The world is analog. Analog circuits model the world and capture real-world information so it can be digitally processed.  
— Joy Laskar, director of the Georgia Electronic Design Center and Schlumberger Chair in the School of Electrical and Computer Engineering

We're seeing opposing effects from these crabs. [They] slow the rate of growth for organisms like oysters that they compete with, but they enhance the ability of those same organisms to survive when young.  
— Mark Hay, professor in the School of Biology

An ability to tailor the porosity and structural integrity of the explosive precursor material is a combination we’ve never had before. We can start with the Navy’s requirements for the material and design structures that are able to meet those requirements.  
— Jason Nadler, GTRI research engineer

We're interested in developing the science of these [inorganic nanotube] materials to the point that we can manipulate their curvature, length and internal structure in a sophisticated way...  
— Sankar Nair, assistant professor, School of Chemical and Biomolecular Engineering
“If you open a textbook and look at what a thin-film transistor should do, we are pretty close now.”

– Bernard Kippelen, professor in the School of Electrical and Computer Engineering and the Center for Organic Photonics and Electronics

“This is the beginning of a new era – the era of visual analytics.”

– Dimitri Mavris, director of the Aerospace Systems Design Lab (ASDL)

“We can do real-time monitoring of avian influenza infections on the farm, in live-bird markets or in poultry processing facilities.”

– Jie Xu, GTRI research scientist

“If we can really understand the fundamentals of these failure mechanisms, then we can use that information to guide the development of new materials or we can develop system approaches to mitigate these failures.”

– Tom Fuller, director of the Center for Innovative Fuel Cell and Battery Technologies
Moving beyond carbon nanotubes, researchers are developing insights into a remarkable class of tubular nanomaterials that can be produced in water with a high degree of control over their diameter and length. Based on metal oxides in combination with silicon and germanium, such single-walled inorganic nanotubes could be useful in a range of nanotechnology applications that require precise control over nanotube dimensions.

At the Georgia Institute of Technology, researchers are studying the formation of these metal oxide structures to understand the key factors that drive the emergence of nanotubes with specific diameters and lengths from a “soup” of precursor chemicals dissolved in water. Their goal is to develop general guidelines for controlling nanotube diameter with sub-nanometer precision and nanotube length with precision of a few nanometers.

So far, the researchers have obtained encouraging results with a model system that produces aluminosilicogermanate (AlSiGeO) nanotubes.

“We have shown that there is a clearly quantifiable molecular-level structural and thermodynamic basis for tuning the diameter of these nanotubes,” says Sankar Nair, an assistant professor in Georgia Tech’s School of Chemical and Biomolecular Engineering. “We’re interested in developing the science of these materials to the point that we can manipulate their curvature, length and internal structure in a sophisticated way through inexpensive, water-based chemistry under mild conditions.”

Using chemical reactions carried out in water at less than 100 degrees Celsius, Nair’s research team – which includes graduate students Suchitra Konduri and Sanjoy Mukherjee – varied the germanium and silicon content during the nanotube synthesis and then quantitatively characterized the resulting nanotubes with a variety of analytical techniques to show a clear link between the nanotubes’ composition and their diameter. Simultaneously, the group’s molecular dynamics calculations showed a strong correlation between the composition, diameter and internal energy of the material.

“There appear to be energy minima that favor or stabilize certain nanotube diameters because they have the lowest energy, and those stable diameters change with the composition of the material,” adds Nair. “This shows that the nanotube dimensions are not just a fortuitous coincidence of the many synthesis parameters, but that there is an underlying thermodynamic basis arising from the subtle balance of inter-atomic forces within the material.”

Specifically, the molecular dynamics simulations – which are corroborated by experiments – show that the variation of germanium and silicon content causes sheets of aluminum hydroxide to form nanotubes with diameters ranging from 1.5 to 4.8 nanometers and lengths of less than 100 nanometers.

Once the researchers fully understand the factors affecting the formation of nanotubes from aluminosilicogermanate materials, they hope to apply similar principles to other metal oxides. The ultimate goal will be an ability to predictably vary the dimensions of nanotubes – and potentially other useful nanostructures – em-

By John Toon
ploying different chemical process conditions across a broader range of metal oxide materials.

Though the chemical reactions that produce the metal oxide nanotubes are complicated, they occur over a period of days at low temperatures and can be carried out with simple laboratory apparatus. That facilitates control over processing conditions and allows the researchers to track many different aspects of the reaction with a variety of characterization tools.

Controlling the dimensions of nanostructures is critical because properties such as electronic band-gap depend strongly upon the dimensions. Dimension control has proven to be difficult in carbon nanotube fabrication processes, leading to an entire area of research focused on purifying nanotubes of specific dimensions from an initial mixture of different sizes.

The metal oxide nanotubes have properties very different from those of carbon nanotubes, which have been studied extensively since they were discovered in the 1990s. “For example, the materials that we are working with are much more hydrophilic than carbon and can load nearly 50 percent of their weight with water,” Nair explains. “There is a whole range of behavior in oxide nanotubes that we cannot explore with carbon-based materials.”

This work, sponsored by the American Chemical Society Petroleum Research Fund, has been published in ACS Nano and in the Journal of the American Chemical Society.
A woman in Phoenix uses a computer and webcam to visit nightly with her young grandson in New York. A pediatrician hiking in the Smoky Mountains consults by cell phone on a critical case in Atlanta. Enemy radar sets off warnings in a U.S. military aircraft, which immediately turns away from the danger.

Everyone recognizes such events, and millions like them, as benefits of digital technology – of microprocessors and software, of bits and bytes.

Fewer know that these and most other electronic miracles would be impossible without an

Indispensable Technology:

Far from Obsolete, Analog Electronics and Expertise Are in High Demand Today

By Rick Robinson

Joy Laskar, right, director of the Georgia Electronic Design Center, and researcher Stephane Pinel are researching technology that sends data wirelessly at several gigabits per second over short distances.
other technology that is also thriving – analog electronics.

Designing these ubiquitous circuits – which feed information and power to digital components – is sometimes called an art form. That’s because analog engineers must choose among a multitude of materials and techniques to best perform a given function. Analog expertise is in high demand globally, and analog microelectronics provide strong revenue for technology companies large and small.

“The world is analog,” says Joy Laskar, director of the Georgia Electronic Design Center (GEDC), a 250-person center at Georgia Tech that specializes in analog and mixed-signal (analog-digital) research. “Analog circuits model the world and capture real-world information so it can be digitally processed.”

Analog electronics “are especially important in mobile devices,” adds Laskar, who is the Schlumberger Chair in Microelectronics in Georgia Tech’s School of Electrical and Computer Engineering (ECE). “Anything that’s untethered, from cell phones to hearing aids, will have heavy analog content.”

Generally speaking, analog technology plays a crucial role in three major electronic areas:

### Input/Output (IO):
Analog microelectronics are essential to radio frequency (RF) and microwave devices, including cell phones and MP3 players; military radar systems and satellites; miniaturized antennas; microphones and temperature sensors; image sensors for cameras and scanners; hard drives and other data-storage devices; biomedical applications, and more.

### Power:
Analog technology supports delivery, management and conditioning of power, which is essential in wireless devices where power issues are critical; it’s especially important for power conservation because analog chips use less power than digital designs.

### New applications:
Today’s analog research is expanding into novel areas, including analog circuits that can be reprogrammed like digital chips; tiny devices called micro-electromechanical systems (MEMS) that actually move at the microscale; and new analog techniques that combine with digital technology to facilitate extremely high data rates and frequencies in both the wireless and wired domains.

## The Indispensable Technology

Analog technology, once the cornerstone of both electronics and computing, was supposed to be on the endangered-circuits list by now. During the digital revolution of the 1980s, when inexpensive microprocessors brought programmable computing to an eager world, experts proclaimed that the flexible new technology would eclipse older, fixed-function analog approaches.

Those predictions didn’t pan out. Not only has analog technology remained essential to microelectronic communications and computing, but today’s engineers are extending analog’s usefulness in many ways. Through continuing miniaturization and sophisticated new techniques, investigators are utilizing both “pure” or “core” analog technology as well as “mixed-signal” approaches that combine analog and digital functions cooperatively in a single integrated circuit.

Georgia Tech is among a handful of universities that has continued to emphasize analog research and education, even during the 1980s and early 1990s when many were downgrading their analog programs. Today, the number of Georgia Tech faculty who focus on analog and mixed-signal engineering stands at 14, and that total continues to grow. This faculty group – combined with numerous research faculty, postdoctoral researchers and hundreds of undergraduate and graduate students pursuing analog degrees – mark Georgia Tech’s analog technology program as probably the largest in the United States.

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Georgia Tech professors and researchers are pursuing new analog-based approaches in a variety of areas, including biotechnology and neuromorphic design, reprogrammable analog circuits, power approaches such as microscale fuel cells and power harvesting, and manufacturing reliability and quality. They are designing improved analog and mixed-signal electronics for a host of uses, from optimizing today’s civilian and military communications to exploiting underutilized frequencies.

Traditional workhorse analog design is important, too. At the Georgia Tech Research Institute (GTRI), some engineers are using their expertise to replace obsolete analog circuits, typically in military aircraft and communications. By using available parts to develop cheaper and more reliable designs, they help keep U.S. aircraft in the air.

The Georgia Electronic Design Center

Nowhere at Georgia Tech is the analog focus more intense than at the Georgia Electronic Design Center (GEDC). Established in 2003, the center occupies 42,000 square feet in the Technology Square Research Building. GEDC’s assets include 13 professors who serve as research-team leaders, some 200 graduate and undergraduate researchers and more than $20 million in test and other equipment.

The Georgia Electronic Design Center’s work is supported by about $13 million in annual research funding. That money comes from federal government agencies, the state of Georgia and more than 40 industry partners, making the center a leader in industry involvement at Georgia Tech.

GEDC’s research is varied, but much of its work focuses on analog and mixed-signal approaches aimed at improving wireless/RF and wired/fiber-optic performance.

The center’s principal research includes four main focus areas:

**Gigabit wireless** – Led by GEDC Director Laskar and head researcher Stephane Pinel, this effort utilizes analog-digital designs to propel vast amounts of data over short distances using extremely high frequencies in the unlicensed 60 Gigahertz (GHz) range. The record data-transfer rates achieved to date – 15 gigabits per second (Gbps) over a distance of 1 meter, 10 Gbps at 2 meters and 5 Gbps at 5 meters – could result in desktop computer setups that need no connecting wires, handheld devices able to download entire movies in a few seconds, and wireless in-room transmission from DVD players to screens. This technology represents the first all-digital-controlled analog CMOS radios operating at such frequencies. GEDC’s gigabit wireless work is expected to lay a foundation for future digital-controlled applications in the millimeter-wave spectrum – frequencies above 20 GHz – including digital radar. The work is supported by the Defense Advanced Research Projects Agency (DARPA), the Department of Defense, the National Science Foundation (NSF) and industry.

**Cognitive radio** – This research, developed in concert with Samsung Electro-Mechanics Co. and led by Laskar and researcher Kyutae Lim, is aimed at forging new international IEEE standards governing more efficient use of wireless frequencies. Cognitive radio (CR) technologies enable wireless transmissions to find low-traffic frequencies and thus bypass bottlenecks or avoid enemy jamming. GEDC recently fabricated a new chip design that could help demonstrate CR’s effectiveness.

**Agile Optical/Photonic** – In partnership with Italian telecommunications giant Pirelli, GEDC is using a testbed equipped

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**THE 20 WATT BRAIN**

Paul Hasler, an associate professor in the School of Electrical and Computer Engineering and a team leader in the Georgia Tech Analog Consortium, researches neuromorphic technology – the use of microelectronics to mimic the neurobiological functions of the human nervous system.

Commenting recently on issues facing neuromorphic engineers, Hasler noted that humans have at least 100 billion neurons in their brains, all powered by about 20 watts supplied by the nervous system.

A theoretical computer able to emulate the brain, he says, might use one Pentium chip – today’s digital-computing powerhouse – to emulate each neuron. That would translate into a power requirement of several trillion watts.

To succeed, he says, neuromorphic designs will likely require extensive use of low-power analog technology.
with 320 kilometers of special optical fiber to research wired high-speed telecommunications networks. The aim is to use nanotechnology and low-cost mixed-signal chips to design flexible fiber-optic networks with tunable components. The new design would replace outmoded fixed networks based on bulky optical components and help providers meet consumer demand for increased bandwidth. Research faculty working on this project include head researcher Chris Scholz, Stephane Pinel and Edward Gebara.

**RFID/Wireless Sensor** – Radio-frequency identification technology (RFID) holds great promise in numerous areas including shipping, industry and retail. By enabling inconspicuous circuits that can be placed in cargo containers, automobiles or elsewhere, RFID allows wireless tracking of myriad items. RFID research at GEDC is led by Manos Tentzeris, an associate professor in the School of Electrical and Computer Engineering (ECE). Tentzeris’ team focuses on using cutting-edge analog techniques to produce low-power devices with high-quality signal performance – including low-cost antennas and sensors that can be printed on paper.

**Teaching Analog New Tricks**

At the Georgia Tech Analog Consortium (GTAC), a long-established analog-design group that is now part of GEDC, Director John Papapolymerou oversees several groups that are pushing analog-technology boundaries. Papapolymerou, an associate professor in the School of Electrical and Computer Engineering, is himself involved in several analog-related projects, including research that is helping to develop CAD software for the design of micro-electromechanical systems (MEMS).

**CELL PHONES: ANALOG-DIGITAL COOPERATION**

“When a person speaks into a cell phone, a transducer or sensor turns the sound into electrical signals. Those signals are then processed in analog form, converted to digital format, encoded with analog information, transmitted through space, received by another phone, processed by analog means, decoded into digital format, converted back to analog form, conditioned, and finally driven into a speaker, the output of which is again a person’s voice.

“And that, of course, is a simplified version.”

– Gabriel Rincón-Mora, associate professor, Georgia Tech School of Electrical and Computer Engineering
Paul Hasler, an associate professor in ECE and a GTAC team leader, has discovered techniques to program analog circuits in ways reminiscent of digital processors. Traditionally, analog circuits have been fixed-function – hard-wired to perform a specific task. Working frequently with David Anderson, an ECE associate professor and GEDC researcher who focuses on mixed-signal design, Hasler has been researching core analog capabilities for many years.

“Just saying that the world ‘went digital’ doesn’t address the crucial point,” Hasler says. “What’s key is that a programmable technology overtook a fixed-function technology.”

In their research, Hasler and his team have developed programmable analog circuits made with conventional materials and techniques but capable of taking over many functions from digital integrated circuits.

“Digital may be a little better for communication, but in terms of computation that’s not necessarily the case at all,” Hasler says. “Programmable analog could be part of the entire-signal processing engine used by mobile devices.”

Analog is important, he explains, because analog chips use up to a thousand times less power than their digital counterparts. That makes them far better for mobile uses.

“When you’re looking at an hour versus a month in terms of your battery life, that’s pretty impressive,” Hasler says. “It just changes the entire game.”

Hasler’s research has led to GTronix, a startup company developing novel technology to extract real-world sensory information for portable consumer electronic products. The company, supported by Menlo Ventures, a major venture capital group, is poised to announce its first product soon.

Farrokh Ayazi, an ECE associate professor and GEDC team leader, is using microelectromechanical analog technology to develop a frequency-spectrum analyzer and processor on a chip that can offer both the performance and power efficiency needed for mobile use. This technology, known as analog spectral processing, guides an RF signal to lesser-used frequencies and has similarities to GEDC’s cognitive-radio work. The research is supported by DARPA.

Ayazi is also researching the integration of microscale MEMS devices with analog, RF and mixed-signal circuits. These micro-mechanical structures could have various applications including minute, highly sophisticated motion sensors.

By converting mechanical signals into electrical signals and processing them using low-power electronics, this motion-sensing technology holds promise in handheld wireless applications such as gaming equipment and for mobile devices that navigate without GPS signals.

Qualtré, a semiconductor-design company based on work at the Integrated MEMS Lab that Ayazi leads, offers six-degree-of-freedom motion sensing devices (three-axis gyroscopes and accelerometers) with low-power integrated read-out and control circuits for consumer products. Qualtré is a member of the Advanced Technology Development Center (ATDC), a startup-company incubator at Georgia Tech.

Ayazi and his team are also investigating silicon arrays of low-power gravimetric gas and bio sensors that are capable of detecting even a single molecule of a target substance. By coating a MEMS device with a molecular-recognition layer, the researchers are bringing the advantages of low-power analog technology to these tiny devices.

In work supported by the National Science Foundation and industry, Ayazi is also studying whether tiny MEMS-based...
“Throughout the 1980s and ’90s, analog design was considered an art form, and to a great extent it still is. And so people really don’t like to have systematic procedures that impact the way things are designed.

“My strategy is to make it less of an art form. There have been many attempts to try to come up with automatic synthesis of analog circuits, but they haven’t worked – yet.”

– Linda Milor, associate professor, School of Electrical and Computer Engineering; Georgia Tech Analog Consortium
resonators, micromachined into silicon, could replace frequency-producing quartz in mobile devices such as cell phones. The MEMS technology handles higher frequencies than quartz can, while maintaining high performance.

**The Silicon-Germanium Connection**

John Cressler, Ken Byers Professor in ECE and a GEDC team leader, develops analog, RF and mixed-signal circuits that exploit the special properties of silicon-germanium (SiGe) alloys. Combining silicon – a common microchip material – with germanium at nano-scale dimensions, Cressler is helping to develop next-generation microelectronic technologies that promise important gains in speed, flexibility and toughness.

Cressler recently made news when IBM and Georgia Tech research teams collaborated to produce a silicon-germanium transistor able to operate at frequencies above 500 GHz – far higher than plain silicon has ever reached. The record was attained at very cold temperatures, but the results suggested that SiGe chips could also attain record speeds at room temperature.

Cressler and his team are also leading a four-year, $14 million NASA program aimed at developing analog/mixed-signal systems for use in exploration of the moon. The work is challenging because of the lunar environment’s extremely wide, 300-degrees Celsius temperature swings and its exposure to space radiation.

The aim: to use silicon-germanium’s robust qualities to replace the bulky, power-hungry, shielded “warm boxes” currently used in space electronics.

**PROGRAMMABLE ANALOG**

Analog’s advantages include small size and low heat production, explains David V. Anderson, an associate professor who studies analog and mixed-signal technology in the School of Electrical and Computer Engineering.

That means analog circuits can be preferable for many tasks suited to future mobile devices, including speech recognition, audio processing, and image and video processing.

Working with ECE colleague Paul Hasler, Anderson has been researching reconfigurable analog and mixed-signal systems at GEDC. The traditional problem with analog systems, he says, is that users cannot simply change function by changing what’s in memory, as they can with a digital system. Instead, they have to go through a costly and time-consuming redesign process.

GEDC researchers, he says, have developed analog chips that can be reconfigured on the fly to perform a variety of tasks. Given what amounts to a software change, this type of analog chip can do a different type of processing.

Such reconfigurable analog chips are not as adaptable as digital chips, but are more adaptable than previous analog designs. In an audio analog chip, for example, one algorithm might clean up audio, then switch to modem processing with a simple software change.
The world, engineers often remark, is analog. Real-world phenomena – sound, images, motion, force, weight, temperature and even time itself – are captured by analog circuits, which often (but not always) hand them over to digital circuits for data manipulation and transmission.

“I’ll put it another way – what is not analog?” asks Gabriel Rincón-Mora, an associate professor in the Georgia Tech School of Electrical and Computer Engineering (ECE). “Everything in the universe is analog – continuous in time and space. It’s only natural then that all electronic systems encase their digital signal processing in an analog shell, to draw energy and to interface with the surrounding environment.”

Like the real world, analog techniques are continuous and linear. And what analog circuits mainly do is capture, condition, amplify, and/or drive real-life signals in one way or another.

Digital technology, on the other hand, processes data in discrete steps using the flexible codes we call software. Digital’s functionality is mostly limited by processing speed and by the effectiveness of the software algorithms being implemented.

A simple example of the analog concept can be found in an old-fashioned, fully mechanical watch. Like time itself, the watch’s hands move continuously around the face – unlike a digital watch, which has numbers that pop up at intervals or hands that move in steps.

A more complex example involves capturing and reproducing sound. The grooves of a vinyl record contain actual peaks and valleys that physically reproduce almost the entire spectrum of the sound recorded on them. By contrast, a digital recording selects parts of that spectrum – in a process called “sampling” – and stores them as digital code. Those pieces are then reassembled and reconstructed into an analog signal that, when driven into a speaker, resembles the original sound but doesn’t truly reproduce it.

Digital sound is very convenient. It’s easy to copy and manipulate on a computer and transmit over the Internet without losing much integrity. Today’s “digital” music players (which actually contain numerous analog elements) are small, handy and offer plenty of storage.

But digital’s piecemeal approach jettisons some of the original audio data, thereby losing content. Serious audiophiles insist on analog sound – complete with records, needles and old-fashioned tube electronics – because they believe that maintaining virtually the entire sound spectrum produces a better listening experience.

“In the digital world, you’re switching between on and off,” explains J. Alvin Connelly, professor emeritus in ECE. “The analog world is always operating in the state between on and off.”

J. Stevenson Kenney, an ECE associate professor who researches radio frequency electronics for wireless communications, explains that digital technology’s flexibility and accuracy can compensate for some of the limitations of analog circuits.

“The accuracy of analog signal processing is inherently limited by the physics of the devices,” says Kenney, who works extensively with Tech’s Microelectronics Research Center. “And that’s not true in digital – you can keep scaling and just have more and more accuracy.”

But, he adds, “I can’t put a Pentium processor in a cell phone and expect the battery to last for more than a few seconds. Analog can do high-bandwidth signal processing at much lower powers than digital.”

By Rick Robinson
“We’re taking legacy parts that are the size of a shoebox and putting a single piece of unprotected silicon-germanium in their place,” he says.

In the core analog realm, Cressler and his team are investigating the application of silicon-germanium to BiCMOS (SiGe transistors plus CMOS) technology used in very high-performance analog ICs. His team is helping industry researchers understand how to improve the design of these high-end analog circuits and find new applications areas for state-of-the-art analog technologies.

In addition, Cressler is studying the use of SiGe technology to improve data conversion in the very high-speed multi-gigabit range. For years, the problem of converting analog signals into digital code has created a bottleneck because analog-to-digital converters that are extremely fast yet affordable haven’t existed. Now, faster data converters using SiGe could help redefine communications and radar capabilities.

“In terms of complexity and challenge in the analog design world, very high-speed data converters are at the top,” Cressler says.

**Energy and Power – Better, Smaller**

Gabriel Rincón-Mora, an ECE associate professor, is focusing analog expertise on powering integrated circuits and other microscale devices, and on using energy and power management to maximize a device’s operational life.

Energy/power generation and management for mobile devices will become even more important in coming years, he says, as new, more capable chips nullify the gains made by advances in power conservation.

“We’re putting a lot more functionality into a single IC,” he says. “So we are ultimately increasing power density while maintaining similar power-source levels.”

Rincón-Mora is investigating how to provide power to chip-based mobile sensors using a system composed of a proton exchange-membrane fuel cell and a thin-film lithium ion battery. Working with Paul Kohl, a Regents’ professor in the School of Chemical and Biomolecular Engineering, Rincón-Mora and his team are studying how to manage power throughout the whole system – fuel cell, battery and chip – in ways that maximize lifetime and minimize footprint.

Rincón-Mora is also investigating microscale techniques to harvest energy from the surrounding environment. In one project, he is working with Texas Instruments to develop an electrostatic harvesting chip that draws power from the kinetic energy in vibrations. He is also working with Sakis Meliopoulos, another ECE professor, to power wireless microsensors in a power grid by using the field that surrounds an electric cable.

In another project, Rincón-Mora is studying how to scavenge energy from the human body. The aim is to power a biomedical implant called a vestibular prosthesis, a device being co-developed by ECE Assistant Professor Pamela Bhatti to help patients regain their sense of balance. Rincón-Mora plans to power the tiny device through piezoelectric harvesting – generating power from the motion of tiny materials that bend as bodily fluids in the inner ear flow around the implant.

Bhatti is also collaborating with Shreyes Melkote, a professor in the Woodruff School of Mechanical Engineering, to develop an electrode array that would provide better results to patients with a cochlear prosthesis, used to treat total deafness.

**Cutting Costs with Analog**

Analog expertise is an important asset at the Georgia Tech Research Institute (GTRI), Georgia Tech’s nonprofit applied-research arm. Several GTRI laboratories focus on the analog-heavy field of radar and RF technology for military and civilian applications. And GTRI researchers are often tasked with finding ways to replace older analog circuits, in aircraft and elsewhere, that are no longer manufactured.

“We’re developing applications as opposed to developing new technologies in analog,” says Richard Levin, a GTRI senior research engineer. “We find new ways to apply existing technology so that we can meet the customer’s needs.”

Levin has been performing analog design that’s helping to re-engineer an older circuit board in an Air Force radar-warning receiver. Key components in the all-analog board are no longer made, and obtaining custom replicas promised to be very expensive. Levin is part of a team that has crafted a plug-in replacement board, using mixed-signal technology that combines analog and digital functions.

“Basically, it’s a more modern, work-alike circuit made from available parts,” says Levin.

Mark Mitchell, a GTRI principal research engineer, reports that his group is working on numerous projects that employ analog-intensive technology to design and develop low-cost phased-array antennas.

“Phased-array antennas have historically been extremely expensive,” he says. “That’s limited the number of applications where they can be used.”

In one program, Mitchell and his colleagues are collaborating with ECE’s Cressler to create a single-chip, phased-array module using cutting-edge silicon-germanium technology.

Current phased-array antennas, which use many multi-chip modules, are bulky. Mitchell and Cressler want to pack that functionality into a single silicon-germanium chip.

“You can’t get the kind of high-frequency performance we want out of these analog circuits with conventional silicon,” Mitchell says. “Only silicon germanium can give us that performance and also cut the cost per element down by a couple of orders of magnitude.”

**Communicating with the Body**

At the Laboratory for Neuroengineering (NeuroLab), the team of Steve DeWeerth, a professor in the Coulter Department of Bio-
Pamela Bhatti, an assistant professor in the School of Electrical and Computer Engineering, is researching the use of analog microelectronics to help treat patients with total deafness.
ince it was chartered in 1885, Georgia Tech has stressed economic development and industry collaboration alongside technological education. Nowhere are industry ties stronger than in the field of analog electronics.

To promote closer contacts with the analog-chip industry, in 1989 three Georgia Tech faculty started the Georgia Tech Analog Consortium (GTAC). Today, GTAC is part of the Georgia Electronic Design Center (GEDC), a 250-person center at Georgia Tech that works with nearly 50 industry and government members on analog and mixed-signal technologies for both wireless and wired applications.

“We have very tight synergies with the major players in the field such as Texas Instruments, National Semiconductor, IBM, BAE Systems, Lockheed Martin and others,” says John Cressler, Ken Byers Professor in the School of Electrical and Computer Engineering (ECE) and a GEDC faculty researcher. “That gives us not only access to state-of-the-art technology, but we’re also able to interface with industry very directly.”

And it’s a two-way street, with both industry and Tech deriving important benefits.

“Industry has an obviously high opinion of the analog engineers coming out of Georgia Tech,” says Hal Calhoun, managing director with Menlo Ventures, a large venture-capital firm in California’s Silicon Valley. “You don’t have to travel far to learn that industry is filled with Tech analog engineers, many in important management positions.”

Dennis Monticelli, chief technologist at analog-industry giant National Semiconductor Corp., reflects that industry interest. “Georgia Tech is a school that’s maintained its excellence in analog education,” he says. Working with GEDC and Tech’s ECE school, National is “able to choose the professors we would like to work with, and we get to work with some top students, both graduates and undergraduates.”

How to Succeed in Business

Besides collaboration with established companies, Georgia Tech’s applications-oriented viewpoint has led to numerous startup companies based on the analog/mixed-signal research of GEDC/GTAC, the School of Electrical and Computer Engineering and other Georgia Tech groups.

GEDC identifies 11 companies, in varying stages of development, as having emerged from its research. All told, they have raised some $100 million in venture-capital funding.

The list includes two established companies with roots in the work of GEDC Director Joy Laskar – RF Solutions, a wireless-LAN company now part of Anadigics, Inc., and Quellan, a collaborative signal-processing company.

Several other analog-heavy companies are now members of the Advanced Technology Development Center (ATDC) or VentureLab – Georgia Tech units that help fledgling companies get going by locating startup money, offering business guidance and leasing office space.

These companies include:

- GTronix, an ATDC member that develops analog-integrated circuits (ICs) for ultra-low power portable consumer electronics, is based on the research of Paul Hasler, an ECE associate professor and GTAC team leader.
- Qualtré, an ATDC company that is developing low-cost, all-axis motion sensors for consumer electronics, is based on the work of Farrokh Ayazi, an ECE associate professor and GEDC team leader.
- Axion Biosystems, a VentureLab company developing products that involve analog neural-interfacing technology, is based on the work of the labs of Steve DeWeerth, a professor in the Coulter Department of Biomedical Engineering at Georgia Tech and Emory University, and Mark Allen, senior vice provost for research and innovation at Georgia Tech and Joseph M. Pettit Professor in ECE.

The world analog market, now topping $32 billion a year and growing, can open corporate doors for young engineers, asserts Laskar, who holds the Schlumberger Chair in Microelectronics in ECE.

He points to an industry publication listing a number of young analog engineers – including several recent Georgia Tech Ph.D.s – who are now working for top technology corporations. All of them are being sent by their employers to study in top M.B.A. programs.

“These are people who are being groomed to play important management roles in their companies,” Laskar says. “As analog engineers, they’re so valuable that they’re worth the extra training.”

Moreover, Laskar says, young analog graduates frequently do well in startup companies as well. He cites the Korean company Future Communications IC, Inc., a designer of chips for mobile television and wireless communications that was acquired recently by Silicon Motion Technology Corp. for $90 million. Two Georgia Tech analog Ph.D.s, Sangwoo Han and Seungyup Yoo, played major roles in Future Communications’ success.

“Analog training can provide a valuable entrée into industry, business and academia,” Laskar says.
Better Testing, Better Chips

Georgia Tech researchers frequently work on problems that affect how industry produces its microelectronic products – issues with direct consequences for the corporate bottom line.

Analog circuits, especially very-high-frequency, small-scale designs, are susceptible to manufacturing flaws. ECE professors Linda Milor and Abhijit Chatterjee work closely with analog chip makers such as National Semiconductor and Texas Instruments to improve circuit testing during manufacture.

"Manufacturing yields of useable chips is very important," Chatterjee says. "A small percentage of change in yield – even 1 percent is a big number – can mean the loss of millions of dollars."

Examining freshly minted circuits can be very expensive, and most analog circuits receive only a cursory automated test during manufacture, says Milor. To enhance robustness and yield, new design approaches with added circuitry could allow chips to examine themselves.

Among other things, Milor has been working on testing of chips’ input and output signals.

"That’s become a problem because of today’s high-speed interfaces between chips," she explains. "Once the delays have gotten down to tens of picoseconds … generating these very precise timing intervals is hard to do off-chip with external testing equipment."

One approach to more reliable and capable chips, Chatterjee explains, involves “adaptive electronics” – circuits that not only test themselves but can also self-recalibrate. Chatterjee and his team are currently researching adaptive electronics technology with support from the Gigascale Systems Research Center (GSRC), a multi-university collaboration sponsored by MARCO, a unit of the Semiconductor Research Corp., and by the Defense Advanced Research Projects Agency (DARPA).

“If there’s a problem in the manufacturing, the circuit can reconfigure itself to compensate for these variations,” he says. “In a sense, the chip becomes self-healing.”

Adaptive electronics could also allow a circuit to adjust to changes in its surroundings, Chatterjee says. For example, cell phones could cut back on circuit performance in a strong signal environment more efficiently than they do now, thereby conserving power.

“Current RF front-end design is relatively static, and most components consume about the same power irrespective of the quality of the signal,” Chatterjee says. “Our design dynamically adapts supply voltages and circuits performance to channel conditions, so that the system consumes less power when signal strength is good and then can increase power for a weak signal.”

By Rick Robinson

Photo: Gary Meek

Professor Abhijit Chatterjee, left, and graduate student Rajarajan Senguttuvan review images showing receiver adaptation to changing wireless channel conditions, as part of research aimed at minimizing power consumption.
Analog expertise is in strong demand just about everywhere. And that’s probably an understatement.

“There’s a huge worldwide shortage of analog engineers,” says Paul Hasler, an associate professor in Georgia Tech’s School of Electrical and Computer Engineering (ECE) and a researcher with the Georgia Tech Analog Consortium (GTAC). “It’s rather remarkable.”

Since the late 1960s, the Georgia Institute of Technology has been a major source of analog graduates. At the dawn of transistor technology and the subsequent integrated-circuit (IC) revolution, Tech emphasized analog electronics right alongside digital, says J. Alvin Connelly, professor emeritus in the School of Electrical and Computer Engineering.

Connelly recalls arriving at Tech in 1968 in time to take on the nascent analog program. He was soon spending his summers working in industry to glean new course material, and in 1974 he published an early analog integrated-circuit textbook. He went on to develop courses in analog bipolar and CMOS integrated-circuit design, operational amplifiers and low-noise circuit design, among other areas.

In coming to Tech, Connelly joined other electronics faculty such as John Peatman, who was becoming well-known in digital design.

“John covered the digital and I covered the analog, and that gave us kind of a one-two punch in the whole broad field of electronics,” Connelly recalls. Meanwhile, he says, numerous other faculty joined Georgia Tech during those years and added tremendously to the program, including Robert Feeney, Marshall Leach, William Sayle and David Hertling.

“From the beginning,” he says, “the analog electronics program became very popular.”

Staying the Course

In the 1980s, inexpensive digital microprocessors extended programmable computing to everyone, and many predicted the end of fixed-function analog approaches.

Georgia Tech was among a handful of universities that continued to emphasize analog research and education – even when many downgraded their analog programs and stopped hiring analog faculty, says Linda Milor, an associate professor in ECE and a GTAC researcher.

“When I was in school in the 1980s, the thinking was that the analog piece would go away,” she says. “Georgia Tech was different, but very few universities were hiring anyone in circuit design. There was an interesting situation where schools had lots of analog courses on their curriculums and nobody to teach them.”

Then the 1990s mobile revolution began, and industry demand soared for communication ICs and other analog chip designs. Analog chips – whose virtues include low power consumption that extends battery life – became once again a hot area as consumers increasingly snapped up cell phones, PDAs, digital cameras, voice
the cellular level for brain-computer interfacing.

At GEDC, Ghovanloo is initiating collaborations on wireless/RF and MEMS technologies to develop electrodes, antennas and packaging needed for implantable microelectronic devices.

Clearly, analog technology is here to stay. Analog engineers are likely to remain in short supply worldwide for years, says GEDC Director Laskar, as demand for both analog research and applications continues to grow.

“Analog and mixed-signal technologies are going to become more important, not less,” he says. “For the entire microelectronic revolution to proceed robustly, analog research has to keep pace – and here at Georgia Tech it’s an ongoing mission to supply the research and the people to help make that happen.”

recorders, portable video and many other handheld devices.

In 1989, three Georgia Tech professors – Connelly, Phillip Allen and Martin Brooke – founded GTAC as a way to forge closer ties with the analog electronics industry. In retrospect, Connelly says, that move was probably even smarter than it looked at the time. It allowed Georgia Tech to strengthen its analog commitment just in time for the analog resurgence.

Recent media coverage in Silicon Valley and elsewhere places Georgia Tech among the elite analog education programs, in such company as the Massachusetts Institute of Technology, Stanford University and the University of California-Berkeley. So does program size: by most counts, Georgia Tech has a larger analog faculty and graduates more analog engineers than any other U.S. institution.

The Well-Rounded Student

Today, demand for analog engineers is intense enough that big companies often keep close tabs on graduate programs and offer fellowships and internships to many students. Awaiting those students are very good jobs – the highest-paying in the electronics industry, many say.

Gregg Lowe, senior vice president for analog at Texas Instruments, Inc. (TI), recently commented on that analog-heavy corporation’s close relationship with Georgia Tech.

“TI’s contact with the faculty and students at the Georgia Electronic Design Center has given us access to highly trained talent … and serves TI customers well,” he said. “These students’ expertise has provided strong support for our research and development efforts …”

J. Stevenson Kenney, an ECE associate professor and a GTAC faculty member, stresses that analog and digital technology are interdependent. Overall systems design is the prime consideration, he says, with both technologies working together for best results.

“Many of these traditional compartments that we put things into are blurring together,” he says. “Where do digital circuits and algorithms stop and RF circuits begin? They overlap.”

As a result, Kenney says, electrical engineers graduating from Georgia Tech need to be knowledgeable about both analog and digital technology.

“If they’re not utilizing the best approaches to both,” he says, “It’s not going to be an optimum solution.”
A dime-sized tropical crab has invaded coastal waters of the Southeast United States. Multiplying rapidly, this green porcelain crab competes for food with native oysters and mussels. But the tiny crab has become the preferred prey for native predators, providing protection for baby oysters.

Tropical Crab Invades Georgia Oyster Reefs, but the Long-Term Impact Can't Be Predicted

By John Toon

A dime-sized tropical crab that has invaded coastal waters in the Southeast United States is having both positive and negative effects on oyster reefs, leaving researchers unable to predict what the creature’s long-term impact will be.

Unlike native crabs that eat baby oysters, mussels and fish, the green porcelain crab *Petrolisthes armatus* is a filter feeder, extracting its food from the water much as oysters do. The fast-reproducing invader therefore isn't directly attacking oyster populations, though it may be competing with them for food – and may impact the predators that normally attack the oysters.

Georgia Tech researchers have spent more than three years studying the effects of the crab, and recently reported their findings in the journal *Biological Invasions*. The research, believed to be the first to document effects of the crab on oyster and mussel populations off the Southeast coast, was supported by the U.S. Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the Harry and Linda Teasley Endowment to Georgia Tech.

“We’re seeing opposing effects from these crabs,” says Mark Hay, a professor in Georgia Tech’s School of Biology. “They are probably having more impact on the ecosystem by being prey than by being predators. Other members of the ecosystem are feeding on them, and that is changing the rate at which fish and other crabs are feeding on the native species.”

The impact of the new crabs is important because oysters are a “foundation species” essential to the health of coastal ecosystems because their reefs provide homes to dozens of other creatures.

“These non-native crabs slow the rate of growth for organisms like oysters that they compete with, but they enhance the ability of those same organisms to survive when young,” Hay says. “They are probably competing with the oysters for food, but the native crabs have switched to eating these green porcelain crabs rather than eating the baby oysters. Even though their growth is suppressed, the baby oysters are not being attacked as much now by the native consumers.”

Though the crabs aren’t killing existing populations of oysters, their long-term impact could still be significant. For instance, Hay notes, their availability as food could potentially increase the population of native crabs, disrupting the delicate balance between those predators and the oysters.

Assessing the long-term impact of the invading crabs has been difficult because the creatures reproduce and grow rapidly, flooding the shallow coastal waters with their young. In research conducted off Skidaway Island and Sapelo Island on the Georgia coast, the researchers found “extraordinarily high” populations of the crab – as many as 11,000 individuals per square meter.

To assess the impacts of the non-native crab population, graduate student Amanda Hollebone placed oysters and mussels into large baskets and located them on mud flats away from existing oyster reefs. Some of the baskets contained only oysters and mussels and were intended to serve as controls; some had a community...
of oysters, mussels, oyster drills and native mud crabs, while others had the same community spiked with non-native crabs. The distance from the existing oyster reefs was expected to prevent adult green porcelain crabs from reaching the baskets.

However, the researchers found that within a month, the control baskets also had large populations of the green porcelain crabs that had reached the containers as juveniles settling from the water column. Entry of the crabs to the control baskets interfered with the researchers’ ability to compare the traits of communities with and without the non-native crabs.

“You get a true understanding of the sheer densities of these crabs only when you actually pick up or dig through clumps of oysters and oyster shell hash,” says Hollebone, now a temporary assistant professor at Georgia Southern University. “Particularly in the summer months, I was never able to find a patch of oysters in the Savannah area that did not have the green porcelain crab.”

Because the crabs quickly took over the control baskets, the researchers only had valid comparison data for four to six weeks. However, information from their baskets supported the observations made under more controlled – but less natural – conditions at Georgia Tech’s laboratory at the Skidaway Institute of Oceanography near Savannah.

As in the lab experiments, the researchers found that the crabs slowed the growth of small oysters, but not small mussels.

The green porcelain crabs were observed in Florida during 1990s, but have since appeared in large numbers in coastal waters of Georgia and South Carolina. Researchers don’t know if they hitched a ride in the ballast of ships, whether warming water temperatures encouraged a northerly migration – or both.

““We’re seeing opposing effects from these crabs. [They] slow the rate of growth for organisms like oysters that they compete with, but they enhance the ability of those same organisms to survive when young.”

- Mark Hay, professor in the School of Biology
Tiny copper structures with pores at both the nanometer- and micron-size scales could play a key role in the next generation of detonators used to improve the reliability, reduce the size and lower the cost of certain military munitions.

Developed by a team of scientists from the Georgia Tech Research Institute (GTRI) and the Indian Head Division of the Naval Surface Warfare Center, the highly uniform copper structures will be incorporated into integrated circuits – then chemically converted to millimeter-diameter explosives. Because they can be integrated into standard microelectronics fabrication processes, the copper materials will enable micro-electromechanical (MEMS) fuzes for military munitions to be mass-produced like computer chips.

“An ability to tailor the porosity and structural integrity of the explosive precursor material is a combination we’ve never had before,” says Jason Nadler, a GTRI research engineer. “We can start with the Navy’s requirements for the material and design structures that are able to meet those requirements. We can have an integrated design tool able to develop a whole range of explosive precursors on different size scales.”

Nadler uses a variety of templates, including microspheres and woven fabrics, to create regular patterns in copper oxide paste whose viscosity is controlled by the addition of polymers. He then thermochemically removes the template and converts the resulting copper oxide structures to pure metal, retaining the patterns imparted by the template. The size of the pores can be controlled by using different templates and by varying the processing conditions. So far, he’s made copper structures with channel sizes as small as a few microns – with structural components that have nanoscale pores.

Based on feedback from the Navy scientists, Nadler can tweak the structures to help optimize the overall device – known as a fuze – which controls when and where a munition will explode.

“We are now able to link structural characteristics to performance,” Nadler notes. “We can produce a technically advanced material that can be tailored to the thermodynamics and kinetics that are needed using modeling techniques.”

Beyond the fabrication techniques, Nadler developed characterization and modeling techniques to help understand and control the fabrication process for the unique copper structures, which may also have commercial applications.

The copper precursor developed in GTRI is a significant improvement over the copper foam material that Indian Head had previously been evaluating. Produced with a sintered powder process, the foam was fragile and non-uniform, meaning Navy scientists couldn’t precisely predict reliability or how much explosive would be created in each micro-detonator.

“GTRI has been able to provide us with material that has well-controlled and well-known characteristics,” says Michael Beggans, a scientist in the Energetics Technology Department of the Indian Head Division of the Naval Surface Warfare Center. “Having this mate-
rial allows us to determine the amount of explosive that can be formed in the MEMS Fuze. The size of that charge also determines the size and operation of the other components.

The research will lead to a detonator with enhanced capabilities. “The long-term goal of the MEMS Fuze program is to produce a low-cost, highly reliable detonator with built-in safe and arm capabilities in an extremely small package that would allow the smallest weapons in the Navy to be as safe and reliable as the largest,” Beggans explains.

Reducing the size of the fuze is part of a long-term strategy toward smarter weapons intended to reduce the risk of collateral damage. That will be possible, in part, because hundreds of fuzes, each about a centimeter square, can be fabricated simultaneously using techniques developed by the microelectronics industry.

“Today, everything is becoming smaller, consuming less power and offering more functionality,” Beggans adds. “When you hear that a weapon is ‘smart,’ it’s really all about the fuze. The fuze is ‘smart’ in that it knows the exact environment that the weapon needs to be in, and detonates it at the right time. The MEMS Fuze would provide ‘smart’ functionality in medium-caliber and sub-munitions, improving results and reducing collateral damage.”

Development and implementation of the new fuze will also have environmental and safety benefits.

“Practical implementation of this technology will enable the military to reduce the quantity of sensitive primary explosives in each weapon by at least two orders of magnitude,” says Gerald R. Laib, senior explosives applications scientist at Indian Head and inventor of the MEMS Fuze concept. “This development will also vastly reduce the use of toxic heavy metals and waste products, and increase the safety of weapon production by removing the need for handling bulk quantities of sensitive primary explosives.”

A section of porous copper precursor material is examined under magnification. The copper is converted into an energetic material for use as a micro-detonator in the MEMS Fuze.

“Today, everything is becoming smaller, consuming less power and offering more functionality. When you hear that a weapon is ‘smart,’ it’s really all about the fuze.”

- Michael Beggans, Indian Head Division of the Naval Surface Warfare Center

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Using room-temperature processing, Georgia Tech researchers have fabricated high-performance field-effect transistors with thin films of carbon 60 (C_{60}), also known as fullerene. The ability to produce devices with such performance with an organic semiconductor represents another step toward practical applications for large-area, low-cost electronic circuits on flexible organic substrates.

The new devices – which have electron-mobility values higher than amorphous silicon, low threshold voltages, large on-off ratios and high operational stability – could encourage more designers to begin working on such circuitry for displays, active electronic billboards, RFID tags and other applications that use flexible substrates.

“If you open a textbook and look at what a thin-film transistor should do, we are pretty close now,” says Bernard Kippelen, a professor in Georgia Tech’s School of Electrical and Computer Engineering and the Center for Organic Photonics and Electronics. “Now that we have shown very nice single transistors, we want to demonstrate functional devices that are combinations of multiple components. We have everything ready to do that.”

Fabrication of the C_{60} transistors was reported in the journal *Applied Physics Letters* [Vol. 91, 092114 (2007)]. The research was supported by the U.S. National Science Foundation through the STC program MDITR, and the U.S. Office of Naval Research.

Researchers have been interested in making field-effect transistors and other devices from organic semiconductors that can be processed onto various substrates, including flexible plastic materials. As an organic semiconductor material, C_{60} is attractive because it can provide high electron mobility – a measure of how fast current can flow. Previous reports have shown that C_{60} can yield mobility values as high as six square centimeters per volt-second (6 cm^2/V/s). However, that record was achieved using a hot-wall epitaxy process requiring processing temperatures of 250 degrees Celsius – too hot for most flexible plastic substrates.

Though the transistors produced by Kippelen’s research team display slightly lower electron mobility – 2.7 to 5 cm^2/V/s – they can be produced at room temperature.

“If you want to deposit transistors on a plastic substrate, you really can’t have any process at a temperature of more than 150 degrees Celsius,” Kippelen adds. “With room temperature deposition, you can be compatible with many different substrates. For low-cost, large area electronics, that is an essential component.”

Because they are sensitive to contact with oxygen, the C_{60} transistors must operate under a nitrogen atmosphere. Kippelen expects to address that limitation by using other fullerene molecules – and properly packaging the devices.

The new transistors were fabricated on silicon for convenience. While Kippelen isn’t underestimating the potential difficulty of moving to an organic substrate, he says that challenge can be overcome.

Though their performance is impressive, the C_{60} transistors won’t threaten conventional CMOS chips based on silicon. That’s because the applications Kippelen has in mind don’t require high performance.

“There are a lot of applications where you don’t necessarily need millions of fast transistors,” he says. “The performance we need is by far much lower than what you can get in a CMOS chip. But whereas CMOS..."
is extremely powerful and can be relatively low in cost because you can make a lot of circuits on a wafer, for large-area applications CMOS is not economical."

A different set of goals drives electronic components for use with low-cost organic displays, active billboards and similar applications.

"If you look at a video display, which has a refresh rate of 60 Hz, that means you have to refresh the screen every 16 milliseconds," he notes. "That is a fairly low speed compared to a Pentium processor in your computer. There is no point in trying to use organic materials for high-speed processing because silicon is already very advanced and has much higher carrier mobility."

Now that they have demonstrated attractive field-effect C$_{60}$ transistors, Kippelen and collaborators Xiao-Hong Zhang and Benoit Domercq plan to produce other electronic components such as inverters, ring oscillators, logic gates, and drivers for active matrix displays and imaging devices. Assembling these more complex systems will showcase the advantages of the C$_{60}$ devices.

The researchers fabricated the transistors by depositing C$_{60}$ molecules from the vapor phase into a thin film atop a silicon substrate onto which a gate electrode and gate dielectric had already been fabricated. The source and drain electrodes were then deposited on top of the C$_{60}$ films through a shadow mask.

Kippelen's team has been working with C$_{60}$ for nearly 10 years, and is also using the material in photovoltaic cells. Beyond the technical advance, Kippelen believes this new work demonstrates the growing maturity of organic electronics.
Georgia Tech was one of three universities contributing to a report published in the journal *Proceedings of the National Academy of Sciences* on the connection between climate change and social impacts such as warfare, population decline and famine. Co-authored by Peter Brecke in the Sam Nunn School of International Affairs, the study used a database of 4,500 wars to study the effects of temperature fluctuations during a 500-year period from 1400 to 1900. More than 80 news outlets worldwide published accounts of the report, including ABC News, the *Christian Science Monitor*, LiveScience.com, MSNBC, *New Scientist*, *The New York Times*, USA Today and *The Washington Post*. A Reuters news agency report on the study appeared in numerous publications throughout Asia and Australia. (See the article on page 36 of this issue of *Research Horizons*).

Research that could allow very high speed wireless downloads over short distances generated media coverage in more than 60 news outlets around the world. This “multi-gigabit wireless” approach could eliminate the tangle of wires running between computers and such peripherals as external drives, and could facilitate quick downloads of movies from commercial kiosks. An Associated Press article on the work was published by a number of major U.S. newspapers. Reporting on the research were the *Boston Herald*, *BusinessWeek*, *The Chicago Tribune*, CNN, Forbes, *Fox News*, *The Los Angeles Times*, *Network World*, *Newsday*, the *San Francisco Chronicle*, *Technology Review*, USA Today and *The Washington Post*. Joy Laskar and Stephane Pinel from the Georgia Electronic Design Center were quoted and pictured in the articles. (See the article on page 46 of this issue of *Research Horizons*).

An improved technique for creating films of barium titanate nanoparticles in a polymer matrix generated considerable attention for researcher Joseph Perry in the School of Chemistry and Biochemistry and the Center for Organic Photonics and Electronics. The material has been of interest for use in capacitors, but creating uniform films has been a major stumbling block. Development of a technique that addresses that issue was reported in the journal *Advanced Materials*. Media outlets including *EDN*, *Electronic Engineering Times*, *Electronics Weekly*, *The Engineer*, *Science News* and *Power Design* reported on the new technique. The visibility led an Associated Press reporter to contact Perry about a Texas startup firm that plans to create a new generation of capacitors. Perry’s comments appeared in more than 50 major media outlets, including *BusinessWeek*, CNN, LiveScience.com, *IEEE Spectrum*, USA Today and Wired. (See the article on page 43 of this issue of *Research Horizons*).

Two National Institutes of Health grants totaling $11.5 million for research on delivering the flu vaccine with microneedles generated attention for Georgia Tech and Emory University, which are partnering on the research project. Use of microneedles could make administering the vaccine painless and more convenient. Reporting on the work were CNN, the *Atlanta Business Chronicle*, WMAZ-TV (Macon, Ga.) and several other news outlets. Mark Prausnitz, a professor in the School of Chemical and Biomolecular Engineering, was interviewed. (See the article on page 42 of this issue of *Research Horizons*).

High-performance field-effect transistors produced with thin films of Carbon 60 attracted attention in major media covering the electronics industry. The work, led by Bernard Kippelen in the School of Electrical and Computer Engineering, represents another step toward the practical application of large-area, low-cost electronic circuits on flexible organic substrates. Two dozen media outlets reported on the work, including *Defense News*, *Electronic Engineering Times*, *Electronics Weekly*, *Semiconductor International*, and *Solid State Technology*. (See the article on page 24 of this issue of *Research Horizons*).

*Industry Week* and *The Atlanta Business Chronicle* reported on a new DARPA-funded research center that will develop computer-aided design techniques for micro- electromechanical and nano-electromechanical systems. The center, which includes both universities and companies, will seek to develop CAD systems that are based on physical models able to predict the behavior of these tiny devices. (See the article on page 45 of this issue of *Research Horizons*).
Georgia Tech Faculty and Staff Receive Recognition

Four Georgia Tech faculty members were named Fellows in the American Association for the Advancement of Science (AAAS). They are Judith Curry, chair of the School of Earth and Atmospheric Sciences; Randall Engle, chair of the School of Psychology; Cheryl Leggon, associate professor in the School of Public Policy, and Rick Trebino, Georgia Research Alliance Eminent Scholar in the School of Physics.

- Curry was recognized for her work on understanding the relationships between global climate change and hurricane intensity, and for contributions that led to an understanding of feedbacks in the Arctic system;
- Engle received the honor for his work in understanding the nature of working memory and individual differences;
- Leggon was recognized for advancing understanding in under-representation and for showcasing academic career pathways;
- Trebino received the honor for developing techniques and devices for measuring ultra-fast laser pulses.

Andres Garcia and Robert Gouldberg, both associate professors in the Woodruff School of Mechanical Engineering, and Rob Butera, an associate professor in the School of Electrical and Computer Engineering, have been named Fellows by the American Institute for Medical and Biological Engineering. The organization is an umbrella group of 14 bio/biomedical engineering societies.

For his sustained contributions to heat mass and radiation transfer, Andrei Fedorov, associate professor in the Woodruff School of Mechanical Engineering, received an American Society of Mechanical Engineers (heat transfer division) Bergles-Rohsenow Young Investigator Award.

Five Georgia Tech faculty members were elected IEEE Fellows:

- Associate professor Steve Kenney was honored for his contributions to microwave power amplifier design, characterization and linearization;
- Professor Vijay Madisetti was chosen for the honor because of his contributions to embedded computing systems;
- Senior research scientist Bill Melvin was honored for contributions to adaptive signal processing methods in radar systems;
- Professor emeritus Teddy Püttgen was chosen for his contributions to international engineering education and electric power research and development;
- Professor Waymond Scott was recognized for contributions to the detection of buried objects using ground-penetrating radar.

Kenney, Madisetti, Püttgen and Scott are faculty members in the School of Electrical and Computer Engineering; Melvin is director of the Sensors and Electromagnetic Applications Laboratory in the Georgia Tech Research Institute.

Awards & Honors

Karim Sabra, assistant professor in the Woodruff School of Mechanical Engineering, was named an Acoustical Society of America Fellow in 2007.

Professor Cheol Eun and Assistant Professor Suzanne Lee, both from the College of Management, won an Outstanding Paper Award for “International Factor Linkages” (co-authored by doctoral student Hyung Suk Choi) at the second annual International Conference on Asian-Pacific Financial Markets, held in Seoul, Korea.

Nico Declercq, assistant professor in the Woodruff School of Mechanical Engineering, received a 2007 Commission on Acoustics Early Career Award.

In recognition of her significant contributions to electrical and computer engineering education, Bonnie Heck Ferri, associate chair of the School of Electrical and Computer Engineering, was named the recipient of the Institute of Electrical and Electronic Engineers (IEEE) Education Society’s 2007 Hewlett Packard/Harriet B. Rigas Award.

Seth Marder, professor in the School of Chemistry and Biochemistry, was elected a Fellow of the Society for Photo-Optical Instrumentation Engineers (SPIE).

Wayne Book, HUSCO/Ramirez Distinguished Chair in Fluid Power and Motion Control in the Woodruff School of Mechanical Engineering, was named a Society of Manufacturing Engineers Fellow in 2007.

David McDowell, Carter N. Paden Chair in Metals Processing, was named a Society of Engineering Science Fellow in 2007 and received a Khan International Medal for outstanding contributions to the field of plasticity.

Chris Paredis, assistant professor in the Woodruff School of Mechanical Engineering, received the 2007 Society of Automotive Engineers Ralph R. Teeter Education Award.

Christine K. Payne, assistant professor in the School of Chemistry and Biochemistry, received the NIH Research Scholar Development Award.

Compiled by Nancy Fullbright
From fuel-cell powered aircraft and multi-mission cruise missiles to supersonic business jets, engineers at Georgia Tech’s Aerospace Systems Design Lab (ASDL) are helping develop the next-generation of land, sea, air and space vehicles. These complex designs involve highly integrated, interoperable systems and enormous amounts of data – which can be cumbersome when presenting a solution to stakeholders.

“How do you visualize hundreds of design parameters, especially in a collaborative environment so decision-makers can discuss the data and come to some kind of consensus?” asks Neil Weston, a research engineer at ASDL.

Enter CoVE, formally known as the Collaborative Visualization Environment. Development of this unique facility was spearheaded by ASDL’s director Dimitri Mavris and funded by the U.S. Office of Naval Research. CoVE’s focal point is an 18- by 10-foot, high-resolution multimedia wall (about 9.4 megapixels) that can simultaneously display and manage more than 60 variables. A plug-and-play interface at 12 computer workstations allows outside visitors to display information on the wall without having to copy or share files, and IP-based video conferencing technology enables off-site participants to join sessions.

CoVE represents a dramatic change in design reviews. Previously, participants had to huddle around a single computer or use PowerPoint presentations. This meant only 15 percent of information associated with a design could be viewed at a time, requiring researchers to switch from screen to screen and constantly open and close programs. In contrast, CoVE enables decision-makers to see ASDL’s solutions in their entirety.

What’s more, CoVE manipulates data on the spot. Decision-makers can ask what-if questions and see – in real time – how altering parameters will affect various aspects of a design. “CoVE isn’t just a static environment where people go to view information,” Weston observes. “It’s a dynamic arena where the audience can interact with the data.”

Prior to CoVE, decision-makers attended design reviews to be informed rather than to participate, Mavris explains: “If someone asked a question, you would have to get back to them, which could take days or weeks. Even if you had an answer the next day, it was too late; decisions had already been made.”

Yet CoVE brings design analysis and decision-making together, says Mavris: “This is the beginning of a new era – the era of visual analytics.”

While analytics is about discovering and understanding patterns, visual analytics is “the science of analytical reasoning facilitated by interactive visual interfaces,” he explains. “This approach provides a mechanism for a user to see and understand large volumes of information at once. Based on the premise that the brain can best process information received through visual channels, this process facilitates the discovery of unexpected trends and highlights transparency of underlying physical phenomena.”

Mosaic of Information

During a design review, ASDL researchers divide CoVE’s multimedia wall into sections and allocate them to different disciplines. Suppose researchers are working on a new military jet design: One section of the wall might show a mission-planning tool, another would reflect engine-performance, with other
areas devoted to aerodynamics, economics and life-cycle management issues. Data is interconnected so various tradeoffs – such as safety, environmental impact or costs – can be assessed.

“If you change something in the left-hand corner, all the other charts update, which is very powerful to see,” explains Kristin Kelly, an ASDL research engineer. “Decision-makers may have been looking at a design simply from one or two perspectives at a time, such as an engine-performance perspective. Yet when they see the effect on a multitude of perspectives, such as environmental issues, they may have to reconsider to meet regulation constraints.”

Making what-if games possible is ASDL’s Collaborative Design Environment (CoDE). A sister facility to CoVE, CoDE simulates a war-room setting where ASDL researchers from different disciplines work as a team to introduce physics-based analyses, probabilistic methods, simulation and modeling into the design process at an early stage. Supplying the necessary computational muscle is a cluster with 256 processors, a 7-terabyte storage subsystem and an Infiniband (extremely high-speed) network.

One of the techniques ASDL uses to come up with real-time answers is surrogate modeling (also known as meta-modeling). “Rather than using actual codes, you can determine which variables are the most important ones and create a model to manipulate those codes,” explains Mavris. “Surrogate models have tremendous accuracy (95 to 99 percent) and also enable you to calculate things instantaneously.”

Another benefit: because surrogate models can’t be reverse-engineered, they provide a safe way to collaborate without participants having to share proprietary information, Mavris adds.

With CoVE, ASDL engineers have been able to develop new tools and techniques to increase the accuracy of systems design – and increase comprehension for decision-makers. For example:

- A dynamic house-of-quality tool translates customer requirements into engineering characteristics.
- A method for ranking multiple attributes that reveals the best design option based on customer-importance weightings.
- Slide bars on importance weightings so customers can change parameters and

The Collaborative Visualization Environment allows decision-makers to see solutions in their entirety and see the answers to “what-if” questions in real-time.
see what tradeoffs might occur.

- A man-in-the-loop genetic algorithm combines physics-based computing with an experienced engineer to eliminate options a computer might not reject, but which aren’t feasible in the real world.

Boon for Business

“CoVE has been a great showcase for ASDL,” says Mavris. “Prior to having this facility, it was difficult to communicate to sponsors what we were doing.”

Since the facility launched in January 2004, hundreds of engineers, technologists and decision-makers have conducted high-level projects at CoVE including Boeing, General Electric, Pratt & Whitney, Raytheon, Lockheed Martin, Rolls-Royce, the National Aeronautics and Space Administration and the Air Force Research Lab (AFRL).

The latter has used CoVE for technology assessments in three key areas: next-generation unmanned vehicles, long-range strike and directed energy applications.

“These assessments are done in a collaborative environment with industry, academia and other government agencies, so you end up with a very large trade space of ideas,” says David Brown, Technology Assessment Office lead at the AFRL’s Air Vehicles Directorate. “CoVE provides an environment to break down those complicated problems so we can make smarter investments in allocating resources.”

Besides benefiting Georgia Tech’s government and industry partners, CoVE plays a vital educational role. Students have full access to CoVE and can use the facility to participate in design competitions and gain experience in design reviews.

“Design is a multidisciplinary activity, so it’s important for students to work closely in teams,” says Mavris. “At ASDL, students come in as fluids or propulsion specialists, but they leave as more valuable systems integrators.”

Benjamin Poole, a graduate student at Georgia Tech’s School of Aerospace Engineering and ASDL research assistant, agrees that CoVE has made a big difference in his education. “As an undergraduate, everything is compartmentalized and discipline-specific, so it was initially difficult to get sense of how a complete design came together,” he explains. “In CoVE, you can see how data is integrated and make educated decisions based on the manipulations of that data in real time.”

ASDL researchers continue to upgrade CoVE’s capabilities and explore new visualization tools and processes.

“CoVE has given us a real edge on the competition,” says Mavris. “Granted, there are other big walls where people are working on visualization, but this is a blend of modeling, simulation, parametrics and decision-making. CoVE isn’t just a place, it’s a process where engineers can work together to fuse their data and eventually roll that data up to the appropriate level where risks can be assessed and a business case can close.”

An aircraft powered by fuel cells takes off on a test run. The aircraft was designed in a collaboration between the Georgia Tech Research Institute and the Aerospace Systems Design Lab using the CoVE.
To support the complex-systems work it conducts for the federal government and industry, the Georgia Tech Research Institute (GTRI) launched a secure version of ASDL’s CoVE in June 2007.

In the SCoVE, researchers can apply techniques developed by ASDL and other Georgia Tech departments along with GTRI’s extensive portfolio of network-centric and visualization solutions.

“The primary impetus for the Secure CoVE was to create an environment that enables GTRI to develop robust system solutions for government customers at an unprecedented rate,” says Allan Williams, associate director at GTRI’s Aerospace, Transportation and Advanced Systems Lab. “The SCoVE allows us to integrate the expertise of the academic departments of Georgia Tech with the decades of experience of GTRI’s systems engineers.”

The SCoVE features a 24- by 7-foot high-resolution display wall and seats up to 30 individuals. Its state-of-the-art computer network and audio-visual system supports:

- almost unlimited video feeds
- two-dimensional graphics
- remote video inputs and cameras
- DVD, VHS, satellite and CATV
- TCP/IP and UDP encoded video feeds.

The SCoVE has been designed from the ground up to link users at the Georgia Tech campus with GTRI field offices and government facilities across the country in real time. “Instead of going from lab to lab, customers and researchers now can assemble in one room and access all of GTRI’s tools,” says Williams.

In addition to providing collaborative visualization for systems design, modeling and optimization, SCoVE can also be configured to provide a command-and-control center environment. “This allows us to provide real-world testing of solutions before they’re delivered to customers,” explains Williams. For example, GTRI’s FalconView (a mapping system for flight-planning software) and GTVC (which allows law enforcement, emergency services and other agencies to collaborate online and respond to events) are available at the SCoVE.

“Many of organizations are building CoVE-like facilities, but few offer the visualization and computational capabilities of the SCoVE, and none offers the extensive system-optimization tools and techniques developed at Georgia Tech,” concludes Williams.
Quick Identification:

New Field-Deployable Biosensor Detects Avian Influenza Virus in Minutes Instead of Days

By Abby Vogel

Quick identification of avian influenza infection in poultry is critical to controlling outbreaks among poultry flocks, but current detection methods can require several days to produce results.

A new biosensor developed at the Georgia Tech Research Institute (GTRI) can detect avian influenza in just minutes. In addition to providing a rapid test, the biosensor is economical, field-deployable, sensitive to different viral strains and requires no labels or reagents.

“We can do real-time monitoring of avian influenza infections on the farm, in live-bird markets or in poultry processing facilities,” says Jie Xu, a GTRI research scientist.

Worldwide, there are many strains of avian influenza virus that cause varying degrees of clinical symptoms and illness. In the United States, outbreaks of the disease—primarily spread by migratory aquatic birds—have plagued the poultry industry for decades with millions of dollars in losses. The only way to stop the spread of the disease is to destroy all poultry that may have been exposed to the virus.

A virulent strain of avian influenza (H5N1) has begun to threaten not only birds but also humans, with more than 300 infections and 200 deaths reported to the World Health Organization since 2003. Of concern is the threat of a pandemic, such as the 1918 Spanish flu that killed about 40 million people, health officials say.

“With so many different virus subtypes, our biosensor’s ability to detect multiple strains of avian influenza at the same time is critical,” notes Xu.

To test the biosensor, the researchers assessed its ability to detect two avian influenza strains (H7N2 and H7N3) that have infected poultry. The results showed that a solution containing very few virus particles could be detected by the sensor. Xu tested a third strain of the virus as a control. When the sensor surface was modified to analyze only the other two strains, the control strain was not detected even at high concentrations.

Results of this study have been reported in the journal Analytical and Bioanalytical Chemistry. The work was funded by the U.S. Department of Agriculture’s (USDA) Agricultural Research Service (ARS), Georgia Research Alliance, and the USDA’s Cooperative State Research Education and Extension Service.

“The technology that Georgia Tech developed with our help has many advantages over commercially available tests—improved sensitivity, rapid testing and the ability to identify different strains of the influenza virus simultaneously,” says David Suarez, a project collaborator and research leader of exotic and emerging avian viral diseases in ARS’ Southeast Poultry Research Laboratory in Athens, Ga. Suarez is providing antibodies and test samples for GTRI’s research.

The biosensor is coated with antibodies specifically designed to capture a protein located on the surface of the viral particle. For this study, the researchers evaluated the sensitivity of three unique antibodies to detect avian influenza virus.

The sensor utilizes the interference of light waves, a concept called interferometry, to precisely determine how many virus particles attach to the sensor’s surface. More specifically, light from a laser diode is coupled into an optical waveguide.
through a grating and travels under one sensing channel and one reference channel.

Researchers coat the sensing channel with the specific antibodies and coat the reference channel with non-specific antibodies. Having the reference channel minimizes the impact of non-specific interactions, as well as changes in temperature, pH and mechanical motion. Non-specific binding should occur equally to both the test and reference channels and thus not affect the test results.

An electromagnetic field associated with the light beams extends above the waveguides and is very sensitive to the changes caused by antibody-antigen interactions on the waveguide surface. When a liquid sample passes over the waveguides, any binding that occurs on the top of a waveguide because of viral particle attachment causes water molecules to be displaced. This causes a change in the velocity of the light traveling through the waveguide.

At the end of the waveguide, the light beams from the sensing and reference channels are combined to create an interference pattern. The pattern of alternating dark and light vertical stripes, or fringes, is imaged on a simple CCD detector. By doing a mathematical Fourier transform, the researchers determine the degree to which the fringe patterns are in or out of step with each other, known as phase shift. This phase shift tells the amount of virus bound to the surface.

The waveguides can be cleaned and reused dozens of times, decreasing the per-test cost of the chip fabrication.

Xu and Suarez are currently working together to test new unique antibodies with the biosensor and to test different strains. In addition, Xu is reducing the size of the prototype device to be about the size of a lunch box and making the computer analysis software more user-friendly so that it can be field-tested.

“We are continuing our collaboration and have provided additional money to Georgia Tech to move the project along faster,” adds Suarez. “Since this technology is already set up so that you can use multiple antibodies to detect different influenza subtypes, we are going to extend the work to include the H5 subtype.”

The technology that Georgia Tech developed with our help has many advantages over commercially available tests – improved sensitivity, rapid testing and the ability to identify different strains of the influenza virus simultaneously.”

- David Suarez, USDA Agricultural Research Service

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GTRI Research Scientist
Jie Xu with a biosensor developed to detect avian influenza.
F
uel cells can be expensive, and they typically don’t last as long as their internal combustion counterparts.

Researchers in the Georgia Tech Research Institute’s (GTRI) Center for Innovative Fuel Cell and Battery Technologies believe that understanding how and why fuel cells fail is the key to both reducing cost and improving durability.

Center Director Tom Fuller has been trying to solve what he deems the top three durability problems since he joined GTRI from United Technologies three years ago.

“My philosophy is if we can really understand the fundamentals of these failure mechanisms, then we can use that information to guide the development of new materials or we can develop system approaches to mitigate these failures,” says Fuller, who is also a professor in Georgia Tech’s School of Chemical and Biomolecular Engineering (ChBE).

The problems Fuller is addressing include chemical attack of the membrane, carbon corrosion and platinum instability. Fuller described progress toward solving these problems at the 212th Electrochemical Society Meeting in October 2007.

In a typical fuel cell, hydrogen is delivered to the anode side of the cell that contains a catalyst, such as platinum. The platinum splits the hydrogen molecules (H₂) into hydrogen ions and electrons. On the cathode side of the fuel cell, an oxidant such as a stream of oxygen or air is delivered.

With a proton exchange membrane in the middle, only hydrogen ions can travel through the membrane to the cathode. Electrons travel on a different path through the electrical circuit to the cathode, creating an electrical current. At the cathode, the hydrogen ions combine with oxygen and the electrons that took the longer path to form water, which flows out of the cell.

Fuller’s research shows that the membrane, commonly made of a synthetic polymer, is prone to attack by free radicals that create holes in the barrier. The free radicals are formed by the decomposition of hydrogen peroxide (H₂O₂), a strong oxidizing chemical that can form near the membrane.

In a paper published in March 2007 in the Journal of Power Sources, Fuller and professor Dennis Hess, research scientist Galit Levi-tin and graduate student Cheng Chen, all from ChBE, used X-ray photoelectron spectroscopy (XPS) to study the membrane degradation. This work was funded by GTRI, ChBE and the Lawrence Berkeley National Laboratory.

The researchers chose XPS because it is a quantitative technique that uses X-rays to measure the presence and quantity of chemical elements and the formation and breakage of chemical bonds within a material.

“We were able to see chemical differences in the membrane with XPS when it went through the degradation process,” explains Fuller. “Now we’re trying to figure out what really limits or controls the rate of degradation.”

Another challenge with low-temperature fuel cells is that a blockage can occur on the anode side of the fuel cell, possibly from a water drop formed in the fuel channel. The blockage causes carbon (used to support the platinum) to corrode, turn into carbon
dioxide and leave the fuel cell as a gas. Frequently starting and stopping the fuel cell also causes this mode of failure.

This can be catastrophic for the fuel cell because without carbon, the platinum catalyst layer collapses and disappears.

"Researchers know this problem exists, but we’re trying to build physics-based detailed models to evaluate different fuel cell designs that will reduce the susceptibility to this type of corrosion," says Fuller, who’s working on this project with Norimitsu Takeuchi from Toyota’s material research department and students Kevin Gallagher and David Wong with funding from Toyota.

Another problem with fuel cells cycling on and off is that platinum has a small but finite solubility in the acidic membrane given the high electrical potential and oxidizing environment at the cathode.

“Platinum is one of the most expensive parts of the fuel cells, so researchers study how to decrease the amount necessary to run a fuel cell,” explains Fuller. “But if there is less platinum in the fuel cell to begin with, you can’t afford to lose any by it dissolving.”

When the platinum layer dissolves, a band of platinum typically forms inside the membrane. Fuller, GTRI senior research engineer Gary Gray and graduate student Wu Bi, developed a model to predict where the platinum band would form to help to understand why it was happening. This work was published in March 2007 in Electrochemical and Solid-State Letters.

“We found that the platinum can also be deposited throughout the membrane and it can move around to different places, but whenever it leaves where it’s supposed to be, it’s no longer effective,” says Fuller.

The Lawrence Berkeley National Laboratory funding came from the Assistant Secretary for Energy Efficiency and Renewable Energy in the Office of Hydrogen, Fuel Cell and Infrastructure Technologies of the U.S. Department of Energy under contract number DE-AC02-05CH11231 through subcontract 6804755.

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...If we can really understand the fundamentals of these failure mechanisms, then we can use that information to guide the development of new materials...

- Tom Fuller, director, Center for Innovative Fuel Cell and Battery Technologies

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Researcher Tom Fuller examines a fuel cell membrane. His research seeks to understand failure mechanisms in the devices.

Photo: Gary Meek
Climate change may be one of the most significant threats facing humankind, and a new study offers more reasons for concern: long-term climate change may ultimately lead to wars and population decline.

The study, published in the journal *Proceedings of the National Academy of Sciences*, reveals that as temperatures decreased centuries ago during a period called the Little Ice Age, the number of wars increased, famine occurred and the population declined.

Data on past climates may help accurately predict and design strategies for future large and persistent climate changes. Acknowledging the historic social impact of these severe events is an important step toward that goal, according to the study’s authors.

“Even though temperatures are increasing now, the same resulting conflicts may occur since we still greatly depend on the land as our food source,” says Peter Brecke, associate professor in Georgia Tech’s Sam Nunn School of International Affairs and co-author of the study.

This new study expands on previous work by Associate Professor David Zhang of the University of Hong Kong and lead author of the study.

“My previous research just focused on Eastern China. This current study covers a much larger spatial area and the conclusions from the current research could be considered general principles,” says Zhang.

Brecke, Zhang and colleagues in Hong Kong, China and the United Kingdom perceived a possible connection between temperature change and wars because changes in climate affect water supplies, growing seasons and land fertility, prompting food shortages. These shortages could lead to conflict – local uprisings, government destabilization and invasions from neighboring regions – and population decline due to bloodshed during the wars and to starvation.

To study whether changes in temperature affected the number of wars, the researchers examined the time period between 1400 and 1900. This period recorded the lowest average global temperatures around 1450, 1650 and 1820, each separated by slight warming intervals.

The researchers collected war data from multiple sources, including a database of 4,500 wars worldwide that Brecke began developing in 1995 with funding from the U.S. Institute of Peace. They also used climate change records that paleoclimatologists reconstructed by consulting historical documents and examining indicators of temperature change like tree rings, as well as oxygen isotopes in ice cores and coral skeletons.

Results showed a cyclic pattern of turbulent periods when temperatures were low followed by tranquil ones when temperatures were higher. The number of wars per year worldwide during cold centuries was almost twice that of the mild 18th century.

The study also showed population declines following each high war peak, according to population data Brecke assembled. The population growth rate of the Northern Hemisphere was elevated from 1400-1600, despite a short cooling period beginning in the middle of the 15th century.
However, during the colder 17th century, Europe and Asia experienced more population declines and wars of great magnitude.

In China, the population plummeted 43 percent between 1620 and 1650. Then, a dramatic increase in population occurred from 1650 until a cooling period beginning in 1800 caused a worldwide demographic shock.

The researchers examined whether these average temperature differences of less than one degree Celsius were enough to cause food shortages. By assuming that decreases in agricultural production triggered price increases, they showed that when grain prices reached a certain level, wars erupted. The ecological stress on agricultural production triggered by climate change did in fact induce population shrinkages, according to Brecke.

Global temperatures are expected to rise in the future, and the world’s growing population may be unable to adequately adapt to the ecological changes, according to Brecke.

“The warmer temperatures are probably good for a while, but beyond some level plants will be stressed,” Brecke explains. “With more droughts and a rapidly growing population, it is going to get harder and harder to provide food for everyone and thus we should not be surprised to see more instances of starvation and probably more cases of hungry people clashing over scarce food and water.”

A study of 4,500 wars over a 500-year period shows that by affecting agriculture and therefore food supplies, climate change can create pressures leading to warfare and population declines. Shown here is a wheat field.
Researchers Find “Memory” in Cells and Molecules

Research reported in the journal Proceedings of the National Academy of Sciences provides evidence that some molecular interactions on cell surfaces may have a “memory” that affects their future interactions.

Researchers who use sequentially repeated tests to obtain statistical samples of molecular properties usually assume that each test they conduct is identical to—and independent of—any other tests in the sequence. In their article, however, Georgia Tech researchers provide examples of test sequences that may not be composed of independent and identically distributed random variables.

“If you are probing a cell to get a bit of information, how do you know that the cell is not going to respond by changing the information it reveals the next time you probe it?” asks Cheng Zhu, a Regents’ Professor in the Wallace A. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University. “If you are probing a molecule, can you assume that the molecule will return to its original configuration before you test it the next time?”

The research was supported by the National Institutes of Health.

Using a micropipette adhesion frequency assay, Zhu’s research team studied a number of receptor-ligand interactions. A sequence data analysis conducted by Veronika Zarnitsyna, a research scientist in the Coulter Department, revealed examples in which an interaction observed in one test affected the outcome of a future test. Depending on the biological system, the effect could either increase or decrease the likelihood of a future interaction.

For instance, interaction between T cell receptors and an antigen bound to major histocompatibility molecules showed positive correlation, with one interaction increasing the likelihood of a future interaction. Interaction between C-adherins exhibited the opposite behavior, with one interaction reducing the likelihood of a future interaction. In a third system the researchers studied, the events appeared to be truly independent, with one interaction not affecting a future one.

The research stemmed from an observation by Jun Huang, a graduate student in the Zhu lab, who examined T cell test data and noted that interactions appeared consecutively in long strings and then disappeared for a long while. Huang asked Zhu about the pattern. Zhu then shared his concerns about the independence of the tests with Zarnitsyna, a biophysicist.

Zarnitsyna analyzed data generated by Huang and Fang Zhang—another graduate student in the Zhu lab—and additional data obtained by Yuan-Hung Chien, a student from the laboratory of Deborah Leckband at the University of Illinois at Urbana-Champaign.

“Positive memory increases the likelihood of having two interactions in a row, which generates long strings of interactions,” says Zarnitsyna. “The negative memory, however, decreases the likelihood of having consecutive interactions, which results in more solitary interactions in the sequence.”

Zhu compares the negative correlation to the effects of strong light on the eyes. “If you go from the dark to the bright, time is required before you can see well again,” he notes. “Exposure to strong light temporarily inhibits the eyes’ response to the next input.”

Zhu’s research team studies single-molecule mechanics using sensitive force techniques, such as atomic force microscopes and biomembrane force probes, to put cells and molecules together and then measure the forces or times required to pull them apart. Ideas developed for the adhesion frequency assay may also be applicable to this research.

As a next step, Zhu would like to further characterize the memory effect to determine how long it lasts. “It seems reasonable that if you prolong the cycle time—the period between trials—the cell or molecule would gradually forget,” he says.

He would also like to study the biological mechanisms of the memory effects.

“We believe this phenomenon may be biologically important, though we don’t yet know the implications for it,” Zhu adds. “This may represent a way for cells to regulate their adhesion and signaling. For T cells, the ability to ‘remember’ even a brief interaction with a pathogen may be related to their ability to tell an intruder from ‘self’ molecules, which is crucial to the body’s defense in the immune system.”

— John Toon

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How much is a kilogram?

It turns out that nobody can say for sure, at least not in a way that won’t change ever so slightly over time. The official kilogram — a cylinder cast 118 years ago from platinum and iridium and known as the International Prototype Kilogram — has been losing mass, about 50 micrograms at last check.

That’s not so good for a standard the world depends on to define mass.

Now, two U.S. professors say it’s time to define the kilogram in a new and more elegant way that will be the same today, tomorrow and 118 years from now. They proposed redefining the kilogram as the mass of a very large — but precisely-specified — number of carbon-12 atoms.

“Our standard would eliminate the need for a physical artifact to define what a kilogram is,” says Ronald F. Fox, a Regents’ Professor Emeritus in the Georgia Tech School of Physics. “We want something that is logically very simple to understand.”

Their proposal is that the gram — 1/1,000th of a kilogram — would henceforth be defined as the mass of exactly 18 x 14,074,481 carbon 12 atoms.

The proposal, made by Fox and Theodore P. Hill — a Professor Emeritus in the Georgia Tech School of Mathematics — first assigns a specific value to Avogadro’s constant. Proposed in the 1800s by Italian scientist Amedeo Avogadro, the constant represents the number of atoms or molecules in one mole of a pure material — for instance, the number of carbon 12 atoms in 12 grams of the element. However, Avogadro’s constant isn’t currently known exactly; it’s a range of values that can be determined experimentally, but not with enough precision to be a single number.

Spurred by Hill’s half-serious question about whether Avogadro’s constant was an even or odd number, in the fall of 2006 Fox and Hill submitted a paper to Physics Archives in which they proposed assigning a specific number to the constant. The authors pointed out that a precise Avogadro’s constant could also precisely redefine the measure of mass, the kilogram.

Their proposal drew attention from the editors of American Scientist, who asked for a longer article that was published in March 2007. The proposal drew five letters, including one from Paul J. Karol, chair of the Committee on Nomenclature, Terminology and Symbols of the American Chemical Society. Karol added his endorsement to the proposal and suggested making the number divisible by 12 — which Fox and Hill did in an addendum by changing their number’s final digit from 8 to 6. So the new proposal for Avogadro’s constant became 84,446,886, still consistent with the best mean value and estimated uncertainty determined by the U.S. National Institute of Standards and Technology (NIST).

Fast-forward to September 2007, when Fox read an Associated Press article about the mass disappearing from the International Prototype Kilogram. While the AP said the missing mass amounted to no more than “the weight of a fingerprint,” Fox argues that the amount could be significant in a world that is measuring time in ultra-sub-nanoseconds and length in ultra-sub-nanometers.

So Fox and Hill fired off another article, this one proposing to redefine the gram as 1/12th the mass of a mole of carbon 12 — a mole long being defined as Avogadro’s number of atoms. They now hope to generate more interest in their idea for what may turn out to be a competition of standards proposals leading up to a 2011 meeting of the International Committee for Weights and Measures.

At least two other proposals for redefining the kilogram are under discussion. They include replacing the platinum-iridium cylinder with measurements using spheres of pure silicon, and using a device known as the watt balance to define the kilogram using electromagnetic energy. Both would offer an improvement over the existing standard — but not be as simple as what Fox and Hill have proposed, nor be exact, they say.

“Using a perfect numerical cube to define these constants yields the same level of significance — eight or nine digits — as in those integers that define the second and the speed of light,” Hill says. “A purely mathematical definition of the kilogram is experimentally neutral — researchers may then use any laboratory method they want to approximate exact masses.”

The kilogram is the last major standard defined by a physical artifact rather than a fundamental physical property. In 1983, for instance, the distance represented by a meter was redefined by how far light travels in 1/299,792,458 of a second — replacing a metal stick with two marks on it.

— John Toon

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Georgia Tech Helps Agency Implement Lean Office Procedures

Mike Parks, Stone Mountain supervisor for Georgia’s Office of Child Support Services (OCSS), shares a letter written by a happy customer: "I would like to thank you for the service I received from you and your staff today. I didn’t have a long wait in the lobby. I came right back to your office and you put all the vital information in the computer about my case. I set up my direct deposit and now I look forward to receiving support for my children. All of my needs were met today and I can use my time working and taking care of my children."

This happy ending might not have been possible had OCSS not implemented rapid process improvement (RPI), also known as lean management, a set of tools that helps to identify and steadily eliminate waste from an organization’s operations. A 60-office state agency, OCSS is responsible for providing regular child support to families.

With support from the Governor’s Office of Customer Service and technical assistance from lean specialists at Georgia Tech’s Enterprise Innovation Institute, OCSS began to identify areas for improvement in August of 2006. The following November, the OCSS leadership team began meeting with Bill Ritsch and Jennifer Trapp-Lingenfelter of Georgia Tech to develop value stream maps — diagrams used to analyze the flow of materials and information required to bring a product or service to a consumer — in five areas of the child support process.

“We didn’t have a baseline on how long it took us to do each step in the area of establishing a court order, one of our core processes,” says Tanguler Gray, OCSS customer service program director. “It revealed a lot of duplicate work. We discovered that it took 71 days for our offices to take a request from intake to legal filing. Following the lean implementation, however, we were able to cut that to same-day service.”

The second RPI event was conducted in the area of enforcement. Typically, enforcement includes a number of administrative tools including the suspension of drivers’ licenses and professional licenses, property and bank account liens, tax refund offsets, garnishment of lottery winnings, and passport denial. The session resulted in what Gray describes as the “soft-glove early intervention approach,” an improved process.

“We had allowed our customers to set the expectation for us, and now we’re setting the expectation for them,” Gray adds. “By the time a case gets to court on our new early intervention process, the non-custodial parent will have been contacted a minimum of four times — two calls, one letter and then an additional letter if we have to move forward with sending the case to court for contempt. Before the RPI implementation and the soft-glove approach, there weren’t any early intervention calls or non-custodial parent education or expectation established at the first point of contact.”

Should a non-custodial parent fail to respond to the early intervention attempts, OCSS moves forward with aggressive enforcement actions once the non-custodial parent is 30 days out of compliance with the order, as opposed to the previous 60 or 90 days. Prior to the RPI implementation, it would take a minimum of 120 days to take “aggressive” enforcement action.

The lean implementation had a number of positive impacts in other areas. The pilot office for the “locate” (the process for locating non-custodial parents) RPI implementation decreased its caseload by 32 percent. Legal secretaries have saved an average of 10 hours a week by having extra documents printed up-front. And the Fatherhood Program, which provides under-employed non-custodial parents with job opportunities and training, cut the number of days for non-custodial parents to be notified about the program from 69 to 14.

The RPI events have proven to be so successful that five additional events have been approved in the areas of review and modification, interstate cases, accounting, enforcement and legal.

According to Ritsch, lean transformation is a journey that does not end. “It’s going to be a couple of years before OCSS really starts seeing impacts and establishing the lean culture,” he notes. “Our goal is to internally create the skill set to drive this forward. Georgia Tech will always be there to assist, but the agency now has the expertise to continue this path forward.”

— Nancy Fullbright

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Carpet Sustainability Standard Encourages Improved Processes

Don’t call it “green” carpet; call it sustainable carpet. A new standard for assessing the environmental-friendliness of carpet was announced at the 2007 Greenbuild International Conference in Chicago.

The new sustainability standard, approved by the American National Standards Institute (ANSI), addresses chemicals and materials used in manufacturing carpet, the energy used in production, the use of recycled or bio-based content, methods of disposal and/or reuse and the overall environmental performance of manufacturers.

“The LEED standards for buildings suggested that standards were an effective strategy for encouraging competition and providing an objective way of evaluating sustainability claims made in the marketplace,” says Matthew Reaiff, an associate professor in Georgia Tech’s School of Chemical and Biomolecular Engineering. Reaiff served as chair of the committee that developed the standard.

This new standard aims to help consumers sort out the complex sustainable attributes and encourage manufacturers and their suppliers to seek out or develop environmentally...
preferable processes, practices, power sources and materials.

NSF International, an ANSI-accredited standards development body, created the standard. A committee consisting of carpet and rug manufacturers, end users such as interior design professionals, state agencies responsible for environmentally preferable product procurement practices, academics and non-governmental organizations approved it. The effort was spearheaded by Robert Peoples, director for sustainability for the Carpet and Rug Institute (CRI), a nonprofit trade association based in Dalton, Georgia.

“This new standard provides tremendous benefit to those decision-makers who specify and purchase billions of yards of carpet annually in the United States. The new unified standard assures those purchasers that they are selecting environmentally preferable carpets,” says Werner Braun, president of CRI.

The sustainability standard builds on earlier efforts by the carpet industry to address environmental issues. The Green Label certification program developed by CRI, which created voluntary and widely adopted standards for carpets to meet emissions criteria for volatile organic compounds and other chemicals, is part of the new standard.

The standard aims to measure the environmental footprint of carpet products by looking at the whole supply chain and considering five major performance categories: public health and environment; energy; energy efficiency; bio-based or recycled materials; manufacturing; and reclaimation and end-of-life management.

The first carpet products certified to the new standard are expected to be available in the marketplace by April 2008, according to Realff.

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Simulation-based Training Helps Utility Industry

Who’ll keep the lights on?
As utility company executives make plans to meet the growing electricity needs of the Southeast, they’re also watching their most experienced personnel approach retirement age. Finding enough skilled personnel to operate complex power-generation facilities poses one of the critical challenges facing the industry today.

Collaboration between Baltimore-based GSE Systems and Georgia Tech offers one solution: a new way of learning that combines traditional classroom training with hands-on experience using advanced computer simulations of complex industrial facilities. Simulations have long been used to train pilots, but are relatively new to other types of industrial training.

This “learning by seeing and doing” offers utility companies a way to more rapidly meet their most critical human resources needs.

“People learn by seeing, experiencing and actually doing something,” explains Eric Johnson, senior operations training specialist for GSE Systems. “We can reinforce what students have learned in class by allowing them to interact with a simulation of a facility. The simulation allows them to gain experience without actually having to be in a real plant, and that helps new employees become productive faster.”

To provide that innovative learning environment, GSE has built a multi-million-dollar simulation and education center at Georgia Tech’s Global Learning Center. The facility is the first of its kind in the United States.

The center includes more than a dozen LCD panels driven by a powerful computer to simulate the many key systems operated from the control room of an electric generating plant. Student operators can adjust controls and immediately see the effects of their actions not only on the system they are controlling, but also on the rest of the plant. Realistic warnings indicate potentially dangerous conditions to which the students must respond. Three-dimensional models show the systems and exact components being controlled.

“The simulation allows plant systems to be integrated so the student operators really see the issue and understand the problems,” adds Johnson.

“W e can show them how to operate everything from the simplest system to the whole interrelationship of the systems.”

The new facility currently offers simulations for gas turbine and combined-cycle gas turbine generating plants. GSE sees a major market for its “education through simulation” training, and plans to add simulations for nuclear power.
Flu vaccine delivered using painless microneedles in patches applied to the skin could soon be an alternative to injections using hypodermic needles. Using new grants from the National Institutes of Health (NIH) totaling approximately $11.5 million over five years, researchers from Georgia Tech and Emory University plan to develop a new vaccine product using the microscopic needles.

"A vaccine administered through a skin patch would have a number of advantages, including less discomfort to the recipients, lower cost and reduced production time," says Richard Comps, professor of microbiology and immunology in the Emory School of Medicine. "Potentially, individuals could administer the vaccine to themselves, perhaps after receiving it in the mail."

The Georgia Tech and Emory team plans to develop and assess the effectiveness of transdermal patches that include arrays of microscopic needles containing or coated with vaccine. They hope to design patches that could be stored for long periods of time at room temperature and that will increase the breadth and duration of immunity to influenza — perhaps with smaller amounts of vaccine.

“We expect that this research will lead to a better way of delivering the flu vaccine, which will allow more people who need it to receive the immunization in a convenient and effective way,” says Mark Prausnitz, a professor in the Georgia Tech School of Chemical and Biomolecular Engineering. "Beyond that, the possibility of replacing a hypodermic needle with a microneedle patch should significantly impact the way that other vaccines are delivered."

The project team has extensive experience in microneedle development, influenza vaccines, vaccine delivery systems, product development and interdisciplinary collaboration. Beyond influenza, the research could have implications for immunization programs in developing countries, where eliminating the use of hypodermic needles could make vaccines more widely available and address the problem of disease transmission caused by the re-use of conventional hypodermic needles.

Prausnitz and his colleagues have been working since the mid-1990s to develop microneedle technology for painless drug and vaccine delivery through the skin. Much smaller than conventional hypodermic needles, the microneedles in the arrays are made of titanium, stainless steel or various polymers — including some that could dissolve into the skin, carrying vaccine with them. The Georgia Tech team has also developed manufacturing processes for microneedle patches and tested the ability of the needles to deliver proteins, vaccines, nanoparticles, and small and large molecules through the skin.

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NIH Grants $11.5 Million for Microneedle Flu Vaccine

Image: Harvinder Gill

Close-up image shows microneedles coated with a powder to simulate how flu vaccine could be administered.

— John Toon
A new technique for creating films of barium titanate (BaTiO₃) nanoparticles in a polymer matrix could allow fabrication of improved capacitors able to store twice as much energy as conventional devices. The improved capacitors could be used in consumer devices such as cellular telephones — and in defense applications requiring both high energy storage and rapid current discharge.

Because of its high dielectric properties, barium titanate has long been of interest for use in capacitors, but until recently materials scientists had been unable to produce good dispersion of the material within a polymer matrix. By using tailored organic phosphonic acids to encapsulate and modify the surface of the nanoparticles, researchers at Georgia Tech’s Center for Organic Photonics and Electronics were able to overcome the particle dispersion problem to create uniform nanocomposites.

“Our team has developed nanocomposites that have a remarkable combination of high dielectric constant and high dielectric breakdown strength,” says Joseph W. Perry, a professor in the Georgia Tech School of Chemistry and Biochemistry and the Center for Organic Photonics and Electronics. “For capacitors and related applications, the amount of energy you can store in a material is related to those two factors.”

The new nanocomposite materials have been tested at frequencies of up to one megahertz, and Perry says operation at even higher frequencies may be possible. Though the new materials could have commercial application without further improvement, their most important contribution may be in demonstrating the new encapsulation technique — which could have broad applications in other nanocomposite materials.

“This work opens a door to effectively exploit this type of particle in nanocomposites using the coating technology we have demonstrated,” explains Perry. “There are many ways we can envision making advances beyond what we’ve done already.”

Reported in the journal Advanced Materials, the research was supported by the Office of Naval Research and the National Science Foundation.

Because of their ability to store and rapidly discharge electrical energy, capacitors are used in a variety of consumer products such as computers and cellular telephones. And because of the increasing demands for electrical energy to power vehicles and new equipment, they also have important military applications.

Key to developing thin-film capacitor materials with higher energy storage capacity is the ability to uniformly disperse nanoparticles in as high a density as possible throughout the polymer matrix. However, nanoparticles such as barium titanate tend to form aggregates that reduce the ability of the nanocomposite to resist electrical breakdown. Other research groups have tried to address the dispersal issue with a variety of surface coatings, but those coatings tended to come off during processing — or to create materials compatibility issues.

The Georgia Tech research team decided to address the issue by using organic phosphonic acids to encapsulate the particles. The tailored organic phosphonic acid ligands, designed and synthesized by a research group headed by Seth Marder — a professor in the Georgia Tech School of Chemistry and Biochemistry — provide a robust coating for the particles, which range in size from 30 to 120 nanometers in diameter.

“Phosphonic acids bind very well to barium titanate and to other related metal oxides,” Perry says. “The use of tailored phosphonic acid ligands to modify the surface of the barium titanate nanoparticles enabled us, with the correct solutions processing, to incorporate them at a high density into polymer systems. This also allowed us to provide good compatibility with the polymer hosts — and thus very good dispersion as evidenced by a three- to four-fold decrease in the average aggregate size.”

Though large crystals of barium titanate could also provide a high dielectric constant, they generally do not provide adequate resistance to breakdown — and their formation and growth can be complex and require high temperatures. Composites provide the necessary electrical properties, along with the advantages of solution-based processing techniques.

“One of the big benefits of using a polymer nanocomposite approach is that you combine particles of a material that provide desired properties in a matrix that has the advantage of easy processing,” Perry adds.

In addition to those already mentioned, the research team included Philseok Kim, Simon Jones, Peter Hotchkiss and Joshua Haddock.

— John Toon

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Scanning electron micrographs of barium titanate (BaTiO₃) nanocomposites show the effect of the coating process on the uniformity of films produced.
Microsensor Measures Volatile Organic Compounds

Georgia Tech researchers have developed a miniature sensor that uses polymer membranes deposited on a tiny silicon disk to measure pollutants present in aqueous or gaseous environments. An array of these sensors with different surface coatings could be used during field-testing to rapidly detect many different chemicals.

Since this new sensor allows water and air samples to be analyzed in the field, it is an improvement over classical techniques that require samples be carried back to the laboratory for analysis. This research, funded by the U.S. National Science Foundation, was presented at the American Chemical Society’s 234th National Meeting.

The heart of the disk-shaped sensor is a microbalance that measures the mass of pollutant molecules.

“When pollutant chemicals get adsorbed to the surface of the sensor, a frequency change of the vibrating microbalance provides a measure of the associated mass change,” says Oliver Brand, associate professor in Georgia Tech’s School of Electrical and Computer Engineering.

Cantilever-type balances, which move up and down like a diving board, are commonly used for measuring the amount of a chemical in the gas phase. However, the mechanical vibrations of the balance used to detect the mass changes are damped in liquids, causing the sensitivity of the balance to decrease. So Brand and graduate students Jae Hyeong Seo, Stuart Truax and Kemal Safak Demirci searched for structures whose vibrations were less affected by the surrounding medium.

The researchers chose a silicon disk platform for the sensor. The disk shears back and forth around its center with a characteristic resonance frequency between 300 and 1,000 kHz, depending on its geometry. With proper actuation and sensing elements integrated onto the microstructures, Brand can electrically excite the resonator and sense these rotational oscillations.

Since each sensor has a diameter of approximately 200 to 300 microns, or the average diameter of a human hair, an array of a dozen sensors is only a few millimeters in size.

To determine how to selectively detect multiple pollutants in the same sample, Brand began collaborating with Boris Mizaikoff, formerly an associate professor in Georgia Tech’s School of Chemistry and Biochemistry.

Mizaikoff and graduate students Gary Dobbs and Yuliya Luzinova selected commercially available hydrophobic polymers and deposited them as thin film membranes on the sensor surface. They continue to investigate innovative ways to consistently deposit the polymers at the disk surface, while ensuring sufficient adhesion for long-term field applications.

“By modifying the silicon transducer surface with different polymer membranes, each sensor becomes selective for groups of chemicals,” explains Mizaikoff.

An array of these sensors – each sensor with a different chemically modified transducer surface – can sense different pollutants in environments ranging from industrial to biomedical.

Brand and Mizaikoff aim to detect volatile organic compounds (VOCs) in aqueous and gaseous environments. VOCs are pollutants of high prevalence in the air and in surface and ground waters. They are emitted from products such as paints, cleaning supplies, pesticides, building materials and furnishings, office equipment, and craft materials.

A common VOC is benzene, with a maximum contaminant level set by the Environmental Protection Agency at 5 micrograms per liter in drinking water. Many VOCs are present at similar very low concentrations, so effective sensors must accurately measure and discriminate very small mass changes.

“We’ve been able to measure concentrations among the lowest levels that have been achieved using this type of resonant microsensor,” notes Brand. “While we have not achieved the required sensitivity yet, we are constantly making improvements.”

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Researchers Boris Mizaikoff and Yuliya Luzinova use a microscope to inspect a microsensor chip coated with polymer layers.
Georgia Tech Edison Fund Supports Early-Stage Companies

Thomas Edison often receives credit for inventing the electric light bulb, though his real accomplishment was in making the device — as well as the phonograph and motion picture camera — commercially successful. That focus on commercializing innovation is now providing the foundation for a new venture bearing Edison’s name at Georgia Tech.

Launched by a multi-year grant from the Charles A. Edison Fund — which is named for the inventor’s son, a successful businessman and former governor of New Jersey — the Georgia Tech Edison Fund will provide seed funding for early-stage technology companies that have a close association with Georgia Tech.

“We will focus on startups at the very early stage, because that’s the hardest money for an entrepreneur to find,” explains Stephen Fleming, manager of the new fund. “Once companies have customers, a product and some traction in the marketplace, they can interest larger investors.”

In his role as Georgia Tech’s chief commercialization officer and director of Commercialization Services within the Enterprise Innovation Institute, Fleming helps faculty members, graduate students and others launch new companies through Georgia Tech’s VentureLab. He sees first-hand how difficult locating early funding can be.

“There is certainly a perception that there’s not enough early-stage capital in Atlanta,” he says. “The Georgia Tech Edison Fund will not by itself be a silver bullet that solves this problem, but I think it will help by putting new energy into and a new focus on early-stage financing.”

Fleming plans to make the requirement for a Georgia Tech connection as broad as possible. For example, the Fund will invest in companies that may be founded by Georgia Tech faculty, students and graduates; licensing technology from Georgia Tech; sponsoring research at Georgia Tech; or even hiring a large number of Georgia Tech alumni.

The Fund will be “evergreen,” meaning it will reinvest the proceeds from any liquidity events back into other opportunities. Fleming is establishing an investment committee to help guide decisions. The investments will generally be less than $250,000.

Donations to the Georgia Tech Edison Fund will be completely targeted to entrepreneurs. The Fund is not charging a management fee, nor is it paying carried interest to the managers, Fleming notes.

Fleming says the Charles Edison Fund and Georgia Tech are natural collaborators. “We are excited to be working with them because Edison is one of the instantly recognizable brand names around the world,” he explains. “Edison means innovation, invention and creativity — all of which are things we are trying to do. This helps us get our message across very quickly.”

For the Charles Edison Fund, the new Georgia Tech initiative represents an opportunity to continue the tradition of innovation and entrepreneurship established by the famed inventor. The collaboration with Georgia Tech is the first university partnership for the Edison organization, which supports a broad range of educational activities aimed at keeping the Edison tradition alive.

“This is a novel idea that I don’t think has been tried before,” says John Keegan, chairman and president of the Charles Edison Fund. “What makes it novel is that it provides support to faculty members whose ideas are literally in the pre-natal stage, before the concept is developed enough to take to a venture capitalist to seek funding.”

— John Toon

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Center Creates MEMS Computer-Aided Design Environment

Georgia Tech researchers have received a Defense Advanced Research Projects Agency (DARPA) award to participate in a multi-university research center that will develop a computer-aided design (CAD) environment for micro-electromechanical systems (MEMS) and nano-electromechanical systems (NEMS).

The new research center, to be called the Investigate Multi-physics Modeling and Performance Assessment-driven Characterization and Computation Technology (IMPACT) Center for Advancement of MEMS/NEMS VLSI, will be led by the University of Illinois at Urbana-Champaign and will include teams from Purdue University and Lehigh University as well as Georgia Tech. A consortium of companies — including BAE Systems, Inc., Innovative Design & Technology, MEMtronics Corp., Raytheon Co., Rockwell Collins, Inc. and the Rogers Corp. — will also participate financially with DARPA on the center.

The research will seek to develop CAD systems that are based on physical models and therefore can conclusively predict the behavior of MEMS devices. Eventually, engineers developing systems with MEMS devices could use a simple drag-and-drop interface to simulate not only the electrical effects of MEMS usage, but also thermal, mechanical and reliability aspects as well.

“This kind of predictive capability could greatly increase the speed
Wireless Research Could Untangle the Office

That tangle of wires under desks could soon be a thing of the past. Scientists at the Georgia Electronic Design Center (GEDC) at Georgia Tech are investigating the use of extremely high radio frequencies (RF) to achieve broad bandwidth and high data transmission rates over short distances.

Within three years, this “multi-gigabit wireless” approach could result in a bevy of personal area network applications, including next generation home multimedia and wireless data connections able to transfer an entire DVD in seconds.

The research focuses on RF frequencies around 60 Gigahertz (GHz), which are currently unlicensed — free for anyone to use — in the United States. GEDC researchers have already achieved wireless data-transfer rates of 15 gigabits per second (Gbps) at a distance of 1 meter, 10 Gbps at 2 meters and 5 Gbps at 5 meters.

“The goal here is to maximize data throughput to make possible a host of new wireless applications for home and office connectivity,” says Prof. Joy Laskar, GEDC director and lead researcher on the project along with GEDC research scientist Stephane Pinel.

GEDC’s multi-gigabit wireless research is expected to lend itself to two major types of applications: data and video, says Pinel. Very high speed, peer-to-peer data connections could be just around the corner, he believes — available potentially in less than two years.

Devices such as external hard drives, laptop computers, MP-3 players, cell phones, commercial kiosks and others could transfer huge amounts of data in seconds. And data centers could install racks of servers without the customary jumble of wires.

“Our work represents a huge leap in available throughput,” Pinel says. “At 10 Gbps, you could download a DVD from a kiosk to your cell phone in five seconds, or you could quickly synchronize two laptops or two iPods.”

The input-output (I/O) system of current devices cannot approach such speeds. Moreover, Pinel said, users of multi-gigabit technology could wirelessly connect to any device that currently uses Firewire or USB.

Wireless high-definition video could also be a major application of this technology. Users could keep a DVD player by their side while transmitting wirelessly to a screen 5 or 10 meters away.

Currently, Pinel said, the biggest challenge is to further increase data rates and decrease the already-low power consumption, with a goal to double current transmission rates by next year. The Georgia Tech team is seeking to preserve backward compatibility with the WiFi standard used in most wireless local area networks (LANs) today.

GEDC researchers are pursuing this goal by modifying the system architecture to increase intelligence and effectiveness in the integrated circuits that transmit the data. The researchers are using advanced computer-aided design tools and testbed equipment to recalibrate system models and achieve the desired improvements in speed and functionality.

Investigators are placing special emphasis on implementing an RF concept called single-input-single-output (SISO) / multiple-input-multiple-output (MIMO), which enables ultra-high data throughput. At the same time, they seek to preserve backward compatibility with WLAN 802.11, the WiFi standard used in most wireless LANs today.

“We are pursuing a combination of system design and circuit design, employing both analog and digital techniques,” Pinel adds. “It’s definitely a very exciting mixed-signal problem that you have to solve.”

— Rick Robinson

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with which MEMS-enabled microsystems can be developed,” says John Papapolymerou, an associate professor in the Georgia Tech School of Electrical and Computer Engineering.

In the first year, Georgia Tech’s efforts will focus on the fundamental physics of MEMS devices — particularly with respect to dielectric charging of MEMS switches, Papapolymerou says.

Although MEMS-enabled microsystems have the potential to revolutionize communications, sensors and signal-processing, he adds, their capabilities have been limited by a lack of understanding of how physical phenomena govern MEMS-device functionality. It’s particularly unclear how much performance is degraded when MEMS devices are exposed to the operating conditions of an integrated circuit.

“When we have a better understanding of the fundamental physics of MEMS devices, we can then proceed to the higher-order models and levels that are required to develop a CAD program,” Papapolymerou notes.

The ultimate goal of the IMPACT center, he said, will be to promote the availability of MEMS/ NEMS-based micro- and nanosystems in military and commercial applications.

This research is sponsored by the Defense Advanced Research Projects Agency (DARPA). The content of this article does not necessarily reflect the position or the policy of the U.S. Government, and no official endorsement should be inferred.

— Rick Robinson

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The blue Porsche Cayenne pulls up to a four-way intersection and stops. After it continues through the junction, it approaches a vehicle stopped in its lane. The Cayenne checks to make sure there are no cars approaching in the opposing lane, passes the stopped car and returns to its original lane.

This scene may not sound unusual, but this is no ordinary Porsche Cayenne—it thinks for itself and requires no driver. This autonomous vehicle was designed by Georgia Tech researchers in collaboration with Science Applications International Corporation (SAIC) for the Defense Advanced Research Projects Agency’s (DARPA) Urban Challenge.

Georgia Tech’s vehicle, named Sting 1, was among 35 vehicles that advanced to the National Qualifying Event held in October 2007 at the former George Air Force Base in Victorville, Calif. However, Sting 1 was not selected to compete in the final challenge.

“As a first-time entrant, the team has done an outstanding job making it to the semifinal round of the world’s most challenging robotics competition,” says Tucker Balch, team lead and associate professor in Georgia Tech’s School of Interactive Computing in the College of Computing.

With six cameras, eight computers, Doppler radar and infrared laser radar on board, Sting 1 was designed to operate without any human intervention and obey California traffic laws while performing maneuvers such as merging into moving traffic, navigating traffic circles and avoiding moving obstacles.

The road to California began in the summer of 2006, when Georgia Tech and 88 other teams signed up to participate in the Urban Challenge.

“Georgia Tech didn’t compete in the two previous Grand Challenges, but SAIC did,” adds Balch. “Their experience helped us develop software that could have enabled a robot to place well in the previous challenges, and then we took it further with additional capabilities necessary for the Urban Challenge.”

The Georgia Tech team, consisting of researchers in Georgia Tech’s College of Computing and College of Engineering and the Georgia Tech Research Institute (GTRI), chose the Porsche Cayenne as their vehicle and in August 2006 began to install computers that would drive the car automatically.

Eight computers networked together through two high-speed networks were programmed to know the rules of the road. This included knowing how to stay in a lane, how to overtake another car, how to make turns in city traffic, how to maneuver the waiting patterns at an intersection, how to merge into traffic and how to behave in a parking lot.

According to the racing team, the car really had to think for itself. “The car needed to detect obstacles in its path and then plan and execute a different route around the obstacles,” says Tom Collins, electronics lead and GTRI principal research engineer.

SAIC engineers developed methods for visual lane detection and tracking. On unpaved dirt roads, the colors of the road and non-road areas were modeled to identify a path, adapting over time as lighting or surface colors changed. On marked paved roads, a camera kept the car in its lane by detecting the typical white and yellow lines that mark a driving lane. If the vision system was unable to find a lane, the car used lasers to follow the curb. Ten laser range finders sent out infrared laser beams that constantly scanned to provide Sting 1 with an accurate measurement of the distance to any objects, such as curbs and other cars.

At intersections, the team used laser and radar sensors to see other waiting or approaching vehicles. Six off-the-shelf Doppler radar systems used to detect moving objects allowed the car to see as far as two football fields away in all directions. Cameras helped guide the car through the intersections and onto new roadways.

“We had to guarantee that there was at least a 10-second window that would allow us to pull out onto a road, accelerate and get up to a reasonable speed without cutting someone off,” notes Henrik Christensen, principal investigator for the team and director of Georgia Tech’s Robotics and Intelligent Machines Center.

The Urban Challenge is the third in a series of DARPA-sponsored competitions to foster the development of robotic ground vehicle technology without a human operator, designed for use on the battlefield.

Georgia Tech researchers are already thinking about life after the Urban Challenge.

“We’ve already talked about expanding this work to other areas,” says Vince Camp, hardware lead and GTRI senior research engineer. “We’re looking forward to using the technologies in applications such as autonomous lane striping for the Georgia Department of Transportation.”

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Explosives on a Chip

Tiny copper structures with pores at both the nanometer- and micron-size scales could play a key role in the next generation of detonators used to improve the reliability, reduce the size and lower the cost of certain military munitions.

Developed by a team of scientists from the Georgia Tech Research Institute (GTRI) and the Indian Head Division of the Naval Surface Warfare Center, the highly uniform copper structures will be incorporated into integrated circuits – then chemically converted to millimeter-diameter explosives. Because they can be integrated into standard microelectronics fabrication processes, the copper materials will enable micro-electromechanical (MEMS) fuzes for military munitions to be mass-produced like computer chips.

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