AUTUMN 2021

MESSENGER

MECHANICAL ENGINEERING | UNIVERSITY of WASHINGTON

A vision for robotics, *Pages 8-9*

Onward

As I begin my term as the new department chair, I reflect on the extraordinary level of perseverance and sacrifice that our community has displayed through the pandemic. I am immensely proud to be part of this remarkable department as we finally come back to campus, reuniting to work and learn together in ways old and new.

Reflecting further back, I gain even more hope for the future. Since I joined ME 15 years ago, this department has reinvented itself, rethinking outdated notions and building a foundation of innovation, collaboration and impact. My goal is to raise the level of excellence in everything we do, embracing new ideas and leading the university and the engineering community in service to the state, nation and our global society.

For me, that leadership starts with diversity and access. I grew up in a small, rural town in Spain and have experienced firsthand the power of education to change people's lives. It is why I took this role; I feel strongly that education is the key to building a more equitable society and that access to quality education is an essential part of our mission.

Fortunately, the demand to join our department remains high. By growing and simultaneously providing resources to those who have not traditionally considered ME, I believe we can make our department an international example of how research and education are done with excellence, benefiting from a diverse workforce and student population, inclusive of all, and treating everyone equitably. We will also continue leveraging our location in a thriving area of the world with a multitude of opportunities to target society's biggest challenges.

Our collaboration with UW Medicine, one of the best medical schools in the world, makes us well positioned to lead changes in the way health care is delivered. There's a clear need for interdisciplinary research that brings all our strengths in mechanics, thermofluids, controls, machine learning, imaging and other core ME disciplines to innovate, leading to new and improved medical diagnoses and treatments. In this issue, you will learn the story of Affiliate Professor Len Nelson, who exemplifies the advantages that come from combining research and education with local collaboration and a passion for service and impact.

Sustainability is also a critical focus, especially in the areas of energy, materials and advanced manufacturing. The world relies on us to find technical solutions that confront the threats of climate change and meaningfully reduce human impacts on our planet.

Our efforts towards excellence and impact are embodied in our strong ongoing partnership with Boeing. We are expanding that relationship and extending it to other partnerships with local industry in the effort to make the next generation of vehicles safer and greener. This issue highlights Steve Brunton and Krithika Manohar, two of our superstars in machine learning and data science, who are at the cutting-edge of efforts to understand the complex dynamical systems and processes at the core of transportation.

Indeed, our ability to understand complex systems and data, coupled with emerging quantum technologies, is one of our strengths that we will be growing in coming years. Increasing our collaborations with the major tech companies of the region will provide great benefits to students, faculty and the economy. This issue's cover story features Associate Professor Xu Chen's MACS Lab, which is doing world-class robotics research to seek better understanding of the complex interplay between machine sensing, controls and intelligence.

I am beginning my term as the new chair of UW ME at a unique time for the department, and truly for all of us in society. It's a time of great uncertainty but also great potential. We have been given a chance to reconsider every aspect of our department and the way we conduct our daily work. I feel extremely positive about the foundation we are building on and the direction we are headed. As ME Chair, I look forward to getting to know more of you — our alumni, donors, friends and partners — and hearing your thoughts on how to raise the level of excellence, together.

Alberto Aliseda

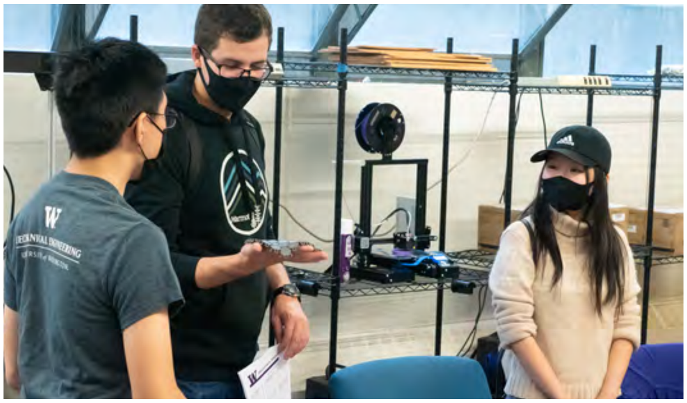
Mechanical Engineering Chair

PACCAR Endowed Professor

BACK TO CAMPUS

This fall the UW reopened to in-person teaching, learning and work. For the first time since the spring of 2020, the halls, classrooms, shops and labs of the department were humming with students, faculty and staff.

(Above) ME Chair Alberto Aliseda talks to students gathered in Sylvan Grove as part of an October event called eMErge, organized by the department's Diversity & Outreach committee to build connections and encourage dialog around diversity, equity and inclusion.



Autumn quarter began with an open house where student groups like the WOOF 3D Print Club demoed their work and recruited new members.

The department gathered in person and virtually for the ME Chair's Distinguished Industry Lecture by Microsoft's José A. Gutiérrez.

During ME's autumn 2021 open house students visited many of the department's research labs, including the Amplifying Movement & Performance Lab.

People pass the Mechanical Engineering Building as they make their way around the reopened campus on an early fall afternoon.

DEPARTMENT NEWS

UW to lead NSF's new AI Institute for Dynamic Systems

"The engineering sciences are undergoing a revolution that is aided by machine learning and AI algorithms," remarks J. Nathan Kutz, UW professor of applied mathematics. Kutz and ME Professor Steve Brunton have been selected to lead a new $20 million center focused on research and education in AI and machine learning for understanding and control of complex dynamic systems. The National Science Foundation (NSF) AI Institute for Dynamic Systems connects AI experts at nine universities, including eight from the UW and two (Brunton and Assistant Professor Krithika Manohar) from UW ME.

Professor Steve Brunton will help lead the new NSF-funded AI Institute for Dynamic Systems. Photo by Dennis Wise / University of Washington

From weather to the functions of the human body, researchers know the basic physical principles behind dynamic systems. However, these complex scenarios are often happening on multiple scales of space and time at once and can be a combination of many types of physics, making it hard for researchers to understand and model exactly what's going on. The institute will train future researchers in this field throughout the education pipeline.

"Some of our specific questions include: Can we develop better machine learning technologies by baking in and enforcing known physics, such as conservation laws, symmetries, etc.?" Brunton explains. "Similarly, in complex systems where we only have partially known or unknown physics — such as neuroscience or epidemiology — can we use machine learning to learn the 'physics' of these systems?"

Learn more about the new AI Institute for Dynamic Systems at **dynamicsai.org**.

NSF backs revolutionary center for optoelectronic and quantum technologies

The NSF announced a $25 million grant to found the Center for Integration of Modern Optoelectronic Materials on Demand (IMOD), a UW-led collaboration of scientists and engineers at 11 universities. IMOD seeks to transform optoelectronics — technologies that combine light with electronics — through the development of atomically-precise semiconductors and scalable manufacturing processes.

ME faculty: J. Devin MacKenzie (jointly appointed with Materials Science & Engineering)

RoboFly tech gets a boost

NSF announced an $833,000 grant supporting the UW Autonomous Insect Robotics Lab's efforts to develop control systems for flying robots all the way down to "gnat-scale," weighing just fractions of an ounce. The researchers envision deploying these miniscule robots one day to help monitor and explore environments that are inaccessible to larger drones.

ME faculty: Sawyer Fuller

New funding for nano-bubbled plastics

With a new $855,000 NSF grant, UW researchers will seek mechanisms for creating tougher, lighter-weight foam plastics using nano-sized bubbles. They will also develop a summer program to give underrepresented community college students experience in nanoengineering.

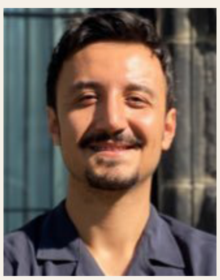
ME faculty: Vipin Kumar, Lucas Meza

FACULTY UPDATES

New faculty

Ayokunle Olanrewaju
Assistant Professor

Acting Assistant Professor Ayokunle (Ayo) Olanrewaju has been named Assistant Professor, starting January 2022. His research focuses on developing point-of-care diagnostics for therapeutic monitoring and precision dosing of polymerase inhibitor drugs used to treat infectious and chronic diseases like HIV, tuberculosis and cancer. Among other honors, he was recently named winner of an International AIDS Society Lange/van Tongeren (IAS-ANRS) Prize for Young Investigators and a UW Undergraduate Research Mentor Award.



Mehmet Kurt
Assistant Professor

Mehmet Kurt will start as an Assistant Professor in ME this winter. He is currently an Assistant Professor in the Stevens Institute of Technology Department of Mechanical Engineering. His research interests include brain biomechanics, neuromechanics imaging, nonlinear systems and smart biomedical devices. His research and neuroimaging work has been recognized with an array of scientific prizes and media coverage, including an NSF Best Scientific Visualization Award, a highlight in the NIH Director's Blog and an Annals of Biomedical Engineering Editor's Choice Award.

Promotions and retirements

Associate Professors **Steve Brunton**, **Jonathan Liu** and **Corie Cobb** have been promoted to Professor.

Assistant Professors **Xu Chen** and **Ashis Banerjee** have been promoted to Associate Professor.

Professor **Joyce Cooper** retired and was named Professor Emeritus. As director of the Design for Environment Lab, she promoted sustainability in engineering through her teaching, research and wider service to the UW during 22 years in the ME faculty.

ME ROBOTICS LEADING THE PACK

UW is home to two student-led robotics teams — Husky Robotics and Advanced Robotics at the UW (ARUW) — and both finished strong at the end of last school year. Competing against teams from around the world in the 2021 Virtual University Rover Challenge, Husky Robotics was the only team to score a perfect final mission and ended up as the competition's top U.S. team. ARUW, led by ME graduate Sig Johnson, BSME '21, also came out on top, taking first place in the inaugural North American RoboMaster University League Competition.

The 2020-2021 Husky Robotics team

The 2020-2021 Advanced Robotics at UW team

PUTTING THE 'AI' IN AIRPLANES

Courtesy of The Boeing Company

Q&A

Machine learning presents tremendous opportunities to improve how we build airplanes. ME Assistant Professor Krithika Manohar is just getting started.

Krithika Manohar,
assistant professor of mechanical engineering

Krithika Manohar is one of ME's newest faculty members, having joined as an assistant professor in January 2021, but she's no stranger to the department. Manohar received her Ph.D. in Applied Mathematics from the UW in 2018 and did her doctoral research through the Boeing Advanced Research Center (BARC), based out of ME.

An expert in the kinds of math that allow engineers to predict and control what's going on inside complex and dynamic systems, Manohar describes machine learning as "nothing but optimizing over data." In the sprawling and complex modern process of airplane manufacturing, she sees many prospects for these emerging approaches to make a big impact.

Can you explain the doctoral research you did with Boeing?

All parts of an aircraft are manufactured separately from each other at different facilities around the world. At the end when they're joined together, any remaining gaps and variations are shimmed to maximize the structural performance.

I studied the connections in the wing and where the wing attaches to the body of the plane. The process used to be done manually — Boeing would put the wing and body together, carefully measure each gap, and then take it all apart and manufacture the necessary shims. That process was labor-intensive, so more recently Boeing moved to robotic laser scans. Boeing technicians gather billions of data points to get a precise measurement of all the parts and do a computationally demanding alignment to determine what shims are needed.

The goal of my Ph.D. research was to find out if we could measure in optimized and specific places to predict where the gaps would be. In this case the machine learning approach works especially well because the parts go through such a stringent manufacturing process, which allows us to extract patterns and optimize with a lot of reliability.

Our algorithm successfully predicts 99% of shim gaps using only around 3% of the typical measurements. Boeing validated the new process, and it now saves them a great deal of time and computational resources.

And you named your approach PIXI-DUST?

Haha, yes, it's known within Boeing as PIXel Identification Despite Uncertainty in Sensor Technology, or PIXI-DUST. We were at a meeting and one of the lead Boeing researchers said it was "like scattering pixie dust on the wing to predict 99% of the places where you need to shim."

Is it challenging to apply machine learning to an area like air travel?

I describe machine learning as optimizing over data. There are a lot of ways to do it, so in areas with strict margins for error, like in aerospace and other safety-critical applications, it's possible to enforce constraints and be sure the results are reliable and robust.

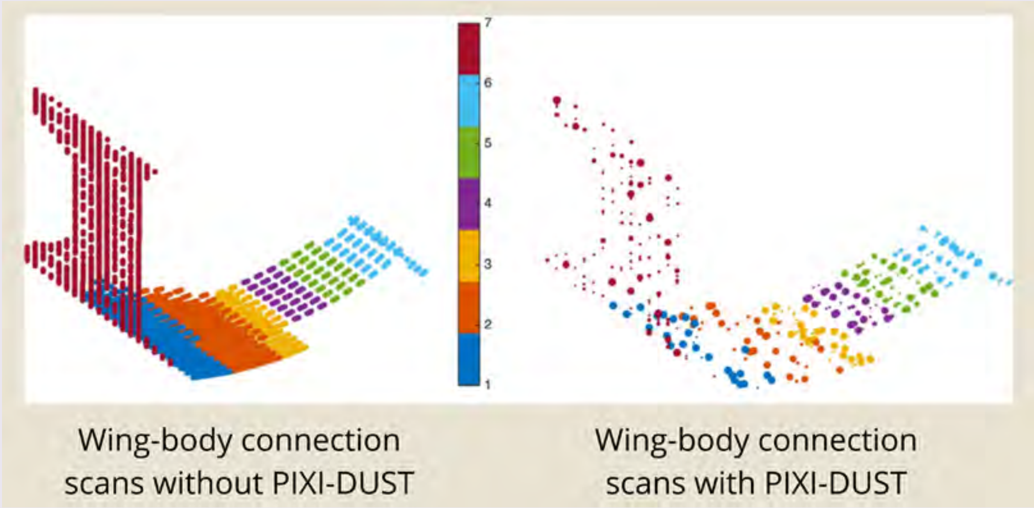
The other crucial factor is redundancy. This is a mathematical question, too — to optimize sensor placement, for example, we need to build backup sensors into our algorithm that will fill in if a sensor fails.

In simulations we can work with almost infinite amounts of data, but a real airplane can only get data from a limited set of sensors. Machine learning can help bridge that gap so that airplanes are engineered to optimize sensor placement and detect sensor failure.

Looking ahead, what excites you most about this research?

I'm excited to further investigate topics like sensor optimization and machine learning reliability through BARC and the new AI Institute for Dynamic Systems. As we get better at incorporating known physics into our models, we'll improve how well we can predict failures, incorporate safety constraints and solve complex engineering problems that fit well into mathematical and data approaches. Beyond airplanes, we're also exploring how machine learning can improve some of Boeing's other manufacturing processes.

As a student who studied these problems and now as an assistant professor, I see so many opportunities in our partnership with Boeing. Engineers at Boeing have a chance to learn these state-of-the-art techniques, while students and faculty at the UW get to collaborate with real-world engineers and see tangible impact from our work. It's a very beneficial relationship both ways.



PIXel Identification Despite Uncertainty in Sensor Technology (PIXI-DUST) is a machine learning-based system Krithika Manohar developed to improve the way Boeing assembles airplanes. This image shows how it uses just 3% of the typical scans to predict 99% of the gaps that need to be shimmed. Image from Manohar et al., Journal of Manufacturing Systems 2018

A VISION FOR ROBOTICS

The MACS Lab builds robots that play games, perform tasks and advance research goals.

By Andy Freeberg

Photos by Dennis Wise / University of Washington

Human vision is a sense that's deeply complex. The way our bodies see and interact with the world is layered, nuanced and difficult to mimic in machines. Despite the challenge, ME Assistant Professor Xu Chen believes that improving the integration of machine vision, intelligence and manipulation is the key to making robotic systems that are better at assisting humans with complex tasks.

"An ultimate goal in robotics is to build a research path to autonomy so that robots can help people do their jobs more effectively," says Chen. "We want to develop systems that will work alongside humans and remove the parts of a job that are strenuous, unsafe or wasteful. Improving their vision and perception is an especially important part of that."

(Above) Xu Chen controls a robot designed to carefully inspect manufactured aircraft parts for flaws or defects.

Playing games

To advance robot vision, Chen and his students in the UW Mechatronics, Automation and Control Systems (MACS) Lab have developed a variety of experimental systems. Some of those have involved teaching robots to master popular human pastimes. It started with the Rubik's Cube.

"Solving a Rubik's Cube is a great integration of machine learning, mechanical manipulation and vision," says Chen. "Our goal was to build robots that could manipulate intelligently enough to solve the Cube with two arms and no additional fixtures. It was a good way to check whether the eyes and the arms of our robot could work with its brain."

Next, the MACS Lab turned to chess. The variations in chess demand greater artificial intelligence. The board is less fixed and more dimensional, therefore requiring a more sophisticated imaging system in a less structured environment. And the ability to pick up and move any given chess piece in an interactive environment, without knocking another one over, requires greater dexterity.

Mingyu Wang, one of Chen's students, recently completed his ME master's thesis based on the vision-based robotic chess player he developed. "Building precision is very important for robotics, and each part of chess allowed us to add to what we learned with the Rubik's Cube," he explains.

Recently, the team has been working on robot air hockey. The key to air hockey is that the robot's eyes and arms can sense and react quickly to beat a human opponent.

"Human vision isn't very fast, at least when compared to vision in other creatures," says Chen. "But professional athletes, like tennis players or hitters in baseball, have extraordinarily fast reaction times. Athletes are able to react quickly, not because of the speed of their vision, but because of training. Our goal is to see if a robotic system can do the same."

The MACS Lab wasn't the first to build robots for these games, but each project was purposely designed to advance the lab toward important research questions. And the same systems can also be tailored to more productive tasks.

Inspecting airplane parts

Over the past year, with support from the Advanced Robotics for Manufacturing (ARM) Institute, Chen was part of a team of engineers from the UW, the University of Connecticut and GKN Aerospace who put their robots to the task of inspecting manufactured parts for imperfections. Specifically, they wanted a system that could spot some of the most difficult to discern defects — those in curved and complex metallic parts like ones used in airplane turbines.

"When working with airplane parts, the smallest defect can lead to a critical structural integrity issue, so the stakes are high," says Alex Strzelecki, a software and automation engineer at GKN Aerospace who worked with Chen on the project. "Inspecting these parts is eye-straining and labor-intensive work for a person, but also a major challenge for a robotic system."

The team has shown that its robot inspector can consistently spot defects 95% of the time, substantially better than most human inspectors. Thanks to the camera's visual feedback, the robot can automatically adapt its motion and even reconfigure its lighting. And because the process uses data, it can be tailored to quickly sort parts that may just need more machining or polishing versus those destined for the scrap heap.

Elegantly structured senses

All of these MACS Lab projects combine machine vision, intelligence and manipulation. In the big picture, Chen is most interested in improving how robotic sensing and mechanical systems are organized and controlled.

The MACS Lab robotic chess player is a demonstration that combines machine intelligence, vision and manipulation with both precision and flexibility.

"As humans we take for granted how intuitively our brain makes choices about prioritizing vision, perception and cognition, but those choices matter a lot," notes Chen. "We already have so many types of robotic sensors and inputs to choose from and in five years we will have even more, so the options are almost infinite."

By finding the most elegant architectures, Chen hopes his research team will learn important lessons about how a robot's brain can better prioritize its senses. In doing so, maybe they'll learn something about our own brains as well.

Visit the MACS Lab at www.macslab.xyz

A screen capture from a video demoing the MACS Lab's vision-based Rubik's Cube solver. Watch this and other videos of their robots in action at me.uw.edu/news/robotvision.

All photos were taken following appropriate protocols at the time.

AFFILIATE IN RESIDENCE

Retired engineers like Leonard "Len" Nelson offer their time and expertise to enrich UW research and education through affiliate professorships.

By Andy Freeberg

After 23 years as a scientist and engineer at Korry Electronics, ME Affiliate Professor Len Nelson had earned his way to retirement. For many people, that would be the end of a successful, productive engineering career. But not for him.

Nelson is among a set of highly accomplished experts who have retired from long careers and now volunteer their time conducting research and mentoring students at the UW. By contributing their considerable experience, these affiliates help provide greater attention to individual students, enrich students' academic curriculum through research, build connections to their professional networks and foster promising future research projects.

Nelson, however, says the pleasure is all his.

"I enjoy woodworking, but after making the third or fourth bench you start to think, 'This is getting a bit old,'" he remarks. "Fortunately, Eric Seibel rescued me from retirement and gave me something more meaningful to work on."

Rescued from retirement

ME Research Professor Eric Seibel first connected with Nelson in 2008 through a chance meeting with Nelson's daughter Elizabeth, a software product manager, at a Washington Research Foundation event. Seibel was looking for someone with expertise in optics and chemistry to help a doctoral student and Elizabeth Nelson was "looking to get dad out of the house," according to her father.

Nelson has a Ph.D. in chemistry and had been the director of research and development at Korry, a company that designs and develops cockpit displays. As a result, he was well versed in many areas: optics, electronics and mechanics, as well as chemistry. In the decade since, Nelson has served as a valued ME affiliate professor and key team member in Seibel's Human Photonics Lab.

Nelson says one of the most rewarding aspects of his role is working with students. He spends time with new student researchers to help them get past early hurdles and not get too discouraged by the challenges inherent to real-world research.

One student Nelson advised was Jasmine Hu, then a bioengineering undergraduate. Hu's research focused on searching for dyes that could be used for dental imaging.

"It was really my first experience with research and Len was a big support in guiding me through it," says Hu. "He taught me how to go into the literature and understand what had been done and how to weed out options. He showed me how to design robust experiments and clearly present my results."

Now working on her Ph.D. at the University of California, San Francisco, Hu credits Nelson as one of the reasons she decided to pursue a research career. Nelson's emphasis on clear and simple communication is something she carries with her; today she enjoys mentoring younger researchers herself.

A successful experiment

While Nelson continues to embrace post-retirement life, his UW work is more than a hobby. In addition to mentoring students, he has co-authored over two dozen scientific papers with Seibel and is an adviser for Engineering Innovation in Health (EIH), a program that pairs UW engineering students with clinicians to address unmet health challenges. A few of the EIH projects Nelson has worked on have earned patents, commercialization funding and other recognition.

One example is a project called UnTape. The UnTape team is developing a medical-grade adhesive to be used in tape or bandages. When gentle heat is applied to UnTape, the adhesive releases without the pain of ripping it off a patient's skin. After several years of development, the project recently won renewed support, built a partnership with one of the world's largest adhesives producers and is nearing approval to begin human trials.

Nelson also worked on a few projects like Hu's involving dental technologies and is contributing to a promising global health project with the goal of creating a new kind of blood test for newborns in underserved areas. He brings a lot to the table, Seibel says.

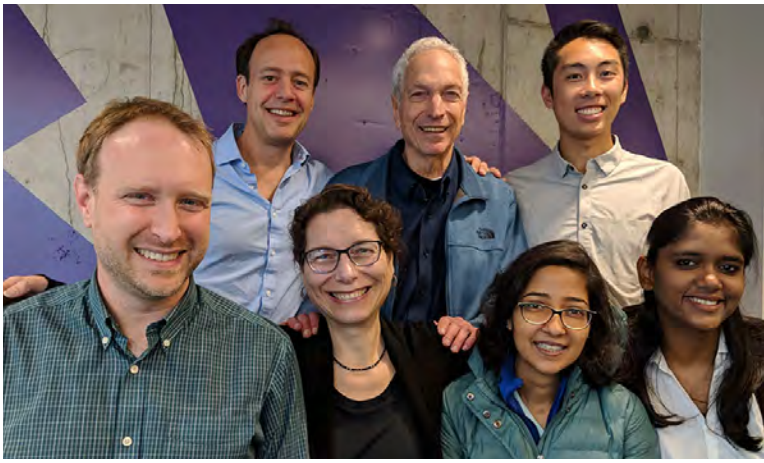
"Since my lab and EIH projects both aim to serve unmet needs, the concepts are often multidisciplinary and also need a business perspective," notes Seibel. "Len has all of that and I am constantly appreciative of his efforts."

A new program takes to the AIR

Earlier this year, Nelson and Seibel had an idea. They see a growing need for experts to support students and research initiatives, and one of the UW's great strengths is its location in Seattle — a city where engineering and innovation have been a foundation for decades and where residents put a high value on contributing to the public good. Surely other retirees would enjoy the chance to volunteer their expertise at the UW, and perhaps Nelson's experience could be replicated for others.

The ME department is now working to build an Affiliates in Residence (AIR) program, aimed at drawing more retirees to contribute to research and mentorship. With a pool of volunteers from local industry, they envision a synergistic match between those winding down their careers as innovators and those just beginning them.

"We don't know of any other initiative like this at other institutions," says ME Chair Alberto Aliseda. "We want to leverage our great Seattle resources and turn AIR into a unique and outstanding feature of UW Engineering's design and research programs."



Seibel, top left, and Nelson, top center, with team members in 2019. Photo courtesy of Eric Seibel

In search of affiliates

If you've retired from a career in research and development and are interested in volunteering to support UW research and mentorship, please reach out to us: **mechair@uw.edu**.

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The board provides the department counsel, mentoring, volunteer leadership, advocacy and vital connections to industry.

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