Next:

Frontiers in Artificial Intelligence, Robotics, and Data Science

University *of* Massachusetts

Testing Valkyrie

In May 2016, NASA's $2 million Valkyrie humanoid robot prototype touched down at the **New England Robotics Validation and Experimentation (NERVE) Center** at UMass Lowell to prep for a potential trip to Mars.

Four of the 6-foot tall, 300 pound Valkyrie prototypes were built for use in disaster relief efforts. But NASA sent three of the robots to university labs for functionality enhancements that will allow Valkyrie—or a successor—to build a habitable space station on Mars. Northeastern University is collaborating with the NERVE team to test and improve Valkyrie's gait, object manipulation skills, and human interactions.

Advances in computer science, with their almost limitless applications, are enabling a societal transformation. Artificial intelligence, robotics, and data science extend our brain and body power in ways that promise broad impacts across all areas of applied science and human endeavor, from medicine to manufacturing to municipal services. These technologies have the potential for great human benefit—potential that is quickly becoming a reality.

Government and industry have both put a spotlight on these three areas of innovation. In February 2019, the President signed an executive order establishing an American AI Initiative to boost and safeguard advances in the field. Its first directive: prioritizing investment in AI research and development (as outlined in the National AI R&D Strategic Plan: 2019 Update, co-authored by UMass Amherst computer science professor Jim Kurose).

The National Science Foundation—which provides 87 percent of academic research funding in computer science—is likewise making major investments in all three fields: establishing National AI Institutes, launching the National Robotics Initiative 2.0, and initiating a major effort titled Harnessing the Data Revolution. The bi-partisan Endless Frontiers Act and National AI Initiative Act aim to significantly increase that funding.

These commitments—and the advancements they lead to—are of particular importance to Massachusetts. The Commonwealth is among the nation's top five states for technology-sector workforce, and the Boston area ranked 6th in the US and 12th in the world in patents related to "Fourth Industrial Revolution" technologies like the Internet of Things, cloud computing, big data, and artificial intelligence between 2010 and 2018. Likewise, the robotics industry in Massachusetts is among the largest in the US. With these priorities and partners in mind, UMass has mobilized to facilitate the faculty work that yields new advances, and built infrastructure to support it.

The Computing Research Association's 20-Year Community Roadmap for Artificial Intelligence Research in the US, to which UMass Amherst computer science professor Beverly Woolf contributed, asserts that to reap the benefits AI offers—improved health, lifelong education, more competitive businesses, accelerated scientific discovery, data-based social policy, and stronger national defense—we must supercharge research and the education of an AI literate workforce. The organization's *A Roadmap for US Robotics 2020*, co-organized by UMass Lowell computer science professor Holly Yanco, emphasizes the role of education in optimizing the nation's future robotics development and use, and the same certainly holds true in data science. Fortunately, as outlined in these pages, UMass is already hard at work.

BIG IDEAS

UMass faculty are thought leaders in these fields, both as policy advisers and as researchers. UMass Amherst professor emeritus Andrew Barto, for example, launched the field of reinforcement learning, a machine-learning technique built around rewards and punishments that is now widely used throughout industry. Carnegie Mellon professor Tuomas Sandholm, who earned his PhD on the flagship campus, used the approach to create his strategic Pluribus AI, selected as runner-up for the Science breakthrough of the year in 2019.

Professor Andrew McCallum pioneered the use of conditional random fields—which use context to improve predictions—in data science. They are now a fundamental part of natural language processing, computer vision, and bioinformatics.

UMass Dartmouth's autonomous undersea glider "Blue" can travel up to 600 km over three to four weeks, transmitting oceanic data every three hours.

MUST seas

In October 2020, UMass Dartmouth received $4.2 million from the Office of Naval Research (ONR)—funding that came fast on the heels of a $4.6 million ONR grant in February 2020, the largest research grant in the university's history. The Navy has made 21 grants totaling almost $14 million to the university since 2015.

The grant supports collaborative research between Dartmouth's **Marine and Undersea Technology Research Program** and the Naval Undersea Warfare Center Division Newport to address a wide range of challenge areas for Navy undersea operations, including modeling of ocean dynamics, biofouling, autonomy, machine learning, and marine robotics.

Today's strengths

Breadth and depth. Everywhere throughout UMass's five campuses, we see the fruits of AI-, data-, and robotics-enhanced approaches, in fields from healthcare to civil engineering to marine research. We range wide and go deep, redefining problems that, once re-imagined, can be solved.

This boundary-breaking spirit and the interrelatedness of these core computing fields are reflected in the broad-based work of research centers like the UMass Dartmouth **Center for Scientific Computing and Visualization Research**, where researchers from many departments tap AI, data science, and robotics in the service of their research. But from this varied research landscape, five areas of particular strength stand out.

Artificial intelligence

Artificial intelligence has potential applications in almost every area of inquiry, and AI research is happening in many labs throughout the system. UMass's hub for AI research is the acclaimed AI research program in UMass Amherst's **College of Information and Computer Sciences**, which comprises seven labs focused on facets of AI research. The program is ranked #5 in the nation by Computer Science Rankings and

#11 by *US News & World Report*, and has 61 active federal research grants.

UMass Amherst is also home to the **Center for Intelligent Information Retrieval**, which launched in 1992 as a National Science Foundation State/Industry University Cooperative Research Center. The center is a leading research program in the areas of information retrieval and extraction, and pioneered internet search using probabilistic methods, event detection, and distributed search. CIIR's INQUERY tool was used by the Library of Congress and the Offices of the President and Vice President during the Clinton administration, and the General Services Administration used CIIR technology to develop GovBot, the first web search capability across the entire federal government.

Robotics

UMass is conducting pace-setting research in many areas of robotics,

including robot testing, exoskeletons, robotic manipulation, legged locomotion, human-robot interaction, swarm robotics, field robotics, and autonomous vehicles.

The **New England Robotics Validation and Experimentation (NERVE) Center** at UMass Lowell is a world-class robotics testing facility that evaluates robot systems across multiple application domains and develops national testing standards for their performance in collaboration with the National Institute of Standards and Technology (NIST). The NERVE team collaborates extensively with the U.S. Army Combat Capabilities Development Command Soldier Center on the development of exoskeletons for soldiers. At UMass Amherst, the **Mechatronics and Robotics Research Lab** and **Human Robot Systems Lab** are developing next-generation intelligent exoskeletons and physical human-robot interaction.

UMass Amherst's **Laboratory for Perceptual Robotics** is another hotspot for advances in robotics. Director Rod Grupen, for example, collaborated with NASA on a "MacGyver-like" robot capable of interpreting data autonomously to solve problems in space. At UMass Lowell, the NERVE Center houses both the **ARMada**, a robotic manipulation testbed that develops metrics for industrial robots for Manufacturing USA's **Advanced Robotics and Manufacturing Institute**, and many test methods for autonomous unmanned ground and air vehicles.

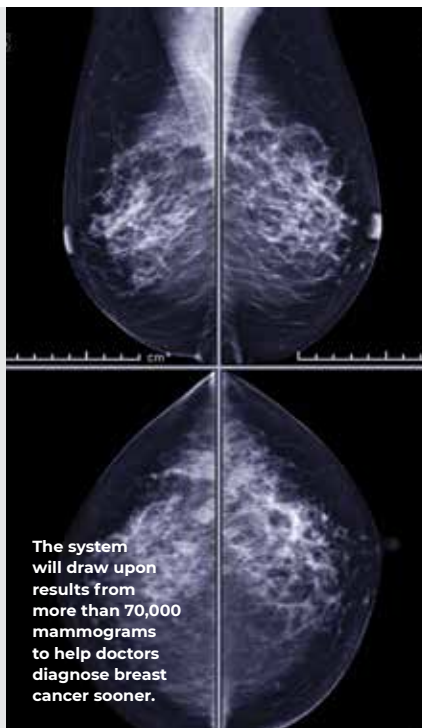UMass Amherst researchers, in collaboration with Nissan Motor Company and the National Science
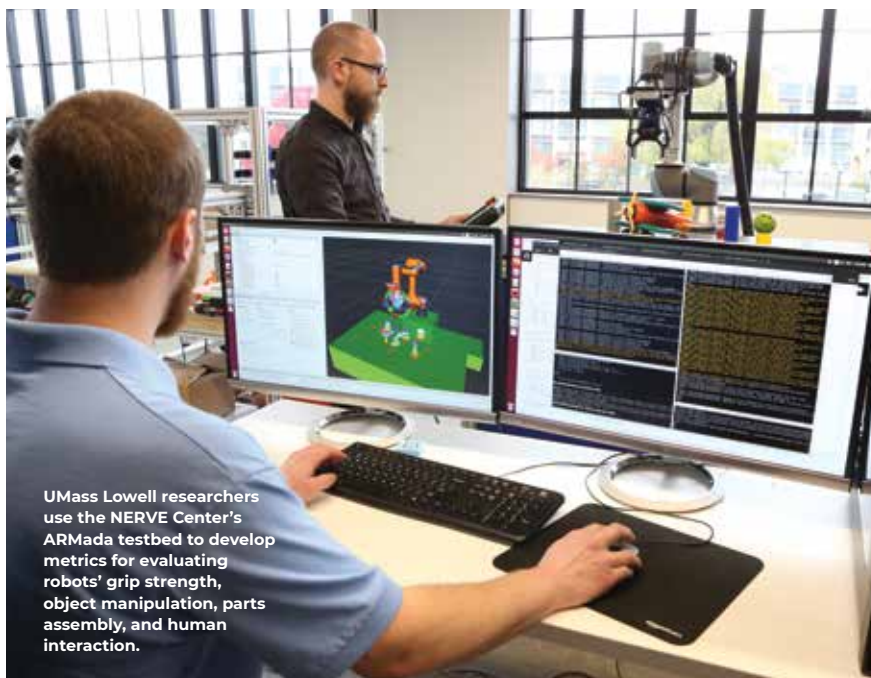
UMass Lowell researchers use the NERVE Center's ARMada testbed to develop metrics for evaluating robots' grip strength, object manipulation, parts assembly, and human interaction.

Medical computer vision

In August 2020, the state-run Massachusetts Life Science Center (MLSC) awarded a $750,000 Bits to Bytes grant to UMass Boston's Oregon-Massachusetts Mammography Database (OMAMA-DB) project, led by Assistant Professor of Computer Science Daniel Haehn. In partnership with local startup DeepHealth, Haehn is using the large database of breast tissue scans and associated results to train deep learning systems to identify earlier signs of breast cancer in mammograms. Haehn and DeepHealth work with UMass Medical School radiology professor Gopal Vijayaraghavan, who received a $750,000 Women's Health Grant from MLSC to improve breast cancer imaging technology.

UMass Medical School faculty members Christina Baer and Dorothy Schafer also won a Bits to Bytes data science grant for their research mapping RNA transcripts to brain inflammation in neurodegenerative disease.

The system will draw upon results from more than 70,000 mammograms to help doctors diagnose breast cancer sooner.

Foundation, are deploying decision-making systems in self-driving cars; UMass Dartmouth is a global powerhouse in autonomous vehicles for underwater applications. Danjue Chen's research at UMass Lowell into the complex traffic interactions between self-driving and human-driven cars won him one of the many NSF CAREER grants that have been awarded to UMass early-career faculty.

Underwater sensing and underwater autonomous vehicles

The **Marine and Undersea Technology Research Program (MUST)**, launched in 2019, grew out of UMass Dartmouth's longstanding collaboration with the Naval Undersea Warfare Center, with the goal of meeting the Navy's most urgent needs: cutting-edge research and a highly trained workforce. In 2020, MUST received $8.8 million in grants from the Office of Naval Research for fundamental research that will form the basis of next generation systems for underwater sensing and sensor fusion, communication, and underwater vehicles driven by AI and robotics.

Program director Ramprasad Balasubramanian, whose research focuses on underwater vehicle autonomy and situational awareness for autonomously controlled multi-vehicle teams, is a renowned leader in this field. UMass Amherst's **Gloucester Marine Station** is being developed as a marine robotics test site.

Data science

More than 200 faculty members across the five campuses of the University are conducting research related to the use of "big data."

UMass Amherst's **Center for Data Science**, established in 2015, is the most prominent locus of data-science discovery in the region. The center received a $12 million grant from Mass Mutual in 2016, and partners with some of the world's largest data-driven companies, including Google, IMB, and Amazon. Center director Andrew McCallum is a renowned data science pioneer, and the research of the 30+ affiliated computer science faculty members is among the most cited in the field. Major research thrusts include virtual- and augmented-reality-enabled 3D data and issues

of fairness, accountability, and transparency.

Data science for improving health is a growing focus across the system, notably at UMass Medical School's **Population and Quantitative Health Sciences Department**—the school's newest department—and its **Program in Bioinformatics and Integrative Biology**; UMass Boston's **Center for Personalized Cancer Therapy**, and UMass Lowell's **Center for Biomedical and Health Research in Data Science**. Center director Hong Yu leads several large National Institutes of Health projects (totaling $20 million in funding) focused on developing natural language processing and data analytic technologies for improving patient-provider communication, reducing adverse drug reactions, and preventing national opioid overdose and suicides. The center is also a leader in research in clinical decision support, including novel algorithms and systems for helping physicians generate personalized assessments for their patients.

UMass Lowell's Archana Kamal, recognized as one of MIT *Technology Review's* "35 Innovators Under 35", is at the forefront of research in quantum information. Her work is helping to bridge the connections between incredibly fast quantum computers and classical computers.

Tech tools

UMass Amherst faculty Beverly Woolf, Shlomo Zilberstein, and Andrew Lan are collaborating with Stanley Black & Decker, the world's largest tool manufacturer, to create a digital platform that can analyze the profiles and skills of workers, then recommend training and education to help them grow in their career path. The multi-disciplinary project—which includes colleagues from sociology, psychological and brain sciences, and economics—is funded by the National Science Foundation's Convergence Accelerator program.

Tomorrow's frontiers

Computing research and application have been advancing at an incredible pace. UMass's strengths in AI, robotics, and data science today have laid the foundation for transformative impacts in virtually every aspect of life and work tomorrow. These are just five of the many vital research frontiers where UMass researchers will be leading the fields of AI, robotics, and data science over the next five to ten years.

Next frontier 1:
Creating trustworthy AI systems
Creating AI systems that safeguard against bias and misuse is a research frontier of critical social importance, and UMass is already taking important steps in research and advocacy.

Through its **EQuity, Accountability, Transparency, and Explainability (EQUATE) Initiative** UMass Amherst's **College of Information and Computer Sciences** is developing coursework in ethics and equitable algorithm design, and conducting research to improve fairness and transparency of AI outcomes. The UMass Lowell **NERVE Center**'s research evaluating human trust in AI is another important aspect of this frontier. Policy work is also underway: CICS professor James Kurose helped develop the Organization for Economic Co-operation and Development's principles for development of

trustworthy AI, later adapted into guidelines adopted by the G20.

Next frontier 2: Transforming the future of work at the human-technology frontier
Applications of AI, robotics, and data science will transform all areas of work in the future. UMass is working on advances at the worker-technology nexus in many industries, including:

- Digital healthcare, optimized by data science, machine learning, and advanced imaging and sensing

- Human-robot interaction, particularly in healthcare—for example, assistive surgical robotics—and manufacturing

- Both human-directed and autonomous AI-enabled, real-time cybersecurity threat response

- AI-amplified scientific discovery, e.g. using machine learning to identify patterns in data

- Machine learning for fraud detection in the financial sector and for calculating life expectancy in the insurance industry

Next frontier 3: Boosting military robotics with AI
Over the next decade, the NERVE team will continue to increase the functionality of military robotics designed to protect the nation's soldiers. Near-term research challenges include enhancing protective bomb suits with robotic exoskeletons, creating AI-based predictive controllers for exoskeletons that enable the wounded to walk, and increasing functionality of unmanned ground vehicles and unmanned aerial systems.

Next frontier 4: Advancing autonomous systems, underwater and land
Autonomous underwater vehicle technology has improved significantly over the past two decades, but challenges remain. The dense undersea environment is harsh on components and challenging for remote communications. Over the next ten years, UMass Dartmouth's **Marine and Undersea Technology Research Program** will be working on problems of communication with autonomous vehicles, sensing and situational awareness, fusion of data from a variety of sensors, and multi-vehicle coordination and cooperation. For land- and sea-based systems, increasingly sophisticated communication, localization, and autonomous decision-making in complex interactions between vehicles and other entities in the environment will make significant contributions to the state of the art in the next decade.

Next frontier 5: Harnessing the power of data
Any single stream of information can provide vital information, but marrying information from many sources paints a more complete picture. Developing intelligent systems to integrate data of different kinds from different sources is a research challenge that UMass researchers from many fields will be addressing over the next ten years. The UMass Medical School **Center for Clinical and Translational Science**, for example, created its **Data Lake**—which collects medical data gathered from 3 million patients over 78 million encounters—to help catalyze data-driven research into patient care best practices.

Informed infrastructure

UMass Dartmouth Civil and Environmental Engineering Assistant Professors Arghavan Louhghalam and Mazdak Tootkaboni received a $224,000 grant from the National Science Foundation in February 2020 to develop a data-centric framework for analyzing the resiliency of buildings, roads, bridges, and other civil structures in the face of hurricanes and other extreme climate events. The project integrates machine learning and data fusion techniques with physics-based modeling to provide a systemic approach to evaluating and predicting how infrastructure performs under climate stress.

Facing bias

UMass Amherst computer science professor Erik Learned-Miller helped develop *Labeled Faces in the Wild (LFW)*, one of the most influential face datasets in the world. (LWF has been cited more than 3,700 times, and is widely used by industry and academia to test the accuracy of their facial-recognition systems). Today, Learned-Miller is working to develop standards for fair use of face-recognition technology and advocating for oversight. With Algorithmic Justice League founder Joy Buolamwini—subject of the recent documentary *Coded Bias*— and others, Learned-Miller co-authored a white paper titled "Facial Recognition Technologies in the Wild: A Call for a Federal Office" calling for a new US regulatory agency to govern facial recognition systems.

Erik Learned-Miller is using his influential database of faces to address social justice issues in facial recognition systems—and pushing for policy change.

Boosting the innovation economy

Massachusetts, long known for its innovation economy, is now home to thriving AI, data science, and robotics industries.

Interest in these industries is strong: venture capitalists invested $16.6 billion in artificial intelligence in 2019—$1 billion in Massachusetts-based robotics companies alone. Drawn in part by its density of world-class university research programs, more than 350 robotics firms are headquartered in the Commonwealth, as are five of the world's top 100 AI companies. Between 2010 and 2018, Boston ranked sixth among US markets and twelfth worldwide in patents for Fourth Industrial Revolution technologies—which include smart devices, the Internet of Things, big data, 5G, and artificial intelligence.

Today, more than 270,000 citizens of the Commonwealth work in fields related to artificial intelligence, robotics, and data science. Over the next ten years, demand for talent in these field is projected to grow by over 8 percent in Massachusetts, more than twice the rate predicted for employment growth overall in the state. Between now and 2030, more than 25,000 related jobs are expected to open in the Commonwealth.

Where will workers qualified to fill these positions come from? In the Commonwealth, the majority will be graduates of the University of Massachusetts. In 2019, UMass awarded 18 percent of all related degrees conferred in the state, making the system the top producer of degree-holders in these fields in our region.
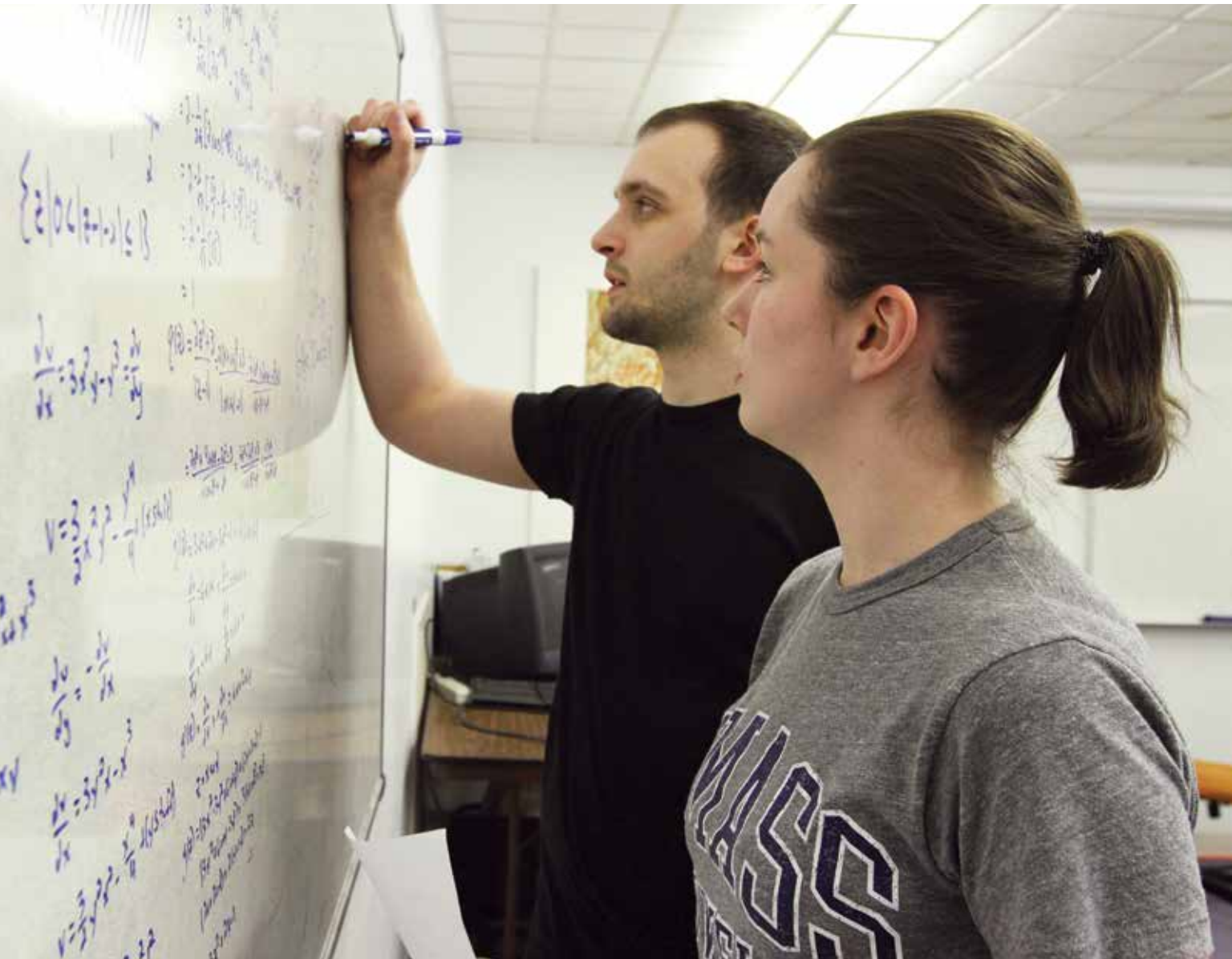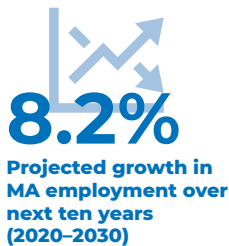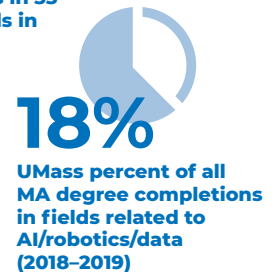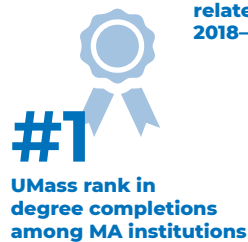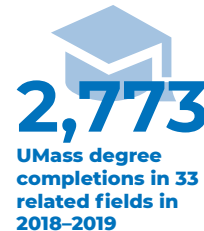
Crossing confusion

UMass Amherst computer science professor Shlomo Zilberstein works with Nissan Motor Company on the challenge that intersections—with their complex interactions of an unbounded number of cars, buses, bicyclists, and pedestrians—pose to self-driving cars. The solution that Zilberstein's team designed has been incorporated into Nissan's experimental autonomous vehicles and is the subject of more than a dozen patent applications. The work has also been supported by several National Science Foundation grants.

Massachusetts employment data in occupations related to data science/AI/robotics

274.4k
Current MA employment in 53 related fields in 2020

8.2%
Projected growth in MA employment over next ten years (2020–2030)

25.6k
Projected estimated MA annual job openings (2020–2030)

UMass degree completions in fields related to data science/AI/robotics

2,773
UMass degree completions in 33 related fields in 2018–2019

#1
UMass rank in degree completions among MA institutions

18%
UMass percent of all MA degree completions in fields related to AI/robotics/data (2018–2019)

Good data

Many nonprofits have mountains of data, but little idea how best to use it in service of their mission. The Data Science for the Common Good program at UMass Amherst teams them with master's students who spend a summer helping them put their data to work. One team of students created a computer-vision tool for The Nature Conservancy that detects animals in photographs. The Conservancy can use this tool to monitor wildlife corridors, easily finding "hits" in the thousands of images captured by remote motion-sensitive cameras placed in the wild.

DSCG participants also helped the Appalachian Mountain Club use lodging reservation data to estimate its greenhouse gas footprint.

The University of Massachusetts prides itself on its "revolutionary spirit," and we are ready to continue to lead in the next phases of the AI, robotics, and data science revolutions—fields that hold so much potential to benefit society.

Of course, we do not advance alone. As always, we look to industry as a partner—both in defining the problems that need to be solved and in deploying the solutions we develop together. We are confident that, over the coming decade, UMass will create the AI-, robotics-, and data-enabled tools that will transform the way business, healthcare, defense, and even science itself are done—and train the tech-literate workers that do them.

Government is another vital partner in this work: the springboard that launched the advances we have made so far, and that propels our researchers into the futures of these fields. The University is proud to serve on the leading edge of the nation's research agenda, and to explore the frontiers ahead.

Center for Data Science director Andrew McCallum with Priscilla Chan and Facebook founder Mark Zuckerberg

Computing knowledge

The sheer volume of peer-reviewed papers published each year—an estimated 1.8 million, or one every 17 seconds—makes it increasingly difficult to keep up with new knowledge and explore established results. UMass Amherst's Center for Data Science is partnering with the Chan Zuckerberg Initiative (CZI) to change that. Their $5.5 million joint project Computing Knowledge, led by Professor Andrew McCallum, is creating a freely available, AI-empowered, navigable topic map of all 60 million articles in scientific literature, to help researchers find relevant results, see patterns in data, and make new connections—a power CZI likens to "being able to tap into the brain of every scientist who ever lived."

Dig deeper

Data science, AI, and robotics research is happening in labs and centers across the University of Massachusetts. Visit the links below to find out more about some of the work going on across the state and the researchers conducting it.

Center for Scientific Computing and Visualization Research (Dartmouth)
cscvr1.umassd.edu

Robotics
NERVE Center
www.uml.edu/research/nerve
Laboratory for Perceptual Robotics
www-robotics.cs.umass.edu

Artificial intelligence
College of Information and Computer Sciences (Amherst)
www.cics.umass.edu/research/area/artificial-intelligence
Center for Intelligent Information Retrieval (Amherst)
ciir.cs.umass.edu
EQuity, Accountability, Transparency, and Explainability Initiative (Amherst)
groups.cs.umass.edu/equate

Underwater sensing and underwater autonomous vehicles
Marine and UnderSea Technology Research Program (Dartmouth)
must.umassd.edu
Gloucester Marine Station (Amherst)

Data science
Center for Data Science
ds.cs.umass.edu
Population and Quantitative Health Sciences (Worcester)
www.umassmed.edu/pqhs
Program in Bioinformatics and Integrative Biology (Worcester)
www.umassmed.edu/bioinformatics
Center for Personalized Cancer Therapy
www.umb.edu/cpct

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