Bridging Departmental Barriers in Search of a New Electronic Imaging Curriculum

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Abstract

In the winter of 1998 six University of Rochester faculty members came together to develop a new, comprehensive undergraduate and first year graduate curriculum in Electronic Imaging. The faculty represented three autonomous departments: The Institute of Optics, the Electrical and Computer Engineering Department, and the Computer Science Department. Each department, through individual faculty efforts, had begun to offer courses specializing in some aspect of electronic imaging. Each course, on its own, provided a real but limited service to students. The need for a harmonized, multi-disciplinary curriculum became self evident to the faculty members working in the Center for Electronic Imaging Systems. The ensuing discussions resulted in a very aggressive proposal combining current research efforts with a series of five new and six enhanced courses. The new curriculum would provide students with an opportunity to earn Bachelors or Masters degree in the discipline of their choice and a strong concentration in one of three areas of electronic imaging. This paper relates how the proposal was developed and provides the details that support the development of the new and enhanced courses. A special freshman course designed to motivate students to consider electronic imaging as a career will start this spring. Two new undergraduate labs are to be created along with a summer, undergraduate research program. A special seminar series was designed to keep both students and faculty up-to-date on the latest technology in industry and academia. Strong input and support from local industry will ensure that the new curriculum will serve both the students' academic pursuits as well as their ability to work in industry at a very proficient level.

I. Historical background of imaging science

The effort of the six faculty members from the University of Rochester to develop a new and comprehensive undergraduate and graduate curriculum in Electronic Imaging Systems needs to be understood within the context of how academic institutions have addressed imaging as a discipline over the past twenty years.

There are four schools in the United States and one in Japan that have, in one way or another, developed programs in Imaging Science. The earliest example is the program developed by Dr. Arnost Reiser at the Polytechnic Institute of New York in 1982 (http://www.poly.edu/research/iis.asp?cno=013). Dr. Reiser with the help of a distinguished set of imaging experts from academia and industry developed a masters degree program that was built around the traditional department structure associated with universities. The Polytechnic program required nine courses ranging from vision and color to electronic imaging. In addition to the required courses, the students had to take two courses from a rich selection of 18. These elective courses were very specialized and allowed a student to focus on research fields ranging from medical imaging to microlithography. A master's thesis was also required.

The second example of a program in Imaging Science is the one developed by Professor Robert N. Beck in 1983 at the University of Chicago. The University of Chicago has no school of engineering; thus, the Center for Imaging Science created by Professor Beck was built around the University of Chicago's outstanding graduate research programs in the sciences. The Center for Imaging Science was organized around research programs that reflected the interests of groups of faculty members from the traditional departments of physics and astronomy, chemistry, mathematics, radiology and computer science. Faculty from the art department and psychology department also participated in the research projects, as did scientists from Argonne National Laboratory. Missing from this research-focused effort was a formal curriculum designed to teach, in a unified way, the underlying science and technology.

The most comprehensive effort to forge a complete program in Imaging Science was undertaken by the Rochester Institute of Technology (http://www.cis.rit.edu/) under the leadership of Dr. Rodney Shaw in 1985. What is so remarkable about this effort is that the Chester F. Carlson Center for Imaging Science is the only doctoral program at the Rochester Institute of Technology. Dr. Shaw and his colleagues developed a complete undergraduate and graduate curriculum for Imaging Science, ranging from traditional silver halide technology to electronic imaging including the fabricating of solid state imaging devices. Very strong, existing programs in color and remote sensing were incorporated into the Center for Imaging Sciences. The Center also established an international industrial affiliates program to support their research efforts. In contrast to the other programs, the Center for Imaging Science has department status, thus enabling it to develop a curriculum to meet their specific needs.

The final example of an evolving program in Imaging Science is the one developed by Dr. Yoichi Miyake at Chiba University in Japan. The modern Imaging Science effort at Chiba University grew out of the image structure analysis component of the photographic science research program under the leadership of Dr. Kubo. While a significant program in silver halide

imaging research still exists at Chiba University, research in Electronic Imaging Systems has grown greatly under the direction of Dr. Miyake in the Graduate School of Imaging Science and Technology (http://www.eng.chiba-u.ac.jp/joho.htm). Japanese universities, individual professors hire younger faculty members to form a distinctive research effort in several important areas. Thus, there is no formal "center" but rather a group of three or four talented faculty members and a continuum of graduate and undergraduate students who work on a wide range of electronic imaging problems. While Dr. Miyake's laboratory will support one or two visiting professors (normally from out side of Japan) there are no formal postdoctoral positions. The funding for the research comes mostly from the school and the Ministry of Education. While there are strong ties to industry, there is little financial support for the research. The students must take the proscribed engineering courses to graduate, but the specialized training takes place in ad-hoc seminars led by Dr. Miyake and his junior colleagues.

A short comment should be made on the program at the University of Arizona. The Optical Science Center (http://www.optics.Arizona.EDU/), which is under the Electrical and Computer Engineering Department, has an outstanding program in optics and related disciplines. When combined with the courses available in the Electrical and Computer Engineering Department (image processing, information theory, etc.), students can develop a course of study that will prepare them well for a career in Electronic Imaging Systems. However, the Optical Science Center has only one formal course in Imaging Science and does not provide a well-defined track in Electronic Imaging Systems.

As can be inferred from the above, there is no clear pattern or agreement on how to teach Imaging Science. Instead, one finds a variety of efforts that have a common goal but have developed structures and processes that best fit the individual school's identity and organization.

II. The Center for Electronic Imaging Systems

The Center for Electronic Imaging Systems (CEIS) is a joint research effort of the University of Rochester and the Rochester Institute of Technology (http://www.ceis.rochester.edu/). This joint research effort is supported by the National Science Foundation (NSF), the New York Science and Technology Foundation (NYSSTF) and a number of large and small companies including the Eastman Kodak Company, Xerox Corporation, IBM, Intel and Bausch and Lomb. Much of the federal and state funding comes from two major programs. The two programs are the State-Industry-University Cooperative Research Centers (NSF and NYSSTF) and the Center for Advanced Technology – Electronic Imaging Systems (NYSSTF). These programs were developed under the leaderships of Dr. Nicholas George (University of Rochester) and Dr. Rodney Shaw (Rochester Institute of Technology). Over the six years of its existence, the CEIS has grown to include 16 faculty members from the two

schools and an annual budget of approximately $3,000,000. The CEIS focuses on a combination of basic research and technology transfer. However, the CEIS also allocates considerable resources to aiding small companies in related technical and business matters. The CEIS also maintains a strong outreach effort by sponsoring a series of lectures, seminars and workshops on all aspects of electronic imaging.

The CEIS draws its faculty from the Center for Imaging Science at the Rochester Institute of Technology and from the following departments and centers at the University of Rochester: Computer Science Department (http://www.cs.rochester.edu/), Electrical and Computer Engineering Department (http://www.ece.rochester.edu:8080/), the Institute of Optics (http://www.optics.rochester.edu/) and the Center for Visual Science (http://www.cvs.rochester.edu/). As indicated above, the Center for Imaging Science is a fully integrated department in contrast to the individual departments at the University of Rochester.

The creation of the CEIS had a very positive impact on the interactions between faculty members from different departments at the University of Rochester. The Center provided a means to form very synergistic research collaborations. Out of these collaborations arose the recognition for the need for a greater focus on electronic imaging systems in the current course offering and the need for new courses. During the third year of the CEIS, Center faculty at the University of Rochester developed two new courses. Professor Murat Tekalp created a graduate course in Digital Video and the author created a graduate course in Digital Imaging Technologies. Other faculty began to include more electronic imaging oriented material in their traditional engineering, optics and computer science courses. This gradual infusion of electronic imaging subject matter into existing graduate courses led to the realization that a unified undergraduate curriculum was necessary to prepare students for a career in electronic imaging regardless of their major discipline (optics, electrical and computer engineering and computer science). This realization led to the development of a new curriculum and a NSF CRCD grant proposal to accelerate the implementation.

III. Developing an undergraduate curriculum in electronic imaging that serves several departments

The authors used the possibility of "winning" a NSF CRCD grant as the stimulus to undertake the challenging task of developing a new, unified undergraduate curriculum in Electronic Imaging Systems. The following faculty members, in addition to the author, accepted the challenge:

1. Chris Brown, Computer Science Department
2. Nicholas George, Institute of Optics
3. Kiriakos Kutulakos, Computer Science Department and Dermatology

4. Kevin Parker, Dean of the School of Engineering and Applied Sciences and Electrical and Computer Engineering Department
5. Murat Tekalp, Electrical and Computer Engineering Department
6. David Hursh, Warner Graduate School of Education and Human Development

Professor Hursh will be leading a systematic assessment of the effectiveness of the curriculum over the next three years.

The above faculty members were picked for several reasons. Each of them has very active research programs that include important components of Electronic Imaging Systems. Each of them had either some direct responsibility for undergraduate or graduate curriculum or had very good relationships with their department colleagues on those committees. It was crucial to the program to be able to convince three separate curriculum committees and department chairs that the proposed curriculum would enhance their respective department's ability to attract highly qualified students and fulfill the growing needs of our industrial partners. In addition to the above, all the faculty members had shown in the past the ability to move beyond traditional teaching and research methods in favor of new ideas. The later criteria may well be the most important, for it freed the group from being weighed down by past failures or successes and allowed us to focus on what we wished to accomplish.

A series of meetings were scheduled to scope out the new curriculum for Electronic Imaging Systems. The first step was to make a comprehensive list of all the courses offered by each department and of the various tracks that were available to the students. This material was reviewed by each member of the team and part of several meetings was allocated to understanding the rational behind the courses and tracks. These exercise proved to be crucial to the development of the new courses and the enhancement of others, for it ensured that the basic thrust of each department was maintained while being enhanced with new material on electronic imaging systems.

After to the first meeting the author developed several ideas on what the curriculum should contain and the scope of activities that should support its implementation. These ideas were sent to each member of the team via Email a few days before the next meeting. During the second meeting the author's "straw man" was thoroughly criticized and reformulated. After the meeting the author would summarize the results, formulated a new "straw man" and send it to the team within one day. This process continued over a period of several weeks, with at least one meeting each week. Slowly a consensus of what the curriculum should be and how it would fit into the overall needs of the students and departments emerged. The discussions at all the meetings took on a repetitive pattern. The author would go over the revised concepts and the new things he had added. Each member of the group would comment on the changes and make some very good

changes or additions. The second phase of each meeting usually entailed one of the faculty members going to the board and elaborating on either one detail or another or on the total structure. The author took notes to ensure that these concepts would be molded into the next stage of the refinement process. At the end of the meeting action items were assigned to each member of the team with a definite time for them to be sent the author the required information or ideas. This rapid turn around enabled the author to quickly revise all aspects of the proposed curriculum and implementation schedule. It is of interest to note how good graphics accelerated the process. The author would create multiple graphical representations of the concepts before each meeting. These graphics became the focal point for the ensuing discussions. A new set was created for each meeting. Figures 1, 2 and 3 below are the final graphics used to visualize the curriculum concepts.

The above process not only served the curriculum development, but it gave each member of the team a much better understanding of the goals and needs of the other departments. This "bonding" will serve the University well as expanded teams take on the revision of the graduate curriculum in Electronic Imaging Systems. The number of truly good and original ideas that came from these discussions was a clear indicator that bringing talented and dedicated faculty together in such a fashion was not only possible but also extremely fruitful. This positive nature of the faculty interactions was one of the most lasting and uplifting results of the whole process.

It took about seven weeks to develop the curriculum and concepts given in the section on the curriculum. During those seven weeks the faculty both refined the material and "sold it" to their respective curriculum committees and department chairs. By the time we were ready to submit the CRCD grant proposal in March of 1998 we had obtained complete agreement from the department chairs, deans and curriculum committees. Each member of the team had worked out a detailed budget for their part of the implementation and had recruited others to work on the project. This included getting colleagues to enhance several existing laboratories and courses to better reflect the importance of electronic imaging. Each version of the final proposal was reviewed by the all the team members and after several iterations the final draft was sent to the various deans and department chairs for their approval.

IV. Industrial support for the electronic imaging systems curriculum

Early in the process the author contacted research managers and scientists at Kodak and Xerox to expose them to the new curriculum initiative. The author sought three things form these corporations. The first was their willingness to support the new curriculum by making their scientist available for teaching some parts of the new courses and giving seminars to the students and faculty on cutting edge applications and technology in Electronic Imaging Systems. The second objective was to obtain financial and in-kind support for the program. Each company said they would support the program with at least $25,000 in cash or equipment for the new

laboratories being created to enhance the new curriculum. The third request was for each company to assign several bench scientists to work with the team to evaluate and refine the curriculum over the period of the grant. The team recognized from the start, that while we had a very good view of the academic needs of the students, we needed a better understanding of the needs of the companies who would be offering the students jobs. Working with the bench scientists from the companies would provide the constant assessment required to change the curriculum in a dynamic manner to meet all the needs of the students. Kodak and Xerox agreed to all three requests. Other companies will be asked to join the effort over the next three years.

V. Current status of the curriculum implementation

A Summary of the full proposal is given below. The following reflects the status as of March 1999.

- A new course, ECE 102, entitled an ***Introduction to Electronic Imaging Systems***, for freshman and sophomores is currently being taught to a small group of students as the first offering of the new curriculum and to gauge the level of difficulty suitable to freshmen and sophomores. See http://www.ee.rochester.edu:8080/courses/EE102/ for course details and notes.
- The laboratories supporting ECE 102 are in place and other new laboratories will be in place the end of the summer of 1999.
- A corporate scientist will teach one of the eight sections of ECE 102.
- Ms. Candice Sanders will teach one section of ECE 102. Her material deals with Digital Art and Photography. This will provide more balance to the course.
- Kodak and Xerox have assigned scientists to the evaluation team.
- Professor Hursh has assembled his evaluation team and the ECE 102 has begun to interview the students to ascertain its relevance to their long-term educational goals.

ECE 102, an Introduction to Electronic Imaging Systems, has the following sections that are given over fourteen weeks and 43 one-hour lectures. Each section has a laboratory experience to reinforce the lecture material.

1. Introduction – M. Kriss (1)
2. Image Acquisition – N. George (6)
3. Digital Photography – M. Kriss (5)
4. Digital Art and Photography – C. Sanders (1)
5. Computer Graphics – K. Kutulakos (5)
6. Digital Video – M. Tekalp (6)
7. Computer Vision – C. Brown (6)
8. Medical Imaging – K. Parker (6)
9. Display Technology – D. Williams (Kodak) (6)

10. Student Critique – All Faculty (1)

VI. Future work.

The creation of ECE102 marks the start of the implementation process. The evaluation of ECE 102, based on Dr. Hursh's interactions with the students, will lay the foundation for changes in the course. The refined version of ECE 102 will be offered in the Fall of 1999 and the expected enrollment will approach 25 to 30 students.

The four new courses (see below) in (an undergraduate version of) ***Digital Imaging Technology, Image Science, Introduction to Medical Imaging and Visual Computing*** will be given during the next school year along with the new seminar series that will expose the students and faculty to the latest academic and industrial discoveries in Electronic Imaging Systems. The author is working with the local chapters of the American Optical Society (OSA), Imaging Science and Technology Society (IS&T) and the Institute of Electrical and Electronic Engineers to coordinate their efforts to attract world leading researchers in Electronic Imaging Systems to speak in Rochester. The guest speakers will lecture as part of the seminar series and as part of an evening program open to the general scientific community. In this fashion, the above societies and the university will greatly leverage their respective abilities to disseminate the latest technical achievements to their membership, faculty and students.

The students for the summer research program are now being selected. It is our hope that some of these students will have joint research programs with Kodak, Xerox and other companies in the greater Rochester area. Whenever possible, we wish to combine academic and industrial research experience to ensure that the students have an appreciation of the differing needs and to draw upon the strengths of each.

An unexpected and very encouraging development has been the reaction by the Dean of the College, Dr. William Green, to the CRCD effort to change the undergraduate curriculum in Electronic Imaging Systems. Dr. Green indicated that he felt that our effort could evolve into the one of the keystones of the University's undergraduate program and that he was prepared to support or effort in all possible ways. We are currently developing an internal "white paper" for Dr. Green that lays out a multiyear plan to give the University of Rochester the most comprehensive undergraduate program in electronic imaging in the world.

VII. Project description: A Unified Image Science and Electronic Imaging Systems Curriculum Development Initiative

The following is a brief summary of the full curriculum proposal. For more details, please contact the author.

A. Overview

A truly cross disciplinary, coherent curriculum development initiative is proposed that will provide the required foundations in Image Science and Electronic Imaging Systems for students who wish to pursue career paths in electronic imaging in industry or academia. This three-year initiative will result in new and enhanced undergraduate and graduate courses and laboratories, new topical seminar series and supervised research opportunities for undergraduates. These educational and exploration opportunities will bring the latest research and technology in Electronic Imaging Systems to undergraduate and graduate students in Computer Science, Electrical and Computer Engineering and Optics. The educational programs developed under this initiative will act as a model for other universities and institutes around the country.

1. Imaging In the Information Age

Images have become the single most important communication medium in the Information Age. There is no aspect of private or professional life that is not affected by the use of sophisticated imagery. Commercial, consumer, medical and scientific imaging systems will constitute one of the largest growing sectors of the international economy. It is vital that United States based corporations have access to the latest research and well trained scientists and engineers in the area of Image Science and Electronic Imaging Systems. This is required if they are to meet the challenge from Asia, the Pacific Rim and the European Common Market.

Ten years ago, the capture, manipulation and display of images were done by specialized, professional organizations or agencies. Today anyone with a personal computer, a small scanner or digital camera, and the appropriate software can create a business, establish a Web Page with vibrant images, or publish a newsletter. Much of the creative efforts associated with professional help in the past is being pushed down to the individual worker. This explosion of creativity and document centers has resulted in a very competitive, multi-billion dollar market. Image Science and Electronic Imaging Systems are central to the development of a wide range of new technologies and product

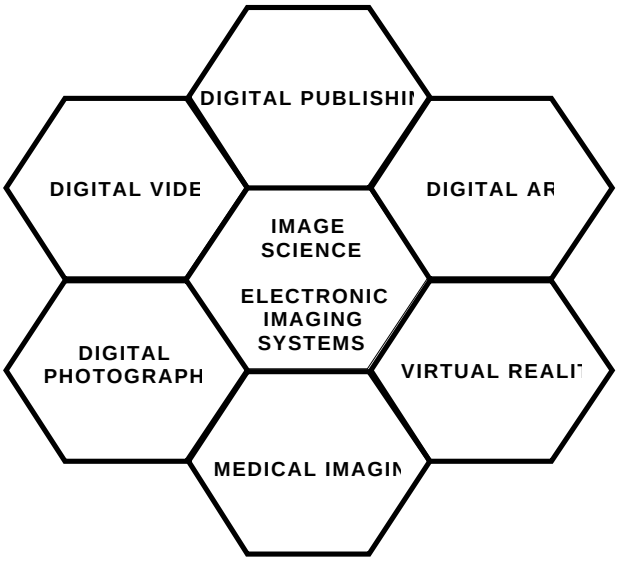

Figure 1. The centrality of Image Science and Electronic Imaging Systems.

offerings. Figure 1 shows the relationship graphically. All the cited research areas and business opportunities are growing rapidly. Each depends heavily on trained engineers and scientists in Image Science and Electronic Imaging Systems. This curriculum initiative is designed to better meet the needs of these growing industries and services.

The breadth of research done within any given department today is far greater than what it was 25 years ago. Ten years from now all research fields will be even more integrated due to the push of industry and the pull of new technological research tools. The traditional role of departments will change. The differentiation of research is (and will be) getting more difficult to define as technology gains enable researchers to follow more diverse paths and opportunities. The curriculum initiative recognizes this reality and provides the first step in a process that will further facilitate cross-disciplinary research efforts by the faculty. The current and proposed course offerings cannot be thought of as three, separate rigid structures, but rather as a moldable set of course offerings that allow students to explore a far greater range of topics, yet still gain a solid foundation in any one discipline. See Figure 2. In short, our proposal helps the three departments move toward a future state that will reflect more accurately how the world will look in ten years.

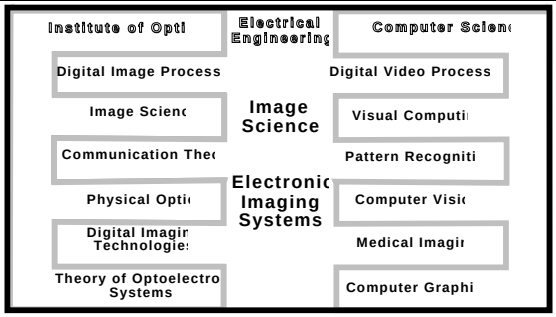

Figure 2. The diffuse boundaries of Optics, Electrical and Computer Engineering and Computer Science make it possible to develop a cross-disciplinary curriculum.

This Unified Image Science and Electronic Imaging Systems Curriculum Development Initiative is directed to the education and training of young engineers and scientists in all aspects of electronic imaging systems. It will add five new courses to the current curriculum in Computer Science, Electrical and Computer Engineering and Optics as well as enhance nine current course and laboratory offerings. Two completely new laboratories will be designed to allow students to put into practice what they learn in the classroom and explore new ideas. Several new seminar series will be initiated to bring current technology and leading edge research to the students and faculty in a timely and coherent fashion. The harmonization of the three individual curriculums will allow a student to gain a solid foundation in one of the three disciplines plus a focused concentration in one of several imaging tracks. Students will graduate with a Bachelors of Science or Masters of Science degree with the knowledge and practical skills required to take on important research and development roles in industry or advance to Ph.D. candidacy and conduct independent research.

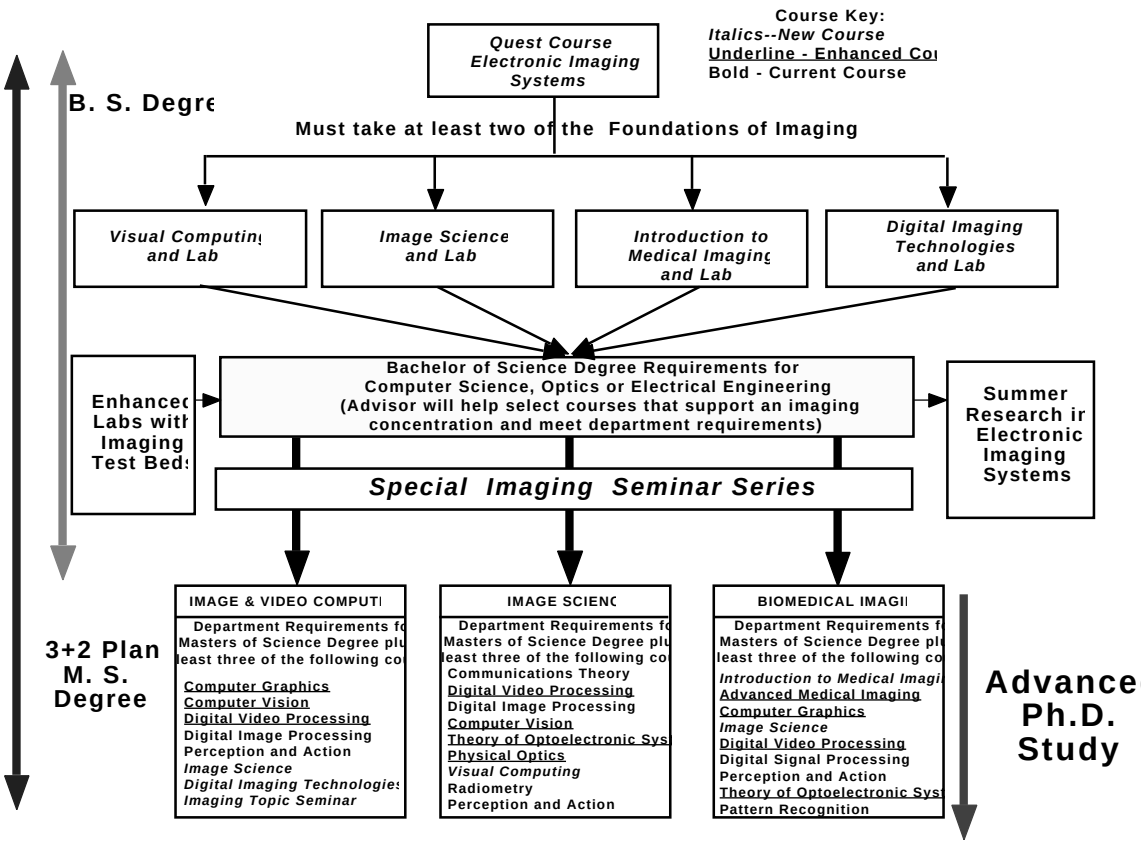

Figure 3. An overview of the proposed curriculum initiative and Imaging Tracks. A student can earn BS or MS degree with a concentration in Electronic Imaging.

2. The University of Rochester Advantage

The University of Rochester has devoted considerable resources from the Department of Electrical and Computer Engineering, the Department of Computer Science, The Institute of Optics, The Department of Brain and Cognitive Science and the Center for Visual Science to basic research in the area of image science, vision, digital imaging and electronic imaging systems. These resources include the NSF, New York State and industry funded Center for Electronic Imaging Systems (CEIS). The CEIS consists of two major programs: (1) the State-Industry-University Cooperative Research Center (S/IUCRC) funded by NSF and the New York State Science and Technology Foundation (NYSSTF) and (2) the NYSSTF funded Center for Advanced Technology for Electronic Imaging Systems (CAT-EIS). Both of these programs have strong industrial support from major imaging and information companies. In addition to these programs, a National Institute of Health (NIH) National Resource for the study of Neural Models of Behavior funded grant on virtual and augmented reality supports research in the Department

of Computer Science. Vision research in Computer Science is funded by among other things, a $1.5M NSF Institutional Infrastructure Program grant (the third back-to-back, five-year award), and a long history of funding from DARPA. The NIH supported Center for Biomedical Ultrasound provides strong connections to the research being done at the Medical Center as does a new Biomedical Engineering program. The CEIS industrial support and past programs like the Center for Advanced Technology in Optics has resulted in having long standing relationships with many of the largest, international imaging corporations including Eastman Kodak, the Xerox, Bausch and Lomb, IBM, Intel, Imation (3M) and Harris/ RF Communications. In addition, the faculty has strong ties to many small local companies involved in electronic imaging who hire many of the graduating students.

The strong CEIS administrative team will provide the necessary program monitoring and reporting functions at no extra cost to the initiative, thus providing more funds for the curriculum development, assessment and dissemination.

B. A unified image science and electronic imaging systems curriculum

1. Curriculum overview

Figure 3 shows an overview of the Unified Image Science and Electronic Imaging Systems Curriculum. The details of each new course can be obtained from the author. This harmonized curriculum is designed to offer students an opportunity to obtain a Bachelor of Science degree or Masters of Science degree in Computer Science, Electrical and Computer Engineering or Optics with a strong concentration in Image Science and Electronic Imaging Systems. This curriculum is seamless across the three departments and extends from the freshman year through the first year of graduate school. The students interested in a concentration in Image Science and Electronic Imaging Systems will be urged to take advantage of the University of Rochester's 3+2 Plan. This plan allows students to take graduate classes during their senior year and obtain a Masters of Science degree at the end of their fifth year in the program. The major components of this unified curriculum are ECE 102 course in Electronic Imaging Systems, four Foundations of Imaging Courses, a Special Imaging Seminar Series, summer research opportunities for undergraduates, several new hands-on laboratories and three Imaging Tracks that includes one new course and several enhanced courses. A potential, entering freshman in Optics, Computer Science or Electrical and Computer Engineering will be informed about the Imaging Concentration by the university as part of the formal recruiting process, including discussions with faculty. A detailed overview of the program will be given to all students accepted by the University of Rochester and choosing to study Computer Science, Optics or Electrical and Computer Engineering. The student's advisor will assist in formalizing the choice of an Imaging Concentration.

2. The ECE 102 course in electronic imaging systems

The ECE 102 in Electronic Imaging Systems must be taken by all students who wish to have an Imaging Concentration. It is a one-semester course of lecture and demonstrations covering all facets of Electronic Imaging Systems. The course will have seven, two-week modules covering computer vision, computer graphics, digital video processing, digital photography, image acquisition, medical imaging and display technology. The course will be taught by a combination of faculty and industrial researchers. The exact contents of the ECE 102 will change each year to reflect advances in research and technology. It will be given during the spring semester of the freshman year to allow students to adjust to the university and have sufficient time to plan their course of study with faculty advisers.

3. Foundations of imaging courses

The Foundation of Imaging courses forms the core of the Bachelors of Science degree with an Imaging Concentration. Each student must take at least two of these courses in addition to the requirements of the individual departments. The four courses are all new to the undergraduate curriculum. They are Visual Computing, Image Science, Introduction to Medical Imaging and Digital Imaging Technologies. These courses have corresponding laboratories which emphasize current research activities at the University and in industry. The laboratory will provide both training in experimental method as well as the opportunity to explore new ideas**.** These laboratories will be designed as small research projects rather than rote, "cookbook" experiments. The students will be asked both to propose the research project (within a range of topics) and then, with the aid of the laboratory instructors and Ph. D. graduate students, carry out the research. In this way, each student can experience the pleasure and pain of doing good research. The outcomes will be far richer, since the students will be doing their own research projects.

4. Special imaging seminar series and open houses

The Special Imaging Seminar Series is designed to keep students and faculty up-to-date on the technology advances in all aspects of electronic imaging. The Spring seminar series will consist of five lectures from faculty, five lectures from local industrial researchers and four Distinguished Speakers from schools and industrial research laboratories outside of the Greater Rochester Area. The seminars will consist of an hour lecture, one-half hour discussion period and a social hour where students and faculty can discuss the lecture and build important personal bonds. All students and faculty in the Concentration in Imaging program will be required to attend. These seminars will be widely publicized and open to the general public.

Each department will coordinate with the others to establish a continual set of Open Houses where each week one of the faculty members will open his laboratory for informal demonstrations and discussions. By the end of each semester, students will have been well exposed to each faculty member's current research. This will give the students a far better perspective of what they are studying in class and provide them a better understanding of the research possibilities that await them as graduate students. Ph. D. graduate students will develop these open houses and will play a critical role in the development of all new and enhanced laboratories.

5. Undergraduate summer research program and laboratory development

Ten highly motivated undergraduate students will be given the opportunity to conduct supervised research during the summer of each academic year. Five will be funded by the grant and five will be funded by the CAT-EIS. Each of the Principal Investigators will mentor one or two undergraduate students and integrate them into their research program. At the start of the Fall semester, a Summer Research Review will be held for all undergraduate students who have signed up for the Concentration in Imaging. The student researchers will present their work and join in a round table discussion about the summer research program and how to improve it. Undergraduates will also have the opportunity to help develop the new imaging oriented laboratories, thus providing more hands-on experience.

6. Master of science degree program and imaging tracks

Those students who have done well in their first three years of the Concentration in Imaging will be invited to take advantage of the University of Rochester's 3+2 Plan and get a Master of Science in their department of choice with a strong concentration in one of the three Imaging Tracks shown in Figure 3. The three Imaging Tracks are Image & Video Computing, Image Science and Biomedical Imaging. The Image & Video Computing Track is designed for students who wish to concentrate on the digital production, processing, and analysis of images. The Biomedical Imaging track is for those students who seek a career in medical imaging. The Image Science track is designed for those students who wish a more general exposure to imaging or a more detailed look at the electro-optical and image quality analysis aspects of electronic imaging.

Each student, in addition to meeting department requirements, must take at least a total of three of the undergraduate and graduate courses listed in the track of interest and the two required Foundations of Imaging courses. Courses that are underlined indicate enhanced versions of the current courses that are being altered to mesh with the new courses that are given in *italics*. The other listed courses are current offerings and need not be enhanced to meet the needs of the new curriculum. New courses in Computer Science include an undergraduate Computer

Vision Lab and an Imaging Topic Seminar course that will deal with advanced topics in computer graphics and computer vision. Two of the current Optics laboratories courses are being revised to include electronic imaging test beds to support this initiative. Details of the courses can be obtained from the author. Students wishing to continue on to a Ph.D. program or new graduate students entering the Ph.D. program can follow one of these tracks in preparation for research careers in electronic imaging.

7. Advantages of the proposed curriculum

The curriculum outlined above represents a logical career path for a young scholar who wishes to work in the rapidly expanding field of electronic imaging. It flows from the freshman year through the first year of graduate school in a seamless less fashion, continuously building on the student's newly acquired knowledge and skills. The curriculum reflects a careful balance between the need to have a strong foundation in a specific discipline and the desire to concentrate on a specific field of electronic imaging. The curriculum provides the students with options that meet their interests, yet maintains high academic standards. All students taking the Image Concentration at the Bachelor of Science level will graduate with a clear understanding of the complexity of modern electronic imaging systems, some practical knowledge in building such systems and a firm foundation in one of the three disciplines. These students will be in a position to quickly adjust to an industrial research and development environment and have the knowledge and skills that will ensure their growth and value to the industry over their entire career. Those students who take the Masters of Science option in Electronic Imaging Systems will graduate with a full understanding of electronic imaging systems, specific, deep knowledge in one of the electronic imaging tracks and the ability to immediately contribute to the development of electronic imaging products. In addition, students who finish the Master of Science option with distinction will be in an excellent position to pursue a Ph.D. in their chosen field. Another advantage of this proposal is that much of the resources are dedicated to students who will fill a fundamental role in the development of the laboratories that support and augment the lectures.

C. Assessment

The six components of assessment for this initiative combine quantitative and qualitative methodologies. Some will provide us useful information from the beginning while others will only provide information as graduates enter doctoral programs and/or industrial careers.

- The first component requires quantitative tracking of students' grades and laboratory experiments. This is easily obtained each semester from student transcripts.
- The second component will be a qualitative joint evaluation, with the corporate sponsors of the CEIS, of how well the emerging curriculum met their need for well-trained engineers and

scientists. This will require interviewing sponsors in order to develop a rubric delineating the knowledge and skills desired by corporate sponsors. The rubric will then be used to evaluate students as to whether they are gaining the desired skills and knowledge.

- The third component (quantitative) will require tracking students beyond the BS and MS degrees in terms of acceptance to Ph.D. programs at the University of Rochester and elsewhere. This will require identifying which students apply to Ph.D. programs and which programs accept or reject their applications.
- The fourth component will be both quantitative and qualitative. Students who choose an industrial career after graduation will be followed for five years. The students will be interviewed regarding their assessment of how well they were prepared for their position. Employers will also be interviewed regarding how well they think the employee was prepared. We will also track which, how many, and what kinds of positions students hold.
- The fifth component will be a qualitative and quantitative evaluation by the students who are in the program and graduate with BS or MS degree. We will develop a questionnaire to evaluate not only whether students felt they are well prepared, but to assess whether courses complemented one another, the strengths and weaknesses of the foundations courses and imaging seminars, and the relationship between seminars, laboratories, and internships.
- The sixth and final component will be an ongoing formative evaluation by academics and industrial scientists in the area of Electronic Imaging Systems and Image Science. A rubric will be developed based on initial interviews with selected academics and scientists. The rubric will then be given to all of those involved, tabulated and written into a yearly report so that we initiative can be refined.

D. Dissemination

The dissemination of the concepts and material developed for the new and enhanced course will be done in the following ways:

- At the end of the second and third years of the grant summer workshops will be held for faculty from other schools who wish to develop their own programs in Image Science and Electronic Imaging Systems. The workshops will last for one week and will included student led demonstration of the laboratory. All course and laboratory materials will be provided to the participants as well.
- At least one text book will be written (Digital Imaging Technology)
- At least one text will be revised (Digital Video Processing)
- The course material will be placed on the CEIS Web Site.
- The faculty will participate in one or more of the virtual classrooms sponsored by companies like Apple Computers.
- Videos of the Special Imaging Seminar Series will be made available to all that wish them. A list of the titles will be on the CEIS and department Web Sites.

Michael A. Kriss

Michael A. Kriss is the Executive Director of the Center for Electronic Imaging Systems and an Adjunct Professor of Electrical and Computer Engineering. Dr. Kriss received his BA, MS and Ph.D. degrees in Physics from the University of California at Los Angeles. Dr. Kriss joined the Eastman Kodak Research Laboratories following his graduation in 1969 where he conducted research in photographic and electronic imaging for 23 years. Dr. Kriss spent three years in Japan as part of a Kodak team that built a state-of-the-art research facility near Tokyo. Dr. Kriss retired from Kodak in 1993 and joined the University of Rochester in 1994 as an Adjunct Professor in Electrical Engineering and as one of the management team of the Center for Electronic Imaging Systems. Dr. Kriss maintains an active research effort in Digital Photography.