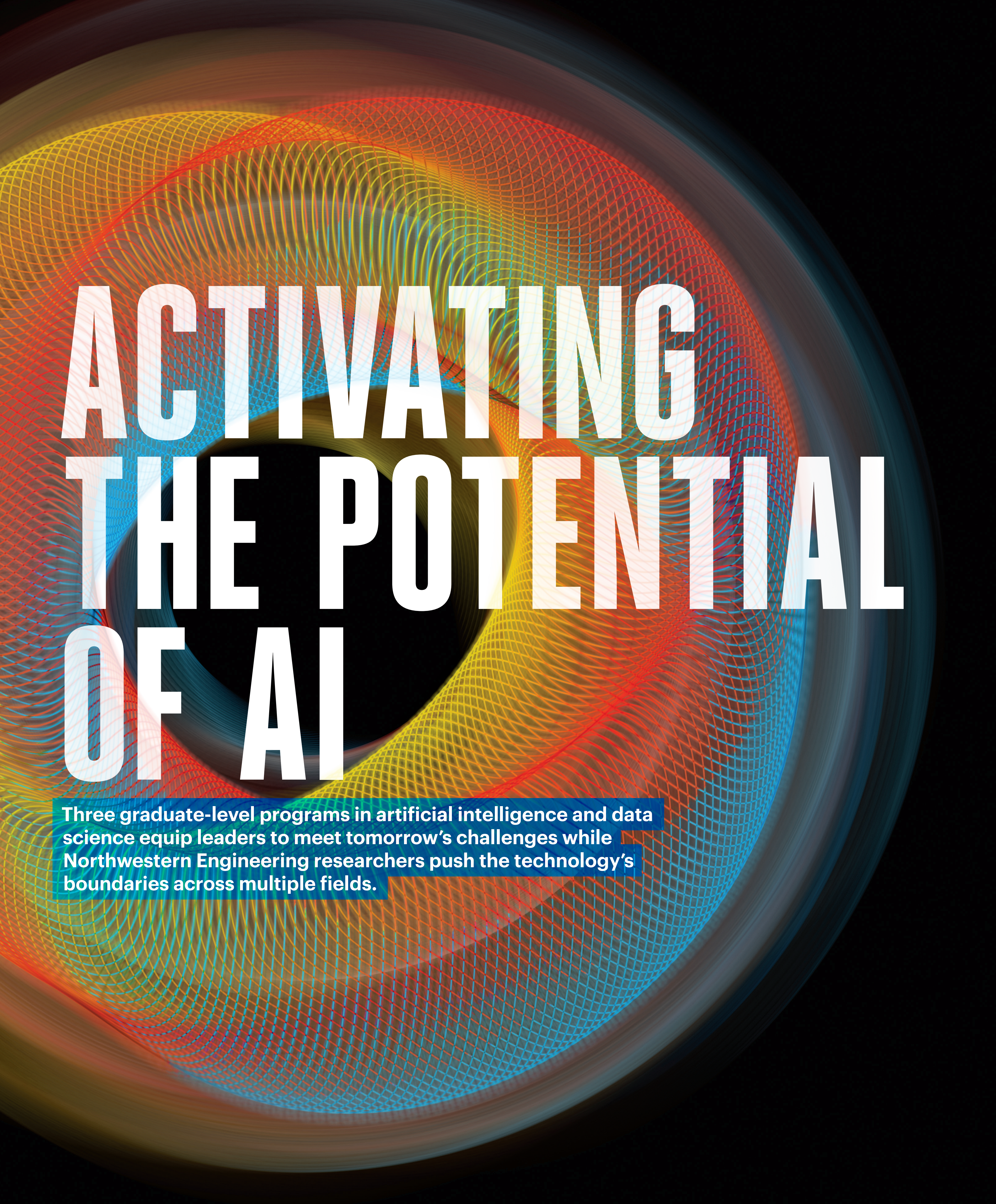


ACTIVATING THE POTENTIAL OF AI

Three graduate-level programs in artificial intelligence and data science equip leaders to meet tomorrow's challenges while Northwestern Engineering researchers push the technology's boundaries across multiple fields.

PREPARING LEADERS FOR THE NEW WORLD OF ARTIFICIAL INTELLIGENCE

AI is poised to impact nearly every domain, including research, business, media, the arts, and even governments. It's already being used to open up new avenues of discovery, develop novel methods of market analysis, and create innovative products, music, books, images, and more. In 2023, McKinsey & Company estimated the economic potential of generative AI alone could be as much as $4.4 trillion annually.

Yet technology alone will not realize this enormous potential. Businesses need to invest in talent capable of developing, applying, and managing these technologies and the products and services that use them.

To equip students to navigate and meet the challenges of this new frontier with confidence, Northwestern Engineering offers a trio of master's degree programs. Each aims to ground tomorrow's leaders in the technology from three unique perspectives—data scientists/machine-learning engineers, AI application developers, and AI executive leadership—as well as prepare them to use it wisely as they assume positions of influence and power in the world.

MS IN MACHINE LEARNING AND DATA SCIENCE

LEVERAGING THE FULL VALUE OF DATA

Enterprise AI applications that use complex data to drive mission-critical business processes rely on the development of rigorous models. The engineers who build these models must have the technical depth, skill, and experience to ensure their accuracy and relevance.

Launched in 2011, the Master of Science in Machine Learning and Data Science (MLDS)—formerly Master of Science in Analytics—teaches students how to use complex data, maximize its value, and develop and deploy enterprise machine learning and AI applications to advance goals and meet the needs of the technology's users. Students also learn how to design creative solutions, communicate effectively with a variety of audiences, and lead teams and projects successfully.

"We hear from our industry advisory board, from project partners, and from internship sponsors about the various ways the program addresses technological changes coming down the pike before they happen," says Diego Klabjan, professor of industrial engineering and management sciences and MLDS director. "What MLDS does very well is prepare students for such changes so they can enter an internship or the job market able to take on the challenges that happen in real time."

MLDS is housed within the Department of Industrial Engineering and Management Sciences. The program's students, who come from a variety of backgrounds, learn how to apply data from practitioners in multiple industries including healthcare, sports, retail, and entertainment. With only 55 or so students admitted into each cohort, MLDS creates strong bonds among participants as they progress through the program together and graduate into positions as software engineers, data scientists, and analysts.

"Students who make the most of their time here are going to investigate industries they didn't think they were personally interested in," Klabjan says. "It helps them take that broad view that generalists have and then go out into the world able to speak to any number of industries using the content they've acquired while in the program."

"STUDENTS WHO MAKE THE MOST OF THEIR TIME HERE ARE GOING TO INVESTIGATE INDUSTRIES THEY DIDN'T THINK THEY WERE PERSONALLY INTERESTED IN."

Diego Klabjan
Professor of Industrial Engineering and Management Sciences, MLDS Director

Prior to entering the MLDS program, Jason Summer (MLDS '22) worked in data science and advanced analytics. Fueled by an internship with Nike where he developed a learning model to predict customer purchases, Summer landed a full-time position as a solution innovation architect at Snowflake, a cloud computing and AI company.

"A couple classes did a wonderful job portraying how data science can be operationalized appropriately and effectively at organizations," Summer says. "These classes helped me better grasp how to engineer AI/ML solutions at scale while successfully communicating and advocating for their success."

While MLDS focuses on technical skills, the program also works to hone the soft skills like communication and translation that graduates will need in the business world.

"We're not training students to work in individual silos. That's not how they're going to function when they graduate. They're going to graduate into team-based roles, so coursework and projects really simulate that environment," says MLDS associate director

Stephen Dowling. "The ability not only to function collegially on a team, but also to lead a team and understand the nontechnical aspects of data science that can often make or break a team is something we focus on."

Summer and students like him put their lessons into practice not only in class or internships, but also in their capstone projects. Such an opportunity proved valuable for Summer, providing him firsthand experience in places he had none before.

"MLDS allowed me to assist a biomedical startup in its game-changing research to identify maternal and fetal risk during pregnancies," Summer says. "It also provided an opportunity to collaboratively develop ML with classmates in a fast-paced environment with multiple interdependent pieces."

Sharika Mahadevan (MLDS '23), now an analytics engineer at Netflix, was impacted in similar ways.

"The program helped me build a strong foundation of skills and knowledge needed to start a career in the data science field," she says. "What's really important to improve yourself is the opportunity to apply this knowledge. I feel that I had that through the practicum and capstone projects. The program also kept up with the latest trends in the industry. This is very important in a field such as data science that is constantly evolving."

MS IN ARTIFICIAL INTELLIGENCE

LEADING AI DEVELOPMENT THROUGH TECH, BUSINESS, AND HUMAN PERSPECTIVES

AI provides new ways of engaging systems using language and reasoning but can be imprecise and risky. Employing these capabilities requires an understanding of how these technologies work and an ability to reap the potential benefits while avoiding myriad potential risks and pitfalls.

Launched in 2018, the Master of Science in Artificial Intelligence (MSAI) program was created to meet the demand from industry for individuals who understand AI systems and the problems they can solve. The program equips students with the skills to create powerful AI systems that integrate with workflows, business applications, and human interactions.

"AI has been involved in transforming a lot of fields," says Kristian Hammond, Bill and Cathy Osborn Professor of Computer Science and MSAI director. "It is incumbent upon us to make sure that our students can lead as opposed to going into organizations and just following along."

For students interested in defining how AI can be used in businesses across domains, MSAI offers a unique educational path. All core courses are AI-focused, starting with classes that establish a baseline of understanding before moving onto advanced topics such as knowledge representation and commonsense reasoning. The program's final three quarters prepare students to work in industry through experiential activities, including a practicum where they work on projects proposed by researchers in other Northwestern

Kristian Hammond

Priyanka Aryal works with classmates during the MSAI Hackathon in 2023. Photo by Joel Wintermantle

schools, and a capstone comprising a collaboration with students from the MBAi program to engage in a project posed by a leading company partner.

"The electives also played a significant role in enhancing our knowledge base," Simon Zouki (MSAI '23) says. "This flexibility allowed us to tailor our education by selecting courses aligned with our career goals and aspirations, which was crucial to understanding the concepts thoroughly."

Priyanka Aryal (MSAI '23), now a full-time research assistant at Northwestern's Center for Advancing Safety of Machine Intelligence (CASMI), partnered with EY for her capstone project to develop a tool designed to streamline portfolio analysis and determine the need for divestiture, employing various prompt engineering techniques and closely integrated large language models (LLMs) and generative AI into the project.

"Collaborating with EY alongside students from Kellogg provided a unique experience that could be possible only through this program," Aryal says. "Exploring emerging technologies and witnessing how companies adapt and evolve with the implementation of new generative AI technologies were fascinating aspects of the project."

Students also learn from Department of Computer Science faculty members, many of whom have extensive industry experience developing enterprise-grade solutions.

"Before enrolling, I didn't have a comprehensive grasp of AI concepts, algorithms, and techniques," Aryal says. "But through the coursework, I developed proficiency in areas like machine learning, deep learning, natural language processing, and computer vision. The emphasis on practical application was invaluable. Collaborating with industry partners on capstone and practicum projects allowed me to implement my knowledge in real-world scenarios."

Today, one of the most pressing needs in industry is solutions that can navigate and harness the power of LLMs, such as ChatGPT. That's an area where MSAI is ahead of the game.

"It's not just language. It's not just a picture. It's several modalities of AI, including audio and video, and they need to be integrated to make impactful and safe systems," says Mohammed Alam, the program's deputy director. "Putting things together is a special skill; you have to know how to do it. That's what we're pushing our students to learn, how to use LLMs and other modalities of AI efficiently, safely, and ethically."

THE MBAi PROGRAM

DEVELOPING TECHNOLOGY-LITERATE LEADERS FOR THE AI AGE

Founded in 2021, this AI-focused MBA program offered jointly with the Kellogg School of Management responds to the growing global need for technically deep executive leaders. The intent of the MBAi program is to develop technical product managers and technology strategists who are as effective engaging a team of data scientists as they are the C-suite—a group that can often be misinformed about the precise capabilities of AI.

Even in the relatively short span of its existence, the program has adapted to the changing AI landscape.

"I reminded our most recent graduating class that at the time they enrolled in the program, ChatGPT hadn't come out yet," says Andrew Fano, clinical professor of computer science and director of the MBAi program. "It was also over the time they were here that LLMs gained real popularity. The proliferation of LLMs has changed everything, including more emphasis in the coursework and the capstone. That reflects the interest shown by companies."

While technology captures the public's interest, MBAi's cohort of 40 to 50 students develops skills in business and technology. MBAi students take the same core MBA courses as Kellogg's standard two-year program, with some courses tailored to emphasize AI and technical topics. Students also take technical courses from the McCormick School of Engineering that accelerate their fluency in analytics and complex technologies. This includes programming in Python, understanding data structures, and techniques for business problem translation, management, applications, and scale. As a result, there is a greater applied focus, with attention paid to the organizational and business implications of technical choices.

"THE PROLIFERATION OF LLMs HAS CHANGED EVERYTHING, INCLUDING MORE EMPHASIS IN THE COURSEWORK AND THE CAPSTONE. THAT REFLECTS THE INTEREST SHOWN BY COMPANIES."

Andrew Fano
Clinical Professor of Computer Science,
MBAi Director

"The program broadened my knowledge of organizational and industry dynamics. It also deepened my knowledge of how data and AI can be leveraged to solve complex problems," says Nolan Hartwick (MBAi '22), now a digital aircraft strategy manager for United Airlines. "Broadening and deepening my knowledge base has allowed me to be more creative and effective in problem-solving."

Students present their capstone projects during the MBAi + MSAI Capstone Showcase in December 2023.
Photo by Carlos Javier Ortiz

While the MBAi curriculum can open career paths for graduates in industries such as financial services or consulting, it also makes them attractive to a wider range of employers. This is accomplished, in part, through MBAi's joint capstone with the MSAI program. In 2023, 17 teams of MBAi and MSAI students worked on projects posed by 15 businesses ranging from Fortune 100 companies to startups. Topics included brand-aligned generative AI content and driving sales effectiveness with AI. The experience culminated in the MBAi + MSAI Capstone Showcase held in December.

"We bring in strengths from the business school, and we understand how to manage teams and how to build a business case, and the other teammates from MSAI, those guys bring in all the technical expertise," says Ameen Shaik (MBAi '23). "Those guys are the brains behind what we built."

Two years ago, one of the program's top capstone projects was for farming-giant John Deere. Several program alumni now work for the company.

"Before coming here, most of our students probably never had a chance to think about problems in agriculture," Fano says. "There are a lot of companies like John Deere that are doing very interesting work not readily visible to students because it's not a business-to-consumer segment."

Hartwick saw that too. His capstone project helped a large business-to-business technology retailer increase its search-to-cart rates by using language models to better categorize and understand the intent of user searches.

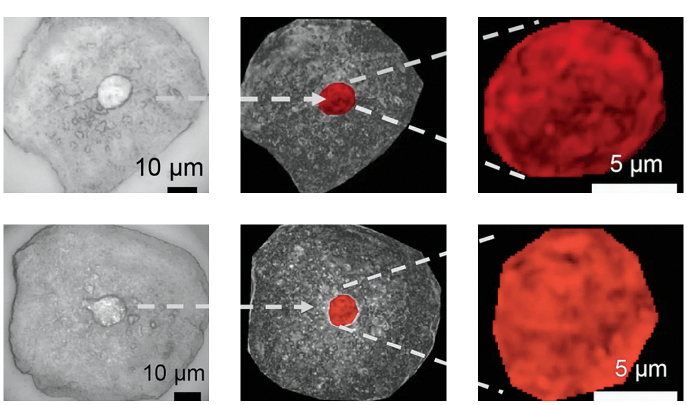
"It was a busy 10 weeks, but our team was able to scope the problem, build a solution, quantify the impact, and recommend next steps," Hartwick says. "Our corporate sponsors were highly engaged with us throughout the whole project, and we were even able to make on-site presentations to a number of executives, including the chief technical officer."

"Each of these three programs prepares students for distinct but related career paths," Fano says. "The collaboration across programs, and between Northwestern Engineering and Kellogg, is a testament to Northwestern's spirit of breaking boundaries and focusing on students and their opportunities."

THE FAR-REACHING IMPACTS OF AI

Northwestern Engineering faculty harness the emerging technologies of AI and data science in fields ranging from materials discovery to robotics to make a positive impact on humanity.

Robotics Project DRIVE aims to bring to market the first active driving assistance system for power wheelchairs, increasing access to safe, independent wheelchair operation. Photo by Shane Collins



Medicine An image of buccal mucosa cells—located in the cheeks and lungs—in a control patient (top) and patient with lung cancer (bottom). The chromatin packing in the cell's nucleus is highlighted in red.

ROBOTICS

MACHINE INTELLIGENCE ACCELERATES POWER WHEELCHAIR ACCESSIBILITY, SAFETY

Autonomous robotics could prove life-changing for millions of people with severe motor impairments who find existing models of power wheelchairs overly burdensome.

Project DRIVE—a multidisciplinary partnership spearheaded by Northwestern Engineering's Brenna Argall and collaborators from academia, industry, and nonprofits—aims to bring to market the first active driving assistance system for power wheelchairs.

To create the wheelchair, the team is making radical changes in how control inputs are interpreted from movements of the human body and communicated to the wheelchair control system. The team is using AI and machine-learning systems to help facilitate wheelchair operation and ensure safety.

"We're aiming to address barriers to independent wheelchair mobility," says Argall, associate professor of computer science and of mechanical engineering at the McCormick School of Engineering and associate professor of physical medicine and rehabilitation at Northwestern University's Feinberg School of Medicine.

"SEEING TECHNOLOGY FROM MY LAB ROLL OUT INTO A COMMERCIAL PRODUCT IS SUPER EXCITING. WE'RE DOING THIS WORK BECAUSE WE WANT TO SEE IT MAKE AN IMPACT IN THE WORLD."

Brenna Argall
Associate Professor of Computer Science and Mechanical Engineering

The wheelchair intelligence thrust will integrate two active driver assistance paradigms built by Argall's team into a commercial assistance system for power wheelchairs. The system's REACT active corrective assistance system adjusts the user's command to avoid collisions and drop-offs, while Project DRIVE's ROUTE assistance system autonomously drives the wheelchair to a target destination within a known environment mapped by recorded data from sensors.

Project DRIVE, supported by a $5 million grant from the US National Science Foundation, aims to roll out the active assistance add-on to beta testers by the end of 2024 and to all users of this type of wheelchair as an opt-in feature by the end of 2025.

"Seeing technology from my lab roll out into a commercial product is super exciting," Argall says. "We're doing this work because we want to see it make an impact in the world."

MEDICINE

HOW AI AND A CHEEK SWAB COULD HELP FIGHT CANCER

The five-year survival rate for lung cancer—the leading cause of cancer deaths in the United States—is 56 percent for cases when the disease is still localized, according to the American Lung Association. Unfortunately, only 16 percent of cases are diagnosed at that stage. When the disease has spread to other organs, the survival rate plummets to 5 percent.

A novel diagnostic test from Northwestern Engineering's Vadim Backman and the Center for Physical Genomics and Engineering (CPGE) could help doctors make that crucial discovery earlier and save more lives.

"SUCH A SIMPLE, EASY-TO-ADMINISTER, AND ACCURATE TEST COULD INCREASE PATIENT UPTAKE, IMPROVE EARLY DETECTION, AND REDUCE MORTALITY AS WELL AS REDUCE FALSE POSITIVES AND UNNECESSARY PROCEDURES."

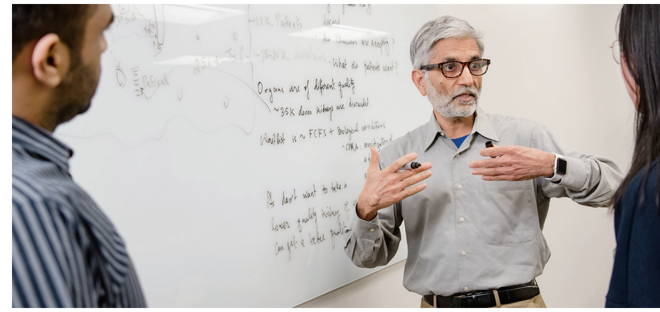
Vadim Backman
Sachs Family Professor of Biomedical Engineering and Medicine, CPGE Director

Based on a new paradigm for cancer detection and designed for use at home or in a primary care office, the test uses artificial intelligence-enhanced optical nanosensing of alterations in the chromatin (genome) structure of cells—changes that are associated with the earliest stages of carcinogenesis and cancer progression.

The test uses a concept called field carcinogenesis as the source of this new biomarker. Chromatin alterations associated with early lung cancer are detectable not just in a lesion or tumor, but in the nucleus of cells throughout the organ "field"—in this case, from the lungs to the cheeks. That means chromatin alterations could be discovered using a simple, noninvasive method, like a swab of cheek cells, at a stage when lung cancer is more curable.

"Such a simple, easy-to-administer, and accurate test could increase patient uptake, improve early detection, and reduce mortality as well as reduce false positives and unnecessary procedures," says Backman, Sachs Family Professor of Biomedical Engineering and Medicine at Northwestern Engineering and director of the CPGE.

For this work, Backman collaborated with Ankit Bharat, Harold L. and Margaret N. Method Professor of Surgery and chief of thoracic surgery in the department of surgery at the Northwestern University Feinberg School of Medicine.



Sanjay Mehrotra has devoted the last half of his research career to improving healthcare decision-making through data science and predictive modeling. Photo by Jason Brown

DATA SCIENCE IMPROVES KIDNEY ALLOCATION

Some 7,000 potential donor kidneys are discarded each year in the United States because of mishandling. To optimize kidney allocation, Northwestern Engineering's Sanjay Mehrotra turned to machine learning.

Mehrotra's work focuses on overcoming "cold time"—the period during which the kidney is out of the donor's body—to improve the discard rate and better serve the 90,000 Americans awaiting a new kidney. A successful transplant often needs to occur within 24 hours. Presently, because of outdated and inefficient systems, there is a 30-minute time lapse in transplant program decision-making that increases the cold time.

"In such a tight timeframe that needs to account for logistics like air and ambulance travel, every 30 minutes matter," says Mehrotra, professor of industrial engineering and management sciences and director of the Northwestern-based Center for Engineering Health.

"IN SUCH A TIGHT TIMEFRAME THAT NEEDS TO ACCOUNT FOR LOGISTICS LIKE AIR AND AMBULANCE TRAVEL, EVERY 30 MINUTES MATTER."

Sanjay Mehrotra
Professor of Industrial Engineering and Management Sciences, Center for Engineering Health Director

To expedite this logistical process, Mehrotra is leveraging his expertise in data science and predictive modeling. He started with baseline kidney characteristics before forecasting the likelihood of kidneys being transplanted based on a diverse mix of data and variables, such as the donor's health history and cause of death. His work demonstrates that kidneys at risk of discard could be more accurately identified using machine-learning techniques.

"If you know that a kidney is going to be rejected in the current allocation system, then you can say, 'Look, this is a kidney I need to pay attention to very early on and send it down a more expedited pathway where it doesn't accumulate that much cold time and can still get transplanted,'" Mehrotra says.

MATERIALS

SCALING MATERIALS DISCOVERY WITH AI

Lattice thermal conductivity, a fundamental property of materials, plays a vital role in many technological applications, including thermal energy conversion and management.

Understanding its lower limit—known as its minimum thermal conductivity—is crucial. Such knowledge helps scientists understand a material's capabilities but is challenging to attain. Professor Chris Wolverton and his teammates built a machine-learning model that unifies different kinds of heat carriers to model the lower limit of lattice thermal conductivity and applies it to thousands of inorganic compounds.

The model allows researchers to calculate the minimum thermal conductivity for upwards of 2,000 compounds. Using the model, Wolverton and his colleagues predicted the minimum thermal conductivity of materials and compared them to experimentally measured values. In some cases, they found similar totals.

"IF YOU COULD SOMEHOW CONVERT A FRACTION OF THAT WASTED HEAT INTO USEFUL ELECTRICAL WORK, IT WOULD BE A GAME-CHANGER."

Chris Wolverton
Professor of Materials Science and Engineering

The system allows scientists to search efficiently for new materials that have low thermal conductivity, which could potentially change the balance of how much energy is used and how much is wasted. This use of artificial intelligence moves researchers closer to harnessing its capabilities to predict which materials have the best thermal conductivity.

"If you could somehow convert a fraction of that wasted heat into useful electrical work, it would be a game-changer," says Wolverton, professor of materials science and engineering.

"If you give a computer many thousands of example pairings of a chemical formula and its thermal conductivity, the question is, can it learn the relationship between those two? It's a very, very complicated relationship, but if you give it many examples, can it learn that? If it can, then it can predict the relationship for new compositions where you don't already know the thermal conductivity."

DESIGNING NEXT-GEN "SMART" MATERIALS

Northwestern Engineering's Wei Chen is using advanced AI technology to discover new ways to create next-generation "smart" materials with embodied intelligence.

In late 2022, Chen received a BRITE Fellow grant from the National Science Foundation to create a data-driven design framework enabled by AI for the real-time digital design and fabrication of programmable material systems (PMS).

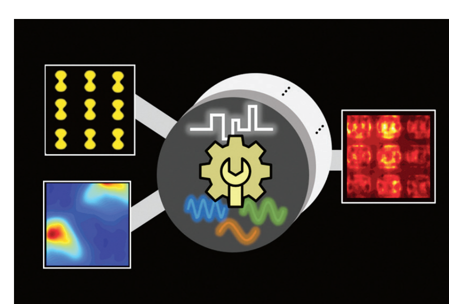
PMS are emerging architectural structures made of smart materials that are responsive to external stimuli and can be programmed to transform between multiple functional states. Impactful applications of PMS are far reaching, including examples such as surgical robots, (bio)sensors, deployable satellites, mechanical computing, and water and energy harvesting.

To address the complex underlying physics and high dimensionality associated with the design of spatially varying materials, architectures, and stimuli, Chen, Wilson-Cook Professor in Engineering Design and chair of the Department of Mechanical Engineering, is working to integrate disruptive technologies across the multidisciplinary domains of design, mechanics, manufacturing, materials, and data science to create a new AI-enabled PMS digital design platform.

Chen is working on a approach named ALGO, which stands for Acquire-Learn-Generate-Optimize. The method employs machine learning and optimization techniques to combine "building blocks" of architectural structures to design the final complex materials and structures. This process aims to increase the speed and efficiency of the design process, leading to better performance and customizable, patient-specific solutions in real-world applications.

"Long-term, our hope is that this research will transform techniques limited to the design of single-material periodic structures into scalable data-driven design of programmable multimaterial systems with heterogenous materials and topological architectures that benefit many physics-driven science and engineering domains," Chen says.

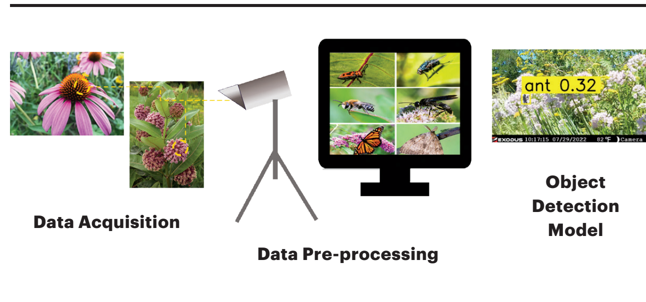
Wei Chen



Wei Chen's interlocking neural operator and concurrent machine learning and optimization techniques boost the optimal design of heterogeneous material systems, enabling dynamic energy hotspot creation on optical metasurface "chessboards."

Amanda Stathopoulos

Kimberly Gray



After collecting field data—such as water storage and pollinator activity—from nearby rain gardens and prairie environments, Kimberly Gray and her team pre-processed the data and then applied machine-learning techniques, which revealed the rain gardens that function most like a natural system and why.

TRANSPORTATION

HOW AI HELPS TEACH US ABOUT HUMAN MOBILITY PATTERNS

Professor Amanda Stathopoulos uses AI and machine learning to understand how humans move through the world.

Stathopoulos, William Patterson Junior Professor and associate professor of civil and environmental engineering, investigates transportation systems to understand how people make transportation decisions. She's also interested in how innovation in transportation impacts society, including its effect on quality of life, prosperity, and equity.

Large-scale geolocated databases are increasingly used by researchers to expand our understanding of mobility patterns. But this type of trace data poses nontrivial analytical challenges in processing and interpretation.

"Researchers often observe only anonymized traces of human activity, but policy makers need to understand how policies affect people and localities," says Stathopoulos, a Northwestern Engineering faculty member since 2014. She and her team have developed analytical methods that consolidate a range of public data sources to understand better the economic and spatial contexts of these big datasets, which, in turn, enables them to understand the impacts of policies without violating privacy regulations.

For example, Stathopoulos investigated the relationship between socioeconomic disadvantages and the availability of on-demand ride-sharing services. Leveraging millions of records from ride-sharing operators coupled with demographics and transit access datasets, Stathopoulos found the highest level of demand for ride-sharing existed in areas that already had other established transportation options.

"In my lab's research on mapping adoption of different ride-hailing options, we relied on knowledge of Chicago-area land use, socio-demographic factors, and coverage of transit to understand the variation in adoption across the city," says Stathopoulos, a member of the Northwestern University Transportation Center. "Our machine-learning techniques illustrated how new mobility options ultimately provided mobility benefits for privileged populations."

Blending math and psychological realism to understand behavior, Stathopoulos uses quantitative and qualitative data streams to generate a holistic understanding of transportation-related behaviors. "My hope is that the behavioral models we put forward have a positive impact on society and address what residents really need from transportation systems," Stathopoulos says.

URBAN ECOLOGY

USING MACHINE LEARNING TO OPTIMIZE GREEN INFRASTRUCTURE

Stormwater that runs off buildings and paved streets frequently carries high levels of pollutants into rivers and lakes, some of which serve as sources of drinking water. Rain gardens, green infrastructure initiatives designed to mimic natural systems such as native prairies, help keep urban runoff out of sewers and sur-face waters, suppressing stormwater's negative effects.

Constructing rain gardens to deliver maximum benefit, however, takes more than just soil, a shovel, and a green thumb. Using machine learning, Northwestern Engineering's Kimberly Gray is working to make sure urban green infrastructure is designed to be ecologically restorative and mitigate climate change.

Gray, Roxelyn and Richard Pepper Family Chair in Civil and Environmental Engineering, and her team collected data on a dozen rain gardens in Evanston. They then compared the rain gardens to natural prairies to identify which characteristics contribute to the best results, taking into consideration biodiversity, pollination, soil quality, weather, and seasons.

"We've taken ecological and chemical data and studied it using machine-learning techniques to identify clusters of the most beneficial areas," Gray says. "We then determined what are the most important attributes that lead to both successful water retention and biodiversity enhancement. In this way we identify when they are most like a natural system, and what causes them to perform differently."

Moving forward, Gray hopes her work will inform and influence the design of green infrastructure networks built by both public and private institutions.

BRIAN SANDALOW