Engineering Research Centers:

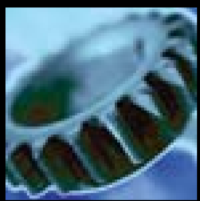
Creating Leading Technologies, Educating Technology Leaders

Since the first Engineering Research Centers were founded in 1985, these pioneering organizations have pushed the boundaries of knowledge across a broad spectrum of technology fields while transferring a continuous stream of cutting-edge technologies to their industrial partners. In the process they have revolutionized engineering education and produced a new generation of graduates who are adept at innovation and primed for technology leadership.

Engineering Research Centers

National Science Foundation

Section One Bioengineering

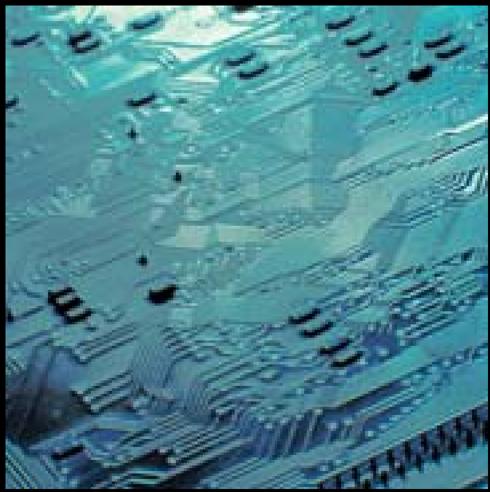


Section Two Manufacturing and Processing

Section Three Earthquake Engineering

Section Four Microelectronic Systems and Information Technology



There is nothing humankind will not attempt when great enterprises hold out the promise of great rewards.

Roman historian Livy

Introduction

The National Science Foundation-sponsored Engineering Research Centers (ERCs) are interdisciplinary centers located at universities all across the United States, each in close partnership with industry. Each ERC provides an environment in which academe and industry collaborate in pursuing strategic advances in complex engineered systems and systems-level technologies that have the potential to spawn whole new industries or to radically transform the product lines, processing technologies, or service delivery methodologies of current industries. Activity within ERCs lies at the interface between the discovery-driven culture of science and the innovation-driven culture of engineering. The centers provide the intellectual foundation for industry to collaborate with faculty and students on resolving generic, long-range challenges, producing the knowledge base needed for steady advances in technology and their speedy transition to the marketplace.

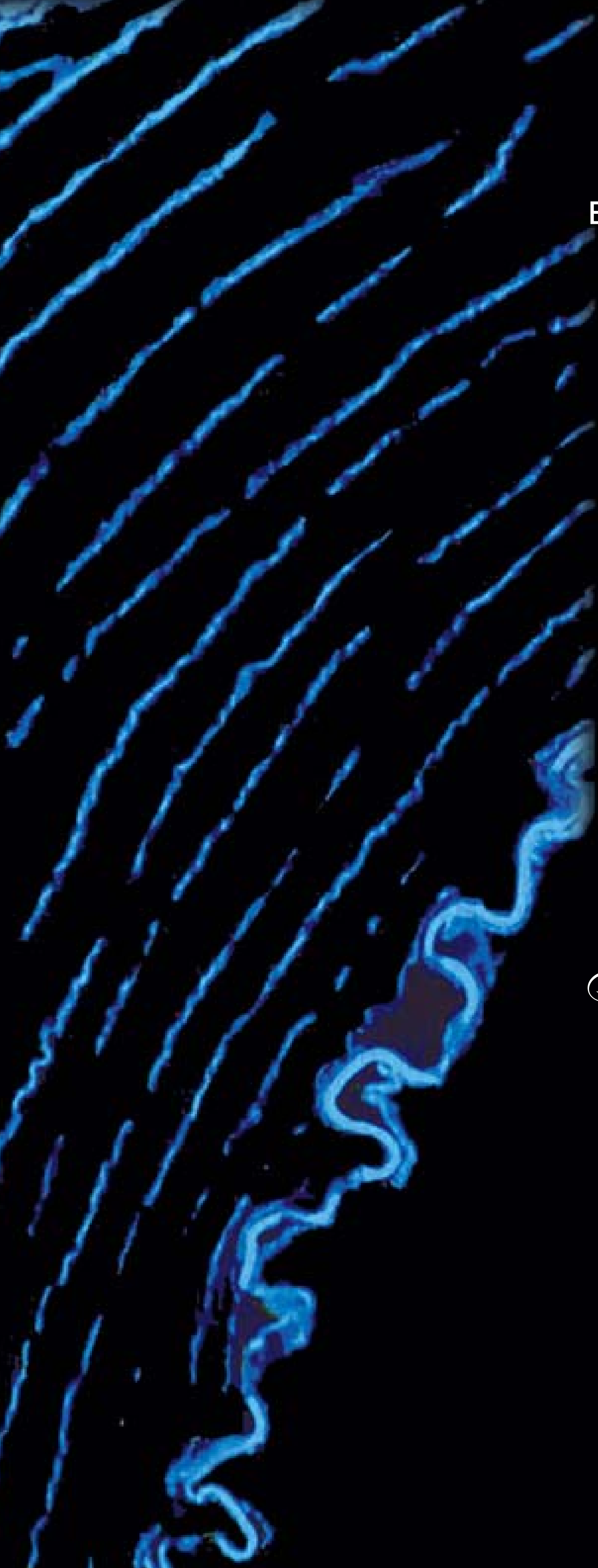
ERC faculty, students, and industry partners integrate discovery and learning in an interdisciplinary environment that reflects the complexities and realities of real-world technology. ERCs expose prospective students (both graduate and undergraduate) to industrial views in order to build competence in engineering practice and to produce engineering graduates with the depth and breadth of education needed for success in technological innovation and for effective leadership of interdisciplinary teams throughout their careers. ERC innovations in research and education are expected to impact curricula at all levels, from precollege to life-long learning, and to be disseminated to and beyond their academic and industry partners.

ERCs fulfill NSF's strategic goal to increase the diversity of the scientific and engineering workforce by including all members of society, regardless of race, ethnicity, or gender, in every aspect of the centers' activities. Because ERCs play critical roles in academe by integrating research, education, diversity, outreach, and industrial collaboration, NSF views ERCs as change agents for academic engineering programs and the engineering community at large. And indeed, over the past 20 years these centers have succeeded in changing the culture of academic engineering to include integrative collaboration across engineering and science disciplines, a greater focus on innovation and engineering systems, and closer interaction with industry, while producing thousands of graduates who are assuming positions of technology leadership all across U.S. industry.

Section One

BIOENGINEERING

The last thirty years have seen an explosion of knowledge in molecular biology and in the application of that knowledge to medical devices and technologies, new materials, and other fields ranging from foods to defense, to forensics, to the environment. Bioengineering is the broad area of technology that lies at the interface between biology and engineering. Six ERCs focus on different aspects of this still rapidly expanding area of technology. Their areas of interest encompass tissue engineering; the development of computer-assisted surgical tools and procedures; therapeutic gene technologies; microelectronic systems that mimic biological processes to restore neural function; new biomaterials for use in long-lasting medical implants; and the development of advanced techniques and technologies for educating future bioengineers.



ERC for the Engineering of Living Tissues (est. 1998)

Georgia Institute of Technology with Emory University School of Medicine

Capturing Innovation for Tissue Engineering and Regenerative Medicine.

The shortage of organs and tissues suitable for transplantation is an ongoing national medical crisis. The Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) is addressing the shortage of transplantable tissues and organs through the development of cutting-edge core technologies for the tissue engineering and medical device industries. These innovative technologies provide therapeutic solutions that cannot be achieved by today's drug, biologic, medical device, or organ transplantation approaches. The products they enable are truly novel—inspired by nature but engineered to produce a specific therapeutic effect.

For the medical implant industry, tissue engineering represents a bridge from the revolution in biology to new clinical therapies and treatments for tissue repair, replacement, and regeneration. While the tissue engineering industry is still in its early stages, the large medical device companies recognize that their future will involve the convergence of biologics with their traditional electromechanical technologies. Thus, GTEC-developed technologies will provide doctors and patients with the next generation of medical implants and will transform an industry that is emerging at the interface of biology and engineering.

■ **For more information about GTEC programs and accomplishments, visit the Center's website at: http://www.gtec.gatech.edu**

Partnership Attracts Diverse Talent to Field

The ranks of scientists and engineers on university faculties and in industry do not reflect the vast talent available within under-represented minority groups in the U.S. To help ensure that the tissue engineering and bioengineering workforce is as strong and diversified as possible, GTEC has formed a partnership with the Atlanta University Center (AUC), a consortium of Historically Black Colleges and Universities in the city of Atlanta. The partnership provides seed grants to Morehouse School of Medicine junior faculty, encourages research collaborations between GTEC and AUC faculty, and provides research opportunities to AUC undergraduate students to promote their interest in the fields of tissue engineering and bioengineering.

The core, enabling technologies resulting from GTEC's research will build a strong technical foundation for the engineering of living tissues.

Response to Hormones Is Gender-specific

The genes that determine gender make men and women different in many ways—from the whole-organism level down to the cellular level. A GTEC laboratory was the first to show that male and female growth plate and articular cartilage cells from rats and humans—as well as human bone-forming cells—respond to steroid hormones in distinctly different ways. The findings have considerable implications for tissue engineering as well as broader implications for tissue transplantation. Current methods are based on studies that have predominantly used cells from male rodents; yet tissue engineered products and tissue transplantation are used for both male and female patients. GTEC researchers are now implanting micro-encapsulated human cells into male and female immuno-compromised rats to test whether these sex-specific differences are biologically significant.

Harnessing discoveries from biology and engineering to develop integrated clinical therapies.

Gelling Polymer Repairs Tissue Defects *in Vivo*

Researchers in GTEC's Neural Tissue Engineering thrust area have developed in situ gelling polymer technology to fill irregular soft tissue gaps in a variety of tissues. This includes spinal cord injuries, where these gels will be injected in their liquid state and gelling will occur within seconds at body temperature. This technology has several advantages, including: (a) no need for 'pre-fabricating' or pre-measuring exact shapes of defects; (b) bioactive agents such as proteins can be coupled to the backbone to 'functionalize' the materials to facilitate growth or differentiation of cells; and (c) cells or slow-release vehicles can be embedded into the gels at the time of injection to facilitate controlled differentiation and migration of cells in vivo. GTEC scientists and engineers are currently pursuing two applications for this technology: bridging spinal cord injuries and bridging non-healing bone defects.

Center for Computer-Integrated Surgical Systems and Technology (est. 1998)

The Johns Hopkins University with the Brigham and Women's Hospital, Carnegie Mellon University, Johns Hopkins Medical Institutions, MIT, and Shadyside Hospital

Reinventing surgical procedures in the 21st century.

The impact of current developments in Computer-Integrated Surgery (CIS) systems on medical procedures during the next 30 years will be as significant as the impact of Computer-Integrated Manufacturing (CIM) systems has been on industrial production over the past 30 years, and for many of the same reasons. Systems combining image processing, patient modeling, treatment plan optimization, and real-time monitoring of the surgical environment with novel robots, sensors, and human-machine interfaces will fundamentally advance the ability of surgeons to plan and perform surgical procedures more accurately, more safely, and less invasively. Development of such systems will address a vital national need to greatly reduce costs, improve clinical outcomes, and improve the efficiency of health care delivery.

The NSF Engineering Research Center for Computer-Integrated Surgical Systems and Technology (CISST ERC) provides the multidisciplinary infrastructure and systems focus required to address fundamental science, technology, and educational barriers impeding the rapid development and deployment of CIS systems.

■ **For more information about CISST programs and accomplishments, visit the Center's website at: http://cisst.org**

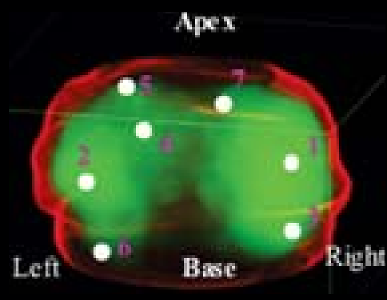
Hands-on Surgery Course For Engineers

"Surgery for Engineers" engages students in new and exciting learning experiences, fosters relationships between engineers and clinicians, identifies and solves relevant problems with engineering principles, and enhances the undergraduate curriculum for career preparation. This course teaches engineering students the fundamental skills and operative procedures for general surgery. It is a hands-on course that is designed for engineers tasked with the development of computer-integrated surgery tools that will improve upon current technologies in use in the Operating Room. The impact is made at three levels: undergraduate, graduate, and in the medical field. Undergraduates get a hands-on laboratory experience unlike any other in their courses, which challenges them to continue this experience into their research at the graduate level. At the graduate level, Surgery For Engineers provides a complementary experience that is often parallel to their current research projects, exposing them to further innovative ideas. The impact then extends to the medical field, where the research continues as engineers work with the medical staff to develop leading-edge instruments for use in the operating room.

Medical procedures will be carried out faster and more accurately. The result: Better health care and reduced costs.

Statistical Atlas Allows Targeted Prostate Biopsy

The Center and its collaborators have constructed a statistical atlas of prostate cancer distribution that can significantly improve the ability to determine the optimal site for biopsy. Diagnosis of prostate cancer is currently problematic, particularly for early-stage and small tumors. Current biopsy procedures are performed by random sampling in suspect locations. Using histological sections from nearly 300 radical prostatectomy specimens, along with deformable registration methodologies, CISST partner institutions—including Johns Hopkins University, The University of Pennsylvania, Brigham and Women's Hospital, Georgetown University, and the Center for Prostate Disease Research—have developed a multivariate statistical model of the spatial distribution of prostate cancer. This statistical atlas can then be combined with an individual patient's images to create a patient-specific optimal biopsy protocol. Simulations performed with the protocol have achieved a cancer detection rate of 96.2 percent, compared with 70.5 percent using the current method. A clinical trial involving 30 patients is underway at Brigham and Women's Hospital, along with further refinements in the methodology. Further information is available at: http://www.rad.upenn.edu/sbia.



Steady Hands for Retinal Surgery

Retinal disorders are one of the leading causes of blindness in people over the age of 60. The delicacy and small size of the retinal structures makes surgery to correct these disorders extremely challenging and, in some cases, impossible to perform by hand. The CISST ERC has developed a system for eye surgery that combines robotic hand stabilization and guidance with information overlays to create a surgical assistant for these delicate procedures. Video information from the left and right "eyes" of the surgical microscope is processed to create a three-dimensional model of the retina and the locations of the surgical instruments. With these three-dimensional models, it is possible to define desirable paths in space to perform the procedure and thus guide the surgeon's movements using "virtual fixtures." At the same time, pre-operative information is registered to the view of the microscope and is also displayed to the surgeon. This system has the potential to give surgeons the "super-human" accuracy and precision necessary to develop new treatments for these blinding disorders.

Biotechnology Process Engineering Center (est. 1985)
Massachusetts Institute of Technology

New therapies for genetic disorders and cancer treatment.

Curing cancer and treating infertility and AIDS—these are lofty goals. But researchers are making important progress at the Biotechnology Process Engineering Center (BPEC) at the Massachusetts Institute of Technology (MIT).

BPEC's aim is to foster cross-disciplinary, systems-driven research and education that merges engineering with molecular cell biology. Advances in mammalian cell bioprocess technology and protein therapeutics made by BPEC—such as the *BioDesigner* for bioprocess simulation, algorithms for the rational design of growth media based on fundamental scientific advances, and methodologies for characterizing protein quality—have enabled the development of a wide range of new pharmaceuticals. BPEC alumni have accounted directly for many of these pharmaceutical developments. At Genentech, for instance, they played key roles in bringing new monoclonal antibody cancer therapies to market. BPEC alumni at Merck, for another example, have played key roles in the battle against AIDS by developing new drugs to treat the disease.

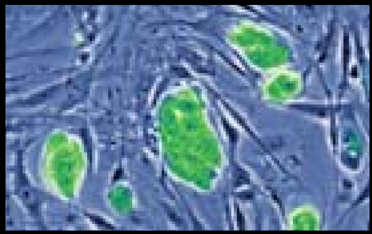
BPEC researchers comprise multidisciplinary teams of molecular biologists, bioengineers, chemists, and medical doctors. Currently, they are focusing on two areas of therapeutic gene and stem cell technologies. One is gene delivery to stem cells that form blood, in order to correct inborn genetic problems. The second area is gene delivery to cells in the liver for treatment of liver cancer. The results of BPEC research will provide a foundation for treating other degenerative diseases such as diabetes, the repair of injured tissues (e.g., spinal cord), and therapies for other types of cancers—as well as preventative DNA vaccines that can arrest the onset of disease altogether.

■ **For more information about BPEC's programs and accomplishments, visit the Center's website at: http://web.mit.edu/bpec**

A library of human antibodies represents a major disease-fighting tool.

MIT's First New Field of Study in 29 Years

MIT, the institution that helped establish the academic fields of chemical engineering and electrical engineering, has created an entirely new course of study with their revolutionary Biological Engineering (BE) undergraduate degree program. The program had its origins some twenty years ago when the faculty at the Biotechnology Process Engineering Center realized that there is a lot of fascinating—and necessary—research to do in the interface between biology and engineering. Their advocacy helped drive the establishment in 1998 of a new Biological Engineering Division at MIT, out of which the new degree program is a natural outgrowth.

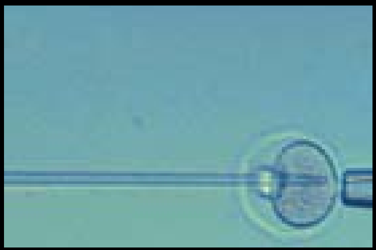


Consider the endless future possibilities of this exciting, emerging academic field: One MIT researcher is studying how animals make their shells, and is using what she learns to develop advanced materials. Another investigator is building tiny chips with living liver cells to employ in drug testing. Still another uses DNA sequencing machines to create models of vast, shifting ocean microbe populations that play a crucial role in the life of the planet. The BE major is starting with just 20 undergrads and will grow in size over time as industry's demand for BE graduates expands.

Creation of a Screenable Library of Human Antibodies

Antibodies are produced by the body's immune system as a disease-fighting mechanism. In many medical treatments, antibodies are injected into the human body to seek out specific proteins on cancerous cells, for example, and target treatment to those cells. BPEC researchers have captured a broad sample of the myriad types of antibodies present in adult humans and expressed those antibodies on the surface of yeast cells in a format suitable for quantitative screening. This work will speed the search for new antibodies—proteins that are effective tools for recognizing specific molecules. The technology provides a powerful and direct route to the isolation of useful antibodies outside a living body. As a result, it could replace the need to produce antibodies within animals, such as mice.

A cure for cancer may depend on finding a defective "on-off" switch in certain cells.



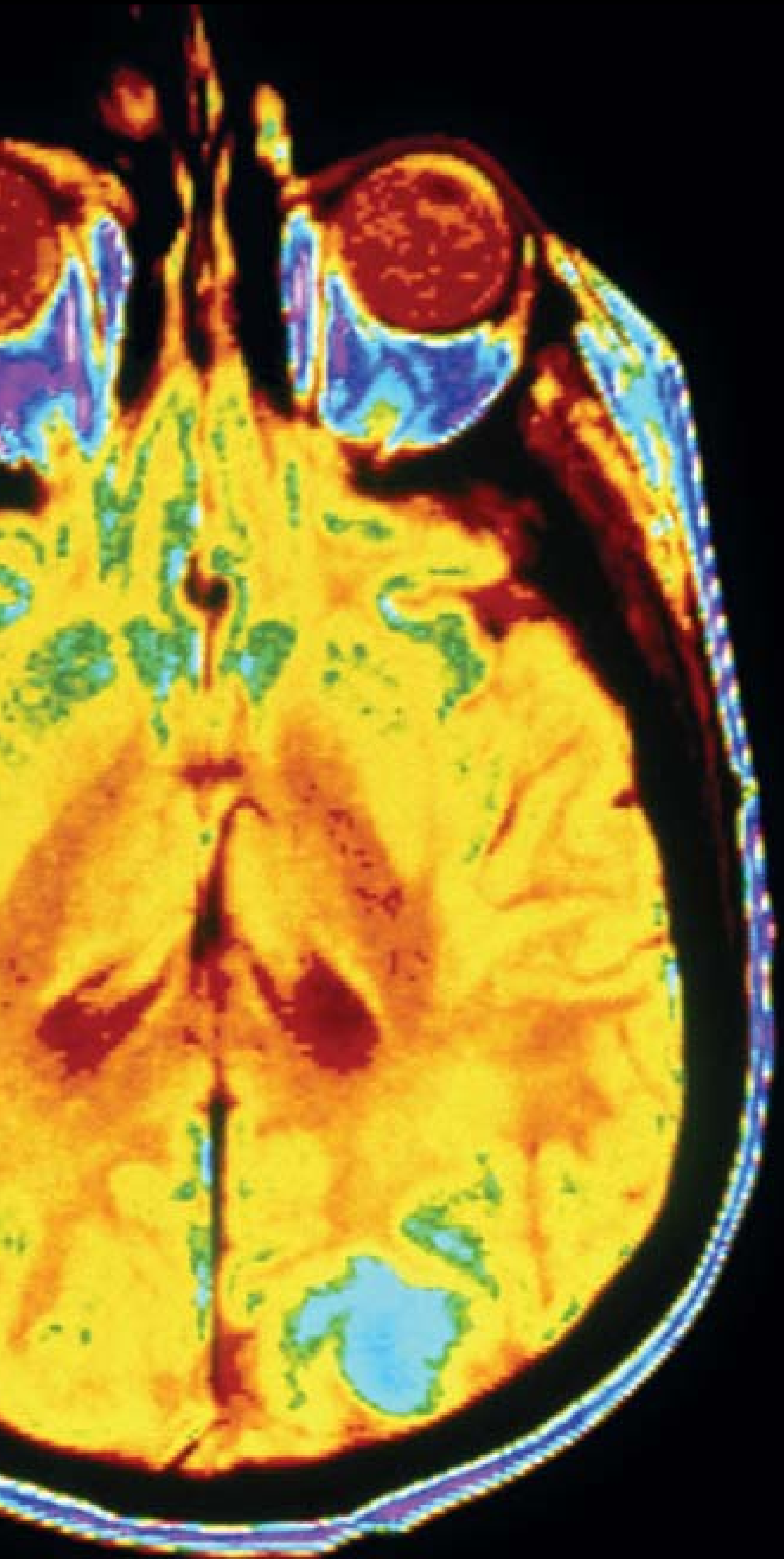
Breakthrough Findings for Treating Cancer and Infertility

Researchers believe that the key to the unchecked growth of some tumor cells can be found through the study of DNA imprinting — the process by which genes are switched on or off during fertilization. In healthy cells there is a balance between genes that promote growth and genes that control growth. In a tumor-producing cell, the on-off switch is disrupted, causing the cell to multiply unchecked.

BPEC investigators have developed novel techniques for culturing primitive germ cells *in vitro* from mouse embryonic stem cells, which allows them to study how the germ cells' natural development is disrupted. They hope that once they fully understand how genes are switched on and off , it might be possible to seek ways to reverse the faulty growth process in afflicted tumor cells. Understanding how these primitive germ cells develop into sex cells capable of fertilizing an egg cell will also provide insight into sperm development, potentially leading to treatments for infertility.

ERC for Biomimetic MicroElectronic Systems (est. 2003)

University of Southern California with California Institute of Technology and University of California at Santa Cruz



Restoring neural function through biomimetic microelectronic systems.

Researchers at this ERC are advancing the science and engineering of novel "biomimetic" microelectronic systems (BMES) based on fundamental principles of biology. The mission of the BMES ERC is to implant into people devices that will communicate with tissue and treat incurable diseases such as blindness, paralysis, and cognitive impairment.

This ERC has brought together engineered-system specifications from medical, scientific, and engineering disciplines with the latest microelectronic and microsystems technology. The ERC gains its strength through the integration of its research thrusts, its testbeds, and fundamental science. The three thrust areas—mixed-signal systems on a chip (SoC), power and data management, and interface technology—are biologically inspired and geared to satisfying the needs of the medical device and diagnostic industry.

Coupled with its research thrusts, the BMES ERC focuses on three testbeds—a retinal prosthesis, a neuromuscular prosthesis, and a cortical prosthesis. The retinal prosthesis is aimed at restoring vision in patients with retinal degeneration. The neuromuscular prosthesis is designed to reanimate paralyzed limbs to perform useful movements via functional electrical stimulation. Lastly, the cortical prosthesis uses biomimetic models of the hippocampus to serve as neural prostheses for loss of cognitive function.

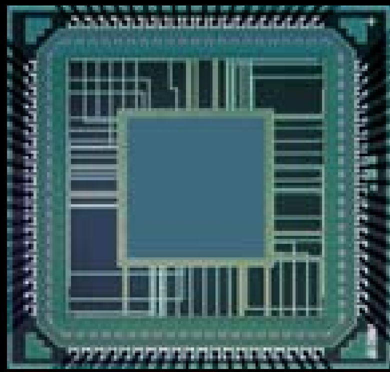
This work will vastly increase the quality of life of patients who suffer from these disabilities. The benefit to society comes not only from alleviating human suffering, but also through reducing the amount of government resources now directed to assist people with disabilities. The development of these prosthetics potentially will *solve* the patient's medical problem, not merely treat it.

For more information about BMES' programs and accomplishments, visit the Center's website at: http://bmes-erc.usc.edu

Incurable diseases such as blindness, paralysis, and memory loss may someday be "cured" using implantable micro-electronic devices.

Systems-on-a-Chip for Powerful Prostheses

The BMES ERC is developing entire platforms for implantable devices that could one day restore vision to the blind, reanimate paralyzed limbs, and overcome certain cognitive impairments. This new genre of implantable microelectronic systems will seamlessly integrate with the human body and, in so doing, replace missing or damaged neuronal function. The essential technologies being developed range from wireless power and data to hermetic packaging and bioelectrodes, as well as novel low-power biomimetic mixed-signal systems on a chip (VLSI solutions).



As a highlight of development in one of these areas, the BMES ERC has made great strides in state-of-the-art mixed-signal systems on a chip. The device shown serves as a vehicle for developing the technology to implement neural functions in silicon. These new mixed-signal circuits will allow center researchers to pack more functionality onto each chip, so that the same piece of silicon will hold both digital circuits inspired by neural processing and analog circuits able to communicate with neurons. Such a device has already successfully replaced the CA3 part of the hippocampus in the lab and in the future could also help meet the needs of a retinal prosthesis to allow the blind to read and recognize faces.

High School Student Conducts Professional-Level Research

Most pre-college programs offered by universities aim to give students a glimpse into the world of science and engineering to spark their interest in further study. The BMES found one student in whom that spark became a flame. She was an 11th-grader who became involved with BMES through her science fair project, to develop an intraocular camera for use in retinal prostheses. This young woman's work, mentored by BMES faculty, was so advanced that she was accepted as the only high school student ever to become a full member of the Optical Materials and Devices Laboratory at USC.

The student was present at an FDA surgical trial of a retinal prosthetic microelectrode array and participated in the successful surgical implantation of the first intraocular camera in a dog's eye. Not surprisingly, she was recognized as one of the top 300 math, science, and engineering high school students in the entire country. Now an undergraduate at USC, she is continuing her research on the visual psychophysics and optical systems design criteria applicable to both intraocular and extraocular camera designs for retinal prosthetic devices.

Delivering Biological Markers Into Tissue

One of the subtler tenets of scientific research is that "the necessity for an observer makes perfect observation impossible." The challenge is to minimize the effect of the observers and their observational tools. For example, investigations into the neurophysiology of the retina often require that "functional indicators" of parameters such as ion concentrations and protein locations be loaded into living retinal neurons, so that the parameters can be measured in real-time.

Until now, the technique for "biolistic loading" of indicators has been to inject fluorescent particles into the neurons. The particles were relatively large and often caused significant damage to the living cells during the loading process. To solve this problem, researchers at the BMES developed a "gene gun" to propel tiny silver nano-particles coated with fluorescent indicators into the retinal neurons. The particles are less than one-tenth the size of the standard particles and cause about 10% of the cell damage — making more accurate observation possible.

The work of this center will extend the microelectronics revolution in medicine.

VaNTH•ERC

VaNTH ERC for Bioengineering Educational Technologies (est. 1999)

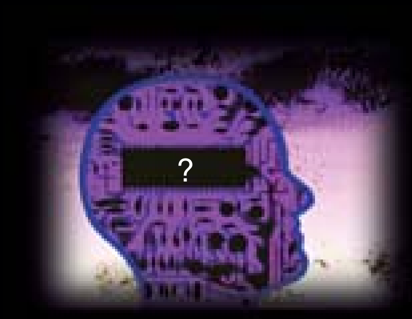
Vanderbilt University with Harvard-MIT, Northwestern University, and University of Texas-Austin

Developing the curricula and technologies to educate tomorrow's bioengineers.

The past decade has seen an explosion of both interest and discovery in bioengineering. This new field lies where biology intersects engineering, physical/chemical sciences, and mathematics. Advances in the basic principles and practical implementation of devices, materials, and instruments to non-invasively diagnose and treat a wide range of human diseases are beginning to stream out of this activity in academe and industry and will occupy many bioengineers in the years to come. The question is: How do we educate future generations of bioengineers in a discipline that is newly emerging and rapidly evolving? While the future of bioengineering is bright with promise, merely extrapolating the present educational paradigm will not fulfill its potential. To attract and retain talented and energetic learners, bioengineering needs a much larger body of integrated, time-tested educational materials.

Like bioengineering itself, the future of bioengineering education also lies within an intersection—at the focal point of bioengineering, learning science, and learning technology. The VaNTH Engineering Research Center brings together professionals in all these disciplines to determine what bioengineering students should learn, how they should learn it, and how that learning can be measured. VaNTH research has specifically targeted methods that can create graduates who are "adaptive experts" in bioengineering. This goal is directly related to national concerns regarding the need for innovation in the national scientific workforce. The overall strategy of the VaNTH ERC is to lay the foundation for a new system of bioengineering education that will allow the field to respond rapidly and effectively to immediate and future challenges.

■ **For more information about VaNTH programs and accomplishments, visit the Center's website at: http://www.vanth.org**



CAPE—From Concept to Courseware

How does a concept for a course get turned into an actual program of instruction? CAPE (Courseware Authoring and Packaging Environment) is a courseware authoring system and an experimental learning management system being used to deliver modules and other courseware in biomechanics, biotechnology, bio-optics, and other areas. While still developmental, the system significantly reduces the time required for instructors to move from concept to implementation of courseware.

This system is the crucial intermediary technology that will take instructional elements from a central repository and enable their assembly into a module or course. Most importantly, CAPE will allow individualized instruction so that students can be tutored in the areas where they need the most help. CAPE will also provide the next generation of "Personal Response Systems" to substantially improve in-class communications and formative assessment between instructors and students.

We're learning how bioengineers learn—and figuring out what they need to know—so we can develop core curricula for an exciting new field.

The "How People Learn" Paradigm for Bioengineers

A major goal of VaNTH is to study educational venues and to provide guidance for the design of bioengineering teaching materials based on the learning science principles discussed in the National Academy of Sciences report "How People Learn" (the HPL Framework). To that end, VaNTH researchers conducted a study that involved interviewing faculty and students; presenting the HPL Framework to bioengineering educators; exploring ways to implement the framework; developing modules; and producing a design document for the construction of bioengineering courses.

Researchers tested the hypothesis that HPL-based teaching materials are effective in bioengineering classrooms. Results show significant gains in learning for VaNTH modules compared to standard approaches studied as controls in the investigation.

Spearheading New Approaches to Bioengineering Education

Investigators at the VaNTH ERC have developed 41 instructional modules aimed at presenting modern bioengineering to undergraduate and graduate students. A particularly good example of these educational advances is an introductory biomechanics course where real-life challenges require students to determine which parts of the biomechanics taxonomy are relevant to the problem at hand.

Students work together on problems in the classroom. An electronic polling system is used periodically to pose questions on recent material. Many lectures are presented through a web-based course management system and web-based home exercises will eventually replace traditional "homework." VaNTH believes that the challenge-driven approach will better prepare students for the workplace and for life-long learning. Studies show that this method makes students more adept in the synthesis of engineering concepts to solve new problems.

Engineered Biomaterials Engineering Research Center (est. 1996)

University of Washington

Learning to mimic nature.

The University of Washington Engineered Biomaterials (UWEB) Engineering Research Center is comprised of a cross-disciplinary team of scientists, engineers, physicians, and industry leaders solving important problems associated with implanted medical devices.

Biomaterials and medical devices are widely used today. They save lives and improve the quality of life for millions. But the $100 billion medical device industry faces a major challenge: existing biomaterial devices do not work as well as the human parts they are intended to replace. For example, a tissue heart valve after 10 years of reliable service begins to mineralize and fail. Or a hip-joint prosthesis begins to loosen after providing 12 years of good mobility for the patient. Prostheses have to be replaced and devices become infected and must be removed. But these problems can be solved—it is possible for medical devices to work better and last longer. Implanted materials can heal normally in the body if we follow nature's own approach. That means gaining a better understanding of the biology of healing, including inflammation and thrombosis. UWEB has shown that adverse tissue and foreign body reactions can be controlled—even precision-controlled—using next-generation biomaterials.

UWEB's role in the medical device industry is vital. The work of UWEB researchers and industry partners is accelerating the pace at which early-stage discoveries can be commercialized. UWEB's forward-thinking models propel out-licensing potential and spin technology development companies out into the marketplace. Thus, UWEB developments not only expand fundamental knowledge but are continuing to transform the clinical practice of medicine.

■ **For more information about UWEB's programs and accomplishments, visit the Center's website at: http://www.uweb.engr.washington.edu**

"Re-Growing" Human Fingers—and Limbs

With over a million Americans undergoing some form of amputation every decade—most commonly the loss of one or more fingers—UWEB researchers are exploring treatments such as regenerative healing and tissue engineering of a replacement digit. They've found that the cells that appear at re-growth in response to injury may represent a type of stem cell that could hold the key to digit re-growth. The hope is that this work might lead to better ways to treat all types of extremity injury, including complete limb loss.

Creating Tissue-Acceptable Biomaterials

Creating "engineered" materials that mimic or interact with natural, biological systems is a challenge for scientists and engineers at UWEB ERC. They are at work creating novel biomaterials that deliver the same biological signal(s) to the tissue surrounding an implant that natural tissues would send. UWEB has produced a variety of innovative technologies, including biomaterial matrices that deliver DNA and proteins, special coatings that allow externally controlled delivery of drugs from implanted reservoirs, and microfibers that heal without causing a foreign-body reaction.

A new generation of biomaterials will trigger the body's natural healing process.

The paradigm of "learning from nature" has profound implications for engineering, education, and industry — not to mention saving lives.

Sparking Interest in Science with Guy Simplant

How do you spark the interest of middle, junior and high school kids when it comes to science and engineering? UWEB ERC and partner institutions have taken an entertaining multimedia approach. Their "Youth Take Heart" cardiovascular education program features an interactive web-based computer game called "Guy Simplant—The Case of the Ailing Heart". The hope is that students will not only learn about a healthier heart, but will be enticed into further study and careers in the areas of science, health and engineering.

To find out more about what ails Guy's heart, and why kids are so interested, go to www.guysimplant.org.

Section Two

MANUFACTURING AND PROCESSING

We tend to think of "manufacturing" as involving assembly lines and machinery for making products. It is that, to be sure; but research in this field encompasses much more, including the materials and components and processes involved in manufacturing, as well as their environmental impacts. ERCs in this technology group are focusing on the development of novel fibers, films, and particles for use in manufacturing as well as in products; the development of environmentally beneficial and economically sound processes for the semiconductor and chemical processing industries; and the development of a radically new manufacturing system to meet the needs of today's manufacturers.

ERC for Environmentally Benign Semiconductor Manufacturing (est. 1996)

University of Arizona with University of California at Berkeley, Cornell University, Massachusetts Institute of Technology, and Stanford University

Developing environmentally friendly manufacturing processes and tools for the semiconductor industry.

To make semiconductors requires large amounts of water, energy, and chemicals. The use of these resources, the safe handling of toxic chemicals, and the safe treatment and disposal of the complex waste that is generated all have major environmental implications, if not controlled. The semiconductor industry strives to safeguard the environmental, safety, and health (ESH) impacts of its operations and develop environmentally benign alternatives. But the industry is one in which processes and products change rapidly. Consequently, it is difficult to foresee and include ESH considerations in the design of new products and processes. The challenge lies in developing ESH-friendly technology early enough to integrate it into the design of tomorrow's chip manufacturing processes and tools. This is the mission of the Engineering Research Center for Environmentally Benign Semiconductor Manufacturing (CEBSM).

Center researchers are developing the science, technology, and educational methods necessary to lead the semiconductor industry to a new era of environmentally benign manufacturing in which the use of consumables is minimized along with emissions of environmentally harmful and unhealthy waste materials. CEBSM attempts to achieve these gains while at the same time reducing costs and improving process-related quality and performance. Overall goals include developing a methodology for incorporating ESH factors cost-effectively in the design of new processes, tools, and protocols for semiconductor manufacturing; integrating research activities with academic programs to provide unique learning opportunities; and providing a technical forum for experts to exchange ideas and information.

■ **For more information about CEBSM's programs and accomplishments, visit the Center's website at: http://www.erc.arizona.edu**

Faster, Cleaner, Cheaper Manufacturing

Currently, in the manufacturing of semiconductor and nano devices, various materials are deposited in layers and then almost completely removed after patterning, in what is called "subtractive processing." Research at CEBSM has laid the groundwork for a more efficient "additive processing" approach that promises to improve performance while lessening materials and energy use and waste.

Researchers made a major breakthrough by developing a new selective deposition process in which metals are added directly to the substrate to form the gates. They also developed new photo-imageable materials. Together, these new approaches eliminate steps in the chip manufacturing process that waste energy, materials, and water. As a result, the new process is also much more environmentally friendly and less expensive than the process it replaces.

CEBSM's new technologies have been lauded as "major innovations that have significantly impacted industry and society."

Reducing Water Use in IC Manufacturing

The growing semiconductor industry's use of large quantities of highly purified water in integrated circuit (IC) chip manufacturing is not only costly but also has large potential environmental implications. Along with its partners, CEBSM set up a unique physical and simulation testbed facility that has allowed researchers to devise improved water conservation and recycling tools and techniques for IC fabrication. The goal has been to provide technology that would make it possible to reduce water usage by 100% to 600%, depending on the fabrication technology being used. Achieving it has involved a series of breakthroughs in low-energy water purification methods, low-water-use wafer cleaning processes, and new treatment methods for low-cost and reliable water recycling in semiconductor fabrication.

Some of the conservation and resource management techniques developed at the facility have already been transferred to industry and are in use, saving between $250,000 and $2,000,000 annually at each manufacturing site. This research has received a number of high-level national and international awards, including from Semiconductor Equipment and Manufacturing International (SEMI) and the Semiconductor Research Corporation (SRC), which has recognized the contributions as "major innovations that have significantly impacted industry and society."

Program Introduces Science to Students in Remote Areas

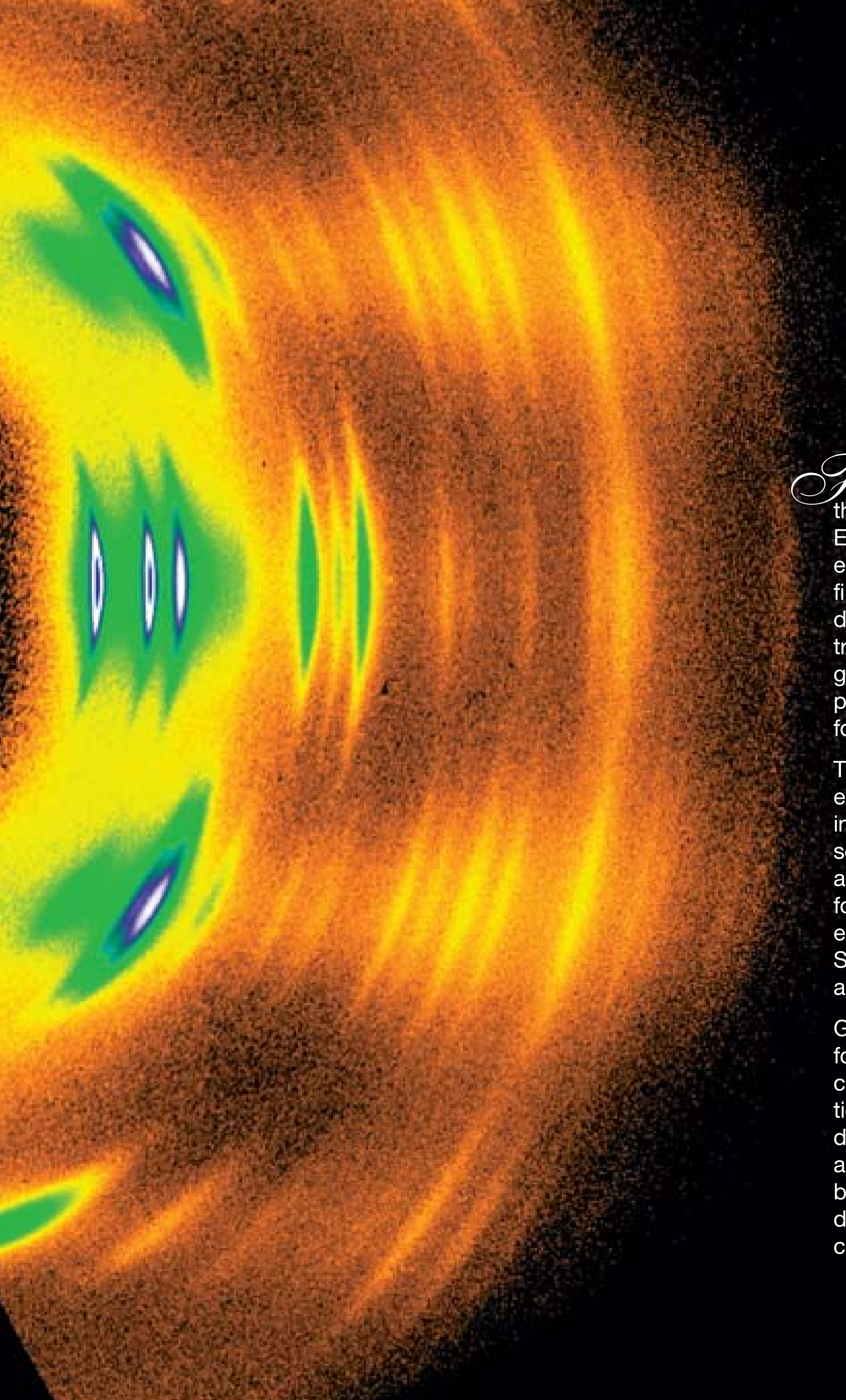
Because knowledgeable, enthusiastic, and inspiring teachers play a key role in attracting middle and high school students to math, science, and engineering careers, CEBSM launched the Teachers Institute in 1997 to "teach the teachers," and secondarily, to organize outreach programs to pre-college students in remote areas.

Recently, teachers from Palo Alto, California, and Phoenix, Tucson, Nogales, San Manuel, and Sierra Vista in Arizona—where several of the participating schools have a high minority population (particularly Hispanic and Native American), and several serve small rural communities—participated in the outreach program. It had a strong, positive, and immediate effect on both the teachers and their students. Teachers who participated in the Institute have developed nearly 200 new lab and classroom exercises as a result of their summer research, reaching thousands of students.

CAEFF

Center for Advanced Engineering Fibers and Films (est. 1998)

Clemson University with Massachusetts Institute of Technology and Clark Atlanta University



Creating a new paradigm for fiber and film development.

Fibers and films are special material forms that are commonly used throughout the manufacturing industries. The Center for Advanced Engineering Fibers and Films (CAEFF) is an integrated research and education environment for the systems-oriented study of fibers and films. The Center's goal is to create a new paradigm for fiber and film development that relies on computational materials design instead of trial-and-error experimentation. CAEFF researchers are pursuing this goal by creating integrated, multi-scale models that can be used to predict optimal combinations of materials and manufacturing conditions, for a range of fiber and film manufacturing processes.

The Center's state-of-the-art materials design environment includes experimental facilities with pilot-scale extrusion equipment and custom instrumentation for property measurements; a materials database; software that comprises modeling and visualization of data; and advanced computing hardware and operating systems. The research focuses on melt processes for fibers and films (fiber spinning, cast film extrusion, and blown film extrusion) and on surface processes. Synthetic polymers, bio-based polymers, and carbonaceous oligomers are used as test-case material systems.

Graduates of the Center have a broad, systems-oriented technical foundation; skills in modeling, simulation, and visualization; an appreciation of the industry perspective; and the teamwork and communication skills necessary to function effectively in collaborative virtual design environments. The paradigm shift envisioned by CAEFF will be accomplished by placing CAEFF graduates in industry positions and by training industry personnel in the use of the modeling approach for developing new products. Disseminating the modeling approach advocated by CAEFF is our most important technology transfer activity.

■ **For more information about CAEFF's programs and accomplishments, visit the Center's website at: http://www.clemson.edu/caeff**

New Models for Process Simulation

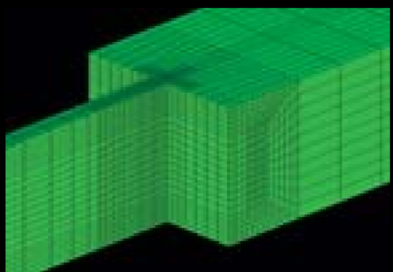
CAEFF has created the first simulation package capable of predicting the final structure and properties of fibers or films produced at given sets of process conditions. The software simulates melt-spinning (the dominant commercial fiber formation process) of synthetic materials, using modules that simulate each stage of the process. It can be easily configured for a variety of processes. Menu-driven through a graphical user interface, the software features flow models at different levels of complexity, which enable the process designer to first gain insight with a quick, one-dimensional simulation. This knowledge is then used to set design parameters for more accurate simulations. The model is directly connected to the CAEFF Polymer Database, which serves not only as a medium for archiving experimental and simulation data, but also as a means of accessing all material data necessary for a simulation by simply specifying the polymer.

A High-Tech Display Wall as a Research Tool

"Scientific visualization" is a research tool that has become increasingly attractive and effective as computer power has increased. CAEFF researchers have constructed a high-resolution "display wall" consisting of 24 video projectors, powered by 240 commodity computers, to provide high-performance rendering. The display wall features "casual alignment" technology developed at CAEFF. Projectors are placed behind the screen and cameras "watch" the screen to dynamically update the generated image to compensate for misalignment between the projectors. This arrangement eliminates the need for expensive and labor-intensive hardware for precision manual alignment.

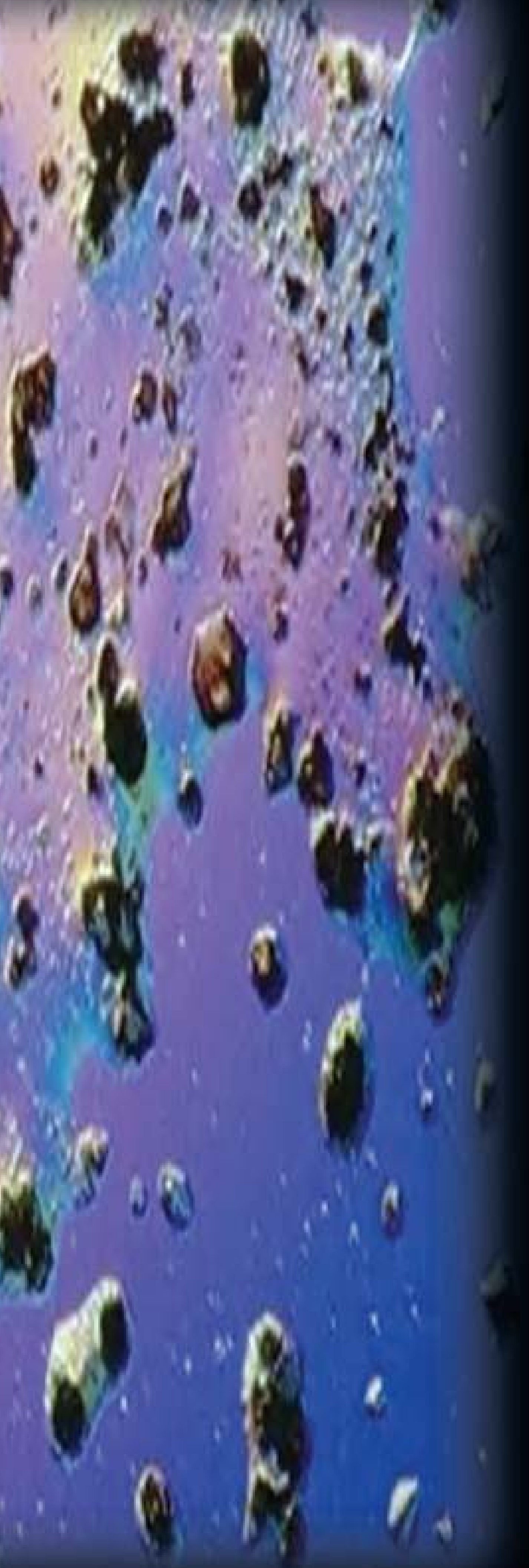
High-resolution visualization plays an increasing role in gaining insight from the results of large scientific visualizations. The ERC's commodity display wall technology makes high-resolution systems both much more affordable to build and more readily accessible to researchers and industry.

CAEFF has created an integrated process model that industrial users can employ as a "virtual laboratory" to simulate the processing of polymeric fibers and films online.



A "Virtual Testbed" for Designing Fibers and Films

CAEFF's materials design environment features an online "virtual testbed" that will allow users to design an entire fiber or film system by inputting precursor specifications, processing parameters, and desired properties. This virtual testbed will bring design improvements to current manufacturing systems and also significantly reduce, if not eliminate, trial-and-error experiments needed for the design of next-generation fiber and film processes.



PERC

Particle Engineering Research Center (est. 1994)

University of Florida

Bringing a world of new products and processes through innovative particulate systems.

Particles are used in a myriad of ways in modern manufacturing, as both tool and product. Particle technology deals with the production, characterization, modification, handling, and utilization of organic and inorganic powders as well as bioparticles, in both dry and wet conditions. Particulate systems are a core technology in many industries including advanced materials, chemical, energy, environmental, mineral, agricultural, pharmaceutical, biotechnology, and food processing.

The aim of the Particle Engineering Research Center (PERC) is to develop innovative particulate-based systems for next-generation processes and devices that improve the nation's industrial strength, environmental quality, and public health, while producing top-flight engineers and scientists in this vital field.

■ **For more information about PERC's programs and accomplishments, visit the Center's website at: http://www.erc.ufl.edu**

Training the Next Generation of Researchers

The field of Particle Science and Technology (PS&T) is important for a wide range of industries, from microelectronics to pharmaceuticals. Experts and advanced level students in the field are scattered all around the world, and no single institution has expertise in all of the multidisciplinary areas that comprise PS&T.

To meet this need, PERC established the Particle Science Summer School in Winter (SSIW). The SSIW program is an intensive, week-long program for graduate students that provides advanced training in PS&T topics in an international forum, taught by world-class experts from both academia and industry. The students come from around the country and abroad. In addition to training the next generation of PS&T researchers, the program gives these students an opportunity to begin to network and collaborate across continents.

Inactivating Hazardous Bioparticulates

Biological warfare agents encompass bacteria, viruses, fungi, and other microorganisms. Techniques for disinfection include the use of chemical disinfectants and irradiation with germicidal ultraviolet — all of which have some unacceptable shortcomings including toxic byproducts and surface damage.

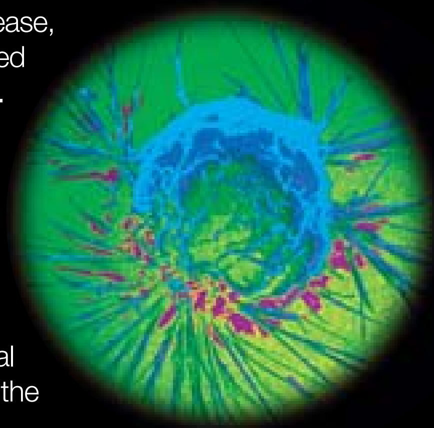
Photocatalysis is an alternative technology for disinfection of air and water environments that does not generate toxic byproducts or cause damage to the surface. Researchers at PERC have synthesized titania-coated multi-wall carbon nanotubes which have been shown to be twice as effective in photocatalytic disinfection of spores as commercially available products are. The improved photocatalysis process could provide a convenient way to deactivate biological contaminants — not only for the defense sector, but for environmental problems in the civilian and industrial sectors as well.

PERC researchers have found a way to disinfect biological agents without leaving toxic byproducts behind.

"Smart nanotubes" deliver drugs only to targeted cells, thereby reducing unwanted side-effects.

Smart Nanotubes for Selective Biomolecule Delivery to Living Cells

Most drugs used to treat life-threatening human maladies such as cancer, heart disease, and AIDS cause serious side effects because, in most cases, the drugs are administered to the whole body, even though they need to act on only a small part of it. Researchers at PERC have developed a major new alternative drug transport technology consisting of an assembly of mono-dispersed tubular nano-particles with and without "chemical sensing" nanocaps at the ends of the tubes. Specific targeting technology is incorporated into the structural platform.



Simply stated, smart nanotubes are able to deliver drugs to only the target cells (diseased cells), thereby greatly reducing the dose a patient would need to take and providing targeted and more effective treatment. By allowing the delivery of several classes of important therapeutic agents to only those cells or tissues that require the medication, the smart nanostructures will markedly improve drug safety and efficacy.

The Center for Environmentally Beneficial Catalysis (est. 2003)

University of Kansas with University of Iowa, Prairie View A&M University, and Washington University in St. Louis

Strengthening the chemical industry through environmentally and economically sustainable new products and processes.

The Center for Environmentally Beneficial Catalysis (CEBC) was designed to address the challenges faced by the chemical industry. This is a $450 billion/yr enterprise that accounts for approximately 10% of U.S. exports and nearly one million jobs. Synthetic fibers used in clothing, life-saving medicines, technology-enhanced agricultural products, clean fuels, and lightweight materials for transportation are a few of its more than 70,000 products. This industry faces many challenges in the 21st century, such as increasing globalization of markets, demands for improved environmental performance, increased productivity to maintain global competitiveness, higher consumer expectations for product quality, and the changing workforce required to meet these challenges. Additionally, in the coming decades, fuels and synthetic chemicals will increasingly have to be produced from non-crude-oil-based feedstocks.

CEBC is addressing these challenges by developing advanced technologies that minimize waste generation and protect environmental quality. Envisioned transformations include: replacement of conventional liquid acids with benign solid acid catalysts; processes that use benign solvents such as carbon dioxide or water; atom-economical use of raw materials to create desired products; production of fuels and synthetic chemicals from alternate feedstocks such as coal and biomass; and process intensification for energy efficiency and safety.

The multidisciplinary CEBC research integrates knowledge from chemical, biological, surface, and catalytic sciences to engineer innovative technologies for new processes and products. Education and training of CEBC graduates is also interdisciplinary, with novel graduate curricula that integrate courses in chemistry, biochemistry, engineering, and the computational fields.

■ **For more information about CEBC's programs and accomplishments, visit the Center's website at: http://www.cebc.ku.edu**

CO_2-Expanded Liquids as Solvents

CEBC researchers are leading the way in the rational exploitation of CO_2-expanded liquids (CXLs) as benign alternatives to conventional organic solvents. A CXL is generated by mixing nontoxic, nonflammable carbon dioxide (from existing, free gaseous sources) with either a conventional organic solvent or a binary mixture of the organic solvent and water to form a single-phase liquid. The resulting CXL greatly reduces the potential for forming explosive vapors and possesses properties desirable as a medium for performing catalytic reactions. Additionally, CXLs reduce the usage of organic solvents and thereby the emissions of organic vapors into the atmosphere. CEBC researchers are exploiting this novel and versatile class of solvents to develop environmentally benign and economically viable alternative processes for a broad range of catalytic reaction systems. For example, continuous bench-scale reactors that employ CXLs have been developed to demonstrate stable solid acid catalyzed alkylations. This finding is significant since it eliminates catalyst fouling as a major barrier impeding the commercialization of solid acid catalyzed processes.

Introducing K-12 Students to Green Engineering

Current research on science education confirms the adage that students learn best and are most engaged when they are actively involved in scientific research that is directly related to their everyday lives. Guided by this knowledge, CEBC education researchers have developed the first online collaborative research unit hosted by Pathfinder Science (http://pathfinderscience.net) to address how green engineering impacts students. The research unit, with components targeting both elementary and secondary students, introduces students to the concepts of environmental assessment and green solvents by investigating the environmental impact of various technologies used by dry cleaners in their own communities. The data and results of this research are available to anyone through the Pathfinder website, and can be further evaluated by comparing data generated by students worldwide with existing information on air and water quality. CEBC research is integrated into the background information for the student projects to reinforce the principles of green engineering and chemistry. Teachers and business owners also benefit from this research experience by learning about how environmentally responsible practices improve the quality of life in the community.

"Industrial Ecology" is a new paradigm for balancing the industrial system with the natural ecosystem—sustainably.

Applying Green Engineering and Chemistry Principles in Synthesis of New Solid Acid Catalysts

The use of environmentally benign solid acid catalysts as replacements for highly corrosive mineral acids (such as sulfuric acid and hydrofluoric acid) in chemical processes has been an elusive grand challenge of the chemical industry for decades. The major barrier to commercialization of solid acid catalyzed processes is rapid catalyst deactivation and/or unacceptable product quality. A key to solving this problem is designing a catalyst that is active enough to rapidly convert the starting materials to desired products while avoiding side-reactions that lead to fouling and catalyst deactivation. CEBC researchers have successfully synthesized C-H–type solid acids whose acid strength is greater than that of sulfuric acid and that show remarkably high catalytic activity. Traditional methods to synthesize these types of materials generate large amounts of solid and liquid wastes. CEBC researchers have developed a "greener" and more economical route that employs a solventless catalyst purification step and produces the solid acid in high (90+%) yields. The Center is now developing novel processes based on the use of solid acid catalysts.

Engineering Research Center for Reconfigurable Manufacturing Systems (est. 1996)

University of Michigan, Ann Arbor

Creating the new manufacturing paradigm for the new century.

To regain its competitiveness in the global and domestic markets, the U.S. transportation manufacturing industries must possess and operate manufacturing systems that are super-productive and reconfigurable to accommodate the frequent changes in market variables caused by global competition. The goal of the Engineering Research Center for Reconfigurable Manufacturing Systems (ERC/RMS) is to design innovative, reconfigurable manufacturing systems that permit rapid response to changes in market demand and cost-effective production of new products. In this new reconfigurable manufacturing paradigm, production lines are always providing exactly the production capacity and functionality needed, exactly when needed. The ERC/RMS has demonstrated in practice that scientific advances can be integrated even into traditional production lines on the factory floor to augment their productivity.

The Center has proven that its numerous patents and inventions can enhance U.S. manufacturing industry productivity, reduce its lead-time for new products, and yield systematic high-quality products despite investing less in measurements, while utilizing innovative measurement instrumentation never seen before.

The ERC/RMS integrates research results into academic programs that teach strategies and tools that enable graduates to compete successfully in the global manufacturing environment. It also offers numerous outreach activities to high schools and the public at large, aimed at increasing the pool of students interested in pursuing manufacturing careers

■ **For more information about RMS' programs and accomplishments, visit the Center's website at: http://erc.engin.umich.edu**

Reconfigurable Factory Testbed

ERC/RMS has built a one-of-a-kind Reconfigurable Factory Testbed (RFT) consisting of both real and virtual machines that are controlled over a communication network and coordinated through a unified software architecture. Part of the testbed is hardware. Another part of the testbed is software—the "virtual factory." There is also a suite of open-source, web-based Remote Viewing and Collaboration tools.

The integration of real and virtual machines together in the same system with the same controllers is unique; no similar facility exists in any other university or company. The expandable scale of the RFT, with the integration of physical and virtual machines, allows control systems of unprecedented complexity to be developed, tested, and validated in a laboratory environment. The research results developed using the RFT are enabling dramatic improvements in factory design and control, increasing the productivity and profitability of manufacturing companies.

Instead of taking three hours, defects can now be identified *within 30 seconds* — dramatically improving productivity and reducing costs.

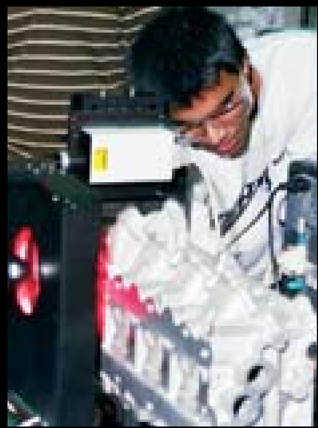
The Portable Manufacturing System Project

To increase the interest in and understanding of manufacturing among middle and high school students, ERC/RMS designed a short course on manufacturing and built a portable manufacturing cell that is taken to local schools to provide hands-on experience. The cell can be also operated via the Internet.

The Portable Manufacturing System Project (PMSP) cell is composed of a CNC milling machine, a robot, and a personal computer that controls the entire system. In a two-week long program, students from the ERC/RMS teach the middle and high school students about basic concepts of manufacturing, computer-aided design (CAD), computer-aided manufacturing (CAM), and simple computer programming. Building upon these skills, the young students learn how to use the robot and a milling machine. The PMSP has introduced manufacturing engineering to over 1000 precollege students. It also reaches the general public through museum exhibits.

Finding Flaws Faster Enhances Productivity

Many critical parts of an automobile (e.g., engine blocks) are produced with precision machinery at a high rate of 100 parts per hour. But what happens when there is a defect in production due to a worn or flawed tool? The current practice is to measure the part using a relatively slow machine that takes about 3 hours. If a bad dimension is identified, the production line is stopped. However, during those 3 hours about 300 engines have been produced—each containing defects.



ERC/RMS has developed a Reconfigurable Inspection Machine (RIM) that utilizes new non-contact sensor technologies to measure—within 30 seconds—features associated with a family of automotive parts. The RIM is capable of inspecting each part on a real-time basis directly on the machining line, thereby identifying problems immediately. The RIM is an example of an innovative idea that was translated to a new machine. RIM machines are being integrated now into production lines of US automotive manufacturers in Michigan, and will dramatically change the way that inspection is performed—in-process instead of after process.

Section Three

EARTHQUAKE ENGINEERING

Major earthquakes are a relatively rare occurrence in the United States. However, extensive fault zones exist not only on the West Coast but across the continent; and in the nation's history major earthquakes have occurred in the Midwest, the Southeast, and other regions. If such events were to take place today, they would cause catastrophic destruction. Three ERCs aim their research and education programs at finding ways to reduce the losses and destruction caused by earthquakes through a variety of means including improved seismic design of structures, protection of critical infrastructure through new technologies, better loss estimation, and faster damage assessment.

Multidisciplinary Center for Earthquake Engineering Research (est. 1997)

University at Buffalo with Cornell University, University of California at Irvine, and University of Colorado at Boulder

Engineering solutions for earthquake loss reduction.

Earthquakes are perhaps the most devastating of all natural disasters because they strike without warning. Like a “surprise attack,” they sneak up unannounced and can instantly transform the everyday into the unthinkable—bringing death, destruction, and disruption for weeks, months, and years into the future.

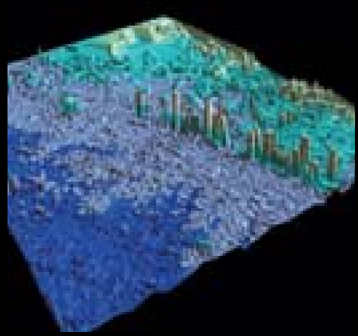
With at least 39 states at risk of moderate or major earthquake activity, how do communities prepare to reduce these potentially devastating effects of Mother Nature? How do they become more resilient in the face of earthquake disaster? Researchers at the Multidisciplinary Center for Earthquake Engineering Research (MCEER) are providing answers to these questions.

MCEER unites a group of leading researchers, students, and partners in business, industry, and government from numerous disciplines and organizations throughout the United States. Together they integrate knowledge, expertise, and a multidisciplinary perspective with state-of-the-art experimental and computational facilities in the fields of earthquake engineering and socioeconomic studies. The result is a strategic and systematic “engineered” program combining basic and applied research with education and outreach initiatives that, together, produce solutions and strategies to reduce the impacts of earthquakes on physical infrastructure and socioeconomic systems.

■ **For more information about MCEER's programs and accomplishments, visit the Center's website at: http://.mceer.buffalo.edu**

Remote Sensing Saves Lives After Earthquakes

Earthquakes can instantaneously destroy property and human life, but a speedy and well-organized response can limit the extent of further losses. An emergency manager's most difficult post-disaster task is to quickly and accurately assess damage and the disruption in efforts to direct available resources to areas of greatest need.



Researchers at MCEER are investigating how remote sensing technologies such as synthetic aperture radar and moderate resolution optical imagery can be used to improve post-disaster damage/situation assessment. For example, MCEER researchers have furthered the integration of such technologies, and expanded their use, in investigations immediately following another type of disaster – Hurricane Katrina. More advances are likely to come from the widening availability of high-resolution images and the use of unmanned airborne vehicles and other means to collect data in near-real-time.

Better Buildings via "Darwinian" Design

Protective technologies have revolutionized the design and retrofit of buildings for earthquake loads by absorbing damaging shock and vibrations. As building design evolves via use of advanced technologies, MCEER researchers are introducing a new computational platform that enables engineers to choose the optimal device and configuration to meet prescribed standards of performance for protection of the building and its contents. The Evolutionary Aseismic Design and Retrofit (EADR) software enables engineers to model a structure and encode its genetic make-up (its important structural and nonstructural attributes). A genetic-based evolution algorithm is then used to analyze and optimize the structure's dynamic behavior to attain the fittest level of performance for prescribed conditions.

Economic losses from recent urban earthquakes in the U.S. recorded losses in tens of billions of dollars.

Successful Deployment of Lifeline Resilience Software

One focus of research at MCEER is finding ways to protect the essential utilities infrastructure, or "lifelines," of cities in the event of an earthquake. MCEER's team has developed a methodology and software tools to evaluate the seismic resilience of electrical power and water supply systems. The Center has deployed the new tools to conduct case studies using the Los Angeles Department of Water and Power's (LADWP's) water and power systems as a testbed.

The software tools incorporate specific information about key subjects such as census and economic data for societal impact assessment; fragility information on system components with and without seismic retrofit; and the utility's organizational and management preparedness. The case studies were able to successfully evaluate — for the first time — the resilience of actual water and power systems interacting under various earthquake scenarios.

Pacific Earthquake Engineering Research Center (est. 1997)

University of California at Berkeley with California Institute of Technology, Stanford University, University of California at Davis, University of California at Irvine, University of California at Los Angeles, University of California at San Diego, University of Southern California, and University of Washington

Developing seismic design technologies to improve safety and manage seismic risk.

Earthquakes in the United States and worldwide have often brought death, great economic losses, and societal disruption. PEER pursues programs aimed at reducing earthquake losses cost-effectively, with an emphasis on understanding and mitigating the potential for collapse of older buildings and developing performance-based approaches to measure the tradeoffs between upfront investments in seismic safety and downstream losses.

Advances in the earth sciences related to seismic hazard, and in computational procedures related to modeling and computation, can be coupled with economic models to simulate the effects of earthquakes on the built environment and society. The challenge to the PEER research program is to bridge the gaps between these different disciplines in order to develop a performance-based, systems-level approach to seismic evaluation and design.

■ **For more information about PEER's programs and accomplishments, visit the Center's website at: http://admin@peer.berkeley.edu**

Earthquake Performance Simulation Tools

PEER is developing the theory and tools so engineers can design facilities whose performance is individually tailored to the resources and needs of the owner as well as society. High-rise buildings can be safer, bridges and hospitals remain functional, and museum collections can be protected. A key component is earthquake performance simulation—whereby specialized software is used to model seismic waves; facility response including damage; and consequences in terms of repair costs, downtime, and casualties. One software innovation, the Open System for Earthquake Engineering Simulation, or OpenSees, takes advantage of modern high-end computing, grid communications, access to databases, and scientific visualizations to improve our ability to model and simulate complex structural and geotechnical systems. With advanced seismic simulations, engineers and owners can visualize outcomes and make critical decisions affecting future facility performance.

Shake Table Competitions for K-16 Students

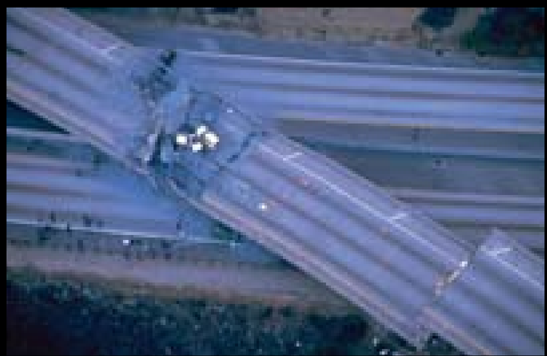
To attract and inform youth in grades K-12 regarding career opportunities available in science and engineering, UC-Irvine created a great example of student outreach called the "Learning with LEGOs" competition. Led by PEER faculty members, the university invites hundreds of K-12 students from the inner city to participate in a shake table competition using LEGOs. This program has spawned an even larger nationwide Undergraduate Shake Table Competition through PEER run by the center's Student Leadership Council, which is open to teams from any college in the country.

Both competitions use earthquake engineering to show that careers in science and engineering are open to students through higher education, including graduate school.

Inner-city students "shake it up" at LEGO competition.

Filling the Gap in Ground Motion Data

In collaboration with seismologists and business and industry partners, PEER is developing a new generation of simulation models to predict the characteristics of future ground motions at a site. The traditional approach has been to use attenuation models that are developed using empirical data from recordings of past earthquakes. But large earthquakes are rare, and measurements of large earthquakes close to the fault are even rarer.



Earthquake simulation studies provide valuable data without waiting years for the next "big one" to hit.

Rather than wait perhaps hundreds of years to record large-magnitude events close to the fault, PEER is predicting ground shaking in large-magnitude earthquakes using computers to simulate fault rupture, propagation of ground waves, and local site amplification effects. As a result, PEER has been able to fill in the missing data from large-magnitude, nearby earthquakes without having to wait for the devastating consequences of the next "big one."

Mid-America Earthquake Center (est. 1997)

University of Illinois at Urbana-Champaign with Georgia Institute of Technology, University of Memphis, University of Michigan, University of Puerto Rico, Texas A&M University, University of Texas at Austin, and Washington University

Reducing earthquake losses through research and education.

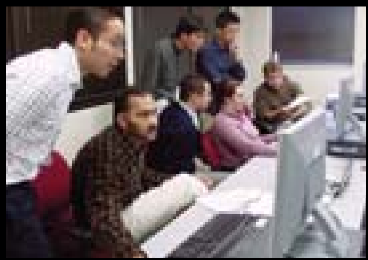
The Mid-America Earthquake (MAE) Center has become a world leader in assessing and mitigating the effects of low-probability/high-consequence earthquakes and other natural disasters. The series of earthquakes in 1811 and 1812 referred to the New Madrid earthquakes shook most of the Central and Eastern US, and were felt as far as Washington, DC. A repeat of those events today would cause losses significantly larger than those caused by Hurricane Katrina, and would have enormous impacts throughout the US and even the global economy. High-impact natural disasters are so infrequent that there is no consensus on how to mitigate their anticipated effects. They require an approach capable of influencing many types of organizations and addressing the needs of a complex society.

The MAE Center has pioneered the development, articulation, and application of Consequence-Based Risk Management (CRM), whereby engineering and consequential social and economic impacts, alongside mitigation options, are assessed in an integrated fashion and presented through high-end Information Technology platforms to decision- and policy-makers. The CRM framework also serves to develop educational and outreach activities that address the complex needs of vulnerable regions and lead to higher risk-awareness and preparedness. The novel integrated approach of the MAE Center is also producing a new type of risk management professional who is capable of dealing with engineering, social, and economic issues and their interactions. Through the MAE Center's highly interdisciplinary CRM framework, risk is assessed in the Central and Eastern US and similar regions around the world, and suitable plans and prioritization of mitigation actions are developed to protect communities vulnerable to natural disasters.

For more information about MAE Center programs and accomplishments, visit the Center's website at: http://mae.cee.uiuc.edu

Educating Tomorrow's Earthquake Risk Experts

The MAE Center is preparing the next generation of earthquake scientists, engineers, and risk managers through a variety of education and research activities. Students can earn a center-wide Certificate in Earthquake Science and Engineering by taking courses at their home institution, enrolling in a distance learning credit course taught by Center faculty, and participating in a residential Consequence-based Risk Management (CRM) Institute focusing on interdisciplinary assessment and mitigation of earthquake effects.



The education programs give students the opportunity to learn about topics ranging from seismology to social science and provide a theoretical and practical framework for understanding the consequences of a damaging earthquake. Learning comes to life through opportunities for MAE Center students to participate in field missions that include travel to earthquake-prone areas of the world and to interact with industry experts through internships.

GPS Array "Sees" Deformation of Earth's Crust

Except for a few cases, the deformation of the earth between earthquakes—during which time the crust is strained to the breaking point—has been invisible to scientists. Technological advances have enabled us to see more. The Global Positioning System (GPS), which revolutionized navigation, has also revolutionized the study of movements of the Earth's tectonic plates.

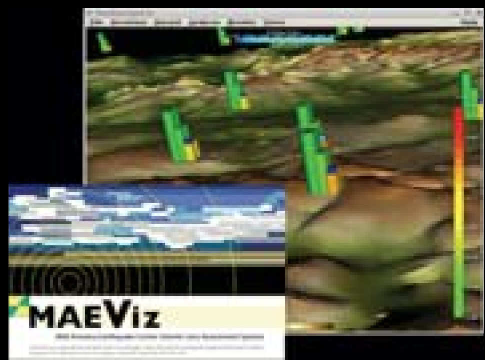
The GPS Array for Mid-America (GAMA) is an MAE Center project designed to determine if deformation is occurring in the interior of the North American plate. The GAMA network comprises a series of GPS stations located in the New Madrid seismic zone in the central Mississippi Valley. Results indicate that rapid deformation is indeed occurring. These observations are leading to a more rapid and complete explanation for the causes of New Madrid earthquakes and will improve seismic hazard estimation.

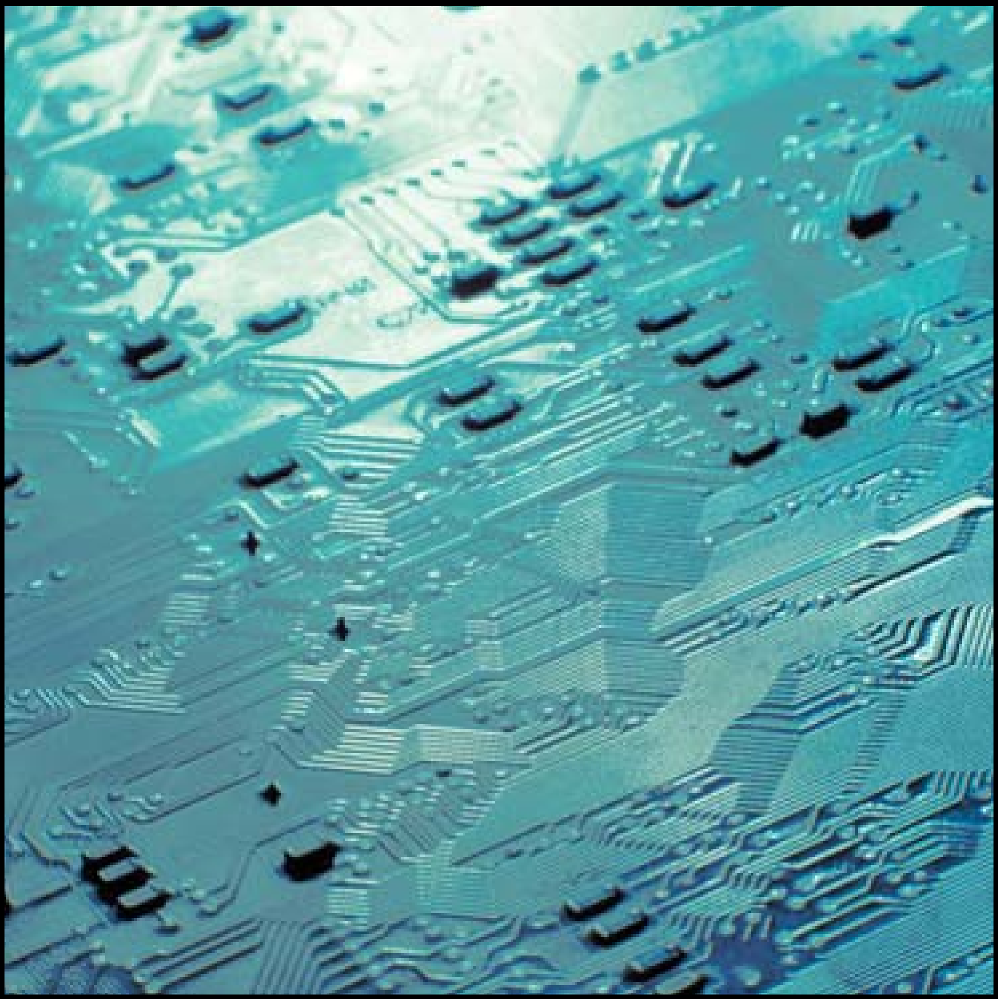
The largest-ever earthquakes in the US were the 1811-1812 New Madrid quakes. The same events today would bring losses of at least $200 billion.

"MAEViz" Allows Earthquake Damage Visualization

MAEViz—the MAE Center's Loss Assessment and Visualization software package—is a framework that integrates spatial information, data, and visual information into an environment for performing seismic loss assessment and analysis. Because MAEViz is a single interface that integrates a variety of data sources and types, it is useful to engineers, state departments of transportation, emergency managers, insurance companies, and others interested in assessing losses due to disasters.

MAEViz capabilities include generating damage estimates; testing multiple mitigation strategies; and supporting modeling of impacts on transportation and utility networks as well as on social and economic systems. The different sources of uncertainty in estimating losses are integrated to give the decision-maker sufficient information for risk-informed action. Application of different structural strengthening approaches and the outcome of different scenarios are fed into a decision-making module that prioritizes the options based on the loss assessment and mitigation calculations. MAEViz has single and multiple screens, versatile visualization capabilities, and is deployable in a distributed computing environment on the grid.





Section Four

MICROELECTRONIC SYSTEMS AND INFORMATION TECHNOLOGY

This area encompasses many of the most advanced fields of engineering research—research that underpins the technologies of tomorrow. The eight ERCs in this group are working at the frontiers of fields as diverse as: intelligent machines with human-like senses; new light sources for use at the nanoscale; a novel approach to microelectronic systems packaging; a radar network that can more reliably detect low-altitude weather phenomena such as tornadoes; wireless microdevices for a multitude of uses; technologies for sensing objects hidden beneath any medium; multimedia and internet research; and new technologies for converting electric power from one form to another.

Center for Neuromorphic Systems Engineering (est. 1994)

California Institute of Technology

Endowing machines of the twenty-first century with human senses.

Today, most machines need a human ‘master’ to tell them what to do via knobs, sliders, keyboards, and pointing devices. But researchers at the Center for Neuromorphic Systems Engineering (CNSE) envision a future where machines sense, interact with, learn from, and adapt to their environment with the same ease as living creatures. The hope is that this generation of smarter machines will greatly improve consumer products, human/computer interaction, healthcare, manufacturing, and telecommunications.

CNSE is following nature’s lead by developing special-purpose systems for specific sensory processing tasks. When these special-purpose sensors and processing electronics are coupled with learning algorithms and appropriate computational architectures, the resulting integrated sensory system can offer robustness in response to environmental variations and useful performance over a very wide range of input magnitude. The goal is to devise technologies and systems that, someday, will allow machines to communicate meaningfully with people.

■ **For more information about CNSE's programs and accomplishments, visit the Center's website at: http://www.erc.caltech.edu**

Microsoft Products Include DigitalPersona Technology

Password management is a growing problem for many computer users. People often have to keep track of many different passwords and user names in order to get secure access to check e-mail, shop at favorite web sites, and use bank accounts or databases. Microsoft is now shipping products that contain fingerprint identification technology developed by a CNSE start-up company, DigitalPersona.

The new Microsoft products introduce biometric password management using software which includes a novel engine that makes fingerprint recognition fast and reliable. These products aim to reduce "password fatigue" by making it more convenient to open password-protected pages while continuing to insure privacy and security. The fingerprint reader is designed to be intuitive and reliable. It is expected that this technology will soon become ubiquitous wherever people use computers.

Neuromorphic engineers seek to design artificial neural systems, such as vision systems and autonomous robots, whose physical architecture and design principles are based on those of biological nervous systems.

Chip Transceiver Could Make Driving Safer

A team of Caltech electrical engineers has created a "phased-array transceiver"—a silicon chip, smaller than a penny, with radar and communication capabilities that could help vehicles avoid obstacles. It works much like a conventional radar system, but takes less space, costs less, and does not require the rapidly turning antennae.

A chip attached to the front of a car could be linked to an interior screen displaying everything in the car's path. The car could then be programmed to avoid obstacles or to stop before crashing—all without human intervention. The phased-array transceiver chip could also be used in military applications to monitor an area in place of human patrols. Operating at 24GHz (meaning it cycles 24 billion times every second) the chip could be used as a wireless alternative to optical fibers for clear, high-speed communication.

NEURO: An Exhibition of Art and Science

National Science Foundation-sponsored research projects often are not easy to explain to the general public — which is why the CSNE director and students decided to reach out in a creative way to devise a program to bring a new appreciation of science and engineering to the public.

The NEURO exhibition, billed as an investigation of "aesthetic possibilities at the intersection of art, science and engineering," aimed at attracting both scientists and gallery-goers through interactive environments. Thousands participated in the exhibition, turning their heads rapidly to experience retinal painting in "Perpetual Perceptual" and moving about the room to trigger brainstorms in "Einstein's Dilemma." The exhibit "Cheese" attempted to determine whether computers could judge the sincerity of a smile.

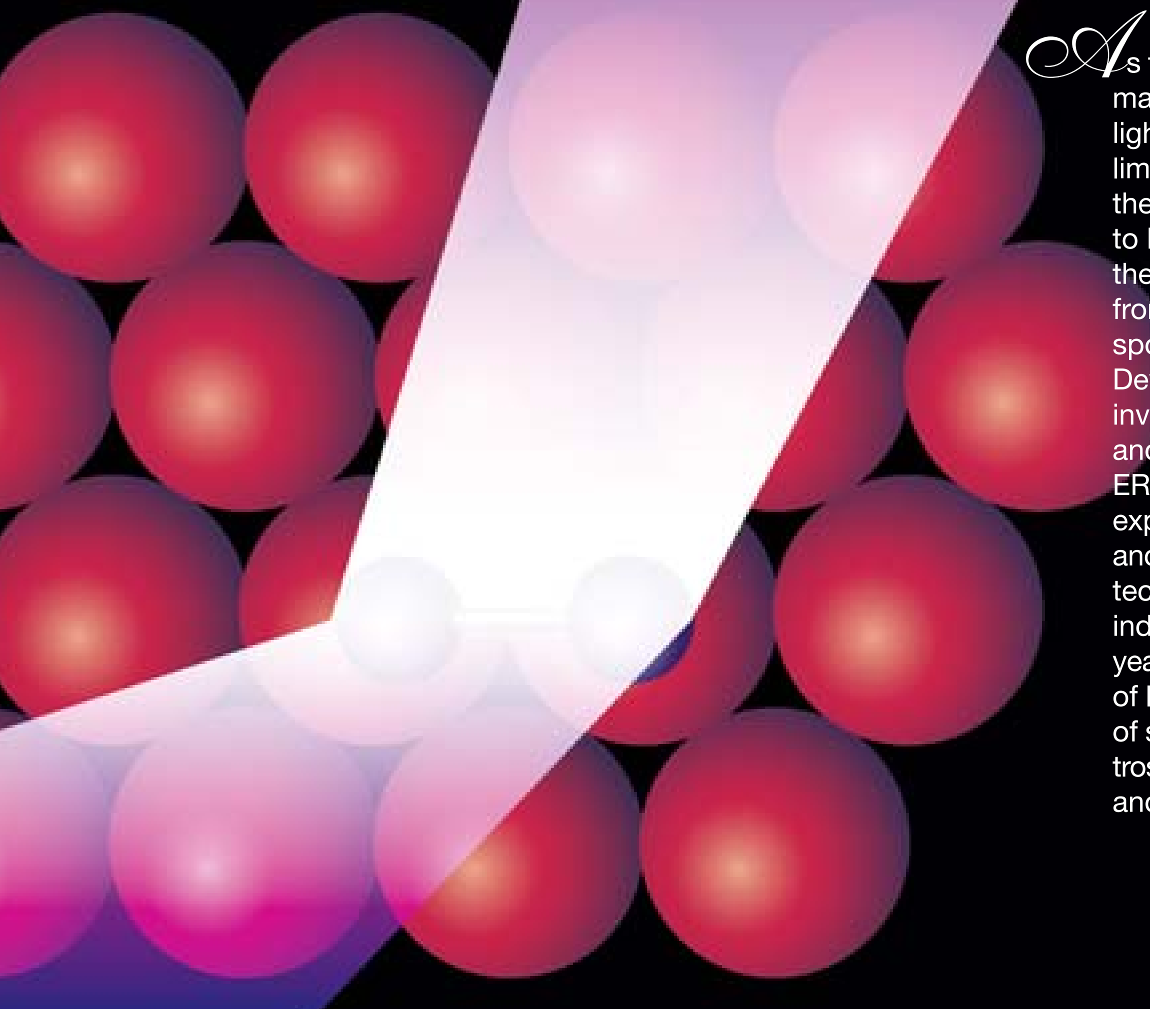
As machines acquire sensory systems and begin perceiving the world around them, we can endow them with autonomous intelligent behavior.

EUV

ERC for Extreme Ultraviolet Science and Technology (est. 2003)

Colorado State University with University of Colorado-Boulder and University of California-Berkeley

Bringing new light to science and nanotechnology.

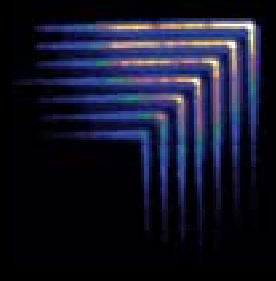


As the size of the most advanced electronic circuits and nanoscale machines continues to shrink below the wavelength of visible light, conventional optical technologies are rapidly reaching their limits. As a result, light in the Extreme Ultraviolet (EUV) region of the spectrum (wavelengths of approximately 3 to 50 nm) is poised to become a key element in technologies of critical importance to the U.S. economy. Exciting new opportunities in science will arise from the possibility of focusing EUV radiation to extremely small spot sizes, short pulse durations, and very high intensities. Development of EUV technologies will open up new areas of investigation, including EUV nonlinear optics, biological studies, and the development of a new generation of nanoprobes. The ERC for Extreme Ultraviolet Science and Technology (EUV ERC) is exploring the development and application of compact EUV lasers and laser-like coherent sources with the objective of making EUV technology widely available to solve challenging scientific and industrial problems. The Center's guiding vision is that, after 10 years of ERC effort, EUV radiation—now mostly limited to a handful of large national facilities—will be routinely used in a broad variety of settings for applications such as high-resolution imaging, spectroscopy, elemental- and bio-microscopy, dense plasma diagnostics, and nano-fabrication.

For more information about EUV's programs and accomplishments, visit the Center's website at: http://www.euverc.colostate.edu

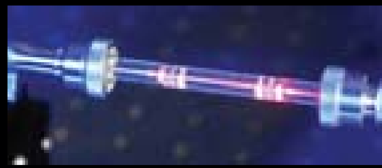
Illuminating the Nanoworld with EUV Light

Optical light microscopes have unsurpassed versatility, but are limited in resolution by the long wavelength of the visible or ultraviolet light used for illumination. The use of EUV light allows the development of compact microscopes that can "see" objects with dimensions of a few tens of nanometers. In addition, EUV microscopes can rapidly render high resolution images covering a relatively large field of view, require little sample preparation, and allow for the sample's environment to be varied. Such capabilities will provide a wealth of information about the physical and biological nano-world. Students and faculty from the EUV ERC have used a new type of EUV laser to demonstrate a compact microscope that produces images with a very high resolution—better than 38 nanometers—in several seconds. Future work promises practical and versatile microscopes with even higher resolution that will allow scientists and engineers to more readily inspect the nano-world and engineer devices on that scale.



Fibers Convert Visible Laser Beams into EUV

The EUV ERC is creating extremely bright beams of short-wavelength light using two complementary techniques: either the direct generation of EUV light using an EUV laser, or using nonlinear optics to combine many visible laser photons together to generate laser-like beams in the EUV and soft x-ray regions of the spectrum. With the latter approach, until now the nonlinear media predominantly used have been atoms contained in a gas jet. Researchers at the EUV ERC demonstrated more efficient conversion of laser light into the EUV by containing the gas inside a hollow fiber. This approach has several advantages. First, it allows the generation medium to be engineered—for example by modulating the fiber, allowing more efficient conversion to short wavelengths. Second, the walls of the fiber also guide the laser beam, allowing a long interaction region between the laser beam and the generated x-ray beam, and preventing defocusing of the laser beam. Finally, the long interaction length in the fiber ensures that the EUV beams that emerge are truly coherent or laser-like. Thus, applying concepts from photonics to the EUV region allows for very compact setups and easy integration into testbed applications. This discovery generated considerable interest when published in a series of articles in *Science* and *Nature*.



As technologies move into the nanoscale, compact extreme ultraviolet sources will become essential.

Excitement of Light Attracts Students to Science and Engineering

Laser technology and optical science provide exciting opportunities to attract some of the best high school students into science and engineering. With that in mind, the EUV ERC has embarked upon several educational outreach activities targeting K–12 students and teachers. For example, the Center annually offers a two-week workshop with appealing hands-on projects on Lasers and Optics for high school students as well as the "Let's Make Light!" workshop aimed at elementary school students. In addition, the ERC also conducts workshops for middle and high-school science teachers in the Pueblo school districts, provides optics kits for them, and provides experiments to aid them in bringing hands-on, inquiry-based learning into their classrooms. The goal of this workshop is to develop "optics suitcases" or kits to be used as part of lesson plans in science, to support teachers in communicating the excitement of science to young students. In these efforts the EUV ERC strives to attract and mentor a diverse group of students, including groups traditionally underrepresented in science and engineering.

Packaging Research Center (est. 1994)
Georgia Institute of Technology

Digital convergence of electronic and bio-electronic systems for the 21st century.

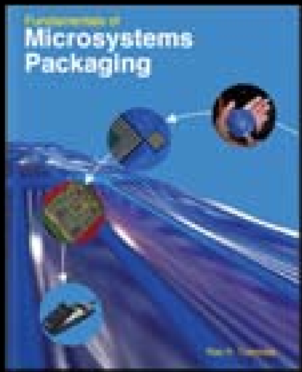
"Packaging" of electronic systems requires integration of active and passive components on system boards. The active components typically are integrated circuits (ICs) for computing, communication, and sensing functions, while the passive components that form the circuits needed to achieve these functions typically are such things as capacitors, resistors, inductors, filters, and switches. The leading-edge active components currently are at nanoscale, but the passives typically are at microscale. The system boards that interconnect these components to form systems such as cell phones are at milliscale—a million times bigger than the active ICs. Consequently, current systems are bulky in size. In addition, the current systems are discrete systems: i.e., digital systems performing computations, communications systems providing voice-based functions, and so on. The result is that consumers own multiple electronic systems—computers, cell phones, audio and video systems, etc. The primary mission of the Packaging Research Center (PRC) at Georgia Tech is to pioneer new ways to enable digital convergence of all types of consumer electronic products into portable and personal systems.

To achieve this convergence, the PRC's technical vision involves integrating all of the components as embedded thin-film components at nano to microscale, either into active ICs or as miniaturized packages into a single-system package. We term this technology "System-on-a-Package" (SOP). The SOP concept is analogous to the earlier integrated circuit revolution leading to a system-on-a-chip by means of transistor integration—but now it is component integration or system integration through SOP to achieve digital convergence.

■ **For more information about PRC's programs and accomplishments, visit the Center's website at: http://www.prc.gatech.edu**

Packaging: An Academic Subject at Georgia Tech

The PRC pioneered the SOP paradigm and developed a multidisciplinary education program with a comprehensive set of courses and curricula, leading to a track called "Devices, Integration, and Packaging." The education program involves faculty and students from four engineering disciplines: Electrical and Computer Engineering, Mechanical Engineering, Chemical Engineering, and Materials Science and Engineering. The 9 undergraduate and 15 graduate courses developed for this program encompass systems design, materials, processes, RF, optical, thermal, assembly, and electrical test. With the availability of these courses and the recently published "Fundamentals of Microsystems Packaging" textbook, a curriculum for both undergraduate and graduate students has been designed and developed. The PRC is now the largest and most sought-after producer of packaging engineers, turning out more than half of all such engineers in the U.S. Industry's feedback about these graduates emphasizes not only their overall quality but also how quickly "they hit the ground running."



Our goal is to create highly miniaturized, multi-functional systems that enable digital convergence.

Partnership Catalyzes SOP-based Industry

The PRC and its industry partners have jointly designed and implemented a strategy to cooperatively develop the new SOP technologies, educate the next generation of packaging engineers, and transfer both technologies and graduates to industry to strengthen its competitiveness. This partnership has resulted in hundreds of industrial internships and well over 300 PRC graduates hired by our industrial partners. Industrial practitioners routinely give distinguished lectures in the classroom and participate on thesis committees. The PRC has hosted over 60 visiting industry engineers on campus, documented numerous examples of technology transfer, and disclosed nearly 200 inventions. The PRC is also impacting local economic development by creating spin-off companies, attracting spin-in companies, and assisting local start-up companies in incubating nascent technologies. By developing a portfolio of critical SOP technologies and graduating well over 500 skilled SOP engineers, the PRC has enabled an SOP-based industry to emerge.

PRC's Leading-edge SOP Facility Is Unique

Established in partnership with NSF, Industry, and the State of Georgia, the PRC has developed a first–of-its-kind system integration facility, unique in academia. This $48.9M, Class 10-10,000 cleanroom complex houses SOP prototype research spanning mixed signal design, fabrication, integration, assembly, electrical test, and reliability of 300 mm SOP wafers. This network of laboratories supports leading-edge fundamental and system-level research by teams of students, faculty, center engineers, and on-campus industry personnel. It provides an environment where these research teams work collaboratively to fabricate system-level proof-of-concept demonstration test vehicles, and where transfer of various SOP technologies to industry is facilitated. In addition, the facility provides for cross-disciplinary education of graduate and undergraduate students via the hands-on Design-Build-Operate (DBO) courses. Thus, it serves as the driving engine for the Center's SOP research, education, and technology transfer activities.

ERC for Collaborative Adaptive Sensing of the Atmosphere (est. 2003)

University of Massachusetts–Amherst with Colorado State University, University of Oklahoma, and University of Puerto Rico–Mayaguez

Revolutionizing our ability to observe, understand, and predict atmospheric and airborne hazards.

Our ability to monitor, anticipate, and respond to events affecting our physical surroundings is increasingly important—especially in the context of the atmosphere, where hazardous local weather as well as chemical, radiological, and biological agents dispersed into the air can quickly destroy or contaminate life and property over vast areas. Despite the tremendous capabilities of existing ground-based Doppler weather radars, these systems are fundamentally constrained in sensitivity and resolution and are unable to observe the lowest few kilometers of the earth's atmosphere, where hazardous weather forms and causes greatest impact. The ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA) is advancing a new paradigm of *Distributed Collaborative Adaptive Sensing* networks designed to overcome these limitations. DCAS networks utilize large numbers of small solid-state radars, closely spaced to overcome blockage due to the Earth's curvature and reduce the drop in resolution caused by beam spreading. DCAS networks will be highly reliable, inexpensive, and capable of targeting multiple radar beams onto atmospheric regions where threats exist in order to pinpoint the location of tornadoes, accurately estimate rainfall levels near the ground for flood forecasting, and detect precursors of future storms—all in response to changing end-user needs.

Center researchers are currently installing a DCAS network in tornado-prone southwestern Oklahoma. The four-radar network will gather data needed to improve our understanding and modeling of severe storm behavior while also demonstrating a capability to pinpoint the location of shear regions within storms for improved tornado warning. CASA's cross-disciplinary efforts to research, develop, field-test, and operate prototype system-level testbeds, working in partnership with the manufacturers of the sensors and the end users of the data, provide a rich environment for educating the next generation of engineers and scientists.

■ **For more information about CASA's programs and accomplishments, visit the Center's website at: www.casa.umass.edu**

Content Institute Produces "Weather RATS"

In July 2004, twenty-two middle school teachers came to the University of Massachusetts-Amherst to learn about cutting-edge scientific and engineering research being done at CASA, at a "Content Institute" hosted by the ERC. The Content Institute featured lectures by expert faculty, hands-on labs and activities, a field trip to a national radar facility, and development and review of classroom resources utilizing communications technologies. The 3-credit graduate-level Content Institute was designed to enable sixth through ninth grade teachers to deepen their knowledge and develop hands-on classroom activities around the engineering/technology and earth and space science curriculum frameworks. Eight of the participants are continuing to work together on a project called "Weather RATS," which places wireless weather stations at their respective schools. The Weather RATS' objective is to use wireless weather stations and Internet data sharing capability, along with NOAA and National Weather Service data, to track and research weather systems across widely separated geographic areas, as well as to investigate the structure and behavior of micro-climates within Massachusetts.

Students Design Advanced Radar Network

An all-student team of 15 CASA graduate and undergraduate students is creating an experimental radar system, to be deployed in Puerto Rico, that will transform our ability to monitor rainfall. Comprised of an array of miniature radar sensors, the system produces accurate rainfall data to be used to predict flooding and support other applications such as crop hydrology that require accurate rainfall estimates. The radar system should be operational by Fall 2006.

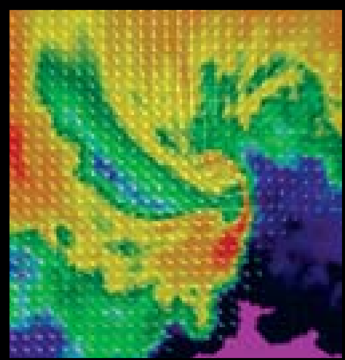
The student-run testbed system offers both a unique research and educational experience. It requires students to work across disciplinary and geographical boundaries and understand all facets of developing and implementing a testbed. When the testbed is up and running it will cover a crucial 1.5 km-high gap in atmospheric weather-monitoring over western Puerto Rico that traditional radar technology cannot sense. The testbed also will explore methods for more accurate measurement of rainfall and wind data than is now possible. And it could be used as a back-up to the current radar system if the Puerto Rican electrical grid blacks out in heavy weather. One of many student design innovations is a system for allocating power-hungry activities (such as computation) to nodes with more reliable access to power, to minimize downtime.

The new DCAS network can see severe weather that forms closer to the ground — such as tornadoes.

Radar Algorithms for Automatically Detecting Tornadoes

The first algorithms for dynamically detecting tornadoes, using data from networks of low-power Doppler weather radars, have been developed. The algorithms are designed to distinguish tornadoes from transient but intense low-altitude shear regions within severe storms. The radar now has for the first time the ability to see close to the ground and thus locate the tornado and specify its intensity. A notable challenge lies in determining what observable conditions on radar constitute a tornado, since the official definition requires visual confirmation that the vortex is in contact with the ground and since no threshold wind speeds exist that can be used to distinguish tornadoes from other columnar vortices.

The algorithms reconstruct the 3D wind field based upon wind estimates from multiple Doppler radars. Because real data are not yet available from the new radars, extremely high resolution computer simulations of storms and their associated tornadoes are being used as a proxy. The image shows one such simulated data set processed by the tornado detection algorithm, with the tornado located in the region of swirling flow in the right-center portion of the image.



Center for Wireless Integrated MicroSystems (est. 2000)

University of Michigan with Michigan State University and Michigan Technological University

Integrated microsystems for information gathering and control.

The Center for Wireless Integrated MicroSystems (WIMS) is focused on miniature, low-cost integrated microsystems capable of measuring or controlling a variety of physical parameters, interpreting the data, and communicating with a host system over a bi-directional wireless link. WIMS are expected to become pervasive over the next two decades, extending the electronic connectivity represented by personal communications and the worldwide web to information provided by (or supplied to) the environment. Implemented as button-sized information-gathering nodes, WIMS will effectively wire the planet and will form bridges between microelectronics and the cellular and molecular worlds. WIMS will monitor the environment (advanced weather forecasting, global change, air and water quality), control adaptive process tools, improve transportation systems (vehicles and infrastructure), provide homeland security (reconnaissance, chemical detection), and revolutionize health care (wearable and implantable microsystems). Operating at less than 1mW, these microsystems will occupy volumes of less than 1cc and communicate over distances ranging from a few inches to a few miles, packing the sophistication of a major laboratory instrument in the space of a sugar cube.

The WIMS Center brings together embedded computing, wireless communications, microelectromechanical systems (MEMS), and advanced packaging. Embedded microcontrollers running at less than 100μW are being developed for data acquisition, and both microelectronic and micromechanical circuits are being explored for wireless interfaces. Wafer-level packaging technology based on deposited coatings and wafer bonding has produced implantable sensors able to work in the body for decades and vacuum-sealed cavities with extremely low leak rates.

■ **For more information about WIMS' programs and accomplishments, visit the Center's website at: http://www.wimserc.org**

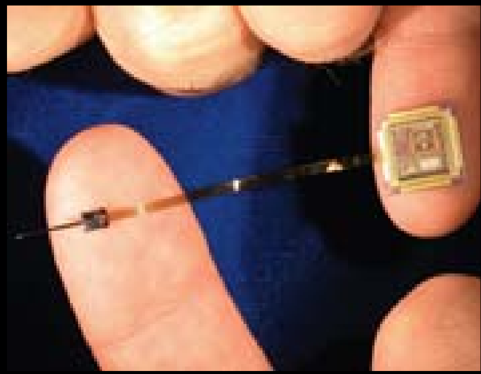
Engineering Enterprise in Integrated Microsystems

Industrial managers often say that the technical skills of most engineering graduates are of high quality, but that their interpersonal and project management skills are not developed to where graduates can quickly become productive in their jobs. Through WIMS, the Integrated Microsystems Enterprise (IME) has created an undergraduate research program to hone those skills and experiences.

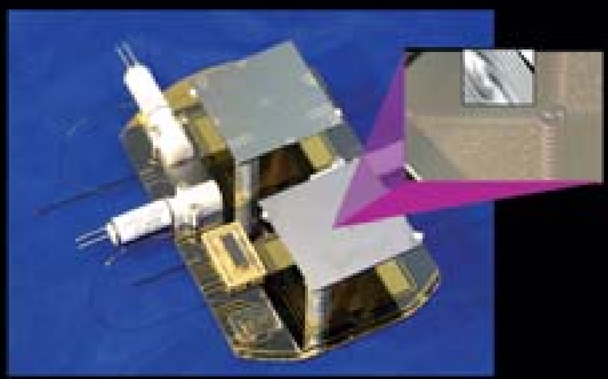
Organized like a real company, the students are developing a PDA-Based Transportable Research Instrument and a Wireless Multifunction Sensor Cube. The system addresses challenges in power sources, embedded systems, signal conditioning, software, curriculum, and documentation. Graduates of the IME get valuable experience operating a virtual company and providing design and testing services. The program gives them a leg up in being able to quickly become productive in the world of work.

Implantable Microsystems for Neuroscience and Neuroprostheses

Building a viable electronic interface to the central nervous system is key in understanding the fundamental operation of neural networks and in developing prosthetic devices for treating disorders such as deafness, paralysis, Parkinson's disease, and epilepsy. The WIMS ERC is developing a cochlear microsystem for the profoundly deaf that contains a custom microcontroller, a digital signal processor that executes speech processing algorithms, a wireless chip that derives power from an external radio-frequency carrier and provides bidirectional data transfer, and an ultra-flexible thin-film electrode array that can be inserted deep within the cochlea of the inner ear. With an order of magnitude more stimulating sites than commercial implants and with position sensors to monitor array position in-vivo, such devices promise significant strides in speech comprehension and sound fidelity. Companion work is also developing a button-sized implant for capturing control signals from the motor cortex. Using 3D electrode arrays and circuitry for in-vivo spike recognition and wireless communication, such microsystems may someday restore limited mobility to quadriplegics as well as enable the treatment of other neurological disorders.



Fostering vital connections between people, their bodies, and their environment.

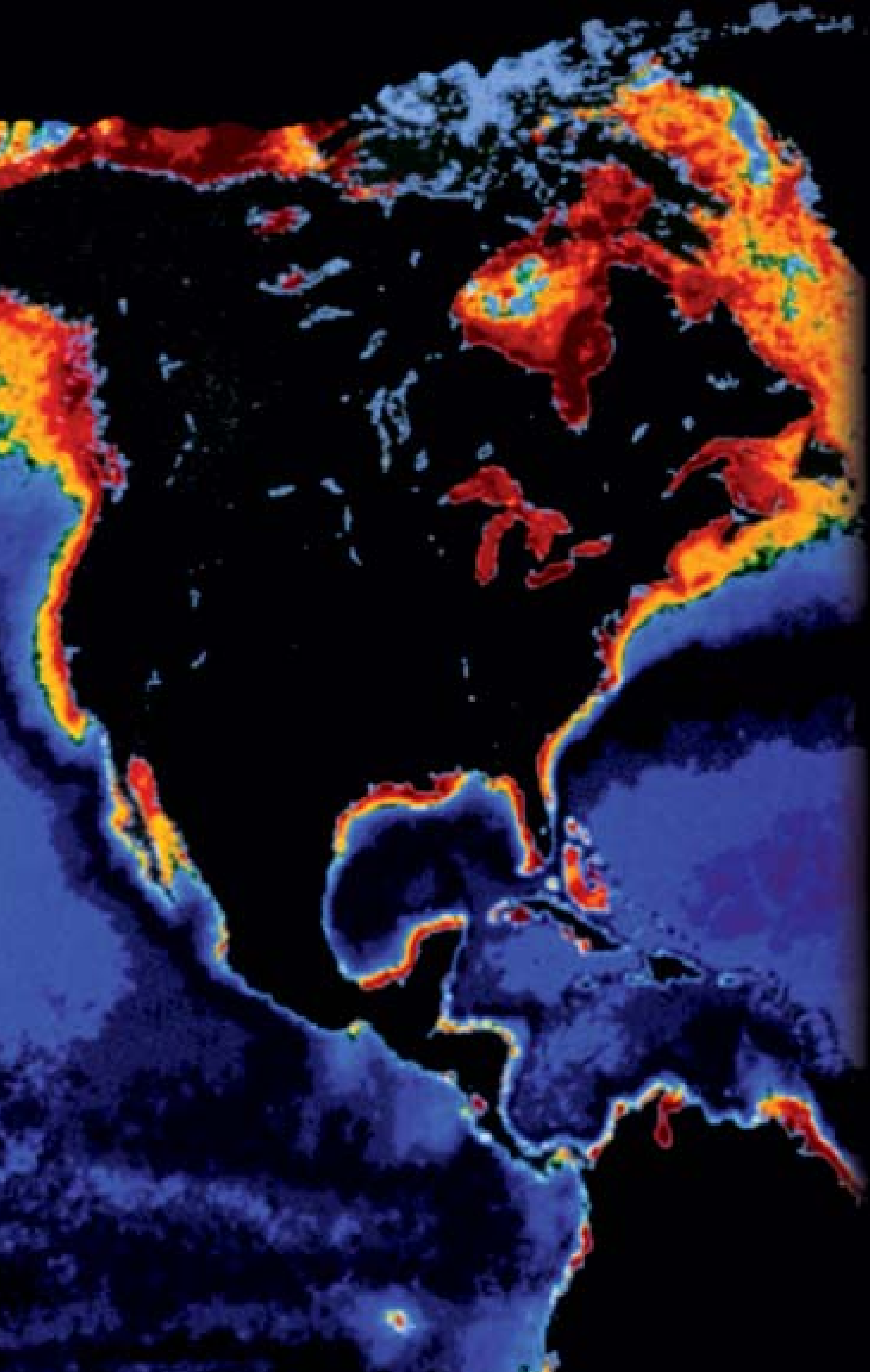


An Integrated Microsystem for Environmental Monitoring

Low-cost distributed gas analysis is badly needed for applications in food processing, homeland security, environmental protection, and monitoring global change. An integrated microsystem containing a miniature gas chromatograph (μGC) is being developed. The μGC includes an inlet filter, calibration source, preconcentrator, separation columns, a multi-element detector, and an electrostatic vacuum pump. Targeted at the size of a small calculator, such systems promise to perform better than their table-top ancestors. Monolithic silicon columns separate complex alkanes and chemical warfare simulants in seconds and permit high-speed temperature programming while operating at a few milliwatts.

Center for Subsurface Sensing and Imaging Systems (est. 2000)

Northeastern University with Boston University, Rensselaer Polytechnic Institute, and University of Puerto Rico at Mayaguez



Exploring Hidden Worlds: Diverse Problems–Similar Solutions

Some of the most difficult problems in sensing and imaging involve detecting, locating, and identifying objects that are obscured beneath a concealing medium. Mapping pollution plumes underground, detecting a tumor inside the body, and identifying developmental defects in an embryo all share the problem of distinguishing the effects of a complex covering medium from the details of the subsurface structure and functionality. The problem is similar whether the medium is soil or tissue, or whether the target is a land mine or a tumor. The solution may be similar as well.

The Center for Subsurface Sensing and Imaging Systems (CenSSIS) is revolutionizing our ability to detect and image biomedical and environmental or man-made objects or conditions that are underground, underwater, or embedded within cells or inside the human body. CenSSIS's approach combines wave physics, sensor engineering, image processing, and inverse scattering with rigorous performance testing to create new sensing system prototypes that are transitioned to the Center's industry partners for further development.

■ **For more information about CenSSIS' programs and accomplishments, visit the Center's website at: http://www.censsis.neu.edu**

The "Mystery Mansion"

Increasing the flow in the "pipeline" of students entering science and engineering study by increasing their interest in these subjects at an early age is a goal of CenSSIS. To present subsurface sensing problems to children, CenSSIS researchers created the first portable "Finding Hidden Things with Science" exhibit in collaboration with the Junior Museum in Troy, NY.

The exhibit, commonly known as the "Mystery Mansion," features three types of subsurface probes: an infrared camera, an EM probe (metal detector), and a Magnetic Field probe (compass). An inviting "**?**" on the mansion's front door signals that it contains treasures inside. Kids quickly learn to use the metal detector and compass to classify objects as metallic or nonmetallic and magnetic or nonmagnetic. It's no mystery why the mansion piques children's natural curiosity about science.

Electrical Conductivity Distinguishes Subsurface Features

What does a breast tumor have in common with radioactive waste leaking from an underground tank? They are both serious subsurface problems that are not well imaged by conventional means. Conventional mammography is difficult to interpret because tumors and breast tissue differ by less than 15% in x-ray attenuation and are thus hard to distinguish.

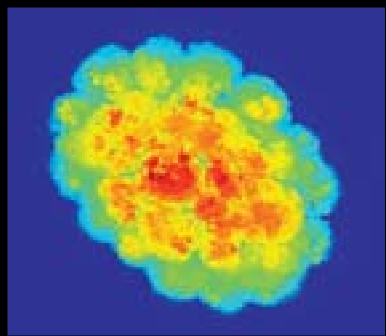
In contrast, the electrical conductivity of tumors is seven times greater than that of normal tissue. CenSSIS researchers have pioneered the use of a fast, non-iterative mathematical inversion for electrical conductivity measurements to locate areas of high conductivity in breast tissue. The ACT-4 instrument they developed will be able to image tumors as small as 3 mm from electrical measurements at the surface of the skin.

The same mathematical inversion techniques are being applied by CenSSIS collaborators at Lawrence Livermore National Laboratory to image radioactive pollution plumes by measuring the electrical resistance between bore holes many meters apart. This technique may detect and locate leaking contaminants that are invisible to conventional seismic measurements and allow appropriate remediation measures to be applied.

"Diverse problems, similar solutions" is a way of thinking that will enable advances in one subsurface domain to be applied in other domains.

New Imaging Technique Aids in Selecting Embryos

For 20 years, medical researchers have been searching for methods to accurately identify healthy embryos for *in vitro* fertilization (IVF), in order to reduce the number of multiple births that can lead to a multitude of problems for mother and children alike. They have determined that an important measure of viability is the number of cells in a developing embryo beyond the eight-cell stage. Unfortunately, present non-toxic imaging technologies, such as Differential Interference Contrast (DIC) microscopy, can't effectively count cells in the center of a developing embryo.



CenSSIS researchers have developed Quadrature Tomographic Microscopy (QTM), which provides a quantitative image of the phase of light passing through the specimen. Working with biologists, CenSSIS researchers have devised a cell-counting technique that captures, registers, and compares DIC and QTM images of mouse embryos to determine the position and optical thickness of surface cells. The phase calculated for a model cell is then subtracted from the QTM image, revealing the background of the image or another cell underneath. The process is repeated until accurate cell counts of up to w26 cells have been produced. This method may improve doctors' ability to select high-quality embryos for IVF and improve the outcomes for human-assisted reproduction procedures.

IMSC

Integrated Media Systems Center (est. 1996)

University of Southern California

Revolutionizing the way we communicate, learn, and play.

When the IMSC was established in 1996 as NSF's first ERC for multimedia and Internet research, the Internet as an economic engine and entertainment medium was in its infancy. The IMSC team saw the potential to leap far beyond the then-state-of-the-art to develop the technologies that would be needed to revolutionize the way we work, play, teach, and learn.

Realizing that goal required strong advances in a myriad of new and very diverse technologies. They included computer vision and computer graphics algorithms that can track human motion and gestures and create highly realistic 3-D models of faces and objects. Novel database and data compression methods were developed to capture and track real-time "immersidata," the data associated with user interactions in highly rich and realistic (immersive) audio/video environments. Immersive audio technologies for capturing and rendering sound that is indistinguishable from reality were a first for the IMSC. Major progress is also being made in "haptics" (touch–related technologies). Along the way the Center has revolutionized Internet streaming of high-quality and precisely synchronized media.

Combining several of these technologies led to the IMSC's concept of Remote Media Immersion (RMI), in which immersive content is captured, transmitted, and rendered over the Internet. The IMSC's goal for immersive environments is for people to interact, communicate and collaborate naturally in a shared virtual space while in distant physical locations. Another goal is to immerse people in information-rich and interactive environments that aid in understanding and relating raw data to high-level problems and tasks and to education, health care, and civic engagement.

The IMSC has established itself as the academic leader in developing the emerging Internet and multimedia technologies that are driving economic expansion and profound social changes.

■ **For more information about IMSC's programs and accomplishments, visit the Center's website at: http://imsc.usc.edu**

Software Adds Blockbuster Special Effects

Hollywood special effects house Rhythm & Hues is using new "augmented reality" software from the University of Southern California's IMSC to add computer-generated effects to movies easier and much faster. Named "Fastrack," the software cuts the tracking time from minutes to just seconds per frame and reduces the need for hand-corrections. Fastrack has played a starring role in movies such as X-Men 2, Daredevil and Dr. Seuss' *The Cat in the Hat*.

Next Generation Surround Sound

The IMSC's Immersive Audio Lab is focusing on developing the next generation of cinema and home theater sound, a 10.2-channel surround sound system that uses 10 speakers in 10 locations, plus two subwoofers, to create a better sense of aural immersion. Technologies from the lab that optimize the sound for every listening environment have already found their way into home theater products available today.

Immersive technology turns the 2D world of TV and computers into 3D—and any time into realtime.

ImmersiNet: "Hear All About It"

IMSC has shown how the Internet can support very high quality media transmissions that allow people to collaborate interactively in real time, in a highly realistic aural and visual environment, from different locations using a sophisticated system they created called "ImmersiNET." They presented a coast-to-coast concert of a performance by the New World Symphony of Miami Beach delivered via the Internet. The musicians and the audience were in different physical locations and interconnected by extremely high fidelity, low-latency multichannel audio and video (immersidata) links. The applause was deafening.

The Internet of the future will surround users with sights, sounds—even smells.

Center for Power Electronics Systems (est. 1998)

Virginia Polytechnic Institute and State University with North Carolina A&T State University, University of Puerto Rico at Mayagüez, Rensselaer Polytechnic Institute, and University of Wisconsin at Madison

Changing the way electricity is used.

Throughout the world, electric power is used at an average rate of 12 billion kilowatts per hour every day of every year. The majority of this power is not used in the form in which it was initially generated. Rather, it is re-processed to provide the type of power (different voltage, wattage, and type of current) needed in the type of technology that is being employed. Power electronics technology uses electronic circuits to convert and control electric energy with optimum efficiency. Today, this technology is part of most electrically powered machines and devices, from railroad trains and industrial robots to telephones and stereos.

Power electronics has a powerful impact on our resources and thus in our environment. By the year 2010, power electronics systems are expected to control up to 80 percent of all electricity used. With the improvements in the power electronics technology that CPES has planned, the U.S. should be able to reduce its energy consumption by 30 percent.

Center researchers have made significant contributions in three areas critical to power electronics evolution: powering of a new generation of microprocessors; developing technologies for integration of power electronics components, such as circuits and sensors; and using the integrated components for standardized methods of assembling power converters, which are still custom-designed. CPES is also helping to train a new generation of power electronics researchers and engineers. In the coming years, CPES will continue to work toward the goals of increasing energy savings and U.S. industrial competitiveness by developing more efficient and integrated power electronics devices.

■ **For more information about CPES' programs and accomplishments, visit the Center's website at: http://www.cpes.vt.edu**

Power Management for Intel Microprocessors

"*Intel Inside!*" Many of the world's personal computers use a Pentium microprocessor manufactured by Intel Corp. Every such computer uses a voltage regulator module (VRM) to power the microprocessor. Each new generation of microprocessor operates at lower voltage and higher current, and requires a faster response time to switch the microprocessor from sleep to power mode. This switching of modes is necessary to conserve energy, as well as to extend the operating time for any battery-operated equipment.

The problem was that existing VRMs were too slow to respond to the new generation of microprocessors' energy demand. To meet the challenge, CPES established a mini-consortium of companies to develop new VRMs for current and future generations of microprocessors. The CPES team developed a multiphase VRM module using an innovative approach based on paralleling multiple Buck mini-converter cells. The new multiphase VRM has now been adopted by the entire industry as standard practice.

"Partnership Team" Reaches Out to Precollege

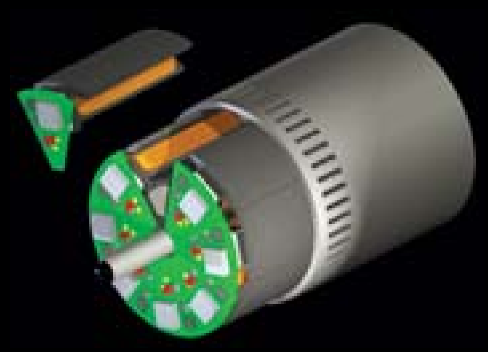
To increase participation in science, technology, engineering, and math programs by precollege students in rural southwestern Virginia, CPES has developed programs focusing on outreach to elementary and middle school students and teachers. In one such program, Virginia Tech students majoring in various disciplines of engineering, engineering science, and technology education formed a "partnership team" to foster participation in the FIRST LEGO League program. This initiative provides participating teachers and students with on-site demonstrations, teacher workshops, and mentoring by engineering undergraduate and graduate students. During Fall semester, the partnership team typically works with more than 70 children from 10 schools, providing mentorship and teaching basic science and engineering concepts. In 2005-2006, the CPES team is developing five computer-based tutorials for use in the classroom. Benefits of the program are not limited to the precollege students and teachers. As one undergraduate engineering student mentor noted, "I think that being part of this team has made me realize how much I really do eventually want to teach…"

Products that are more powerful, more dependable, more durable, smaller, lighter weight, and less costly are on the horizon.

Integrated Modular Motor Drive (IMMD)

The Integrated Modular Motor Drive (IMMD) is a new motor drive architecture that promises reduced cost and increased reliability. The motor is constructed from a number of modular phase-drive units interconnected in a ring to form the electrical core of the motor. Each of these phase-drive units includes both the iron pole piece with its winding and an integrated power electronic module (IPEM) attached to the end of the pole piece inside the motor housing. By eliminating the need for a separate housing for the motor drive electronics, the resulting "smart" motor reduces the losses associated with the cables used to connect external drive electronics to the motor, thereby increasing performance. By allowing standardization and high-volume production, modular phase-drive units promise reduced manufacturing costs. The modularity of the IMMD allows the motor drive to continue operating when one or more of the phase-drive units fail, improving overall drive reliability.

Several CPES technology innovations will be incorporated into the IMMD, including the elimination of electrolytic capacitors and the use of integrated current and temperature sensors inside the IPEMs. Based on these advances, the IMMD architecture is being aggressively pursued as the template for future generations of low-cost, robust motor drives.



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