ISSUE 1 2017

GEORGIA TECH RESEARCH

HORIZONS

SMART CITIES

Bright Lights, Big Technology

An interdisciplinary approach to urban challenges is helping cities serve their residents better *Page 22*

NIGHTTIME Coda – a 750,000-square-foot mixed-use project – is located between Spring Street and West Peachtree Street in Georgia Tech's Technology Square. The project will enhance Tech's innovation ecosystem, which fosters collaboration among the Institute, start-ups, and industry. Georgia Tech will be the anchor tenant, occupying approximately half of the 620,000 square feet of office space. The project includes an 80,000-square-foot data center and incorporates the historic Crum & Forster Building owned by the Georgia Tech Foundation. *Image courtesy of John Portman & Associates.*

CONSTRUCTION Coda broke ground in December 2016. Construction will be an enormous undertaking. About 60 Olympic-size swimming pools full of dirt will need to be removed from the site – requiring more than 20,000 dump truck loads – and developers estimate it will be eight months before construction even moves above ground. Coda is scheduled for completion in 2019. Portman Holdings owns the facility. *Georgia Tech photo.*

INSIDE Coda will feature about 1,000 smart glass windows – able to adjust their tint intelligently to reduce glare. Floor-to-ceiling glass windows are expected to increase energy efficiency by about 25 percent while allowing for unobstructed views of Tech Square and Midtown. The design includes a "collaborative core" to foster innovation and creativity. Besides Georgia Tech, the property will house companies working on big data technologies and retailers occupying nearly 40,000 square feet of space. *Image courtesy of John Portman & Associates.*

GEORGIA TECH RESEARCH
HORIZONS

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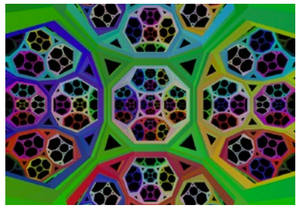
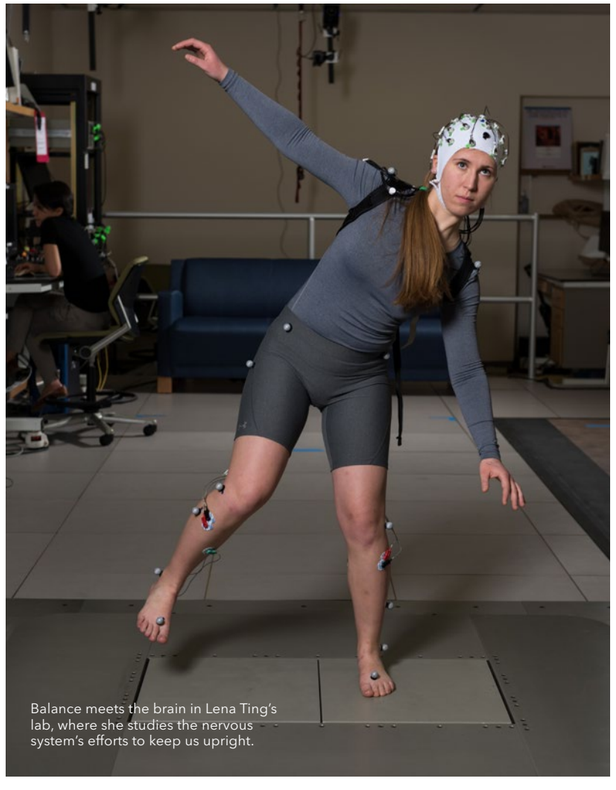
DEPARTMENTS

FRONT OFFICE





Balance meets the brain in Lena Ting's lab, where she studies the nervous system's efforts to keep us upright.

STAFF
Editor John Toon
Art Director Erica Endicott
Writers T.J. Becker, Josh Brown, Ben Brumfield, Laura Diamond, Jason Maderer, Péralte C. Paul, John Toon
Photographers Rob Felt, Christopher Moore
Copy Editor Margaret Tate

COVER
A majority of the world's people now live in cities like Atlanta, creating both challenges and opportunities. Back cover: *Cichlids swimming in nursery tanks. The fish provide researchers with insights on how genes underpin brain structures and behaviors.* Photos by Rob Felt.

ADDRESS CORRECTIONS
Please send address corrections to John Toon (jtoon@gatech.edu) or 404-894-6986.

POSTMASTER
Please send address changes to:
Research News & Publications
Georgia Institute of Technology
177 North Avenue NW
Atlanta, Georgia
30332-0181 USA

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Research Horizons magazine is published to communicate the results of research conducted at the Georgia Institute of Technology.

Research Horizons is a member of the University Research Magazine Association (URMA).

Web www.rh.gatech.edu

Twitter @gtresearchnews

 ISSN #1060-669

N17C10203

ROB FELT

THE FUTURE IN MIND

SMARTER CITIES, UNDERSTANDING THE BRAIN, CREATING JOBS FROM FEDERAL RESEARCH

***Steve Cross** is Georgia Tech's executive vice president for research.*

By 2030, more than 60 percent of the world's population will be living in cities, a projection that creates both dramatic challenges and significant opportunities. Georgia Tech is at the forefront of applying engineering, technology, and the social sciences to help cities become smarter and better able to serve their residents with less impact on the environment. The cover story of this *Research Horizons* describes a sampling of our efforts to boost the "urban IQ."

Speaking of IQ, this issue also takes a deep look at our research into the brain and what makes us uniquely human. Georgia Tech researchers, often working with Emory University and other collaborators, are seeking to understand how the brain's 160 billion cells work together. What they learn may provide clues to fighting diseases such as Alzheimer's, which is destroying lives and creating a worldwide public health crisis.

Also in this issue, you'll read about a company commercializing research originally supported by the U.S. Department of Energy. Quest Renewables builds solar canopies using technology developed at Georgia Tech to reduce costs through improved design and more efficient construction. This company shows how our innovation ecosystem converts research discoveries to jobs and new business.

Finally, I'd like to congratulate John Toon, editor of this magazine and Georgia Tech's director of research news, for an important honor received from IEEE-USA — a technical professional organization which counts many Georgia Tech researchers among its members. The award is for "sustained journalistic efforts to expand public understanding and the advancement of science and technology in the United States."

Georgia Tech powers an impressive innovation ecosystem that facilitates transformative opportunities, strengthens collaborative partnerships, and maximizes the economic and societal impact of the Institute's research. Our goal is to conduct leading-edge research and then transition the results of that research into use. Our strategic plan leads us to innovate not only in the results of research, but also in how we conduct research and transition it into use more rapidly and effectively.

As you read this issue of *Research Horizons*, you'll see how we're leveraging these collaborative partnerships to create game-changing solutions to society's most challenging problems. We truly are creating the next generation of advances in neuroscience, bioengineering, sensing, transportation, energy, and many other areas.

As always, I welcome your feedback. Enjoy the magazine!

STEVE CROSS
Executive Vice President for Research
June 2017

FRONTOFFICE

A research team led by Sonia Chernova, an assistant professor in the School of Interactive Computing, is making it easier for nonspecialists to control robots.

ROB FELT

USER FRIENDLIER

'Robot, hand me that coffee' is as easy as point and click

The traditional interface for remotely operating robots works just fine for roboticists, who use a computer screen and mouse to independently control six degrees of freedom, turning three virtual rings and adjusting arrows to get the robot into position to grab items or perform a specific task.

But for someone who isn't an expert, the ring-and-arrow system is cumbersome and error-prone. A new interface designed by Georgia Tech researchers is much simpler and more efficient, and doesn't require significant training time. The user simply points and clicks on an item, then chooses a grasp. The robot does the rest of the work.

"Instead of a series of rotations, lowering and raising arrows, adjusting the grip, and guessing the correct depth of field, we've shortened the process to just two clicks," said Sonia Chernova, the Catherine M. and James E. Allchin Early-Career Assistant Professor in Georgia Tech's School of Interactive Computing, who advised the research effort.

Her team tested college students on both systems and found that the point-and-click method resulted in significantly fewer errors, allowing participants to perform tasks more quickly and reliably than using the traditional method.

"Roboticists design machines for specific tasks, then often turn them over to people who know less about how to control them," said David Kent, the robotics Ph.D. student who led the project. "Most people would have a hard time turning virtual dials if they needed a robot to grab their medicine. But pointing and clicking on the bottle? That's much easier."

Presented at the 2017 Conference on Human-Robot Interaction, the research was supported by the National Science Foundation and Office of Naval Research.
— JASON MADERER

PROFILE

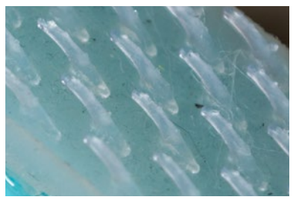
MECHANICAL MENAGERIE

Alexis Noel
Ph.D., Mechanical Engineering
Hu Laboratory for Biolocomotion

Alexis Noel is a Ph.D. student in Georgia Tech's Hu Laboratory for Biolocomotion, led by David Hu, an associate professor of mechanical engineering. Noel's research on adhesion and gripping with soft tissues is at the intersection of fluid mechanics, solid mechanics, and biology. She's also a leader in the Invention Studio, the Institute's student-run maker space.

YOU RECEIVED A BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING FROM GEORGIA TECH AND ARE CLOSE TO FINISHING YOUR PH.D. WHY DID YOU COME AND STAY AT GEORGIA TECH?

I'm a lifer. I started as an aerospace engineering major. I got my pilot's license in high school and was really into engines and designing cool planes and thought that would be my life. My first year in college I realized maybe aerospace wasn't the best fit because I'm more of a hands-on learner. I made a lot of friends in mechanical engineering and heard about their cool classes where they built robots. I did an internship in NASA after my freshman year and I did a lot of mechanical engineering there, so I switched my major and kept aerospace as a minor. I love mechanical engineering, both the hands-on building and the community.



Noel made this 3-D cat tongue (at four times the scale of the real thing) in the Invention Studio at Georgia Tech.

I met David Hu and heard about the work in his lab, and it blew my mind. I had no idea mechanical engineers could work with animals.

DESCRIBE YOUR CURRENT RESEARCH.

I'm really excited about my cat research. I watched my cat, Murphy, lick this soft, plush microfiber blanket and his tongue got stuck. After I laughed and helped detangle him, the scientist in me wondered why this happened.

We had a cat tongue in the freezer in the lab, and I did some tests and scans and found out cat tongues have these little micro hooks on the surface that look just like tiny claws. We found these little spikes are really good at detangling because the tip can actually pierce tangles, and as the tongue spine rotates, it can tease apart any tangles.

WHAT'S THE NEXT STEP WITH THE CAT RESEARCH?

We have a provisional patent, and we're hoping to develop some really cool technologies with it. The obvious use would be hairbrushes for humans or pets that are really good at detangling. But it could be anything from carpet cleaners to new, novel ways to grab rocks in space.

HOW DID YOU DO SOME OF THIS RESEARCH?

My hobby is 3-D printing, so I created a 3-D cat tongue about four times the scale. I made it in the Invention Studio.

I've been going to the studio for about six years now. I love it. It's a unique place. Besides the amazing equipment there, it's the students who make the space special. It's this collection of really passionate, interesting students all coming together to build and invent and tinker and teach one another. — LAURA DIAMOND

ROB FELT

A SWARM FIRST: DOGFIGHTING

Aerial dogfighting began more than a century ago in the skies over Europe, with propeller-driven fighter planes carried aloft on wings of wood and fabric. An event held recently in southern California could mark the beginning of a new chapter in this form of aerial combat.

In what may have been the first aerial encounter of its kind, researchers from the Georgia Tech Research Institute (GTRI) and Naval Postgraduate School pitted two swarms of autonomous aircraft against each other over a military test facility. While the friendly encounter may not have qualified as an old-fashioned dogfight, the engagement between two swarms of unmanned air vehicles (UAVs) nevertheless allowed the teams to evaluate different combat tactics.

"The ability to engage a swarm of threat UAVs with another autonomous swarm is an area of critical research for defense applications," said Don Davis, division chief of GTRI's Robotics and Autonomous Systems Branch. "This experiment demonstrated the advances made in collaborative autonomy and the ability of a team of unmanned

Two swarms of autonomous aircraft were pitted against each other in a mock dogfight between the Georgia Tech Research Institute and the Naval Postgraduate School. The engagement, which may have been the first of its kind between UAVs, allowed the teams to evaluate different combat tactics.

vehicles to execute complex missions. This encounter will serve to advance and inform future efforts in developing autonomous vehicle capabilities."

Each team launched 10 small propeller-driven Zephyr aircraft, though two of the aircraft experienced technical issues at launch. The UAVs were physically identical, but their computers used different autonomy logic, collaboration approaches, and communications software developed by the two institutions. For this demonstration, GPS tracking allowed each aircraft to know the location of the others. In the future, this information will be provided by on-board cameras, radars, and other sensors and payloads.

"Both teams were trying to solve the same problem of flying a large swarm in a meaningful mission, and we came up with solutions that were similar in some ways and different in others," said Charles Pippin, a GTRI senior research scientist. "By comparing how well each approach worked in the air, we were able to compare strategies and tactics on platforms capable of the same flight dynamics."

The foam-wing aircraft couldn't actually shoot at one another, so a ground computer determined when an aircraft would have been in a position to attack another aircraft. The event took place in February 2017 at Camp Roberts, a California National Guard facility in Monterey County, California. — JOHN TOON

UAVS: U.S. NAVY PHOTO BY JAVIER CHAGOYA; SANDWICH: ISTOCKPHOTO

Sounds Important

Lower pitches in voices or music in advertisements lead consumers to infer a larger product size, a new study has found.

Sound is a fundamental element of nearly all marketing communications, from commercials to spokespeople and sales associates. But Michael Lowe, assistant professor of marketing in Georgia Tech's Scheller College of Business, and Kelly Haws, associate professor of marketing in Vanderbilt's Owen Graduate School of Management, found that marketers don't have a firm grasp on what sound communicates to customers.

"Research to date suggests that managers too often select music and spokespeople by intuition, with limited understanding regarding how these elements might affect actual product perceptions," Lowe and Haws wrote in their paper for *The Journal of Marketing Research*. "Some degree of importance, then, should be given to understanding what is actually being communicated about the product at a sensory level."

The co-authors showed in six different studies how the effects of acoustic pitch on consumer beliefs depend on "cross-modal correspondence," defined as the compatibility of stimuli perceived by one sense, such as sound, with a sensory experience in another, like sight.

For instance, one study found that acoustic pitch differences in voice affect perceptions of size. Participants listened to a radio advertisement for a new sandwich at a fictitious sandwich chain where a spokesperson's voice was digitally altered to be higher or lower. Participants who heard the ad featuring the lower-pitched voice believed the sandwich was significantly larger than those who heard the higher-pitched version. — VANDERBILT UNIVERSITY

NEW POWER FOR MASS SPEC

Triboelectric nanogenerators (TENG) convert mechanical energy harvested from the environment into electricity for powering small devices such as sensors. Now, researchers have harnessed this technology to dramatically boost the sensitivity of mass spectrometers, instruments that identify molecules by their mass.

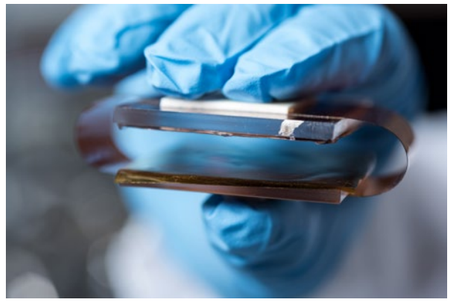
Beyond boosting sensitivity, replacing conventional power supplies with TENG devices allows identification to be done with smaller samples, conserving precious biomolecules or chemical mixtures that may be available only in minute quantities. Georgia Tech researchers believe the unique aspects of the TENG output — oscillating high voltage and controlled current — improve the ionization process, increasing the voltage applied without damaging samples or the instrument.

"Our discovery is basically a new and very controlled way of putting charge onto molecules," said Facundo Fernández, a professor in Georgia Tech's School of Chemistry and Biochemistry. "We know exactly how much charge we produce using these nanogenerators, allowing us to reach sensitivity levels that are unheard of — at the zeptomole scale. We can measure down to literally hundreds of molecules without tagging."

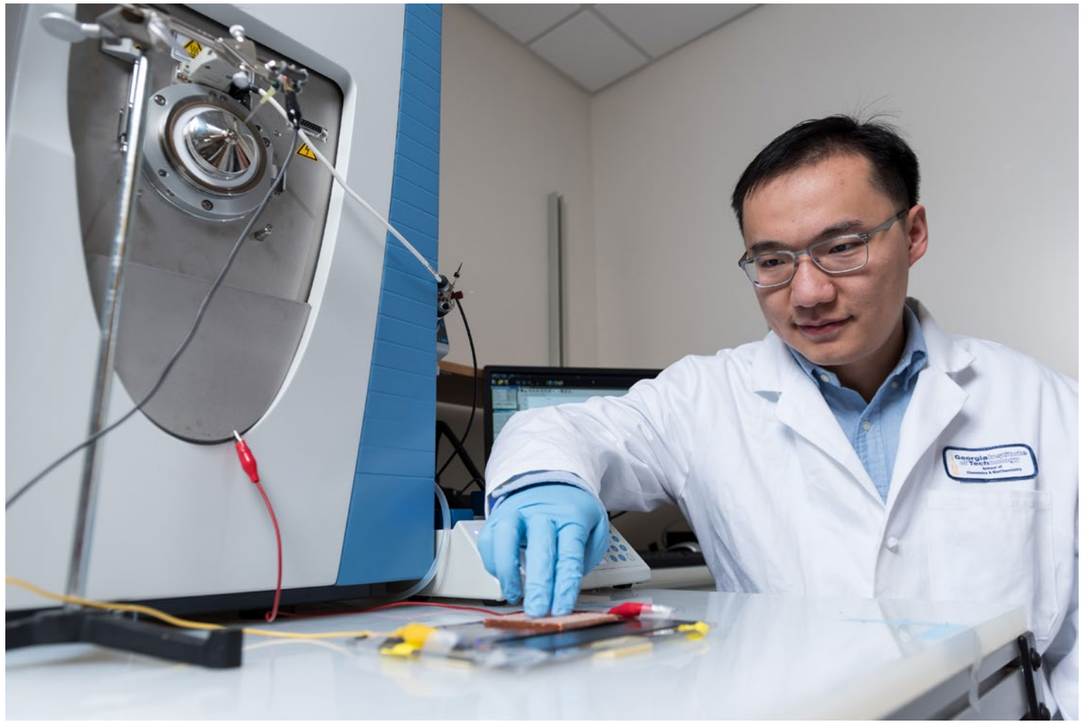
Fernández and his research team worked with Zhong Lin Wang, a pioneer in developing the TENG technology and a Regents Professor in Georgia Tech's School of Materials Science and Engineering.

"The total charge delivered in each cycle is entirely controlled and constant regardless of the speed at which the TENG is triggered," Wang said. "This is a new direction for the triboelectric nanogenerators and opens a door for using the technology in the design of future instrumentation and equipment."

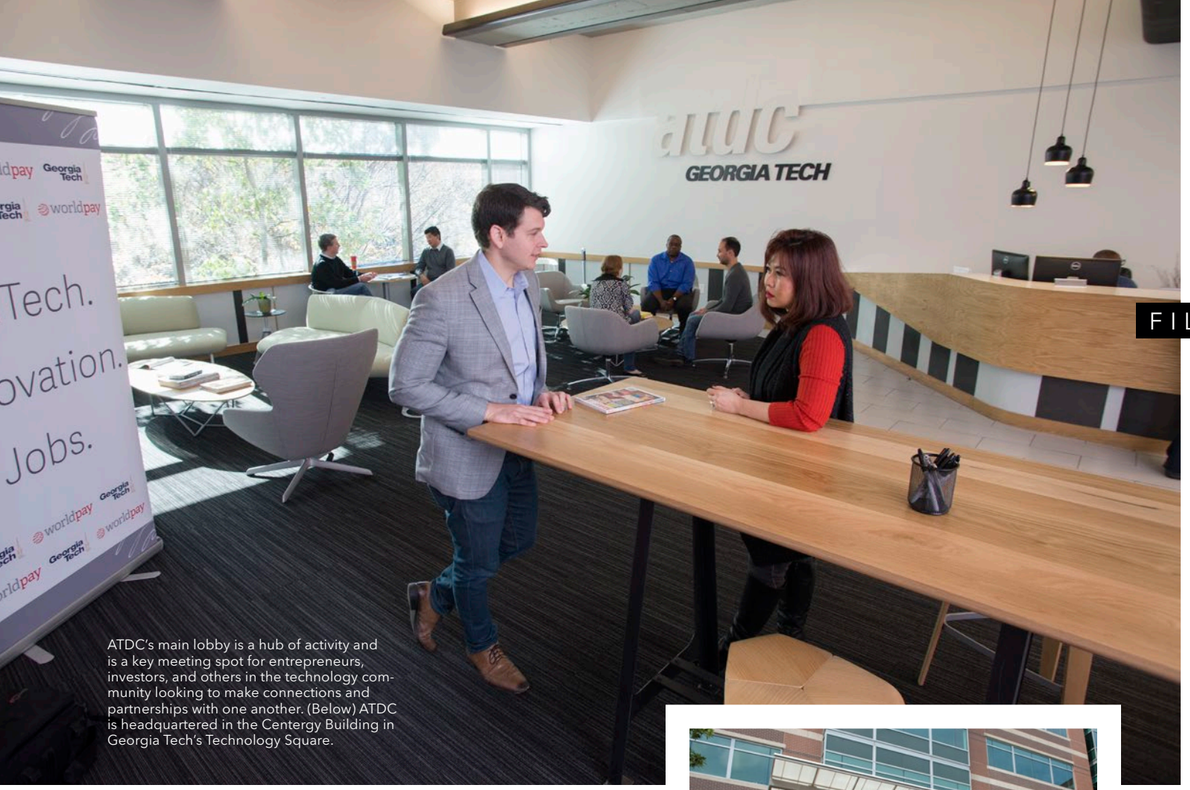
The research, which was supported by the National Science Foundation, NASA Astrobiology Program, and the Department of Energy, was reported in the journal *Nature Nanotechnology*. — JOHN TOON



(Left) A contact-separation triboelectric nanogenerator produces electrical charge when surfaces are brought together and then separated. (Below) Postdoctoral fellow Anyin Li demonstrates the use of a sliding triboelectric nanogenerator to produce electrical charges for the mass spectrometer shown next to him.



ROB FELT



ATDC's main lobby is a hub of activity and is a key meeting spot for entrepreneurs, investors, and others in the technology community looking to make connections and partnerships with one another. (Below) ATDC is headquartered in the Centergy Building in Georgia Tech's Technology Square.

LAUNCH PAD

Since 1980, Tech's startup incubator has helped companies generate $12 billion in revenue

The formula was simple: Entrepreneurs with viable technology-based ideas to create companies — and jobs — needed a base of expertise and support in which they could develop and thrive.

Georgia, wanting to remain economically competitive and build its base of technology companies, sought to keep those talented idea makers here, creating new companies and jobs in the Peach State.

So in 1980, the Georgia General Assembly created and funded a technology incubator — the Advanced Technology Development Center (ATDC) — to work with entrepreneurs.

Thirty-seven years later, ATDC — a program of Georgia Tech — has grown into one of the longest running and most successful university-based incubators in the country.

As an internationally recognized organization that was twice named to Forbes' list of the world's top incubators, ATDC's core mission is to help entrepreneurs in Georgia learn, launch, scale, and succeed in the creation of viable, disruptive technology companies. Since its founding, ATDC has graduated more than 170 startups. Those companies have raised nearly $3 billion in investment capital and generated more than $12 billion in revenue.

"What is unique about the ATDC experience is that we're part of Georgia Tech," said ATDC General Manager Jen Bonnett. "And while a connection to Tech is not required for companies in ATDC, a number of our startups, including Quest Renewables (see page 50) and Pointivo, have built their businesses by leveraging Georgia Tech intellectual property."

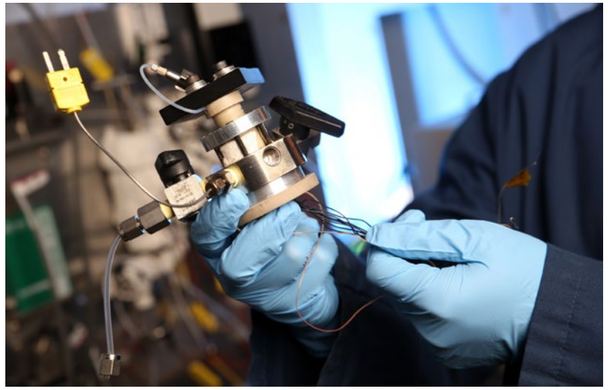
ATDC works closely with VentureLab, a sister incubator program that offers guidance and support to faculty and students who want to commercialize their ideas. ATDC companies Quest Renewables and Pointivo, among others, graduated from VentureLab before joining ATDC.

Committed to its statewide mission, ATDC has expanded efforts and offers its educational startup programming across Georgia through its ATDC @ initiative in Athens, Augusta, Peachtree Corners, Savannah, and FlatironCity in downtown Atlanta. ATDC is currently incubating more than 130 startup technology companies in its ATDC Signature and ATDC Accelerate portfolios in metro Atlanta and across the state.

Several of the startups from those cities were among the more than 70 companies that exhibited May 11 at the 2017 Startup Showcase, ATDC's largest yearly event. — PÉRALTE PAUL

***Jen Bonnett** is the general manager of ATDC.*

LOBBY: CHRISTOPHER MOORE; INSET: FITRAH HAMID



Georgia Tech researchers have demonstrated a CHAMP reactor, which uses the four-stroke engine cycle to create hydrogen while simultaneously capturing carbon dioxide emissions.

LIKE A CHAMP

By inserting a catalyst, hydrogen separating membrane, and carbon dioxide sorbent into the conventional four-stroke engine cycle, researchers have created a modular, hydrogen-reforming system that produces the green fuel from natural gas at relatively low temperature in a process that can be scaled up to meet specific needs.

The process could provide hydrogen at the point of use for residential fuel cells or neighborhood power plants; electricity and power production in natural gas-powered vehicles; or fueling of hydrogen-based vehicles. It could also supplement intermittent renewable energy sources.

Known as the CO_2/H_2 Active Membrane Piston (CHAMP) reactor, the device operates at temperatures much lower than conventional steam reforming processes, consumes substantially less water, and could also work with fuels such as methanol or bio-derived feedstocks.

"We already have a nationwide natural gas distribution infrastructure, so it's much better to produce hydrogen at the point of use rather than trying to distribute it," said Andrei Fedorov, a professor in Georgia Tech's Woodruff School of Mechanical Engineering. "Our technology could produce this fuel of choice wherever natural gas is available, which could resolve one of the major challenges with the hydrogen economy."

Key to the reaction process is the variable volume provided by a piston rising and falling in a cylinder. As with a conventional engine, a valve controls the flow of gases into and out of the reactor as the piston moves up and down. The system works like this:

• Natural gas (methane) and steam are drawn into the reaction cylinder through a valve as the piston is lowered. The valve closes once the piston reaches the bottom of the cylinder.

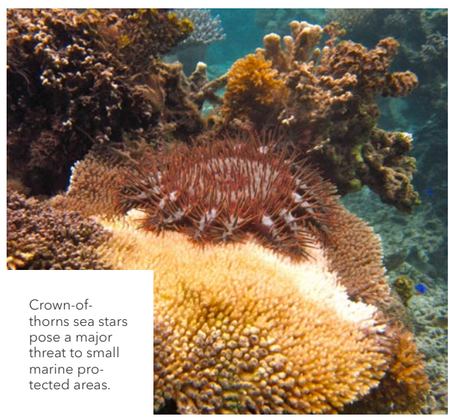
• The piston rises into the cylinder, compressing the steam and methane as the reactor is heated. Once the temperature reaches approximately 400 degrees Celsius, catalytic reactions take place inside the reactor, forming hydrogen and carbon dioxide. The hydrogen exits through a selective membrane, and the pressurized carbon dioxide is adsorbed by the sorbent material.

• Once the hydrogen has exited the reactor and carbon dioxide is tied up in the sorbent, the piston is lowered, reducing the volume and pressure in the cylinder. The carbon dioxide is released from the sorbent into the cylinder.

• The piston is again moved up into the chamber and the valve opens, expelling the concentrated carbon dioxide and clearing the reactor for the start of a new cycle.

A paper published in the journal *Industrial & Engineering Chemistry Research* describes the process. The research was supported by the National Science Foundation, the Department of Defense through NDSEG fellowships, and the U.S. Civilian Research & Development Foundation (CRDF Global). — JOHN TOON

FOR MARINE PROTECTED AREAS, SIZE MATTERS



Crown-of-thorns sea stars pose a major threat to small marine protected areas.

CHAMP: CANDLER HOBBS; CORAL: CODY CLEMENTS

For marine protected areas established to help coral reefs recover from overfishing, size really seems to make a difference.

In a study that sounds a new alarm for endangered corals, researchers found that small community-based marine protected areas may be especially vulnerable to attack by crown-of-thorns sea stars, which can devastate coral reefs. The findings, published in the journal *PLOS ONE*, don't diminish the importance of protected areas but point to a threat that may emerge from the degraded areas that often surround healthy coral ecosystems.

"The marine protected areas that are enforced in the Fiji Islands are having a remarkable effect," said Mark Hay, Regents Professor and Harry and Linda Teasley Chair in Georgia Tech's School of Biological Sciences. "The corals and fishes are recovering. But once these marine protected areas are successful, they attract the sea stars which can make the small marine protected areas victims of their own success."

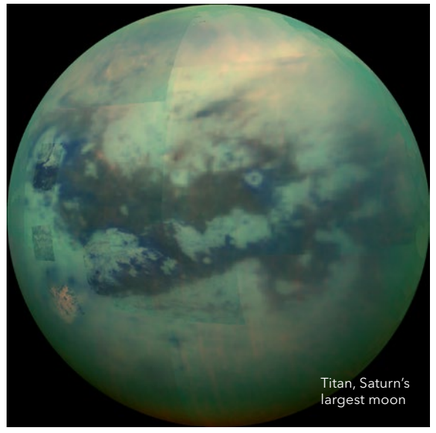
The research was supported by the National Science Foundation, the National Institutes of Health, and the Teasley Endowment.

"Successful small marine protected areas are like oases in the desert that may attract the sea stars, which can move tens of meters per day from degraded areas into the more pristine areas," said Georgia Tech graduate student Cody Clements, who conducted the research. "One of the potential benefits of marine protected areas was supposed to be protection against these outbreaks, but that didn't seem to be the case in the areas we studied." — JOHN TOON

Electric Sand

New experiments suggest the particles that cover the surface of Saturn's largest moon, Titan, are electrically charged. When the wind blows hard enough, Titan's non-silicate granules get kicked up and start to hop in a motion referred to as saltation. As they collide, they become frictionally charged, like a balloon rubbing against hair. They clump together in a way not observed in sand grains on Earth.

"If you grabbed piles of grains and built a sand castle on Titan, it would



Titan, Saturn's largest moon

perhaps stay together for weeks due to their electrostatic properties," said Josef Dufek, the Georgia Tech professor who co-led the study. "These charged grains will stick to each other and other surfaces. Think of putting a cat into a box of packing peanuts."

The electrification findings may help explain an odd phenomenon. Prevailing winds on Titan blow from east to west across the moon's surface, but sand dunes nearly 300 feet tall seem to form in the opposite direction.

"These electrostatic forces increase frictional thresholds," said Josh Méndez Harper, a Georgia Tech doctoral student. "This makes the grains so sticky and cohesive that only heavy winds can move them.

The researchers modified a pressure vessel to test the charging of particles like those on Titan. The research was supported by the National Science Foundation and reported in the journal *Nature Geoscience*. — JASON MADERER

Factoid

Titan is the second-largest moon in the solar system, 50 percent larger than Earth's moon. It is the only moon known to have a dense atmosphere.

TESTING BOOSTS GENE THERAPIES

DNA 'barcoding' tests nanoparticles

Using tiny snippets of DNA as "barcodes," researchers have developed a new technique for rapidly screening nanoparticles for their ability to selectively deliver therapeutic genes to specific organs of the body. The technique could accelerate the use of gene therapies for such killers as heart disease, cancer, and Parkinson's disease.

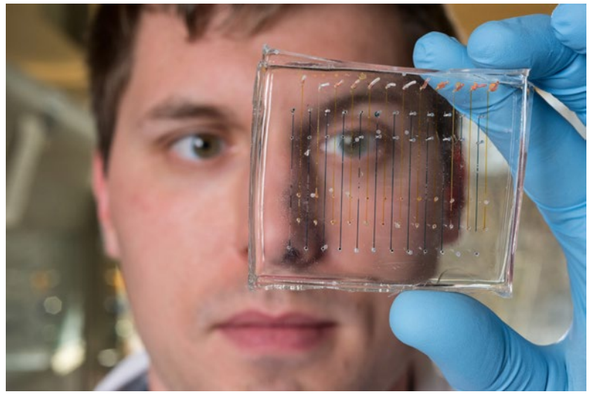
Genetic therapies, such as those made from DNA or RNA, are difficult to deliver into the right cells in the body. For the past 20 years, scientists have been developing nanoparticles made from a broad range of materials and adding compounds such as cholesterol to help carry these therapeutic agents into cells. But the nanoparticle carriers must undergo time-consuming testing — first in cell culture, then in animals. With millions of possible formulas, identifying the optimal nanoparticle to target each organ has been challenging.

Using DNA strands just 58 nucleotides long, researchers from Georgia Tech, the University of Florida, and the Massachusetts Institute of Technology (MIT) have developed a new evaluation technique that skips the cell culture testing altogether — and could allow hundreds of different types of nanoparticles to be tested simultaneously in just a handful of animals.

"We want to understand at a very high level what factors affecting nanoparticle delivery are important," said James Dahlman, an assistant professor in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University. "This new technique not only allows us to understand what factors are important, but also how disease factors affect the process."

To prepare the nanoparticles for testing, the researchers insert a snippet of DNA that is assigned to each type of nanoparticle. The nanoparticles are injected into an animal model, whose organs are then examined to determine the presence of the barcodes indicating where specific nanoparticles have gone. By using genome sequencing technologies to identify the barcodes, many nanoparticles can be tested simultaneously, each identified by its unique DNA barcode.

The original research was done in the laboratories of Robert Langer and Daniel Anderson at MIT. Supported by the National Institutes of Health, the research was reported in the journal *Proceedings of the National Academy of Sciences*. — JOHN TOON



Assistant professor James Dahlman holds a microfluidic chip used to fabricate nanoparticles that could be used to deliver therapeutic genes.

DNA: ROB FELT; TITAN: NASA/JPL/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO

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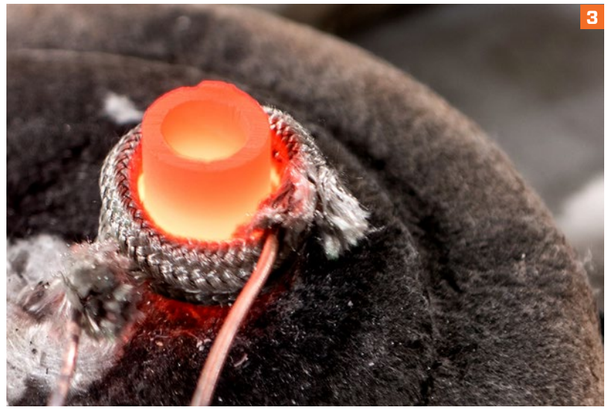


3

1–3 Fabrication of oxide nanowires begins with creating a bimetallic alloy, in this case aluminum and lithium, by heating in a crucible.

SIMPLER **NANOWIRES**

A simple technique for producing oxide nanowires directly from bulk materials could dramatically lower the cost of producing the one-dimensional (1-D) nanostructures. That could open the door for their use in lightweight structural composites, advanced sensors, and electronic devices — as well as thermally stable and strong battery membranes able to withstand temperatures of more than 1,000 degrees Celsius.

The technique uses a solvent reaction with a bimetallic alloy — in which one of the metals is reactive — to form bundles of nanowires using reactive metal dissolution. The process takes place at ambient temperature and pressure without the use of catalysts, toxic chemicals, or costly processes such as chemical vapor deposition.

"This technique could open the door for a range of synthesis opportunities to produce low-cost 1-D nanomaterials in large quantities," said Gleb Yushin, a professor in Georgia Tech's School of Materials Science and Engineering. "You can essentially put the bulk materials into a bucket, fill it with a suitable solvent, and collect nanowires after a few hours, which is way simpler than how many of these structures are produced today."

Yushin's research team has produced oxide nanowires from lithium-magnesium and lithium-aluminum alloys using a variety of solvents, including simple alcohols. The research, reported in the journal *Science*, was supported by the National Science Foundation and California-based Sila Nanotechnologies.

Fabrication of the nanowires begins with formation of alloys composed of one reactive and one non-reactive metal, such as lithium and aluminum. The alloy is then placed into a suitable solvent, which could include a range of alcohols, such as ethanol. The reactive metal (lithium) dissolves from the surface into the solvent, initially producing aluminum nuclei (nanoparticles).

Though bulk aluminum is normally not reactive with alcohol due to the formation of a passivation layer, the continuous dissolution of lithium prevents the passivation and allows gradual formation of aluminum alkoxide nanowires, which grow perpendicular to the surface of the particles starting from the nuclei until the particles are completely converted. The alkoxide nanowires can then be heated in open air to form aluminum oxide nanowires and may be formed into paper-like sheets. — JOHN TOON

***Gleb Yushin** is a professor in the School of Materials Science and Engineering.*

4

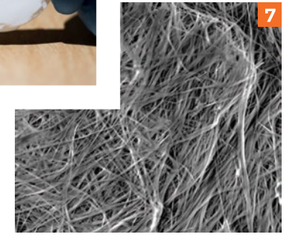
4–5 The resulting alloy sample is then placed in a test tube containing a solvent such as ethanol, where the reactive lithium dissolves out into solution.

5

6

6 The aluminum nuclei left behind seed the growth of aluminum alkoxide nanowires, which can be heated in the open air to form paper-like sheets.

7 A microscope image shows the fibers.



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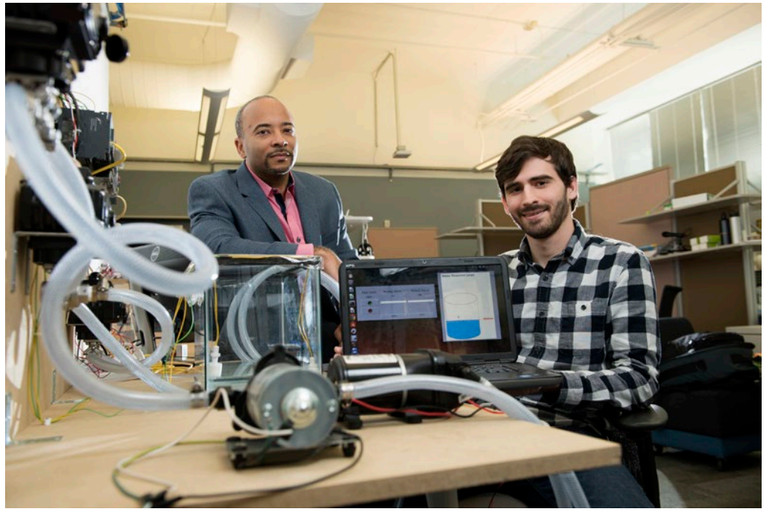


To highlight vulnerabilities, Georgia Tech researchers have developed a new form of ransomware that can take control of a simulated water treatment plant. Shown are Raheem Beyah, associate chair in the School of Electrical and Computer Engineering, and David Formby, a Georgia Tech Ph.D. student.

RANSOM(A)WARE

Cybersecurity researchers have developed a new form of ransomware that was able to take control of a simulated water treatment plant. After gaining access, the researchers were able to command programmable logic controllers (PLCs) to shut valves, increase the amount of chlorine added to water, and display false readings.

The simulated attack was designed to highlight vulnerabilities in control systems used to operate industrial facilities such as manufacturing plants, water and wastewater treatment facilities, and building management systems. Believed to be the first to demonstrate ransomware compromise of real PLCs, the research was presented at the RSA Conference.

Though no ransomware attacks have been publicly reported on the process control components of real industrial control systems, such attacks have become a significant problem for patient data in hospitals and customer data in businesses. Attackers gain access to these systems and encrypt the data, demanding a ransom to provide the encryption key that allows the information to be used again.

"We are expecting ransomware to go one step further, beyond the customer data to compromise the control systems themselves," said David Formby, a Ph.D. student in Georgia Tech's School of Electrical and Computer Engineering. "That could allow attackers to hold hostage critical systems such as water treatment plants and manufacturing facilities. Compromising the PLCs in these systems is a next logical step for these attackers."

Many industrial control systems lack strong security protocols, said Raheem Beyah, Motorola Foundation Professor and associate chair in the School of Electrical and Computer Engineering, and Formby's faculty advisor. That's likely because these systems largely haven't been targeted by ransomware so far, and because their vulnerabilities may not be well understood by their operators. — JOHN TOON

CHINA'S HAZE TIED TO CLIMATE CHANGE

Modeling and data analysis done by Georgia Tech researchers suggest that changes in sea ice and snowfall have shifted China's winter monsoon, helping create stagnant atmospheric conditions that trap pollution over the country's major population and industrial centers.

China's severe winter air pollution may be worsened by changes in atmospheric circulation prompted by Arctic sea ice loss and increased Eurasian snowfall — both caused by global climate change.

Modeling and data analysis done by Georgia Tech researchers suggest that the sea ice and snowfall changes have shifted China's winter monsoon, helping create stagnant atmospheric conditions that trap pollution over the country's major population and industrial centers. Those changes in regional atmospheric conditions are frustrating efforts to address pollution through emission controls.

"Emissions in China have been decreasing over the last four years, but the severe winter haze is not getting better," said Yuhang Wang, a professor in Georgia Tech's School of Earth and Atmospheric Sciences. "Mostly, that's because of a very rapid change in the high polar regions where sea ice is decreasing and snowfall is increasing. This perturbation keeps cold air from getting into the eastern parts of China where it would flush out the air pollution."

Reported in the journal *Science Advances*, the research was sponsored by the National Science Foundation and the U.S. Environmental Protection Agency. — JOHN TOON

Yuhang Wang *is a professor in the School of Earth and Atmospheric Sciences.*

CYBERSECURITY: CHRISTOPHER MOORE; CHINA: COURTESY YUHANG WANG

Did Methane-Making Microbes Warm Early Earth?

For much of its first two billion years, Earth was a very different place: Oxygen was scarce, microbial life ruled, and the sun was significantly dimmer than it is today. Yet the rock record shows that vast seas covered much of the early Earth.

Scientists have long debated what kept those seas from freezing. A popular theory is that potent gases such as methane created a thicker greenhouse atmosphere than is required to keep water liquid today.

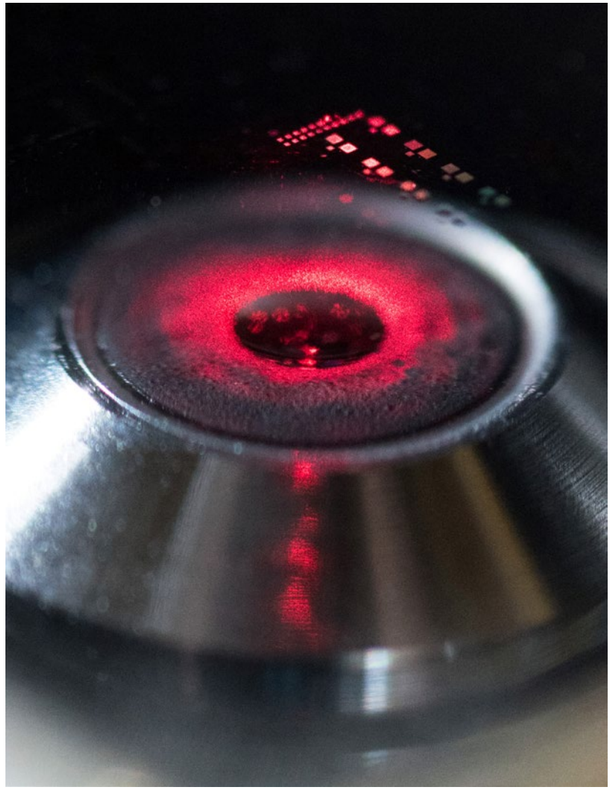
In the absence of oxygen, iron built up in ancient oceans. Under the right chemical and biological processes, this iron rusted out of seawater and cycled many times through a complex loop, or "ferrous wheel." Some microbes could "breathe" this rust to outcompete others, such as those that made methane. When rust was plentiful, an "iron curtain" may have suppressed methane emissions.

"The ancestors of modern methane-making and rust-breathing microbes may have long battled for dominance in habitats largely governed by iron chemistry," said Marcus Bray, a biology Ph.D. candidate in the laboratory of Jennifer Glass, an assistant professor in Georgia Tech's School of Earth and Atmospheric Sciences and principal investigator of the study, funded by NASA's Exobiology and Evolutionary Biology Program. The research was reported in the journal *Geobiology*.

Collaborator Sean Crowe, an assistant professor at the University of British Columbia, collected mud from the depths of Indonesia's Lake Matano, an anoxic iron-rich ecosystem that uniquely mimics early oceans. Bray placed the mud into tiny incubators simulating early Earth conditions and tracked microbial diversity and methane emissions over a period of 500 days. Minimal methane was formed when rust was added; without rust, microbes kept making methane despite multiple dilutions.

The team concluded that methane production could have persisted in rust-free patches of ancient seas. Unlike the situation in today's well-aerated oceans, where most natural gas produced on the seafloor is consumed before it can reach the surface, most of this ancient methane would have escaped to the atmosphere to trap heat from the early sun.

ROB FELT



Laser light shows the nanopatterned structure of a chiral metamaterial developed by researchers in the Georgia Tech School of Electrical and Computer Engineering.

CHIROPTICAL ADJUSTMENT

Sean Rodrigues *is a Ph.D. student in the School of Electrical and Computer Engineering.*

Researchers have demonstrated an optical metamaterial whose chiroptical properties in the nonlinear regime produce a significant spectral shift with milliwatt power levels.

The researchers recently demonstrated the properties of their metamaterial, in which they spectrally modified two absorptive resonances by incrementally exposing the material to power intensities beyond its linear optical regime. With just a 15-milliwatt change in excitation power, they measured a 10-nanometer spectral shift in the material's transmission resonances and a 14-degree polarization rotation.

"Nanoscale chiral structures offer an approach to modulating optical signals with relatively small variations in input power," said Sean Rodrigues, a Ph.D. candidate who led the research in the laboratory of Associate Professor Wenshan Cai in Georgia Tech's School of Electrical and Computer Engineering. "To see this kind of change in such a thin material makes chiroptical metamaterials an interesting new platform for optical signal modulation."

Modulating metamaterial responses through the manipulation of input power offers the potential for new types of active optics useful in all-optical switching.

Chiral materials exhibit optical properties that differ depending on the right or left circular polarization incident on them. The differences between these responses, which are created by the nanoscale patterning of absorptive materials, can be utilized to create large chiroptical resonances.

The materials are made by nano-patterning layers of silver onto glass substrates and include a dielectric material between them. The research, supported by the National Science Foundation and the Air Force Research Laboratory, was reported in the journal *Nature Communications*. — JOHN TOON

VIRTUALLY HYPER

This is hyperbolic space viewed through virtual reality. The VR program depicts hyperbolic geometry, which is a twist on more customary geometry and a departure from the realm of usual human perception.

The world we see day to day is described by Euclidean geometry, taught in high school, with its lines, planes, rectangles, and spheres. To picture hyperbolic geometric space in your mind, grab a plane and warp it like a potato chip, then apply that to all of space.

Or take the easy route and don a VR headset. It will take you to a reality where parallel lines curve away from each other, the angles of triangles don't add up to 180 degrees, and customary rectangles don't exist.

Hyperbolic geometry has aided insight into physical realities that bewilder conventional perception, like space-time warping from the Theory of Relativity.

This virtual reality headset program is a collaboration of Georgia Tech applied mathematician Sabetta Matsumoto, an assistant professor in the School of Physics; mathematician Henry Segerman from Oklahoma State University; and the eleVR research group. It translates head movements into movements in hyperbolic geometry and then translates that back into VR optics for physicists and mathematicians to see.

People don't usually have an opportunity to see hyperbolic spaces. The colorful shapes help them do so. — BEN BRUMFIELD

In motion, hyperbolic geometry makes shapes warp around like reflections in a special kind of funhouse mirror. Want to try it? Steer your VR here: **h3.hypernom.com**.

BRAKING BAD

Though tailpipe emissions could fall in the years ahead as more zero-emission vehicles hit the streets, one major source of highway air pollution shows no signs of abating: brake and tire dust.

Metals from brakes and other automotive systems are emitted into the air as fine particles, lingering over busy roadways. Now, Georgia Tech researchers have shown how that cloud of tiny metal particles could wreak havoc on respiratory health.

In a study published in the journal *Environmental Science & Technology*, the researchers described how vehicle-emitted metals such as copper, iron, and manganese interact with acidic sulfate-rich particles already in the air to produce a toxic aerosol.

"There's a chain reaction happening in the air above busy highways," said Rodney Weber, a professor in Georgia Tech's School of Earth and Atmospheric Sciences. "Acidic sulfate in the atmosphere comes into contact with those metals emitted from traffic and changes their solubility, making them more likely to cause oxidative stress when inhaled."

The study, which was sponsored by the National Science Foundation and the U.S. Environmental Protection Agency, showed how the metals are emitted mainly in an insoluble form but slowly become soluble after mixing with the sulfate.

"Sulfate has long been associated with adverse health impacts," said Athanasios Nenes, a professor and Georgia Power Scholar in the School of Earth and Atmospheric Sciences and the School of Chemical and Biomolecular Engineering. "The old hypothesis was that the acidic sulfate burns your lung lining, which in turn leads to bad health effects. But there is not enough acid in the air alone to really have that impact."

The researchers analyzed samples of ambient particulate matter at two locations in Atlanta — one near a major interstate highway and the other at an urban site 420 meters away from a roadway. — JOSH BROWN

Factoid

Honeybees obtain all of their nutritional requirements from two sources: pollen and nectar. Pollen is the only natural protein source for honeybees.

Clean Bees

With the health of honeybee colonies wavering and researchers trying to find technological ways to pollinate plants, a new Georgia Tech study has looked at how the insects do their job and manage to stay clean.

A honeybee can carry up to 30 percent of its body weight in pollen because of the strategic spacing of its nearly three million hairs. The hairs cover the insect's eyes and body in various densities that allow efficient cleaning and transport.

The research found that the gap between each eye hair is approximately the same size as a grain of dandelion pollen. This keeps the pollen suspended above the eye and allows the forelegs to comb through and collect the particles. Hair on the legs is packed five times more densely than the hair on the eyes, helping the legs collect as much pollen as possible with each swipe.

The research team tethered bees and used high-speed cameras to create the first quantified study of the honeybee cleaning process. They watched as the insects removed up to 15,000 particles from their bodies in three minutes.

"Without these hairs and their specialized spacing, it would be almost impossible for a honeybee to stay clean," said Guillermo Amador, who led the study while pursuing his doctoral degree at Georgia Tech in mechanical engineering.

The research was supported by the National Science Foundation and published in the journal *Bioinspiration and Biomimetics*. — JASON MADERER

WHAT'S HAPPENING INSIDE DROPLETS

For most people, the drip, drip, drip of a leaking faucet is an annoyance. But for Ph.D. candidate Alexandros Fragkopoulos, the droplets are the sound of serious research.

The research has implications for the life sciences, where biological materials, including cells, undergo shape changes reminiscent of the droplet behavior. The findings could also improve industrial processes such as fuel injection that depend on droplet formation.

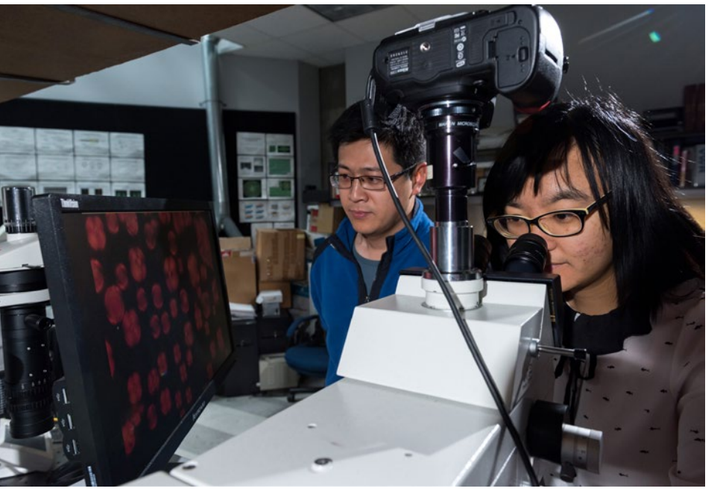
"Surface tension drives the evolution of the droplets," Fragkopoulos said. "Fluids tend to minimize their surface area for a given volume because that minimizes the energy required to have an interface between different fluids. Spherical shapes minimize that energy, and as a result, toroidal droplets want to evolve to become spherical. We're studying how that transition occurs."

Using a sheet of laser light to observe the scattering from polystyrene particles in water droplets formed within thick silicone oil, the researchers have observed how droplets change shape and identified the factors that set the droplets on the path to either collapse or break up. The research, which was supported by the National Science Foundation, was reported in the journal *Proceedings of the National Academy of Sciences*.

The researchers also studied how charge affects the toroidal-droplet evolution and addressed the role of mechanical non-linearities in the surrounding fluid. Though fundamental, the research findings could aid in manipulating fluid streams and drops in microfluidics and other areas. — JOHN TOON

Georgia Tech Ph.D. candidate Alexandros Fragkopoulos adjusts equipment used to create unstable toroidal droplets in silicone oil.

DROPLETS: JOHN TOON; BEE: ISTOCKPHOTO



Georgia Tech students Jinxin Fu and Rui Chang view liquid crystals created from a common food dye.

THE DYE IS RE-CAST

A material used for decades to color food items could potentially have a new use.

In a study published in the journal *Proceedings of the National Academy of Sciences*, researchers described how a class of water soluble materials, called lyotropic chromonic liquid crystals, exhibited unexpected characteristics that could be harnessed for use in sensors and other applications.

"We were seeking to understand the aggregation and phase behavior of these plank-like molecules as a function of temperature and concentration," said Karthik Nayani, a former Georgia Tech student who worked on the study. "When observed under crossed polarizers in an optical microscope, liquid crystals can exhibit beautiful textures that hint toward how the molecules themselves are arranged."

To answer some fundamental questions pertaining to the material's phase behavior, the researchers used the microscopes to observe the molecules' textures when they were confined to droplets known as tactoids.

"Surprisingly, we found a configuration that hasn't been seen before in the 70 years that people have been studying liquid crystals," said Mohan Srinivasarao, a professor in Georgia Tech's School of Materials Science and Engineering. "Historically, liquid crystals in tactoids conform to what is known as a bipolar and a bipolar configuration with a twist. At lower concentrations, we found that these liquid crystals arrange in a concentric fashion, but one that appears to be free of a singular defect."

These new findings add to the growing understanding of how chromonic liquid crystals could be used in sensing applications, Srinivasarao said. The crystals are water soluble and respond dramatically to being confined to certain patterns — such as tactoidal droplets — concentrations, and temperatures. — JOSH BROWN

THE GERM STOPS HERE

A little empathy can go a long way toward ending infectious disease outbreaks, report researchers who used a networked variation of game theory to study how individual behavior during a simulated influenza outbreak affects the progress of the disease.

The study pitted the self-interests of susceptible individuals against those of infected persons and found that only if sick persons took precautions to avoid infecting others could the illness be eradicated. Healthy people attempting to protect themselves couldn't, by themselves, stop the disease from spreading.

"We wanted to understand disease dynamics from an individual's perspective," said Ceyhun Eksin, a postdoctoral fellow in the laboratory of Joshua S. Weitz, a professor in Georgia Tech's School of Biological Sciences. "In particular, we wanted to know what role individual behavior plays in disease spread and how behavior might affect forecasting and consequences when there is an outbreak."

The research, reported in the journal *Scientific Reports*, was sponsored by the U.S. Army Research Office. The work used mathematical models that took into account how infectious diseases spread and the effects of measures taken to control them.

Public health initiatives against seasonal diseases like influenza tend to initially focus on immunization programs, which move individuals out of the "susceptible" category. Once an outbreak begins, health campaigns focus on encouraging susceptible persons to take precautions such as handwashing and avoiding infected people.

The success of those measures may depend on individual perceptions of how great the risk of infection might be, Eksin noted. The more awareness individuals have of infected persons around them, the more likely they are to protect themselves. Perception can also affect the empathetic behavior of infected individuals, who may be more likely to stay home from work or cover their cough if they believe their presence could infect a significant number of people. — JOHN TOON

Ceyhun Eksin *is a postdoctoral fellow in the School of Biological Sciences.*

DYES: ROB FELT; GERMS: ISTOCKPHOTO

POWERPOINT COMES INTO THE FOLD

Projected patterns cause special polymer film to bend along the direction of light, creating self-folding origami structures

Researchers have found a new use for the ubiquitous PowerPoint slide: producing self-folding three-dimensional origami structures.

The technique involves projecting a grayscale pattern of light and dark shapes onto a thin layer of liquid acrylate polymer placed in a plate or between two glass slides. A photoinitiator material mixed into the polymer initiates a crosslinking reaction when struck by the patterned light produced by an ordinary LED projector, causing a solid film to form. The complicated interaction between the evolution of the polymer network and volume shrinkage during photo curing causes areas of the polymer that receive less light to exhibit more apparent bending behavior.

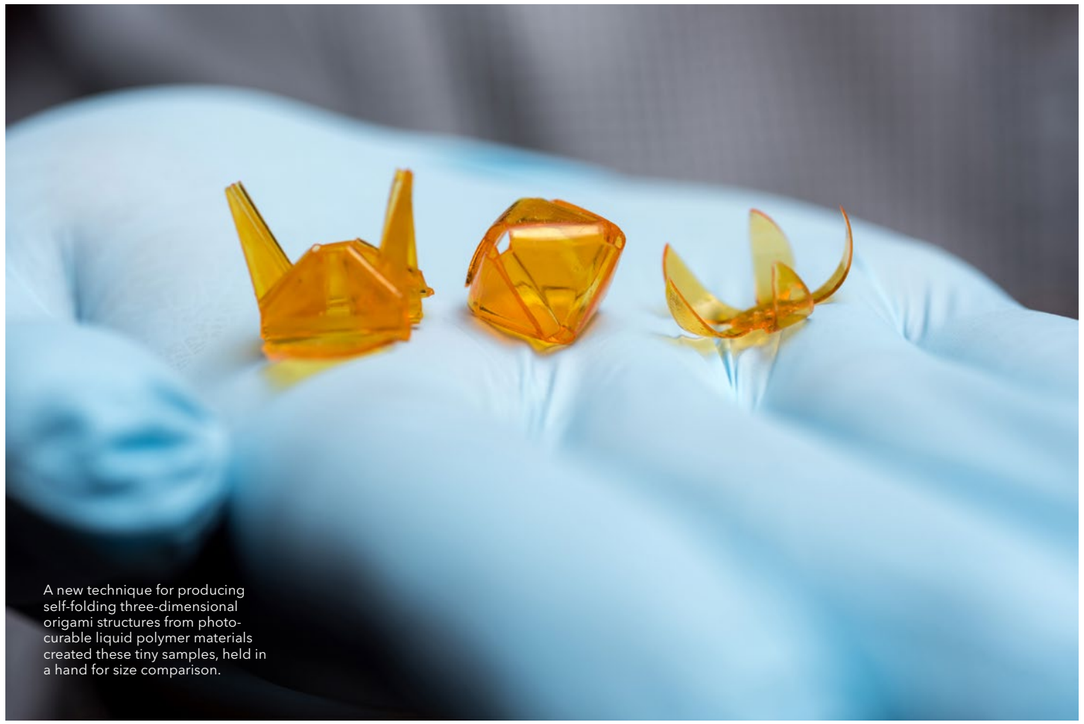
When the newly created polymer film is removed from the liquid polymer, the stress created in the film by the differential shrinkage causes folding to begin. To make the most complex origami structures, the researchers shine light onto both sides of the structures. The patterning comes from simple PowerPoint slides.

Origami structures produced so far include tiny tables, capsules, flowers, birds, and the traditional miura-ori fold — all about a half-inch in size. The origami structures could have applications in soft robots, microelectronics, soft actuators, mechanical metamaterials, and biomedical devices.

"The basic idea of our method is to utilize the volume shrinkage phenomenon during photo-polymerization," said Jerry Qi, a professor in Georgia Tech's Woodruff School of Mechanical Engineering. "During a specific type of photopolymerization, frontal photopolymerization, the liquid resin is cured continuously from the side under light irradiation toward the inner side. This creates a nonuniform stress field that drives the film to bend along the direction of light path."

Details of the work were published in the journal *Science Advances*. The research was supported by the National Science Foundation, the Air Force Office of Scientific Research, and the Chinese Scholarship Council. Researchers from Peking University also contributed to the project. — JOHN TOON

Jerry Qi *is a professor in the Woodruff School of Mechanical Engineering.*



A new technique for producing self-folding three-dimensional origami structures from photo-curable liquid polymer materials created these tiny samples, held in a hand for size comparison.

ROB FELT

SMART CITIES

INNOVATIVE APPROACHES COMBINING ENGINEERING, TECHNOLOGY, AND THE SOCIAL SCIENCES ARE BOOSTING THE URBAN IQ

BY T.J. BECKER
PHOTOS BY ROB FELT

Cities have been around for thousands of years, so urbanization is hardly a new phenomenon — but it's happening now at an unprecedented pace. In 1950 about 30 percent of the world's population lived in cities, a number that shot up to nearly 55 percent by 2016 and is expected to hit 60 percent by 2030, according to United Nations statistics. This dramatic growth brings challenges on a variety of fronts, transforming "smart cities" from a catchy phrase into a critical endeavor.

Georgia Tech has been intensifying its smart cities initiative, including membership

ATLANTA RENDERING BY IMAGINE LAB/CGIS, COLLEGE OF DESIGN

in the national MetroLab Network (see opposite page) and the launch of a new faculty council with members from more than a dozen university units.

"Smart cities is a highly complex area, encompassing everything from resiliency and environmental sustainability to wellness and quality of life," said Elizabeth Mynatt, executive director of Georgia Tech's Institute for People and Technology (IPaT) and distinguished professor in the College of Computing, who is co-chairing the new council. "Although Georgia Tech has been working in this area for some time, we're organizing research so we can be more holistic and have combined impact."

"Instead of discrete projects, we're moving into a programmatic approach," agreed Jennifer Clark, associate professor of public policy and director of Georgia Tech's Center for Urban Innovation. "Smart cities research touches on everything from computing and engineering to the social sciences. It's a different way of thinking about technology — not just in the private sector but also the public sector — so we make cities more efficient and economically competitive places."

Author of an upcoming book on smart cities, Clark notes that metro areas generated nearly 91 percent of the U.S. gross national product in 2015. "Technology and economic growth are interlinked," she said. "Just like a world-class airport, you need a world-class IT infrastructure, and it has to be deployed in such a way that people can access it for their own economic activities, whether it's large or small companies. We need a technological infrastructure that will work for the 21st century economy and the centuries beyond."

SMART CITIES DATA

At its core, smart cities research is all about data — on how people move throughout the city, how they consume energy, and much more. Georgia Tech's smart cities strategy aims to understand the different forms of smart cities data and then find ways to both curate that data and make it available for innovative projects. A first step was seeding a set of exploratory projects focused on city data as well as data generated on the Georgia Tech campus.

Matthew Swarts, Brian Stone, and Noah Posner, all research faculty in Georgia Tech's College of Design, are designing, building, and deploying environmental sensor stations alongside the current Georgia Tech Climate Network. The stations are solar powered and report real-time data on wind and humidity. Taken together, this sensor network provides micro-climate data across campus, informing efforts to combat the urban heat island effect and conserve energy.

Christopher Le Dantec, an associate professor in the School of Literature, Media, and Communication, is prototyping and deploying specialized sensors to track cyclist stress, integrating information about noise and environmental pollution with proximity sensors to capture information on why cycling in Atlanta can be a harrowing experience.

But not all data comes from sensors. Clark and Thomas Lodato, who is a postdoctoral fellow in the School of Public Policy, are poring over the city of Atlanta's budget and fiscal data to better understand spending and accountability issues, creating techniques for automated analysis and greater transparency.

Faculty members are also exploring how to aggregate smart cities data in virtual environments. John Taylor, Frederick Law Olmsted Professor in the School of Civil and Environmental Engineering, aims to manage urban scale data through virtual reality. Streaming reality data "creates exciting opportunities for real data analysis and contextualization, as well as testing simulated 'what if' scenarios," he explained.

Taylor's research found a natural ally with Dennis Shelden, associate professor and director of the Digital Building Lab. Shelden and his team developed a city data aggregation, visualization, and analytics platform that includes 3-D virtual reality and augmented reality interface capabilities.

The data projects support Georgia Tech's wider plans for creating, building upon, and applying smart cities data for research, operations, and implementation.

"It's important to think about the data collection, storage, and analysis in an integrated way so a city can benefit from having multiple types of sensors instead of being tied to one vendor," said Margaret Loper, chief scientist at the Georgia Tech Research Institute's (GTRI) Information and Communications Laboratory.

GTRI is also leveraging its long track record of security expertise to help cities protect their data. "The more technology a city uses, the more vulnerable it is," Loper said. "Cities need to be prepared for malicious attackers because warfare is changing in two ways. It's moving from very kinetic activities into cyberspace — and it's moving from wide open spaces to urban environments."

Civic engagement is another important aspect of smart city data strategy. Carl DiSalvo, an associate professor in Georgia Tech's School of Literature, Media, and Communication, is leading a series of design workshops where community residents meet with university researchers, city officials, and urban planners. These are interactive sessions where participants use visual tools, create maps, and act out scenarios. The goal is for residents to consider services they might want to result from the data collection — and voice any concerns about privacy and security.

> "SMART CITIES RESEARCH TOUCHES ON EVERYTHING FROM COMPUTING AND ENGINEERING TO THE SOCIAL SCIENCES. IT'S A DIFFERENT WAY OF THINKING ABOUT TECHNOLOGY."
> — JENNIFER CLARK

"We want to make sure advocacy groups and residents have a say in how smart cities develop," DiSalvo explained. "This isn't just about where to put a speed bump or a stop sign. What does it mean when sensors are being placed on your street, and who gets to use that data?"

"Smart cities may conjure up images of shiny technology and futuristic gadgets, but behind that is an effort to improve citizens' quality of life, providing not only better services but also more equitable access," said Debra Lam, who recently joined IPaT as managing director of the smart cities initiative. "What attracted me to Georgia Tech was its entrepreneurial spirit, greater sense of purpose, and willingness to collaborate — all important components to a successful smart city deployment."

NEW APPROACHES TO ENGINEERING

Another strength Georgia Tech brings to the table is systems thinking, said Reginald DesRoches, a professor and chair of the School of Civil and Environmental Engineering (CEE). "The urban environment is complex, and we have the ability to integrate physical, environmental, and social components into one large program."

A quick look at some smart cities projects within CEE includes:

CARL DISALVO

Jennifer Clark, associate professor of public policy and director of Georgia Tech's Center for Urban Innovation, is shown in Georgia Tech's Clough Undergraduate Learning Commons.

ROBOTIC BRIDGE INSPECTIONS Working with Missouri University of Science & Technology and other universities, CEE researchers are converting bridge inspections from manual to automated processes via drones and advanced data technologies. This should enable less costly and more frequent inspections, resulting not only in better decisions for regular maintenance but also faster recovery after a disaster.

GREENER CEMENT The world's most widely used construction material — concrete — accounts for nearly 5 percent of carbon dioxide (CO_2) emissions generated by human activities. These emissions stem from the calcining of limestone and burning of fuel to manufacture Portland cement, the traditional binder used in concrete, explained Kimberly Kurtis, a CEE professor who is leading a study to find greener binders. Funded by the Federal Highway Administration, the project is being done in collaboration with

continued on page 27

TED RUSSELL

SMART PARTNERSHIPS

When it comes to smart cities innovations, collaboration is king – not just across the campus, but also nationally and internationally.

METROLAB NETWORK Georgia Tech, Georgia State University, and the city of Atlanta were among the first city-university partnerships to join the MetroLab Network, which is part of the White House's Smart Cities Initiative. Announced in September 2015, the federal initiative earmarks more than $160 million to fund new technologies that address urban challenges.

"MetroLab is a framework for sharing how smart city technology can best be used," said Jennifer Clark, director of Georgia Tech's Center for Urban Innovation, noting that the network's website showcases projects from around the country. "We can see what other people are doing, and they can look at us. MetroLab is the first network of its kind to focus on the public sector, and it's already pushing forth experimentation and implementation."

HEALTHY CITIES SUSTAINABILITY RESEARCH NETWORK With $12 million in funding from the National Science Foundation, a consortium of scientists, industry leaders, and policymakers from across the United States and other countries are striving to create cities that are not only highly functional, but also healthier, more equitable, and more desirable places to live and work.

"A focus of the network is to identify interventions that can be done quickly and in a targeted fashion," explained Ted Russell, co-director of the network and a Regents Professor in Georgia Tech's School of Civil and Environmental Engineering. For example, the researchers are looking at how large cities in China can use waste heat from industry to help heat homes, Russell said. "So it's not just data coming in, but using the data to have effective interventions and work with city partners to affect change."

IMPROVING SITUATIONAL AWARENESS

The Georgia Tech Research Institute (GTRI) is working with the Georgia Tech Police Department to bring a wide variety of data – drawn from vehicle sensors, video cameras, call centers, floor plans, and more – into a common operating picture. This geographic-based interface shows the location of different sensors across campus and enables police to dive deeper and see what data the sensor is viewing or collecting at the time, explained Margaret Loper, chief scientist at GTRI's Information and Communications Laboratory.

An initial prototype is now being tested by police. The next step will be adding more data sources and improving the interface.

In a related project, GTRI is conducting research with the College of Computing to enhance campus video cameras with fog computing – decentralized computing at the edges of a network. Fog computing enables real-time analysis before data is sent to the cloud, resulting in less data being sent, increased transfer speed, and fewer security risks. Although current camera systems can retrieve and review data to see what occurred at a certain location, they don't have the ability to communicate and track activities in real-time across cameras simultaneously.

"With fog computing, the different sensors could talk to each other and push information to officers more quickly," Loper said. "This isn't needed in all situations but can help police and first responders in the event of an emergency, such as letting them know how fast a fire is spreading and where people are located or tracking a criminal who is fleeing across campus."

Although the two projects are being developed for the Georgia Tech campus, both have relevance for smart cities, Loper added. "Real-time situational awareness will help city officials make more effective and efficient decisions."

Margaret Loper, chief scientist in the Georgia Tech Research Institute's Information and Communications Laboratory, is shown on North Avenue, where Georgia Tech and the city of Atlanta jointly work on smart city innovations.

> "IT'S IMPORTANT TO THINK ABOUT THE DATA COLLECTION, STORAGE, AND ANALYSIS IN AN INTEGRATED WAY."
>
> — MARGARET LOPER

Oklahoma State University, the Army Corps of Engineers, and a consulting group. "Second to water, concrete is the most widely used substance on earth," Kurtis said. "We use more concrete each year than oil and coal combined, so even small improvements in how we produce concrete will have a huge impact."

Two years into the project, the researchers have shown that alternative cement chemistries, such as calcium sulfoaluminate and magnesium phosphate formulations, can cut CO_2 emissions almost in half while increasing the strength and durability of concrete. Each alternative binder has pros and cons, Kurtis points out. "Some are excellent for bridge substructures, while others are better for bridge decks, pavements, or tall buildings. Right now we're focused on identifying the right technology for the right application."

KIMBERLY KURTIS

CLASS: BRANDEN CAMP

A vertically integrated projects class led by Georgia Tech Research Institute researchers Lee Lerner and Mike Ruiz has been researching sensors and their broader smart city applications.

DOUBLE-DUTY PARKS CEE researchers are evaluating the impact of city parks, looking beyond their recreational role to see how they improve transportation, economic development, health, and resiliency. For example, the city of Atlanta saved $16 million by constructing a water retention pond in its Fourth Ward Park, which eliminated the need to install tunnels and piping to reduce flooding in nearby areas.

"We're trying to show urban parks are just as important, if not more so, than traditional infrastructure because of their multiple benefits," said DesRoches, pointing to increased job creation, improved air and water quality, reduced traffic, and lower health care costs. In contrast to anecdotal correlations, his team is using hard-core data to quantify such positive impact. "The availability of data has really exploded, especially in regard to air quality, traffic, and people's movement patterns," DesRoches said.

RETHINKING ENERGY DEMAND

Better data is also helping find new ways to approach energy distribution.

Urban areas account for more than 70 percent of global energy usage and about 50 percent of greenhouse gas emissions, according to United Nations statistics. Traditionally, energy demand has been estimated by looking at occupancy of individual buildings or population demographics, points out Taylor. "Yet there's a disconnect between energy use at the building and city level — in fact, people have a fairly narrow understanding of their overall energy use," he said.

"For example, people may practice low energy consumption habits at home where they get utility bills and pay directly for their energy use," Taylor explained. "At work, however, where they don't get feedback on their energy use or pay directly for it, people may then consume disproportionately large amounts of energy. They also make transportation choices without much knowledge about how the energy footprint of one mode compares to another."

To predict energy demand more accurately, Taylor's team is analyzing how people's movements and activities fluctuate over the course of the day. Such spatiotemporal trends once were impossible to study because data was sparse, available only from surveys and monthly energy bills. That has changed, however, due to advances in technology such as cellphones with GPS data, smart-card commuting data, and location-embedded data from online social networks. "The things we carry around in our pockets every day can now be leveraged as sensors," Taylor said.

Using data from Chicago and London, Taylor's team has shown a correlation between mobility and fluctuations in gas and electricity consumption across the cities. The researchers are now gathering data to study fluctuations in energy use across Atlanta.

"This could be a paradigm shift," Taylor said. "A spatiotemporal framework can provide a new picture of energy demand and help cities make better decisions about evolving infrastructure to accommodate shifting demand — along with better strategies for abating CO_2 emissions."

There's also a tie-in with resiliency and how natural disasters affect mobility in urban areas. Using data from social media, Taylor's team is trying to create a framework that not only can communicate real-time conditions for improved evacuations, but also predict the location of displaced people after a natural disaster.

ENHANCING TRANSPORTATION

As cities sprawl larger, getting around quickly and safely becomes even more difficult, particularly from a sustainability perspective. Public transit is attractive because it reduces gasoline consumption, CO_2 emissions, and roadway congestion, but transit authorities are challenged by low ridership.

Improving service is one way to fill seats, and Georgia Tech researchers are developing new ways to avoid "bus bunching" (when transit vehicles are delayed and end up following each other in close proximity). With that in mind, a group led by John Bartholdi in Georgia Tech's School of Industrial and Systems Engineering has created a "self-equalizing" system to keep campus buses spaced more evenly. Via GPS sensors, the system constantly reports each vehicle's location to a central server. When a bus reaches a stop, an algorithm compares its headway with the trailing bus and then sends a message to the drivers' cellphones to let them know when to depart.

Taking this idea to another level, Kari Watkins, an assistant professor in CEE, and doctoral student Simon Berrebi have

Kari Watkins, assistant professor in Georgia Tech's School of Civil and Environmental Engineering, and doctoral student Simon Berrebi are helping cities improve their transit services.

devised a real-time dispatching method now being tested on the Atlanta Streetcar system. Similar to Georgia Tech's buses, the system also operates on headways rather than fixed schedules. "Yet instead of looking only at the most recent vehicle, our algorithm uses real-time predictions for all vehicles on the route, which increases accuracy when multiple vehicles are running on the same route," Watkins explained.

Another hallmark of the system is a barometric sensor kit developed by Russell Clark, a research scientist in Georgia Tech's School of Computer Science, and Bill Eason, a research scientist in IPaT. The kit tracks elevation changes to determine each vehicle's location, thus solving the "urban canyon" problem, where streets with tall buildings can block GPS signals. "Even if the vehicle isn't getting a great GPS signal, the information from the barometric sensors helps us to determine the vehicle location," Clark said.

SANFORD AND COLLEAGUES ARE DEVELOPING ALIGN — AN APP THAT HELPS PEOPLE PLAN ROUTES BASED ON THEIR ABILITIES AND PREFERENCES. IT INCLUDES DATA ON:

- CURB CUTS
- WALKWAYS
- TRAFFIC SIGNALS
- UPHILL CLIMBS
- HIGH-CRIME AREAS
- UNSHADED SIDEWALKS

Beyond operational improvements, simply giving people better information about what's going on can work wonders, points out Watkins, co-creator of OneBusAway, a phone app that provides real-time information about the arrival time of buses and trains. Launched in 2008, OneBusAway and rebranded versions are now used by a dozen cities.

Researchers continue to make improvements to the open-source app and add more information for riders, such as trip planning. OneBusAway also collects information to evaluate the impact of real-time data on ridership. In Seattle, 92 percent of riders reported higher satisfaction with public transportation, and in New York City, annual ridership increased by an estimated 8 million. "Real-time data enables cities to provide riders with improved service without necessarily adding more buses or trains on the street," Watkins said.

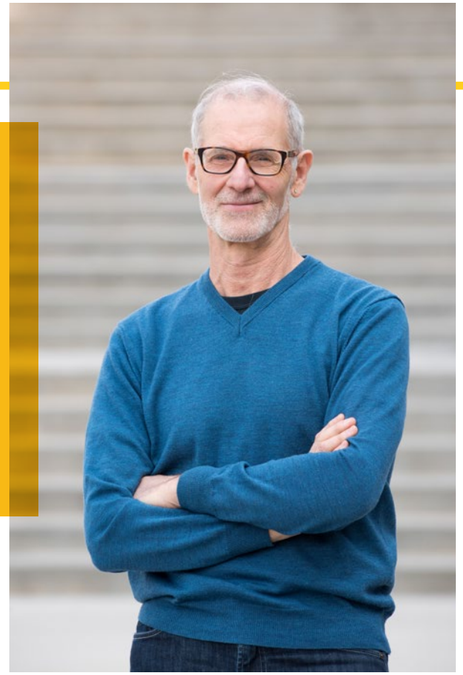
BETTER BIKING

In another project, Watkins and Le Dantec have created an app to help city officials improve infrastructure for bikers. Introduced in 2012, Cycle Atlanta enables cyclists to record their trips on smartphones in real time, reporting any problems they encounter.

The app also collects information about participants' age, gender, income, reason for biking, and confidence levels about riding in traffic. "This segmentation helps planners understand where they can address the largest population when thinking about new cycling infrastructure," Le Dantec said, noting the data goes to city officials and the Atlanta Regional Commission. "We get more commuters than fitness riders, and there are statistically interesting differences in the route choices those riders make."

Le Dantec and graduate students are now enhancing Cycle Atlanta for more targeted sensing. The idea is to develop a sensor package that volunteers can attach to their bikes and collect more detailed data, such as number of lanes on a street, bikers' proximity to other vehicles and parked cars, and traffic speed. "A street may have a posted speed for drivers, but everyone goes 10 mph faster," Le Dantec explained. "We want to get a better understanding of what's actually going on — things that you wouldn't know from looking at the paper specs."

Cycle Atlanta stands out from other biking apps by informing city planners where biking infrastructure should be built — and it enables a new form of civic advocacy. "Instead of having to show up at a city meeting and shout into a microphone that you want a bike route on Peachtree Street, you can have input by riding on Peachtree on your daily commute and sharing that data with



Jon Sanford, professor in the College of Design and director of the Center for Assistive Technology and Environmental Access, is helping improve mobility for older residents.

the city," Le Dantec said. "Smart cities research is about finding new ways for people to have a role in creating the kind of cities they wish to inhabit."

Le Dantec points to a community engagement playbook he has created for five neighborhoods on Atlanta's west side, a year-long project with the city of Atlanta, Atlanta Housing Authority, and the Westside Future Fund. The first of its kind in Atlanta, the playbook is geared to help city personnel, community organizations, and residents work together better on planning and development projects.

"This doesn't mean groups will always come to agreement, but at least there is a process they can go through to determine outcomes," Le Dantec said. "Smart cities is about smarter citizens — building not only technologies but also processes and relationships that connect citizens to each other and local institutions."

SENIORS AND THE CITY

"Aging may not seem like part of the smart city mix, but it should be," observed Jon Sanford, a professor in Georgia Tech's College of Design and director of its Center for Assistive Technology and Environmental Access (CATEA). Cities are where the majority of elderly adults live, and they are most vulnerable to the demands of the urban environment, he points out. "We can fix housing, but what good is that if people become prisoners in their own homes? Community mobility is crucial for older adults to successfully age in place."

One way to make urban areas more accessible for older residents is to provide the right kind of environmental information to guide them. "It gets people over the hump of not venturing outside because they fear that an uneven sidewalk might cause a fall or a missing curb ramp might make destinations unreachable," Sanford said.

With that in mind, Sanford's team at CATEA and the Center for Geographic Information Systems (CGIS) are developing a software app that helps people plan routes based on their abilities and personal preferences. Known as ALIGN (Application for Locational Intelligence and Geospatial Navigation), the app includes more than 50 factors, ranging from accessibility issues, such as curb cuts, walkways, and traffic signals, to things like avoiding high-crime areas, uphill climbs, or unshaded sidewalks. An initial prototype has been successfully tested, and the researchers are now incorporating more real-time data about traffic and weather conditions as well as crowd-sourced information on actual route conditions. Although the current app uses GIS data from Atlanta, it could be deployed anywhere.

In contrast to existing apps for wayfinding and accessibility, ALIGN enables each user to choose the specific information that is important for him or her to get around. "Obviously the more factors you select, the less likely you are to find a route meeting all requirements," Sanford said. "So we've designed ALIGN to let you know exactly where the route doesn't meet your criteria."

GREGORY ABOWD

Get all the Georgia Tech research news as it happens. Visit **www.rh.gatech.edu/subscribe** and sign up for a monthly e-newsletter and more.

INTELLIGENT WELLNESS

In another twist on smart cities, Gregory Abowd, a Regents Professor and J.Z. Liang Chair in Georgia Tech's School of Interactive Computing (IC), is investigating how digital footprints can provide insights into wellness and performance.

The project, known as CampusLife, builds upon an earlier study with Dartmouth College students. During a 10-week period, a continuous sensing app on participants' smartphones collected data about their location, physical activities, eating habits, and apps they were using. This data, as well as answers students provided to occasional survey questions, was then used to correlate students' academic performance with mental health and behavior.

Expanding on this, Abowd, along with IC chair Annie Anton and assistant professors Munmun DeChoudhury and Lauren Wilcox, have organized a consortium with Dartmouth and other universities to collect more data over longer periods of time. The goal is to create a sort of virtual wellness coach.

By looking at participants' interactions with mobile and wearable technology, social media, and the environment, along with self-reported data, the researchers hope to create software that reflects back actionable information. For example, if participants report feeling stressed, the system could help them understand whether they are experiencing good stress or bad stress and what to do. Another objective is to help students take advantage of various university services available to them. "By having a device and infrastructure that knows a lot about the person, appropriate guidance can be triggered at the right time and place," Abowd said.

Pilot studies are being conducted as the researchers strive to standardize software tools and research protocols that can be easily repeated. Another task is evaluating the right mix of passive and self-reported data to collect. Over the next two years, the researchers hope to conduct large-scale studies and build a bigger picture of students' interaction with the campus.

Besides helping individuals, this could be used with different cohorts, such as engineering majors versus business majors or second-year students versus first-year students. "We want to understand the behavior of a group and then reflect information back so they can achieve desired outcomes," Abowd said.

Ultimately, the software could be adapted for businesses or even an entire city, Abowd added. "Just as we use electronic devices to navigate geographic routes or find entertainment venues, the idea is to have wellness information delivered as we need it and tailored to our interests and location."

T.J. Becker is a freelance writer based in Michigan. She writes about business and technology issues.

THE BRAIN

COSMOS IN THE CRANIUM

Neuroscience researchers explore our most magnificent and vast organ — from the mighty effects of tiny genes to the building blocks of thought.

STORY BY BEN BRUMFIELD — ILLUSTRATION BY MICHAEL MARSICANO

NEURONS: ISTOCKPHOTO.COM; LU: ROB FELT; *C. ELEGANS*: OPEN WORM PROJECT

TUCKED AWAY INSIDE YOUR HEAD IS A LIVING GALAXY.

The human brain is believed to have more than 160 billion cells; more than half of them are neurons. And they often share thousands of connections with neighboring neurons to form somewhere between 100 trillion and a quadrillion circuits flashing day and night. That's many hundreds of times more circuits than there are twinkling stars in the Milky Way.

Innumerable barrages of electrochemical transmissions adjust your pulse and immune system, hold you upright, and allow you to do carpentry or calculus — all at the same time. Neural circuits let us eat, love, dream, or just be.

No room-filling supercomputer consuming millions of watts of power has come close to the composite abilities of our two heaping handfuls of gray and white matter. And our brain needs only 20 watts to operate, less than many lightbulbs.

At the Georgia Institute of Technology, a rare synergy of engineers and scientists, in cooperation with Emory University School of Medicine and other collaborators, is expanding data collection and analysis on the brain.

The research road ahead feels endless, many neuroscientists say, and comprehending how the brain generates the human psyche may be decades beyond the horizon. But neuroscience is in a forward lunge powered by sweeping national funding programs such as the BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies), which is tapping into the brain to understand it and support well-being.

In this article, a sampling of Georgia Tech's many neurological researchers share fascinating insights about the brain and relate them to their work. We start microscopically with single molecules that have colossal effects on the brain, and end macroscopically with how the brain finds its way home, watches a movie, and how it never switches off.

1 MOLECULAR DESTINIES

One misplaced molecule can steer a brain to ruin. A rare form of Alzheimer's disease called early onset familial Alzheimer's, for example, can be caused by one small mutation.

But mutations happen all the time and are almost always harmless. So, in the lab, when a slip in a strand of DNA triggers a cascade of changes to a tiny animal's nervous system and overhauls its behavior, that piques researchers' interest.

Patrick McGrath and Hang Lu at Georgia Tech develop experiments to identify these interesting mutations in microscopic *C. elegans* roundworms. They study changes in the structure of the nervous system or the animals' behavior and try to locate the genetic alterations behind them.

Though they work with worms, McGrath, an assistant professor in the School of Biological Sciences, and Lu, a professor in the School of Chemical and Biomolecular Engineering, look for cues on how genetics can raise the risk of human neurological diseases.

"The nerves in roundworms can be like our own, and important genes in *C. elegans* are quite similar to those in humans," Lu said. "That's the way evolution works. When something works well, like the basic structure of neurons, it gets passed on to other beings."

C. elegans are like baggies of 302 neurons connected in a concise neural network that researchers can easily study. "In 1986, a team of researchers figured out how the neurons are all connected to each other," McGrath said. "And the sequence of the DNA has been known since 1998."

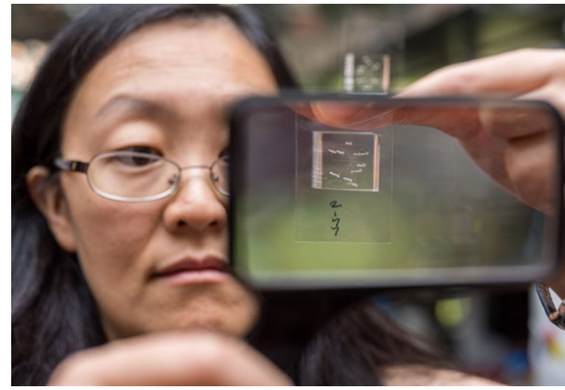
With the connectome and genome so well laid out, the little worm has led the way in research relating the two. And some insights have shown potential to improve understanding of human neurology, like a marked mutation that turned up on a gene labeled *npr-1*.

C. elegans usually eat together in groups of 40 or 50, but after living in the lab for a few years, a strain suddenly turned up that ate alone. "It could have been caused by mutations on 100 genes," McGrath said, "but in fact, it was just a single genetic change." In *npr-1*.

That affected the workings of a neuromodulator, a signaling molecule that touches large parts of the nervous system. The mutation triggered sweeping alterations in the sensing of oxygen, CO_2, pheromones, and pain, which led to the isolative behavior.

"This gene has a homolog in humans that is, in some way, modifying our brain activities," McGrath said. Exactly how is yet unclear.

The neural traits most interesting to science and medicine are much subtler ones, virtually undetectable when taken alone, but when added together by the

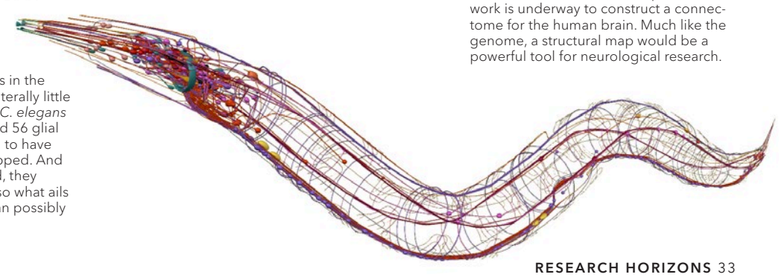


To detect nearly invisible traits, School of Chemical and Biomolecular Engineering Professor Hang Lu has engineered microfluidic devices that hold *C. elegans* worms still, so a digital camera can photograph them.

NEUROLOGY TERMINOLOGY

C. elegans

Microscopic roundworms in the genus *Caenorhabditis*. Literally little bundles of nerves (each *C. elegans* contains 302 neurons and 56 glial cells), it is the first animal to have its connectome fully mapped. And since nerves first evolved, they haven't changed much, so what ails a roundworm's nerves can possibly ail ours too.



NEUROLOGY TERMINOLOGY

Connectome

A map of neural connections in the brain, or the entire nervous system. In the case of *C. elegans*, the connectome has been completely constructed (below). Partial connectomes of a mouse's retina and visual cortex have been completed, and work is underway to construct a connectome for the human brain. Much like the genome, a structural map would be a powerful tool for neurological research.

Todd Streelman, a professor in the School of Biological Sciences, which he also chairs, studies evolutionary genetics in fish to find links to human behavior.

STREELMAN, CICHLID: ROB FELT; PATCH CLAMP: ERICA ENDICOTT

thousands, raise the risk of diseases like autism, depression, and schizophrenia.

To develop the capability to detect such nearly invisible traits, Lu has engineered microfluidic devices that hold *C. elegans* worms still, so a digital camera can photograph them, while an algorithm determines if neuron phenotypes (traits) have subtly malformed. Then software maps individual trait changes to individual gene mutations, so researchers can study possible links to disease.

2 BEHAVING FISHY

Behavior is much of what the brain is for, so when studying how the brain evolved, it makes sense to give behavioral evolution abundant attention. That could lead to insights relevant to human disorders that diminish behavioral abilities, such as autism.

Oddly, autism's suspected genetic foundations have correlations with genes tied to the mating behavior of colorful fish called cichlids, which Georgia Tech evolutionary geneticist Todd Streelman studies.

"The genes that are activated in behaving fish brains have human homologs that are over-represented in a catalog of genes involved in autism spectrum disorder," said Streelman, a professor in Georgia Tech's School of Biological Sciences, which he also chairs.

Streelman pointed out that autism and cichlid mating rituals are not the same thing, but the rituals are social behavior, and also extremely repetitive. And autism, as well, typically involves social deficits and repetitive behavior.

To attract females ready to mate, some cichlid males build underwater sand castles; other species dig pits. In both cases, they spit mouthfuls of sand some 700 times in an hour.

When researchers crossed a castle-building species with a pit digger, the offspring constructed both pits and castles in sequence. "That suggested that you have two genetically determined neural networks," Streelman said. And they dictated complex behavior.

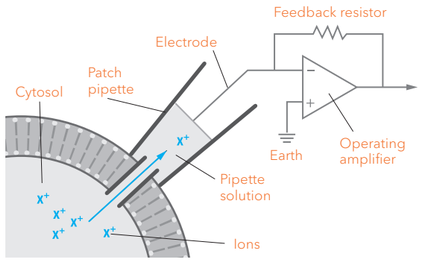
Streelman correlates genes with encoded behaviors — which some may call "instincts." He also checks the cichlid's brains for physical characteristics linked to the genes and behaviors.

Malawi cichlids are ideal genetic study subjects because they are evolutionary wonders. In just a million years, the branch of

NEUROLOGY TERMINOLOGY

Patch clamp

The patch clamp technique allows for electrical measurements of a single neuron. A tiny glass pipette, its opening only one micron wide, is sealed to the outside of the cell membrane. As ions flow across the gradient through the channels, an electrode reads the current.



Genes tied to the mating behavior of cichlids, a type of fish, have correlations with autism's suspected genetic foundations.

fish has popped out hundreds of species specialized for life in various ecological niches.

Cichlids have clearly identifiable varieties of phenotypes (traits), including varying behaviors, but their genomes fluctuate only slightly from species to species, making it easier than in most complex animals to pin down genes suspected of being behind specific traits. And RNA helps scientists locate them.

Genes not only orchestrate embryonic development but are also active in cells during life, including to influence behavior. They encode RNA in the process, which leaves a convenient marker.

"The technologies we have now enable you to figure out what parts of the brain have been activated during behavior, then sample RNA from those parts of the brain to find out what genes have been expressed," Streelman said.

3 GROUND NEURO

Recording the flickers of one or a few neurons is important for understanding how the whole brain computes.

But for decades, scientists have been lucky if a hard day's work yielded even a single decent measurement from a neuron firing in a mouse's brain. Now, engineer Craig Forest has designed systems using robotics that can reliably take many measurements in a day.

"We're seeing a renaissance in tools to see how the brain works," said Forest, associate professor in Georgia Tech's George W. Woodruff School of Mechanical Engineering. "In the past decade, due to the BRAIN Initiative, there has been a paradigm shift in the tools."

Forest is a prime example of this shift, improving upon good technologies to exponentially burgeon the yield of data.

A Nobel Prize-winning hollow glass needle, called a patch-clamp pipette, has long been considered the gold standard for electrical measurements of a single neuron. It has an opening at its tip just a micron across, and a skilled researcher with a few hours' time might be able to fiddle it onto a neuron in a living brain by hand. Mild suction clasps it onto the cell membrane, so it can pick up the neuron's electrical activity.

Forest and colleague Ed Boyden at the Massachusetts Institute of Technology thought there must be an algorithm that could do the job more precisely, so they built robots to operate

patch-clamps, freeing scientists to do other things. But an annoying hitch remained.

After every attempted measurement, the scientist or the robot would have to discard the patch-clamp, because it was dirty, and get a fresh one. So, Forest and his team went to work on a robot that also self-cleaned the patch-clamp, making the needle reusable and multiplying the number of automated measurements per day.

Forest started his career fascinated by machines, until he discovered the most wondrous one, the brain, and dedicated his attention to it. "In one cubic millimeter of the cortex, there's 10,000 neurons. That's 10,000 microcircuits processing something. Humans have never made anything that complicated," he said.

That cubic millimeter is a functional unit called a cortical column.

Neuroscientist and biomedical engineer Bilal Haider deploys tools in awake brains to see how the rumblings inside an individual neuron relate to its neighbors' activities. He also uses computational analysis to predict the overall relation of a cortical column to a single neuron's firings.

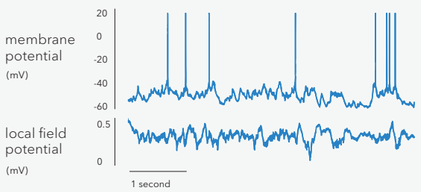
Neurons are great at holding their fire — at *not* sending signals. Without this inhibition, our brains would crash in a frenzy of activity.

Most cortical neurons excite neighboring neurons to fire, but a fifth of them inhibit their neighbors instead. "They are very critically important for, first, not letting activity generate things like epilepsy, but also to set the clock of when messages are being passed," said Haider, an assistant professor at the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University.

In brain signaling, timing is quality; it's the difference between tapping out clear digital code to other neurons or just handing them noisy static. Inhibitory neurons create pauses between the taps.

In the cerebral cortex, which many refer to as gray matter, those taps constantly bombard neurons, but their reaction is usually stoic.

WHAT'S ON YOUR NERVES



When Bilal Haider's team measured electric potential in a cortical column, they saw an orchestra of activity in the group of neurons (the local field potential) – excitatory and inhibitory forces were constantly at work, even though neurons actually sent signals (spikes in the membrane potential) only at comparatively rare intervals.

Funding for McGrath, Lu, Streelman, Forest and Haider was provided by the National Institute of Neurological Disorders and Stroke, the National Institute of General Medical Sciences, the National Institute of Biomedical Imaging and Bioengineering, and the National Institute on Aging, all part of the National Institutes of Health. Funding was also provided by the BRAIN Initiative, the Single Cell Grant program, and the National Science Foundation.

"IN ONE CUBIC MILLIMETER OF THE CORTEX, THERE'S 10,000 NEURONS. THAT'S 10,000 MICROCIRCUITS PROCESSING SOMETHING.

HUMANS HAVE NEVER MADE ANYTHING THAT COMPLICATED."

School of Mechanical Engineering Associate Professor Craig Forest has developed automated patch-clamping instruments to accelerate the recording of information from neurons. In this photo, an instrument is protected by a Faraday cage.

"The state is usually in balance, with the neuron sitting there happily between the excitatory and inhibitory forces," Haider said.

An orchestra of activity runs through a neuron even without it firing a single spike down to its synapses — or contact points — with other neurons. Then a person does something that activates that part of the brain, and the neuron readily fires, and usually not alone: A mass of its neighbors fires together with it.

4 PARADOX LABYRINTH

The brain is a master of contradiction.

Though individual neurons are hesitant to fire, the brain's neural networks can still compute in milliseconds. Also, while the brain plays by many rules that are nearly the same across many species, from rodents to humans, viewed up close, those rules bend like eels.

Garrett Stanley, a mechanical engineer turned neuroscientist, studies the brains of rodents to understand neural networks, patterns that fire through the brain as it computes.

"We record from multiple parts of the brain simultaneously, which is signature work for our laboratory," said Stanley, a professor at the Wallace H. Coulter Department of Biomedical Engineering. Stanley's lab is able to measure many elements in neural pathways triggered by prodding a rat's whisker.

The tactile stimuli make their way as impulses traveling up

ROB FELT

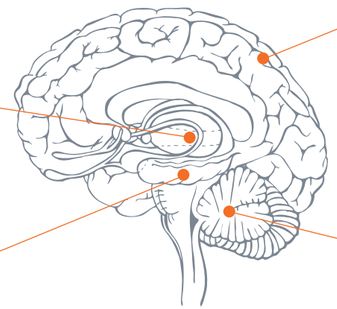
NEUROLOGY TERMINOLOGY

Thalamus

The thalamus acts as a kind of "super-turnstile" for signals in the brain – it relays inputs coming from sensory systems to the cortex and also regulates states of sleep and wakefulness.

Hippocampus

From the Greek for "sea monster" (a description of its shape), the hippocampus is responsible for spatial memory and navigation. It also plays an important role in the consolidation of memory.



Cerebral cortex

The cerebral cortex is the outer layer of gray matter of the cerebrum, the large outer part of the brain. Neurons in this layer connect vertically to form cortical columns.

Cerebellum

The cerebellum, along with the brainstem, is primarily concerned with motor control, contributing to our coordination, precision, and accurate timing of muscle movements.

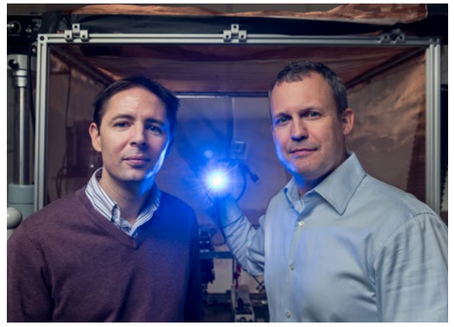
nerves to the brain, which then fires signals to multiple brain regions to compute information together and create perceptions.

The neural pathways are pretty shifty.

"Unlike a network of computers, our brain is always changing what it's doing and how it's doing it, based on what it's experiencing," said Chris Rozell, associate professor in Georgia Tech's School of Electrical and Computer Engineering, who collaborates with Stanley to produce new designs for experiments.

Neural pathways constantly reroute.

"Imagine a subway map where the rules are changing on the fly," Stanley said. "New lines suddenly appear, and old ones go away, and fewer or more cars appear on the line spontaneously depending on passenger demands."



Chris Rozell, associate professor in the School of Electrical and Computer Engineering, and Garrett Stanley, professor in the Wallace H. Coulter Department of Biomedical Engineering, show a light used in their optogenetics work.

Those paths can engage a neuron that Stanley and Rozell are trying to study in a calm state, thus confounding observation, but they and former Georgia Tech researcher Steve Potter have devised a way of slightly distracting neural activity away from it. They have used genetically modified brain cells that they can make fire more by shining a light on them, a method called optogenetics.

And the team has added an innovation: a neural cruise control. "We use neural recordings as the speedometer to instantaneously raise or lower doses of light, which act as a gas pedal," Rozell said. That allows them to make neurons do a lot more of what they'd like them to do.

Rozell also makes computer science-based models that emulate the way the brain computes perceptions, though brain-machine comparisons face a challenge. For example, machine networks have discrete parts for memory, graphics, processing, and also firm wiring.

"In a brain, those functions are all intertwined in flexible shared elements," Rozell said. Multiple back-and-forth pathways light up simultaneously, and Rozell wonders if the brain's computing may have something to do with those pathways coming into some sort of equilibrium.

The brain is so highly interconnected that every part of it seems like it's closely wired to every other part, opening up countless possible neural signaling pathways. But some very strong tendencies put reins on them.

"Not all of those paths are equally likely to be traveled," Stanley said. "Some connections are much better wired than others due to genetic determination, or learning behavior." Human behavior is partly genetically encoded and formed during development, like the capacity to speak, and partly learned, like mastering a language.

Some neural pathways are well paved, like signals for perception and motor movement traveling via the thalamus, a structure in the deep brain that acts as a neural super-turnstile. It is critical to coherent brain function, as it routes and modulates signals to and from the cortex, where some locations, like the visual cortex or the motor cortex, are assigned to specific functions.

5 SEAHORSE GPS

The hippocampus is aptly named. "Hippo" is ancient Greek for "horse," "kampos" for "sea monster." The deep brain region is curve-shaped like a sea horse, and it helps you get around from place to place by facilitating orientation.

It also slows down noticeably with age, and in Alzheimer's disease, the hippocampus succumbs early on, leaving sufferers disoriented. That disease helps put the hippocampus in researchers' focus.

Work on its encoding of location garnered scientists a Nobel Prize in 2014 for describing the brain's GPS. They also found that the hippocampus, which is important for memory as well, lays down some consistent neural code, contrasting with neural networks' often fluxing firing patterns.

"It was shown back in the 1970s that there are neuron groups in the hippocampus that fire in a particular location in space," said neuroscientist and biomedical engineer Annabelle Singer, who studies hippocampal function in mice at the Wallace H. Coulter Department of Biomedical Engineering. "If the mouse is running around this room, for example, when it gets to this one spot, there's a subset of cells that will fire." Other subsets fire when the mouse arrives at other spots.

The existence of such neural activity has also been corroborated in humans.

Let's label the cell groups that do this A, B, C and D. As you stroll to your local coffee shop (or as a mouse in a lab runs through a video maze toward a reward), neurons fire in sequence corresponding to recognized physical locations along the way. Sidewalk, fire A. Crosswalk, fire B. Supermarket entrance, fire C. Coffee shop counter, fire D.

Singer is researching how such cell groups collaborate to encode paths in the first place. And she has observed them firing in other instances. For example, when a mouse licks a delicious reward for running a maze, the pattern re-fires. "You get, really quickly, A-B-C-D. That's called reactivation, or replay."

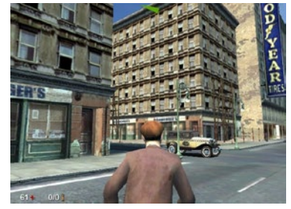
What Singer does in mice, researcher Scott Moffat from the School of Psychology mirrors in his work with humans. He has human subjects navigate through video mazes inspired by video mazes rodents run, in part because, if mice and humans perform the same task, it makes comparing their brain activity easier.

But whereas Singer zeros in on finer neuron activities in a mouse's brain, Moffat uses functional magnetic resonance imaging (fMRI) to measure broader patterns in humans' brains. He focuses on diminishing navigational abilities in aging.

"There are very consistent areas of the human brain that are activated during navigation tasks," Moffat said. The hippocampus taps into nearby brain regions like the parahippocampus, which has an area for computing place recognition. It even lights up when people just look at pictures of places.

Annabelle Singer, assistant professor in the Wallace H. Coulter Department of Biomedical Engineering, studies how the hippocampus' neurons fire as the brain creates orientation in a video maze seen in the background.

"There are very consistent areas of the human brain that are activated during navigation tasks," said Scott Moffat, associate professor in the School of Psychology. He uses an fMRI machine, above, to record the patterns of brain activity in humans who are navigating a virtual landscape, right.



ROZELL AND STANLEY: ROB FELT; SINGER, MOFFAT: CHRISTOPHER MOORE; VIRTUAL LANDSCAPE: COURTESY STEPHEN MOFFAT

Lena Ting, professor in the Wallace H. Coulter Department of Biomedical Engineering, covers subjects in tracking markers and video records them while they are thrown off balance by a floorboard that shifts abruptly.

"Younger people activate these areas when doing spatial tasks," Moffat said. "When we run older people through these virtual navigation tasks, what we see pretty consistently is underactivation in the same areas."

In Alzheimer's patients, as these areas break down, sufferers begin to lose their way and can even go missing.

6 I, ROBOT

Want to try an experiment that shows how your brain, without your even noticing, keeps you from tipping over?

Reach out your hand like you're going to pick up a glass, and then pull your hand back. Repeat that motion and observe your torso. That back-and-forth sway is balance correction courtesy of your lower brain: the cerebellum and brainstem, which are adjusting multiple muscles to preserve your balance.

Funding for Singer, Moffat, and Ting was provided by the National Institute for Neurological Disorders and Stroke and the Eunice Kennedy Shriver National Institute of Child Health and Human Development, both part of the National Institutes of Health, and the National Science Foundation.

Now you have a small sampling of what mechanical engineer Lena Ting observes to study the nervous system's control of balance. She looks at the body in motion to gain insights about the brain.

"I can describe the mechanics, and if I have a good model of that, I should understand something about how the system is controlled, which gets me to what the brain and the nervous system are doing," said Ting, a professor in the Wallace H. Coulter Department of Biomedical Engineering. She started out studying biological motion control to apply it to robots, but now also concentrates on evaluating rehabilitation techniques for people suffering from neurodegenerative diseases like Parkinson's.

"We're looking at how muscles are controlled in functional units we call motor modules," she said. One motor module might be the combination of muscles that go to work when you extend your arm. Others would kick in when you hop on a bike.

Though motor modules work for the most part automatically, initially, they probably had to be learned, like when a child learns to stay balanced on a bike.

Also, our huge cognitive brain regions can override automatic balance to make us willfully walk upright when we otherwise couldn't, perhaps due to a neurological ailment. But that overriding has limitations, because the brain regions that do it aren't optimally wired for balance control.

"If you ride a bicycle, and you go through a narrow gap, if you think about it too much, you may wobble a lot," Ting said, "whereas, normally, you could probably pass through that space."

Elsewhere in the nervous system, your spinal cord is doing some things on its own, like triggering reflexes.

To watch these various functions interplay, in her lab at Emory University, Ting covers subjects in tracking markers and video records them while she purposely throws off their balance using a floorboard that shifts around abruptly. Cameras roll as the subjects strive to maintain posture — not an easy thing to do.

But watching them flail may help Ting assess the effectiveness of rehabilitation methods in treating neurological disabilities.

TING: ROB FELT; FMRI: COURTESY SHELLA KEILHOLZ

7 ALL TOGETHER NOW

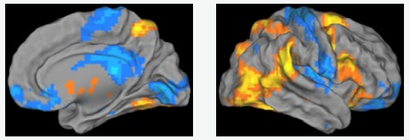
When cognitive neuroscientists say "cognition," they're not usually referring to how the brain ponders, but instead to how its networks learn facts, recall memories, or pay attention.

Though scientific understanding of "thought" and "psyche" may lie far down the research road, elements of "cognition" could be their building blocks, and the brick layer could be something called "cognitive control." Cognitive psychologist Eric Schumacher studies how cognitive control employs functions like attention, memory, and learning to make very simple decisions or complete a nominal task.

"When you're reading a book, you may want to understand the facts," said Schumacher, an associate professor in Georgia Tech's School of Psychology. "Your brain has to guide your eyes, encode the words, and link them up to knowledge you already have. There's a way your brain recruits systems to achieve that, which is what we mean by control."

Cognitive control constantly adjusts this coordination of senses, movements, knowledge, memory, and more. It's an array of processes not yet completely understood, so to get a handle on some of them, Schumacher lets volunteers watch action movies and observes their brain activity in an fMRI.

GETTING SOME ACTION



Broad patterns of brain activity measured by functional Magnetic Resonance Imaging (fMRI).

"Things change as we go through the world, and movies, with their flow of actions, allow us to study that in a scanner," he said. For example, there's a marked contrast in the way the brain lights up during moments of high suspense and low suspense in the story line.

"With increasing suspense, you become more interested in the story, and regions of the brain's visual systems that process the center of the screen, where the movie is, become more active, selecting more information from the film, and regions that process the visual periphery become less active."

"That's neural evidence for the focusing of attention," Schumacher said.

Other brain regions — in the parietal and frontal lobes — are known for allocating that attention from one thing to the next. "There's more activity in those regions in moments of high suspense," Schumacher said.

And that cognitive control appears to link suspense with learning. "People are more likely to remember information presented at moments of high suspense than in moments of low suspense," Schumacher said.

"WHEN WE STARTED DOING THESE STUDIES, WE THOUGHT RESTING STATE ACTIVITY BASICALLY WOULD FLY UNDER THE RADAR. THERE'S MORE INFORMATION IN THIS MRI THAN WE'D EVER HOPED TO FIND."

8 THE ZONE-OUT ZONE

Relax. Zone out. Welcome to the brain's default mode network, where it may feel like the mind is just wandering. But a lot is still going on in the brain, which never shuts off.

Don't believe it? Initially, Shella Keilholz didn't quite either. The physicist, who researches in neuroscience as associate professor in the Wallace H. Coulter Department of Biomedical Engineering, thought that any activity in a brain in default mode would be extremely faint.

"When we started doing these studies, we thought resting state activity basically would fly under the radar of our detection possibilities," she said. She's glad that was wrong. "There's more information in this resting state MRI than we'd ever hoped to find."

"All these areas like visual cortex and auditory cortex that are ready for input from the outside world, their activity goes down, and the activity in this default mode network and the areas attached to it go up," she said. The energy level, in sum, doesn't change. It just kind of spreads around the brain.

Even though a volunteer subject may be lying flat and still, areas in the brain responsible for hand movement appear to be softly talking to each other. The default mode network stays on during most of sleep. It's even on during a coma.

The brain transitions a lot between the default mode network and the task positive network, which becomes active when people do externally focused activities.

To research this, Keilholz has people gaze at a little blue dot and relax.

When the dot suddenly turns purple, the research subjects are supposed to punch a button, which requires the brain to quickly suppress the default mode network and jump into the task positive network.

Surprisingly, the more strongly a test subject went into default mode network, the more quickly they could bolt out of it and into the task positive network.

Keilholz has found an innovative way to address one of neuroscience's great challenges. In rodents, she is taking measurements on a neuronal level and is correlating them with broader measurements of the fMRI. This may someday allow scientists to know what is going on between small bunches of neurons just by looking at an MRI image.

Ben Brumfield is a senior science writer with Georgia Tech's Institute Communications. He is a former CNN.com editor.

Funding for Schumacher and Keilholz was provided by the National Institute for Neurological Disorders and Stroke and the National Institute of Mental Health, both part of the National Institutes of Health. Funding was also provided by the National Science Foundation and the Defense Advanced Research Projects Agency.

KILLING THE MIND FIRST

This could be your own story someday, unless medical research makes significant strides against Alzheimer's

STORY BY BEN BRUMFIELD — ILLUSTRATION BY MICHAEL MARSICANO

Van Earl Wright, Scotland Wright, Alice Wright-Stephens, and Bryant Wright. "That was just real sad grief for me, a lot of crying time," Wright-Stephens said of her experience watching her mother, Beth, decline. Beth died in 2013 from Alzheimer's disease, and their father now has the same illness.

When George Wright buried his wife, Beth, in 2013, he was probably easing into the same illness that had killed her at age 84. But his adult children hadn't yet noticed that he, too, had Alzheimer's disease.

Their eyes had been fixed on their mother while her mind unraveled, and doctors had no way of stopping or slowing the deterioration. Her last three years had been particularly painful for them.

"That was just real sad grief for me, a lot of crying time," said Beth and George's daughter, Alice Wright-Stephens. "Just watching that great lady disappear right before my eyes. She was there, but she wasn't."

That's almost exactly how the first patient with "senile dementia" ever recorded by Dr. Aloysius Alzheimer described herself: "I've lost myself, so to speak," Auguste Deter told the psychiatrist again and again in 1901.

"She was there, but she wasn't."

— ALICE WRIGHT-STEPHENS, *on her mother's last three years living with Alzheimer's*

Urgent need

In the 116 years since Dr. Alzheimer was unable to help Deter, unfortunately, not much has changed. The research path has been vexing, while the need for progress has become urgent — especially as people live longer.

Among people who make it to age 85, some 50 percent will have Alzheimer's, which afflicts slightly more women than men. Consequently, most everyone knows someone who is suffering or has died from the disease.

Late last year, U.S. research on Alzheimer's received a significant boost in funding. And recently — aided by new tools — scientists, doctors, and engineers around the world have been making fascinating inroads, including at the Georgia Institute of Technology, which collaborates with Emory University's highly regarded Alzheimer's research center.

Some of their insights include: Alzheimer's may work much like mad cow disease. It also may have aspects of inflammatory disease. And a special light has caused immune cells in the brains of mice to clean up bad proteins that are a hallmark of Alzheimer's.

The Wrights

Chances are, if you reach your golden years, you or someone close to you will get Alzheimer's — like the late Beth Wright and her husband, George, who now requires 24-hour care.

Their children — Alice, an etiquette teacher; Bryant Wright, an Atlanta-area pastor; Van Earl Wright, a TV sportscaster; and Scotland Wright, a business owner — hope that by sharing touching and harrowing moments from their parents' decline, they can help others who are caring for loved ones with Alzheimer's.

Alzheimer's kills so many neurons (core nerve cells) that it riddles the brain with gaping crevasses and can remove 30 percent of its total mass, debilitating mental functions. But in the beginning, it can move slowly and cause momentary memory lapses or personality breakdowns, like those that beset Beth.

"There was an elegance about her, a genteelness about her," Bryant recalled. "She was the consummate Southern lady, and so gracious," Scotland said.

But suddenly, their mother began blowing up in rage, and extreme fear displaced her inborn self-confidence. "It was so opposite of the person we were reared by," Van Earl said. "I remember us being on conference calls. We didn't know what was going on."

Square one

In 1906, Dr. Alzheimer autopsied Deter's brain. Examining the tissue under the microscope, he found two characteristics that became the pillars of official Alzheimer's diagnosis. "One was amyloid plaque, and the other was neurofibrillary tangles," said Dr. Allan Levey, director of the Emory Alzheimer's Disease Research Center.

Both the plaque, which is outside the neurons, and the tangles, which are inside them, are made of protein molecules that naturally exist in the brain, but they appear to have gone wrong. The amyloid beta plaque, in particular, forms scruffy, large clumps, and researchers have been fixated on it as the cause of Alzheimer's for decades, resulting in a single-minded drug-development approach.

"The bias has been enormous," Levey said. "Bias is a very conservative word in this example."

Drugs focusing on removing amyloid beta plaque have all failed so far. "We're now looking at a disease that is one of the leading causes of death, for which we don't have a single treatment," he said.

Research has sunk billions of dollars, and one failed drug can financially ruin a drug maker. "Many of the biggest pharmaceutical companies have gotten out of the Alzheimer's business," Levey said.

It's time to go back to square one, he said, and really figure out what's causing this disease.

Data detective

To guide future research, Levey would especially like to see the data collected in countless studies mined to sort the wheat from the chaff.

Cassie Mitchell does just that. The informaticist at the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University has combed thousands of studies focused on the proteinaceous amyloid beta plaque and fibrillary tangles, which are made of a protein called tau, to mine suitable datasets for clearer associations with cognitive decline.

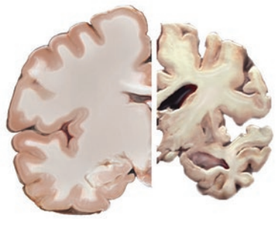
In the composite data, amyloid beta plaque has not looked like a fruitful treatment target.

"When you pull everybody's data together, there's no correlation that can be seen through all the data," Mitchell said. In other words, across masses of data, high levels of amyloid beta plaque in a brain do not correspond to more mental decline. (Alzheimer's lab studies are based on models of diseased brains in mice.)

But data analyses look very different for the protein behind the fibrillary tangles — that tau, particularly "phosphorylated" tau, or p-tau. "There's a very strong correlation with mental decline," Mitchell said. "We need to look more into how p-tau fits into the picture."

Phosphorylation is a normal part of cell life that makes protein molecules more chemically active, but in Alzheimer's, too much tau gets phosphorylated, Mitchell said, and that may create those tangled fibrils inside of neurons.

HEALTHY BRAIN VS. SEVERE ALZHEIMER'S



Alzheimer's kills so many neurons (core nerve cells) that it riddles the brain with gaping crevasses and can remove 30 percent of its total mass, debilitating mental functions.

BRAIN: NATIONAL INSTITUTE ON AGING, NATIONAL INSTITUTES OF HEALTH

CHRISTOPHER MOORE

Cassie Mitchell (right), an informaticist at the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University, has combed thousands of studies focused on amyloid beta plaque and fibrillary tangles.

Prion problems

Yury Chernoff agrees with the take on p-tau but has a slightly different assessment of amyloid beta.

He studies proteins gone bad, particularly prions, which are widely known as the cause of mad cow disease, which, like Alzheimer's, destroys the brain. Chernoff implants human amyloids in yeast cells to experiment with them, and he firmly believes that bad versions of the protein are indeed the cause of Alzheimer's disease, the way prions are the cause of mad cow disease.

"The whole mechanism is very similar to a lot of proteins which occur in different diseases and different organisms," said Chernoff, a professor in Georgia Tech's School of Biological Sciences.

But Mitchell's conclusions make sense to him. Having amyloid beta bound up in clunky plaque wads might make it less able to enter neurons and damage tau. He has seen similar scenarios in which harmful proteins became less harmful as their accumulations grew.

Chernoff thinks the culprits in Alzheimer's may be short, very chemically reactive splinters of amyloid beta.

Like Mitchell, Chernoff believes malformed tau inside of neurons may ultimately be at the root of neuron breakdown. But Chernoff believes it's likely that amyloid beta splinters touch tau, deforming that protein, leading to those fibrillary tangles.

"The proteins (tau) of these fibril structures are losing their normal cellular function," Chernoff said. Robbing the neuron of a functioning protein could start the cognitive decline.

Disturbed 'stranger'

Forgetful blunders, like fumbling an acquaintance's name, are normal, even before aging makes them more confounding. They're probably not due to Alzheimer's.

But this was: "We got a very stressful call from mom that we need to get over to the house, that there's a stranger in the house," Scotland Wright said. "It was Dad."

George stood helplessly next to his wife, Beth, who beseeched him — the "stranger" — to go away. "For Dad, it was just so disturbing."

A brain region instrumental in memory, the hippocampus, is one that Alzheimer's attacks early and thoroughly. It's the section of the brain also responsible for orienting us as we navigate our world, and Alzheimer's damage can make patients wander haplessly.

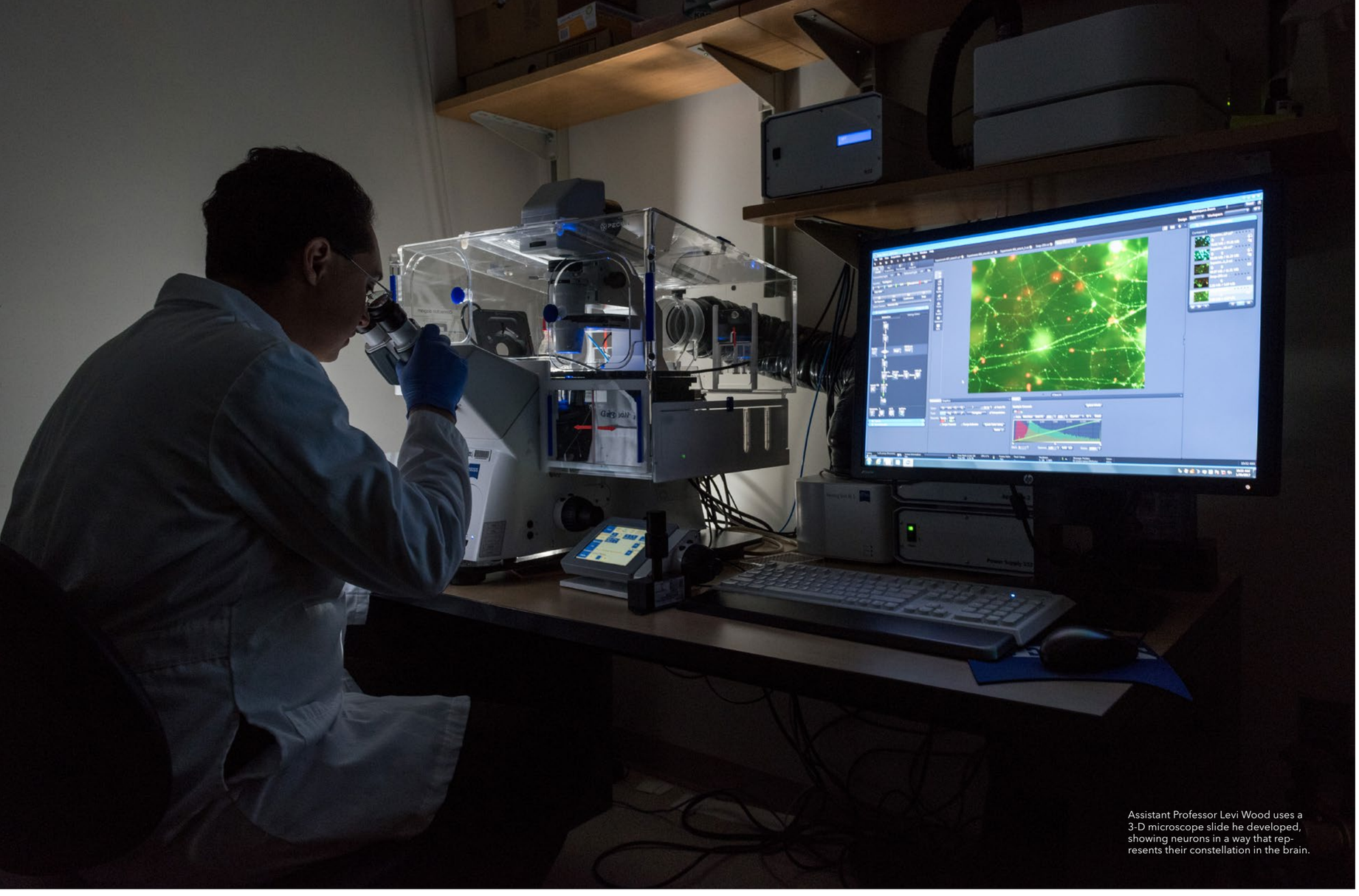
"They get lost in unfamiliar places but also in familiar places, like between home and the store," said Scott Moffat, an associate professor in Georgia Tech's School of Psychology who studies Alzheimer's as well as changes in brain performance during healthy aging. "Getting lost a lot may be a good early marker of someone having Alzheimer's."

Beth began leaving her car door open after driving to work, and she left the engine running. Then one day, she started meandering at the church where her son Bryant preaches. "She was found in the parking lot," Bryant said. Near a very big street.

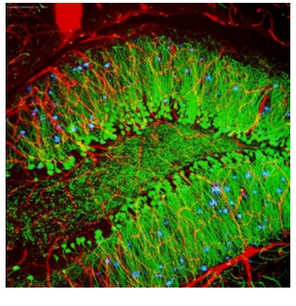
Beth could have wandered into traffic. Her children realized it was time for round-the-clock Alzheimer's care.

ROB FELT

Professor Yury Chernoff, who studies proteins gone bad, has found similarities between the prions that cause mad cow disease and the amyloid beta plaques found in the brains of people with Alzheimer's.



Assistant Professor Levi Wood uses a 3-D microscope slide he developed, showing neurons in a way that represents their constellation in the brain.



AMYLOID PLAQUES

Along with blood vessels (red) and nerve cells (green), this mouse brain shows abnormal protein clumps known as plaques (blue).

WOOD: ROB FELT; PLAQUES: ALVIN GOGINENI/ GENENTECH/NATIONAL INSTITUTES OF HEALTH

Blood stains

The hippocampus has a reputation for having vulnerable tissue, and Alzheimer's may start early there in part due to localized bleeding, said Levi Wood, an assistant professor in the George W. Woodruff School of Mechanical Engineering. Together with Assistant Professor Amit Reddi in Georgia Tech's School of Chemistry, he's inspecting heme (part of red blood cells) to see how it might influence amyloid beta plaque.

Heme might be breaking down clumps of amyloid into those potentially dangerous shorter splinters that interest Chernoff. "De-aggregated amyloid beta is much more toxic than clumped-up amyloid," Wood said, "and it may be more inflammatory."

Inflammation is important in Wood's research. Some rare patients who have amyloid plaques don't get Alzheimer's in spite of that, and their immune response is markedly different from that of Alzheimer's sufferers. Their brains don't show inflammation typical in Alzheimer's.

Along with the effects of heme, Wood is studying proteins involved in brain inflammation. "What we're trying to understand now is how a combination of these proteins may be triggering the immune response that in turn stresses out the neurons, causing them to die."

To observe this, Wood uses a 3-D microscope slide he developed while getting his Ph.D. at the Massachusetts Institute of Technology. It's a scaffold that holds neurons in a way that represents their constellation in the brain.

Wood also thinks brain immune cells called microglia, which are also responsible for pruning parts of neurons that are no longer needed, may get overly activated in inflammation and attack neurons.

Wood's research is broader based for a reason. Like Emory's Levey, he thinks the previous focus has been too narrow. In addition to neurons, for example, there is a brimming handful of other cell types in the brain "which are only recently getting substantial attention."

Dreadful certainty

A doctor showed Beth Wright's children an image of her brain activity. "One side was just black; the other side looked like brain matter," her daughter, Alice, said.

A surprise cure for Alzheimer's is unlikely, but researcher Annabelle Singer has had some jaw-dropping results with diseased mice using a simple light.

Singer has reversed the research approach. Instead of focusing on how proteins might cause brain dysfunction, she looks at how brain activity deficits might contribute to the disease.

"A particular activity is lacking. It's called gamma," said Singer, an assistant professor of neuroscience in the Wallace H. Coulter Department of Biomedical Engineering. Gamma is a kind of rhythm for neuron activity, like a techno dance beat for the brain, with a very specific frequency of 40 hertz.

"It's lacking early in the disease, before mice develop any symptoms, before plaques develop," Singer said. The research team she was on previously at MIT tried to stoke gamma to see if it improved things.

It was so simple, and it worked. The short version: They showed mice a light flickering at 40 hertz. That put microglia to work cleaning up bad proteins in the visual cortex of their brains.

"So, you can actually reduce the pathology of the disease (in mice). That's really surprising," Singer said.

Forty hertz is really fast, sort of like the quivering light from a faulty fluorescent bulb. But scientists caution against experimenting with this at home. They don't know what could happen if someone got the frequency wrong, and flickering light can sometimes trigger seizures in epilepsy patients.

Goodbye mom

Bryant choked back tears as he recalled a dinner with his mother that left no doubt death was near. "She couldn't swallow. She didn't know how to bring the spoon or fork to her mouth. I realized that was it."

Soon, the family gathered at Beth's bedside, where they stayed for four days. "It was tears. It was hilarious. It was stories of growing up," Alice said. They coped as they always had as a family — leaning on one another, on faith and on prayer.

George never seemed to understand what was wrong with his wife of 63 years. His children say caring for him has had harrowing moments, but fun ones as well. George has always had a great sense of humor and still does, despite Alzheimer's.

Perhaps the disease will pass his children by. Only the rarest forms of Alzheimer's are directly hereditary. In common Alzheimer's, genetic risk factors do play a significant role, but many researchers believe a healthy lifestyle that is good for the heart can also protect the brain. And hopefully new inroads in medical research will bear fruits.

Ben Brumfield is a senior science writer with Georgia Tech's Institute Communications. He is a former CNN.com editor.

The National Institute on Aging has funded much of Emory University's, Yury Chernoff's, and Annabelle Singer's work. The National Institute of Mental Health has funded Annabelle Singer's past work. The National Institute of Neurological Disorders and Stroke has funded Cassie Mitchell's work. The above agencies are members of the National Institutes of Health. The National Science Foundation has also funded Yury Chernoff's work. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the sponsoring organizations.

It's Gonna Be a Bright, Sunshiny Day

Atlanta startup Quest Renewables helps power Atlanta's new football stadium with technology developed at Georgia Tech

By Péralte C. Paul
Photos by Rob Felt

On a sunny afternoon,

Norman "Finn" Findley stands beneath a canopy of shiny solar panels that covers a parking lot adjacent to what will be Atlanta's new football stadium.

"It blows people's minds," Findley said, explaining to two visitors how his company's QuadPod Solar Canopy system will work. "It still blows my mind a little bit."

Findley is CEO of the startup Quest Renewables, and this project is one of their most expansive undertakings to date. It comprises two sets of canopies that measure about 130 feet by 250 feet each.

Solar canopies are high ground-clearance structures designed for solar panels, but they also function as carports by providing shade for vehicles parked beneath them.

Quest Renewables' technology allows for about 90 percent of the canopy construction to take place on the ground. Then, cranes hoist the solar panels up in the air to mount them atop the company's specially engineered trusses and members.

The total system will produce 617.5 kilowatts of power for each hour of sunlight. When fully operational, the system will generate enough electricity to power nine home games per season.

For Findley, this show-and-tell at the stadium is all in a day's work. This particular day will be filled with meetings. Some are planned — there's the staff meeting, a new employee orientation, and an investor call — but others come up unexpectedly, such as an impromptu meeting with another investor who is touring the Georgia Institute of Technology's Advanced Technology Development Center (ATDC), the startup incubator that's home to Quest Renewables' operations.

"This is an angel investor," said Frank Tighe, ATDC's lead entrepreneur-in-residence and advisor to Quest Renewables' leadership team, making the introduction between Findley and the visitor. "He wanted to know a little bit about ATDC, and I wanted to take him around to meet some of the companies."

Straight away, Findley goes into presentation mode, giving his 30-second "elevator pitch" to the visitor, explaining as succinctly as possible what his company does and how it creates value for its customers.

"We manufacture racking systems that hold solar panels up off the ground for solar commercial installations at lower cost and in a shorter time frame," Findley said, before going into a deeper conversation with the investor.

Planned or unplanned, these opportunities are all part of the pattern in the life of a startup CEO, said Findley, a former Coca-Cola executive who left the beverage giant in 2016 to focus on Quest Renewables full time.

And while each new day is different, Findley pointed out, he begins and ends each one the same way.

"It's get the kids up and out the door for carpool to school and get out to the gym," the married father of two said. "Then it's work and then to get out in time to go home and put the kids to bed."

A Strong Team

Although Findley has always had an entrepreneurial mindset, he joined The Coca-Cola Company in 1996 and held several managerial positions in sales and marketing.

Going the corporate route before venturing into the startup world was part of a long-term career strategy.

"I'll take risks, but only calculated risks," Findley said. "And for me, the corporate life made sense 20 years ago, while I was taking some risks on the side through investing in some startups."

Over time, his entrepreneurial interest would grow, and in 2013, a friend introduced him to Joseph Goodman, who at the time was a senior research engineer at the Georgia Tech Research Institute, Georgia Tech's applied research and development organization.

"Our mutual friend encouraged us to meet, and we met once a month to see how things were going with his research," Findley said, explaining that their match-making friend thought his commercialization experience at Coke could be beneficial to Goodman. "Joseph said he thought there might be a business in his research, but he couldn't be certain. As we spent time together and I saw how things were going, I got to understand the size of the business opportunity."

The year after that initial meeting, Findley, along with Beau Baldock and Will Arnold, founded Quest Renewables, licensing a patent from Georgia Tech based on research that Goodman and others at the Institute had conducted.

On Quest Renewables' team, Goodman is chief technology officer, Baldock is senior vice president of supply chain, and Arnold is senior vice president of operations.

"I went to Babson College to get my MBA in entrepreneurship, and what they tell you is, the three most important things to have are a strong team, a strong team, and a strong team," Findley said. "If you have a great idea but a weak team, you won't be able to execute on that idea."

As the founding team members began to build the company, they went through Georgia Tech's VentureLab, the Institute's startup and incubation support program for Tech faculty and students who want to create companies based on their research.

After graduating from VentureLab, Quest Renewables was accepted into ATDC's Signature portfolio. ATDC, a sister incubation program to VentureLab, works with entrepreneurs across Georgia (no Georgia Tech affiliation required) who have a proven business model and customers, and are most likely to succeed long term in the marketplace.

In the Energy Space

The Georgia Tech research that got Findley's attention led to a foundation design and support structure that takes up less physical space and uses less than half the steel found in traditional solar canopy construction. Because of the design and the weight it can support, the canopy can hold more solar panels than other canopies without having to expand the support structure's footprint.

The goal behind the initial research and development was to see if there was a way to increase cost efficiencies in the non-photovoltaic part of solar panel installations, Findley said. That meant focusing on the labor, support structure, and electrical costs. The U.S. Department of Energy's SunShot Initiative funded the original research.

The design is a modular space frame, which makes it easier to construct and allows crews to erect the canopies in half the time it takes to build competing structures.

"It blows people's minds. It still blows my mind a little bit."

Quest Renewables makes systems that hold solar panels up off the ground, allowing for parking beneath. The total system being installed here will produce 617.5 kilowatts of power for each hour of sunlight.

"I'll take risks, but only calculated risks."

Above: James Keane, a system specialist at Quest Renewables, reviews the schematics for a solar canopy design.

Below: Norman "Finn" Findley (far right) holds one of his weekly Monday meetings with members of his staff to go over projects and other ongoing company initiatives.

"We're extremely efficient from the standpoint that we can put them up faster, we can put more of them up per acre — so we can generate more power over a given parking lot — and we can put them up generally at a lower cost to the customer," Findley said.

Since the solar canopy structures are elevated, they create functional parking lots in addition to energy.

"We can build on surface parking lots and elevated parking decks, which allows us to produce the energy close to where the power is needed, which puts less stress on the electrical grid because you don't have to produce it in south Georgia, for example, and then try to pipe it all the way up here," Findley said.

While the energy industry doesn't track the solar canopy sector specifically, the solar energy business is growing and accounted for 39 percent of all new electric capacity that was added to the U.S. electric grid in 2016, according to the Solar Energy Industries Association (SEIA), a trade group based in Washington, D.C. The industry attracted $23 billion in investments in 2016, up from about $18.3 billion in 2015, according to SEIA/GTM Research's U.S. Solar Market Report and the National Renewable Energy Laboratory.

Under Findley's leadership, Quest Renewables tripled its revenue between 2014 and 2015, repeating that feat again in 2016. The company projects it will quadruple revenue in 2017.

The company remains linked to Georgia Tech through its work with T. Russell Gentry, an associate professor, structural engineer, and building materials researcher in the School of Architecture.

Partnering with Gentry, Quest Renewables presents challenges to his students, who are tasked with coming up with ways to improve the canopy's efficiency.

"The question we asked them is, do you see where we could be better and more efficient in our use of materials," said James Keane, Quest Renewables' system specialist and a 2013 Georgia Tech graduate with a bachelor's degree in architecture.

"We're asking them whether there is a more optimal size for these components or whether they should somehow be designed differently."

The technology has garnered the company some national attention. In the spring of 2016, then-U.S. Energy Secretary Ernest Moniz visited Georgia Tech, noting the Institute's role as a leader in developing innovative energy solutions in the Southeast and meeting with a select group of ATDC companies in the energy space, including Quest Renewables.

That same year, the Georgia Research Alliance, which seeds and funds startup companies in the state, announced it was making an investment in Quest Renewables via its GRA Venture Fund, which was established to finance high-potential companies spinning out of Georgia's universities.

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Lauren Terris, operations manager at Quest Renewables, runs with Norman "Finn" Findley, the company's CEO. The two regularly run on and around the Georgia Tech campus while discussing corporate strategies and initiatives.

Big-Picture Perspective

The stadium initiative is the largest to date for Quest Renewables, though the company has other projects in its portfolio, including a canopy array at Agnes Scott College in Decatur, Georgia, and projects in other states including Maryland, Oregon, California, and Maine.

One recently completed project is with Standard Solar, a Rockville, Maryland-based company that specializes in the development and financing of solar electric systems.

The company hired Quest Renewables to design and put together a canopy for a Rockville-area parking deck.

Parking decks are more challenging than surface lots for solar canopy projects, said C.J. Colavito, Standard Solar's director of engineering.

That's because the canopy has to be integrated within and anchored to an existing structure and requires a customized engineering approach, he said.

"There are a number of things Quest does well where they are able to add value where other providers have struggled," Colavito said, adding that his firm is working on another project with Quest Renewables, scheduled for completion by the second quarter of 2017. "One of the things Quest does better than anybody else is, they have a system that's capable of having very long spans between connections. You get a lot more density at lower costs than other systems because of their proprietary truss system while maintaining the canopy's structural integrity."

Accolades such as this come with a hiccup that most startups would love to have: demand for services — so much so that the company is scaling back its growth. Findley wants each customer to have a quality experience.

"We created such a compelling product that we have demand that exceeds our ability to deliver a quality customer experience, so we've been ratcheting back our growth to make sure that every customer we work with is delighted," he said.

This approach, he said, fits in with the company's long-term goal regarding its place and impact on the industry.

"The inspiration for our company comes from a very big-picture perspective. The idea that we could lower the cost of solar and be able to produce it near where the demand is located while still using existing spaces like parking lots rather than covering up natural green fields with solar panels is what drives what we do," Findley said. "What we would really like is that in 10 years, for people to say that we really made solar and renewable energy to be preferential to fossil fuels."

Péralte C. Paul is a business and technology writer in Georgia Tech's Institute Communications and the Enterprise Innovation Institute. He's a former newspaper reporter.

This structure supports Quest Renewables solar canopies over a surface parking lot.

Smart Cities

PAGE 22, *BOOSTING THE URBAN IQ*

Smart cities integrate multiple technologies to help manage their assets, improving the lives of residents while reducing the cities' impact on the environment. At Georgia Tech, researchers are boosting the urban IQ to enhance everything from resiliency and environmental sustainability to wellness and quality of life, bringing together public and private efforts in such areas as computing, engineering, and the social sciences.

ALIGN

PAGE 29, *SENIORS AND THE CITY*

A software app known as Application for Locational Intelligence and Geospatial Navigation (ALIGN) helps older people plan walking routes based on their abilities and personal preferences. The app can account for more than 50 factors, ranging from accessibility – such as curb cuts, walkways, and traffic signals – to preferences such as avoiding high-crime areas, uphill climbs, or unshaded sidewalks. ALIGN is under development in Georgia Tech's Center for Assistive Technology and Environmental Access (CATEA) and the Center for Geographic Information Systems (CGIS).

Neuron

PAGE 30, *COSMOS IN THE CRANIUM*

Neurons are electrically excitable cells that process and transmit information in our brains using both electrical and chemical signals. Signals are transmitted between neurons using specialized connections known as synapses. The human brain is believed to include more than 160 billion cells, of which about half are neurons. Georgia Tech researchers are conducting basic research to better understand how these brain cells, synapses, and other cells work together to make us human.

Alzheimer's Disease

PAGE 42, *KILLING THE MIND*

Alzheimer's is a progressive disease that destroys memory and other important mental functions. In patients who have the disease, brain cell connections and the cells themselves degenerate and die. Georgia Tech researchers are working with collaborators at Emory University and other centers to develop a better understanding of the disease in the hope of someday finding a cure.

PAGE 50, *BRIGHT SUNSHINY DAY*

Solar Canopies

(sōlər kanəpēs)

Generating electricity while shading vehicles parked beneath them, solar canopies are high ground-clearance structures designed to hold solar panels above parking lots and parking decks. Technologies used by Georgia Tech spinoff Quest Renewables allow about 90 percent of the canopy construction to take place on the ground before the solar panels are hoisted up and mounted atop the company's specially engineered trusses and members.

ROB FELT

Research News & Publications Office
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Volume 34, Number 1
Issue 1, 2017