



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 research and development in color and appearance,
- 3) To maintain the facility to perform spectrophotometric, colorimetric, and geometric measurements at the state of the art, and
- 4) To provide an essential ingredient for the success of the first three — namely, liaison with industry.

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. Dr. Berns' interests span colorimetry, color modeling, color tolerances, and image archiving and reproduction of artwork.

Who We Are

The Munsell Color Science Laboratory is made up of four faculty, three 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, and image reproduction. MCSL is made up of six 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 web site < <http://www.cis.rit.edu/research/mcsl> >.



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Director's Report



One year ago, I wrote my first report as Director of the Munsell Color Science Laboratory. As I said last year, 1996 was a year of significant change for MCSL. As I write my second report as Director, I look back at 1997 with two main thoughts; the changes we implemented in 1996 have been quite successful and we have quickly reached a rather stable state. Of course, those statements must be tempered with the reality that, by design, nothing is really stable at a university.

Our faculty and staff have remained almost completely stable through 1997 with one addition and no departures. Jon Arney and Ethan Montag have adjusted well to their new roles and associations with MCSL. We expect their impact on MCSL to continue to grow in the coming years. Dave Wyble has now completed a full year as a staff scientist. Now that he has survived the initiation to his new academic environment you should expect to hear a lot from him in the future years. Colleen Desimone and Lisa Reniff have remained, undaunted by a year's passing, in their positions as key members of the MCSL staff. Of course, Roy Berns and I haven't gone anywhere. I do want to welcome our one staff addition in 1997; Francisco Imai joined MCSL as a post-doctoral fellow working with Roy Berns.

One disappointment for 1997 is that we have yet to fill the open position of the Xerox Professorship in the area of color imaging systems. We hope that this position can be filled in the coming year and that whoever assumes this important role will work closely with MCSL.

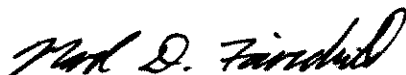
MCSL is housed within RIT's Chester F. Carlson Center for Imaging Science. As of September, 1997 Ian Gatley joined RIT as Director of the Center for Imaging Science. This makes Ian the new RIT administrator who directly oversees the activities of the MCSL faculty and staff (*i.e.*, he's my new boss!). I want to take this opportunity to welcome Ian to his new position and I look forward to working with him for many years to come. Ian, who himself is an astronomer, has already impressed the MCSL staff by taking the time from his hectic schedule to travel to the IS&T/SID Color Imaging Conference this past November so that he could meet the color imaging community and learn more about what we do. Now he knows why I really insist on spending a week each November in Scottsdale, Arizona. Welcome, Ian!

As usual, in more ways than one, MCSL would come to a grinding halt if it weren't for the students. I am happy to report that Peter Burns, Mihai Cuciurean-Zapan, Chris Hauf, Brian Hawkins, and Alex Vaysman each completed their degrees in the past year. Alexi Krasnoselsky and Mark Shaw have joined the laboratory as new graduate students during 1997. We all wish the recent graduates the best of luck and welcome the new students to the MCSL family. Akihiro Ito and Hideto Motomura, Akio Tsujita, Katsuya Itoh, and Shinya Yamaguchi spent some time during 1997 in the lab as visiting industrial scientists. Kazu Takemura and Koichi Iino completed their stays and returned to their "real jobs"; we wish them the best in the future.

The remainder of this report details the research, teaching, outreach, facilities, and external support at MCSL for the past year. I will not summarize them all again here, but I do want to comment that along all dimensions the lab is continuing along its plan of controlled growth while providing the highest-possible-quality experience for its graduate students. 1997 was a very successful year and we look forward to an even better 1998.

I now turn to some of my personal activities in the past year. As many of you know, I am currently on sabbatical leave. I spent the first half of the year at RIT, but have been at Cornell University as a Visiting Associate Professor since July, 1997. I will return to my full-time duties at RIT in September, 1998. Before I left RIT, I taught my *Color Appearance* course and a new course on digital color imaging called *Color Systems*. I will certainly be teaching the *Color Appearance* course when I return, but it is quite likely that whoever fills the Xerox Professorship will teach the *Color Systems* course in the future. The *Color Appearance* course should be made easier since my new book, *Color Appearance Models*, was published in November. Initial response to the book has been quite positive, but it remains to see how it will be received in 1998. I traveled to Japan for the second time to attend AIC Color 97 in Kyoto and the associated CIE meetings. The CIE meetings were highlighted by the agreement on a CIE color appearance model, CIECAM97s, within TC1-34, which I chair. You are sure to be hearing more about this event in the coming year. I also enjoyed some time to site see and renew old friendships during my trip to Japan. I also traveled to Baltimore for the ISCC annual meeting, a preview of the 1998 ISCC meeting that I am chairing and which will be held in Baltimore with the OSA annual meeting. In November I traveled to Scottsdale for the 5th IS&T/SID Color Imaging Conference and the 2nd CIE Experts Symposium on Standards for Color Imaging Technology. Both of these meetings went very well and provided a forum for the presentation of the new CIE appearance model. During the last half of the year at Cornell I have been concentrating on several research projects. These include development of some color appearance software, work on spectral image synthesis for imaging systems evaluation and color science education, reflectance measurement for material modeling and image synthesis, and the development of a model of spatial vision and adaptation for image reproduction applications. I hope you will hear more about the results of this work in the coming year. I am learning a great deal on my sabbatical and I am looking forward to its successful conclusion during the coming year. I expect to develop several collaborations with Cornell that should last a good number of years into the future.

Thanks again to everyone who has supported the activities of the Munsell Color Science Laboratory in any way during 1997. Our success would not be possible without the support we receive from industry and government and the hard work of our staff and students. Thank you all. For more information on our activities please visit the lab's web site at <<http://www.cis.rit.edu/research/mcsl>>.



Mark D. Fairchild, Ph.D.
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Richard S. Hunter Professor's Report



As the Hunter Professor, I have the privilege of defining my responsibilities in ways that best serve the color community. This past year I focused on education, both for the community and myself.

One tool is the classroom. Over time, my color courses at RIT have become more and more oriented towards imaging. I made a conscious effort to increase both the theoretical and non-imaging content. For example, where two years ago my colorimetry theme was analysis and synthesis stages of color reproduction, metamerism was the focus most recently. In the past, I have used continuous tone printers to teach Kubelka-Munk theory; I have switched back to mixing paints. I'm reminded of my freshman physics class where a number of physics principles were derived using the human ear, the professor's area of research. Twenty five years later, I remember the ear but not the principles. Finding a balance between principles and relevant applications is always a struggle.

I have spent time refining my imaging-oriented industrial training courses. I have continued to add numerical examples to try to bridge the gap between teaching and practice. I am also advising several part-time graduate students (John Moore, M.S. Computer Science and Sharon Kruger, M.S. Imaging Science) who are developing real-time computer demonstrations using Java. Our goal is to have interactive demonstrations that reinforce my colorimetry lectures. (This will require a switch from overhead transparencies to computer-controlled projection display.) If all goes well, my lectures will be improved and the demos will be available on the internet.

Publishing can be another educational tool. This year, my educational article was titled, "A Generic Approach to Color Modeling," published in *Color Research and Application*. I attempted to show the commonality between models used for materials and imaging. This article will be used to introduce the topic of color modeling.

The theory and practice of setting industrial tolerances has always been an important area requiring education. During May, I was invited to the Detroit Color Council to describe CIE94 and methods of optimizing tolerance ellipsoids.

International conferences are an educational vehicle, usually for myself. The AIC conference, held in Kyoto, was no exception. I learned about the Japanese culture, color tolerance equation development, color appearance models, and color management. I was asked to participate in a symposium on color management where I presented a paper describing the required steps to convert between device and profile-connection space coordinates. The process of writing the proceedings article and logically presenting the information has helped my understanding of color management immensely. (My impressions about the conference were published in the December issue of *Color Research and Application*.)

Other conferences I attended included the Inter-Society Color Council Annual Meeting held in Baltimore, the 5th IS&T/SID Color Imaging Conference held in Scottsdale, and the 2nd CIE Experts Symposium on Standards for Color Imaging Technology, also in Scottsdale.

Compared to traditional disciplines such as physics and psychology, color science is a challenge to market. The world-wide web has become a useful vehicle to educate the "world" about color science. Dave Wyble has brought my ideas to life with a personal web page describing the Hunter Professorship, conferences I attend, publications, and current research. My recent interest in digital photography has led to a gallery of famous color scientists, available on the MCSL home page. We are also working on improving the color science M.S. page. The MCSL page averages about 20 visits per week. Most of our curriculum inquiries originate from our web site.

As an educator, my primary job is to prepare the next generation of color and color-imaging scientists. The more I learn about the needs of the color community, the better prepared our students will be when they begin (or resume) their careers. This past year, I visited companies including Eastman Kodak, Hunter Laboratories, Hewlett Packard, Fuji-Xerox, Sony, Toppan, and Rockwell. They reinforced our educational philosophy and reminded me that the transfer of knowledge requires continuous commitment.

I hope to transfer knowledge to my full and part-time students who continue to persevere in their studies. Through their efforts, the entire color community benefits. They include: Scott Bennett, Doug Corbin, Greg Howell, Pat Igoe, Glenn Miller, Bob Poetker, Deepthi Sidavanahalli, Di-Yuan Tzeng, and Dave Wyble.

Mark has already pointed out that many faces have changed during the year. My first Ph.D. student, Peter Burns, completed his degree, joining the ranks of Dr. Burns'. I look forward to continued collaborations with Peter. Filling the mathematical void left by Peter is Di-Yuan Tzeng, also a doctoral student, who is quickly becoming the laboratory's expert on multivariate statistics. Di and I are working together to develop printing systems that yield spectral matches to original objects. For two and one half years, Koichi Iino of Toppan Printing and I have been working closely on developing spectral models of printing and incorporating them into color management systems. It was very sad to see Koichi and his wife, Junko, leave Rochester but our contact continues through the publication process. Before I could get lonely, visiting scientists from Panasonic (Hideto Motomura) and Fuji-Xerox (Akihiro Ito) arrived in time for Fall quarter.

I have been slowly building a research program whose ultimate goal is to develop a color reproduction system that is spectral based, thereby minimizing metamerism between original objects and their reproductions. During Fall, Dr. Francisco Imai, a recent graduate from Chiba University, has joined my research effort as a postdoctoral fellow. He will concentrate on image acquisition. With students and staff in place to attack this problem, significant funding and collaborations with the museum community are required. Through discussions with our new director, Dr. Ian Gatley, I have begun writing a proposal, "Multispectral Based Color Reproduction - Preserving National Treasures." The research will consider image acquisition, storage, retrieval, soft display, and hard copy through on-demand printing. We will work closely with one or more museums to insure the system is practical.

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.

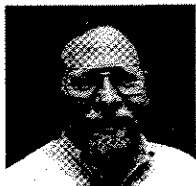


Roy S. Berns, Ph.D.
Richard S. Hunter Professor
berns@cis.rit.edu



Faculty & Staff Activities

Jonathan S. Arney, Associate Professor, (716) 475-7322, jsapci@rit.edu



MCSL plays an essential role in the Center for Imaging Science, and over the past year I have served both as an MCSL research scientist and as the program coordinator for the undergraduate academic program in imaging science. The coordinating job has taken lots of time, but the close ties between imaging science and color science at RIT have made the effort quite worthwhile. It also fits well with my responsibilities as the advisor to the Student Chapter of IS&T (Imaging Science & Technology). The student chapter has been particularly active this year with programs ranging from a mid-winter party, outings to the RIT observatory, fund raisers, and various service activities in support of RIT and the Center for Imaging Science. I also serve as an advisor to the campus amateur radio club and have enjoyed contributing to RIT and our students through a favorite hobby of mine. However, after a couple of sub-zero experiences on top of the student union building repairing antennas, I have decided it is time to play a more passive role in some activities of the radio club!

Professional activities have also kept me busy this year. I continue to play an active role in the Society for Imaging Science and Technology as a councilor in the Rochester Chapter. I also serve as liaison between the Rochester Chapter and the Student Chapter. On the national level I had the pleasure of chairing the IS&T Awards committee for 1997. With all the new activities I undertook this year I had to relinquish my duties as an associate editor of the Journal of IS&T. I miss working with the journal, but I still keep my hand in it by serving as a reviewer.

A particularly rewarding activity this year was service on a PhD student's examination committee. The student was Mr. Stefan Gustavson of Linkoping University in Sweden, and I was invited to go to Linkoping to serve as the "Opponent" to Stefan's PhD defense. My Swedish wasn't up to the task, but fortunately most of the proceedings were conducted in English! Stefan did a very fine job indeed, and his research advisor, Prof. Bjorn Kruse, has become a close friend and collaborator for us here at MCSL.

What does the future hold? Well, I hope it holds fewer committee responsibilities. This year I seem to have gotten in over my head. However, thanks to the hard work of several very good students, the research in the microstructures lab has continued to be quite successful. I look forward to the development of new instruments for color and spatial analysis of hard copy imaging systems in the microdensitometry laboratory, and plans currently will focus on electrophotographic systems. It looks like 1998 is shaping up to be a very active year for research.

Colleen M. Desimone, Secretary, (716) 475-7189, cmd9553@rit.edu



Time flies when you're having fun! That's how it is here for me. I can't believe another year has come and gone. I think time passes quickly for me because over the many years I have been given opportunities to grow and learn. I enjoy finding new projects that are challenging and educational. Therefore, my responsibilities have evolved and developed to encompass a wide variety of tasks for MCSL. Generally my annual projects are the same: annual report publication, *ChromaZone* newsletter (quarterly-except summer), summer shortcourse planning, inquiries for potential MS color students, and handling MCSL administrative responsibilities.

Each year I strive for improvement on a few designated tasks. Early last winter I worked hard and learned a lot in the process of publishing our first QuarkXpress annual report; it was a much needed change and I think it turned out well. In the early spring I was finalizing arrangements for the June short courses and finished just in time to put on my "visiting scientist coordinator hat" that kept me busy answering questions and making arrangements for our new visiting scientists and post doctoral fellow who arrived at the end of summer. As usual, I am thankful MCSL faculty and staff support and I look forward to new endeavors for the coming year.

Ethan D. Montag, Research Assistant Professor, (716) 475-5096, edmpci@rit.edu



This past year was my first full year with teaching responsibilities. It has been very challenging because it takes more time than I expected with deadlines for accomplishing something for every class. The best part, however, is getting to know each student individually.

Color Science Seminar was again very rewarding. We covered a wide variety of topics in the class that included many novel aspects of color that have not previously been discussed. This class is a great opportunity for the students and other faculty to broaden our knowledge and interests. It is also an opportunity to discuss the current directions of research in the lab. Teaching the Color Measurement Laboratory felt a little bit like being thrown into the deep end of the pool. One of the aims of this course is to develop the skills involved in carrying out lab research. One such skill is taking advantage of the local resources, *i.e.*, fellow student, staff, and faculty. Working together with the students, I learned a great deal and hopefully the students also learned that they are resources for each other and the lab.

At the time of this writing I am involved in team teaching an undergraduate psychology class on Motion and Depth Perception. This class is a new one in the Visual perception Track, a new option for psychology students. This has involved the development of the course from scratch.

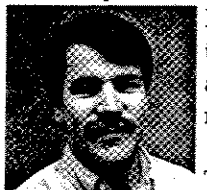
Lisa A. Reniff, Color Scientist, (716) 475-7188, larpci@rit.edu



It seems like as I get older the years fly by faster. I guess everything is relative (Weber's Law?). I have continued working in the Munsell Color Science Laboratory on a half-time basis, to give more time to my family. Sometimes I feel like I have a split personality. A large part of my responsibility in the laboratory can be grouped under the heading "care and feeding" of the laboratory. This includes helping students, fixing things that are broken and buying new equipment to satisfy our habit. This past spring, I was chosen

by the staff to be on the CIS Director Search Committee. Although the meetings were a bit time consuming, I gained satisfaction in being apart of the decision process, especially one that proved to be successful with the installation of our new Director, Ian Gatley. This academic year, with Mark being on sabbatical, I was given the additional tasks of teaching *Color Measurement Laboratory I* in the fall and keeping track of Mark's various grants and interests. As we enter in the new year I am refocusing some of my attention on bringing the instrumentation in the laboratory back up to snuff.

Dave Wyble, Color Scientist, (716) 475-7189, wyble@cis.rit.edu



My first year with the Lab went by very quickly! So much has happened, I find it difficult to compress everything to a paragraph or two. First, I want to thank everyone in the Lab and the Center for helping my in the transition to the academic environment. It was a major change in my life, but certainly a change for the better.

This year started with the installation of the IBM camera. That activity went well; the camera is now operational and Fransisco is beginning his research. After the camera work, I started familiarizing myself with many of the demos that have been used in the past. I spent some time organizing, documenting, and improving these. This is about done, but will continue to require minor adjustments. Another major task has been improving the integration of the Lab computers into the Center. This is not yet complete, but is ongoing with the help of the Center systems support staff. Another ongoing task is keeping the Lab web pages up to date. I think it is an important item, and I am glad to have the active support of Lab and Center people. Throughout the year, I have spent a lot of time towards the completion of my Color Science masters degree. I am happy to say this is now complete! I wish to thank everyone who helped this become a reality, but most especially Mark and Roy for their support and understanding through it all.



Francisco Imai, MCSL Post Doctoral Fellow, (716)475-7842, fhipci@rit.edu



I have been here at MCSL since I came to Rochester in the end of September after getting Ph.D. degree in Imaging Science from Chiba University, Japan. As a postdoctoral fellow in this laboratory, my research has been a project involving multi-spectral image capture that is a natural extension of a part of my doctoral dissertation about facial pattern image reproduction based on colorimetry and linear modeling techniques.

The main focus of my research is concerned with overcoming the limitations of low spatial resolution of current multi-spectral image acquisition and it can be achieved by combining low-resolution multi-spectral images with high-resolution conventional trichromatic images. In the fall, surrounded by beautiful natural scenes, I studied the bibliographical references related to my research and defined the experimental system, methodology and analyzed the parameters involved in the proposed experimental design. In winter I started the experiments by characterizing the high-resolution digital camera in order to achieve colorimetric accuracy. At the same time I have been studying image merging between low and high resolution images by optimization methodologies developed for multi-spectral remote sensing applications.

The lab has provided many opportunities for me to learn more about color science. I also attended the weekly Color Science Seminar in the fall in which I learned a great deal of many aspects of color research via discussions between faculty and students. So far the experience of working here has been very enriching both professionally and personally. In closing, I would like to thank the faculty, staff, students and colleagues for helping me in my research.

Faculty & Staff Credentials

Jonathan S. Arney

Ph.D., Chemistry, University of N.C., Chapel Hill, 1975.
B.S., Chemistry, Wake Forest University, 1968.

Roy S. Berns

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.

Colleen M. Desimone

A.A.S., Business, Rochester Institute of Technology, 1995.

Mark D. Fairchild

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.

Francisco Imai

Ph.D., Imaging Science, Chiba University, 1997.

M.S., Electronics and Computer Engineering, Technological Institute of Aeronautics, Brazil, March 1993.

B.E., Electronical Engineering, Technological Institute of Aeronautics, Brazil, December 1990.

Ethan D. Montag

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.

Lisa A. Reniff

M.S., Color Science, Rochester Institute of Technology, 1989.

B.S. Chemistry, Rochester Institute of Technology, 1986.

David R. Wyble

B.S., Computer Science, SUNY Brockport, 1992.

MCSL Technical Liasion List

AIC Color 2001 Rochester:

Fund Raising, *Roy Berns*, Chair

Publicity, *Dave Wyble*, Chair; *Colleen Desimone* and *Lisa Reniff*, Members

Technical Program, *Roy Berns* and *Mark Fairchild*, Members

ASTM E12, *Roy S. Berns*, Member.

CIE TC1-27, Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons, *Mark D. Fairchild*, Member, *Roy S. Berns*, Ex-Officio.

CIE TC1-34, Testing Colour-Appearance Models, *Mark D. Fairchild*, Chair.

CIE TC1-43, Rod Intrusion in Metameric Color Matches, *Roy S. Berns*, Chair.

CIE TC1-48, Revision of CIE Publication 15.2, Colorimetry, *Mark D. Fairchild*, Member.

CIE TC2-11, Gonioreflectometry of Standard Materials, *Roy S. Berns*, Member.

CIE TC2-28, Methods of Characterizing Spectrophotometers, *Roy S. Berns*, Member.

Color Research and Application, *Roy S. Berns*, Editorial Board.

ISCC Board of Directors, *Mark D. Fairchild*.

ISCC 1998 Annual Meeting, *Mark D. Fairchild*, General Chair

IEEE Transactions on Image Processing, *Mark D. Fairchild*, Associate Editor, Special Issue.

IS&T/SID Color Imaging Conference, *Mark D. Fairchild*, Technical Committee Member

Journal of Imaging Science and Technology, *Jonathan S. Arney*, Assistant Editor.

OSA Voting Delegate to ISCC, *Mark D. Fairchild*.

OSA Rochester Section Councilor, *Mark D. Fairchild*.



Visiting Scientists

Hideto Motomura, CIS Visiting Scientist, Matsushita Research Institute Tokyo, Inc. (Panasonic) Japan



I have spent five months in the Munsell Color Science Laboratory. During this time, I participated in Roy's class and Ethan's class to study color science, vision and psychophysics. These classes gave me many answers for what I want to know. The 5th Color Imaging Conference, which was held in Scottsdale, Arizona, was very exciting. I enjoyed my presentation, which is titled "Categorical Color Mapping for Gamut Mapping", through valuable advises by the MCSL.

I am making a research plan with Roy. I would like to design a practical color management system which is useful for the general public. Current color management system is available on the limited condition. For example, the already existing CRT characterization is useful only in a dark room. A CRT, however, is viewed under some lightings. Moreover, a printer driver, a scanner driver, a color rendering software, etc., have a lot of parameters to control color quality. Color optimization of device driver or rendering software, however, is so complicated for amateur users. To solve these problems, I would like to develop new device characterization method and new device connection method which are useful for the general public under typical office/home lighting condition according to the following procedures: estimation of existing models for device characterization, development of new device characterization model, estimation of existing models for device connection, and development of new device connection method. On my research into device connection, I would like to focus on gamut mapping technique and chromatic adaptation.

There are a lot of research terms as mentioned above. So, it might be very hard to carry out every thing but the MCSL has already developed many excellent technologies in terms of color management systems. I believe I can reach to my goal by piling up an effort step by step and collaborating with the MCSL. In closing, I want to thank faculty, staff, and colleagues of the Munsell Color Science Laboratory and Center for Imaging Science.

Akihiro Ito, CIS Visiting Scientist, Fuji Xerox Co., Ltd. , Japan



In the past year, the biggest event in my life happened. It was that I came to and lived in America. It excited me, but, on the other hand, I felt anxious about American life. I came to Rochester in September, and during the past year I spent 4 months with perplexity by American culture and English. At long last I recently get a little acclimated to American life and I can enjoy it.

In this year, I plan to research color management systems. I will focus on problems in actual products, directing my attention to image data size and calculation accuracy. In building the pilot color management system, I will use a CRT and a xerographic printer. The system will include technologies such as device profiles, color gamut mapping and color appearance matching. During the design process I will identify potential problems. When the system is completed, I will evaluate the image quality produced. I will select one from the problems that are identified from above process and I will decide my research theme.

Akio Tsujita, CIS Visiting Scientist, Hitachi-koki Co., Ltd., Japan



My work involves the micro-densitometric analysis of halftone images printed by laser printers and continuous tone images made with an office copy machines. The objective of the work is to understand the mechanisms of interaction between toner, paper, and light and to model these interactions. Then the plan is to examine the impact of printing conditions on the parameters of the model. Of particular interest is the effect of fuser temperature, dot shape, and dot thickness on the optical characteristics of halftones printed by a laser electrophotographic printer. The expertise in MCSL in microdensitometry is considerable, particularly in the area of halftone color modeling and the optical properties of paper and colorants, and this is why my work is best carried out here at MCSL. Hitachi-koki is very happy for me to study here at MCSL because in the digital market improvements in image quality are important for electrophotographic printers, and tone reproduction is one of the important image quality parameters.

Katsuya Itoh, CIS Visiting Scientist, Toyobo Co., Ltd., Osaka, Japan



I am a visiting scientist from Toyobo Corporation, Osaka, Japan and am working with Dr. Arney in a study of the optical properties of special synthetic substrates manufactured to replace paper in several digital printing systems. Toyobo makes special plastic substrates for systems such as electrophotography, ink jet printing, thermal printing and silver halide photography. We are particularly interested in how the properties of the substrate effect tone and color reproduction. We are particularly interested in the MTF of the new substrates and have already seen some very interesting differences between paper and these substrates. The MTF is much higher, and the spatial variation in the MTF is much less than is the case for plain paper used in electrophotography copy machines. We are particularly interested in measuring how the internal structure of the substrates influences the MTF and other optical properties. My goal is to develop improved methods for measuring substrate MTF and then measure the MTFs of the special substrates. We will then compare the MTF with the quality of images printed on the substrates. An additional project is to measure the impact of Kubelka-Munk absorption coefficient, K , and scattering coefficient, S , on the MTF. Published theory relating MTF to these two parameters appears to be in error, and we want to confirm the relationship experimentally.

Shinya Yamaguchi, CIS Visiting Scientist, Nippon Paper Industries Co., Ltd., Japan



I am a research scientist with Nippon Paper Industries in Japan, and I am working in the image microstructure laboratory at MCSL to learn about the microstructure of paper. I am particularly interested in measuring the MTF of different kinds of paper to understand how different types of paper behave in tone and color printing. An interesting part of the project is to see how the MTF varies spatially across the paper. For some papers, the distance over which significant variations in MTF occur appear to be about the same order of magnitude as the mean scattering distance. In such cases we want to find out if the mean value of the MTF is a sufficient parameter for describing tone and color reproduction or if an additional noise parameter is needed. The way we are examining this is to measure the microstructure of the paper in both reflected and transmitted light. We also measure the paper MTF with a sharp edge trace and a Fourier Transform calculation. I am especially interested in the properties of papers used for printing ink jet images, and the properties of the paper will be correlated with image quality metrics from images printed with ink jet. Another project I am interested in exploring is the new method for measuring the micro-goniophotometry of papers. This new method was developed at MCSL and may be of special use in testing papers and other substrates for application as reflectors in LCD displays.



Graduate Students



Scott Bennett, Part-Time, M.S. Candidate, Color Science
B.S., Computational Mathematics, Rochester Institute of Technology, 1995.
Thesis Topic: Gamut Surface Generation given a Set of Colorants

Animesh Bose, Full-Time, M.S. Candidate, Color Science
B.S., Printing, Regional Institute of Printing, India, 1985.
Thesis Topic: The Influence of Print Size on Color Appearance



Gus Braun, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Imaging Science, Rochester Institute of Technology, 1991.
B.S., Imaging Science, Rochester Institute of Technology, 1989.
Thesis Topic: Color Gamut Mapping



Peter Burns, Full-Time, Ph.D. GRADUATE, Imaging Science
M.S., Electrical & Computer Engineering, Clarkson, 1977.
B.S., Electrical & Computer Engineering, Clarkson, 1974.
Thesis Topic: Image Noise in Multispectral Color Imaging



Doug Corbin, Full-Time, M.S. Candidate, Color Science
M.S. Photographic and Imaging Science, RIT, 1982.
B.S. Chemistry, University of California at Santa Barbara, 1974.
Thesis Topic: Colorimetric Modeling of a CRT-Based Digital Film Recorder

Mihai Cuciurean-Zapan, Full-Time, M.S. GRADUATE, Imaging Science
B.S. & M.S., Mathematics, University "Al. J. Cuza," Romania, 1982.
Thesis Topic: Preferred Color Reproduction in Ink-Jet Prints



Fritz Ebner, Part-Time, Ph.D. Candidate, Imaging Science
M.S., Electrical Engineering, University of Rochester, 1990.
B.S., Electrical Engineering, Carnegie Mellon, 1986.
Thesis Topic: Gamut Mapping Derived from Observer Matches in Simple Graphics and the Influence of Context on Gamut Mappings



Barbara Grady, Part-Time, M.S. Candidate, Color Science
B.S., Imaging Science, Rochester Institute of Technology, 1993.
A.A.S., Optical Engineering Technology, Monroe Community College, 1990.
Thesis Topic: TBD

Chris Hauf, Full-Time, M.S. GRADUATE, Color Science
B.S., Imaging Science, Rochester Institute of Technology, 1993.
Thesis Topic: Device Independent Color Modules for Silicon Graphics Iris Explorer



Greg Howell, Part-Time, M.S. Candidate, Color Science
B.S., Electrical Engineering, Ohio University, 1985.
Project Topic: Predicting Colorant Concentrations Using a Digital Camera



Pat Igoe, Part-Time, Ph.D., Candidate, Imaging Science
M.S., Software Development & Management, RIT, 1996.
B.S., Computer Science, RIT, 1992.
Thesis Topic: Development of a New Cone-Fundamental Based Color Space with Uniform Small Color Differences



Garrett Johnson, Full-Time, M.S. Candidate, Color Science
B.S. Imaging Science, Rochester Institute of Technology, 1996.
Thesis Topic: Spectral Computer Image Synthesis



Alexi Kranoselsky, Full-Time, M.S. Candidate, Color Science
Ph.D., Chemistry, Inst. for Bioorganic Chem., Moscow, Russia, 1990.
Thesis Topic: TBD



Susan Lubecki, Part-Time, M.S. Candidate, Color Science
B.S., Mathematics and Computer Science, University of Notre Dame, 1984.



Glenn Miller, M.S. Candidate, Color Science
B.S., Professional Photography, Rochester Institute of Technology, 1966.
Project Topic: Correlating Gloss and Colorimetric Measurements with Psychophysical Estimates of Lightness

Robert Poetker, Part-Time, M.S. Candidate, Color Science
B.S., Computer Engineering, University of Evansville, 1983.
Project Topic: Building Printer Device Profiles Using MATLAB



Mark Reiman, Part-Time, M.S. Candidate, Color Science
B.S., Chemistry, RIT, 1987.
Project Topic: TBD



Mark Shaw, Full-Time, M.S. Candidate, Color Science
B.Sc., Graphic Media Studies, Print. & Pub. Tech., Wester Herts College, England, 1997.
Thesis Topic: TBD



Deepthi Sidavanahalli, Full-Time, M.S. Candidate, Color Science
M.S., Graphic Arts System, Rochester Institute of Technology, 1996.
B.S., Photography & Photo Journalism, University of Mysore, India 1990.
Thesis Topic: Parametric Effects on Lightness Perception in Color-Difference Evaluation



Quan Shuxue, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Optical Instrument, Beijing Inst. of Technology, 1997.
B.S., Opto-Electronic Technology, Beijing Inst. of Technology, 1994.
Thesis Topic: TBD



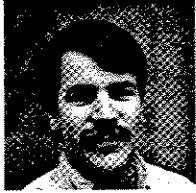
Qun (Sam) Sun, Full-Time, Ph.D. Candidate, Imaging Science
M.S., Physics, Florida Int'l University, 1997.
B.S., Electronic & Science Technology, East China Normal University, 1985.
Thesis Topic: TBD



Di-Yuan Tzeng, Full-Time, Ph.D. Candidate, Imaging Science
M.A., Mathematics, Central Connecticut University, 1994.
B.S., Printing Technology, Chinese Culture University, 1988.
Thesis Topic: Spectral-Based Color Separation Algorithm Development for Multiple-Ink Color Reproduction

Alex Vaysman, Part-Time, M.S. GRADUATE, Imaging Science
B.S., Computer Science, RIT 1994.
Thesis Topic: Trade-off between Spatial and Color Resolution in Digital Printing

Tuo Wu, Full-Time, M.S. Candidate, Color Science
M.S., Printing, Rochester Institute of Technology, 1991.
B.S., Mechanical Engineering, Beijing Printing Institute, 1984.
Thesis Topic: Color Microstructure Analysis



Dave Wyble, Part-Time, M.S. Candidate, Color Science

B.S., Computer Science, SUNY Brockport, 1992.

Project Topic: A Critical Review of Spectral Models Applied to Binary Color Printing

MCSL Alumni

Seth Ansell, M.S., Color Science, 1995.

Richard Alfvin, M.S., Color Science, 1995.

Mitch Balonon-Rosen, M.S., Imaging Science, 1993.

Karen Braun, Ph.D., Imaging Science, 1996

Cathy Daniels, M.S., Color Science, 1996.

Denis Daoust, M.S., Imaging Science, 1987.

Mark Fairchild, M.S., Imaging Science, 1986.

Sue Farnand, M.S., Imaging Science, 1995.

Wayne Farrell, M.S., Imaging Science, 1987.

Mark Gorzynski, M.S. Imaging & Color Science, 1992.

Brian Hawkins, M.S. Color Science, 1997.

Taek Kim, M.S. Imaging Science & Color Science, 1992.

Audrey Lester, M.S., Color Science, 1994.

Yan Liu, M.S., Color Science, 1991.

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.

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.

Lisa Reniff, M.S., Color Science, 1989.

Rich Riffel, M.S., Imaging Science, 1992.

Brian Rose, M.S., Color Science, 1992.

Hae Kyung Shin, M.S., Imaging Science, 1996.

James Shyu, M.S., Color Science, 1994.

Greg Snyder, M.S., Imaging Science, 1991.

Michael Stokes, M.S., Color Science, 1992.

Debra Seitz Vent, M.S., Imaging Science, 1994.



Research - Mark D. Fairchild

Imaging Color Perceptions

Recent technological advances have brought the capabilities to manipulate and display color images to typical users of desktop personal computers. However, users desires and expectations are often not completely fulfilled by these technologies. Part of this might be due to unreasonable expectations, but significant improvement is still possible once several scientific problems have been addressed. My research on various areas of color imaging and perception aims to solve some of these problems through projects focusing on color appearance modeling, color-gamut mapping, image perception, and computer graphics.

Since my main research activities revolve around the projects of my graduate students, it is most effective to review the past year's research of these eight students independently. Animesh Bose continued his M.S. thesis on the influence of print size on color appearance. During my leave, Ethan Montag supervised the completion of his experiments. Gus Braun completed the first phase of his Ph.D. dissertation by developing techniques for the specification and visualization of gamut boundaries. He presented this work at the 5th Color Imaging Conference in November and received the "cactus award" for the best poster presentation. Gus continues this work by psychophysically examining the selection of color spaces for gamut mapping. Mihai Cuciurean-Zapan completed his M.S. thesis in May on the topic of color preference reproduction for ink-jet prints. Meanwhile, Clara Cuciurean-Zapan is just beginning work on her Ph.D. dissertation on texture modeling while working full-time at Xerox. Fritz Ebner, another part-time Ph.D. student from Xerox, made significant progress toward the completion of his dissertation. A paper on his work with simple graphical images appeared in *Color Research and Application* and he will be presenting further results on a constant-hue experiment at the Electronic Imaging conference. Chris Hauf completed his M.S. thesis on the development of software modules for color reproduction and appearance research. Garrett Johnson completed a Kodak-sponsored project on color appearance reproduction under typical standard viewing conditions. Garrett is currently working on his M.S. thesis developing an OpenGL-based procedure for the full-spectral rendering of synthetic images. Alex Vaysman completed his M.S. thesis on the trade-offs between bits-per-pixel and pixels-per-inch in digital printing and he will present this work at the Electronic Imaging conference.

I am also involved in some projects that are of personal interest or collaborations with MCSL staff. In the past year these have included: the evaluation of gamut-mapping algorithms with Ethan Montag, an evaluation of the *Munsell Book of Color* in various color appearance spaces with Dave Wyble, the development of IDL functions for a variety of color appearance models, and work on reflectance measurement and visual modeling with Donald Greenberg and his staff at Cornell.

A number of publications on past work also appeared during 1997. These include my book, *Color Appearance Models*, previous student projects by Rick Alfvén, Karen Braun, Cathy Daniels, and work completed by Kazu Takemura while he was a visiting scientist with the lab. Further information on the research and publications described above can be found at my personal web site, <http://www.cis.rit.edu/people/faculty/fairchild>.

Book

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

Publications

F. Ebner and M.D. Fairchild, "Gamut Mapping from Below: Finding Minimum Perceptual Distances for Colors Outside the Gamut Volume," *Color Res. Appl.*, **22** 402-413 (1997).

E.D. Montag and M.D. Fairchild, "Evaluation of Gamut Mapping Techniques using Simple Rendered Images and Artificial Gamut Boundaries," *IEEE Transactions on Image Processing*, **6** 977-989 (1997).

R.L. Alfvén and M.D. Fairchild, "Observer Variability in Metameric Color Matches using Color Reproduction Media," *Color Res. Appl.*, **22** 174-188 (1997).

K.M. Braun and M.D. Fairchild, "Testing Five Color Appearance Models for Changes in Viewing Conditions," *Color Res. Appl.*, **22** 165-174 (1997).

T. Tanaka, R.S. Berns, and M.D. Fairchild, "Predicting the Image Quality of Color Overhead Transparencies Using a Color-Appearance Model," *J. Electronic Imaging* **6**, 154-165 (1997).

M.D. Fairchild, "Predicting Color Appearance of Simple and Complex Stimuli," *John Dalton's Colour Vision Legacy*, Taylor & Francis, London (1997).

Presentations

F. Ebner and M.D. Fairchild, "Finding Constant Hue Surfaces in Color Space," *SPIE/IS&T Electronic Imaging*, San Jose in press (1998).

A.Vaysman and M.D. Fairchild, "Degree of Quantization and Spatial Addressability Tradeoffs in Perceived Quality of Color Images," *SPIE/IS&T Electronic Imaging*, San Jose in press (1998).

M.D. Fairchild, "The ZLAB Color Appearance Model for Practical Image Reproduction Applications," *CIE 2nd Symposium on Colour Standards for Image Technology*, *CIE Pub.XXX*, in press (1997).

M.D. Fairchild, "Progress Report of CIE TC1-34 with an Introduction of the CIECAM97s Colour Appearance Model," *CIE 2nd Symposium on Colour Standards for Image Technology*, *CIE Pub.XXX*, in press (1997).

K. Takemura and M.D. Fairchild, "Some Considerations about Corresponding Hues Across Cross-Media Color Reproductions," *CIE 2nd Symposium on Colour Standards for Image Technology*, *CIE Pub.XXX*, in press (1997).

C.M. Daniels, E.J. Giorgianni, and M.D. Fairchild, "The Effect of Surround on Perceived Contrast of Pictorial Images," *IS&T/SID 5th Color Imaging Conference*, Scottsdale, 12-16 (1997).

G. Braun and M.D. Fairchild, "Techniques for Gamut Surface Definition and Visualization," *IS&T/SID 5th Color Imaging Conference*, Scottsdale, 147-152 (1997).

M.D. Fairchild and K.M. Braun, "Investigation of Color Appearance Using the Psychophysical Method of Adjustment and Complex Pictorial Stimuli," *AIC Color 97*, Kyoto, 179-186 (1997).

K. Takemura, M.D. Fairchild, and R.S. Berns, "The Preferred Reproduction of Skin Color and Chromatic Adaptation," *AIC Color 97*, Kyoto, 574-577 (1997).



Research - Roy S. Berns

Color Tolerances

Color tolerance research is supported through the MCSL Industrial Color Tolerance Consortium. We currently have nine members. Two years ago, Yue Qiao performed a visual experiment to evaluate CIELAB's lack of uniformity with respect to CIELAB hue. This year, Ethan Montag performed a supplemental experiment to validate four of the color centers using the same samples, new samples made from automotive paint, and stimuli displayed on a computer-controlled CRT display. The results were combined and an article will appear during 1998 in *Color Research and Application*. Ethan has begun writing an article about the CRT portion of the experiment. A new set of visual experiments has begun to evaluate the influence of several parametric factors on lightness discrimination, to be carried out by Deepthi Sidavanahalli.

Color Modeling

Through collaborative research with our visiting scientist from Toppan, Koichi Iino, we have been modeling the spectral properties of desktop and offset printers using the Yule-Nielsen modified Murray-Davies/Neugebauer models where optical parameters were optimized as functions of wavelength. Combined with a spectral-based scanner model and simple minimum ΔE^*_{ab} gamut mapping, color-management modules were prepared and tested. A two-part article is in press for the *Journal of Imaging Science and Technology*. A portion of this research was also presented at the AIC conference in Kyoto. For four-color printers, the black printer algorithm is a key determinant of spatial image quality. A visual experiment was performed to evaluate several black printer algorithms, presented at the Color Imaging Conference in Scottsdale. A final experiment was performed evaluating the influence of transparency viewing conditions on tone reproduction. Refereed articles describing these latter research efforts are in preparation.

CRT models have resurfaced as an area of research through standards activities of the IEC. My activities were largely advisory where the CIE and IEC are attempting to have a consistent approach to CRT colorimetry. As a M.S. degree capstone, Geoff Woolfe, studied methods of modeling channel interdependence using spectral rather than colorimetric data. This was presented at the CIE Expert Symposium on Colour Standards for Image Technology.

Multi-Spectral Color Reproduction

This research has, thusfar, been component based: noise in multispectral imaging (Peter Burns), methods of combining low-resolution multispectral and high-resolution trichromatic images (Francisco Imai), spectral printing algorithms (Koichi Iino), and multi-ink separation algorithms (Di-Yuan Tzeng). Peter and Koichi published articles on their efforts. To tie this research together, a research proposal was written, "Multi-Spectral Graphic Reproduction" and sent to several dozen companies for funding consideration. A component of the printing research was funded by DuPont Photopolymers & Electronic Materials towards the end of the year. Another proposal was initiated, "Multispectral Based Color Reproduction - Preserving National Treasures." This proposal is designed to address the needs of the next-generation digital archives. Papers have been submitted to several conferences for presentation during 1998 including ISCC Williamsburg and International Symposium on Electronic Image Capture and Publishing. A digital camera laboratory has been developed in MCSL consisting of an IBM Pro3000 system (3072x4096 or 3072x2460 pixels, 36 bit colorimetric RGB), Kodak DCS200 (1524x1012 pixels, 8 bit monochrome) with various interference filters, and Sony DKC-D5PRO (768x576 pixels, 24 bit color).

Publications

R.S. Berns, "A generic approach to color modeling," *Color Res. Appl.* 22 318-325 (1997).

R.S. Berns and L.A. Reniff, "A practical technique to diagnose spectrophotometric errors," *Color Res. Appl.* 22, 51-60 (1997).

M. Melgosa, E. Hita, A.J. Poza, D.H. Alman, and R.S. Berns, "Suprathreshold color-difference ellipsoids for surface colors," *Color Res. Appl.* 22, 148-155 (1997).

T. Tanaka, R.S. Berns, and M.D. Fairchild, "Predicting the image quality of color overhead transparencies using a color-appearance model," *J. Electronic Imaging* 6 154-165 (1997).

P.D. Burns and R.S. Berns, "Error propagation in color signal transformations," *Color Res. Appl.*, 22, 280-289(1997).

K. Iino and R.S. Berns, "Building color management modules using linear optimization I. desktop color system," *J. Imag. Sci. Tech.*, in press (1997).

K. Iino and R.S. Berns, "Building color management modules using linear optimization II. prepress system for offset printing," *J. Imag. Sci. Tech.*, in press (1997).

Y. Qiao, R.S. Berns, L. Reniff, E. Montag, "Visual determination of hue suprathreshold color-difference tolerances," *Color Res. Appl.*, in press (1997).

Invited Presentations

R.S. Berns, "The importance of color appearance models in color management systems," AIC Color 97, *proceedings of the 8th Congress of the International Colour Association*, 110-115 (1997).

R.S. Berns, "Color management: a philosophy for improved color reproduction accuracy," Fuji-Xerox, Ebina, and Sony Research Laboratories, Tokyo, May 1997.

R.S. Berns, "The case for instrumental color tolerancing," Color Measurement and Control of Automotive Materials, Detroit Color Council, June 1997.

R.S. Berns and N. Katoh, "The digital to radiometric transfer function for computer controlled CRT displays," *Proceedings CIE Expert Symposium '97 Colour Standards for Image Technology*, in press (1997).

Presentations

P.D. Burns and R.S. Berns, "Modeling colorimetric error in electronic image acquisition," *Proceedings OSA annual meeting*, in press (1997).

R.S. Berns, Y. Qiao, L.A. Reniff, "Visual determination of hue suprathreshold tolerances," AIC Color 97, *proceedings of the 8th Congress of the International Colour Association*, 110-115 (1997).

K. Takemura, M.D. Fairchild, R.S. Berns, "The preferred reproduction of skin color and chromatic adaptation," AIC Color 97, *proceedings of the 8th Congress of the International Colour Association*, 574-577 (1997).

K. Iino and R.S. Berns, "A spectral based model of color printing that compensates for optical interactions of multiple inks," AIC Color 97, *proceedings of the 8th Congress of the International Colour Association*, 610-613 (1997).

K. Iino and R.S. Berns, "The effect of black printer separation algorithms on perceived spatial image quality," *Proceedings IS&T/SID Fifth Color Imaging Conference*, 163-168 (1997).

G.J. Woolfe and R.S. Berns, "An improved method for CRT characterization based on spectral data," *Proceedings CIE Expert Symposium '97 Colour Standards for Image Technology*, in press (1997).



Research - Jonathan S. Arney

The Optics of Paper

One of the optical properties of paper which makes it so useful as a medium for color imaging is its ability to scatter light. By strongly scattering light, the paper is able to be very thin but maintain its diffuse appearance and hide images printed on the reverse. However, scattering also governs the MTF of the paper, and this property has a major impact on the reproduction of color by halftone imaging processes. Thus, the relationship between light scattering, S , and the quality of tone and color reproduction, MTF, remains a major topic of research. A recent theories published by Engeldrum (*TAGA*, 353, 1995) derives the MTF of paper from Kubelka-Munk theory. This theory predicts that both scattering, S , and absorption, K , should govern the MTF of paper. However, a recent project conducted here at MCSL shows MTF to depend strongly on S but almost not at all on K . The relationship between MTF and the Kubelka-Munk constants S and K continues to be a very active area of investigation, and collaboration with Engeldrum and other theorists is expected to lead to improved understanding of the fundamentals of tone and color reproduction in printed images.

Measuring and Modeling Halftone Imaging

Closely related to the study of paper MTF is a project to relate MTF to practical color and tone reproduction with various printing technologies. Microdensitometric measurements of halftone systems performed at MCSL has shown that the reflectance of *cm*y dots and the overlap colors, *rgb*, are not constant, as typically assumed with various forms of the Neugebauer equations, but change as a function of the dot area fractions that are printed. This effect has been measured quantitatively and shown experimentally to be the fundamental manifestation of the Yule-Nielsen effect of optical dot gain. Current work involves the development of theoretical models to describe the effect. MCSL has focused on a new "Probability" model (*JIST*, 41, in press 1997) to describe the effect on monochrome halftone images. Extension of this work to full color reproduction in halftone imaging is currently under way. Moreover, theoretical work carried out in collaboration with colleagues in the field (Engeldrum, Rogers, and Kruse) is leading to new theories justifying the probability model and showing how the model relates theoretically to the fundamentals of paper MTF.

The Performance of Printers

In addition to the theoretical and experimental analysis of paper and halftone imaging, a major effort is being made to the application of these theories to practical printing technologies. As a part of this work, a study of ink jet printing has shown that the probability based halftone model can be modified easily to describe the effects of ink penetration into the paper (*JIST*, 41, in press). Electrophotographic printers also are under study. The behavior of laser printers is quite different from ink jet, but work is underway to show how the fundamental probability models may be modified to describe tone and color reproduction in these systems also.

Advances in Experimental Microdensitometry

Microdensitometry provides the experimental data that guides the work in understanding the fundamentals of tone and color reproduction with ink/paper systems. Thus a significant part of the past year has been devoted to the development of new and better instruments for carrying out reflection microdensitometry. One new instrument brought on line this year is a full color microdensitometer consisting of a three chip CCD camera coupled to a microscope. By calibrating the RGB signals from the camera to the colorants in a particular system, very high accuracy can be achieved in the measurement of color resolved to microscopic dimensions. Moreover, the spatial resolution of the system is maintained by using a camera with separate CCD arrays and RGB beam splitters integral to the camera. Additional advances in reflection microdensitometry planned for the coming year include the acquisition of a new camera with a much larger array CCD for diffraction limited reflection microdensitometry.

Publications

J.S. Arney, "A Probability Description of the Yule-Nielsen Effect", *J. Imag. Sci. & Tech*, 41(6), 34 (1997).

J.S. Arney and M. Katsube, "A Probability Description of the Yule-Nielsen Effect II: The Impact of Halftone Geometry", *J. Imag. Sci. & Tech*, 41(6), 38 (1997).

J.S. Arney and M.L. Alber, "Optical Effects of Ink Spread and Penetration on Halftones Printed by Thermal Ink Jet", *J. Imag. Sci. & Tech*, 42, in press (1998).

J.S. Arney, T. Wu, and C. Blehm, "Modeling the Yule-Nielsen Effect on Color Halftones", *J. Imag. Sci. & Tech*, 42, in press (1998).

E. Pray and J.S. Arney, "Wavelength Dependence of the Yule-Nielsen Effect", *TAGA*, in press (1998)

Presentations:

J.S. Arney, T. Wu, and C. Blehm, "Modeling the Yule-Nielsen Effect on Color Halftones", IS&T/SID 5th Color Imaging Conference, Scottsdale, p.62, (1997).



Research - Ethan D. Montag

Color Gamut Mapping

During the past year I have been continuing research on color gamut mapping funded under the auspices of the NYF-NYS/IUCRC and NYSSTF-CAT Center for Electronic Imaging. The research continues the previous work that was published during the past year. The previous findings were based on experiments in which chroma and lightness were mapped separately in images of monochromatic rendered spheres in isolation. The goal of this research is to implement the previous findings and test their viability in more realistic situations.

The images used in the new research contain more texture and shadow. These features are more susceptible to changes in appearance when color gamuts are reduced. The images are again isolated uni-colored spheres, but in addition to testing them in isolation they will be presented together to see whether different mapping algorithms are needed for different regions in color space or whether a global algorithm can be tested.

The new research gauges the sequential application of mapping algorithms determined to be the best from the previous research. In order to test the applicability of these algorithms, three reproduction gamuts have been created. One is based on a reduced CRT gamut; a second is based on an ink-jet printer gamut; and a third is a gamut of arbitrary shape. The idea is to test whether different algorithms are needed for different devices.

New methods of chroma clipping have also been implemented. The implementation is in a graphical user interface (GUI) in which the user can change a number of parameters associated with gamut mapping. These include the destination gamut, the preservation of saturation or lightness in the original image, and the choice of chroma clipping strategies. The mapping of lightness can be adjusted manually so that arbitrary input/output lightness transfer functions can be tested. This GUI will help in implementation of the psychophysical experiments by facilitating the production of test images.

Industrial Color Tolerance

The results from our work on implementing color tolerance experiments on a CRT was completed and presented to the MCSL Industrial Color Difference Consortium. The major results of this work was that the findings of Yue Qiao's master thesis were replicated and that the large fiducial limits were likely a result of variations in appearance of hard copy samples viewed in a light booth. When samples are presented on a CRT, the fiducial limits are reduced. We found that one could successfully measure color tolerance on a CRT.

Interestingly enough, when the samples are colorimetrically matched to the original hard copy samples, the tolerance settings are very similar to those of the hard copy experiments, yet the appearance of the colors differ dramatically from the hard copy stimuli. When the CRT samples are matched in a relative manner using CIELAB, the appearance of the samples are more like the original samples but the color tolerances are different. These results may be surprising to some, but an indication of this could be seen in the results from our gamut mapping experiments: linearly scaling L^* does not produce veridical reproductions and is not optimal for mapping gamuts that have different lightness ranges.

We are now looking forward to doing research on parametric effects on color tolerance. During the last year we have been able to implement 10-bit/channel color on a Macintosh so that we will be able to measure small color differences. I look forward to this continued research.

Publications

E.D. Montag and M.D. Fairchild, "Evaluation of Gamut Mapping Techniques using Simple Rendered Images and Artificial Gamut Boundaries," *IEEE Transactions on Image Processing*, **6**, 977-989 (1997).

E.D. Montag, "The Influence of Boundary Information on the Perception of Color," *Journal of the Optical Society A*, **14**, 997-1006 (1997).

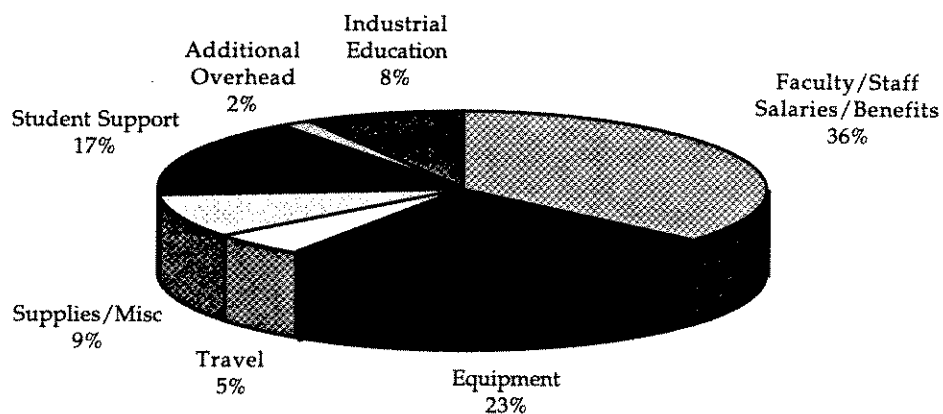
Y. Qiao, R.S. Berns, L. Reniff, E. Montag, "Visual determination of hue suprathreshold color-difference tolerances, *Color Res. Appl.*, in press (1977).



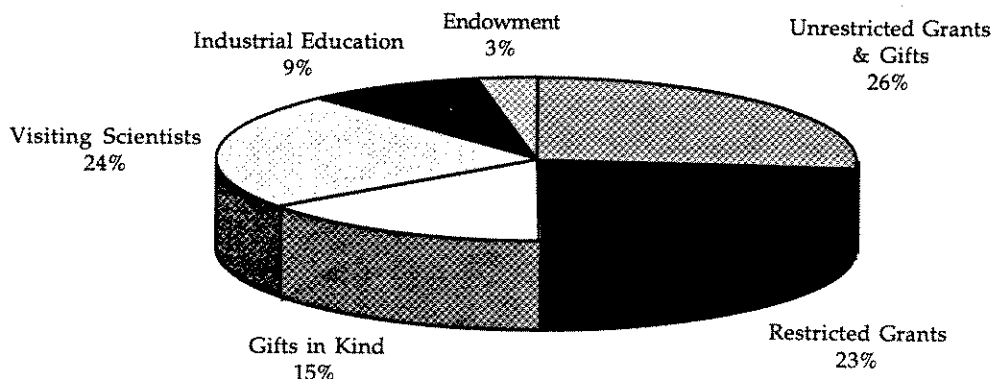
Funding

The total MCSL budget for 1997 was approximately \$600,000 (excluding the Hunter Chair and related accounts). This represents significant growth over 1996 in line with our plans and expectations. Income for the year comfortably exceeded expenses assuring uninterrupted operation of MCSL programs and projects. The charts below illustrate the distribution of MCSL income and expenditures. The majority of our income (73%) is cash generated by research projects through grants, gifts, and visiting scientist research. The largest expenditures (53%) are for student, staff, and faculty salary and benefits. Sources of grants, gifts, and equipment donations are acknowledged below. All financial calculations are based on the fiscal year from 7/1/96 to 6/30/97.

MCSL Expenditures



MCSL Income



Sources of Support

Gifts & Grants

3M, Bayer, Datacolor International, Detroit Colour Council, DuPont, DyStar, Eastman Kodak, Fuji Xerox, Hewlett Packard, Inter-Society Color Council, Gretag-Macbeth, NYSSTF-CAT, NSF-NYS IUCRC, Society of Plastics Engineers, PPG, Sony, Toppan Printing and Xerox.

Other Donations

Mrs. C. James Bartleson, BYK-Gardner, Color Curve Systems, and Eastman Kodak Company.

Color Science M.S. Curriculum

Enrollment in the Color Science M.S. program during 1997 was 6 full-time and 8 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
1050-801 Color Science Seminar	3 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
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Fall (Yr. 2)

1050-801 Color Science Seminar	3 Credit Hours
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Many of our students have interests in color imaging. The following is a typical schedule of courses for full-time students. Two color imaging courses are included in this schedule, *Color Reproduction* and *Color Systems*.

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
0307-801 Design of Experiments I	3 Credit Hours

Winter

1050-703 Color Appearance	3 Credit Hours
1050-722 Color Measurement Laboratory II	2 Credit Hours
1051-749 Color Reproduction	4 Credit Hours
1051-726 Computing for Imaging Science	4 Credit Hours

Spring

1050-813 Color Modeling	4 Credit Hours
1051-816 Color Systems	4 Credit Hours
0307-802 Design of Experiments II	3 Credit Hours

Fall (Yr. 2)

1050-801 Color Science Seminar	3 Credit Hours
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* If a student does not want the M.S. degree to concentrate in the color imaging area, other course options are available under advisement.



1997 Industrial Short Course Report

Color Measurement and Formulation

Some participating companies included: Milliken Research, DuPont Polymers, Honda of Canada, iimak, ColorTec Associates, DataProducts, PPG Industries, Technidyne, Boise Cascade and Eastman Kodak Company.

Principles of Industrial Color Measurement

- *Instructors:* Drs. Roy S. Berns and Mark D. Fairchild
- 31 participants

Industrial Instrumental Color Matching

- *Instructor:* Mr. Ralph A. Stanziola
- 27 participants.

Foundations of Color Management Systems

Some participating companies included: Xerox, Eastman Kodak, Polaroid, DuPont, Sony and Hewlett Packard.

Colorimetry

- *Instructor:* Dr. Roy Berns
- 14 participants

Device Characterization

- *Instructor:* Dr. Roy Berns
- 17 participants

Color-Appearance Models: Theory & Practice

- *Instructor:* Dr. Mark Fairchild
- 16 participants

1998 Scheduled Short Courses

"Principles of Color Technology for Materials Systems"

June 1-3, 1998 Principles of Industrial Color Measurement

A three-day intensive short course designed to teach the color science principles necessary to make effective use of color measurement instrumentation. Key topics include spectrophotometry, derivation of colorimetry through CIELAB, and CIE94 and CMC color tolerance equations. The course consists of lectures, instrument demonstrations, visual experiments, and an open laboratory session. Instructed by Dr. Roy S. Berns and Dr. Mark D. Fairchild.

June 4, 1998 Industrial Instrumental Color Matching

A one-day intensive short course designed to help participants make more effective use of computer colorant formulation systems. Key topics include spectral analyses of colorants, color matching theory, batch correction, and getting the most out of a system. The course consists of lectures, in-class formulation hand calculations, current software demonstrations, and a problem-solving session. Instructed by Mr. Ralph A. Stanziola of Industrial Color Technology.

"Foundations of Color Management Imaging Systems"

This is a five-day, intensive short course designed to teach the underlying principles for implementing color management. The course is divided into three sections: colorimetry, modeling imaging peripherals for device profiles, and color appearance models. Participants *can participate in any or all of the sections*. These foundations are incorporated into color management systems such as Postscript Level II, ICC, and KPCMS providing "plug and play" capabilities.

Section one, Colorimetry for Imaging, offered on June 8, 1998 will be taught by Dr. Roy S. Berns, the R. S. Hunter Professor in Color Science, Appearance, and Technology. Topics include an overview of color vision and appearance, photometry, colorimetry mathematics, color measurement instrumentation, color space transformations, and color quality metrics.

Section two, Colorimetric Device Characterization, offered on June 9-10, 1998 will be taught by Dr. Roy S. Berns. Topics include scanner colorimetry using multiple-linear regression and spectral estimation techniques; CRT colorimetry using the CIE technique; binary printer colorimetry for cluster dot, FM screening, and conventional rotated screen halftoning devices; continuous tone printer colorimetry using Kubelka-Munk theory; and the basics of building device profiles.

Section three, Color Appearance Models, offered on June 11-12, 1998 will be taught by Dr. Mark D. Fairchild, Director of the Munsell Color Science Laboratory. Color-appearance models extend basic colorimetry, as typified by CIE tristimulus values, to the prediction of color matches and color appearance across widely varying viewing conditions. Topics include important aspects of human vision, color appearance terminology, color-appearance phenomena, derivation of color appearance models (including, Nayatani, Hunt, RLAB, LLAB, CIELAB, ATD, and CIECAM97s), testing of color-appearance models, applications, and implementation.

The courses will consist of classroom lectures, demonstrations, laboratory sessions, and social times for informal interaction with other students and staff. Early registration is recommended. For further information or to pre-register contact:

For more information see our WebSite at:
<http://www.cis.rit.edu/research/mcsl/courses.html>

or contact:
Colleen M. Desimone,
Telephone: (716)475-7189 FAX: (716)475-5988
E-mail: CMD9553@rit.edu



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 six 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 six 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

This laboratory includes high accuracy spectrophotometers, material standards, a spectroradiometer, and a research goniospectrophotometer.

76-3105 Color Image Perception

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 Color Media Systems

Research in this laboratory is aimed at colorimetric and multispectral digital image capture and output. It also includes a flexible optical table setup that can be used in various experiments.

76-A110 Imaging Materials

The imaging materials laboratory provides areas for chemical analysis of various colored materials, inks, dyes, substrates, etc.

76-A120 Image Microstructure

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.

Technical Reports

The following is a list of MCSL Technical Reports written by faculty, staff, and students studying color science. 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.

- R. S. Berns, A. Bose, D. Tzeng, "The spectral modeling of large-format ink-jet printers," MCSL technical report, 1996.
- A Simple Printer Calibration Technique for "Good Enough" Color Reproduction of CRT Images, M. Fairchild, January 1994.
- Colorimetric Characterization of the Solitaire 16 Film Recorder for Kodak Ektachrome Plus Professional 100: A Pilot Study, R. Berns, May 1993.
- Spectral Modeling of a Dye Diffusion Thermal Transfer Printer, R. Berns, May 1993.
- Colorimetric Characterization of Sharp JX610 Desktop Scanner, R. Berns, April 1993.
- MCSL Apple Macintosh-Gretag Spectrophotometer Software Interface, M. Stokes, January 1993.
- Munsell Color Science Laboratory Plug-In Filter Modules for Adobe Photoshop, M. Fairchild, September 1992.
- Colorimetric Optimization of a NTSC Broadcast Color Video Camera, N. Katoh, August 1992.



Publications

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Munsell Color Science Laboratory Advisory Board

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

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