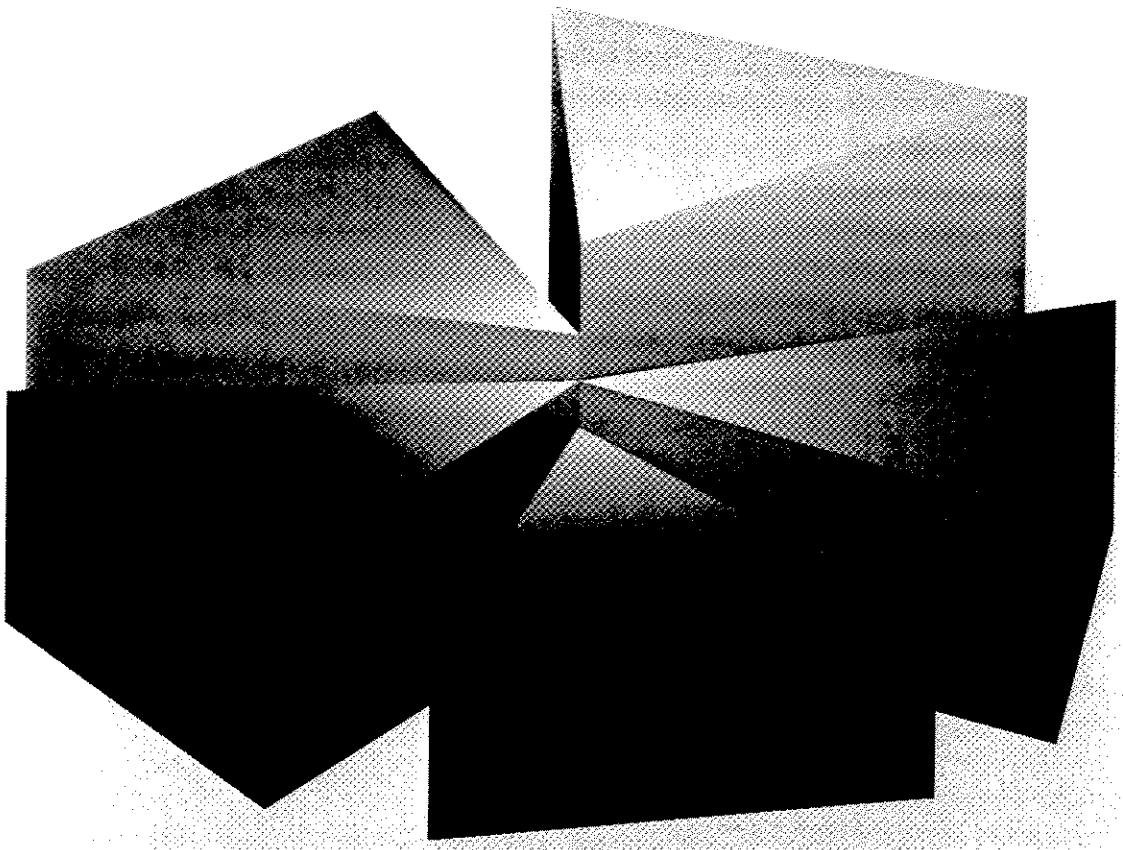
Munsell Color Science Laboratory



1996 Annual Report

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.

Who We Are

The Munsell Color Science Laboratory is made up of four faculty, three staff, and approximately 20 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. During 1996 the laboratory undertook a strategic plan to increase the number of faculty from 2 to about 5, the total number of people working in the lab from about 25 to about 40, and approximately double the research budget over the ensuing five years. The aim of this plan is to better fulfill the objectives of the laboratory defined above. Further information can be found throughout this report and by visiting our world-wide web site at http://www.cis.rit.edu/research/mcsl.

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Director's Report

We look back upon 1996 as a year of significant change for the Munsell Color Science Laboratory. We look forward to 1997 and the years beyond with hopes and expectations that these changes will result in a continuation and growth of the high quality programs we have worked so hard to establish.

Why did we feel changes were necessary in 1996? The laboratory had grown to capacity, and perhaps beyond, in its configuration at the beginning of the year. The volume of teaching, research, and outreach to the color science community had exceeded the capabilities of two faculty members. Simultaneously, the supply of incoming students interested in the field and the demand for graduates have grown steadily and significantly. We were presented with the challenge of maintaining quality while growing to serve a larger community. Our solution was to divide the administrative responsibilities and bring more faculty into the laboratory. This plan was implemented mid-year and appears to be successfully on course as, we hope, reflected in this annual report.

In the beginning of 1996, Roy Berns was the R.S. Hunter Professor of Color Science, Appearance, and Technology, the Director of the Munsell Color Science Laboratory, and the Coordinator of the Color Science M.S. program. As of July 1, I became Director of MCSL with responsibility for the facilities and research program. Roy remained the R.S. Hunter Professor and Coordinator of the M.S. program with responsibilities for the academic programs. This division of responsibility has allowed both of us to dedicate ourselves more fully to the administrative activities that are most suited to our skills and interests. It has also assured that both of us can remain active faculty members with time available for our students, courses, and research activities.

Two new faculty joined the MCSL family. Jon Arney, already an Associate Professor in the Center for Imaging Science, has become more formally associated with the laboratory. This enhances our research activities in the areas of color imaging materials and processes. Ethan Montag moved from his position as a post-doctoral fellow to that of Research Assistant Professor. With this move, Ethan has taken on course teaching and will be developing independent research activities. It is anticipated that a third position, the Xerox Distinguished Professorship in Imaging Science, will be filled by a candidate with expertise in digital color imaging systems. It is likely that the person filling this new position will perform research associated with MCSL in some way. We welcome Ethan and Jon to these new positions, which have already proven quite advantageous.

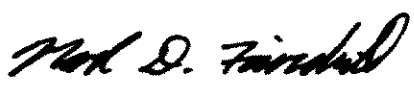
We have also expanded our staff to a total of three. Colleen Desimone remains as the MCSL secretary. Lisa Reniff has returned from maternity leave on a half-time basis as a Color Scientist. Dave Wyble joined the laboratory as a full-time Color Scientist beginning Jan. 1997. Dave comes to us from Xerox with a background in computer science and will soon be completing an M.S. in Color Science that he undertook on a part-time basis. We are happy to welcome Dave to the staff.

Of course, our students are the main reason MCSL exists. We are happy to report that Karen Braun, Cathy Daniels, Jack Rahill, Hae Kyung Shin and Yue Qiao completed their degrees in the past year and have all moved on to exciting and interesting positions in industry. Doug Corbin, Mihai Cuciurean-Zapan, Garrett Johnson, Mark Reiman, Deepthi Sidavanahalli, and Di-Yuan Tzeng joined the laboratory as new graduate students during 1996. We are happy to welcome them to the family and look forward to their successful careers as students and beyond. Kazu Takemura, Koichi Iino, and Tsuneo Kusunoki spent time at MCSL as visiting industrial scientists during 1996. Kazu and Tsuneo returned to Japan in 1996 after completion of their productive and enjoyable visits to the lab.

As presented in detail elsewhere in this report, the facilities and support for MCSL continue to be maintained at a high level as is necessary to provide a positive learning and research environment for our students. We are most grateful to our industrial and governmental sponsors who have generously provided research funding and equipment. Outreach to the color community continues to be a hallmark of our laboratory. This is evinced by our industrial short courses, which continue to be popular and well received, or collaborative research with industry, and our many activities within professional societies and technical committees. These activities are paramount for the success of our other educational objectives.

At this point I turn to some of my personal activities and thoughts regarding the laboratory. (The research activities of each faculty member are summarized in a separate section.) The first topic is our number one lunch-time conversation topic lately. There is apparently something in the MCSL environment that has led to a recent "baby boom" among the faculty, staff, and students. In the past 14 months, Colleen, Lisa and myself, Ethan, Dave, and Di-Yuan have had additions to their families. We are happy to see the MCSL family grow in this way and happy to report that all of the little ones and parents are doing very well, despite some new sleep patterns. I'd like to add my personal welcome and best wishes to all of the new "little color scientists" crawling around the greater Rochester area. I was fortunate to visit Japan for the first time this past year. While there, I spent some time touring Tokyo, visited Fuji Photo-Film and Konica, and gave an invited presentation at a conference in Chiba. I was also able to spend some time getting re-acquainted with a few of our previous visiting scientists. I enjoyed the trip very much and look forward to my second visit during the 1997 AIC meeting in Kyoto. Much of my time in the past year was spent working on my first book, *Color Appearance Models*, to be published by Addison-Wesley during 1997. I have just completed the full draft, which has gone out for final review. Writing a book has been an interesting and challenging experience that I am not likely to repeat any time soon. I have also been planning my first sabbatical leave. I will be spending the 1997-98 academic year at Cornell University's Program of Computer Graphics. I will be working with Professor Donald Greenberg there on topics involving the use of computer graphics in color image perception research and the application of color image perception research to realistic image synthesis. I am very excited about this opportunity and look forward to expanding my own knowledge and developing future collaboration opportunities for MCSL. On the teaching side, I taught the *Color Appearance* course in the spring and *Color Measurement Laboratory I* in the Fall. It was enjoyable to return to my "roots" in spectrophotometry and spectroradiometry in teaching the lab course. In the coming year I will teach the new *Color Systems* course on digital color imaging systems prior to going on leave. While my teaching activities have decreased slightly in recent years, they still provide one of the most rewarding and enjoyable dimensions of my work.

In closing, I want to once again thank everyone who has supported the activities of the Munsell Color Science Laboratory in any way during 1996. I'd also like to invite you to explore the MCSL world-wide web site at http://www.cis.rit.edu/research/mcsl.



Mark D. Fairchild, Ph.D.
Director, Munsell Color Science Laboratory

Richard S. Hunter Professor's Report

As the Hunter Professor, my activities included teaching courses and mentoring students in the graduate programs in Color Science and Imaging Science; coordinating the Color Science M.S. program; directing MCSL, performing applied research, and participating in national and international color community activities, and fund raising. When MCSL ended its first year in 1984 there were two faculty (Franc Grum and myself), one secretary, and two students. At the close of the 1995 academic year, there were still two faculty (Mark Fairchild and myself). In addition, there were three staff, three visiting scientists, six full-time graduate students, thirteen part-time graduate students, two seniors, and four new students on the way beginning in the fall. In addition, our research funding had increased ten fold during our first decade. As we have expanded, it has become exceedingly difficult to carry out all of the stated objectives of the Hunter Professorship and direct MCSL. Beginning July 1, 1996, I appointed Mark Fairchild as the new Director of MCSL. The main purpose of this appointment was to reduce my administrative responsibilities. As Director, Mark's primary responsibilities will consist of managing our research efforts, supervising staff, managing various budget centers, and overseeing the health of the Laboratory. As you can see by his Director's report and this Annual Report, there will be plenty to direct!

Obviously, this year is transitional for me. I expect this will continue for a good deal of 1997 as MCSL becomes comfortable with its expansion and I define my short and long term goals.

There have been a number of activities I would like to share with you. Three of my students completed their graduate degrees. Helen Hae-Kyung Shin earned her M.S. in Imaging Science. Her thesis focused on developing a statistical model for predicting the spectral transmittance of Kodak Ektachrome film exposed by a Management Graphics CRT-based film recorder. We used principal component analysis to model the film's inter-image effects. During 1997, an article describing this technique will be written. Helen is now working at Xerox, here in Rochester. Yue Qiao finished her Imaging Science M.S. Yue's research was supported by our Industrial Color Difference Consortium and involved measuring hue discrimination. Through Yue's hard work, we have a new data base of color tolerances that may lead to an improved color difference equation. My first part-time Color Science M.S. student in the graduate project option, Brian Hawkins, finished his degree requirements. His project involved writing a visual basic software package, "Munkit," that calculates color gamuts for Kubelka-Munk colorant data bases. Using Newton-Raphson iteration, the maximum chroma at various lightnesses is estimated for each pigment mixed with white and black. The user then removes inner gamut colorants and forms additional mixture of neighboring colorants, interactively, to build up a data set of CIELAB coordinates. My goal is to use this software along with computer graphics software to redetermine the gamut of real surface colors, research performed by Mike Pointer many years ago. I have three additional part-time students engaged in graduate projects. Greg Howell will be using a digital color camera for paint match prediction. Bob Poetker is writing a Matlab software package that will enable the testing of different types of numerical optimization when inverting printer forward models. Dave Wyble will be using eigenvector analysis to predict the color of electrophotographic halftone prints as an alternative to the Yule-Nielsen n value. Other student research is described within this report. It is very gratifying to mentor student research. I am continually surprised how much I learn along with my students.

I have worked closely with two of our visiting scientists. Koichi Iino from Toppan Printing has developed spectral models of halftone printing and incorporated them into color management modules for desktop publishing and conventional printing. We have learned quite a bit about the differences between derivative and direct search methods when inverting printer forward models. We are nearing the completion of a two-part article submission for the Journal of Electronic Imaging. Tsuneo Kusunoki from Sony performed a visual experiment where observers scaled differences in image quality between displays

with different surface reflection properties. We plan to submit an article on this research to the *Society for Information Display.*

Every year, I try to write one article that is educational and helps the field of color science. Last year, I wrote a two-part overview on colorimetry that was published in Optics and Photonics News. This year, I wrote an article on the theory and practice of deriving instrumental tolerances from visual and colorimetric data. It recently appeared in *Color, Research, and Application.* My goal is that this article will enhance our industrial short course on color measurement.

I attended four conferences during the year. In March, the CIE sponsored a symposium on color standards for image technology. I presented a review paper on colorimetry for imaging and led a roundtable discussion on calibration, characteriztion, and test targets. The symposium was very effective in defining problems requiring the attention of the CIE. In May, I attended the ISCC Annual Meeting in Orlando, Florida. I presented a paper describing an abridged technique to diagnose spectrophotometric errors. This work was done in collaboration with Lisa. An article on this topic will soon be published in *Color, Research, and Application.* Also in May, the University of Rochester and RIT sponsored a conference honoring Dr. David L. MacAdam. Dr. MacAdam was a faculty member at the Institute of Optics following retirement from Kodak. I presented an invited paper on the history and current status of color difference equations. November was devoted to the IS&T/SID Color Imaging Conference held in Scottsdale, Arizona. I was asked to speak about the new CIE technical report on CRT colorimetry. My graduate student, Peter Burns, presented a paper we co-authored on multispectral image capture. There was quite a bit of interest in Peter's research.

I am very excited to report that I have finally finished my obligation to the CIE as chair of TC 2-26, the colorimetry of color self-luminous displays. We have published a technical report, Publication 122, that summarizes methods of characterizing the colorimetry of computer-controlled CRT displays. Following publication, the committee is disbanded. Given that it took two years to get the final draft accepted (the CIE strives for international consensus), I wish that my graduate degree was in psychology rather than chemistry.

I would like to acknowledge, in particular, two supporters. R.R. Donnelley & Sons, through Russ Fling's efforts, donated an IBM colorimetric camera system to us. This will greatly enhance our research capabilities in multispectral and colorimetric image acquisition. Elizabeth Hunter continues to provide annual monetary support to the Hunter Professorship. Her contribution provides me with the freedom to pursue ideas that really matter.

In closing, I want to thank all of my students, colleagues, staff, alumni, and supporters for their continued belief in color science and color imaging as practiced at MCSL. We can't do it without you!

Roy S. Berns, Ph.D.
Richard S. Hunter Professor

Faculty & Staff Activities

Jonathan S. Arney, Associate Professor, (716) 475-7322, jsapci@rit.edu
This past year was a very fruitful one for the Image Microstructure effort in the Munsell Color Science Laboratory. Results of research projects were reported in archived journals and also in professional meetings. I presented the current state or research on image microstructure of halftone images at the 12th Non-Impact Printing Congress in San Antonio, TX in October. Our work in this area has been well received over the past several years and has resulted in research collaborations and co-publications with P.G. Engeldrum of Imcotek, Inc. and with the Swedish PFT (Paper-Print-Ink) Project, a consortium of Swedish companies and universities concerned with the physical and optical properties of ink-paper interactions in printing applications. In June I served on a Project Review Team for the PFT consortium and maintains close professional liaison with members of PFT.

I continue to serve as one of the Associate Editors of the *Journal of Imaging Science and Technology*, published by the Society for Imaging Science and Technology, IS&T. I also serve as the faculty advisor for the Student Chapter of IS&T. In my latter capacity I helped to foster growth in student professional involvement in imaging science at RIT. As a result of these activities, I was nominated and elected to receive the Bowman Award by IS&T for my work in student education in Imaging Science.

During the past year I undertook a new assignment in the Center for Imaging Science as the Coordinator of the Undergraduate Program. In this capacity I have been leading an effort to reorganize the undergraduate program at CIS. The thrust of the reorganization is to offer co-op educational opportunities to imaging science undergraduates and to update the curriculum following the 10th anniversary of CIS. In addition, as Coordinator of the Undergraduate Program, I also devote significant time coordinating with the College of Science in order to foster the smooth transition of CIS and MCSL into the College. At this point it can be reported with some pride that the transition has gone well, and excellent relationships and collaborations exist between MCSL and COS.

Ethan D. Montag, Research Assistant Professor, (716)475-5096, edmpci@rit.edu
During the past year I was fortunate enough to make the transition from Postdoctoral Fellow to Research Assistant Professor. I feel very fortunate to join Mark, Roy, and Jon as faculty in the Munsell Lab. So far the experience has been very enriching both professionally and personally and I expect this to continue.

During the first six months of the year my focus was on getting the first part of the gamut mapping research written up for publication as well as completing an article based on research I worked on at the University of Rochester. I have also been developing algorithms for use in the next series of gamut mapping experiments.

In May, Roy invited me to participate in the meeting of the MCSL Industrial Color Difference Consortium. Based on the needs of the consortium I am undertaking research on using CRT displays for the measurement of color tolerance. Two of the goals I hope for this project is the ability to use computer displays to quickly and accurately measure color tolerances and to simulate various surface appearance attributes so that the CRT can be used to evaluate tolerances for different media. In addition I would like to study the underlying perceptual mechanisms involved in the perception of color differences.

My duties as a faculty member went into high gear in the Fall quarter when I taught *Vision and Psychophysics* and the *Color Science Seminar*. Although I spent more time on the *Vision and Psychophysics* course than I had planned, I found the experience to be enjoyable and rewarding. I probably would have

had more fun if the class were not at 8:00am. Recently I received the course evaluations from the students who seemed to be a bit overwhelmed by the amount of material in the course. However, for most of the students this was their first taste of graduate school. The students said that I got better as I loosened up during the quarter but it's hard to get loose so early in the morning. Again I was impressed with the quality of the students in the *Color Science Seminar* which has continued to be a terrific learning opportunity for me.

On the home front, our third child, Matthew, was born in July. I've had my hands full with three small children and new job responsibilities, but I have been enjoying it nonetheless. I look forward to interacting more with faculty, staff, and students in the coming year as well as continuing teaching and doing research.

Colleen M. Desimone, Secretary, (716) 475-7189, cmd9553@rit.edu
The majority of 1996 I worked part-time and in September I came back full-time. It was a year filled with using alot of prioritization skills. I found it somewhat unsettling to leave the office without organizing my desk for the next day, but it happened quite often during my part-time months. I had mixed feelings returning full-time; I wish I could be two people, one full-time-mom and the other full-time-employee. Anyway, I think I have found a happy medium, I am lucky enough to work four longer days and take one day at home to spend with my son, Michael.

While reflecting back on this year I find it difficult to focus on any particular good deeds, I was kept *busy* doing my regular responsibilities in half the time. The majority of my winter and spring was spent planning and organizing the summer short courses. After the summer courses were over, I began focusing on the fall and thinking about the new academic year. In August, I attended a three-day training course for QuarkXpress and I am now attending a Desktop Publishing course. I hope that these courses will enhance my ability to present some more interesting and, hopefully, colorful publications. I am looking forward to the coming year and it's new projects. I hope to serve everyone well during 1997.

Lisa A. Reniff, Color Scientist, (716)475-7188, larpci@rit.edu
This past year has brought much change to my life with the addition of my daughter, Acadia. I was out on maternity leave from February until the end of August when I returned on a half-time basis. I really enjoyed and needed the time away from work to fulfill Acadia's needs (which were many) and develop a relationship with her. Check out Mark's web site for a picture. I am now enjoying being at work three days a week and stretching my brain back into shape. I am continuing my involvement in the Color Difference Consortium, facilitating the preparation of a cross-over experiment of the current digital photographic media with newer CRT display and older style paint samples. We will be repeating a few hue angles to verify a hue angle dependence we found in the previous study and look at the strength of each type media for color tolerance experimentation. I continue to play a major role in maintaining and upgrading the facilities in the MCSL and welcome the help having Dave on board will bring. I also continue to enjoy helping anyone who needs assistance experimenting in color.

Koichi Iino, Visiting Scholar, Toppan Printing Co., Ltd.
I am still here! I think that I am the first visiting scientist who has written something for the MCSL annual report three times. I would like to thank my company for giving me this extended study period and to thank MCSL for taking care of me. During my study period, I first tried to colorimetrically characterize a desktop color system using analytical modeling techniques in which a dot-on-dot halftone system for an inkjet printer, a flat-bed scanner, and a comparison between iteration methods to inverse forward models were considered. Second, a colorimetric characterization of a prepress and proofing system simulating offset printing was researched, in which a random-cluster-dot halftone system, a drum scanner, and a black printer model for four-color reproduction were targets for modeling. Both color reproduction systems were successfully characterized. Third, I performed a quantitative visual assessment of different back printer models for colorimetric four-color reproduction to find what basic psychophysical rules are necessary in order to make good quality black printer models. Now, Professor Berns and I are trying to finish writing articles that describe our research. I hope that these are going to be public soon. Finally, I am interested in visually determining corresponding colors between transparencies and prints viewed under typical prepress conditions.

I believe that printing has a great deal of empirical know-how and procedures to provide high quality color reproduction rather than systematic scientific knowledge, and that the key issues for image quality are hidden under this know-how. I am sure that colorimetric knowledge, psychophysical techniques and whatever I have learned at MCSL are very effective and useful to explore and analyze this world.

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., Chemistry, 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.

Ethan D. Montag
Ph.D., Experimental Psychology, University of California at San Diego, 1991.
M.S., Experimental Psychology, Universify of California, at San Diego, 1986.
B.S, Psychology, University of Pennsylvania, 1985.

Lisa A. Reniff
B.S. Chemistry, Rochester Institute of Technology, 1986.
M.S., Color Science, Rochester Institute of Technology, 1989.

David R. Wyble
B.S., Computer Science, SUNY Brockport, 1992.

Technical Liasion

AIC Color 97 Kyoto, International Scientific Committee, *Roy S. Berns*, Member.

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

ASTM E12.06 Appearance of Displays, *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 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.*

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

IS&T/SID 1995 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.*

Graduate Students

Scott Bennett, M.S. Candidate, Color Science
B.S., Computational Mathematics, Rochester Institute of Technology, 1995.
Thesis Topic: TBD

Animesh Bose, 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, Ph.D. Candidate, Imaging Science
B.S., Imaging Science, Rochester Institute of Technology, 1989.
M.S., Imaging Science, Rochester Institute of Technology, 1991.
Thesis Topic: Color Gamut Mapping

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

Doug Corbin, M.S. Candidate, Color Science
B.S. Chemistry, University of California at Santa Barbara, 1974.
M.S. Photographic and Imaging Science, RIT, 1982.
Thesis Topic: TBD

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

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

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

Brian Hawkins, M.S. Graduate, Color Science
B.S., Electrical Engineering, Clarkson University, 1988.
Project Topic: Defining a Gamut Space Given a Set of Colorants

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

Pat Igoe, Ph.D., Imaging Science Candidate
B.S., Computer Science, RIT., 1992.
M.S., Software Development & Management, RIT, 1996.
Thesis Topic: TBD

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

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

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

Deepthi Sidavanahalli,M.S. Candidate, Color Science
B.S., Photography & Photo Journalism, University of Mysose, India 1990.
M.S., Graphic Arts System, Rochester Institute of Technology, 1996.
Thesis Topic: TBD

Di-Yuan Tzeng, Ph.D. Candidate, Imaging Science
M.A., Mathematics, Central Connecticut University, 1994.
B.S., Printing Technology, Chinese Culture University, 1988.
Thesis Topic: Multi-Ink Printing

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

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

Dave Wyble, M.S. Candidate, Color Science
B.S., Computer Science, SUNY Brockport, 1992.
Project Topic: Modeling the Spectral Properties of Halftone Prints Using Principal Component Analysis

MCSL Alumni

Seth Ansell, M.S, Color Science, 1995.
Richard Alfvin, M.S., Color Science, 1995.
Mitch Balonon-Rosen, M.S., Imaging Science, 1988.
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.
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

Color Imaging & Perception

A great deal of technology exists to allow users to manipulate and display color images in a variety of media. There remain several scientific problems that must be solved before these systems will be capable of simply and reliably producing and reproducing the colors that users desire. My research on topics in cross-media color reproduction is addressing several of these problems such as color-appearance modeling, color-gamut mapping, image preference, image perception, and computer graphics.

My research activities are best summarized by reviewing the projects of the ten graduate students that I advised at various points through 1996. Animesh Bose is doing his M.S. thesis research on the influence of print size on color appearance in large-format ink-jet printing with the aim of developing algorithms that can be used to generate consistent color for various size prints. Gus Braun is putting together his Ph.D. dissertation proposal on the development and testing of general purpose gamut-mapping algorithms to deal with the colors that cannot be produced on a given imaging device. Karen Braun completed her Ph.D. dissertation on the testing of color appearance models in CRT-to-print image reproduction and has begun working at Xerox. Mihai Cuciurean-Zapan joined the group this year and is performing a psychophysical evaluation of preferred color reproduction for low-end ink-jet prints to help develop better printer driver software to complete his M.S. thesis. Cathy Daniels completed her M.S. with a project examining the influence of surround relative luminance on the perceived contrast of black and white images. We hope to extend this work to the various color dimensions in the future. Cathy continues to work at Eastman Kodak. Fritz Ebner, a Xerox employee and part-time Ph.D. student, is doing his dissertation research aimed at measuring perceptual preferences for gamut mapping and making detailed measurements of constant-hue contours in the CIELAB color space. Chris Hauf, a part-time student and Kodak employee, is finishing up development SGI Iris Explorer modules for color reproduction and color appearance research and education that will make up his M.S. thesis. Garrett Johnson joined the graduate program and is working on a cross-media image matching experiment and a computer graphics project aimed at the development of colorimetrically accurate, full spectral, synthetic images that can be used in the evaluation and development of color imaging systems. Jack Rahill completed his M.S. thesis evaluating and revising the Nayatani et al. color appearance model as a part-time student. He is now continuing his work at Kodak. Alex Vaysman, a part-time M.S. student from Xerox, is working on a thesis to psychophysically measure the tradeoff between dots-per-inch and bits-per-pixel in printed images.

I still manage to find occasional time to squeeze in some personal research. In the past year this focused on topics of gamut mapping with Ethan Montag (who is carrying on with those experiments), Monte Carlo simulation of color matching in order to derive more reliable estimates of the variation in color matching functions, computer-graphics rendering of sampling of various color spaces and color order systems, and authoring my forthcoming book, Color Appearance Models. Further details can be found at my world-wide web site, http://www.cis.rit.edu/people/faculty/fairchild.

Publications

K.M. Braun and M.D. Fairchild, "Testing Five Color Appearance Models for Changes in Viewing Conditions, "*Color Research and Application*, **22** in press (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** in press (1997).

R.L. Alfvin and M.D Fairchild, "Observer Variability in Metameric Color Matches using Color Reproduction Media," *Color Research and Application*, **22** in press(1997).

M.D. Fairchild, "Standard Guide for Designing and Conducting Visual Experiments," *ASTM* **E12.11.05** in press(1996).

M.D. Fairchild, "Refinement of the RLAB Color Space," *Color Research and Application*, **21** 338-346(1996).

M.D. Fairchild, A.A. Lester, and R.S. Berns, "Accurate Color Reproduction of CRT-Displayed Images as Projected 35mm Slides," *Journal of Electronic Imaging*, **5** 87-96(1996).

K.M. Braun, M.D. Fairchild, and P.J. Alessi, "Viewing Environments for Cross-Media Image Comparisons," *Color Research and Application*, **21** 6-17(1996).

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*, in press, 1997.

Invited Presentations

M.D. Fairchild, "Using Color-Appearance Models in Device-Independent Color Imaging," *Proceedings of 5th International Conference on High Technology: Imaging Science and Technology - Evolution and Promise*, Chiba, Japan 128-135(1996).

M.D. Fairchild, "Using Color-Appearance Models in Device-Independent Color Imaging," *Horizons in Color Science - A Tribute to David L. MacAdam*, Rochester (1996).

Presentations

K.M. Braun and M.D. Fairchild, "Psychophysical Generation of Matching Images in Cross-Media Color Reproduction," *IS&T/SID 4th Color Imaging Conference*, Scottsdale, 214-220(1996).

M.D. Fairchild and L. Reniff, "A Pictorial Review of Color Appearance Models," *IS&T/SID 4th Color Imaging Conference*, Scottsdale, 97-100(1996).

M.D. Fairchild, "Modeling Observer Metamerism through Monte Carlo Simulation," *OSA Annual Meeting* 126(1996).

M.D. Fairchild, "CIETC1-34: Testing Colour Appearance Models," *CIE Symposium on Colour Standards for Image Technology*, in press(1996).

E.D. Montag and M.D. Fairchild, "Simulated Color Gamut Mapping Using Simple Rendered Images," *Proc. SPIE 2658, San Jose*, 316-325(1996).

Research - Roy S. Berns

Color Tolerances

Color tolerance research is supported through the MCSL Industrial Color Tolerance Consortium. We currently have nine members. I wrote an article on methods of generating tolerances from pass-fail decisions and colorimetric data. A master's thesis was carried out by Yue Qiao that was supported by the Consortium. Her research resulted in a data base of hue discrimination data showing that CIELAB does not have visual uniformity as a function of hue angle. Of interest was that the lack of uniformity was not well described by either CMC or BFD equation. Articles are in preparation for submission to *Color, Research, and Application* and to the *AIC Quadrennium* in Kyoto. I have also been collaborating with the University of Granada in Spain with Professor Manuel Melgosa. He has derived ellipsoids from the RIT-DuPont tolerance vectors. Our goal is that vision researchers will use these population results rather than single-observer results such as the MacAdam ellipses.

Multi-Spectral Image Acquisition

A long-term goal is to develop practical methods of color printing that minimize metamerism between original objects and their printed reproductions. I have a particular interest in improving the color accuracy of art books and catalogs. One component of this research is to have spectral images rather than trichromatic images. We need so-called multispectral images. There are various techniques to estimate spectral scene data rather than make direct measurements at every 10nm or 20nm throughout the visible spectrum. This has been a portion of the doctoral research of Peter Burns. Peter has also been concerned with describing noise in multispectral imaging and adding this factor to camera design. This year, we presented research results at the Optical Society of America's annual meeting and the Scottsdale Color Imaging Conference. We also had a paper accepted in *Color, Research, and Application* on noise propagation.

Color Modeling

In the past, MCSL has focused on continuous tone imaging systems. Recently we have become interested in halftone printers, particularly ink jet. Hewlett Packard's Barcelona Division is supporting a two year research effort. The first year focused on modeling the spectral properties of their large-format ink jet printers. Animesh Bose and Di-Yuan Tzeng assisted me in this research. We found that both the Yule-Nielsen modified Murray-Davies and transparent Kubelka-Munk models well predicted the spectral properties of primary ramps. Colors within the gamut were poorly predicted by both models necessitating the addition of a "relaxed colorant selector" based on a FM screening halftone algorithm with 100% gray component replacement. A technical report has been written. Through collaborative research with our visiting scientist from Toppan, Koichi Iino, we have been modeling the spectral properties of ink-jet printers using a dot-on-dot halftone algorithm. Koichi evaluated both the the Yule-Nielsen modified Murray-Davies and Omatsu models where optical parameters were optimized as functions of wavelength. This was combined with a simple multiple-linear regression scanner model to build and test color-management modules for desktop publishing. We have prepared a manuscript for submission to the Journal of Electronic Imaging. Following this research, Koichi applied the same techniques to 3M Matchprint as a representation of offset lithography. In this case, an interaction stage was required to model tertiary and quaternary colors, a result of "optical trapping." The modeling was incorporated into a color-management module for offset printing. The results of this research will also be submitted to the *Journal of Electronic Imaging* and the *AIC Quadrennium* in Kyoto.

Finally, three past projects have finally found their way into print. About two years ago, I was asked to write an overview article for *Displays* that has finally found its way into print. During the same time period, Toru Tanaka from Fuji-Xerox was in residence with us as a visiting scientist. His research evaluating appearance models as predictors of image quality for overhead transparencies was accepted into the *Journal of Electronic Imaging*. Three years ago, Lisa Reniff noticed that simulated spectrophotometric

errors were linearly related to CIELAB coordinates for many of the BCRA tiles. This lead to research in developing an abridged technique to diagnose photometric and wavelength errors in color spectrophotometers. An oral presentation was given at the ISCC annual meeting in Orlando and an article detailing this technique was accepted for publication in *Color, Research, and Application*.

Publications

R.S. Berns, "Deriving instrumental tolerances from pass-fail and colorimetric data," *Color Res. Appl.* **21**, 459-472 (1996).

R.S. Berns, "Methods for characterizing CRT displays," *Displays*, **16**, 173-182 (1996).

M.D. Fairchild, R.S. Berns, and A.A. Lester, "Accurate color reproduction of CRT-displayed images as projected 35mm slides, *J. Electronic Imaging* **5**, 87-96 1996.

M. Melgosa, E. Hita, A.J. Poza, D.H. Alman, and R.S. Berns, "Suprathreshold color-difference ellipsoids for surface colors," *Color Res. Appl.* **20**, in press 1997.

P.D. Burns and R.S. Berns, "Error propagation in color signal transformations," *Color Res. Appl.*, in press 1997.

R.S. Berns and L.A. Reniff, "A Practical Technique to Diagnose spectrophotometric errors," *Color Res. Appl.*, in press 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*, in press, 1997.

Invited Presentations

R.S. Berns, "Color Difference Equations from MacAdam to the Present," *Horizons - In Color Science- A Tribute to David L. MacAdam*, Rochester, (1996).

R.S. Berns, "Review of Colorimetry in Image Technology," Proceedings CIE Expert Symposium '96 Colour Standards for Image Technology, *Pub. CIE x010-1996*, 29-34 (1996).

R.S. Berns, "Computer-controlled CRT colorimetry: a view from CIE," *Proceedings IS&T/SID Fourth Color Imaging Conference*, 227-229 (1996).

Presentations

P.D. Burns and R.S. Berns, "Analysis of multispectral image capture," *Proceedings Fourth IS&T/SID Color Imaging Conference*, 19-22 (1996).

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

R.S. Berns and L. Reniff, A Practical Technique to Diagnose Spectrophotometric Errors, *ISCC Annual Meeting*, Orlando, (1996).

Technical Reports

R. S. Berns, A. Bose, D. Tzeng, "The spectral modeling of large-format ink-jet printers," MCSL technical report, 1996.

Research - Jonathan S. Arney

The Optics of Papers: MTF Analysis

Paper remains a major medium for non-impact printing, and the optical properties of paper have a significant impact on tone and color reproduction. Most printing processes use some form of halftone to control tone and color reproduction, and the way light scatters within paper governs the probability that the light will be absorbed by the halftone dots. This lateral scattering acts, in effect, is an optical blurring of the halftone dots and results in an overall darkening of the image. Few reports had been published on the lateral scatter properties of paper, so a project was initiated to carry out a systematic study of the scattering characteristics of a series of papers and other substrates commonly found in non-impact printing applications. The substrates ranged from recycled, non-coated papers, to coated papers, to non-fiber plastic substrates. The substrates were characterized by their scattering "point-spread function," expressed in the Fourier frequency domain as the MTF. The project compared the results of direct measurements of MTF with the MTF calculated from reflectance measurements and Kubelka-Munk theory. The results, published as "An MTF Analysis of Papers," were used as a foundation for an experimental and theoretical study of tone reproduction in halftone printed images, as described below.

Modeling Halftone Imaging: The Yule-Nielsen Effect

Tone reproduction in halftone images has long been modeled empirically with the so called Yule-Nielsen equation. The thrust of the current work was to develop a mechanistic understanding and a quantitative model of the microstructure of halftone images and the microscopic interaction between light, ink, and paper. Direct measurements were made of the microscopic reflectance of halftone dots and the paper between the dots. The results provided a quantitative, experimental measure of the way in which ink and paper reflectance changes as a function of the fractional area of the paper covered by the halftone dots. The observed behavior was found to be in agreement with theoretical predictions based on the paper MTF and the dot, or line, pattern of the halftone. In addition, an empirical model of the microstructure change in ink and paper reflectance with dot area fraction which had been published earlier was rationalized theoretically. Published reports of this work are "An Expanded Murray-Davies Model of Tone Reproduction," and "Modeling the Yule-Nielsen Effect."

Further Work in Image Microstructure

The current focus of research in image microstructure is on the impact of different halftone patterns (clustered dots, disperse dots, error diffusion, *etc.*) on tone and color microstructure and on the characteristics of ink jet and laser jet technologies. These projects will move from the experimental analysis of tone reproduction into the area of color microstructure analysis. The results are expected to lead to improved understanding of the physical and optical limits and potentials of non-impact printing.

Publications

J.S. Arney, P.G. Engeldrum, C.D. Arney, and M. Katsube, "An MTF Analysis of Papers," *J. Imag. Sci. & Tech.*, **40**, 19-25 (1996).

J.S. Arney, C.D. Arney, and P.G. Engeldrum, "Modeling the Yule-Nielsen Effect," *J. Imag. Sci. & Tech.*, **40**, 233-238 (1996).

Presentations

J.S. Arney, C.D. Arney, M. Katsube, and P.G. Engledrum, "The Impact of Paper Optical Properties on Hard Copy Image Quality," *Proceedings of the 12th International Conference on Digital Printing Technologies*, San Antonio, TX, 166-170 (1996).

Research - Ethan D. Montag

Color Gamut Mapping
During the past year I completed the first part of an extended research project dealing with color gamut mapping funded under the auspices of the NYF-NYS/IUCRC and NYSSTF-CAT Center for Electronic Imaging. This part of the project dealt with the evaluation of gamut mapping algorithms in which only one color attribute, lightness or chroma, of the image was mapped at a time. There were quite a few algorithms tested so the data analysis was quite involved, however a clear picture of the results soon emerged.

I presented the results of these experiments at the IS&T/SPIE Symposium on Electronic Imaging in San Jose at the end of January . A paper was submitted and subsequently accepted for publication in a special issue of the *IEEE Transactions on Image Processing*. Some additional data analysis was of course necessary in order to please the reviewers and through this process I have come to a better understanding of the results.

Based on these results I have been developing the next series of experiments in which simultaneous gamut mapping of chroma and lightness will be studied with gamuts more similar to those found in real devices. I am working on new images to use as stimuli that will push the algorithms to their limits in order to test how well they succeed for difficult subject matter such as detail in the dark, shadowy regions of an image. Another focus of this research is whether gamut mapping algorithms can be used globally on an image as opposed to using different algorithms for different regions of color space.

Vision Research
During the summer I finished writing up a project I began as a postdoctoral fellow at the University of Rochester studying the relationship between form and color. This work has been accepted for publication in the *Journal of the Optical Society A*. This study involved the measurement of the changes in thresholds for chromatic stimuli due to the influence of boundary information. I found that sensitivity to color can be enhanced or degraded depending on how close the color to be detected is to a superimposed grating.

Industrial Color Tolerance
I also became involved in a research project with Roy Berns and Lisa Reniff involving the measurement of color differences. This project is part of the work being done for the MCSL Industrial Color Difference Consortium. One aspect of this project involves confirming some previous results found by Yue Qiao as part of her Masters Thesis by repeating part of the experiments with the original stimuli, reformulated paint samples, and simulating it on a CRT. We hope that we can acquire the ability to perform these types of color tolerance experiments using a computer controlled CRT in order to gain speed and flexibility in data collection and analysis. In addition we hope that through the use of CRT displays we can simulate different appearance aspects of different media and thereby measure tolerances for the different media.

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** in press (1997).

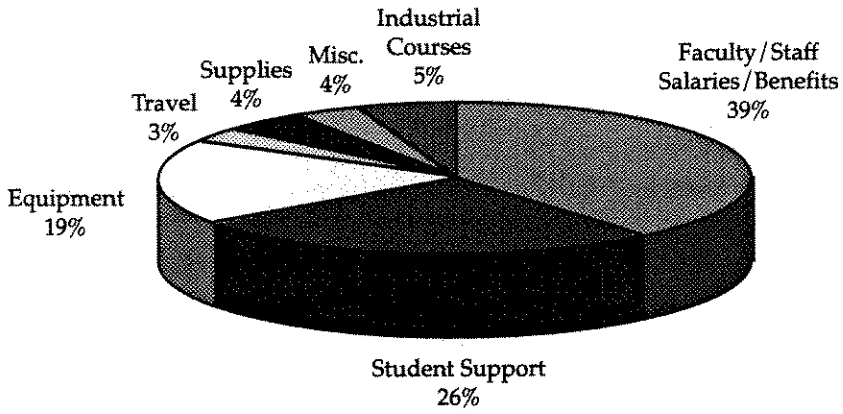
E.D. Montag, "The Influence of Boundary Information on the Perception of Color," *Journal of the Optical Society A*, **14** in press (1997).

Presentations
E.D. Montag and M.D.Fairchild, "Simulated Color Gamut Mapping Using Simple Rendered Images," *Proc. SPIE 2658*, San Jose, 316-325(1996).

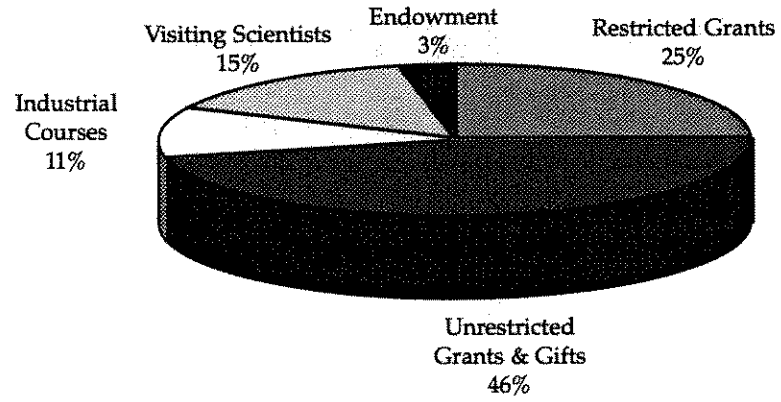
Funding

The total MCSL budget for 1996 was in excess of $500,000 (excluding the Hunter Chair and related accounts). 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 (71%) is generated by research grants and gifts while the majority of our expenditures (65%) are for student, faculty, and staff salaries and benefits. Sources of grants, gifts, and equipment donations are acknowledged below.

MCSL Income



MCSL Expenditures



Sources of Support

Gifts & Grants

3M, Bayer, Datacolor International, Detroit Colour Council, DuPont, DyStar, Eastman Kodak, Fuji Photo Film, Hewlett Packard(Barcelona and San Diego Divisions), Inter-Society Color Council, Macbeth, NYSSTF-CAT, NSF-NYS IUCRC, Society of Plastics Engineers, Sony, Toppan Printing, and Xerox.

Equipment Donations

5D Ltd, Accuracy Microsensors, Inc. Hewlett Packard, Management Graphics, Calvin S. McCamy, R.R. Donnelley & Sons, and Sony.

Color Science M.S. Curriculum

Enrollment in the Color Science M.S. program during 1996 was 5 full-time and 7 part-time students. With an increase in the number of faculty able to teach color science courses, we have made some scheduling changes this year that will be implemented beginning Fall, 1997.

Required Courses

Fall (Yr. 1)

1050-701 Vision and Psychophysics	4 Credit Hours
1050-702 Applied Colorimetry	4 Credit Hours
1050-811 Color Measurement Laboratory I	2 Credit Hours
1050-801 Color Science Seminar	3 Credit Hours

Winter

1050-703 Color Appearance	3 Credit Hours
1050-712 Color Measurement Laboratory II	2 Credit Hours

Spring

1050-813 Color Modeling	4 Credit Hours

Many of our students have interests in color imaging. The following is a typical schedule of courses for full-time students. Two new color imaging courses are included in this schedule, Color Reproduction and Color Systems.

Color Imaging New Course Track*

Fall (Yr. 1)

1050-701 Vision and Psychophysics	4 Credit Hours
1050-702 Applied Colorimetry	4 Credit Hours
1050-811 Color Measurement Laboratory I	2 Credit Hours
0307-801 Design of Experiments I	3 Credit Hours

Winter

1050-703 Color Appearance	3 Credit Hours
1050-712 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

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

1996 Industrial Short Courses

Principles of Industrial Color Measurement

- *Instructors:* Drs. Roy S. Berns and Mark D. Fairchild
- 42 participants
- Some participating companies included: Barco Graphics, BASF, Dupont, John Deere and Olan Mills.

Industrial Instrumental Color Matching

- *Instructor:* Mr. Ralph A. Stanziola
- 24 participants
- Some participating companies included: Eastman Kodak, Dupont, PPG and ReedSpectrum.

Device-Independent Color Imaging

- *Instructor:* Dr. Roy Berns
- 24 participants **[SOLD OUT]**
- Some participating companies included: Pantone, Eastman Kodak, Xerox, and L'Oreal.

Color-Appearance Models: Theory & Practice

- *Instructor:* Dr. Mark Fairchild
- 20 participants **[SOLD OUT]**
- Some participating companies included: Dupont, 3M, University of California at San Diego, and Xerox.

1997 Scheduled Short Courses

June 16-18, 1997 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 19, 1997 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.

NEW "Foundations of Color Management Systems"

June 23-27, 1997 Foundations of Color Management 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 Postcript Level II, ICC, and KPCMS providing "plug and play" capabilities.

Section one: Colorimetry, offered on June 23, 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: Device Profiles, offered on June 24-25, 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 26-27, 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, and ATD), 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 more information contact:
Colleen M. Desimone
Telephone: 716-475-7189 Fax: 716-475-5988
Electronic 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 truncated list of MCSL Technical Reports published during the last five years. These reports contain various types of information and are 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.

- **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

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

1995

M.D. Fairchild and L. Reniff, "Time-Course of Chromatic Adaptation for Color-Appearance Judgements," *J. Opt. Soc. Am. A*, **12**, 824-833 (1995).

J.S. Arney, P.G. Engledrum, and H. Zeng, "An Expanded Murray-Davies Model of Tone Reproduction in Halftone Imaging", *J. Imag. Sci. & Tech.*, **39**, 502-506 (1995).

P.C. Hung and R.S. Berns, "Determination of Constant Hue Loci for a CRT Gamut and their Predictions using Color Appearance Spaces," *Color Res. Appl.*, **20**, 285-295 (1995).

M.D. Fairchild, and R.L. Alfvin, "Precision of Color Matches and Accuracy of Color Matching Functions in Cross-Media Color Reproduction," *IS&T/SID 3rd Color Imaging Conference*, Scottsdale, 18-21 (1995).

E. Pirrotta and M.D. Fairchild, "Directly Testing Chromatic-Adaptation Models using Object Colors," *Proceedings of the 23rd Session of the CIE* (New Delhi) Vol. **1**, 77-78 (1995).

R.S. Berns, "Rochester Institute of Technology Promotes Color Science," *Digital Output*, Vol.1, No. **2**, 40 (1995).

M.D. Fairchild, "Considering the Surround in Device-Independent Color Imaging," *Color Res. Appl.*, **20** 352-363(1995).

N. Moroney, and M.D. Fairchild, "Color Space Selection for JPEG Image Compression," *J. Electronic Imaging*, **4** 373-381(1995).

R.S. Berns and M.J. Shyu, "Colorimetric Characterization of a Desktop Drum Scanner using a Spectral Model," *J. Electronic Imaging* **4**, 360-372 (1995).

K.M. Braun, and M.D. Fairchild, "Evaluation of Five Color-Appearance Transforms Across Changes in Viewing Conditions and Media," *IS&T/SID 3rd Color Imaging Conference*, Scottsdale, 93-96 (1995).

M.D. Fairchild, "Considering the Surround in Device-Independent Color Imaging," 1995 C. James Bartleson Lecture, ISCC Pan-Chromatic Conference, Williamsburg (1995).

R.S. Berns and K. Iino, "Spectral Modeling of an Ink jet Printer," *Electronic Imaging*, **5** No. 2, 3 (1995).

R.S. Berns, "Applied Colorimetry Part I: Materials," *Optics Photonics News*, September, 23-27 and 53 (1995).

R.S. Berns, "Applied Colorimetry Part II: Imaging," *Optics Photonics News*, October, 23-27 (1995).

M.D. Fairchild, "Testing Colour-Appearance Models: Guidelines for Coordinated Research," *Color Res. Appl.*, **20** 262-267 (1995).

M.D. Fairchild, "Testing Colour-Appearance Models: Guidelines for Coordinated Research," *CIE Publication* **118/5**, 39-46 (1995).

R.S. Berns and H.K Choh, "Cathode-Ray-Tube to Reflection-Print Matching Under Mixed Chromatic Adaptation using RLAB," *J. Electronic Imaging*, **4**, 347-359 (1995).

1994

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Munsell Color Science Laboratory Advisory Board

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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
10 Kewferry Road
Northwood, Middlesex
United Kingdom HA6 2NY

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

Mr. Rolf G. Kuehni
Dystar L.P., Pine Brook III
9844 Southern Pine Blvd.
Charlotte, NC 28201

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

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

Mr. Ricardo Motta
Hewlett-Packard Laboratories
1501 Page Mill Rd.
Palo Alto, CA 94304-1181

Dr. Yoshinobu Nayatani
Osaka Electro-Communication University
18-8 Hatsu-uho
Neyagawa, Osaka 572
Japan

Dr. Noboru Ohta
Fuji Photo Film Company, Ltd.
210 Kakanuma, Miniami-asigara
Kanagawa-ken 250-01
Japan

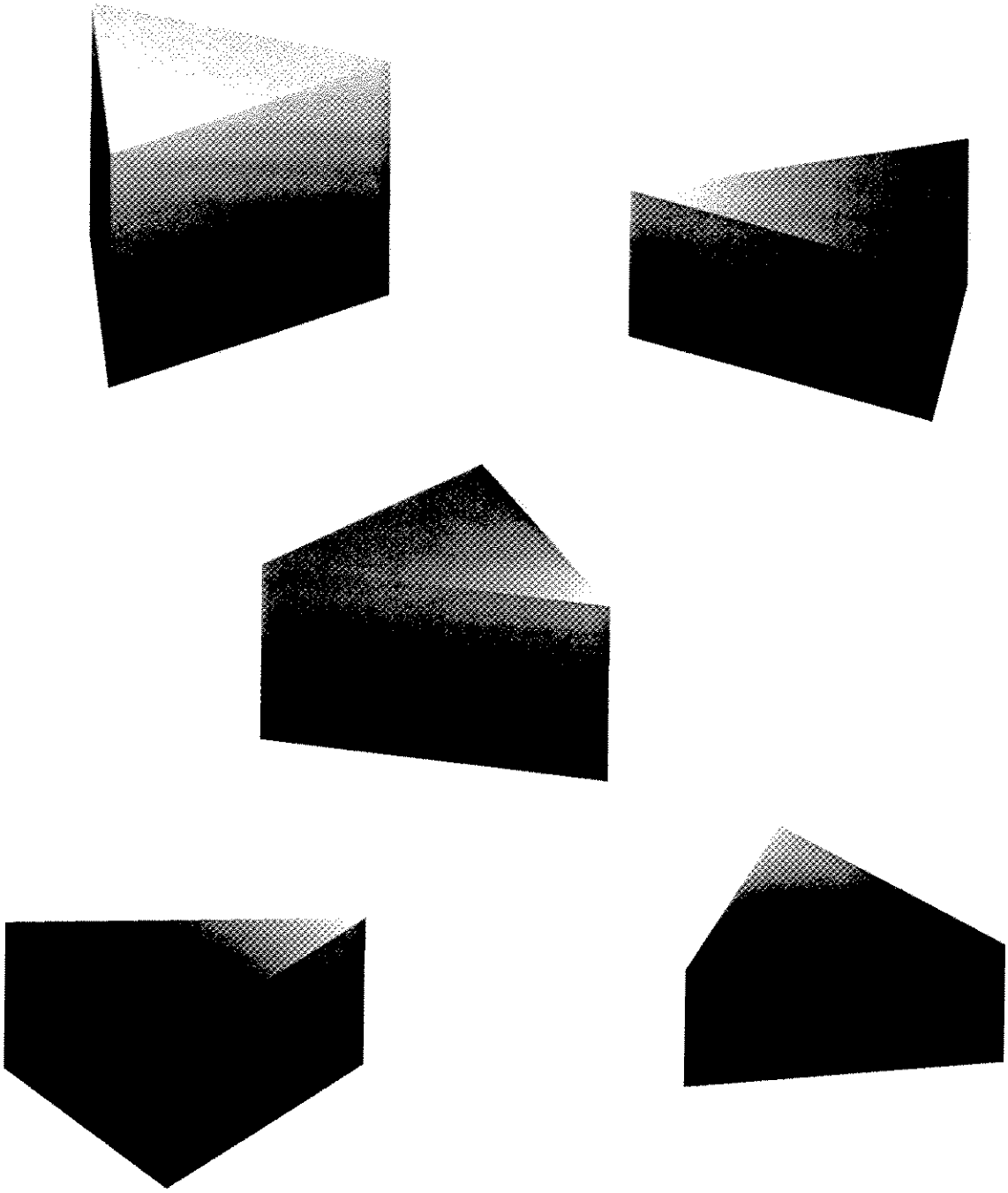
Mr. Milton Pearson
RIT Research Corporation
125 Tech Park Drive
Rochester, NY 14623

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

Dr. Danny C. Rich
Datacolor International
P.O. Box 5800
Princeton, NJ 08540

Dr. Alan R. Robertson
National Research Council
Division of Physics
Ottawa, Ontario K1A OR6
Canada

Dr. Joann Taylor
Color Technology Solutions
17890 NW Deercreek Court
Portland, OR 97208



Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology
54 Lomb Memorial Drive
Rochester, New York 14623-5604