quantitative measurement of visual perceptions and have use in areas such as color tolerances, image quality and algorithm evaluation.

Prerequisites: Principles of Color Technology (or equivalent)

Instrumental-Based Color Matching, Roy S. Berns

Colorists are aided in matching colors through automated systems built upon colorimetry, color physics, and computer science. Color mixing laws such as Kubelka-Munk theory are used to choose colorants and determine amounts for matching a standard. This course covers basic concepts of color mixing for transparent and opaque materials, spectral and colorimetric matching, and colorant identification. Hands-on laboratories expose the importance of the colorant database and attaining least metameric matches.

Prerequisites: Principles of Color Technology (or equivalent), familiarity with Microsoft Excel (or equivalent).

Color Appearance Models, Mark Fairchild
This course provides a detailed review of the CIECAM97s color appearance model. Also covered are the fundamental phenomena and techniques of color appearance modeling. These models extend basic colorimetry to the prediction of color matches and appearance across widely varying viewing conditions. Advances in open systems for electronic image reproduction have accented the need for accurate and efficient color appearance models to promote transformations across media and viewing conditions.
Prerequisites: Principles of Color Technology (or equivalent)

Device Profiles for Color Management, Roy Berns and Mitch Rosen
Device profiles incorporate device characterization, color gamut mapping, and color appearance models. This course focuses on device characterization techniques and their incorporation into an ICC-compatible device profile. Various characterization techniques are explored such as direct measurement, multi-dimensional interpolation, multiple-linear regression, and analytical modeling. Laboratories provide experience in profiling a variety of input and output devices.
Prerequisites: Principles of Color Technology (or equivalent), familiarity with matrix algebra.

Color Reproduction, Jonathan Arney
The basic principles behind the detection and reproduction of color are modeled within an idealized Maxwell Color Copy System consisting of five generic functions: capture, processing, transmission, processing, and output. Several color reproduction systems including TV, color film, electrophotographic copy machines and various hybrid systems are dissected in terms of these functions. The impact on color reproduction quality of chemical and/or physical subsystems is examined with specific attention given to output mechanisms, including CRT, continuous tone film, and halftone printing.
Prerequisites: Principles of Color Technology (or equivalent)

2000 Industrial Short Course Report

MCSLhas been teaching industrial short courses since it's inception. Each year the course information was updated to take advantage of the newest educational technologies and ensure topical relevance. However, over fifteen years, courses became mostly lecture with demonstrations rather than hands-on laboratories. Although the format was effective, we sensed that participants would prefer a hands-on approach. We surveyed past course participants and consulted with our Advisory Board. Everyone agreed that a change was in order.

During the year MCSL faculty and staff worked diligently to re-design the format where we would offer lecture and hands-on experience in the our laboratories. Due to the hands-on portion, the courses have limited enrollment. Additionally, we invited other faculty members to join our efforts and expand the areas of expertise offered. This resulted in six different courses and seven possible course combinations. As we anticipated, the registration was overwhelmingly high. All the courses filled and we actually had to turn participants away.

Facilities

The Munsell Color Science Laboratory is very fortunate to be one of the world's most well-equipped laboratories for color science research and education. The estimated value of the instrumentation, computers, materials, and literature in the laboratory is in excess of two-million dollars. Much of the equipment has been donated or loaned by our many industrial sponsors over the laboratory's history. The equipment is housed in seven large (and several smaller) laboratories within R.I.T.'s Chester F. Carlson Center for Imaging Science. A complete list of MCSL facilities is available upon request. A brief explanation of the function of the seven large laboratories is given below.

76-3215 MCSL Main Laboratory
This laboratory houses the main meeting facilities for classes and general-purpose spectrophotometers, color order systems, materials, light booths and the MCSL library. Adjacent rooms are dedicated to cross-media image reproduction research, image I/O, spectroradiometry, and color modeling research and education.

76-3111 Optical Radiation Measurement Standardization Laboratory
This laboratory includes high accuracy spectrophotometers, material standards, a spectroradiometer, and a research goniospectrophotometer.

76-3105 Color Image Perception Laboratory
The color image perception laboratory is dedicated to psychophysics research and houses SGI workstations for interactive image display, an image projection area, and a custom-built room for critical viewing of prints and comparison with other displays.

76-3234 Spectral Color Reproduction Laboratory
Research in this laboratory is aimed at spectral-based input, processing, and printed output. The goal is to create an end-to-end color reproduction system in which original objects and their printed reproductions match spectrally. The main objects of interest are cultural heritage.

76-3150 Color Engineering Laboratory (CEL)
This facility houses a variety of state-of-the-art color imaging devices and high-end computational platforms used to support research in imaging systems simulation and other related work.

76-A110 Imaging Materials Laboratory
The imaging materials laboratory provides areas for chemical analysis of various colored materials, inks, dyes, substrates, *etc.*

76-A120 Image Microstructure Laboratory
This laboratory houses a microdensitometer, microscopes, black and white and color microscopic analysis cameras and various output devices for the study and measurement of the microstructural properties of hard-copy imaging media.

Publications

The following is a list of previous articles published by faculty, staff, and students of the Munsell Color Science Laboratory.

1999

J.S. Arney, E. Pray, and K. Ito, "Kubelka-Munk Theory and the Yule-Nielsen effect on Halftones," *J. Imag. Sci. and Technol*, 43(4), 353 (1999).

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D. Y. Tzeng and R. S. Berns, "Spectral-Based Ink Selection for Multiple-Ink Printing II. Optimal ink selection," *Proceedings IS&T/SID Seventh Color Imaging Conference*, 182-187 (1999).

F. H. Imai and R. S. Berns, "A Comparative Analysis of Spectral Reflectance Reconstruction in Various Spaces Using a Trichromatic Camera System," *Proceedings IS&T/SID Seventh Color Imaging Conference*, 21-25 (1999).

P. D. Burns and R. S. Berns, "Quantization in mMultispectral Color Image Acquisition," *Proceedings IS&T/SID Seventh Color Imaging Conference*, 32-35 (1999).

F. H. Imai and R. S. Berns, "Spectral Estimation Using Trichromatic Digital Cameras," *Proceedings Intl. Sym. Multispectral Imaging and Color Reproduction for Digital Archives*, Chiba University, 42-49 (1999).

R. S. Berns, "Munsell Color Science Laboratory Industrial Color Difference Consortium – Current Initiative and Future Directions," *Proceedings ANTEC 99*, Plastics bridging the Millenium, SPE, 2873-2877 (1999).

D. Y. Tzeng and R. S. Berns, "Spectral Reflectance Prediction of Ink Overprints by Kubelka-Munk Turbid Media Theory," *Proceedings TAGA*, 682-697 (1999).

R.S. Berns, "Challenges for Colour Science in Multimedia Imaging Systems," in L. MacDonald and R. Luo, eds., *Colour Imaging: Vision and Technology*, John Wiley & Sons, England, 99-127, (1999).

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G.J. Braun and M.D. Fairchild, "Image Lightness Rescaling Using Sigmoidal Contrast Enhancement Functions," *Journal of Electronic Imaging*, **8**, 380-393 (1999).

G.M. Johnson and M.D. Fairchild, "Full-spectral Color Calculations in Realistic Image Synthesis," *IEEE Computer Graphics & Applications*, **19:**4, 47-53 (1999).

M.D. Fairchild, and G.M. Johnson, "Color Appearance Reproduction: Visual Data and Predictive Modeling," *Color Res. Appl.,* **24**, 121-131 (1999).

1998

M.D. Fairchild, *Color Appearance Models,* Addison-Wesley, Reading, Mass.(1998).

Y. Qiao, R.S. Berns, L. Reniff, and E.D. Montag, "Visual Determination of Hue Suprathreshold Color-Difference Tolerances," *Color Res. Appl.,* **23**, 302-313 (1998).

E.D. Montag and R.S. Berns, "Visual Determination of Hue Suprathreshold Color-Difference Tolerances Using CRT-Generated Stimuli," *Color Res. Appl.,* **24**, 164-176 (1998).

K. Iino and R.S. Berns, "Building Color Management Modules Using Linear Optimization I. Desktop Color System," *J. Imag. Sci. Tech.*, **42**, 79-94 (1998).

K. Iino and R.S. Berns, "Building Color Management Modules using Linear Optimization II. Prepress System for Offset Printing," *J. Imag. Sci. Tech.,* **42**, 99-114 (1998).

J.S. Arney and M.LAlber, "Optical Effects of Ink Spread and Penetration on Halftones Printed by Thermal Ink Jet," *J.*
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R.S. Berns and L.A. Reniff, "A Practical Technique to Diagnose Spectrophotometric Errors," *Color Res. Appl.,* **22**, 51-60 (1997).
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Technical Reports

The following is a list of MCSL Technical Reports written by faculty, staff, and students studying color science over the last five years. The purpose of these reports is to provide additional information on subjects that are not appropriate for journal publications, either due to their information content or their length.

- **Evaluation and Correlation of Color Discrimination Abilities,** Sun Ju Park, Scot R. Fernandez, Lawrence Taplin, June 2000.
- **Colorimetric Characterization of Three Computer Displays (LCD and CRT)**, J. Gibson and M. Fairchild, January 2000.
- **Multi-spectral Image Acquisition and Spectral Reconstruction using a Trichromatic Digital Camera System Associated with Absorption Filters, Part II Iterative Non-Linear Spectral Reconstruction**, F. Imai, September 1998.
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- **A Critical Review of Spectral Models Applied to Binary Color Printing**, D. Wyble and R. Berns, May, 1998.
- **Colorimetric Characterization of the Apple Studio Display (Flat Panel LCD)**, M. Fairchild and D. Wyble, July 1998.
- **The Spectral Modeling of Large-Format Ink-jet Printers**, R. Berns, A. Bose, and D. Tzeng, 1996.

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Ms. Paula Alessi
Eastman Kodak Company
1700 Dewey Ave.
Rochester, NY 14650-1907

Dr. David Alman
DuPont
P.O. Box 2802
Troy, MI 48007-2802

Dr. Fred W. Billmeyer, Jr.
1294 Garner Avenue
Schenectady, NY 12309-5746

Mr. Peter Engeldrum
Imcotek, Inc.
P.O. Box 17
Winchester, MA 01890

Dr. Henry Hemmendinger
438 Wendover Drive
Princeton, NJ 08540

Dr. Jack Hsia
National Institute of Standards and Technology
Bldg. 220 B-306 / Div. 534
Gaithersburg, MD 20899

Dr. Robert Hunt
Barrowpoint, 18 Millennium Close
Odstock Road, Salisbury,
Wiltshire, SP2 8TB England

Mr. Norbert Johnson
3M
3M Center 582-1-15
St. Paul, MN 08540

Mr. Rolf G. Kuehni
4112 Blaydes Court
Charlotte, NC 28226

Mrs. Joy Turner Luke
Studio 231
Box 18 Route 1
Sperryville, VA 22740

Dr. M. Ronnier Luo
University of Derby
Color & Imaging Institute
Kingsway House East
Kingsway
Derby DE22 3HL
United Kingdom

Mr. Calvin S. McCamy
54 All Angels Hill Road
Wappingers Falls, NY 12590

Dr. Yoichi Miyake
Dept. of Information and Image Sciences
Chiba University
1-33 Yayoi-cho, Inage-Ku, Chiba
263-8522, Japan

Mr. Ricardo Motta
PiXIM, Vice President
883 North Shoreline, C-200
Mountain View, CA 94043

Dr. Yoshinobu Nayatani
Oomori-cho 12-11, Nishinomiya
663-8023, JAPAN

Mr. Milton Pearson
16 Colleen Way
Pittsford, NY 14534

Dr. Joel Pokorny
University of Chicago
939 E. 59th Street
Chicago, IL 60637

Dr. Danny C. Rich
Sun Chemical Research
631 Central Avenue
Carlstadt, NJ 07072

Dr. Alan R. Robertson
National Research Council
Division of Physics
Ottawa, Ontario K1AOR6 Canada

Mr. Michael Stokes
Microsoft Corporation
One Microsoft Way
Redmond, WA 98052

Dr. Joann Taylor
Color Technology Solutions
2894 NW 127th Ave.
Portland, OR 97229-8386