# *Contents*

A researcher prepares a sample of DNA for inspection as part of Georgia Tech's bioengineering experiments. (See Biotechnology below)

## Biotechnology

Research in bioscience and bioengineering is leading the way toward amazing medical breakthroughs in the next millenium.

**By Amy Stone**

## Training Workstations

Researchers create an interactive, computer-based how-to guide for test engineers.

**By Rick Robinson**

## Researching the Revolution

At Georgia Tech, an interdisciplinary group is investigating present and future consequences of information technology. — Also see related story: **Future of Information Technology Predictions**.

**By Lea McLees and Rick Robinson**

# *Departments*

## Research Notes

- **Refining Gas Refining**
- **Letting the Flip-Chips Fall as They May**
- **Ultimate Customers**
- **Microrelay Breakthroughs**
- **On the Record**
- **A Case for Microwave Packaging**
- **Researchers Honored**
- **Cough, Choke, Wheeezzzzzee**

## Update

- **Plucky Research Tool for Carpal Tunnel Risks**

- **Soundproofing With New Acoustic Liner Material**

- **New GTRI Director: Dr. Edward Reedy**

# BIOTECHNOLOGY

**At Georgia Tech, bioengineering and bioscience are leading the way into an amazing future for medicine.**

**by Amy Stone**

**IN YEARS PAST,** biologists researched living organisms while engineers, often working in distant buildings, focused on building machines. Now, developments in technology and a better understanding of biology have enabled engineers to apply the principles of their science to biological problems.

This union has created the hybrid field of bioengineering, which is elevating the expectations of many people. They hope the field will generate products and innovations that improve human health and boost the nation's economy. Indeed, bioengineering already has produced innovations such as artificial skin, pacemakers and new pharmaceuticals. It also is boosting the bankrolls of researchers, institutions and companies who develop, license and market the innovations.

Faculty at the Georgia Institute of Technology are leaders in applying engineering principles to some of the largest biological questions of our time. To enhance and encourage research in this area, Georgia Tech is physically bringing together all of the bioengineering and biosciences research on campus under one umbrella — the Parker H. Petit Institute for Bioengineering and Bioscience.

The Petit Institute comprises three centers: the Bioengineering Center, the Biosciences Center and the Biomedical Interactive Technology Center. Faculty also have forged interinstitutional partnerships with Emory University (the Emory-GT Center) and the Medical College of Georgia (the MCG-GT Center). Current external research funding is about $10 million.

"The role of the institute is to foster biomedical research by bringing together engineering, information technology and the sciences," says Dr. Robert Nerem, director of the Petit Institute. "Georgia Tech has long been a strong engineering school. But, in the future, to be a premier technical institute will require a strong commitment to biosciences and the engineering and technology that flow from it."

The institute, endowed by a $5 million gift from Healthdyne founder Parker H. "Pete" Petit, will be housed in a new building, which broke ground in March. The facility is designed with multi-disciplinary research in mind, Nerem says. By assigning space based on projects, rather than on departments, the institute hopes to break down barriers to collaborations.

"When I decided to make the endowment, I had already seen 10 years of exciting progress at Georgia Tech in this area," Petit says, referring to his endowment of a chair in engineering and medicine a decade before his gift to the Petit Institute. "In the years ahead, we will see breakthroughs come out of this program that will enhance the quality of life for many."

Following are examples of Petit Institute projects that exemplify the excitement and promise of bioengineering.



photo by Billy Howard

Ph.D. student Stewart McNaull investigates endothelial cell adhesion related to sickle cell anemia. Such adhesion leads to blockage of microvessels in sickle cell patients. The work is being done in Dr. Timothy Wick's laboratory at Georgia Tech.

## BIOMECHANICS AND TISSUE ENGINEERING

**Researchers are applying engineering principles to human physiology, enabling them to create artificial substances to aid or replace damaged or defective body parts.**

### Creating artificial tissues

In addition to directing the Petit Institute, Nerem maintains an active research agenda. Half of his laboratory is devoted to understanding the effects of blood flow on endothelial cells — those lining blood vessels. Because atherosclerotic plaques form on endothelial cells in response to injury, this is an important area of research. Nerem's research team also hopes to create substitute blood vessels from natural biological materials. Synthetic vessels can cause problems, such as blockage. Thus, physicians need naturally made blood vessels the body will not reject.

Dr. Athanassios Sambanis, an associate professor in the School of Chemical Engineering, works in the same field, but with a different emphasis. Sambanis' research focuses on an artificial tissue, which once implanted can control the body's level of blood glucose. Functioning as an artificial pancreas, this tissue would negate the need for insulin injections among diabetics. Sambanis has encapsulated cells that produce insulin in response to glucose in a membrane that allows passage of nutrients into cells and insulin out of cells.

The pores of this membrane are small enough to exclude antibodies and lymphocytes, thus preventing an immune system rejection of the artificial tissue. Sambanis also is developing a "smart" membrane, which would allow blood vessels to grow in its outer part, thus providing the cells within with increased amounts of oxygen and other nutrients. He is conducting experiments with such a membrane implanted in rodents.

### Understanding blood flow

Blood vessel damage occurs in specific places in the human body. This damage eventually causes plaque build-up, which can rupture and cause heart attacks and strokes. Dr. David Ku, a professor of mechanical engineering at Georgia Tech and a professor of surgery at Emory University, wondered why this damage always starts in the same places. By studying the mechanics of blood flow in those places, he found that oscillatory shear stress is occurring. Simply, in those areas prone to developing problems, blood may flow back and forth, instead of just one way. The back-and-forth motion can lead to focal disease.

Because one area of blockage occurs in the heart, Ku is applying his findings to create a biomaterial for a replacement artery. The material is a hydrogel, mainly composed of water. It allows new cells to grow into it, effectively making it part of the body. This substance is a platform technology, meaning it can be applied to different biological problems. For example, drug delivery — where multiple drugs could be placed in an implant and diffused in the correct amount over a predetermined time — is an additional use of this material.

Ku also is working in the tissue culture area of keeping entire arteries alive outside of the body. "Growing individual cells in culture may not tell you how they will behave when they work together in tissues," he says. So Ku simulates many disorders, including high blood pressure, in these arteries to see what happens when interventions, such as balloon angioplasty, are applied.

Another promising project of Ku's could allow physicians to predict a patient's risk of atherosclerotic plaque ruptures. Scientists know arterial blockage can occur years before patients feel symptoms. Ku examined this phenomenon from a mechanical engineering point of view. He found that blood flow increases to the constricted part of the artery, causing decreased pressure in the diseased artery near the plaque. Because the pressure is lower inside, the compression can cause plaques to break. In turn, this causes platelets to stick to the exposed collagen underneath, building up an occlusion. Using this information, Ku has developed a model to predict which patients have a high likelihood of arterial blockage.

## BIOINSTRUMENTATION AND MEDICAL IMAGING

**Engineering can define the body mathematically. Thus, engineers can quantify the body's blood flow and electrical currents, and then use probabilities to predict certain biologic aspects of those systems.**

### Closed circuits

If you reduce the movements and senses of the body to their bare essences, you are left with circuits. Hands clap, and the resulting sound waves are funneled into your ear and translated into electrical impulses the brain understands.

**Georgia Tech Bioengineering Timeline:**

**1985:** Bioengineering Center formed

**1987:** Establishment of the Emory/Georgia Tech Biomedical Technology Research Center

**1992:** Establishment of the Medical College of Georgia/Georgia Tech Biomedical Technology Research Center

**1993:** Receipt of $3 million Whitaker Foundation Biomedical Engineering Development Award

**1994:** Ph.D. program in bioengineering approved

**1994:** Institute for Bioengineering and Biosciences (IBB) established

**1996:** IBB renamed the Parker H. Petit Institute for Bioengineering and Bioscience

If the sound signals danger, your brain instructs various muscle groups to move. Dr. Stephen DeWeerth, an associate professor in the School of Electrical and Computer Engineering, uses integrated circuit technology to create models of neurobiological systems. The models help researchers understand how and why these systems work, and may eventually lead to replacement of defective links in them.

"We're taking what physiologists have learned and are building mathematical, software and hardware models of systems," he says. "We are trying to find the structure underlying complex systems."

The applications of this research are broad. They include the existing example of cochlear implants, which provide the missing bridge to translate sound waves into electrical impulses the brain understands. In the future, this type of research will yield artificial limbs that respond to electrical signals from the body. Also, engineers may be able to create implantable electrical stimulators. These devices could connect electrodes in the brain to the spinal cord, allowing people with spinal cord injuries to regain movement. DeWeerth's group is primarily interested in motor systems — specifically, how muscles are controlled and reflexes occur, and what patterns of muscle movement and feedback develop in activities such as walking.

Georgia Tech graduate students examine a rat used in testing new selenium-based antihypertensives. (200-dpi JPEG version - 210k)

### Defibrillating hearts

When a heart goes into fibrillation, the cells of either the atrium (one of the upper chambers) or ventricle (lower chamber) fire out of sync, creating a rapid, irregular heartbeat that does not properly pump blood. Dr. William Ditto, an associate professor of physics and electrical and computer engineering, uses sensory dyes that plot electrical activity in the body to capture on film the wave pattern of these misfiring cells. He has shown that electrical waves start circling the damaged cells, creating spiral waves.

"Think of a rock near the shore in the ocean and how waves break around it," Ditto explains. "The defective cells are like that rock, in that they cause the normal pattern of electrical waves to be disrupted."

This spiral pattern falls into the category of chaos behavior — that which lies between purely random behavior and periodic behavior. Some call it controlled irregularity. By characterizing the chaotic system of fibrillation, Ditto hopes to find keys that will help the heart defibrillate itself. For now, doctors rely on large machines that deliver a hefty electrical wallop to defibrillate the heart. Ditto's work may make possible smaller machines, which require less energy to get the heart restarted on a normal rhythm.

In a related project, Ditto is exploring the feasibility of an implantable pacemaker in the brain to decrease seizures. The pacemaker would create an electromagnetic field, which could be adjusted to suppress seizures.

### Viewing vessels

Meanwhile, Ku is addressing an important imaging problem. Imaging arteries with magnetic resonance imaging (MRI) is safer and cheaper than imaging arteries with radioactive dye X-rays, the standard method of examining blocked vessels. But the turbulence inside of an artery near an occlusion causes a signal loss when imaging with MRI. This loss of image at the crucial point creates a dilemma because physicians base their recommendations for bypass surgery on quantifying the degree of blockage in an artery. To counter the MRI signal loss, Ku has created a knowledge-based software that allows computers to learn signal loss pattern recognition and equate it with a specific amount of disease. It has proven 98 percent accurate, can be adapted to current MRI machines and should enable physicians to make more accurate diagnoses, Ku says.

Dr. Ajit Yoganathan, the associate director of the Petit Institute, is using MRI technology to understand blood flow patterns in children who are born with heart defects. In an example of research physicians are taking directly to the operating room, Yoganathan consults with pediatric surgeons to create better surgical correction techniques.

## QUANTITATIVE ANALYSIS

**As genetic knowledge grows, so too does the need to manage this knowledge. For example, the amount of information contained in a strand of DNA is staggering. To be useful, it must be translated into genes, which ultimately control inheritable traits, and proteins. Such quantitative analysis research develops tools to manage and decipher biological information.**

Dr. Mark Borodovsky, a professor of biology and mathematics, develops statistical pattern recognition for DNA and protein sequence analysis. He has developed a

software program called "GeneMark," which enables scientists to find genes in long sequences of DNA, and then identify the resulting protein sequences. GeneMark has already helped scientists decipher the genome of key organisms.

The Human Genome Project is striving to completely decipher the genome of the human species, as well as the genomes of certain organisms, including bacterial pathogens. For instance, understanding the genomes of Haemophilus influenzae (bacteria that cause lung disease) or Heliobacter pylori (bacteria that cause peptic ulcers) could help scientists design new drugs. Researchers used Borodovsky's GeneMark software to decipher the genome of these organisms.

Now, GeneMark is the most popular software tool for finding genes in bacterial species, including archeabacteria. Also, Borodovsky and his colleagues have created a new program, GeneMark.hmm, to find genes in DNA of higher organisms, including humans.

Since 1993, researchers from around the world have sent DNA sequences to Georgia Tech via the Internet to obtain important information on gene locations. Now they can plug sequences into the Web server to see immediate results of their analyses. Borodovsky's lab also has supplied the gene-finding programs to academia and industry.

## TELEMEDICINE AND SURGERY SIMULATION

**Technology is allowing researchers to create innovative ways to remotely manage patients' health and to economically teach medical students new techniques.**

### Long-distance medicine

The concept of the "electronic house call" is a new twist on the long-forgotten practice of physicians visiting patients in their homes. Researchers at Georgia Tech and the Medical College of Georgia (MCG) have placed two-way audio/visual systems in patients' homes and connected them to monitoring stations in remote locations. This connection has enabled physicians to monitor their patients' health, while allowing patients to stay in their homes. Physicians have tested this example of what is known as telemedicine technology in private homes and a nursing home. Now, Georgia Tech and MCG have entered into a licensing agreement with a private firm, CyberCare Inc., to bring the technology to market.

"A client/server database structure has been developed to capture and store vital signs measurements performed by the patient," says Michael Burrow, a senior research engineer at Georgia Tech. "This allows the care provider to access the patient's data from any location and to input additional data. Eventually, the system will be compatible with hospital database systems, which will create another avenue to input and access patient data."

Burrow sees "electronic house calls" as including not only patients in private homes, but also in institutions, such as prisons, where it is costly to transport patients to medical facilities.

Through the telemedicine technology of the Georgia Statewide Academic and Medical System (GSAMS), physicians can consult with specialists in different locations. The largest such distance learning and medical network in the country, GSAMS is operating 32 out of 54 planned telemedicine sites.

A related telemedicine project lets healthcare workers measure vital signs from a distance. The concept of remotely measuring heart rate and respiration was originally developed for the military to assess the status of wounded soldiers. Now, scientists are adapting this technology in homes and hospitals: A microwave device mounted in a patient's room will provide physicians with medical information on the patient.

### Virtual Surgery

Allowing surgeons to practice procedures on a simulator can give them valuable feedback. Researchers at Georgia Tech, including Dr. Norberto Ezquerra, John Peifer and Michael Sinclair, are creating simulations for endoscopic procedures and eye surgery. Surgeons operate using virtual tools with force feedback on computer-generated anatomical models.

## RATIONAL DRUG DEVELOPMENT

**Scientists base rational drug design, discovery and development on an in-depth understanding of chemistry, and the biochemistry and physiology of the human body. The process can yield compounds that are both effective and selective, which can result in fewer side effects.**

Dr. Sheldon May, associate director of the Petit Institute and Regents' professor in the School of Chemistry and Biochemistry, recently announced a new class of antihypertensive drugs that may do more than control hypertension. May's drugs are selenium-based compounds, which, in addition to their antihypertensive qualities, possess the benefits of an antioxidant. In fact, strong, recent evidence indicates that selenium, in low levels, may protect humans against cancer.

"There are lots of antihypertensive drugs out there," May says. "This compound may not be significantly better in controlling hypertension, but it demonstrates the feasibility of harnessing the unique chemistry and biochemistry of selenium for a therapeutic purpose."

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### Patented Ideas:
#### Technology transfer possibilities abound in bioengineering

The future for bioengineered products is bright, but it has not always been so. Before 1980, federal law prohibited universities from obtaining patents on research projects funded by the federal government, effectively taking away much of the incentive to apply scientific knowledge to a practical area. The Bayh-Dole Act, passed in 1980, lifted this ban.

The Act has achieved its intended effects: The number of new technologies reaching the market has increased, which, in turn, has strengthened the economy and should decrease universities' dependence on taxpayer support. Indeed, Research Triangle Park in North Carolina and Silicon Valley in California stand as examples of how university-based research can translate into companies generating valuable products and services and igniting economic growth.

Aside from the development of important products, bioengineering also will pay off monetarily for Georgia Tech. The field has helped increase both the number of disclosures (the notification, by the researcher, to the technology licensing office regarding a potentially patentable idea) and U.S. patent applications filed by the university. Total disclosures at Georgia Tech rose from 60 in 1990 to 103 in 1997. Already, 57 disclosures have been filed in the first half of the 1998 fiscal year. There also has been a steady growth in the number of patent applications filed by Georgia Tech.

As of December 1997, Georgia Tech held 241 patents, had 129 patent applications pending and had licensed 76 inventions to companies, in total.

"The area of bioengineering has a lot of promise as an engine for growth," says Barry Rosenberg, director of technology licensing, for Georgia Tech. "Significant breakthroughs are emerging from

The development of this class of drugs exemplifies the collaborative nature of the Petit Institute: May's colleagues in engineering disciplines performed much of the background work, such as blood flow analyses and Doppler imaging.

Another example of rational drug design hinged on a discovery by May into how the body works. The body's process called amidation occurs to activate certain peptides. Amidation requires two enzymes to proceed; May's research group identified one of them. In inflammatory diseases, such as arthritis and colitis, amidation occurs too frequently. May has developed inhibitors of these amidating enzymes, which exhibit anti-inflammatory activity.

### BRIGHT HOPE FOR THE FUTURE

As the above examples show, the products and innovations originating in laboratories at Georgia Tech are rich with potential for improving the quality of life for many.

"The future of bioengineering represents a new initiative for Georgia Tech in the 21st century," Nerem says. "It is one that will further enhance Georgia Tech's reputation, will provide significant benefits to the public and also add to the region's economy."

**For more information, you may contact Dr. Robert Nerem, Petit Institute for Bioengineering and Bioscience, Georgia Institute of Technology, Atlanta, GA 30332-0363. (Telephone: 404/894-2768) (Email: robert.nerem@ibb.gatech.edu)**

the life sciences, which will open up new opportunities not only for Georgia Tech, but also for local economic development."

Healthdyne founder Parker H. "Pete" Petit, who endowed Georgia Tech's Institute for Bioengineering and Bioscience, is also aware of the impact a strong research program in this area can have on the local economy. "There is no reason Atlanta can't have what MIT, Harvard and Stanford bring to their communities," he says, alluding to the spin-off companies created by researchers at those institutions.

**-- Amy Stone**

Send questions and comments regarding these pages to Webmaster@gtri.gatech.edu

Last updated: April 7, 1998

# Test Engineer's Workstation

## Researchers create an interactive, computer-based how-to guide for test engineers.

### by Rick Robinson

**AS ANYONE WHO** has ever hefted a massive auto-repair or computer-software manual knows, how-to guides can be intimidating. Engineers, too, face daunting manuals, so researchers at the Georgia Tech Research Institute (GTRI) turned a computer into an interactive how-to guide called the Test Engineer's Workstation (TEWS). The machine uses hypertext links and multimedia — graphics, video and sound — to hasten the learning curve on complex test and evaluation jobs.

Developed by GTRI's Electronics Systems Laboratory (ELSYS) at the request of the U.S. Air Force, TEWS grew out of an ongoing Air Force need to bring new test engineers up to speed quickly in electronic-warfare systems testing. GTRI developers distilled massive test manuals into on-screen programs that lead test engineers through evaluations of new or upgraded systems, helping them plan, conduct and accurately

analyze a test.

"Users were lacking in automated tools," says Brian A. Keeton, an ELSYS research engineer who works in the Test Process Development Branch of the Systems Evaluation Division. "They had hard-copy documents and word of mouth from people who had done it before, but nobody had turned that into something where you can sit down at your PC and do something real with it. Now you can quickly find out what a piece of equipment does and what it did the last time, rather than having to try to find the guy down the hall who handled it the last time, but who may not be there anymore."



TEWS program developed by GTRI researchers shows customizable menus that guide users through test processes. Click screen for 150-dpi JPEG version - (145K)

In developing the TEWS platform, the GTRI team combined a host of video and audio materials — from taped lectures to slides and video — onto CD-ROM discs that users access from high-end Windows personal computers. Users click an on-screen subject and then listen to associated lecture materials and graphics, replaying any segment they want.

Researchers primarily developed TEWS with two software programs: Microsoft Word for Windows and its associated macro language; and Adobe Acrobat, a program that lets users view documents online in a non-editable graphical format that hinders document corruption or misappropriation.

TEWS aids users in the analysis of test data through its ability to use the Automated Data Reduction Software (ADRS), which computes performance and effectiveness measures to satisfy test program requirements for electronic warfare systems. Implemented as a Microsoft Windows application, ADRS helps ensure the quality of data collected and the ability of the resulting analysis to satisfy the test objectives.

Users can customize TEWS, if they wish. They can modify menu screens and hyperlinks built into the Workstation. Moreover, a video-capture card lets users add standard video input to existing test programs. This feature allows users to customize the system to their location and test facility type, and add on-line information about defense systems as they are tested.

"Maintaining good descriptions of results means that if, say, two years later you make

another change and you have to retest, you don't have to start over," Keeton says. "You can compare it to the last test pretty easily."

Just as important, TEWS helps users develop their own test plans from scratch. Following existing Air Force-approved outlines, GTRI developed a helper program that walks users through the task of creating test plans, along with template documents they can follow as they go.

"The Workstation goes through the format of a given document and tells the user what types of things should show up, what level of detail they need to really have a complete document and what's normally expected to be covered," Keeton explains. In a move that's a bit reminiscent of computer tax-form software, this program even has help boxes that pop up with questions users need to ask themselves.

The GTRI researchers were deliberate in their choice of the IBM PC for TEWS, rather than another, more exotic computer system. The PC platform, they determined: had the required computing capacity; was relatively inexpensive to purchase and maintain; and was user-expandable with handy, off-the-shelf extras such as CD-ROM recording drives.

Several TEWS systems have been installed at the Air Force Development Test Center at Eglin Air Force Base, the Air Force Flight Test Center at Edwards AFB and at GTRI to support the defense-systems testing arena. The TEWS approach may have applications in other fields as well, especially those that require an efficient combination of on-the-job training, system testing, and archiving of test results and methods.

Such control over testing can be quite valuable, Keeton says. "Taking time to carefully plan a test and predict the results means you can say, 'Let's not spend $30,000 tomorrow to fly the next mission until we figure out why this data's not matching up.' "

**For more information, you may contact Andrew Henshaw, Electronics Systems Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA 30332-0840. (Telephone: 404/894-7270) (Email: andrew.henshaw@gtri.gatech.edu)**

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# RESEARCHING THE REVOLUTION

**An interdisciplinary group is investigating present and future consequences of information technology.**

**by Lea McLees and Rick Robinson**

**NO ONE CAN FORESEE** exactly what tomorrow will bring, but two things are certain: Change will continue, and much of it will be linked to information technology. For those concerned about this future's myriad possibilities, perhaps the best way to prepare is to think about it.

Such is the premise of "The Information Revolution: Its Current and Future Consequences,"

See related story:
[Future of Information Technology Predictions](#)

a book by an interdisciplinary group of researchers from the Georgia Institute of Technology. Published this spring by Ablex Publishing of Greenwich, Conn., the book addresses information technology's potential impact on the

photo by Stanley Leary



Faculty at Georgia Tech are learning the latest in instructional technology. "There is no question that electronic learning is going to ...

workplace, academia, political affairs, "information societies" and management of the modern organization by the year 2020, says Dr. Bill Read, a professor in the School of Public Policy.

dramatically change the college educational process," says Dr. Farrokh Mistree, a mechanical engineering professor.

"What we now know about information technology is that it's a very powerful transforming resource, leading into a whole new age," says Read, one of the project's organizers. "This age is overtaking the Industrial Age, and by the mid-21st century, the way we work, play and even the way we fight wars will be entirely different."

The book evolved out of a series of Georgia Tech undertakings organized by Read and Dr. Alan Porter, a professor of industrial and systems engineering. A year of "brown-bag" lunch meetings resulted in a commitment by more than 20 faculty members to pursue original research on the information revolution. That led to a graduate seminar on the subject, which was followed by a distinguished-speaker series. And then 10 resulting research reports appeared in the journal Technology Analysis and Strategic Management.

"Looking ahead, even imperfectly, is better than putting one's head in the sand," Porter says. "We can pick up vectors of change and their implications, reducing uncertainty by identifying powerful forces. We can help depict alternative futures and say, 'Here's a reasonable range of possibilities.' We don't know where we'll actually end up, but we can do some planning."

Below, Research Horizons spotlights the thinking of several of the interdisciplinary group's members.

## More Work or Less Work?

Dr. Ann Bostrom is a School of Public Policy assistant professor with expertise in cognitive aspects of survey methodology and in risk perception and communication. Both she and Porter believe dramatic policy actions are needed to confront the effects of technology. Such changes will help the United States alter its dependence on the traditional job, and provide a better quality of life for a growing number of older citizens.

Bostrom and Porter conclude that though technology will result in job loss for many, huge changes in the jobs available, hours worked and the age and gender of workers could mean a net employment gain.

Porter, whose field is technological trends, believes that redefining work will involve broadening its practical definition to include not only volunteer and market work, but other work that society deems important — such as childcare, whether performed by a

stay-at-home mother or a daycare center.

"Which job tasks is society willing to pay for?" Bostrom asks. "A lot of our cultural weave has been volunteer work, but most of the women who did that are now employed. Is society willing to pay for that?"

An important step toward such redefinition would be getting accurate estimates of the amount of time people spend working at various jobs. Bostrom is exploring methodological issues related to this question.

"People have mental models of work — of arriving at certain times, being with co-workers, doing specific tasks, taking breaks, leaving at certain times," she says. "I believe we'll find that people's mental models of work influence their quantitative estimates of how much they work."

One thing seems certain: The future will favor those with training. "It's harder and harder for people without education to get good-paying jobs," Bostrom says. "People who are at the top already in the information cycle are doing better and better. People at the bottom, without the skills or access to ways of learning them, are having a harder time."

## How Efficient Is the Work?

Dr. Peter Sassone, an associate professor of economics, has done extensive studies of today's computerized companies. He found that businesses formerly focused on physical aspects of work — number of calls taken, time spent at the desk. But nowadays it is more informative to look at office work using a range of key measurements.

A diary study of a given office can help achieve the best staff mix, Sassone says. In such a study, a representative cross-section of workers log time spent over a month. Once the total amount of work and percentage done by each worker is determined, straightforward math can determine the correct staffing mix.

Companies commonly err when they try to pay for new information technology by eliminating clerical staff. They think computers will take up the slack. This is often not the case, Sassone says. In fact, Sassone studied 20 companies, none of which had optimal staffing. Usually, they had a surplus of managers.

Sassone found an expensive tendency for staff professionals to teach themselves about computers and to perform their own computer support. Companies can aid efficiency by adding computer support people to the staff.

"In many cases, my work is just verification of what people know," Sassone reports. "Few

people in business want to make decisions based on emotion. This gives them evidence that confirms or denies their gut feelings, and puts numbers on what they suspected."

## New Approaches for Manufacturing

"Because they provide flexibility, open systems will be the key for the manufacturing organization of 2020 and beyond," says Dr. Farrokh Mistree,

a professor of mechanical engineering and founding director of the Systems Realization Laboratory at Georgia Tech.

"Typically, when you design a product to meet a particular need, you quickly hone in on your design, sacrificing design flexibility and creating a product that cannot evolve and meet new needs," Mistree says."The Information Revolution gives us the flexibility to postpone commitment of resources to a particular course of action until the last minute, allowing us to make better decisions about our design before the freedom to make those decisions is lost."



Manufacturing's future could hold economies of scope, in which cost reductions on a product group are achieved via shared components — versus economies of scale, which offer large amounts of a specific product.

Competitive advantage will go to companies that provide exactly what their customers want at a low cost, says mechanical engineering graduate student Tim Simpson. He co-authored a chapter of the book with Mistree.

"When you buy a computer, do you want to buy the standard off-the-shelf model, or do you want to specify what components you want and don't want? For most people, I'd say it's the latter. . . and they shouldn't have to pay more for it," Simpson says.

Such flexibility means the future of manufacturing could hold economies of scope, in which cost reductions on a group of products are achieved via components all the products share. This approach differs from the concept of economies of scale, which today offers large amounts of a specific product.

Mistree and his students also are developing the Decision Support Problem Technique — rooted in the Decision-Based Design paradigm — for designing open systems. "It's about transforming information into knowledge that can be used by humans to design," Mistree says.

Manufacturers and their customers can expect these new directions in manufacturing research to help produce better products more quickly in the future.

## Public Space, Private Space

Information technology brought us virtual reality, real-time fantasy computer games and increasingly convincing simulations, allowing us to fashion private worlds we can totally control, says Micha Bandini, a professor in the College of Architecture.

"We have entered a realm in which we don't know what is fantasy and what is not — especially in the realm of advanced technology," Bandini argues. "Today we actually possess a lot of the devices from the early Star Trek shows. But many people, I think, don't know which gadgets we actually have now, which gadgets we will have in a year and which we will never be able to have. The fantasy, the actual and the possible are blurred."

Moreover, changes in the way people live have increased this tendency to retreat into controllable private worlds analogous to the cyber world, Bandini says. Traditionally, a city was a place to go to work — it had street life, shopping, restaurants, theaters. The suburbs were a place to sleep, exercise and sometimes shop.

In recent years, however, more of life has shifted to the suburbs. The new suburban "edge cities" meet many people's needs and keep them away from the city centers, which are still the home to most of our traditional public places. A hallmark of the new type of city is the mall, which is privately owned and not always accessible to everyone. For many people, it has taken the place of truly public places, such as the downtown area, the town square and the city park, Bandini says.

The delivery of information and products to the home via computer also reduces the necessity to leave our private worlds and visit public places. The Internet can't provide a worthwhile public space for us; it is too easy to seek out what and who we want in cyberspace, she says.

Such seclusion can create problems because visits to public spaces are vitally important, particularly in a democracy, Bandini says. Public spaces prevent us from isolating ourselves from those who are different. Moreover, contact with all kinds of people is important to the socialization of children.

"One way we can learn how to deal with difference is in a public space," Bandini says. "It is much too easy to isolate ourselves, to choose who we encounter, in cyberspace and in the suburbs. Toleration of differences and the ability to compose differences is a prerequisite for democracy."

Societies need to recognize themselves; they need public realms that allow the display of socially significant symbols — from the personal level to the community and national levels, Bandini says. The full experience of a public realm cannot be achieved via digital means only.

"I believe it would be difficult for the civil rights movement to happen in 1990s Atlanta because no one is in the streets," she says.

## Remaking the World Power Structure

Technology's impact will not stop with individual homes and lives; information technology already is affecting power, and ultimately commerce and politics, on the international scene.

Some of these technologies are fiber optics, computers, networks, improved human-computer interfaces, digital transmission and compression, communication satellites and cellular devices. They are influencing interactions among states, international governmental organizations such as the United Nations, multinational corporations and non-governmental organizations, such as religious movements and even terrorist groups.

"The capability to provide for the economic well-being of populations, for example, will increasingly reside with types of international actors other than states," says Dr. Daniel Papp, former executive assistant to Georgia Tech President Wayne Clough and now interim president of Southern Polytechnic State University in Marietta, Ga. "This phenomenon is already occurring. International finance and banking have been transformed by the ability to make global electronic fund transfers at a moment's notice."

Among the future possibilities Papp envisions are:

- International governmental organizations like the United Nations will continue to have difficulty gaining authority over nation states' decision-making and actions.

- An integrated world banking and financial market may evolve.

- Non-governmental organizations will proliferate and become more active, cohesive, organized and influential because of information technology.

- State sovereignty will be increasingly challenged because of the inability of states to control financial flows and information dispersal.

- Distribution of wealth will be increasingly skewed within and between states.

At present, it is unclear whether information technology's influence will push society in the direction of localization or globalization, Papp says.

"Will it be the United States of America or the Untied States of America? We don't have a sufficient degree of sophistication to know which will eventuate," he says. "Right now, it appears that globalization is winning."

Openness to change, at both the individual and cultural level, is an important and unpredictable factor with major influence on the world's future, Papp says. "Cost and system reliability are important, but they are irrelevant if you are not going to use a machine that is put in front of you."

Papp believes the next step is to try to manage change assertively to move toward desired outcomes. To that end, he and David S. Alberts of the Institute for National Strategic Studies, National Defense University (NDU) have written The Information Age: An Anthology on Its Impacts and Consequences. NDU published this multi-volume work last year for congressional offices, military officers, the academic community and others interested in the impact of information and communication technology on international change.

"The only way to manage change is to think about what possible changes technology might bring about," Papp says. "We have to think about where technology might drive us, and then we have to share that information with decision-makers.... One of the big problems with academics has been that they've been doing a great deal of thinking, but not sharing it with the outside world."

\* \* \* \* \*

The Tech interdisciplinary group, expected to adopt a formal name soon, will continue with its information revolution research after its book appears. In another initiative, the newly formed Georgia Tech Forum on the Information Enterprise of Tomorrow is working to develop stronger links between the College of Computing and the School of Management. This effort will help computer science graduates be more aware of business computing concerns, while making the management student more informed about technological issues.

Other Tech initiatives addressing the information revolution include an important symposium on April 6-7 at Georgia Tech's Ferst Theatre. Former Georgia Sen. Sam Nunn, IBM CEO Lou Gerstner, CIA Director George Tenet and many other business and government leaders will take part in a national summit on information security.

**For more information, you may contact Dr. Bill Read, School of Public Policy, Georgia Institute of Technology, Atlanta, GA 30332-0345. (Telephone: 404/894-0826) (Email: william.read@pubpolicy.gatech.edu); or Dr. Alan Porter, Technology Policy and Assessment Center, Georgia Institute of Technology, Atlanta, GA 30332-0205. (Telephone: 404/894-2330) (Email: alan.porter@isye.gatech.edu).**

# Refining Gas Refining

**New class of polymeric membranes could expand gas separation uses through improved thermal and chemical resistance.**

High temperatures? Harsh chemical environments? No matter. They don't present a problem for a new type of polymeric gas separation membrane.

Its use could potentially allow recovery of large volumes of hydrogen gas now discarded in petrochemical processing. And that recovery would reduce the environmental impact of refining processes.

Researchers from the Georgia Institute of Technology created the gas separation membrane by blending polyimide materials containing cross-linkable diacetylene groups. A solid-state cross-linking reaction initiated after formation of the membranes accounts for its improved thermal and chemical resistance, researchers say.

Photo by Stanley Leary



A new class of polymeric membranes could expand gas separation uses through improved thermal and chemical resistance.

They believe the reaction occurs in the more ordered regions of the blend; therefore, it does not significantly increase sample density. Thus, the researchers were able to improve the membrane's mechanical properties and chemical and thermal resistance without

reducing the material's gas transport and separation abilities.

"We have jumped a very large hurdle in having a material that is chemically and thermally resistant while retaining very attractive gas transport properties," says Dr. Mary E. Rezac, assistant professor in Georgia Tech's School of Chemical Engineering. "There could be a very large commercial market, but there are a number of technical hurdles still ahead of us."

The research is sponsored by the U.S. Environmental Protection Agency, the National Science Foundation and Georgia Tech. Rezac's collaborators on the project are Dr. Haskell W. Beckham, Birgit Bayer, E. Todd Sorensen and Njeri Karangu.

Rezac believes the new membranes could make the recovery of hydrogen from petrochemical processes economically feasible. The temperature of refinery gas streams — containing hydrogen, propane, methane and other hydrocarbons — exceeds the thermal operating range of current membranes. Cooling those gas streams can cost more than the recovered materials would be worth.

If the new system can operate at high temperatures unaffected by gas stream contaminants, the industry could recover hydrogen the U.S. Department of Energy has estimated would be worth several hundred million dollars a year.

"If we can achieve these types of separations, we can reduce operating energy, waste production, and the pollutants going into the atmosphere," Rezac notes. "The dollar value of the hydrogen is significant, but there are external issues in terms of recycling and pollution control that are just as important."

Beckham believes there may be other applications for such materials that can undergo crosslinking without shrinkage, he says. Dental fillings and high-strength composites are two applications that would benefit from such properties.

*— John Toon*

**For more information, you may contact Dr. Mary Rezac, School of Chemical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0100. (Telephone: 404-894-1255) (Email: mary.rezac@che.gatech.edu)**
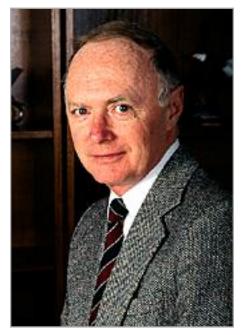
# Ultimate Customers
**New GTRI director of Research Operations focuses on users.**

Maj. Gen. George B. Harrison (USAF Ret.) has spent 5,800 hours in the pilot's seat of 68 different aircraft types, from gliders and Piper Cubs to F-16 fighters and B-1B bombers. So when the new director of Research Operations talks about "customers" for the Georgia Tech Research Institute's work, his meaning is very specific.

"My real focus is on the ultimate customer, the person who has to use the equipment we help develop," he says. "Modeling and simulation to support the decision-makers is very interesting, but modeling and simulation so that the individual soldier, aviator or sailor knows how much to depend on the equipment is far more important to me. I care a lot about the lieutenants and privates, the people whose lives depend on what we do in GTRI."

During a 35-year career in the U.S. Air Force, Harrison served in a wide range of capacities. As commander of the Air Force Operational Test and Evaluation Center at Kirtland Air Force Base in New Mexico, he directed the evaluation of major Air Force systems, including the C-17, F-22, and Joint STARS.

**Gen. George Harrison**

He also commanded the Air Force Air Warfare Center at Fort Walton Beach, Florida, and was deputy chief of staff for operations with the U.S. Air Forces in Europe. His background also includes two years as commander of the Air Force Center for Studies and Analysis at The Pentagon, and 260 Vietnam combat missions.

His service to GTRI began in July 1997, when he was chosen to lead the Electronic Systems Laboratory, one of nine GTRI research units. On Dec. 19, GTRI Director Edward K. Reedy chose Harrison to fill the Research Operations position. In that capacity, he is responsible for operation of all GTRI research laboratories.

With this unique background, Harrison has had an opportunity to view GTRI's work from both sides of the production cycle.

"I've spent a lot of time actually using the equipment that GTRI either produces or supports," he explains. "I am here because my field experience has convinced me that GTRI and Georgia Tech are committed to excellence and quality."

Harrison believes GTRI has a bright future. He feels the organization's primary challenge is to broaden its sponsor base while continuing to meet the needs of its long-time customers in the Department of Defense.

*— John Toon*

# Letting the Flip-Chips Fall as They May
**New technique reduces cost of flip-chip manufacturing.**

Researchers in Georgia Tech's Packaging Research Center have developed a novel, no-flow underfill material and process that eliminates long underfilling and curing process times. The innovations significantly reduce flip-chip manufacturing cost and provide for throughputs compatible with surface mount assembly.

Led by Dr. Daniel F. Baldwin, an assistant professor in the Woodruff School of Mechanical Engineering, and Dr. C.P. Wong, a professor in the School of Materials Science and Engineering, the research team created this new, no-flow assembly process and material. Wong's group has filed two U.S. patents for the materials' invention.

"The process and material contain a self-fluxing agent and a latent catalyst that eliminates the flip-chip fluxing, cleaning, and long underfilling and curing times," Wong says. "It simultaneously reflows and cures the solder joints and underfill using a conventional surface mount reflow furnace."

Conventional underfill flow lasts from 15 seconds to 30 minutes, Baldwin says, depending on the material, die size and temperature. Curing commercially available underfill materials takes one to two hours and involves several time-consuming cleaning steps before underfill application.

In contrast, the no-flow underfills flow simultaneously with chip placement, typically 0.5 to 5 seconds, and the cycle times during cure and reflow last 3 to 5 minutes. Also, this process allows for interconnect testing and flip-chip repair, before the high value-added solder reflow joining process.

"Our analysis of the cost and processing times indicates a two- to six-fold reduction in assembly cost and at least a 50 percent reduction in processing cycle time over conventional flip-chip processing," Baldwin said. "Once the no-flow underfill has been printed onto the organic substrate, and the flip-chip is placed piercing the underfill, the assembly is reflowed, forming the solder interconnects and curing. No further post-curing of the underfill is required."
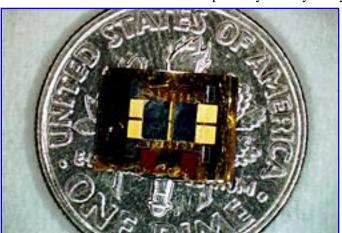
*— Jackie Nemeth*

# Microrelay Breakthroughs

**New type of magnetically actuated microrelay offers significant advantages.**

A new type of magnetically actuated microrelay could have applications in automobile electronics, test equipment and other areas where low actuation voltages are required.

And these microrelays can be batch-produced using established micromachining techniques.

The devices, which are smaller than a dime, have set records for their low contact resistance and ability to switch large current loads. Developed by researchers at the Georgia Institute of Technology, the microrelays can be integrated with circuit boards because their fabrication techniques are compatible with standard microelectronic processing. The design allows similar configurations to be used for both normally-on and normally-off relays, as well as for multi-pole relays.

New type of magnetically-actuated microrelay could have applicatons in automobile electronics, test equipment and other areas requiring low actuation voltages. (200-dpi JPEG version - 335k)

"The significant issue in using a magnetically-actuated relay is that you can achieve larger forces and a greater air gap between contacts when compared to electrostatic relays," says William P. Taylor, a former researcher in Georgia Tech's School of Electrical and Computer Engineering. "The larger gap holds off a higher voltage, which allows you to switch higher voltage signals than would be permitted with other types of microrelays."

Competing microrelay technologies use electrostatic forces that require higher actuation voltages than magnetic relays, though they operate with lower currents. The magnetic and electrostatic approaches offer advantages that depend on the specific application, Taylor notes.

The Georgia Tech microrelays operate at less than five volts, which would allow them to be driven by digital logic circuits and used as part of equipment for which higher voltages could be undesirable. Their contact resistance of less than 100 milliohms and ability to switch currents of up to 1.2 amperes set a new record for microrelays, Taylor says.

**For more information, you may contact Dr. Mark G. Allen, School of Electrical and**

**Computer Engineering. Georgia Institute of Technology, Atlanta, Ga., 30332-0269. (Telephone: 404-894-9419) (Email: mark.allen@ece.gatech.edu)**

# Georgia Tech electrical engineer receives prestigious Presidential Award

Dr. Steven W. McLaughlin, assistant professor in the School of Electrical and Computer Engineering (ECE) at the Georgia Institute of Technology, received a $500,000 Presidential Early Career Award for Scientists and Engineers (PECASE) during a White House ceremony last November.

The PECASE awards were presented to 60 young researchers from a variety of disciplines. The awards are the highest honor bestowed by the U.S. government on outstanding scientists and engineers who are beginning their careers.



photo by Stanley Leary

"I am extremely surprised and honored to receive this award," says McLaughlin, who joined Tech's faculty in 1996 after spending four years at the Rochester Institute of Technology in Rochester, N. Y. "While the award appears to single out individual accomplishments, it is really a tribute to the support I have received from the School of ECE and Georgia Tech."
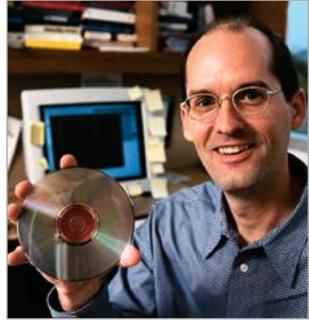
Research by Georgia Tech scientist Steven McLaughlin has led to increases in the storage capacity of CDs — 50 gigabytes on a disk.

A member of ECE's telecommunications faculty, McLaughlin will use his $500,000 award over a five-year period to support his research in optical recording systems, similar to compact discs (CDs) and digital video discs (DVDs). Optical recording systems are capable of storing information in high-capacity, non-binary formats.

"The storage capacity of CDs (about 680 megabytes on a 4.5-inch disc) makes their useful lifespan about 15 years. DVDs just coming into today's market have sufficient capacity (up to 17 gigabytes on a 4.5-inch disc) to be useful for an additional 15 years. Beyond that, new approaches are beginning to be proposed. Both CD and DVD systems currently store about 1 to 1.5 bits in every 'pit' stored on the surface of the disc," McLaughlin says.

"We are developing techniques that increase the storage density to between 3 to 5 bits per pit, resulting in an overall storage capacity of over 50 gigabytes on the same size disc. As a result, discs will be able to hold much more audio and video information."

He describes his research as reasonably high risk, because his ideas and technologies go against conventional wisdom. But they are of great interest to optical recording companies. Recently, the National Institute of Standards and Technology funded a $10 million project in which McLaughlin will collaborate with the University of Arizona, Calimetrics Inc., Energy Conversion Devices Inc. and Polaroid Corporation. The partners will develop high-capacity optical storage media and high-speed data transfer systems for desktop digital media systems or even low-cost portable devices.

— *Jackie Nemeth*


# A Case for Microwave Packaging
## Research provides inexpensive way to maintain signal integrity.

As consumer electronics continue to use higher and higher operating frequencies for personal communications, low-cost microwave packages are becoming a major concern.

Traditional microwave packages, well-suited for high-performance and low-volume applications, are expensive and often not well-suited for mass production. Plastic surface mount packages are adequate for components operating below 5 GHz, but they do not meet the performance needs of microwave/millimeter-wave applications.

To meet the consumer electronic needs of the near future, Dr. Joy Laskar, assistant professor in Georgia Tech's School of Electrical and Computer Engineering, and his wireless electronics team have designed a low-cost microwave package. They have leveraged current plastic package technologies, but modified the physical footprint. Researchers engineered this low-cost, shielded vertical interconnect package (VIP) in collaboration with Hewlett-Packard Company to maintain radio- frequency signal integrity.

"The surface mount package footprint has been redesigned to provide near waveguide-like properties with the potential for operation to millimeter wave frequencies," Laskar says. "The initial VIP prototype has been designed, fabricated and characterized, and represents a significant breakthrough for low-cost microwave packaging."

His team has measured a 10-decibel improvement in return loss with a non- optimized design, resulting in improved signal-to-noise ratios.
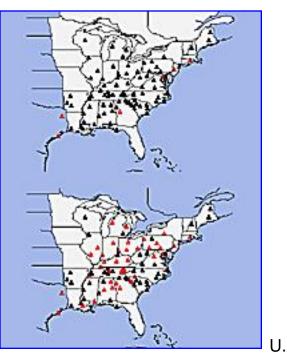
*— Jackie Nemeth*

# Cough, Choke, Wheeezzzzeee

## U.S. air unhealthy under new pollution standard, study shows.

A day in the country may not be as healthy as you think, according to a Georgia Tech study analyzing the impact of an air pollution standard proposed by the U.S. Environmental Protection Agency (EPA).

The proposal sets a standard for ground-level ozone, a pollutant associated with photochemical smog. The new standard could cause large portions of the rural eastern United States to be cited as ozone non-attainment areas, according to the study, led by Dr. William L. Chameides, a Regents professor in the School of Earth and Atmospheric Sciences.

The journal Science published the results of the study last year. Chameides collaborated on the research with Dr. Rick D. Saylor of Georgia Tech and Dr. Ellis B. Cowling at North Carolina State University.



U. S. EPA data shows acceptable sites in black for current ozone standards (top) and for proposed standards (bottom). (larger JPEG version - 225k)

If enacted, the new standard will require a major change in the nation's air pollution control strategies, which until now have largely focused on urban pollution, Chameides said.

Ground-level ozone is produced from chemical reactions in the atmosphere fueled by air pollutants such as hydrocarbons and nitrogen oxides. The federal Clean Air Act empowers the EPA to establish a National Ambient Air Quality Standard (NAAQS) for ozone to protect human health. In response to new medical data indicating adverse health effects at lower ozone concentrations, the EPA has proposed a new NAAQS.

Analysis of ozone levels measured at rural locations in the eastern half of the United States indicates that nearly half the sites would not meet the new ozone standard.

"This implies that the harmful effects of air pollution may be a lot more ubiquitous in the United States than previously thought," Chameides says. "Non-attainment of the current standard is mostly limited to urban areas, and thus most people's perception is that air

pollution is an urban problem. But if EPA's new standard better reflects the health effects of ozone pollution, it suggests that you could probably go just about anywhere in the eastern United States during the summer and encounter unhealthy air."

— *John Toon*


# Researchers Honored

**Phillips, Bayor, Hertel, Scranton and Cowan are honored by awards and appointments.**

**Dr. Michael Phillips**, a faculty research associate in the College of Engineering, was appointed director of the Electronic Data Application Division for SOLE — The International Society of Logistics. As director, Phillips will work to achieve the Society's goal of fostering the professional development of its members.

**Dr. Ronald H. Bayor**, who co-edited the book "The New York Irish," received the James S. Donnelly Sr. Prize for the best book in history and social sciences. The American Conference for Irish Studies presented the award. Bayor is a professor of history in the Georgia Tech History, Technology and Society Department.

**Dr. Nolan Hertel**, a professor in the George W. Woodruff School of Mechanical Engineering, was a co-winner of the 1997 Protection and Shielding Best Paper Award at the 1997 American Nuclear Society winter meeting. Hertel and his co-authors (Drs. Dominic Napolitano, Nick Romano, and Y. J. Yu) won the award for their paper titled "Shielding Analysis of the NAC-MPC Storage System." Hertel won the same award at the 1996 winter meeting for a paper on which he was co-author.

**Dr. Philip Scranton**, Kranzberg professor of the history of technology, authored "Endless Novelty: Specialty Production and American Industrialization, 1865-1925," which was released in December 1997 by Princeton University Press. "Endless Novelty" was profiled as a "hot topic" book in the publication Lingua Franca earlier this year. It is expected to alter the ways in which Americans understand the dynamics of industrial growth.

**Richard Cowan**, program manager of the Multiuniversity Center for Integrated Diagnostics at the School of Mechanical Engineering, is participating in the Congressional Science and Engineering Fellowship Program coordinated by the American Association for the Advancement of Science. The program is a cooperative effort of about 25 national engineering and scientific organizations, each of whom sponsors one or more mid-career professionals for a one-year fellowship in Washington, D. C. Cowan's fellowship, which began in January, is sponsored by the American Society of Mechanical Engineers. Fellows are selected in a national compettiton from among outstanding, mid-career

scientists and engineers.

Send questions and comments regarding these pages to Webmaster@gtri.gatech.edu

Last updated: April 7, 1998

# Future of Information Technology Predictions:

## Selected predictions from researchers who participated in the "Information Revolution: Its Current and Future Consequences" project.

### Next comes the information (not technology) revolution.

"In the 1980s information technology (IT) took off. Computing went from an occasional activity for specialists to routine in the lives of most technical professionals.

Then it did likewise for white collar workers and students. Then, for many blue collar workers and on into our homes. In the 1990s, we've gotten networked — first the technical community, then business and school, then home — via modems, Ethernet, some broadband and wireless. That's an 'IT Revolution.'

> See main story: [Researching the Revolution](#)

"Now we're poised for the Information Revolution. Newly accessible digitally formatted information is weaved into our daily lives. Technical professionals first, then white collar workers and students, then most of us will rebuild our work and home lives around this resource — ubiquitous electronic information."

**— Alan Porter, Director, Technology Policy and Assessment Center**

### Interpersonal aspects of commerce and education will remain.

"Just as the photocopier and the desktop computer did not eliminate paper, secretaries and offices (as many had forecast), the devices of the Information Revolution, will not eliminate the interpersonal aspects of commerce and education. For those with access, the pace and volume of human interactions on the network will increase enormously, and for many this change will be enriching.

"But the important social aspects of commerce and education — gathering, sharing, learning about behavior, spontaneously connecting with others — that require face-to-face contact will not decrease significantly. People will continue to congregate in classrooms, offices, churches, bars and shopping malls.

"The cumulative impact will be a continuing increase in the speed and number of total 'information events,' and people 50 years from now will wonder why so many in our era thought that the Information Revolution would increase our leisure."

**— Dr. Richard Barke, Associate Professor, School of Public Policy**

## Most lives will remain untouched.

"In the years ahead, the vast majority of people of the world will go about their daily lives largely untouched by the Information Revolution. The requisite massive expenditures on technology infrastructure, operations and personal equipment will not be justified in developing countries until more fundamental needs of adequate food, clothing, shelter, medical care and basic education are widely satisfied.

"Satisfying those needs will absorb most of the income of the increasingly populous Third World for the foreseeable future. To be sure, there will be many juxtapositions of the old and the new — for example, when a peasant walks half a day over dirt trails to visit a village doctor in a hut equipped with a satellite link to a distant medical center. But those instances will be the exceptions, not the rule, in people's daily lives."

**— Dr. Peter G. Sassone, Associate Professor, School of Economics**

## Who will win the new power struggle?

"The ongoing computer revolution, the Internet and other new information technologies have resulted in a remarkable array of new applications.

Technology-driven socioeconomic change is occurring. However, there will be many

struggles between forces for central control (as has been encouraged in the Industrial Age and existing power bases) and those for individuality (as is encouraged by the two-way communications of the Internet and similar technologies).

"Already the power of technology for free exchange of information has been seen in the breakup of the Soviet Union. While there will be considerable pressure by many governments and commercial and social interests to 'regain control,' the fact is — and will remain — that technology-aided information exchange will remain 'free.'

"The genie is out of the bottle."

**— Frederick B. Dyer, Principal Research Scientist Emeritus**

## What is beyond the human-machine interface?

"Two revolutions have occurred in information technology: We use electronic machines instead of paper to store information, and we have successfully connected these machines together. As a consequence, computer users suffer a lot of 'red eye' as they interface with their information machines.

"The next revolution will move beyond today's human-machine interface — and liberate all those 'red-eyed' users. Machines interfacing with machines — 'knowledge-based systems,' 'automatic search systems,' 'preprogrammed abstracting systems' and much more — will become commonplace. Look for the coming of the automatic 'information finding, classifying and processing' machine."

**— Dr. Donghua Zhu, Visiting Professor, Technology Policy and Assessment Center**

## Decentralization is the future.

"The Industrial Age was based upon the centralized coordination of large numbers of manual laborers and service workers. The 'Knowledge Age,' in contrast, is based upon the decentralized coordination of large numbers of knowledge workers. One should therefore expect that decentralized mechanisms of all sorts (e.g., products, services, business processes, business strategies, markets, government agencies) will flourish at the expense of centralized ones in the future.

"Predictions: The network computer will not be a successful product; governments will lose control of their currencies and the ability to control interest rates; communications industries that developed as monopolies, oligopolies or because of sheer size will wither."

— **Gary S. Tjaden, Director, Center for Enterprise Systems, Information Technology & Telecommunications Laboratory, Georgia Tech Research Institute**

## An ethical dilemma exists.

"Ethical issues and concerns have always underscored the utilization, management and control of information. In the Age of Information, political and societal tensions will increasingly surface and coalesce, creating significant differences among groups within nations, as well as among nations. The quality of information content will be deliberated by the perceived haves and the have-nots. Who controls information will be a major issue for 21st century scholars and politicians."

— **Don Frank, Assistant Director for Information Services**

## Management of knowledge capital will take off.

"Because knowledge is becoming the key wealth-creating asset, and because high-value knowledge is hard to accumulate in organizations — and even harder to organize and effectively deploy — managers in both the private and public sectors will want to learn how to master the process of knowledge management. And, they will want to become innovators in creating knowledge capital in order to achieve competitive advantage. As a consequence, leading schools of business and public administration will make major curriculum changes early in the 21st century."

— **Dr.William H. Read, Professor, School of Public Policy**

## Mere access to information will not be enough.

"The development of information networks has not followed a purely technological imperative. They have been shaped by social networks. New social networks will interact in their own way with the current information infrastructure to lead the next stages in its implementation. The Internet, for instance, serves to keep track of the dynamics of various socio-economic phenomena.

"Networks not only bring about change, but are the ideal means to monitor change. Because of the importance that this has for both business and government, it is foreseeable that the automatic feeding of transaction information to control and decision centers of various kinds will become ubiquitous.

"The key strategic issue in this environment will be the ability to bring processing power, broadly construed, to bear on any point in time and space that circumstances may demand. Mere access to information will not be sufficient. Making something happen with information, from attribution of meaning to rapid incorporation into ongoing decision processes, is what will make a difference."

**— Dr. Juan D. Rogers, School of Public Policy**

## Science will move online.

"By 2010, scientific publication will be a fully electronic medium. Journals will no longer be the major means of organizing scientific information; browsers will help scientific readers select new papers from across a variety of disciplines and sources. Scientific 'papers' will contain digital information of all sorts, including, but not limited to, text, graphics, movies, audio, simulations and visualizations. The life cycle of scientific publication will be considerably shortened by electronic media. Collaboration, authorship, submission and review will become more intertwined as science moves online. Quality assurance will be provided by electronic labeling services — entities neither fully academic, corporate, nor governmental in nature."

**— Scott Cunningham, Science Policy Research Unit, University of Sussex**

## Electronic learning is the future.

"The evidence is clear that there are many problems with the current academic system. The fact of the matter is that college instructional methods have not changed much over the last 50 years. Those institutions that properly assess the changes coming and respond in the appropriate manner will grow and prosper, while many others will decline and close up shop.

"The present educational process can be likened to an ancient cottage-shop industry that is neither efficient (costs are growing relative to income), nor effective (does not do a very good job of increasing learning). Clearly college education is ripe for major technological change that makes education both more efficient and effective.

"There is no question that electronic learning is going to grow rapidly in importance and dramatically change the college educational process."

**— Dr. Farrokh Mistree, Professor, School of Mechanical Engineering**

## Authentication will be more important than copyright.

"The creative human process of authoring is in part based upon the collection, interpretation and analysis of existing information. In the future the source, ownership and authentication of information become significant issues as intelligent processors duplicate these human processes to become both primary and secondary publishers.

"Authentication of information sources becomes more important than copyright to ensure these processors do not reuse data that is out of context, thus resulting in false conclusions. As this prediction matures, changes will occur in the publishing business, in educational use of information, and in the purpose and use of libraries."

**— Robert G. Patterson, Manager of Knowledge Transfer, Institute of Paper Science and Technology**

## Winners will apply and use technology.

"Our physical ability to send, process and display data will increase enormously with cost-effective developments in bandwidth, computing, optical storage, imaging and display technologies.

"But the real challenge of the Information Revolution isn't the development of technology, but how to apply and use it. The technology is developing faster than our ability to adopt it. The greatest difficulty is getting people to change. Companies spent huge sums on information technology in the 1980s, with limited improvements in productivity.

"The winners in the Information Revolution will be the people and organizations that can adopt change to the way they work and live."

**— Dr.William H. Bellinger, Visiting Professor, School of Management**
**— William M. Riggs, Director, Management of Technology Program**

## Software dependency will become a problem.

"Traditional approaches to use of information systems has lead to a naive dependence on these systems. In the future, information systems will continue to support more complex and critical functions, resulting in even more dependence on these systems. It is my prediction that such dependence will result in an IS-based crisis with national and/or

global implications.

"Further, use of these systems will have a negative impact on quality of life. Whether or not continued integration of information systems into organizational processes leads to the optimization of these processes, information technologies will not decrease the length of the workday. Rather, they will allow organizations to claim more hours of the worker's day as these technologies continue to become accessible and mobile. Work will permeate more and more aspects of our lives."

**— Dr. Judith P. Carlisle, Assistant Professor, School of Management**

## Information organizing is not the future.

"Organizing information will not be so important in the future; evaluating, validating and analyzing information will be. Consequently, there will be a growing need for information and knowledge analysts whose activities are focused on content, meaning and value of information. They will need to know how to use the most modern information technologies and at the same time be educators and mentors in a changing learning environment."

**— Julie Yang, Librarian**

**For more information, you may contact Dr. Bill Read, School of Public Policy, Georgia Institute of Technology, Atlanta, GA 30332-0345. (Telephone: 404/894-0826) (Email: william.read@pubpolicy.gatech.edu); or Dr. Alan Porter, Technology Policy and Assessment Center, Georgia Institute of Technology, Atlanta, GA 30332-0205. (Telephone: 404/894-2330) (Email: alan.porter@isye.gatech.edu).**

Contents | Research Horizons | GT Research News | GTRI | Georgia Tech

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