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Program Objectives

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. The Munsell Color Science Laboratory 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."

Both endowed programs operate hand in hand on a daily basis. The following four basic objectives help guide their activities: 1) To provide undergraduate and graduate education in color science, 2) To carry on research and development in color and appearance, 3) To establish a sound standardization program in areas where standards are either void or difficult to obtain from other sources, and 4) To provide an essential ingredient for the success of the first three — namely, liaison with industry.
The Year In Review

One of the cliches to appear in 1991 is "cultural diversity;" during the past year I experienced tremendous cultural diversity through my travels relating to color. During June, I went to Australia to attend the International Association of Color (AIC) interim conference on Light and Color held in Sidney followed by the International Commission on Illumination (CIE) 22nd Session held in Melbourne. I met many new faces from around the world, rekindled old relationships, and thoroughly enjoyed the color enthusiasts from the Australian Color Society. Many were artists and designers; I always find their views insightful and challenging, particularly since I presented a paper at the AIC conference about the influence of cognitive clues and instructions on color perception. Interestingly, the aesthetic constituency were more receptive to my ideas than the colorimetrist.

During December, I went to Japan for the first time along with other faculty and staff from RIT to take part in a meeting of the Center for Imaging Science Industrial Associates Program. I also made several site visits to Japanese companies. The experience was exhilarating. I found the Japanese social and work cultures very different from my previous experiences. In particular, the Deming team approach to research and development made quite an impression on me; I hope to apply my new-found, first-hand knowledge within MCSL.

Within the laboratory, there were many changes this year. Our first visiting scholar from Konica Corporation, P.-Chieh Hung, returned to Japan. Konica sent a second scholar, Toru Hoshino. He will continue researching color reproduction concentrating on gamut mapping and preferred color reproduction. Near the end of the year, a visiting scholar from Dupont joined us, Taek Kim. Taek returns to RIT having been a undergraduate and graduate student in imaging science. Taek will also perform research in color reproduction. Mark Gorzynski, an associate scientist with MCSL for the last two years, left RIT and joined Tektronix in Beaverton, Oregon. Mike Stokes, one of our color science graduates, assumed Mark's position. In addition, Mike will pursue a doctoral degree in imaging science on a part-time basis.

Another area of change was the establishment of several industry-sponsored scholarships. R.R. Donnelley & Sons, who supported Mike Stokes last year, renewed their support; Elizabeth Pirrotta will be the Donnelley Scholar. Elizabeth will be performing experiments to test current color appearance models. BASF Corporation, Carpet Fibers Division, established a scholarship in the area of color and texture analysis using image processing. Seth Ansell, as the BASF Scholar, will be continuing the pilot experiments on texture analysis I described in April 1990 at the Symposium on Color and Appearance of Instrumentation (SCAI) in Cleveland, Ohio. Eastman Kodak established a scholarship in color appearance psychophysics for hybrid imaging. Kodak will be supporting Amy North throughout her doctoral studies. We are very excited since this scholarship is a multi-year commitment.
Instrument manufacturers and a variety of corporations continue to support our programs by generously donating hardware and unrestricted funds. We have two new supporters: Monsanto Chemical Company and Welch Allyn, Inc. It is exciting to be supported by such diverse companies. In addition to scholarship support, R.R. Donnelley & Sons is also supporting our research efforts by loaning a Pixar II image computer. This is our second Pixar system and will greatly enhance our ability to make color appearance measurements.

As I write this review, I realize that our most important accomplishment has not been documented, the development of a color science "family." The commitment of Mark, Lisa, Mike, Colleen, and our students and visiting scholars to our shared vision of becoming an international color science resource is difficult to express in words. I am so proud of everyone. Mark was made a chairman of a CIE technical committee. Lisa developed a 45/0 measurement assurance program. Mike had his master's research accepted for presentation at the upcoming Williamsburg conference. Colleen now directs our industrial short courses and has begun making spectrophotometric measurements. Daily I am amazed by the care and thoughtfulness of the staff and their commitment to excellence. During 1992 I hope to expand our "family" by interacting with the rest of the RIT color community. Color is exploding in graphic design, the School for the American Craftsman, printing, electronic photography, and animation. I plan to use the personal monetary support of Mrs. Elizabeth Hunter to support my efforts in this area.

In closing, the future, as my secretary Colleen would say, looks colorful, indeed!

Roy S. Berns, Ph.D.
Richard S. Hunter Professor
Director, Munsell Color Science Laboratory

January, 1992
The following reports summarize the activities during 1991 of faculty, staff, and visiting scholars.

Mark D. Fairchild, Assistant Professor, (716) 475-2784

Could it be that my life is settling down? This is the first year that I can honestly say I did pretty much the same things as I did the year before ... how boring. Not really, there's no time for boredom at MCSI. It's tempting to use this section to write about research, papers, courses, technical committees, etc. But that information is elsewhere in this report. Instead, I'm using this space to try to share how my thinking about color science has developed over the past year.

My overall objective has been to better understand why colored stimuli appear the way they do. During the past 12 months, I've had 3 major influences: computers, photography, and psychology. I've been using and programming new computers with color imaging capability. The surprising thing about this is that these capabilities are quickly becoming part of general purpose computers such as NeXT and Macintosh workstations. Specialized hardware is no longer required. The capabilities of these machines make possible color appearance research that we couldn't have imagined just a few years ago. I've also been interpreting gallery shows at the International Museum of Photography. Training for this volunteer work and teaching a color reproduction course last spring have rekindled my enthusiasm for photography. Thinking about the history, aesthetics, and technology of photography has reminded me of many factors that influence the color appearance of objects and reproductions. It is no wonder so many significant contributions to color science were made by photographic researchers. Lastly, much of my research has pointed to factors beyond the physical that influence the appearance of colors. These cognitive factors are very important in color appearance and reproduction and I've been trying to learn more about them. I think these influences have given me a better understanding of why colors appear the way they do. I hope I'll be able to share.

Some of that sharing should take place through two new responsibilities I assumed this past year. I am co-chair of ISCC Interest Group #2, Appearance, Vision, and Modeling and chair of CIE TC1-34, Testing Color Appearance Models. I hope I can fulfill these duties to everyone's satisfaction.

Thanks to all involved with MCSI: students, staff, faculty, advisors, and supporters.
Lisa Reniff, Associate Scientist. (716) 475-7188  

It's hard to believe I've been working in the Laboratory for three years now. I can now say with experience that I enjoy my job very much. This position allows me to continue to learn deeper aspects of color science and areas of many other fields. The academic setting is very conducive to this with more courses and seminars than time allows. The seminar class that Roy and Mark lead every year is one that is fun with a different subject discussed every week based on recent journal articles. The various research projects continue to be interesting and expand my knowledge. Recently, I performed a project on the time course of adaptation, which required my introduction into the land of UNIX and C.

Another large component of this position that I find enjoyable is the opportunity to help people. A large portion of my day is spent helping students either with research ideas, how to work equipment or helping TA's set up laboratories. I also provide a service of measurement or characterization of materials for calibration for industrial use. However, interpreting the vocabulary of industry people to answer their questions is always challenging.

Having Mike join our staff in June was great. His enthusiasm and helpfulness are wonderful and infectious.

Mike Stokes, Associate Scientist. (716) 475-7186  
B.S., Mathematics, University of Texas at Austin, 1989.  

I joined the Munsell Lab in June after spending the last two years here as a graduate student. Before coming to RIT I had spent fifteen years in the slide reproduction and video transfer industries. My industry training is in research, quality control, computer programming and production management. I have also been accepted into RIT's Ph.D. program in Imaging Science and am working part-time toward this degree.

My first six months on staff here have been very busy. I officially received my Master's degree in August and submitted my first article for publication in September. A second article has been accepted for presentation and publication at the Williamsburg Conference on Cross-Media Color Reproduction in 1992. Both of these articles relate to my research on colorimetric tolerances for digital images.

The laboratory has continued to grow and I have been busy trying to install and maintain the computer systems. The student color modeling lab has been converted to a Macintosh based system making it much easier for the students to work with. A second Macintosh based prepress system for research in color appearance and reproduction is currently being installed in a room with controlled illumination. A mobile IBM-PC based system for doing color measurements around the lab was created, after receiving a second Photo-Research Spectroradiometer. R. R. Donnelley generously donated a second Pixar Imaging Computer which was promptly installed on our second Sun computer system.
I am finding it exciting to work with the students, forcing me to shore up my knowledge of color science.

**Toru Hoshino, Visiting Scholar**  
B.S., Imaging Science and Engineering, Chiba University, 1986.  
Working for Konica Corporation from 1986 to present

Time goes too fast. I have already spent nine months here since February when I came here as the second visiting scholar from Konica. Being in a new country and living by myself, I felt that there were lots of hard things to do: cooking, washing dishes, laundry, and so on. Would I be doing these same things if still in Japan? Maybe. Anyway, I think I should have found a wife and come here with her.

This year has been in preparation for my research. Besides English language and C language, I learned lots of new things in color science in this laboratory. I now have many ideas about color manipulation using a recent color appearance model which will be my major concentration as my research project.

I would like to try to get good results in my research project and improve myself with the good facilities and people in this laboratory during the next fifteen months.

**Taek Gyu Kim, Visiting Scholar**  
M.S. Imaging Science, RIT.  
Working for DuPont from 1989 to present.

Moving back to Rochester was quite a challenge after being spoiled by the California weather. But thinking back about my previous time at RIT where my "office" was a converted photographic darkroom, it is really exciting to have a room with a view in the Center for Imaging Science. I am still trying to get used to the new environment. I am gears up. I am ready to explore fundamentals of the color world.

My current interest is in the calibration of devices for independent color space including color imaging processing using new appearance models. I am learning more about color instruments with a different view point, too. Getting answers from people at Munsell Color Science Laboratory for all kinds of trivial questions that I had while working in the industry is really helpful. I found the questions were not trivial after all.

I will go back to DuPont Imaging System at the end of 1992. The kind of relationship I have found with the Munsell Color Science Laboratory I will keep with me as my contribution to DuPont grows.
Students

The following are students studying in color science.

FULL TIME GRADUATE
Seth Ansell, M.S. Candidate, Color Science
Gaurav Govil, M.S. Candidate, Computer Science
Timothy Kohler, M.S. Candidate, Color Science
Nathan Moroney, M.S. Candidate, Color Science
Amy North, Ph.D. Candidate, Imaging Science
Elizabeth Pirrotta, M.S. Candidate, Color Science
Brian Rose, M.S. Candidate, Color Science

PART-TIME GRADUATE
Jim Adams, Ph.D. Candidate, Imaging Science
  B.S., Physics, Monmouth College, 1979.
  B.S., Electronic Device Physics, Monmouth College, 1979.
  M.S., Optics, University of Rochester, 1984.
Richard Riffel, M.S. Candidate, Imaging Science
Mike Stokes, Ph.D. Candidate, Imaging Science
  B.S., Mathematics, University of Texas at Austin, 1989.
Debbie Vent, M.S. Candidate, Imaging Science
  B.S., Optics, University of Rochester, 1988.
Jeffrey Wang, Ph.D. Candidate, Imaging Science
  B.S., Graphic Arts, Chinese Culture University, 1982.

FULL-TIME UNDERGRADUATE
Paul Doll, B.S. Candidate, Imaging Science
Alex Granica, B.S. Candidate, Imaging Science
Rebecca Ouellette, B.S. Candidate, Imaging Science
Adam Portnoy, B.S. Candidate, Imaging Science
Funding

The Richard S. Hunter Professorship and Munsell Color Science Laboratory has been generously supported by industrial and individual donors. Many of our research efforts, the maintenance of our facilities, and the support of students would not be possible without this support. The support from instrument manufacturers continues to flourish. Having state-of-the-art instrumentation makes our industrial seminars and our academic coursework much more relevant.

The following lists our supporters during the time period of this annual report.

SCHOLARSHIPS
Scholarship support is difficult to quantify. Corporations may contribute direct and future funding, technical support, hardware, and Summer intern positions. The total costs for a full-time student including course work, 12 month stipend, and laboratory support are approximately $40,000 per calendar year. The following scholarships were established during 1991:

BASF Corporation
Eastman Kodak Company
R.R. Donnelley & Sons, Incorporated

UNRESTRICTED RESEARCH GRANTS AND GIFTS
3M Company..................................................$5,000
Elizabeth Hunter.................................$10,000
Monsanto Chemical Company..............$10,000
PPG Industry Foundation.....................$5000
Tektronix Incorporated......................$10,000
Welch Allyn, Incorporated..................$5,000
DEVICES

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<tr>
<th>Donor</th>
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<tr>
<td>BYK Gardner, Incorporated</td>
<td>BYK Color Sphere</td>
<td>$12,000</td>
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<tr>
<td>Datacolor International</td>
<td>Tape Series</td>
<td>$350</td>
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<tr>
<td></td>
<td>Paint II software upgrade</td>
<td>$2,000</td>
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<tr>
<td>Hewlett Packard Laboratory</td>
<td>Graphic Accelerator</td>
<td>$17,000</td>
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<td>Hunter Associates Laboratory</td>
<td>Portable Spectrophotometer w/utilities</td>
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<td>LMT</td>
<td>The Photonic Directory</td>
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<tr>
<td>Macbeth/Munsell Color Co.</td>
<td>Munsell Color Samples</td>
<td>$350</td>
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<td>Minolta Corporation</td>
<td>CM-1000 Spectrophotometer</td>
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<td></td>
<td>CA-100 Color Analyzer</td>
<td>$5,880</td>
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<td>Data Processor DP 101</td>
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<td>CM 2002 Spectrophotometer</td>
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<tr>
<td>Photo Research</td>
<td>PR703A Spectroradiometer</td>
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<td>R.R. Donnelley &amp; Sons, Inc.</td>
<td>Pixar II - Long Term Loan</td>
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<td>Tektronix, Incorporated</td>
<td>TekColor System Implementor's Guide</td>
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<td></td>
<td>TekColor software</td>
<td>$50</td>
</tr>
<tr>
<td>Welch Allyn, Incorporated</td>
<td>Ophthalmoscope</td>
<td>$200</td>
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Research Contracts:

DuPont Company
  Topic: Industrial color tolerances

Xerox Corporation
  Topic: Measurement assurance program for 45/0 spectrophotometry
Research and Development

Research topics that were investigated in the past year are listed below in no particular order. The sources of funding are listed in brackets. The acronym MCSL means that the research was supported with the general research funds of the Munsell Color Science Laboratory. The acronym RSHP means that the research was supported through the Richard S. Hunter Professorship. We have provided a brief description on what each topic is about and this year's progress. Please refer to the publications list on pages 18 and 30 for references to more information on this research and feel free to contact any of us at the laboratory.

Chromatic Adaptation and Color Appearance Modeling
[MCSL, Du Pont Imaging]
Mark Fairchild

A chromatic adaptation model was reported at the 22nd CIE session and appeared in *Color Research and Application* in 1991. This model and other color appearance models have been implemented for use in color reproduction research. Preliminary experiments have shown this model to perform very well for cross-media color reproduction. Much of this work will be discussed at the upcoming ISCC/TAGA Williamsburg meeting in 1992.

Measurement Assurance Programs for Spectrophotometry
[Xerox Corporation, MCSL]
Lisa Reniff, Mark Fairchild, Roy Berns

A measurement assurance program (MAP) was developed for 45/0 spectrophotometry. Research on a d/0 program is ongoing. These programs allow subscribers to measure a small set of tiles and then return the data to MCSL for evaluation. The subscribers then receive a report indicating the accuracy of their instrument and possible systematic errors it might be suffering from. The 45/0 MAP has been carried out with several sites.

Helmholtz-Kohlrausch Effect Modeling
[MCSL]
Mark Fairchild, Elizabeth Pirrotta

Given high and low chroma object colors of equal luminance factor, the high chroma color will appear lighter. This phenomenon is sometimes referred to as the Helmholtz-Kohlrausch effect. A model has been developed to correct the CIE L* equation so that it can predict the perceived lightness of chromatic as well as achromatic object colors. This model was reported at the 1991 ISCC meeting and has
appeared in the December *Color Research and Application*. Additional data have been obtained from CIE TC1-21 for further testing of this model.

**Exemplifying Photographic-Observer Metamerism**  
[MCSL, RSHF]  
Roy Berns, Brian Rose

One of the difficulties in demonstrating metamerism in an article is including real examples. In this project, three color charts were prepared, one of textiles, one dyed paper, and one using artists' acrylic paints. The charts were reproduced using a photographic transparency system, a negative-positive system, and a four-color proofing system. Slides were produced that demonstrate the effects of photographic-observer metamerism. A tutorial article that includes these images is being prepared and a talk was presented at the 1991 ISCC annual meeting.

**Evaluation of Object Texture Using Colorimetry-Based Image Processing**  
[BASF, MCSL]  
Seth Ansell, Roy Berns

The aim of this project is to find a color space that can be used for representing images in which it is possible to separate the visual aspects of color and texture. These analyses will aid in the formulation of textured materials and the simulation of images of these materials. For example, an image of a blue piece of carpet could be changed to an image of a red piece of carpet without destroying the information that allows an observer to recognize it as carpet. This will serve as the M.S. thesis topic for Seth Ansell.

**Testing Chromatic Adaptation Transforms**  
[R.R. Donelley & Sons Company, MCSL]  
Elizabeth Pirrotta, Mark Fairchild, Roy Berns

Prediction of the effects of chromatic adaptation is critical in many areas of color science. This project, Elizabeth's M.S. thesis, will mathematically compare the predictions of various chromatic adaptation models for a limited set of object colors and a range of viewing conditions. Then a pair of viewing conditions will be chosen for which the models make the most different predictions. A paired-comparison visual experiment will be carried out under these conditions to derive an interval scale that quantifies the quality of the models. This work should be completed in 1992.
Colorimetric Calibration of a Digital Film Recorder
[MCCL]
Mike Stokes, Roy Berns

Accurate color reproduction requires detailed knowledge of the characteristics of imaging devices. The objective of this project is to use physical and statistical models of photographic film to relate the tristimulus values of transparencies to the digital values sent to a film recorder. This work has already resulted in the ability to produce slides from computer images with significantly better tone and color reproduction than is typically available from standard digital film recorders.

Color Appearance of Images Presented in Different Media
[Eastman Kodak Company, MCCL]
Amy North, Mark Fairchild

Amy North is now in the Imaging Science Ph.D. program and will be investigating the appearance of color images in different media and viewing conditions. This research will be directly applicable to the work of CIE TC 1-27. The objectives are to test various color appearance models for predicting matches between various imaging modalities. Currently, a room is being designed and constructed with specialized lighting specifically for this type of research. Also a new Macintosh-based hybrid imaging system is being constructed that will be capable of scanning, displaying, and printing full-color images.

Color Science Education through Interactive Computer Graphics
[MCCL]
Brian Rose, Mark Fairchild

Graphics-based computer systems have provided new tools for scientists and designers that allow the manipulation of color in ways that are unfamiliar to many. Education in the fundamentals of color science, perception, and design would be very beneficial to these users. Brian Rose, for his M.S. thesis, is creating an interactive computer graphics program for the Macintosh that will be used by anyone with access to a color Macintosh and an interest in color to explore fundamental concepts of color science.

Color Tolerances of Pictorial Images
[R.R. Donnelley & Sons Company, Hewlett Packard, MCCL]
Mike Stokes, Mark Fairchild, Roy Berns

A large amount of data exists on the perceptual tolerances of individual colors. However, in color reproduction all of the colors in an image are changed simultaneously. This project examines just how far entire images can be
manipulated along perceptual dimensions of lightness, hue, and chroma before they become perceptually different and also until they become unacceptable. The results provide useful measurements of how close images have to be colorimetrically to be indistinguishable. The results will be presented at the upcoming ISCC/TAGA Williamsburg meeting in 1992.

Colorimetric Evaluation of Color Quantization in Digital Image Displays
[MCGL]
Alex Granica, Mark Fairchild

This is a senior research project designed to investigate the effects of quantization on color images. The result will be distributions of CIELAB color differences between nearest neighbor colors when images are quantized using 4, 6, 8, 10, and 12 bits per RGB channel and displayed on a typical graphics display monitor.

CIE-to-Munsell Conversion using Neural Network Models
[MCGL]
Paul Doll, Mark Fairchild

Neural networks, due to their huge number of free parameters, inherently nonlinear nature, and ease of implementation are finding many application in the realm of color science. This is a senior research project in which neural network models will be evaluated for performing CIE tristimulus value to Munsell notation transformations.

Color Difference Modeling
[Du Pont Automotive Products Department]
Roy Berns

The RIT-Dupont data base is comprised of 312 color difference pairs, each of equal visual difference. Equations are being derived from CIELAB and primary fundamentals (Stiles-Estevez-Hunt-Pointer) that model the data. The data base will also be used to test the performance of CMC and BFD. At the current stages of analysis, linear weightings of the chroma of the standard reduce the CIELAB variance as much as either CMC or BFD. Final equations will be tested by CIE TC 1-29 on industrial color difference evaluation.
Imaging Device Colorimetric Characterization Software
[Konica Corp., M CSL]
Po-Chieh Hung

Software has been developed that can be used to characterize color imaging devices using multidimensional look-up tables and interpolation. This software will allow the characterization of devices such as image scanners. The software allows the RGB signals from a scanner to be transformed to CIE tristimulus values given a look-up table that has been constructed with known samples of the same material. An article describing this research is in preparation.

Visual Determination of Constant Hue Loci
[Konica Corp., M CSL]
Po-Chieh Hung, Roy Berns

A visual experiment was performed using a CRT graphics display to determine loci of constant perceived hue for a wide variety of colors. The data are currently being analyzed in the CIELAB and CIELUV color spaces in order to determine which space might be better utilized for color gamut mapping when it is desired to keep hue constant. These data might also serve as valuable test data for color appearance models. An article describing this research is in preparation.

Investigation of Observer Metamerism
[Kollmorgen Foundation, New York State Center for Advanced Technology in Optics, M CSL ]
Amy North, Mark Fairchild

This project was designed to measure inter- and intra-observer variation in the measurement of color matching functions and served as Amy North's M.S. Thesis. Measurements of color matching functions were made for a large number of observers utilizing an abridged method reported previously. In addition, the measurements were compared with similar ones that were made using the National Research Council (NRC) trichromator in Ottawa, Canada. An article on the techniques has been submitted to Color Research and Application and a second that evaluates the CIE method for predicting observer metamerism will be submitted soon.

Modeling the Spectral Reflectance of Ink-Jet Printer Output
[Hewlett Packard Co.]
Ken Parton, Roy Berns

This study, which served as Ken Parton's M.S. thesis, evaluated the applicability of single-constant K-M theory to predicting the spectral reflectance
factor of printed ink jet samples. Several important results were found for the particular system studied. First, the choice of surface correction parameter was critical in determining model effectiveness. Second, because of fluorescent quenching and the manner that ink-jet drops mix on paper, the usual Duncan mixing equations were only approximate. As a consequence, for high accuracy modeling, more complicated mixing equations should be developed. However for many product development needs, this approach will be adequate. These results were presented at the Non-Impact Printing Conference during October in Oregon.

Lightfastness of Color Hard Copy
[MCSL, Image Permanence Institute]
Rebecca Ouellette, Roy Berns

The technology available to create a color reproduction by other than conventional silver halide has expanded greatly in the past few years. Images created with these devices are used for information and artistic purposes. It is not well documented whether these images have sufficient lightfastness. This senior project will investigate the light fading properties of several technologies including ink jet, dye diffusion, and electrophotography in comparison to conventional silver halide systems.

Characterization of a Flatbed Scanner
[MCSL]
Adam Portnoy, Mike Stokes

With the explosion of color desktop publishing in the last few years, the need for simple characterization methods for color desktop devices has become critical. Such characterizations include spatial non-uniformities, tone reproduction, and colorimetric reproduction. This senior project will characterize a typical flatbed scanner and test simple methods to calibrate these properties.

Gamut Mapping
[MCSL, Konica]
Toru Hoshino, Rab Govil, Roy Berns, Mark Fairchild

There are many issues that must be resolved in order to provide transparent cross-media reproduction to users. One of these issues is the disposition of colors that can be produced in one medium but are not producible in a second medium. Some of the colors produced in one medium might not be within the gamut of a second medium. When this occurs, an algorithm to move the out-of-gamut colors into the gamut of the printer must be implemented. Rab Govil will be implementing various algorithms to perform gamut mapping for his M.S. thesis in computer science. Toru Hoshino will be studying the theory of these techniques while visiting MCSL from Konica.
1991 Publications

The following is a list of reviewed articles and paper or abstract proceedings published or accepted for publication by faculty, staff, visiting scholars, and students of the Munsell Color Science Laboratory (listed in bold) during 1991. Past publications are listed beginning on page 27.


1991 Presentations


R.S. Berns, "Master of Science Degree Program in Color Science at Rochester Institute of Technology," presented to The Colour Society of Australia, Inc., Melbourne, Australia, July.


R.S. Berns and M.E. Gorzynski, "Characterizing the Total Uncertainty of the Colorimetric Calibration of Color Video Displays," poster paper and invited paper for CRT workshop, 22nd Session CIE Quadrennium, Melbourne, Australia, July.


Munsell Color Science 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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Dr. Danny C. Rich  
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Dr. Alan R. Robertson  
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Dr. Joann Taylor  
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Tektronix Industrial  
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Color Science Courses

There were no major revisions in the color science curriculum during the past year. However, considerable enhancements in the teaching facilities have been made. Two teaching laboratories have been constructed within the Munsell Laboratory. The first is a spectroradiometry laboratory that contains an optical bench and two array radiometers. This lab is heavily utilized in the Applied Colorimetry, Theory of Color Measurement and Optical Radiation Measurements courses. Students make various measurements of the characteristics of light sources and the instruments and construct various devices such as tristimulus colorimeters and spectrophotometers. The color modeling lab is the second addition. This laboratory houses a hybrid imaging system that consists of a monochrome CCD video camera, a frame grabber, a digital image processor, a full-color CRT display, and a dye-diffusion video printer. Various filters can be placed in front of the camera to allow capture of RGB, CIE tristimulus, or spectral images. The images can then be manipulated and displayed through the image processor and hard-copy generated with the thermal printer. This system will allow students to study the colorimetric problems in all aspects of image capture, display, and reproduction and will be mainly used for the Color Modeling course. The need to teach the fundamental aspects of color digital imaging has also been recognized and these topics will be addressed in the Color Modeling course. The Color Science Seminar has proven to be a great success, giving students valuable experience in oral communication and critical literature review. A list of the current catalog descriptions of the required courses for the M.S. in Color Science follows.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Credit Hours</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIMC-700</td>
<td>4</td>
<td>VISION AND PSYCHOPHYSICS</td>
</tr>
<tr>
<td>Registration#0926-700</td>
<td></td>
<td>This course provides an overview of the human visual system and psychophysical techniques used to investigate it. Topics include: the optical design of the eye; mechanisms of photoreception; neural coding; processing of visual information; and experimental techniques. Emphasis is placed on the mechanisms of color vision.</td>
</tr>
<tr>
<td>PIMC-701</td>
<td>4</td>
<td>APPLIED COLORIMETRY</td>
</tr>
<tr>
<td>Registration#0926-701</td>
<td></td>
<td>An introduction to the measurement and specification of color. The CIE system of colorimetry is presented with an emphasis on its practical application to common problems in quality control, reproduction, imaging, and formulation. The laboratory stresses the instrumental measurement of color and appearance.</td>
</tr>
<tr>
<td>Course Code</td>
<td>Credit Hours</td>
<td>Course Title</td>
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</tr>
<tr>
<td>PIMC-702</td>
<td>4</td>
<td>THEORY OF COLOR MEASUREMENT</td>
</tr>
<tr>
<td>Registration#0926-702</td>
<td></td>
<td>This course is designed for students with an understanding of the applications of colorimetry and presents the fundamental research leading to modern color measurement techniques. Material is presented to provide the background for further studies and research and development in the field of color science. Topics include; daylight specification, instrumental geometries, color matching functions, color appearance, color difference, and metamerism.</td>
</tr>
<tr>
<td>PIMC-801</td>
<td>3</td>
<td>COLOR SCIENCE SEMINAR</td>
</tr>
<tr>
<td>Registration#0926-801</td>
<td></td>
<td>A seminar course in which the students will study the literature in particular areas of color science and present that material to the class. Topics will be chosen based on student interest and current issues in the field.</td>
</tr>
<tr>
<td>PIMC-802</td>
<td>4</td>
<td>OPTICAL RADIATION MEASUREMENTS</td>
</tr>
<tr>
<td>Registration#0926-802</td>
<td></td>
<td>An in-depth treatment of the instrumentation and standardization required for accurate and precise measurements of optical radiation. The optical properties of objects and radiation sources will be covered. The optical and electronic design of spectroradiometric and spectrophotometric instrumentation is discussed in detail. The use of standard reference materials for the calibration and evaluation of instrumentation is explored. The laboratory is heavily stressed with students fully analyzing the design and performance of various instruments.</td>
</tr>
<tr>
<td>PIMC-803</td>
<td>4</td>
<td>COLOR MODELING</td>
</tr>
<tr>
<td>Registration#0926-803</td>
<td></td>
<td>This course explores mathematical techniques for predicting the coloring of various imaging systems including self-luminous displays, reversal color films, thermal dye transfer printers, and color scanners. Emphasis is placed on both analytical-physical and empirical-phenomenological approaches. Models include Kubelka-Munk turbid media theory for opaque, transparent, and translucent systems; Grassmann's laws for additive systems; and linear and higher order masking equations. Statistical techniques include multiple-linear regression and non-linear optimization via the simplex method. Accompanying laboratory stresses the characterization, calibration, and prediction of various imaging devices in a systems approach.</td>
</tr>
<tr>
<td>PIMC-890</td>
<td>9</td>
<td>RESEARCH AND THESIS</td>
</tr>
<tr>
<td>Registration#0926-890</td>
<td></td>
<td>Thesis based on experimental evidence obtained by the candidate in an appropriate topic as arranged between the candidate and the coordinator of the program.</td>
</tr>
</tbody>
</table>
Industrial Courses

Short Courses

This last year, our short course entitled COLORIMETRY: An Intensive Short Course for Scientists and Engineers was again a success; 49 participants attended the June course. This three day course is designed to teach the effective applications of colorimetry to persons involved in coatings, textiles, polymers, reprographics, and electronic imaging. The course stressed instrumental measurements particularly useful for instrumental quality control. This course will be offered June 3-5, 1992.

Our newest industrial Course, Principles of Color Reproduction: An Intensive Short Course taught by Dr. R.W.G. Hunt was held in September. This course nicely complements our COLORIMETRY course. Dr. Hunt spends half of the course teaching about how color is formed using photographic, television, and reprographic imaging modalities. The COLORIMETRY course intentionally omits any information about color formation. This course will be offered October 14-16, 1992.

During 1992, two new advanced courses will be presented for the first time. The first course, CRT Colorimetry for Image Displays, will focus on CRT metrology and device independent characterization. The second course, Psychophysical Techniques for Color and Imaging Sciences, will focus on methods of visual scaling and experimental design. Both courses will be enrollment limited to facilitate in-depth laboratory sessions. We are very excited about these new courses; based on our recent interactions with industry, we have found a growing need for more information about these topics. These courses will be conducted on June 8-11, 1992.

The Munsell Laboratory's short courses for industry have and will continue to be a major part of the laboratories dedication to a useful interaction with industry.

The faculty of the Munsell Color Science Laboratory also instruct many seminars throughout the year at technical conferences, at RIT through other programs, and on site. Below is a list of these seminars from the past year.

1. Colorimetry for Electronic Imaging, presented as part of Imaging Science and Technology at Eastman Kodak Company, Rochester, NY, April, 1991. (1 day)
2. Colorimetry for Electronic Imaging Systems presented to Dupont Imaging, Eagle Run, DE, May, 1991. (3 day)
4. Colorimetry for Electronic Imaging, presented to Xerox, El Segundo, CA, May 1991. (3 day)
5. Colorimetry for Electronic Imaging, presented to Xerox, El Segundo, CA, December, 1991. (2 day)
6. Colorimetry for Electronic Imaging, presented to Polaroid Corporation, February, 1991. (1 day)
Industrial Liaison

Site Visits to Rochester Institute of Technology

Representatives of the following companies visited to tour facilities and discuss color-related issues during 1991:


Site Visits to Industry

Dr. Berns visited the following companies during 1991:

Eastman Kodak Company, Rochester, NY
Dupont Company, Eagle Run, DE
R.R. Donnelley & Sons, Incorporated, Lisle, IL
Fuji Photo Film Co., Ltd., Japan
Toyo Ink Mfg. Co., Ltd., Japan
Konica Corporation, Japan
Xerox Corporation, El Segundo, CA and Rochester, NY

Dr. Fairchild visited the following laboratories:

Eastman Kodak Copy Products Division, Rochester, NY
Eastman Kodak Desktop Color Imaging, Rochester, NY
Eastman Kodak Imaging Science Research Labs, Rochester, NY
Technical Reports

The following list Munsell Color Science Laboratory Technical Reports published to date. 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.

1. Long-Term Calibration of a Diode-Array Radiometer, Fairchild and Berns, May, 1986.


Past Publications

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

1990


1989


1988


1987


1986

R.S. Berns, "A FORTRAN Program for Predicting the Effects of Chromatic

**1985**


Facilities

The Munsell Color Science Laboratory is housed on the third floor of the Chester F. Carlson Center for Imaging Science, at the Rochester Institute of Technology. This a facility, dedicated on October of 1989 in the memory of Chester Carlson, inventor of Xerography, and will serve as a comprehensive center for education and research in imaging science. Color science is one of several major research themes of The Center for Imaging Science. The main laboratory contains many color measuring instruments, while small rooms off the main area are dedicated to specific tasks. These areas contain low and high resolution image processing and display systems with input and output devices, spectroradiometric and photometric measurement equipment and visual apparatus. One room was specially designed for high accuracy optical radiation measurements and houses several spectrophotometers used for research and calibration services, and goniospectrophotometric research. Research on color vision and image perception is performed in another laboratory located on the same floor. This laboratory contains computer systems optimized for visual display and psychophysical experimentation, and other apparatus for the study of vision. Color Science research and education through the color science master’s degree program and industrial seminars is conducted in the Munsell Color Science Laboratory and associated laboratories. The current list of equipment is given below.

Optical Properties of Materials

BYK-Gardner Colorgard System 1000 Colorimeter
0/45
Donation by BYK-Gardner

BYK-Gardner Glossgard II
20, 60 and 85 degree
Donation by BYK-Gardner

BYK-Gardner Spectrogard Spectrophotometer
d/0, 380-720nm, grating monochromator,
color matching software
Donation by BYK-Gardner

BYK-Gardner The Color Machine
Spectrophotometer
380-720nm, 45/0, 32 diode array detector,
color matching software
Donation by BYK-Gardner

BYK-Gardner The Color Sphere Spectrophotometer
380-720nm, 4d/0, 32 diode array detector,
color matching software
Donation by BYK-Gardner

Cary 17D Spectrophotometer
186-2650 nm range, digital and analog
Donation by Eastman Kodak Co.

29
Cosar Pressmate I Densitometer
Hand held, Status T, reflection
Donation by Cosar Corp.

Cosar 75 CompuPlus Densitometer
Status A and M, transmission/reflection
Donation by Cosar Corp.

Datacolor Intl. Chroma-Sensor CS-5
Spectrophotometer
400-700 nm, d/0, interference wedge mono
Chroma-Calc color matching software for
paints, textiles, and inks
Decorator 300 software
VCS-11 software
Donation by Datacolor Intl.

Diano Match Scan II Spectrophotometer
380-1000nm, d/0, reversible optics,
grating monochromator
Donation by MiltonRoy APD

General Electric Recording Spectrophotometer
380-700nm, 0/d, analog,
D & H tristimulus integrator

HunterLab D25A-9 Tristimulus Colorimeter
45/0, 4 filtered detectors, Ill. C
Donation by Hunter Associates Laboratory

HunterLab D25D-2 Tristimulus Colorimeter
45/0, 4 filtered detectors, Ill. C
Donation by Hunter Associates Laboratory

HunterLab Dori- gon Meter D47-6
Abridged Goniospectrophotometer
Donation by Hunter Associates Laboratory

HunterLab Labscan Spectrophotometer
400-700nm, 0/45, interference-wedge mono
Donation by Hunter Associates Laboratory

HunterLab MiniScan Spectrophotometer
Portable, 400-700nm, 45/0
Donation by Hunter Associates Laboratory

HunterLab Modular Model D48-7 Gloss Meter
20 and 60 degree heads
Donation by Hunter Associates Laboratory

HunterLab UltraScan SpectroColorimeter
375-750nm, d/0, 76 diode-array detector
Donation by Hunter Associates Laboratory

IBM Model 9420 Spectrophotometer
190-900nm, transmission/reflection
Donation by IBM

Macbeth 1500/Plus Spectrophotometer
400-700nm, d/0, 16 diode-array detector,
Optiview, Optimatch, CIE-to-Munsell
Donation by Macbeth

MCSL Goniospectrophotometer
Variable illumination and viewing angles
Partially donated by Eastman Kodak Co.

Milton Roy Color Mate HDS Spectrophotometer
400-700nm, 45/0, 16 diode array detector
Donation by MiltonRoy APD

Milton Roy ColorScan Spectrophotometer
350-780nm, d/0, grating monochromator
Donation by MiltonRoy APD

Minolta ColorScan/45 Spectrophotometer
350-780nm, 45/0, grating monochromator
Donation by Milton Roy APD

Minolta Chroma Meter CR-221 Colorimeter
compact, 45/0, D65, C
Donation by Minolta Corp.

Minolta CM-1000 Spectrophotometer
Portable, 400-700nm, d/0, diode array detector
Donation by Minolta Corp.

Minolta CM-2002 Spectrophotometer
Portable, 400-700nm, d/0, diode array detector
Donation by Minolta Corp.

Optronic 746-D Spectrophotometer
280-2500nm, 0/d, grating monochromator

Photodyne 99XL Densitometer
Portable, transmission/reflection
Donation by Photodyne

X-Rite 968 Spectrophotometer
400-700nm, 0/45, portable
Donation by X-Rite
Radiometry

LMT C1200 Colorimeter
17 filtered detectors, $2^\circ$ obs.
*Donation by LMT*

Minolta Chroma Meter II Incident Colorimeter
Hand held, $2^\circ$ obs.
*Donation by Minolta Corp.*

Minolta Chroma Meter CS-100 Colorimeter
Hand held, spot reflex viewing
*Donation by Minolta Corp.*

Minolta Color Analyzer CA-100 Colorimeter
4 filter, designed to measure CRT, $2^\circ$ obs.
*Donation by Minolta Corp.*

Optronic Model 740 Spectroradiometer
280-1100 nm range, double monochromator, calibrated detector
*Donation by Optronic Laboratories Inc.*

Photo Research PR-703A Spot SpectraScan
Spectroradiometer (2)
256 diode-array, Pritchard optical system
*Donation by Photo Research*

Photo Research PR-1500 Spot Meter
Radiometer/Photometer
FMT, Pritchard optical system
*Donation by Photo Research*

Schoeffel Monochromator (2)
blazed at 500nm and 300nm

Tracer Northern DARSS Spectroradiometer
240-870 nm range, 512 diode-array

Partial List of Visual Apparatus

Breneman Visual Colorimeter
*Donation by Eastman Kodak Co.*

Color Curve Color Communication System
Master and gray & pastel atlases
*Donation by Color Curve*

Dianolite Viewing Booth (3)
D65, A, and UV
*Donation by Milton Roy APD*

D & H Color Rule (3)
Metameric slide rule

Datacolor Intl. VCS-10
Maxwell disk colorimeter
*Donation by Datacolor Intl.*

Datacolor Intl. Tru-Vue Viewing Booth
D65, A, CWF, and UV
*Donation by Datacolor Intl.*

Farnsworth-Munsell 100 Hue Test (2)
Color discrimination test

Graphiclite Show-Off Portable Viewing Booth
D50, reflection and transparency viewing

ICI Color Atlas
Color order system

ISCC Color Aptitude Test
Color discrimination and aptitude test

Isochromatic Plate Color Blindness Charts
Versions by Ishihara, Dvorine, and American Optical Co.

Japan Color Research Institute Chroma Cosmos 5000
Munsell based color order system

Lovibond Tintometer Visual Colorimeter (2)
Model E and Mark 3, Subtractive versions.
*Donation by Tintometer Co.*

Macbeth SpectraLight Viewing Booth
D65, CWF, horizon, and narrow band fluorescent

Macbeth SpectraLight Viewing Booth
D75, CWF, Horizon, and UV
*Donation by Macbeth*
MCSL Visual Colorimeter
CRT light source, mouse controlled

Munsell Book of Color
Glossy and matte editions
Donation by Munsell Color Company

Nagel Anomaloscope
Protan and deuteran test

**Color Display and Reproduction**

**Barco "Calibrator" Color Video Monitor**
19V, black dot mask,
Donation by Barco Industries

**HP 9000/375TSRX Computer System**
HP 9000/375 host computer
HP 98731 graphics accelerator,
HP 98550 graphics processor, 1280x1024x8
Donation by Hewlett-Packard

**HP 98745A Color Video Monitor**
Sony Trinitron, 19V
Donation by Hewlett-Packard

**HP 98789 Color Video Monitor**
Sony Trinitron, 16V
Donation by Hewlett-Packard

**HP Paintjet Color Printer**
Donation by Hewlett-Packard

**Howtek Scanmaster Color Scanner (Sharp JX450)**
300DPI flat bed color scanner

**Javelin JE2362 CCD Camera.**
RS-170 sync, 576x485

**Kodak SV-6510 Still Video Printer**
Color dye-diffusion printer

**Konica VP-1000 Color Video Printer**
1024x1248, 24 bit, photographic printer
On loan from Konica Corporation

**Matrix ProColor Film Recorder**
35mm digital film recorder

**Natural Color System Atlas**
Color order system.
Donation by Swedish Standards Institute

**Ophthalmoscope**
Donation by Welch-Allyn Inc.

**OSA Uniform Color Scales**
Color order system

**Macintosh II Computer System**
Sony 13V, 24 bit

**Pixar II Computer System**
Sun Microsystems 3/160HM, host computer,
Pixar II Image Computer 2M Pixels x 48
60MB

**Pixar II Computer System**
Sun Microsystems 3/260HM, host computer,
Pixar II Image Computer 10M Pixels x 48,
60MB
Donation by R. R. Donnelley

**Sony GDM-1950 Color Video Monitor**
19V, Trinitron CRT

**Sony PVM-1942Q Digital Color Video Monitor(2)**
19V, Trinitron CRT, RS-170, RGB, NTSC,
PAL, SECAM

**Tektronix 650HR-C Color Video Monitor**
13V, Trinitron CRT,
Donation by Tektronix

**Tektronix 690SR Color Video Monitor**
19V, dot mask
Donation by Eastman Kodak Co.

**Tektronix Color Quick Ink-jet Printer**
216 DPI, CMYK ink system
Donation by Tektronix

**NEXTdimension Computer System**
4m pixels x 32
Phillips color 17V, 1120x832x32 monitor
For More Information

For more information concerning the activities of the Richard S. Hunter Professor or the Munsell Color Science Laboratory, please contact:

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