Solutions

INSIGHT • INNOVATION • IMPACT®

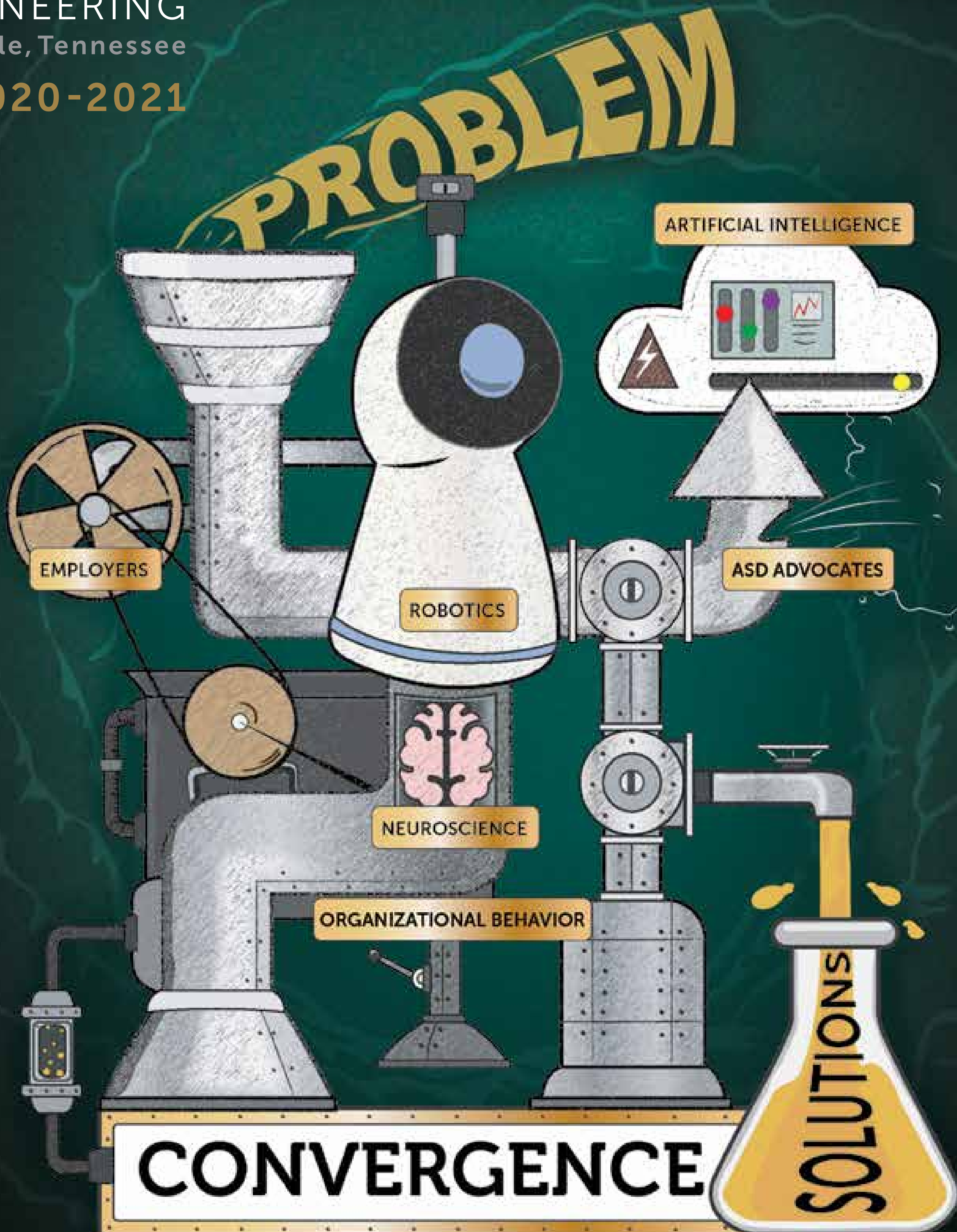
VANDERBILT
SCHOOL OF
ENGINEERING
Nashville, Tennessee

2020-2021

RECREATING
T-cell adaptive immune response

CELEBRATING
A century of female students

ADVANCING
Inclusion Engineering℠



Numbers of note

first-year students

41% are women

22% undergraduate minority students

#16 best undergraduate engineering program among private research universities**

85% of graduates have job offers before graduation*

33% of the Class of 2021 have studied or interned abroad for at least a month

10% undergraduate international students

55% of undergrads participate in research projects outside the classroom

119 faculty honors from 36 societies

$60M+ in new and anticipated grants through Q3, 2020

18 institutes, centers and groups

*U.S. citizen and permanent residents (Class of 2020)
**US News and World Report, Sept. 2020

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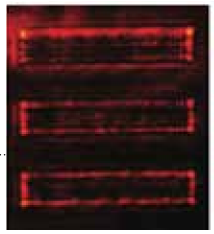

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Convergence
The NSF has increased its efforts to have experts from diverse fields converge to tackle a profound challenge through its Convergence Accelerator program. NSF Convergence grants support fundamental research leading to rapid advances that can deliver significant societal impact. In 2020 the School of Engineering received one Phase 2 grant (page 31) and two Phase 1 grants (page 17).

Convergent thinking is our CIVIC duty

by Philippe Fauchet
Bruce and Bridgitt Evans Dean of Engineering

One of the most exciting challenges in engineering lately is that of smart and connected cities. The vast amounts of data and electronic infrastructure create complex interconnectedness and allow for systems to help optimize our lives while addressing inequality, climate change, environmental impact, safety, resource management, and risk mitigation.

City Innovations through the Vanderbilt initiative on Infrastructure Connectivity (CIVIC) builds on our demonstrated expertise in bringing together scientists and engineers from across campus to collaborate on innovative solutions that improve the quality of life in cities. Through partnerships with strategic test beds, CIVIC is turning cities into classrooms and laboratories where our researchers and students put their ideas into practice.

Projects in Houston, Nashville, Chattanooga, and the sustainable Sterling Ranch community development, plus the Vanderbilt campus itself, all provide invaluable data for Vanderbilt researchers across disciplines. Particularly in this time of a worldwide pandemic and international calls for social justice, drawing on real-world data to provide solutions to the challenges cities face has never been more important.

For example, our faculty already have deployed sensors across cities to measure how self-driving vehicles perform, and these same sensors can help manage traffic surge as cities open up again amidst COVID-19. We already help community transit agencies by analyzing their real-time data, which can aid in their response to the pandemic from a planning, scheduling, and operations perspective. We also have been investigating the disparate impacts of transportation solutions on the lowest income communities, including many urban communities of color, and this knowledge can be used to guide city officials as they work to improve transit access and the opportunities mobility provide.

CIVIC's mission is four-fold:

- Develop new ways to sense and analyze how cities operate by understanding the connections between the services cities deliver, including mobility, housing, energy, water, health care, and education;
- Develop new ways in which to build cities with materials and construction technologies that are less costly and use less energy;

Photo: Adobe Stock

Photo: Mickey Bernal

Photo: Mickey Bernal

- Provide elected officials and organizations that build and operate cities with data and options for improving services and quality of life for residents;
- Educate and train students to be future leaders and innovators in the science and engineering of interconnected and smart cities.

One may ask, "Isn't this what engineering is about already?" The answer is yes, of course! But the problems are so complex, and the data sets so vast, the analyses require convergent thinking and multidisciplinary teams in new ways and with more urgency.

We've written about smart cities before, and we've been solving problems of infrastructure for decades. Our new approach is more comprehensive and draws from our expertise across disciplines. You'll read in these pages about Professor Karsai's research on green energy and better managing microgrids, Professor Dubey's work on the challenges of mass transit in a COVID world, Professor Mahadevan's blueprint for planning and operating the U.S. power grid, and Professor Work's project to optimize traffic on cities' commuter corridors. With well over $30 million in recent research grants in this area alone, the School of Engineering truly is a leader in this field.

Of course, this issue of *Solutions* also includes our faculty's work in the advanced frontiers of fighting cancer, our novel area of **Inclusion Engineering**SM and breakthroughs in flat optics. Of particular note is a special section reflecting on the roles and contributions of women in the School of Engineering as we celebrate the centennial of the ratification of the 19th Amendment. Nashville played a pivotal role as an epicenter of social change throughout 20th Century and continues to in the 21st Century. Such change contributes to the realization of a better life for all, which is the School of Engineering's primary mission.

Closing out Navy project shows the many moving parts

By Julia Finfrock, Class of 2021, Civil Engineering

As a Summer Associate for Clark Construction in Chicago, I was assigned to a U.S. Navy building north of the city that was a few months from completion. The project was new housing for more than 600 enlisted military personnel, totaling 160,000 square feet.

My main task was to collect closeout documentation, such as operation and maintenance manuals and parts and service warranties from over 20 independent subcontractors and assemble a comprehensive operation and maintenance manual to present to the Navy.

In June, my experience was entirely remote, and I discovered intricate details about the submittal and contracting process, and the building itself, from 1,100 miles away. In July, I moved from Florida to Chicago to begin the onsite portion of my internship. After weeks working on the project, seeing the structure in person was almost surreal. Once on site, my additional responsibilities included creating RFIs, identifying punch list items on the interior and exterior of the building and interviewing employees.

I have always been drawn to construction and was definitely influenced to be a civil engineer. My great-grandfather started a concrete manufacturing plant in 1945 in central Florida, and my grandfather, father and uncles expanded the company into the multifamily housing, retail and student housing markets. The company makes precast concrete components but offers services for the entire building process, from design to closeout. Although I've been exposed to many stages of construction and worked at the company, I was surprised by the number of moving parts that all have to come together simultaneously at the end of the job.

The work I had done in construction before my internship only involved one element of the process at a time, but once the building passes the structural construction phase, many more elements and details than I had ever imagined must come together to make the building functional and livable.

During my final week, I combined 3,000-plus pages of closeout documentation into 15 separate volumes and submitted the final product to the Navy. Maintaining a tracking system helped me develop organizational skills and working with subcontractors improved my communication skills. I have learned so much about the construction and project management. The skills I developed working and learning remotely—communication, document control and time management, to name a few—will prove vital far into the future.

Collaboration with VUMC distinguishes Ph.D. journey

By Colette Abah, Ph.D. candidate, Mechanical Engineering

My accent is a strange combination of French with a Cameroonian twist, and British English with a Nigerian twist. The strangest part is that I have only ever stepped foot in Nigeria once, in June 2019 for one weekend.

I was born and raised in Yaoundé, Cameroon (also known to soccer fans as Samuel Etoo's country). Although French and English are Cameroon's official languages, I grew up speaking only French. I learned English in school the same way most American kids learn Spanish or French in school—not very well.

At 16, I was awarded a scholarship to study the International Baccalaureate at the United World College of the Atlantic, an international school in Wales. I moved to a foreign country, by myself, with a minimal proficiency in the spoken language. It was there that I somehow picked up a Nigerian-British accent. I think it was by osmosis because many of my closest friends were from Nigeria.

It was also at United World College that I first learned about engineering. When I was ready to apply for college I wanted a discipline that combined my science background and my desire to create practical solutions to real-life challenges. After conversations with friends and the school's guidance counsellor, I decided engineering was an excellent fit. I was admitted to Massachusetts Institute of Technology. Off to the United States I went, armed with my improved language skills and my odd accent.

I discovered my interest in research late in my undergraduate career. In the spring of my senior year I did a research project in a bioinstrumentation lab and enjoyed that experience so much that I decided to go to graduate school. As a stepping stone, I did a research fellowship at the Wyss Institute for Biologically Inspired Engineering at Harvard University. In fall 2015, Professor Robert Webster visited Harvard and gave a lecture about needle-size robots for minimally invasive surgery. That lecture and a subsequent phone conversation with him sold me on the surgical robotics program at Vanderbilt University.

Photo: Anne Rayner

In Fall 2016, I enrolled at Vanderbilt in mechanical engineering and joined Professor Nabil Simaan's Advanced Robotics and Mechanism Applications laboratory. The Ph.D. journey has been an amazing (scary, thrilling, frustrating, exhilarating) learning experience so far.

Close collaboration with VUMC surgeons made Vanderbilt an especially attractive program for me, and one of my favourite aspects has been the relationship my lab has with VUMC's Department of Neurological Surgery through the Vanderbilt Institute for Surgery and Engineering. As a VISE fellow, I shadowed Dr. Rohan Chitale, my clinical mentor, and observed several neuroendovascular procedures (e.g. stroke, aneurysms, AVM, etc). We identified knowledge and technical gaps in stroke care and formulated research questions that guide our current collaboration. The proximity of VUMC to our lab allows me to observe surgical cases multiple times a week.

Our team works toward expanding access to stroke care through robotic assistance. Being mentored by both a robotics expert and an endovascular surgery expert has challenged and improved how I think about implementing engineering solutions to bridge technical gaps in this field of care.

Engineering Neighborhoods

The Vanderbilt University School of Engineering has nine core areas of impact in which faculty, staff, students and outside researchers provide insight, drive innovation and create solutions. The neighborhood concept aptly describes as well as defines our distinctive culture of collaboration.

Vanderbilt Engineering has a long and successful tradition of collaboration with colleagues at other universities and at Vanderbilt University Medical Center, the College of Arts and Science and the other colleges and schools that make up one of the nation's top research universities.

A Vanderbilt engineer's research routinely spans more than one neighborhood. Neighborhoods celebrate and leverage our commitment to trans-institutionality, collaboration and cross-pollination both within and beyond the traditional walls of departments, schools, institutions and disciplines.

Rehabilitation Engineering
develops mechanics and robotics to help restore lost physical and cognitive functions.

page 31

Cyber-Physical Systems
technology develops processes, protocols, networking and technology needed for the seamless and secure integration of cyber (software) and physical (hardware, networks and users) systems.

page 24

Regenerative Medicine
involves understanding behavior of unhealthy and healthy cells at a molecular level and development of methods to disrupt disease processes, as well as drug delivery, drug efficacy and tissue engineering.

page 12

VANDERBILT SCHOOL OF ENGINEERING

Risk, Reliability and Resilience
advances risk quantification; improves predictability; increases reliability of systems, infrastructure and materials; and creates technology and materials with more resilience.

page 34

Nanoscience and Nanotechnology
concerns the discovery and application of how materials and processes behave on the nanoscale in diverse areas of engineering, science and health care.

page 14

Energy and Natural Resources
targets transformative research to enable sustainable resource and energy conservation, production and recovery.

page 28

Biomedical Imaging and Biophotonics
uses physical phenomena such as magnetic fields, radiation and light to aid diagnoses and treatments of disease and dysfunction.

page 8

Surgery and Engineering
concentrates on the collaborative efforts of engineers and surgical experts to create, develop, implement and evaluate technology, methods and tools that improve patients' outcomes and experiences.

page 10

Big Data Science and Engineering
develops tools and processes to harvest and leverage knowledge from data sets too large and complex for traditional software to handle and often involves predictive or user behavior analytics.

page 17

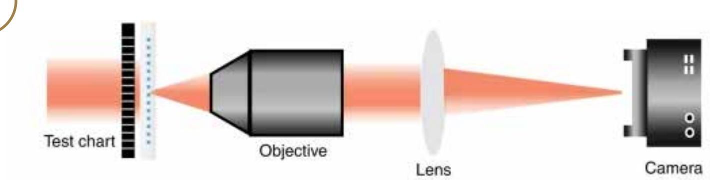
Breakthrough in flat optics could transform biomedical imaging and computer vision

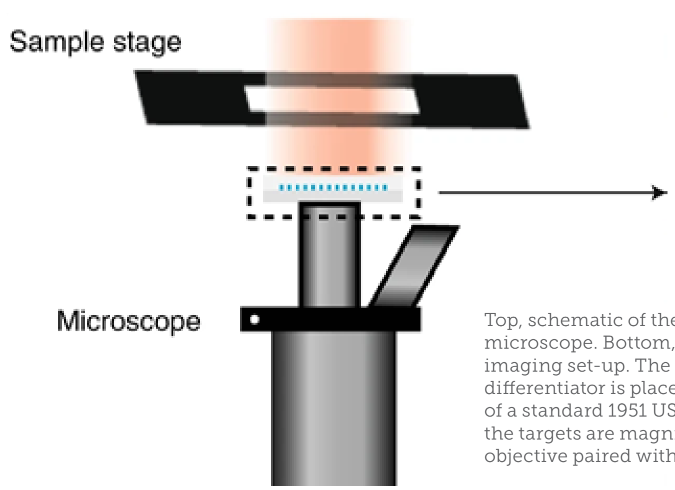
Vanderbilt engineering researchers have developed a first-of-its kind ultrathin filter that processes images at the speed of light and supports direct imaging of an object's boundaries.

Their work marks a significant breakthrough in using optics for image processing and holds transformative potential for applications in biological imaging and computer vision.

Digital image processing, including the use of neural networks, has become essential for identifying features and objects in images for many science and engineering disciplines, but it requires advanced computers, space to accommodate them, and substantial power to run them. Optical image processing actually predates its digital counterpart but requires multiple optical lenses and filters resulting in a large multi-optic system. The advance by the Valentine lab allows placement of a thin filter in front of a conventional camera for achieving the same functionality—significantly reducing the system's size and complexity.

The Vanderbilt project demonstrated "two-dimensional image differentiators with high resolution, thin form factor and a simple geometry that allows rapid and cost-effective large-scale manufacturing," said the team, led by Jason Valentine, associate professor of mechanical engineering. The work, "Flat optics for image differentiation," was published online in *Nature Photonics* earlier this year.





Top, schematic of the edge detection microscope. Bottom, schematic of the imaging set-up. The nanophotonic differentiator is placed directly in front of a standard 1951 USAF test chart and the targets are magnified through an objective paired with a tube lens.

"Optical analog processing has the advantages of being low power and high speed," said Valentine, also deputy director of the Vanderbilt Institute of Nanoscale Science and Engineering.

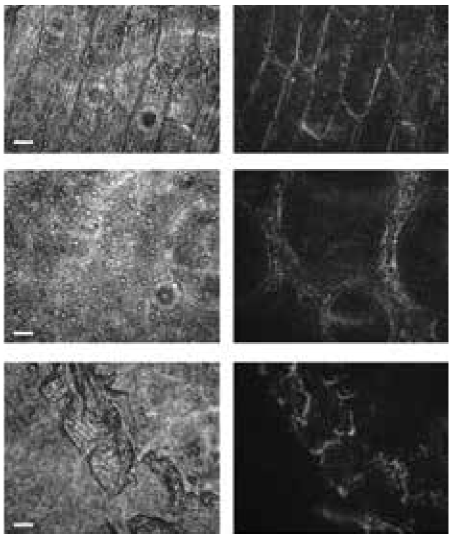
The team's filter is based on a two-dimensional photonic crystal made from silicon. It can be integrated into an optical microscope or onto a camera sensor, easily adapting an existing image processing system. The filter—100 times thinner than a human hair—also was integrated with a metamaterial-based lens, resulting in a completely flat, compact and ultrathin optic that can perform edge imaging.

"One of the primary benefits

IMAGING TEAM AIMS SMALL, WITH A MORE QUIET, MORE PORTABLE MRI SYSTEM

A significant component of the cost of an MRI system has been the massive superconducting magnet to produce a strong radiofrequency current and the bulky system that keeps it cool. The magnet for a 3-Tesla scanner, for example, weighs more than 12,000 pounds.

Vanderbilt engineers believe it's time to downsize. A team led by William Grissom, associate professor of biomedical engineering, will use a very low-field human 47.5 millitesla scanner that it built, which is installed and working at the Vanderbilt University Institute for Imaging Science. With it as a testbed and a $1.4 million NIH grant, Imaging and edge detection results for three types of cells. Top, onion skin; middle, pumpkin stem; bottom, pig motor nerve. Images on the left are obtained at a wavelength of 900 nanometers, which is away from the resonant frequency, and the images on the right correspond to the results at the working wavelength of 740 nm.



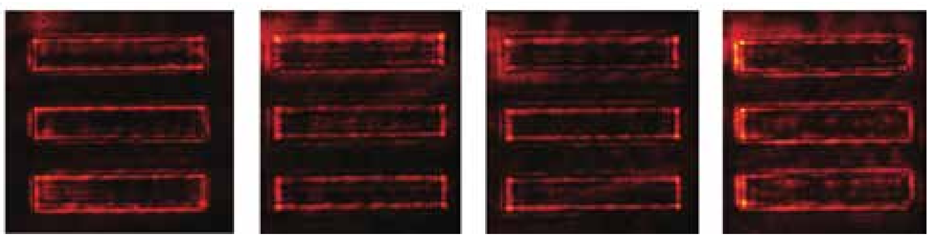
of our approach is the ability to integrate the metamaterial with traditional optical systems. As an example, we built an edge detection microscope by simply placing the metamaterial filter within a commercial optical microscope," said You Zhou, a Ph.D. student in the Interdisciplinary Materials Science Program and one of the four authors.

Testing included imaging the cells of onion epidermis, pumpkin stem and pig motor nerve and differentiating their boundaries, a task for which accuracy carries critical implications.

Edge filtering is a common preprocessing step in object recognition. "It is important, for instance, in detecting the edge of a lane for autonomous vehicles. It can also be used for detecting margins of tumors in medical imaging or in classifying cell size and type in the case of cell sorting for cancer detection," Valentine said.

"The key feature is the ability to perform image processing at the speed of light while requiring no input power and doing so in an extremely thin form factor," Valentine said. "This opens new doors for real-time and high speed optical analog image processing in applications such as machine vision and biological imaging."

His group is now working to adapt the technology for use in object recognition, not just edge imaging. Those projects include more complex object recognition, funded by DARPA, and related technology for cell identification, which received internal Vanderbilt funding for projects with transformative potential. **V**



Edge detection when the differentiator targets a standard 1951 USAF test chart across wavelengths ranging from 1,100 to 1,180 nanometer.

researchers will work toward a compact, silent, less expensive and potentially portable MRI device.

"That is 100 times weaker than normal research magnets," he said. "Rather than weighing tons we are looking at a few hundred pounds."

Researchers will develop new hardware, including low-field radio frequency transmission coils and amplifiers, and software that will together translate signals measured from the body into images of anatomy. And they'll use new spatial encoding approaches that are completely different from those found on conventional clinical MRI scanners.

"The time is right to do this kind of work," Grissom said. "Computational and electronic technologies have advanced so much over the last 40 years and become cheap enough that we can now look at whether we can get clinically useful images from less expensive and more portable magnets."

The project builds on earlier work by the Grissom lab in coil design, spatial encoding using radiofrequency field gradients, and radiofrequency pulses. A key advancement will replace the type of gradient fields the scanner uses by taking advantage of the Bloch-Siegert shift, a phenomenon historically viewed as a nuisance in magnetic resonance. In this project, it will be used to match up signals received from the body to their location of origin and form images.

The gradient fields used now are problematic: they are loud and induce peripheral nerve stimulation, compromising patient comfort. They require bulky cooling systems and customized amplifiers. Together, that represents up to 30 percent of the cost of a clinical scanner.

Researchers will use a low-field MRI lab at VUIIS in developing new hardware and software for a less expensive and more portable system. They also will use new spatial encoding approaches.

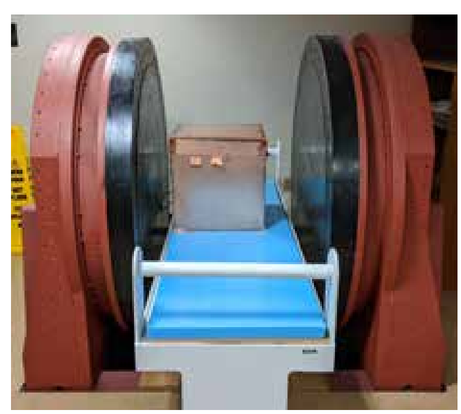


Photo: Vanderbilt University

Customized CI programming targets improved auditory nerve stimulation

Cochlear implants can help someone with serious hearing loss better understand human speech, converse on the phone, enjoy music and watch television. When successful, the device allows a user to perceive different types of sounds, such as doors slamming and dogs barking.

In the United States, however, it is estimated that only 10 percent of those who could benefit from the technology pursue implantation. Results with cochlear implants have been successful in general, but many cochlear implant recipients continue to have poor ability to understand human speech. Outcomes range from near normal ability to understand speech to no hearing benefit at all.

A team of Vanderbilt University and Vanderbilt University Medical Center researchers will reduce uncertainty with advanced patient-specific cochlear implant programming. The team received a five-year, $3.1 million National Institutes of Health grant in June 2020 to develop computational models for simulating how the cochlear implant activates the auditory nerves for individual patients. That follows a $3.9 million NIH grant in 2019 with many of the same researchers to develop customized implant programming for children with hearing loss.

Cochlear implants are small electronic devices with an external portion that sits behind the ear and a second portion surgically placed under the skin. The device uses an array of implanted electrodes to stimulate auditory nerves and induce hearing sensation.

Rene Gifford, director of the Cochlear Implant Program at Vanderbilt Kennedy Center, adjusts an implant. She is part of a team awarded $7 million in NIH grants in the last two years to develop customized implant programming.

The implants use from 12 to 22 electrodes, depending on the manufacturer. Although the implanted electrodes can be seen on a CT scan, the nerve cells they stimulate are not easily identified. Traditionally, all the electrodes are turned on and programmed to stimulate any surrounding nerve cells.

Sub-optimal nerve stimulation has been a big part of the variability in cochlear implant outcomes, but existing approaches for estimating how the electrodes stimulate the nerves on each patient have not been reliable enough to help audiologists make programming adjustments for consistent improvement. The vast majority of programming settings for commercial cochlear implants are left on the default values, with the ability to customize them untapped.

The new models will enable development of next-generation programming strategies to identify settings that greatly improve sound quality compared to the traditional programming approach.

Jack Noble, assistant professor of electrical engineering and computer science, leads the team and is the principal investigator. Co-investigators are Rene H. Gifford, professor of hearing and speech and director of the Division of Audiology's Cochlear Implant Program; Robert Labadie, MD, professor of otolaryngology, and Cornelius Vanderbilt Professor Benoit Dawant, professor of electrical engineering. All are Vanderbilt Institute for Surgery and Engineering affiliates.

"Even among the most successful cases, restoration to normal auditory fidelity is rare," Noble said. "It is estimated that less than 10 percent of those who could benefit from this technology pursue implantation, in large part due to the high-degree of uncertainty in outcomes."

Outcomes also depend on successful positioning of the implant during surgery. The multidisciplinary team has developed image-guided techniques for more accurate detection of the location of implant electrodes relative to the auditory nerve cells they stimulate. The strategy supports deactivation of electrodes that imaging information suggests create overlapping stimulation patterns and audio "noise."

The image-guided methods have significantly improved the quality of hearing for cochlear implant users. Now, Noble said, the five-year grant will enable "new, more advanced patient-custom programming strategies using novel methods for comprehensive patient-specific modeling of neural stimulation with cochlear implants." **V**

Biomedical Image Analysis for Image Guided Interventions Laboratory

An electrode array surgically implanted into the cochlea stimulates auditory nerves to restore hearing. Customized electrode placement and stimulation improves patient outcomes.

TARGETING CHRONIC PAIN

A team of Vanderbilt engineers, clinicians and imaging scientists is developing a focused ultrasound neuromodulation device as a non-invasive and non-addictive method for treating chronic pain.

The device will look like an MRI head coil and combine functional MRI with ultrasound neuromodulation. The combination will allow researchers to simultaneously alter neuronal activity in brain regions associated with pain and monitor the response in real time using functional MRI.

The team from the Vanderbilt University Institute for Imaging Science received a $3.6 million grant from the National Institutes of Health as part an initiative to improve chronic pain treatments, curb opioid abuse use and overdose, and achieve recovery from opioid addiction.

While other devices to treat pain exist, their efficacy is limited by inaccurate targeting of pain regions and circuits in the brain, the researchers said. They hypothesize that ultrasound neuromodulation technology will allow for accurate and reliable stimulation of specific pain targets through enhanced, image-guided control.

"Ultrasound neuromodulation is a pretty new and exciting area because it allows you to alter activity non-invasively, with fine spatial precision, in deep or superficial brain targets," said Will Grissom, associate professor of biomedical engineering.

Device testing will occur in collaboration with Vanderbilt Institute for Surgery and Engineering.

Photo: Adobe Stock

NIH backs team's sustained work in T-cell immune response with $11 million P01 grant

Parsing T-cell activation is precursor to manipulating immune response to better fight diseases

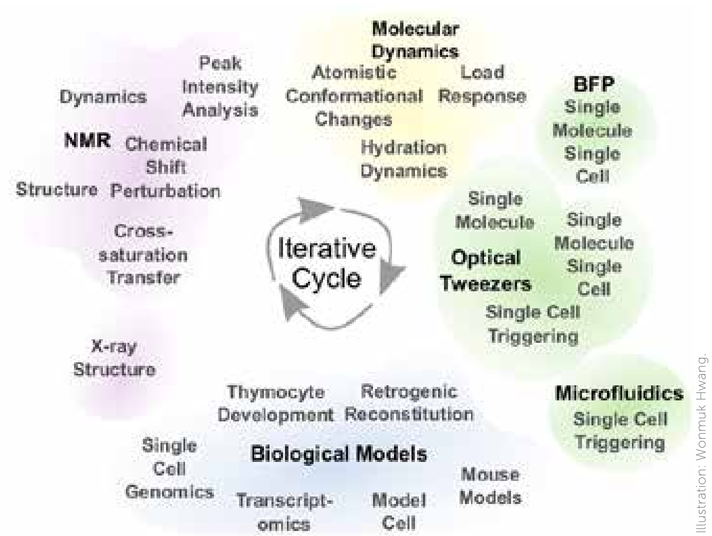


Illustration: Wonmuk Hwang.

The multidisciplinary team includes experts in structural biology, molecular dynamics, immunology and physics using many imaging modalities, modeling approaches and advanced techniques to understand—and recreate—structures and forces involved in T-cell signalling.

For more than a decade Matt Lang and collaborators across the U.S. have worked to recreate key components of T-cells and how they know when to start fighting disease. Conventional wisdom suggested that T-cells formed regular, force-free bonds with infected cells, and in doing so caused the chain reaction of immune response. The team slowly built on its groundbreaking and controversial 2009 work that suggested the opposite—that the T-cell receptor required a force of some kind to activate.

In 2017 they finally measured the near immeasurable, down to a piconewton of force. They showed a directional nudge of ~10 piconewtons will launch the cascade of interactions in T-cell response. A piconewton is roughly the force exerted by dropping 1/1,000th of an eyelash, but it had been enough to cause a tsunami of dissent. Because they bucked decades of thinking, their findings were highly controversial and required a paradigm shift in research aimed at manipulating T-cell response.

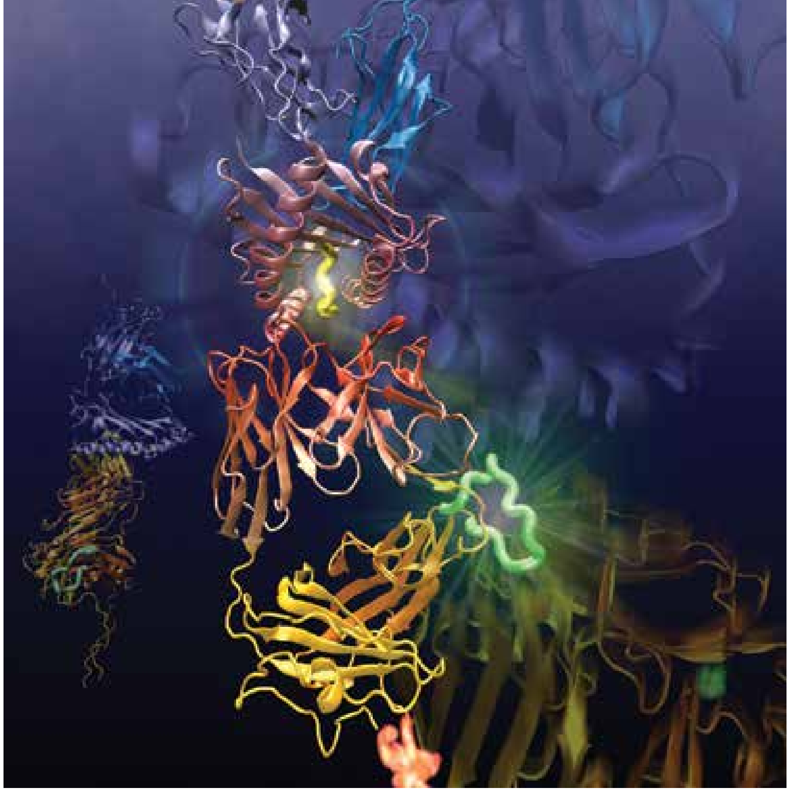
Their meticulous, painstaking work just received a big green light. The National Institute of Allergy and Infectious Diseases, the division of the National Institutes of Health that studies COVID-19 and seasonal flu, awarded the group a combined $11 million in the form of a rare and highly coveted program P01 grant. Managed by the Dana-Farber Cancer Institute, the five-year grant includes three synergistic projects and three cores. All of them involve characterizing the biological and structural features of T-cell signaling in even greater detail.

The first project uses a panel of T-cells and receptors sensitive to influenza virus to parse the conventional T-cell receptor response and understand the physical and chemical rules underpinning subcellular level triggering. The second follows T-cells as they are minted in the thymus and how they shuffle receptors through maturation to determine "the mechanical and physical rules that allow a cell to progress through developmental stages," Lang said. The third project is about the receptor's structure and dynamics where subtle changes among flavors of receptors will be mapped to their performance biologically such as repertoire, proliferation and protection. Lang has roles stitched within all three projects.

A more complete understanding of T-cell activation paves the way for manipulating this line of defense,

Photo: Wonmuk Hwang.

Right side, front to back: Collaborators Wonmuk Hwang, Ellis Reinherz, Matt Lang and, left side, front to back, Haribabu Arthanari , Gerhard Wagner and Robert Mallis share a dinner north of Bethesda, Maryland, in January 2018 prior to a reverse site visit with NIH officials for the P01 proposal.



At the subcellular level adaptive immunity involves multiple components. The bright green segment is the FG loop believed to be involved in the mechanosensing machinery of a CD8 T-cell. The receptor binding peptide MHC peptide itself is shown in yellow.

switching them on to fight diseases or, for individuals with autoimmune disorders, blocking unwanted activation.

"We want to figure out not only what it takes to turn on but how that signal drives a cell into long-term memory," said Lang, a professor of chemical and biomolecular engineering.

Lang was an associate professor at MIT in 2009 when the group first published together and suggested the T-cell receptor is a small machine that needs directional force to activate. The group, including experts in immunology, biophysics, molecular dynamics and structural biology, from Vanderbilt, Dana-Farber, Harvard and Texas A&M universities, kept at it.

"After we first published we would get attacked at conferences," he said. "I was brand new to this field. We each were teaching each other our specialties and combined focus to bring people together over several different areas.

"It is about the synergy," said Lang, who, with Ellis Reinherz of Dana-Farber, is a co-principal investigator on the program grant. "Little by little we started to build up evidence that there is a little machine in there."

A T-cell is a type white blood cell, or lymphocyte, that develops in the thymus gland. This project focuses on CD-8 T-cells, which have ~30,000 copies of receptors unique to that cell on the cell surface. CD-8 T-cells play a big role in the adaptive immune response, an ancient feature that arose in jawed mammals 20 million years ago.

Although the grant targets seasonal flu (another ancient adaptive system) the work has application to cancer and other diseases including COVID. "If we figure this out, this will provide a way to trigger a cellular response and open new strategies for T-cell therapies and vaccine development," Lang said.

They discovered and now seek to explain a set of rules in play that underlie the body's immune response. "We are excited to do the work," Lang said. "We are all in." V

A new look at what drives metastasis

A bold engineering approach to sort breast cancer cells based on their behavior *first* has produced compelling data that show less migratory cells create more metastases, contradicting the prevailing hypothesis on how cancer spreads.

Preliminary discoveries by Cynthia Reinhart-King, Cornelius Vanderbilt Professor of Engineering, have led to surprising results. The ability of cells to move has been considered integral to the ability of cancer to spread to secondary sites. Reinhart-King is changing that paradigm.

Her research has the potential to lead to new, more effective cancer treatments. Melanoma, colorectal, lung and prostate cancers are highly metastatic cancers with low survival rates. Lung cancer is the most significant cause of cancer-related deaths, followed by colon, and both are among the least funded cancer types compared to their societal burden.

"This is a novel and comprehensive approach to studying disease. We are collecting, analyzing, verifying and validating a massive amount of data in order to sort cells based on their ability to move," said Reinhart-King, professor of biomedical engineering.

Cancer cells must leave the primary tumor, enter the circulation or the lymph system, travel to a secondary site, exit and multiply to form a secondary tumor. The same mechanisms that apply to slowing the spread of breast cancer may hold true for lung, skin, colorectal and other cancers.

Expanding her research on breast cancer metastases to other highly metastatic and lethal cancers has earned Reinhart-King a prestigious three-year, $1 million grant from the W. M. Keck Foundation, which awards grants for high-risk medical research projects with transformative potential.

The goal is to use multiple cell lines and to investigate each step along the metastatic cascade using both animal models and tissue-engineered models of tumors. Researchers will use a broad range of techniques to sort cells based on their behaviors and their ability to move, including sophisticated tissue-engineered models of the tumor microenvironment, advanced optical imaging techniques, protein and chemical analysis, patient databases, and computational analysis. They will use genomic, epigenomic and proteomic analyses to identify the key drivers of successful metastasis.

Photo: Joe Howell

Cynthia Reinhart-King

"Studying multiple cell types and cancers opens the possibility that we will find commonalities that exist across cancer types," Reinhart-King said. "The underlying research could be vital to learning how we might defeat several types of metastatic cancers."

Shaping materials at the atomic scale

An introduction to membrane nanoscience

Peifu Cheng, postdoctoral scholar, Chemical and Biomolecular Engineering

Membrane research has significantly benefited from nanotechnology, and many sectors of the global ecosystem have benefited from membrane research. Water treatment or desalination is one example. Membranes with nanoscale pores also are used to separate gases for carbon capture and storage to alleviate climate change. Dialysis tubing made of semi-permeable membrane with pores of 1 to 10 nanometers is used in artificial kidney research, with the goal of improving the lives of millions of people.

Membranes with different sieving sizes have made a tremendous impact on food processing, from dairy products to juice filtration and sugar purification. Membranes play an important role in energy fields, such hydrogen fuel cell cars and energy generation from the mixing of rivers into the sea.

Challenges remain. An ideal membrane has minimal thickness and a high density of uniform nanoscale pores for ultrafast transport and precise ionic/molecular sieving. However, scalable fabrication of such membranes remains difficult, and a single large nanopore can compromise membrane performance.

One big goal—and big challenge—is fine-tuning membranes on atomic scale, and Vanderbilt engineers are at the forefront of such research. The following two pages contain more detailed examples of recent breakthroughs. Shihong Lin, assistant professor of civil and environmental engineering, and his collaborators changed the conventional membrane fabrication process itself and made nanofiltration membranes with sub-Angstrom precision that can successfully separate two ions with extremely small size differences (p 15). Piran Kidambi, assistant professor of chemical and biomolecular engineering, and his team developed atomically thin graphene membranes with trillions of controlled holes in the range of 0.3 to 0.6 nanometers over a square centimeter. These membranes allow for ultrahigh water permeance, about 23 times higher than commercially available membranes, with excellent rejection of salt ions and small organic molecules (p 16).

Using nanotechnology, we can make materials stronger, lighter, more durable, more reactive, more sieve-like, or better electrical conductors, among many other traits.

Team achieves solute-solute separation with sub-Angstrom precision

A research team that includes Vanderbilt engineers is the first to successfully separate two ions with minute small size differences, a major advancement in separation science with widespread potential application.

Their process is first to achieve solute-solute separation with sub-Angstrom precision. An Angstrom is one hundred-millionth of a centimeter, or one-tenth of a nanometer.

Use of nanofabrication for solute-solute separation makes the work significant as well. In most cases, nanofabrication is used to separate ions and small molecules from the solvent, not each other. Separating solvents from each other would allow easier recovery of valuable metals and other materials.

"Membranes capable of precise separation of ions and small molecules will have a transformative impact on the energy, water, chemical, and pharmaceutical industries," the authors said.

The key to achieving solute-solute separation, the authors discovered, is to use membranes with highly uniform pore size so they reject solutes larger than the pores but not just slightly smaller, said Shihong Lin, assistant professor of civil and environmental engineering and one of the project investigators. The work was reported in *Nature Communications* in April 2020.

"Such separations require membranes with highly uniform pore sizes to obtain precise molecular sieving and solute differentiation," Lin said.

State-of-art commercial nanofiltration membranes are fabricated using interfacial polymerization, in which two chemical precursors, one in the water phase and the other in the oil phase, react. The reaction creates a thin film of polymer at the water/oil interface that acts as the active separation layer. This layer has Angstrom-scale pores, but the complex process happens within seconds and makes obtaining smaller, uniform pores very challenging.

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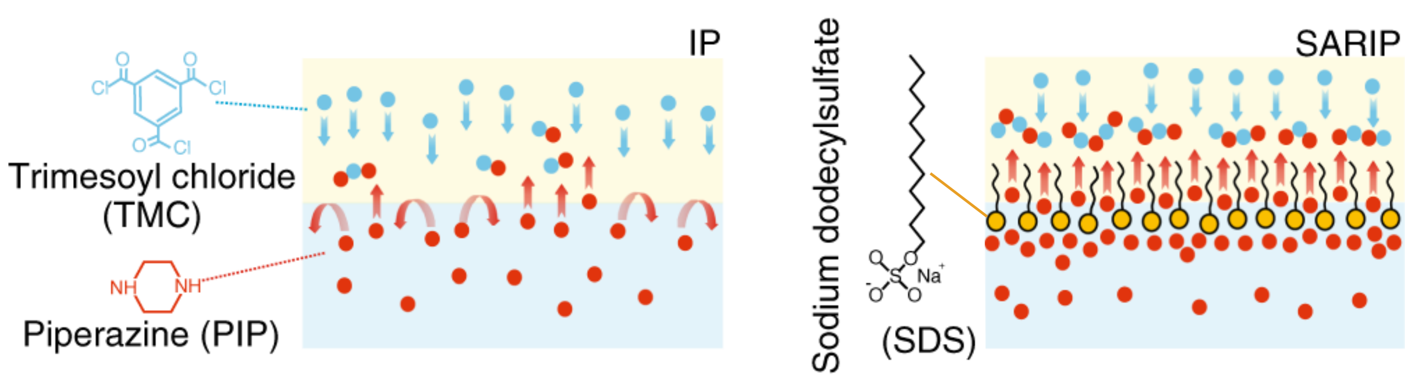
The team achieved solute-solute separation at sub-Angstrom scale, a first.



SELF-SEALING TECHNOLOGY CORRECTS FOR PORE SIZE

Membrane desalination is an efficient way to desalinate water but maintaining uniformity of the pore size is a challenge.

A single "large" hole can cause high leakage, compromise membrane performance and contaminate the water. How do you drill trillions of holes between the size of 0.3 and 0.6 nanometers over a square centimeter of material just one atom thick?

Vanderbilt engineering researchers developed a new way. They have reported a breakthrough in scalable fabrication of graphene membrane with a sealing technology that corrects for size so all the pores remain small enough to trap salt ions and small molecules but allow water to pass. Their work is published in the American Chemical Society's journal *Nano Letters.*

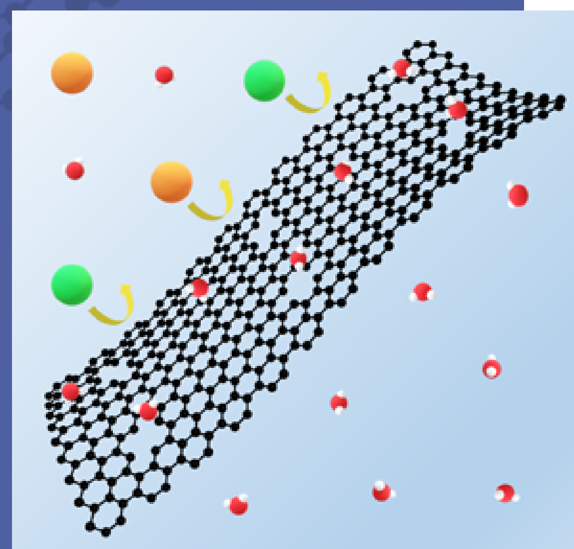
Piran Kidambi, assistant professor of chemical and biomolecular engineering, and his team designed a simple defect-sealing technique based on a gatekeeper analogy. The process in most prior studies ends with the formation of holes in graphene membranes, but the team flipped the steps. They formed holes in the graphene first, using a low-temperature chemical vapor deposition process followed by ultraviolet light in the presence of ozone gas. The holes act as a gatekeeper.

A sealant molecule on one side has to pass through the gate to meet another molecule on the other side and form a seal. If the size of the molecule is smaller than the gate, it will pass through, meet the other molecule and seal the gate. If the molecule is larger than the gate, it won't get through and the gate remains open.

"Think of it like a fishing net that catches only large fish," said Peifu Cheng, postdoctoral scholar in chemical and biomolecular engineering and a member of Kidambi's lab.

Their work is a significant contribution to membrane engineering. It has the potential for transformative advances in high-quality commercial graphene membranes that filter a variety of microscopic ions and molecules, including salts, proteins or nanoparticles, and relevant to industrial applications beyond water desalination, such as gas separations. Such membranes also should be useful for chemical, biological and medical research and the purification of substances used in pharmaceuticals.

"To the best of our knowledge, this is the first demonstration of size-selective defect sealing for nanoporous atomically thin membranes," Kidambi said.



Researchers created an ultra-thin graphene membrane with a sealing technology that corrects variations in the pore size so they remain small enough to trap salt ions and small molecules but allow water to pass.

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The team's novel method uses a dynamic, self-assembled network of surfactants to facilitate faster and more homogeneous diffusion of specific molecules, or monomers, across the water/oil interface, when the monomers bond with each other to form a polymer. The key to "surfactant assembly regulated interfacial polymerization," or SARIP, as it is called, is in adding the right kinds of surfactants to promote the formation of a highly organized network of very narrow and highly uniform pore size at the water/oil interface.

The work results from an extensive international collaboration between Vanderbilt, the Suzhou Institute of Nano-Tech and Nano-Bionics of the Chinese Academy of Sciences, Yale University and several other institutions. V

Two sweeping public health projects awarded NSF Convergence grants

One project aims to set the stage for global monitoring of the biome for the early detection of pathogens and prevention of potential pandemics. A second project targets creation of a standardized platform that will streamline the development, testing and dissemination of technology to improve human health, starting with public and private COVID-19 data sets.

Vanderbilt engineers have the lead role in these ambitious efforts, which have their foundations in data science and artificial intelligence. The NSF has awarded both projects initial 2020 Convergence Accelerator Pilot grants.

The NSF Convergence Accelerator Phase 1 grants provide up to $1 million for nine months for teams to build a proof-of-concept for their solutions.

Janos Sztipanovits, E. Bronson Ingram Distinguished Professor of Engineering and director of the Vanderbilt Institute for Software Integrated Systems, is the principal investigator for "Deep Monitoring of the Biome Will Converge Life Sciences, Policy, and Engineering."

The project is the academic side of PREMONITION, a massive research initiative Vanderbilt started with Microsoft five years ago that is directed by Ethan Jackson, Ph.D.'07. Collaborators include Johns Hopkins University, the University of Washington, University of Pittsburgh Medical School, Microsoft, ClimaCell and the Harris County (Texas) Department of Public Health.

The project combines robotics, genomics, big data collection—and mosquitos. The goals include fusing novel biome and ecological data streams into unified data sets and generating predictive AI models for use across disciplines. New science and technology that emerges would have wide impact on human health, agriculture, national security and ecology.

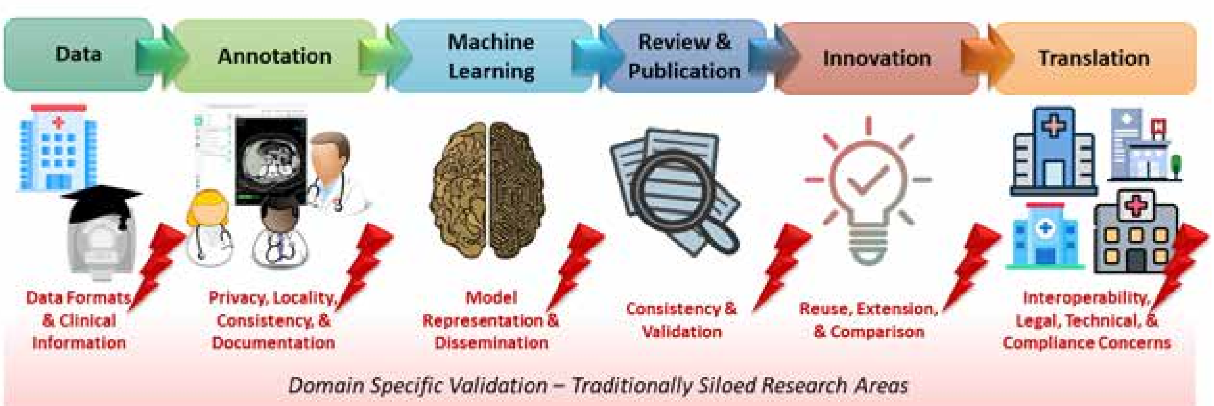
"By accelerating the development of new predictive mosquito models, especially by generalizing them to additional species, this project will provide long lasting contributions to human health and pandemic preparedness," Sztipanovits said.

The second project, "Scalable, Traceable AI for Imaging Translation: Innovation to Implementation for Accelerated Impact," looks specifically at public health innovations based on artificial intelligence. Co-principal investigators Bennett Landman, professor of electrical engineering, computer engineering and computer science, and Ipek Oguz, assistant professor of computer science and computer engineering, are partnering with researchers from VUMC, the Society for Imaging Informatics in Medicine, and industry partners MD.ai and Kaggle.

The group will start with public and private COVID-19 data sets, including the National Institute for Health's open-source resources to address COVID-19, and COVID-Net, an open-source repository of chest X-rays developed by Canadian AI researchers.

There has been no standardized way of validating AI algorithms and calculating the true cost of bringing a technology to market, creating significant implications for product development.

"We are stopping the game of musical chairs when it comes to validating technology by building a clearer and more connected chain of events," Oguz said. "We're reframing the big picture by pulling everyone together to plan a system that works for the entire community." V



Mining EMRs and clinical journals to find novel disease associations

A new Vanderbilt-developed big data tool reveals novel associations between chronic diseases and lesser-known conditions that may help detect disease earlier and identify new research paths.

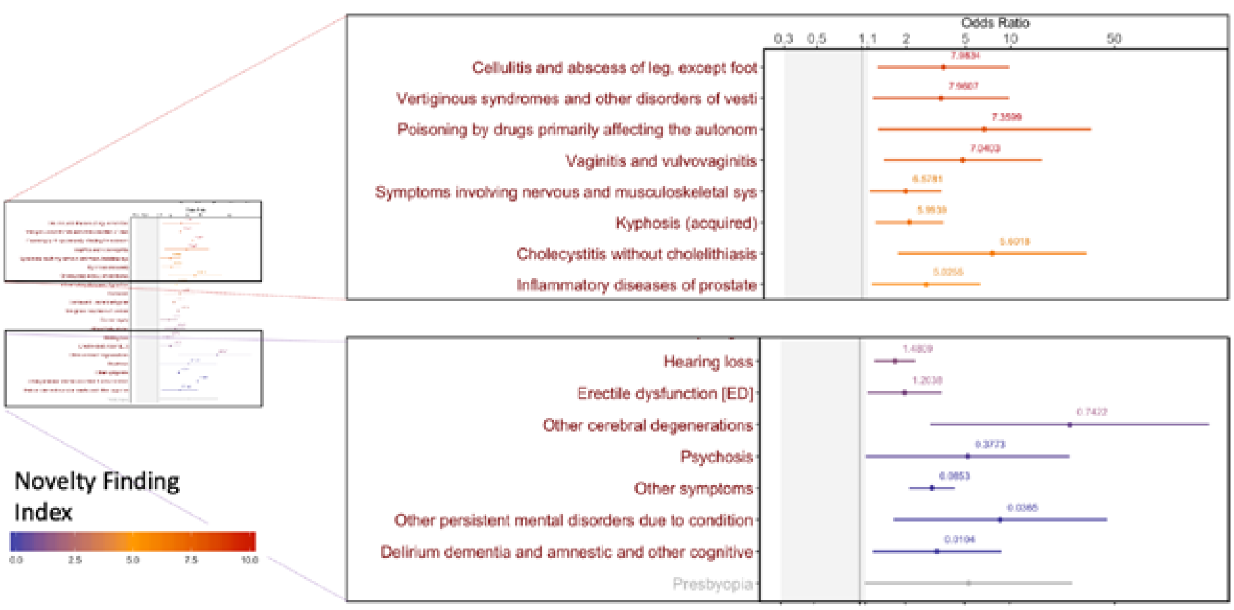
Using machine learning, anonymized electronic medical records, and peer-reviewed journal articles, a team of engineers, clinicians and informatic experts tested the tool for three conditions. In all three—Alzheimer's Disease, Autism Spectrum Disorder and Optic Neuritis—the tool found lesser-known conditions that may support earlier monitoring or medical intervention. The novel associations also provide potential new insights into disease progression.

"We are excited about the opportunities to discover new risk factors and associations of diseases in the clinical record," said Bennett Landman, professor of electrical engineering, computer engineering and computer science.

"Overall, our goal is to advance engineering and clinical science to improve the understanding and care of patients," said Landman, who led the group.

For the project, researchers used de-identified EMRs of patient groups with each of the three conditions and appropriate control groups with comparable demographics but without the disease diagnosis. They mined real-time journal article abstracts from PubMed, a search engine maintained by the U.S. Library of Medicine, because well-known associations likely will have more papers published about them than novel ones, said Shikha Chaganti, Ph.D'19, first author and a former student in Landman's Medical-image Analysis and Statistical Interpretation Lab.

The algorithms searched for and tallied mentions of associations to each condition from article head-



The Novel Finding Index assigns well-known disease associations a low ranking, as shown above with Alzeheimer's Disease.

lines, abstracts and keywords, said Chaganti, who is now at Siemens Healthineers as a senior deep learning research scientist.

The resulting tool, Phenome-Disease Association Study, or PheDAS, performs association studies and identifies disease comorbidities across time. It also solves a thorny issue for these types of studies: how to prioritize apparent correlations for clinical relevance. PheDAS correctly identified well-known associations with each of the three target conditions. But some associations will be so random they are likely to be unrelated or have extremely limited relevance.

A “Novel Finding Index” guides researchers to significant associations that may be clinically relevant but have not been well-studied in medical literature. The index gives well-known disease associations a low ranking.

In the case of Alzheimer’s, for example, well-known associations identified included psychosis, cerebral degenerations and gait abnormalities and were given a low novelty score. Infections and inflammatory processes across several organ systems were among the novel associations identified in the five years prior to diagnosis and received higher scores.

“Our results demonstrate wide utility for identifying new associations in EMR data that have the highest priority among the complex web of correlations and causalities,” the team concluded.

The team made the tool free and available to the public online. The new tool kit, with its machine learning algorithms, creates easier, user-friendly access to a daunting amount of data.

Clinical collaborators already are digging into findings for each of the three example conditions. Additionally, researchers can use the tool kit to investigate other diseases if they have their own approved data sets from the Synthetic Derivative (the database containing anonymized clinical information derived from Vanderbilt’s electronic medical record of 2.2 million people) the Baltimore Longitudinal Study on Aging or other institutions. **V**


Photo: Vanderbilt University

In the case of Autism Spectrum Disorder, the data mining tool found several co-occurring conditions that are not widely studied and could improve early screening practices among children. The Vanderbilt Treatment & Research Institution for Autism Spectrum Disorders holds several annual events for families.

KNOWING CONDITIONS THAT APPEAR BEFORE DIAGNOSIS CAN IMPROVE SCREENING AND TAILOR TREATMENT

Novel association toolkit available online

With the ability to more easily find co-occurring conditions, Vanderbilt researchers already have identified some conditions that appear prior to a diagnosis of Autism Spectrum Disorder.

They parsed the data to look at the medical histories of children less than two years old who were later diagnosed with ASD. Convulsions, constipation and strabismus, which is improper eye alignment, were the most significant comorbid conditions. Prior to their diagnosis, children in this group also had more medical visits associated with convulsions, diseases of the esophagus and allergic reactions to food.

Early screening practices could be improved with such information.

In a related effort, researchers investigated disease associations in two groups – those who were less than five years old and more than five years old at the time of an ASD diagnosis. Children diagnosed later had more conditions like asthma, hearing loss and mood disorders.

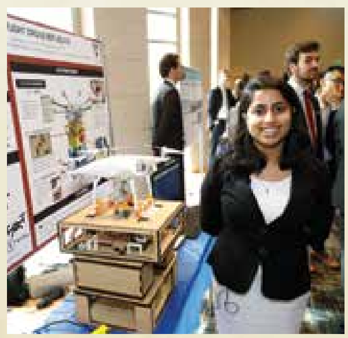
Researchers aim to build predictive models of co-occurring condition progression, introduce targeted risk assessments across the lifespan, and move toward more personalized medicine.

The new tool kit, called pyPheWAS, is available online at **https://github.com/MASILab/pyPheWAS**. It was validated with three sample conditions, including ASD.

Women in Engineering 1911-2020

In the centennial celebration of the ratification of the 19th Amendment, which took place two short miles from our campus, we thought it important to reflect on the past 110 years of women in the School of Engineering. We did not make it easy for women, a fact no one is proud of anymore and should never have been proud of originally. We have heard the retelling of comments by professors to young women that they were too emotional, not smart enough, had to sit in the back row, looking for a husband, or otherwise not "cut out" for engineering study. We know too few women were enrolled to provide a suitable peer network of support, nor were there effective role models or mentors to provide advice.

Women have been attending the School of Engineering for over a century. The first female student on



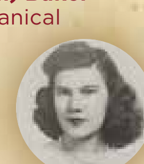
1910 · 1920 · 1930 · 1940

1911—Trevania Dallas Smith—First woman, on record, to enroll in the School of Engineering as a special student during the 1911-12 academic year. She became a landscape designer.

1914—Harriet Fogle arrived on campus in her roadster to study in engineering. Left school before graduating and did not return. During WWI she served as an ambulance driver for the Army Air Corps.

1929—Frances Long enrolled in civil engineering. Left school at end of junior year.

1945—Vera Jane Jones (Mackey), BA'44, BE'45, earned a B.E. degree in engineering and went to work for TVA as their first woman engineer.

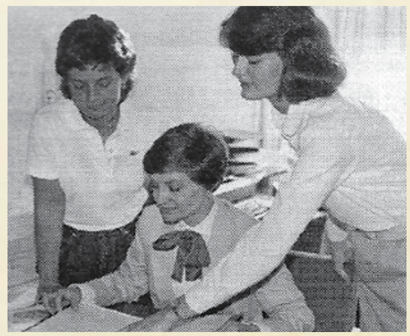


1946—Patricia (Brown) Baker earned a B.E. in mechanical engineering. The first woman to complete a four-year curriculum and graduate. First woman P.E. in Tennessee. She became an engineer for Chance-Vought Aircraft.

record who enrolled was Trevania Dallas Smith in 1911. That same year, Anne Dallas Dudley, her elder sister, formed the Nashville Equal Suffrage League. Anne would later lead a march of 2,000 women from downtown Nashville to Centennial Park, the first suffrage parade in the South, and became a mobilizing force in the Tennessee and U.S. movements. In this time of mindful reflection on women in STEM, racial justice and gender equality, we highlight a few of our notable alumnae who persisted against the headwinds of a male-dominated field, and who succeeded in spite of messaging they could not. This list certainly is far from complete because it took the participation of every woman to enable the evolution of our academic environment, and we owe each one our gratitude, however belated.

Yes, women often had to work harder and were held to higher standards than their male counterparts. It should not have been that way, and it should not be that way. We would like to believe times have changed. And to a degree, they have. We are approaching equal representation of women vs. men in undergraduate enrollment. The diversity of our student and faculty populations has never been greater. Intentional support networks exist now where none or few used to be. Formal and informal mentoring and individualized support efforts are better organized and more available.

Are we done? Have we arrived at an environment where our female students of all races and backgrounds feel equally supported and have equal opportunity to succeed? Certainly not. However, we are working very hard toward these goals. The investments in effort and resources to create such an environment have never been greater, the stakes never higher. The collective conscience is starting to pay attention. As our stakeholders, we need to hear from you, we want your input, we will continue to listen to your stories, and you must continue to tell them. To our alumnae already involved in this effort, thank you! Together, we can do this. **V**

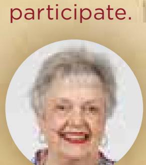


1950

1960

1963—The youngest female graduate of the school, **Joyce Ann Hill Taylor**, BE'63, graduates at 19.

1963—Honors program adopted, **Susan Porzelius**, BE'65, was the first student to participate.



1970—First Ph.D. in engineering earned by a woman: **Ann Alsobrook Hicks**, in civil engineering.

1970

1973—Leslie Ann (Freeman) Benmark was a computer science instructor from 1973-1975; PhD'76 in Systems and Information Science (precursor to CS forming in 1978); director of the university's women in engineering program until 1979.

1973—Catherine Connette, BE'74, becomes the first woman president of the undergraduate Engineering Student Council.

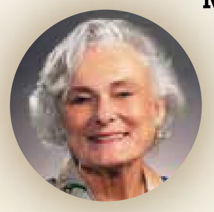
1975—Cynthia Ustruck, BE'75, ChemE, first woman to lead Tau Beta Pi and first recipient of the new Vanderbilt Engineering Honor Scholarship.

1976—Rebecca Jane Bowers, BE'76, ES, is the first woman as a third generation Vanderbilt Engineering undergraduate in the same family.

1977—Mary Yarbrough, BE'77, MD'81, named Henry Luce Scholar.

1979—Jane Martin, BE'79, worked on the successful effort to preserve Radnor Lake as a State Natural Area.

Notable Alumnae



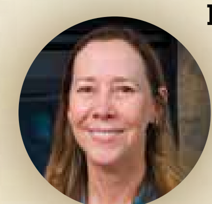
Maryly Van Leer Peck, BE'51
- First woman to graduate with four-year degree in chemical engineering
- Worked at Rocketdyne and U.S. Naval Research Lab, formulated rocket fuel for the space program
- First woman named president of a Florida community college

Yvonne Young Clark, MS'77
- First woman to earn a master's degree in engineering management

Sandy Cochran, BE'80
- Majored in chemical engineering
- Former Army paratrooper
- CEO, Cracker Barrel

Mia (Canariis) Hardcastle, BE'56
- Majored in mechanical engineering
- First female engineering student to earn a Founders Medal
- First woman president of the Engineering Alumni Council

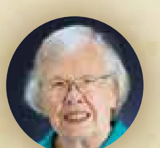
Cynthia (CJ) Warner, BE'80
- Majored in chemical engineering
- President and CEO of Renewable Energy Group Inc., a leading provider of lower carbon-intense products and services
- Member, Board of Visitors of the Vanderbilt University School of Engineering



Cathy Jo Thompson Linn, BS'74, MS'78, PhD'80
- Worked for IBM, was a faculty member at SMU and SW Louisiana, then moved to the Institute for Defense Analyses
- Recruited to Microsoft in 1990, key developer on Object Linking and Embedding and Windows CE

Kimberly Bryant, BE'89
- Majored in electrical engineering
- Founder, Black Girls CODE, which plans to train 1 million girls by 2040
- *Forbes* magazine's "40 Women over 40" to watch, *EBONY'S* "Power 100," *Marie Claire* magazine's 20 women changing the world, CNN 10: Visionary Women

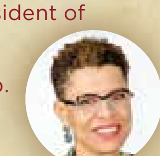
1980—Charlotte Fischer, professor of computer science, hired as first woman tenured in the School of Engineering.



1981—Carol Rubin hired as tenured associate professor in mechanical and materials engineering department.

1981—Linda Dulin wins Founder's Medal.

1984—Sheryll Cashin, BE'84, president of NSBE, wins Marshall Scholarship.



1987—Courtney Ann Reynolds, BE'87, named *TIME* College Achievement winner.

1988—Camille Chammas wins Founder's Medal.

1991—Rebecca Golden wins Founder's Medal.

1993—Cynthia B. Paschal hired as assistant professor of biomedical engineering and becomes the first woman faculty member to receive tenure from the tenure track.

1996—Nikki Sikes wins Founder's Medal.

1997—Michelle Palmisano wins Founder's Medal.

2004—Heather Brant wins Founder's Medal.

2008—Sesha Pinnaduwage, BE'09, wins prestigious Goldwater Scholarship.

1980 1990 2000 2010

Krista Donaldson, BE’95

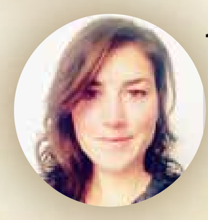
- Majored in civil engineering
- CEO, D-Rev, which designs and develops medical technologies for underserved populations around the world
- *Fast Company*’s “50 Designers Shaping the Future,” World Economic Forum Tech Pioneer

Erica Brown Wagner, BE’00

- Majored in biomedical engineering
- Blue Origin, Payload Sales Director
- National Academies Standing Committee on biological and physical sciences in space

Abbey Carlson, BE’20

- Majored in mechanical engineering
- Award-winning Vanderbilt Aerospace Design Lab, Vanderbilt Women’s Golf team, and pilot
- Advanced design engineer on the Space Launch System at Boeing’s north Alabama facility



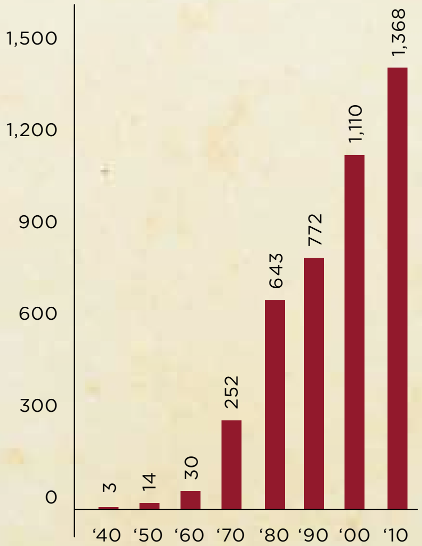
Amelia Cousins Greenhall, BE’09

- Majored in electrical engineering
- User experience designer, user interface designer and data scientist
- Cofounded feminist tech blog and publication Model View Culture and Double Union, a feminist women-only hackerspace in San Francisco

Leslie Labruto, BE’11

- Majored in civil engineering
- Leads efforts for Acumen, an NGO, to provide access to energy with low-cost home solar projects in Southeast Asia and sub-Saharan Africa
- Young alumni trustee on Vanderbilt’s Board of Trust

Engineering Degrees Granted to Women, by Decade



4,192

Total Degrees Granted to Women in 75 Years

2016—ChemE major **Marie Armbruster**, BE’18, wins prestigious Goldwater Scholarship, named Fulbright Scholar in 2018.

2017—Lauren Branscombe, BE’18, MS’18, wins prestigious Goldwater Scholarship.

2018—Crystal Loehman wins Founder’s Medal.

2018—Philanthropist **Jennifer Frist**, BS’93, endows Frist Center for Autism and Innovation.

2014—Kasey Hill wins Founder’s Medal.

2012—Kathryn Maxwell wins Founder’s Medal.

2020

2016—Julie Schnur wins Founder’s Medal.

2020—Tamara Baynham, BE’93, wins Alumni Association’s Volunteer Award.

2020—First-year student **Meredith Hunter** arrives on campus from La Jolla, CA. She produced a documentary on women in CS for a Girl Scout Gold Award. It is publicly available on YouTube.

Photo: Adobe Stock

Cyber-physical systems come of age

Projects attract more than $20 million in recent grants

It would take some effort to not encounter a cyber-physical system during a routine day. They run traffic lights. Mass transit. Electrical grids. Medical devices. Many of the apps on your smart phone are cyber-physical systems. They are everywhere and not going anywhere.

With the Institute for Software Integrated Systems, the School of Engineering has been at the forefront of CPS research before it had a name. Vanderbilt is the "home" base for CPS-VO, a global virtual organization for researchers and engineers. It is a one-stop shop to find research results that could help move the field forward, improving the relationships between humans, computers and the physical world to make life safer, energy-efficient and more convenient.

Broadly defined, CPS comprises the development of processes, networking and technology needed for glitch-free and secure integration of software with hardware systems. The institute has expanded significantly since its founding in 1998 and now has nearly 100 research scientists, staff engineers and computer science/electrical engineering faculty members.

And they've been busy. In less than six months, projects have been awarded more than $20 million in federal grants.

Rewriting how complex software evolves

Vanderbilt computer engineers are leading a nearly $9 million project to fundamentally change how complex software systems such as those used in airplanes, logistics, satellites, nuclear power plants and other critical infrastructure evolve.

They want to develop technologies that capture the intentions of software engineers and enable rapid code generation that supports continual adaptation and evolution of software-enabled systems.

Photo: Adobe Stock

"You can't throw them out and start from scratch," said Gabor Karsai, professor of computer engineering, computer science and electrical engineering, who leads the effort. "You may have new requirements and new features or new hardware and network platforms, but you don't want to mess up what you already have."

The $8.8 million project is one of four funded by DARPA and the Air Force Research Laboratory. The main idea is that changes in the requirements will result in the developer making changes in the models that will result in changes in the generated artifacts, or changes in the target system, Karsai said. And these derived changes should take place with minimal human involvement.

"We consider software development as a continuous process, where the software is undergoing sustained change, improvement and extension," Karsai said. "Our goal is to build the tools to support this."

Working with Vanderbilt on the four-year project is the Kestrel Institute, a nonprofit computer science research center located in Palo Alto's Stanford Research Park. The proposed new framework—Model-based Intent-Driven Adaptive Software—requires more intense work at the outset, including mathematical verification and validation, which has been at the end of the process.

Vanderbilt leads green energy project to better manage microgrids and local energy systems

Microgrids can be major sources of renewable energy—if they are managed properly.

"The problem is that microgrids don't have the same huge resources, like large generators, that existing energy companies have."

— Gabor Karsai

Photo: Adobe Stock

Solving energy management is more than flipping a switch or connecting and disconnecting to the main grid when necessary. Such actions require a high degree of precision, involving complex computer controls and logic.

Gabor Karsai, professor of electrical engineering, computer science and computer engineering, and his team are building software that customizes solutions for effective energy management across microgrids in a variety of environments. He is leading a $2.5 million DARPA-funded project that extends an earlier project on managing microgrids, the relatively small energy systems that rely on local energy generation and storage.

"Microgrids often are very green sources of energy, and of interest to organizations looking to enhance their sustainability initiatives or decrease their reliance on the main power grid," said Karsai, also associate director of the Vanderbilt Institute for Software Integrated Systems. "The problem is that microgrids don't have the same huge resources, like large generators, that existing energy companies have. There needs to be a better way to manage the energy that is captured by microgrids in order to maximize its potential."

The advanced software is intended to address control and energy management functions ranging from alternating current power control mechanisms to management of inbound energy generated from photovoltaics and energy stored in batteries. The research prototype, like its predecessor, will be free and open-source.

"We'd like anyone to use the software that we develop," Karsai said. "This is a research prototype, not commercial, but we hope that it becomes good enough that other people can build on it and develop it further."

Photo: Adobe Stock

Adjusting bus capacity for COVID-19 protocols

COVID-19 concerns pose distinct challenges for public transit providers. In an NSF-funded project, Vanderbilt engineers are applying artificial intelligence to analyze Nashville and Chattanooga bus occupancy as well as changes in overall demand for public transit.

The goal is a real-time map of available seats within physical distancing protocols available for public use. Abhishek Dubey, assistant professor of electrical engineering and computer science, likens the map to how seats are selected on ticket sales websites for concerts or sporting events.

With updated ridership estimates, the two public transit agencies also will have better data to determine which routes need more buses to ensure passenger safety, said Dubey, who leads the project and is also senior research scientist at the Vanderbilt Institute for Software Integrated Systems.

The project has a direct and immediate connection to the development of smart city technologies and can eventually be applied to other transit agencies across the country. Its blend of technical research and community engagement promises to improve the overall resilience of essential public transit services in the face of challenges, pandemic or otherwise.

Microtransit with major impact

Two federal grants, $2.1 million from the NSF and $1.8 million from the DOE, are enabling engineers to reimagine how regional transit systems operate, making them more accessible and efficient.

Both projects, headed by Abhishek Dubey, assistant professor of electrical engineering and computer science, are with the Chattanooga Area Regional Transportation Authority.

As agencies attempt to serve people migrating from the city to suburban areas, public transportation options often shrink for people in low-income and minority urban neighborhoods. Lack of access impacts educational attainment, job prospects and community service use.

Photo: Adobe Stock

The NSF project will focus on developing the technology to establish and integrate microtransit systems with CARTA's fixed-route service. Microtransit uses dynamically generated routes that enable passengers to get to and from common drop-off or pick-up locations. Community engagement to understand key challenges and share ideas is another component.

Dubey and collaborators spread across the U.S. will deliver a deployment-ready software system any transit agency can use to design and operate a microtransit service focused on technological efficiency and equitable access to transit.

The DOE project intends to seamlessly integrate fixed-route transit and low efficiency, high cost paratransit—individualized transit for people with disabilities—to develop solutions that retain operations with more energy efficient outcomes. A harmonious integration of these transit modes requires the simultaneous and time-sensitive accommodation of dynamic stops, fixed-route schedules and constantly shifting road conditions.

The ability to design and configure complex artificial intelligence algorithms that improve over time and learn with new scenarios and situations is central to both projects

"Our goal with these synergistic projects is to rethink entirely both the on-demand and fixed-line transit operations to make them more efficient and user friendly for passengers over the next four years," said Dubey, who also is senior research scientist at the Vanderbilt Institute for Software Integrated Systems. **V**

Photo: Adobe Stock

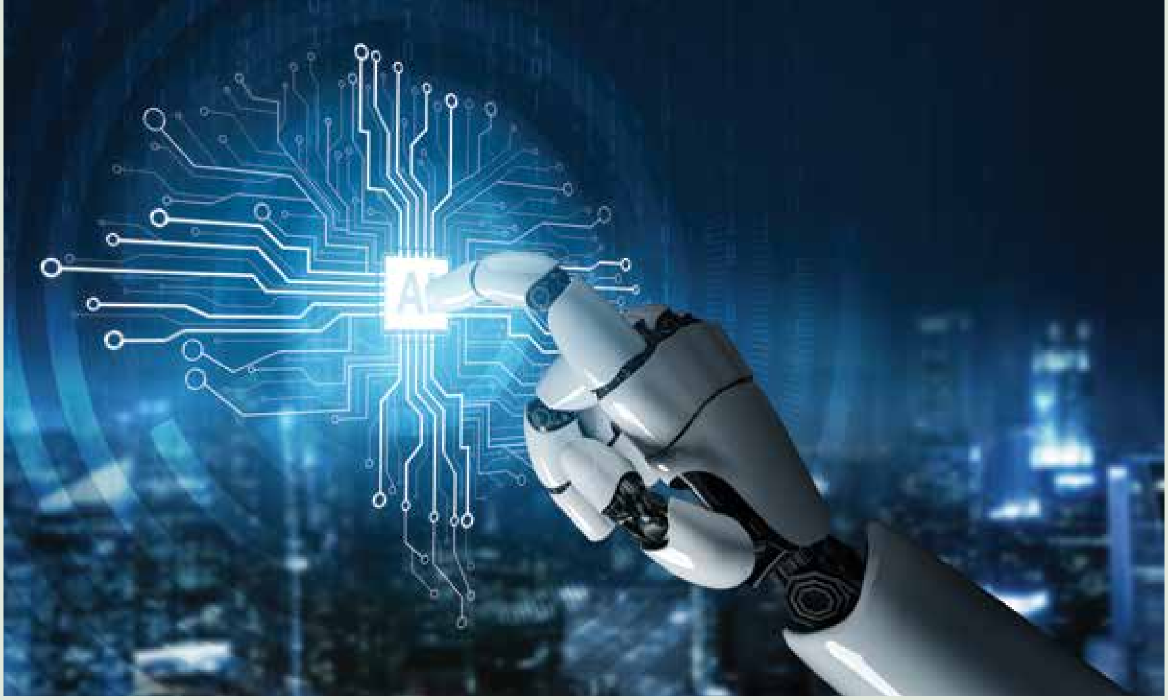


Photo: Adobe Stock

Automating CPS Engineering with AI co-designers

Future cyber-physical systems will rely less on human control and more machine learning algorithms and artificial intelligence processors. Smart grid, driver-assist and autonomous automobile systems, health and biomedical monitoring, smart cities, robotics systems, and new agricultural technologies are just a few CPS that interact with users in a lot of ways that change with context.

Data-driven AI methods also can play an increasing role in the design and implementation of CPS and are expected to have a significant impact on engineering processes.

A new, $8.7 million project—Design.R–AI-assisted CPS Design—will continue pathbreaking AI-assisted design work for the Defense Advanced Research Projects Agency. "Our vision is the reformulation of the conventional engineering process of CPS as a continuously learning, self-improving process of collaborative discovery," said Péter Völgyesi, principal investigator and senior research scientist in the Vanderbilt Institute for Software Integrated Systems. The chief scientist on the four-year project is Csaba Szepesvári, University of Alberta computer science professor and Foundations leader at Google DeepMind. Miklós Maróti, Ph.D.'02, a mathematics professor at University of Szeged, Hungary, is a key team member along with several Vanderbilt engineering faculty.

The goal is to develop open-source AI-based co-designers that are integrable with CPS design flows and tool suites. The critical challenge is the reformulation of notoriously hard problems in model-based CPS design as AI/machine learning problems and integrating the solution into continuous learning, AI-based co-designers that interact with human designers. The result could have a profound effect on design productivity and agility in the CPS design flow process, Völgyesi said.

"Our Vanderbilt team also has gained a broad and deep understanding of the fundamental and practical limitations of model- and component-based design of complex CPS as prime developers of the OpenMETA design automation tool suite for DARPA," Völgyesi said. For more than 20 years, ISIS has pioneered generations of metaprogrammable tool suites for modeling and model transformation.

"We have identified and understand the roadblocks and looked at existing and emerging AI methods to solve those problems," he said. Advances in deep learning and reinforcement learning, plus vast increases in computing power offer the team the potential to develop and deliver fundamentally new design capabilities. V

$14 million to steer I-24 corridor traffic, decrease trips to and from campus and improve air quality

Photo by Mickey Bernal

U.S. and Tennessee transportation agencies want to make examples of Nashville, Murfreesboro and Vanderbilt—but not in a bad way.

Grants totaling $14 million will support development of wide-ranging initiatives, from an AI system to manage a traffic-choked commuter corridor to improved shuttle service and a bike sharing program to encourage more university faculty, staff and students to leave their vehicles at home.

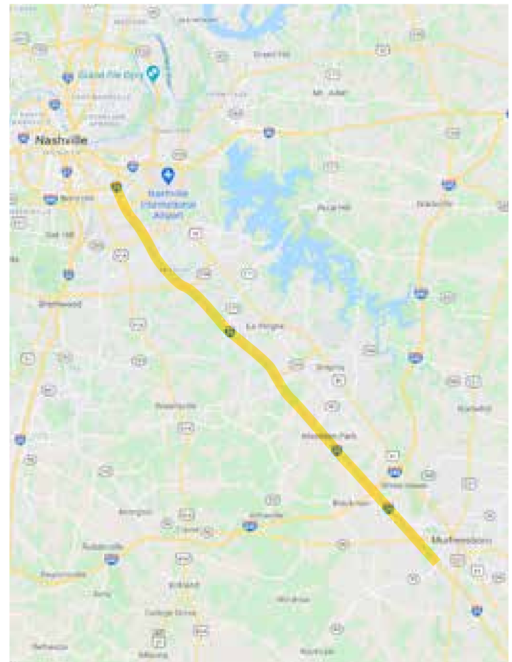
Traffic has increased 60 percent in 15 years along the area of Interstate-24 that connects Nashville with Murfreesboro. Now, Murfreesboro is the fastest growing city in Tennessee; Nashville is the 19th most congested city in the U.S.

At the same time, the Vanderbilt campus and surrounding area represent one of Middle Tennessee's largest activity centers and trip generators, most of which are done in single-occupancy vehicles.

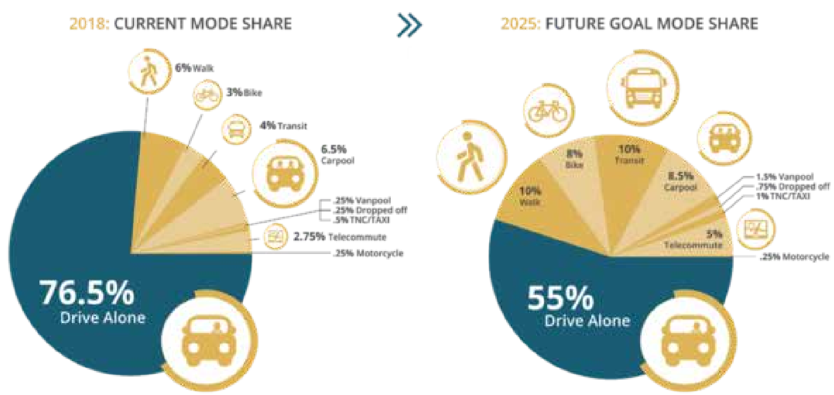
Together, these challenges have converged to create a regional test bed for new technology designed to reduce traffic congestion and fossil fuel use, encourage more sustainable transportation options and improve air quality.

In collaboration with the state Department of Transportation and the Southwest Research Institute, Vanderbilt engineers will develop an artificial intelligence-based decision support system to manage traffic on the corridor between Nashville and Murfreesboro.

The $5.6 million program, half each from TDOT and USDOT, for more effective integrated corridor management will deploy strategies that include dynamic messaging, changeable speed limits and ramp metering.



Researchers install poles with sophisticated sensors and cameras to capture data on I-24 and work toward an AI-based system to manage traffic dynamically.



Left: A morning commute slow down occurs on I-24 between Murfreesboro and Nashville. Right, MoveVU aims to decrease the share of community members who drive to campus alone.

To manage traffic incidents, the support system will deliver response plans to address primary traffic incidents and deliver lane guidance to drivers near the accident to mitigate secondary collisions. The project builds on previous Vanderbilt-TDOT partnerships to develop predictive analytics related to car crashes and to add high resolution cameras along the same corridor that provide real-time vehicle trajectory information using computer vision algorithms.

"This project is a civil engineer's dream," said Craig Philip, research professor of civil and environmental engineering and director of the Vanderbilt Center for Transportation and Operational Resiliency. "The research that VECTOR has been doing over the years in concert with our team's technological expertise have put us in the best possible position to execute our work successfully."

Continued on next page

MoveVU wants to create a more park-like setting by reducing single-occupancy traffic and adding features such as a separate lane for walking and bicycle use around the campus perimeter.

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Dan Work, associate professor of civil and environmental engineering, leads development of the AI support system.

"The AI Decision Support System can harmonize large quantities of traffic information from radar, CCTV, and Bluetooth readers on Interstate-24," said Work, who is also affiliated with the Vanderbilt Institute for Software Integrated Systems.

Federal Highway Administrator Nicole R. Nason said the project stands out.

"Tennessee's project is unique in providing other states with a roadmap for the implementation of similar ICM corridors at an accelerated pace," Nason said in a news release.

Similarly, federal and state agencies, plus Vanderbilt itself, have committed an additional $8.4 million to scale up activities of the MoveVU sustainable transportation program. MoveVU began in 2018 as part of the federal Congestion Mitigation and Air Quality Improvement Program, an initiative to support state departments of transportation with projects that improve air quality and reduce congestion.

The next phase will demonstrate how high-activity centers and major employers can lead change.

"Investing in bringing MoveVU to maturity will serve as an important proof of concept and template for other major employers and activity centers to emulate," said Mark Abkowitz, professor of civil and environmental engineering and the project's principal investigator.

Plans include a bikeshare service, shuttle service improvements and traffic-detection technologies as well as data analytics to assess the efficiency and effectiveness of system operations. **V**

High-resolution cameras atop poles along the I-24 corridor will provide real-time vehicle trajectory information using computer vision algorithms.

EVALUATING MARITIME TRANSPORTATION AMID SEA ICE AND CLIMATE UNCERTAINTIES

As the Arctic ocean responds to a warming climate it becomes a less icy, more viable and eventually more convenient shipping route.

Maybe.

Vanderbilt researchers are analyzing whether the Northern Sea Route that runs along the border of northern Russia is quicker and less costly to shippers, and weighing environmental concerns that could exacerbate already serious threats to the region.

Travel along that route, between Japan and the Netherlands, is 37 percent shorter than comparative routes along the Suez Canal in the Southern Hemisphere during times of little or no sea ice.

But distance is far from the only factor to be considered, said Hiba Baroud, assistant professor of civil and environmental engineering. "There are many factors that must be taken into consideration to determine if a trip along the NSR is a net benefit to the shippers, surrounding environments, and coastal communities," Baroud said. "For example, cargo ships must be outfitted for protected navigation, have safe places to dock and be reachable by emergency responders before we could definitively say that the NSR is a safe and cost-effective way to move shipments around the world."

Baroud, Littlejohn Dean's Faculty Fellow, and Ralf Bennartz, professor of earth and environmental sciences, are collaborating with Alice DuViver, a scientist at the National Center for Atmospheric Research, to develop risk analysis framework that evaluates the economic and environmental tradeoffs between this new potential trade route and established southern routes.

"A preliminary analysis of a simulation comparing the two routes enabled us to make a projection for what global shipping routes could look like through 2100," Bennartz said. "Until 2050, the Suez Canal will remain a better option for shippers because of the increased risk of navigation along the northern route."

The research, conducted through an interdisciplinary lens and with input from Arctic communities, is funded through Navigating the New Arctic, a National Science Foundation initiative.

$5 million NSF Convergence project revolutionizes neurodiverse employment through AI

NSF grant aligns with school's **Inclusion Engineering**SM focus

The National Science Foundation has awarded a highly competitive $5 million grant to Vanderbilt University that greatly expands a School of Engineering-led project for creating novel AI technology and tools and platforms that train and support individuals with Autism Spectrum Disorder in the workplace.

The significant federal investment follows a successful $1 million, nine-month pilot grant to the same team that forged partnerships with employers and other stakeholders and produced viable prototypes through immersive, human-centric design. The multi-university team includes Yale University, Cornell University, Georgia Institute of Technology and Vanderbilt University Medical Center as academic partners.

The grant, made through NSF's Convergence Accelerator program, advances the School of Engineering's focus on **Inclusion Engineering**,SM which uses the disciplines within engineering to broaden meaningful participation for people who have been marginalized.

Through a new framework called Inclusion AI, the project supports "meaningful, individualized workforce engagement of an existing, underutilized neurodiverse U.S. talent pool, in addition to supporting a more inclusive national employment landscape," said David K. Wilson Professor of Engineering Nilanjan Sarkar, who leads the effort.

"This is a critical but overlooked public health and economic challenge: how to meaningfully include individuals

Continued on next page

- One in 54 people in the United States has ASD;
- Each year 70,000 young adults with ASD leave high school and face grim employment prospects;
- More than 8 in 10 adults with ASD are either unemployed or underemployed, a significantly higher rate than adults with other developmental disabilities;
- The estimated lifetime cost of supporting an individual with ASD and limited employment prospects $3.2 million.
- **Approximately $50,000 per person *per year* could be contributed *back* into society when individuals with ASD—are employed.**

Below: Dan Burger, BS '12, MS '13, demonstrates an early version of the AI interview tool during the grand opening of the Frist Center for Autism and Innovation in July 2019.

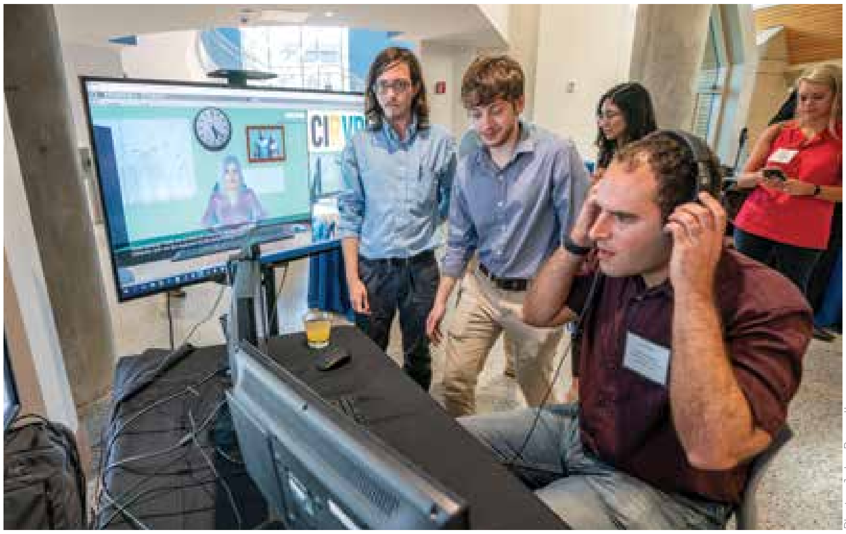
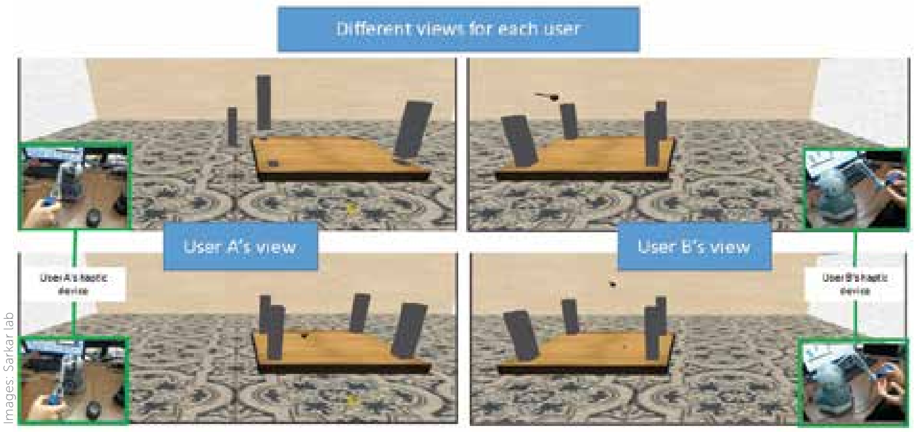
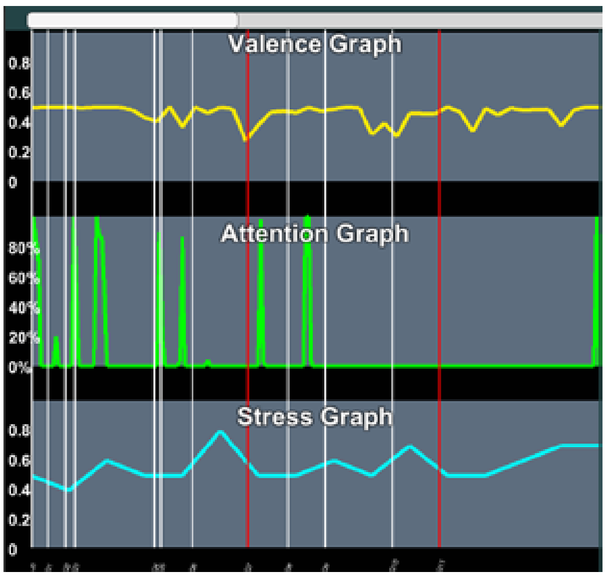


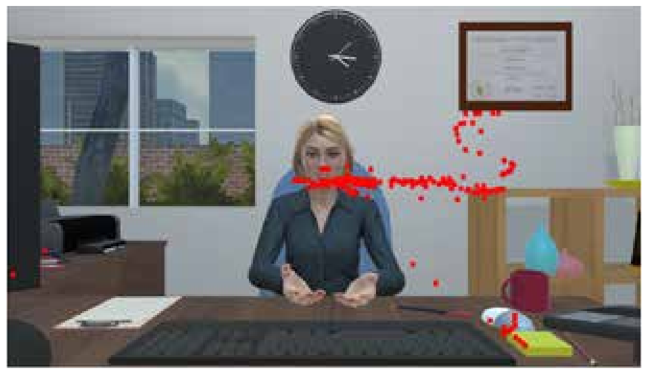
Photo: John Russell



Images: Sarkar lab

Left: One tool is a collaborative virtual environment in which two people must work together to complete a task, in this case assembling a table. The views differ for each user.





An AI-based job interview tool tracks a user's gaze and with a virtual interviewer and stress response to questions.
Left: Charts of attention and stress levels during a simulated interview give users feedback about their performance.

Continued from previous page

with ASD—a large, chronically unemployed and underemployed population," said Sarkar, professor of mechanical engineering and department chair.

"We want to harness the power of AI, stakeholder engagement and convergent research to include neurodiverse individuals in the 21st century workforce," Sarkar said. "We feel that there is a big opportunity to turn great societal cost into great societal value."

The NSF in recent years has increased its efforts to have experts from diverse fields converge to tackle a profound challenge through its Convergence Accelerator program. By definition, NSF Convergence grants support fundamental research leading to rapid advances that can deliver significant societal impact.

For this project, organizational, clinical and implementation experts are integrated with engineering teams to pave the way for real-world impact. The multi-university, multi-disciplinary team already has commitments from major employers to license some of the technology and tools developed.

Researchers will address three themes: 1) individualized assessment of unique abilities and appropriate job-matching; 2) tailored understanding and ongoing support related to social communication and interaction challenges; and 3) tools to support job candidates, employees and employers.

In all, the project includes further development, refinement and testing of five separate technologies prototyped in Phase 1. They are:

- An assessment system that integrates a wearable eye tracker, scene cameras and computer vision algorithms to produce a detailed record of a person's performance in visuo-spatial cognitive tasks;
- A virtual reality-based job interview simulator that senses a user's anxiety and attention through wearable computing and provides feedback and coaching;
- A collaborative virtual reality platform to assess and help team-building skills through

peer-based and intelligent agent-based interaction;

- A social robot for use in home environments to improve resilience and tolerance with job-related interruption; and
- A computer vision-based tool to assess non-verbal communication in real-world settings.

Frist Center for Autism and Innovation Director Keivan Stassun is among other Vanderbilt experts involved and will be pivotal in coordinating with industry and advocacy stakeholders. Other key Vanderbilt collaborators are Maithilee Kunda (computer science), and Joshua Wade (mechanical engineering) and Tim Vogus (Owen Graduate School of Management).

Already, notable private-sector companies that employ people with ASD have committed to using at least one of the technologies developed under this program: Auticon, The Precisionists, Ernst & Young and SAP among them.

Two other companies, Floreo and Tipping Point Media, will make their existing VR modules available for adaptation to the program. Microsoft, which has a long-standing interest in hiring people with ASD, is involved as well and provided seed funding and access to cloud services for technology integration.

The five technologies can be used separately or as an integrated system, and the work has broader potential beyond ASD to expand employment access. In the U.S. alone, an estimated 50 million people have ASD, attention-deficit/ hyper-activity disorder, learning disability or other neurodiverse conditions.

"A more diverse workforce benefits employers as well as individuals with neurodiverse conditions," Sarkar said. "These tools and technology will have an even larger impact in helping marginalized populations with meaningful employment." **V**

Run 50% faster—with a spring in your step

Running feet take turns hovering in the air for the briefest of moments. During that time, the airborne foot does nothing to advance the cause of running.

But what if it could?

A pair of Vanderbilt engineers has proposed a pogo stick-like device that takes advantage of the airtime, allowing humans to run nearly twice as fast as is possible naturally.

The invention, an exoskeleton worn on the legs, would add cycling mechanics to the human body and enable people to approach top cycling speeds.

To leverage the continuous motion of bike pedaling, David Braun, Ph.D.'09, assistant professor of mechanical engineering, and graduate student Amanda Sutrisno designed the theoretical exoskeleton device to allow the legs to supply energy while in mid-air. They realized that a device strapped in parallel to each leg and housing a robotic spring could achieve the same technological advances as a bicycle.

Here's how it works: During a stride, the device springs compress and release in time with the motion of the legs, allowing one spring to contract when the leg pulls up into the air and the other to extend as it comes into contact with the ground.

Their study, "How to run 50 percent faster without external energy," appeared in *Science Advances*.

"While bicycles rely on human energy the same as running, cycling is faster because of the energy-efficient processes engaged while on a bike," Braun said. "Our lab took those processes and sought a way to more effectively augment human performance."

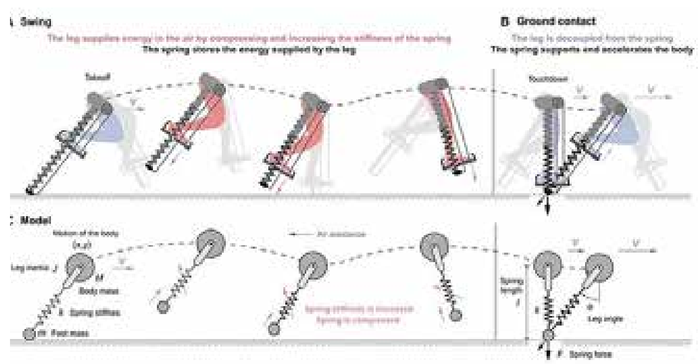


Illustration: Braun lab

A theoretical exoskeleton uses cycling mechanics to take advantage of a running stride and nearly double the potential speed.

Existing devices with springs, such as jumping stilts, reduce the energy losses when runners step, but do not support the body or allow the legs to move the body forward while in the air. This device could not only support the body but also allow the legs to provide energy in the air so runners can use all their leg power as when pedaling the bicycle to accelerate, meaning they can run faster than ever.

The researchers are working on a prototype device but face a hurdle: Existing materials such as carbon fiber lack the energy-holding capacity needed to propel a runner to such speeds. Something new must be developed to fully test the idea.

Minimizing risks in wind and solar power forecasts

Team will model time horizons from 15 minutes to 24 hours

Photos: Adobe Stock

The price for electricity on the wholesale market fluctuates every five minutes based on demand. Adding renewable energy to the mix greatly complicates matters. Historical methods that predict supply and demand are not accurate. Supply varies as the wind blows, or doesn't, and as the sun shines, or doesn't. Pricing electricity to maintain market equilibrium becomes a fast-moving target with ever more uncertainty.

Renewable energy sources make predicting supply and demand more difficult for grid operators. As part of a DOE project, engineers will develop new machine learning algorithms that enable decision-making in near real time to maintain market equilibrium.

Vanderbilt risk and reliability experts are part of a $3.25 million Department of Energy project that ultimately seeks to assign risk scores to energy assets to support quicker and more accurate market forecasts. The goal is to develop new machine learning algorithms that enable decision-making in near real time. The project is in concert with MISO, the Midcontinent Independent Supply Operator, a power consortium that operates the grid in all or parts of 15 states.

"The impact stands to be enormous," said John R. Murray Sr. Professor of Engineering Sankaran Mahadevan. "This approach has the potential to transform how system operators plan and operate the U.S. grid, leveraging renewable energy sources, while minimizing the system risk."

Mahadevan and Hiba Baroud, assistant professor of civil and environmental engineering and Littlejohn Dean's Faculty Fellow, will lead Vanderbilt's efforts. Their team will develop comprehen-

Photo courtesy of MISO Energy

The DOE project is in concert with MISO, the Midcontinent Independent Supply Operator, a power consortium that operates the grid in all or parts of 15 states. Above, one of the MISO control centers.

sive risk metrics to support operational decisions that account for fluctuations and economic impact and handle statistical analysis of historical data to identify patterns and relationships among the many factors. They will use machine learning to speed up decision-making, based on optimum decision solutions for multiple scenarios generated by Georgia Institute of Technology, the project lead.

The goal of the project—Risk-Aware Market Clearing—is a blueprint for an end-to-end, data-driven approach that balances cost and minimizes system-level risk. Market clearing is the process that keeps the supply level to the demand with no leftover of either.

Central to the project is a new statistical approach to forecast supply and demand. Historically the electricity market has relied on deterministic models, which predict outcomes with near certainty. Recent and fundamental advances in risk assessment, computational statistics, optimization and machine learning make it possible to use stochastic models that consider inherent randomness and uncertainty.

MISO, which acts much like an air traffic controller for the electric grid, has used traditional prediction models at three different time horizons: 24 hours, 15 minutes to three hours, and 10 minutes. Evolving factors that include randomness in renewable generation, load fluctuation with solar panels "behind" meters, and extreme weather increasingly affect all three predictions.

And that is with wind energy making up less than 20 percent of MISO's energy portfolio. As the asset mix relies more on renewables and less on fossil fuels—MISO in February 2020 said it had projects totaling 57 gigawatts of solar power generation in the queue—forecasting risks escalate.

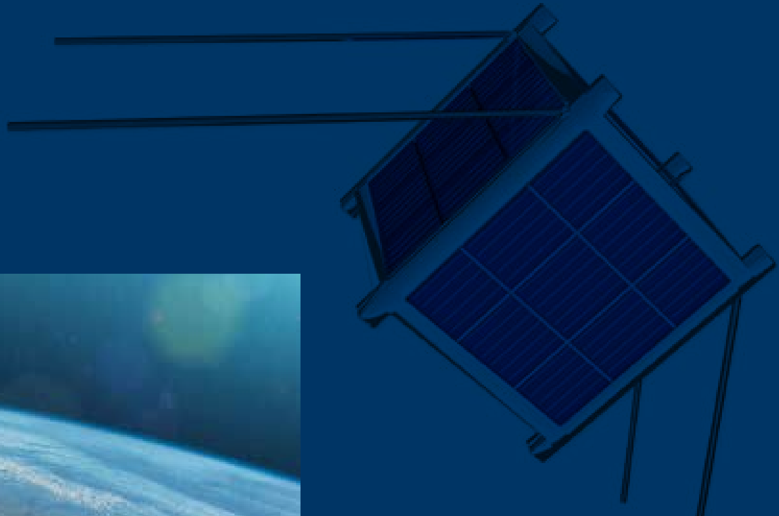
> "This approach has the potential to transform how system operators plan and operate the U.S. grid, leveraging renewable energy sources, while minimizing the system risk."
>
> **Sankaran Mahadevan**

The team will use six years of historical data to build and train neural networks. The historical data covers:

- Renewable resource forecasts, including over 200 wind generators;
- Interchange and loop flows;
- Load forecasts for 38 Local Balancing Authorities;
- Generator non-compliance and status changes such as outages;
- Extreme weather events related to emergency conditions.

"We will leverage ideas developed in actuarial science to develop a composite risk metric that is similar to credit scores used in the financial industry, where we learn system-level risk based on many factors, individual asset risks and their correlations," Baroud said.

The project is one of 10 funded by DOE's Advanced Research Projects Agency as part of the Performance-based Energy Resource Feedback, Optimization, and Risk Management program. **V**



Electronics institute advances employer partnerships and undergraduate training

Photos: Adobe Stock

The Institute for Space and Defense Electronics is answering a market need for highly specialized knowledge at two distinct but vital points—training for radiation effects engineers and internships for undergraduates in a subject usually reserved for graduate students.

As the largest academic program of its kind in the U.S., ISDE is uniquely positioned to meet such future workplace demands. Institute researchers have designed customized online training modules to help advance the skills of radiation effects engineers at L3 Harris Technologies.

L3 Harris is a Melbourne, Fla.-based aerospace and defense company with 50,000 employees worldwide. Its leaders say the five-year partnership with ISDE shows the company's commitment to provide the most technically advanced training curriculum to their engineers, most of whom hold graduate degrees.

The technological updates, available online 24/7, offer the latest information from one of the very few university-based programs involved in microelectronics research for space applications.

"This is an exciting opportunity to work with a company in the field on system-specific problems of practical importance. Our tech updates will save the company time, which will ultimately benefit L3Harris customers," said Ronald Schrimpf, ISDE director and Orrin H. Ingram Professor of Engineering.

Radiation-hardened electronics, as well as microelectronic design and reliability, is a priority for national security and resilience. The L3 Harris—ISDE partnership provides cutting-edge training without taking employees offline for weeks or months at a time. Equally important is reaching the next generation of students with learning that offers core competencies earlier and faster.

To that end, Vanderbilt is the Lead Technical University in a public-private-academic partnership to boost the engineering talent pipeline in highly specialized engineering fields. Through ISDE, a five-year $4.6 million program funded by the Office of the Under Secretary of Defense kicked off this summer in a virtual internship for undergraduates that focused on future workforce needs in secure microelectronics.

"In this case, we're introducing undergraduates to opportunities in the radiation effects field much earlier as well as facilitating internships starting as early as the summer after freshman year," said Mike Alles, associate director of ISDE and research professor of electrical engineering. **V**

"This is an exciting opportunity to work with a company in the field on system-specific problems of practical importance."

Ronald Schrimpf

Selected Honors and Leadership

Vanderbilt School of Engineering faculty are fellows of the following organizations as of Sept. 1, 2020.

American Academy of Environmental Engineers and Scientists

American Academy of Forensic Sciences

American Association for the Advancement of Science

American Geophysical Union

American Heart Association

American Institute of Aeronautics and Astronautics

American Institute of Chemical Engineers

American Institute for Medical and Biological Engineering

American Physical Society

American Society of Civil Engineers

American Society for Engineering Education

American Society for Laser Medicine and Surgery

American Society of Mechanical Engineers

American Vacuum Society

American Welding Society

Association of Women in Science

Biomedical Engineering Society

Combustion Institute

Council on Basic Cardiovascular Sciences of the American Heart Association

Electrochemical Society

Engineering Mechanics Institute

Heart Rhythm Society

Geological Society of America

Hungary Academy of Sciences (External Member)

Institute of Electrical and Electronics Engineers

Institute of Physics (U.K.)

Institute of Transportation Engineers

International Society for Magnetic Resonance in Medicine

International Society for Optical Engineering

Materials Research Society

Microscopy Society of America

National Academy of Engineering, Members

National Academy of Inventors

National Academy of Sciences, Advisory Committee Members

National Academy of Sciences, National Associate

Optical Society of America

Prognostics and Health Management Society

Royal Danish Academy of Sciences and Letters

Royal Society of Chemistry (U.K.)

Royal Swedish Academy of Engineering Sciences

Society of Experimental Mechanics

U.S. Air Force Scientific Advisory Board, Member

U.S. Nuclear Waste Technical Review Board, Presidential Appointee

Research Groups

Vanderbilt University School of Engineering fosters strong partnerships inside the university and with its research peers. The combination of innovative research, commitment to education, and collaboration with a distinguished medical center creates an invigorating atmosphere for faculty members, research staff, graduate students and undergraduates.

Biophotonics Center at Vanderbilt
Anita Mahadevan-Jansen, Orrin H. Ingram Professor of Engineering, Professor of Biomedical Engineering
vanderbilt.edu/vbc

Vanderbilt Center for Mechanobiology
Cynthia Reinhart-King, Cornelius Vanderbilt Professor of Engineering, Professor of Biomedical Engineering

Center for Rehabilitation Engineering and Assistive Technology
Michael Goldfarb, H. Fort Flowers Professor of Mechanical Engineering

Karl Zelik, Assistant Professor of Mechanical Engineering
engineering.vanderbilt.edu/create

City Innovations through the Vanderbilt initiative on Infrastructure Connectivity (CIVIC)
Douglas Adams, Daniel F. Flowers Professor, Distinguished Professor of Civil and Environmental Engineering

Consortium for Risk Evaluation with Stakeholder Participation
David Kosson, Cornelius Vanderbilt Professor of Engineering, Professor of Civil and Environmental Engineering
cresp.org

Data Science Institute
Douglas Schmidt, Cornelius Vanderbilt Professor of Engineering, Professor of professor of computer engineering and computer science
vanderbilt.edu/datascience/

Frist Center for Autism and Innovation
Keivan Stassun, Stevenson Professor of Physics & Astronomy, Professor of Computer Science
my.vanderbilt.edu/autismandinnovation/

Institute for Software Integrated Systems
Janos Sztipanovits, E. Bronson Ingram Professor of Engineering
isis.vanderbilt.edu

Institute for Space and Defense Electronics
Ron Schrimpf, Orrin H. Ingram Professor of Engineering
isde.vanderbilt.edu

Laboratory for Systems Integrity and Reliability
Douglas Adams, Daniel F. Flowers Professor, Distinguished Professor of Civil and Environmental Engineering
vu.edu/lasir

Multiscale Modeling and Simulation Group
Peter Cummings, John R. Hall Professor of Chemical Engineering
my.vanderbilt.edu/mums

Vanderbilt Center for Environmental Management Studies
Mark Abkowitz, Professor of Civil and Environmental Engineering
vanderbilt.edu/VCEMS/

Vanderbilt Center for Transportation and Operational Resiliency
Craig Philip, Research Professor of Civil and Environmental Engineering
vanderbilt.edu/vector

Vanderbilt Institute for Energy and Environment
George M. Hornberger, Craig E. Philip Professor of Engineering, University Distinguished Professor of Civil and Environmental Engineering
vanderbilt.edu/viee

Vanderbilt Institute for Integrative Biosystems Research and Education
John Wikswo, Cain University Professor, Professor of Biomedical Engineering
vanderbilt.edu/viibre

Vanderbilt Institute of Nanoscale Science and Engineering
Sharon Weiss, Cornelius Vanderbilt Professor of Engineering, Professor of Electrical Engineering
vanderbilt.edu/vinse

Vanderbilt Institute for Surgery and Engineering
Benoit Dawant, Cornelius Vanderbilt Professor of Engineering, Professor of Electrical Engineering
vanderbilt.edu/vise

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Selected Awards

Douglas Adams, Daniel F. Flowers Professor, was named a Fellow of the American Association for the Advancement of Science (AAAS). He is a professor of mechanical engineering as well as civil and environmental engineering and serves as chair of the latter department.

Hiba Baroud, assistant professor of civil and environmental engineering and Littlejohn Faculty Fellow, received an NSF CAREER Award.

Prodyot (P.K.) Basu was named Professor of Civil and Environmental Engineering, Emeritus. He joined the engineering school faculty in 1984.

Audrey Bowden, Dorothy J. Wingfield Phillips Chancellor's Faculty Fellow and associate professor of biomedical engineering, was elected to the American Institute for Medical and Biological Engineering's (AIMBE) College of Fellows and the Optical Society of America (OSA) Fellows.

Joshua D. Caldwell, associate professor of mechanical engineering, was named a 2020 Materials Research Society fellow and an inaugural Flowers Family Faculty Fellow.

Janey Camp, research associate professor of civil and environmental engineering, was elected to the board of directors of TennSMART, a public-private consortium whose goal is to create a technology roadmap and strategic plan for intelligent mobility issues in Tennessee.

Peter T. Cummings, John R. Hall Professor of Chemical Engineering and the School of Engineering's associate dean for research, was named a Fellow of the Royal Society of Chemistry.

Mark Does, professor of biomedical engineering, was selected as a Fellow of the International Society for Magnetic Resonance in Medicine.

Craig Duvall, professor of biomedical engineering, was named a Cornelius Vanderbilt Professor in Engineering. He also was selected a Fellow of the Biomedical Engineering Society (BMES).

Daniel M. Fleetwood, Olin H. Landreth Professor of Engineering, was named an AAAS Fellow. He is a professor of electrical engineering.

Kelsey Hatzell, assistant professor of mechanical engineering, was named an inaugural Flowers Family Faculty Fellow. She also received a Sloan Research Fellowship in 2020 and the Materials Research Society Nelson "Buck" Robinson Science and Technology Award.

Piran Kidambi, assistant professor of chemical and biomolecular engineering, received an NSF CAREER grant and an Electrochemical Society Toyota Young Investigator Fellowship.

Ethan Lippmann, assistant professor of chemical and biomolecular engineering, received an NSF CAREER grant.

Anita Mahadevan-Jansen, Orrin H. Ingram Professor of Biomedical Engineering, was elected a National Academy of Inventors Fellow. Additionally, an optical imaging technology she developed in partnership with a medical device company won a 2019 R&D 100 Award.

Clare McCabe, Cornelius Vanderbilt Professor of Engineering, was named an AAAS Fellow. A professor of chemical and biomedical engineering, she also was elected as a Fellow of the American Institute of Chemical Engineers.

Victoria Morgan, associate professor of biomedical engineering and radiology and radiological sciences, was elected as a fellow of AIMBE.

K. Arthur Overholser, who served Vanderbilt from 1971 through 2019, was named Professor of Biomedical Engineering and Chemical Engineering, Emeritus.

Marjan Rafat, assistant professor of chemical and biomolecular engineering, was awarded a Young Investigator Grant by the Breast Cancer Alliance.

Cynthia Reinhart-King, Cornelius Vanderbilt Professor of Engineering, received a $1 million grant from the W.M. Keck Foundation.

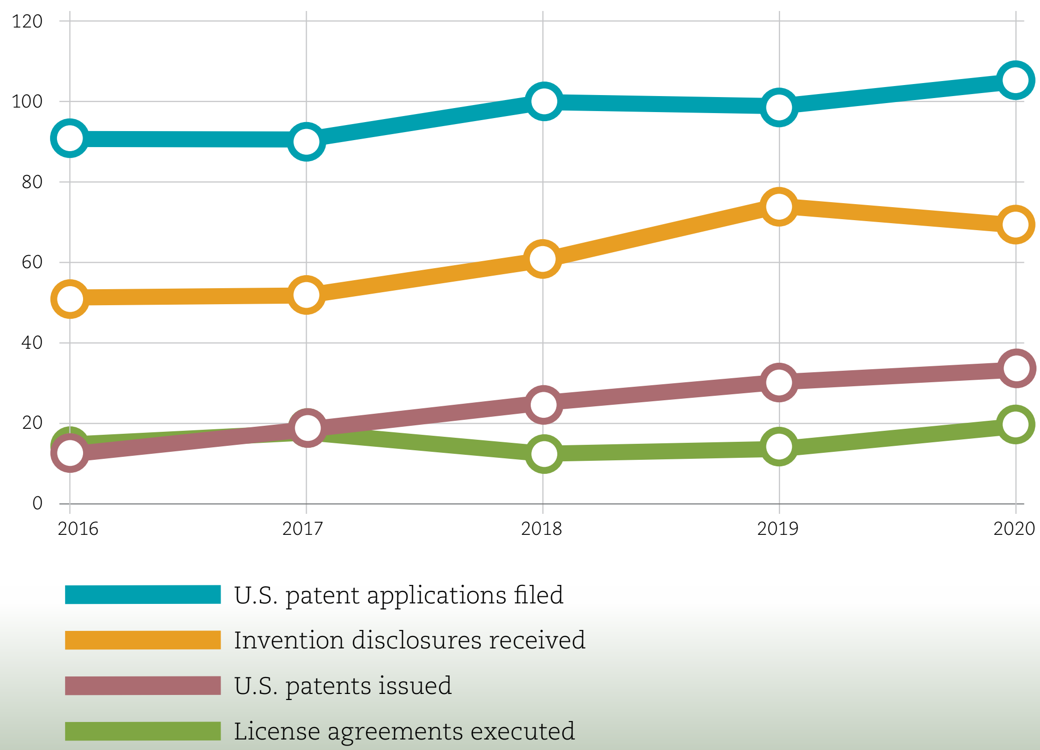
Nilanjan Sarkar was named the David K. Wilson Chair in Engineering. He is a professor of mechanical engineering and chairs the department.

Nabil Simaan, professor of mechanical engineering, was elected as Fellow of the Institute of Electrical and Electronics Engineers.

Matthew Walker III, professor of the practice of biomedical engineering, was elected as a Fellow of AIMBE.

Jason Valentine, associate professor of mechanical and electrical engineering, was selected as the new faculty liaison with Oak Ridge National Laboratory.

Commercial Impact



5-year totals

494
U.S. patent applications filed

318
Invention disclosures received

122
U.S. patents issued

83
License agreements executed

$7,273,178
Revenue generated from VUSE technologies

Most Recent Fiscal Year

108
U.S. patent applications filed
representing 133 VUSE inventors

70
Invention disclosures received
representing 97 VUSE submitters

35
U.S. patents issued
representing 68 VUSE inventors

20
License agreements executed

$1,761,968
Revenue generated from VUSE technologies

These figures were provided by Vanderbilt's Center for Technology Transfer and Commercialization for the most recent fiscal year (July 1, 2019 through June 30, 2020).

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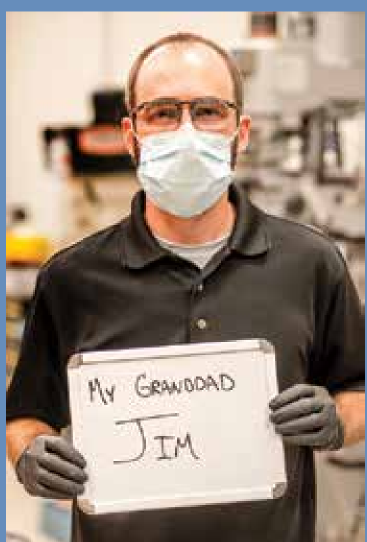

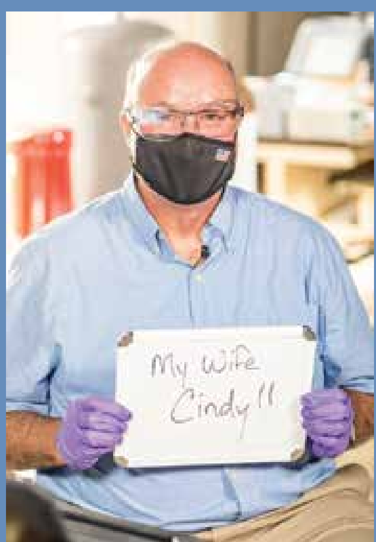

Who do you mask up for?