IPOD, IPHONE, NEST.
TONY FADELL ON HOW TO DISRUPT.
DANCING ON THE SIDE OF LURIE TOWER

It was part athletic prowess, part ballet, part trapeze act 167 feet off the ground. Members of BANDALOOP performed — vertically — on the sides of the Ann and Robert H. Lurie Tower. The performance was part of the 20th Anniversary celebration of a tower dedicated to the memory of Michigan alumnus Robert H. Lurie (BS ‘64, MSE ‘66) from his wife, Ann, in 1996. It houses a 60-bell grand carillon, one of two grand carillons at the University of Michigan (the other is in Burton Tower on central campus).
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UNVEILING A NEW VISION

MICHIGAN ENGINEERING 
ASPIRES TO BE THE WORLD'S PREEMINENT COLLEGE OF ENGINEERING 
SERVING THE COMMON GOOD

W hen Alex D. Gallimore, the Robert J. Vlasic Dean of Engineering, took office in July 2016, he was already well on his way to thinking big for the College. As a faculty member and associate dean, Gallimore had experienced first-hand the changes at the College over the past 25 years. While preparing for his candidacy as Dean, he deepened that knowledge with additional research that included benchmarking other institutions. His conclusion: “We had a ship that was heading in the right direction,” said Gallimore. “We were already really good at developing an entrepreneurial mindset, not looking at department or research boundaries and being able to collaborate. And we’ve always provided students really excellent experiential learning and instruction.” But Gallimore identified a missing element. “What we weren’t doing, in my opinion, was defining a reason for our work at a high level. We didn’t have guiding principles for why we were – or weren’t – focusing on specific areas.” That’s what Gallimore set out to do in his first term as dean. Through large-scale work sessions among faculty and College leadership, speaking with deans of other institutions and learning from alumni and investors at top companies, Gallimore and his team sought not only to define the strengths and values of Michigan Engineering but to create a vision and mission statement that would lead the College to the next level.

In January, Gallimore rolled out the new strategic vision, along with a mission to serve the greater good – and to strive for preeminence. All involved agreed that we were doing a lot of the right things, but that we needed a defining mission that sets a clear path for the College and explains ourselves to the world.

“The concept that really seemed to resonate with everyone was the idea of serving the common good,” said Gallimore. “It goes back to the old mantra of an uncommon education for the common man or woman.” Being a public institution, we have a broader mission – you simply can’t be preeminent without serving the people.”

With that as a framework, the additions of improving the quality of life, developing intellectually curious and socially conscious minds, creating collaborative solutions to societal problems, and promoting an inclusive and innovative community of service flowed naturally.

“It all comes together,” said Gallimore. “And we’re pushing to be the best because I think it’s within reach. We are in a great place in terms of finances, our reputation and having an amazing resource with the larger University. The University itself is doing really well. And our mission of serving the people and broad interdisciplinary solutions is a timely theme in my opinion. “Frankly, there is no other place than Michigan that can tackle that at scale.”

One of the first steps, Gallimore believes, is refining the collaborative process. “We focus on collaborative processes because, for the kind of complex and wicked problems we want to address, it depends on a group of people coming together. We’d like to identify the grand challenges that we feel we are best in a position to tackle, that take full advantage of our relationship with the rest of the campus and our ability to work at scale.”

But it must be done in a way that is structured for success, said Gallimore. Simply getting the right people into a room or on a project doesn’t ensure that they won’t fall short of their potential. An infrastructure for collaboration with the right tools – whether they be systems, resources or facilities – will ensure the best possible outcomes. Even day-to-day tactics for how staff, faculty and students operate together will contribute to a better result.

“We’re thinking very creatively,” said Gallimore. “Essentially starting from scratch to see what a collaborative environment of the 21st century looks like, and how can we create it to tackle research, education and learning challenges.” Another piece of the puzzle lies in setting the stage for students to succeed and fostering an inclusive environment to help them achieve their goals.

“There are segments of our society who, through no fault of their own, have experienced an educational background or socioeconomic status that puts them at a disadvantage,” said Gallimore. “It’s acknowledging that we have different types of people and different styles of learning. The question is, what role do we play in the College in working to close the gap by the time they graduate?”

And, said Gallimore, we need to reinforce these goals with our culture and values. Things like removing administrative barriers, empowering faculty and staff to fully engage, and equipping them with resources and incentives to ensure they are striving for the best are critical. Not addressing these subtle administrative issues could result in inadvertently communicating that something isn’t important.

“For example,” said Gallimore, “the notion of ride-taking and taking a nice one, but how do we change the culture and values at the College so that people are actually willing to take risks and fail?”

The results of these efforts should lead not only to better rankings, but also a shift in the quality of people the College is able to recruit – and to an enhanced public perception of Michigan. “Once we reach that level, there will be some telltale signs,” said Gallimore. “We will be on a more level playing field with the top two or three institutions that often beat us for top talent. Other institutions and the public will tune to us for matters of technology and social change, to be an honest broker of information and a place where new ideas incubate and innovation succeeds.

“We could do all these things if we were just a little more deliberate. It goes back to the reason we created a mission and vision in the first place – to help us acknowledge our strengths and work towards making them even stronger.” – Jennifer Judy Henel
Climate change

Reaction to a letter published in this section in the fall issue. That letter stated skepticism about climate change in reaction to the spring 2016 article about geosmartening.

Why would you publish a comment like Stupel’s regarding climate change? Engineering is an objective endeavor in which we create, improve and use mathematical models to create or our world positive changes to our environment which improve our living condition. It is not subjective.

Global temperatures have, in fact, risen over the last 15 years and there is ample objective data to prove this. (For instance, see: “The Skeptic’s Series,” articles from the Earth Institute at Columbia University.) It’s one thing to publish subjective opinion on how good a building looks, or how a topic in one of the articles might or might not have affected an individual. But for The Michigan Engineer to publish false, misleading information about such an important scientific topic as climate change in an engineering magazine is unpatriotic and irresponsible.

Bill Boyd (BSE EE ’87)

Wolverines in space

Ken Ludwig

You asked our article “Wolverines in Space” in the fall issue (Bicentennial section). It brought back some great memories of my 13 years on the Apollo Program in the 60s and 70s. Although I also graduated in 1959, the same year as astronauts Ed White and James McDivitt graduated, I don’t believe that I knew them. But on July 26, 1971, as I was serving as the Boeing Chief Engineer for the S-IC booster rocket built at the Michoud Assembly Facility in New Orleans, I was at the Cape for the launch of Apollo 15. The S-IC was the first stage of the Saturn V moon rocket which carried James Irwin, Al Worden, and David Scott to the moon. Later, as was the custom, the Apollo 15 astronauts visited Michoud to thank us for our part in the program.

By the way, the article about the “Vulcans” on the same page also caught my eye, being a Vulcan myself and having applaud over my head in 1958 for my initiation. John Eddie (BSE EE ’58)

Alaska research

In response to our article about engineering alumna Brie Van Dam (BSE AES ’07) and the Arctic Circle.

Good for her! Great message for young women. Set a goal and make it happen.

MaxGzzillza & Coach Jared Lasser

Final exam

Response to the article on how engineers are using social media to help cities like Jakarta, Indonesia, deal with flooding.

Go Blue! Thank you for helping my homeland get to a better place. I am very honored as an alum to see the engineers innovating for a great cause!

Il-aidebong

Despite the odds

Reaction to our story and video about Matthew Haviland (BSE IDE ’15) and how he used his own difficult journey to encourage other non-traditional students.

This gave me goosebumps. You embody what the University of Michigan is all about. I will get the opportunity to talk to you. I would thank you for being an inspiration to those who know some of your story. Forever Go Blue.

Hoang Nguyen

Rocket launch

Mixture for MESSA, the student team that finished second in the 2016 Intercollegiate Rocket Engineering Competition with its nitrous hybrid motor rocket.

Maybe you just should consider using hydrogen peroxide as the oxidizer. You’d get superior performance, I think.

Cadek Risner

True, but nitrous oxide is less toxic and at a standard temperature generates a strong vapor pressure of about 50 bar, eliminating the need for external pressurant or pumps.

Nick Glorioso

Fall 2016 correction

The graph in “Innovation for Finshers” should have been labeled as the number of university startups in the nation, not at U-M.
VICTOR, VALIANT

Michigan Engineer and World War II veteran John E. Franklin sent the letter below to Alec D. Gallimore after learning that he had been named the Robert J. Vlasic Dean of Engineering. Franklin earned his chemical engineering degree in 1949 but said he found it impossible to get an engineering job because of the color of his skin. So he went into medicine, overcoming his fear of blood to become a surgeon.

“Back then, there were four professions where blacks could make a living,” he said. “You could be a funeral director, a dentist, a lawyer or a doctor. I picked doctor out of those four.”

Today, Franklin and his wife live in North Carolina and Florida. They have four children: John E. Franklin Jr. (MD ‘80) is now associate dean and professor of psychiatry at Northwestern University. Paula Franklin (MD ‘92) is a practicing pediatrician. Michael Franklin attended U-M and is a psychiatrist. Renee Franklin Hill is a graduate of Brown University and Harvard Law School; she taught at North Carolina Central University and Charlotte School of Law. Grandson John E. Franklin III studied engineering at Northwestern University and will intern with Google this summer.

Members of the Franklin family, from left to right: Michael Franklin, MD; Paula Franklin, MD; Arlena Franklin, John Franklin Sr., Lorna Renee Hill, John Franklin Jr.
Knowing how to code is a cool skill to have. Back in the early 1900s, U-M students were learning a different kind of code – Morse. One instructor would work with 24 young engineers on mastering the device, dots and dashes.

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THE MICHIGAN ENGINEER NEWS CENTER WILL KEEP YOU UPDATED ON GROUNDBREAKING DEVELOPMENTS IN:

- Robotics
- Autonomous Vehicles
- Sustainability
- Space Systems Research
- Health Care
- And much more

THERE ARE SIXTEEN DECODABLE EXTRAS IN THIS ISSUE.
Decoder delights can be found on these pages: 5, 11, 16, 20, 47, 53, 67, 71, 74, back cover.

The Michigan Engineer News Center. More from the magazine you love – but much more often.
news.engin.umich.edu

Or scan this page with the Decoder. See facing page for details.

Those are just a few of the features that U-M’s new Robotics Laboratory will offer when it opens in 2020, making the University one of an elite few in the U.S. with a dedicated robotics facility.

The sleek, slate gray and silver edifice will also house: two large shared lab spaces, a startup-style open collaboration area, offices for 30 faculty members and more than 100 grad students and postdoctoral researchers and classrooms. And in a unique collaboration, Ford Motor Co. is providing funding for a fourth floor that it will lease for dedicated space where Ford researchers will eventually be based.

“The new building will give us cutting-edge lab space to test our theories on a broader scale, and in a collaborative environment that invites the exchange of ideas,” said Jessy Grizzle, who has been named director of robotics at U-M. Grizzle is the Elmer G. Gilbert Distinguished University Professor and the Jerry W. and Carol L. Levin Professor of Engineering, as well as a professor of electrical and computer engineering.

You may have seen a familiar face announcing NASA’s latest triumphs, like the momentous discovery of seven nearby exoplanets in the TRAPPIST 1 system. Former professor Thomas Zurbuchen is now associate administrator for NASA’s Science Mission Directorate. Zurbuchen served for 20 years in the U-M departments of Climate and Space Sciences and Engineering and Aerospace Engineering, among other College and University-wide posts.

At startup Clinc released its first product: Finie, the “financial genie,” is a voice-controlled platform for banks to integrate with their mobile apps. Users can ask Finie questions like, “Where can I withdraw cash?” and, “Can I spend $2,500 on a trip?” VentureBeat covered Clinc’s $6.3 million funding round in February. Its founders are Jason Mars and Lingjia Tang, assistant professors of computer science and engineering.
A mash-up of Uber-style ride sharing and fixed-route high-frequency buses is set to create a first-of-its-kind mobility system on the U-M campus.

The RITMO (Reinventing Mobility) project has proposed a hub-and-shuttle scheme that would work with the existing campus bus system to deliver quicker trips. It will combine buses serving the busiest transportation centers with a fleet of around 50 on-demand shared shuttles. At first, human drivers would pilot those shuttles, but eventually, developers envision that they’d be autonomous.

A smartphone app will calculate passengers’ most efficient journey. It could be a direct shuttle ride from A to B, a shuttle followed by a bus trip or any similar combination.

The development team has been studying traffic flow across campus with help from students and staff members who, through U-M’s existing app, volunteered to provide autonomous data about their movement. “From a data science standpoint, it’s a fascinating optimization problem,” said lead researcher Pascal Van Hentenryck, the Seth Bonder Collegiate Professor of Industrial and Operations Engineering. “What are the mobility patterns in Ann Arbor? How do you define the size of the fleets? Where do you put the high-frequency buses and how many? Those are the kinds of questions we’re answering with the data we collect in this initial part of the study.”

The first shuttle rides are expected to be available this summer.

“WHAT WE DECIDED TO DO WAS LITERALLY BREAK EVERY RULE I’D EVER BEEN TAUGHT AS A SCIENTIST OR ENGINEER.”

– Marc Edwards, Virginia Tech professor of civil engineering, giving the Walter J. Weber Jr., Distinguished Lecture in Environmental and Energy Sustainability at Michigan Engineering in October 2016. Edwards helped to bring the Flint water crisis to light. Watch his hour-long talk by scanning this page with the Decoder in the One Cool Thing app. Details on p. 10.

Electric utilities now have a better sense of when solar storms are headed for their stretch of the power grid, thanks to a space weather forecast model developed by researchers in the Department of Climate and Space Sciences and Engineering. Before, the National Oceanic and Atmospheric Administration could give only planet-wide projections. The new model, which NOAA adopted, makes regional predictions at an unprecedented 350-square-mile resolution – and with a 45-minute lead time. That gives utilities precious time to prepare and prevent grid damage.
Next-generation lithium metal batteries could boast 10 times the capacity of today’s lithium ion cells. So what’s keeping them out of our electronics? Dendrites. These whiskers of lithium that grow inside batteries can cause短路 fires like those that landed Samsung’s Galaxy Note 7 on the FAA’s no-fly list.

In an effort to understand exactly how dendrites form, Michigan Engineers built a see-through lithium metal battery. Their “visualization cell” serves as a window into the belly of the battery. With it, they can watch dendrites grow in real time and simultaneously measure any changes in voltage. (See for yourself in a research video. Scan this page with the Decoder in the One Cool Thing app. Details on p. 10.)

Engineers built a see-through lithium metal battery. Their “visualization cell” serves as a window into the belly of the battery. With it, they can watch dendrites grow in real time and simultaneously measure any changes in voltage.

Their approach improves upon previous techniques that could make electrochemical measurements while the battery ran but had to rely on battery autopsies after the experiment to reveal what physical changes occurred inside.

Understanding dendrite growth is the first step toward controlling it, said Neil Dasgupta, assistant professor of mechanical engineering. His research group is enabling more than their own investigations.

“Our window battery is a simple platform that can be used by researchers worldwide,” Dasgupta said. “It can be reproduced in any lab with an optical microscope, simple electrochemical equipment, a machine shop and a $100 budget.”

We characterized the resulting multifunctional composite through controlled vibration testing. The electrical power generated by small oscillations was measured across a load. We found that the composite material could generate enough power to run small sensors. Moreover, we saw that increasing the vibration amplitude leads to an increase in the voltage and current generated by the composite. This linear relationship means that the composite structure can measure vibrations through the electrical response, an embedded sensing capability.

Typically, the addition of functionality – energy harvesting in this case – deteriorates the intrinsic structural performance of the initial materials. To ensure that this composite is able to withstand mechanical loading, we subjected the composites to tensile testing. Assessing the structural performance of these composites revealed a significant increase in the elastic modulus and tensile strength of the composites by 18.4 percent and 34.3 percent, respectively. These results indicate that integrating ZnO nanowires not only provides energy harvesting capability but also enhances the mechanical properties of the composite, therefore creating an ideal multifunctional material.

With embedded intelligence and wireless sensors becoming ubiquitous, future efforts will seek to convert structural composites into smart structures capable of sensing, actuating and generating power. The embedded sensing and energy generation capabilities of these materials would open wide-ranging applications in the aerospace, automotive and defense fields. For instance, it may be possible to remotely monitor the health of a composite material through the embedded sensors to improve safety through state awareness and reduce maintenance costs by replacing schedule-based maintenance with data-based repairs.

By Henry Sodano
Associate professor of aerospace engineering

We are surrounded by unused ambient sources of energy that could be converted to useful power through energy harvesting. Many energy-harvesting devices are designed to convert ambient kinetic energy, such as vibration, into electrical power with the goal of eliminating the need for batteries. One potential drawback is that energy-harvesting devices can increase the weight and complexity of the systems in which they operate. In order to make energy harvesting more practical, my students and I build multifunctional materials that incorporate energy harvesting capability into structural materials. We developed the first methodology to simultaneously improve both strength and functionality in an energy-harvesting structural material, which could lead to a paradigm shift in the design of multifunctional materials.

Fiber-reinforced polymer (FRP) composites are an ideal choice for building multifunctional materials since they are inherently multiphase and offer high strength and stiffness. Energy can be scavenged from the interaction between two phases of the composite. FRP composites are already used in applications such as aerospace and automobile structures. During operation, the composites are exposed to perpetual vibration, which makes them excellent hosts for mechanical energy harvesting units.

In order to design a structural material with embedded energy harvesting, we focused on the interface between the fiber and polymer matrix. This interface is typically a source of structural weakness. The vastly different mechanical properties of the rigid fiber and polymer surrounding it leads to a stress concentration, which then leads to cracking. In order to alleviate this and add energy harvesting capability, we grew zinc oxide (ZnO) nanowires on the fiber surfaces, creating a functionally graded interface. The piezoelectric properties of the ZnO nanowires convert mechanical load to electrical charge while their hierarchical architecture enhances the bonding between fibers and polymer matrix.

We characterized the resulting multifunctional composite through controlled vibration testing. The electrical power generated by small oscillations was measured across a load. We found that the composite

By Henry Sodano
Associate professor of aerospace engineering
The nation's preeminent group for advising on engineering and technology policy has elected another two Michigan Engineering professors to its ranks.

The 2016 members of the National Academy of Engineering (NAE) include Ellen Arruda, professor of mechanical engineering, and Mark Daskin, professor and chair of industrial and operations engineering. Induction into the NAE is one of the highest honors given to U.S. engineers, and brings the college's total representation in the academy to 27.

Arruda, also a professor of biomedical engineering and macromolecular science and engineering, was commended for her pioneering research in polymer and tissue mechanics and their application in innovative commercial products. Among her recent projects is a shock-absorbing material that could be used in protective gear, including helmets.

Daskin, the Clyde W. Johnson Collegiate Professor, was recognized for leadership and creative contributions to location optimization and its application to industrial, service and medical systems. His current research focuses on supply chain design under uncertainty, humanitarian logistics and drug shortages.

"This signature accomplishment by these esteemed faculty members represents the leadership and excellence we value at Michigan Engineering," said Alec D. Gallimore, the Robert J. Vlasic Dean of Engineering and Richard F. and Eleanor A. Towner Professor of Engineering. Gallimore is also an Arthur F. Thurnau Professor of aerospace engineering.

DESTINATION CUBA

In late 2014, three days after President Obama announced a new era in US-Cuba relations, Professor Brian Love was making phone calls and writing emails – trying to start a dialogue with his counterparts at the University of Havana.

Love was eager to help Michigan Engineering develop educational and research ties ahead of the inevitable flood from other higher ed institutions. Simultaneously, he saw an opportunity to trailblaze a new model for international education at the University of Michigan – less disruptive to one’s academic itinerary than a typical semester abroad.

Over spring break, 2017, 22 Michigan Engineering students participated in one of the first technical interactions between a U.S. university and Cuba since the thawing of relations. They toured manufacturing facilities and attended lectures at the University of Havana.

The new relationship is an opportunity to establish exchange programs and research collaborations that have been impossible for more than fifty years.

"I think the attending students came away more empowered about making a difference as engineers even without a carte blanche supply budget," said Love, a professor of materials science and engineering. "Personally, I was struck by the variety of new thinking achieved by the students who participated in the program. I heard more than once about the ingenuity, persistence and pride exuded by the Cuban professionals we interacted with on the island."

To prepare for the trip, Love taught in an accelerated eight week course called "Design in a Resource-Constrained Environment in Havana, Cuba." It included as much cultural education as it did engineering. The class explored the similarities and differences between how things are made in the U.S. versus Cuba – a country highly invested in education, but constrained by limited resources.

This experience set an application record for the college’s International Programs in Engineering. Not only is Love hopeful that the Cuba collaboration will continue in the future, but that the accelerated structure culminating in a week abroad can be a template for other study abroad opportunities – giving students a chance to have an international experience with less expense or disruption to their graduation timeline.

"This trip provided me with perspective on different ways to solve problems," said James Mitchel, a junior studying computer science. "In an academic setting, it is easy to know the standard solution and apply it, but in Cuba the standard solution is rarely available due to the embargo and other economic limitations. So to solve a problem they have to evaluate different solutions and find the best match for their situation. This is the way problems are solved in the real world, but this can often get lost in school when we’re looking for the textbook answer."

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ALGORITHMS CAN BE MORE FAIR THAN HUMANS

By H V Jagadish
Bernard A. Galler Collegiate Professor of Electrical Engineering and Computer Science

Amazon recently began to offer same-day delivery in selected metropolitan areas. This may be good for many customers, but it also showed that computerized decision-making can be biased—often in subtle, unintended ways. But, these biases can be easier to detect and correct in machines than in humans.

Sensibly, Amazon began its service in areas where delivery costs would be lowest, by identifying ZIP codes of densely populated places home to many existing Amazon customers with high enough incomes to make frequent purchases. The company provided a web page letting customers enter their ZIP code to see if same-day delivery served them. Bloomberg News used that page to create maps of Amazon’s same-day delivery service areas.

Their analysis revealed that many poor urban areas were excluded, while more affluent neighboring areas were included. Many of these excluded poor areas were predominantly inhabited by minorities. Such unfairness can arise for many reasons, including hidden biases—such as assumptions that populations are distributed uniformly. Algorithm designers likely don’t intend to discriminate, and may not even realize a problem has begun.

We should pause a moment to consider whether we are unduly demanding of algorithmic decisions. Companies operating brick-and-mortar stores make location decisions all the time, taking into account criteria not that different from Amazon’s. Store owners screen candidates that are convenient for a large pool of potential customers with money to spend.

In consequence, few stores choose to locate in poor inner-city neighborhoods. For example, I looked at the 55 Michigan locations of Target, a large comprehensive retail chain. When I sorted every Michigan ZIP code based on whether its average income was in the top half or bottom half statewide, I found that only 16 of the Target stores were in ZIP codes from the lower income group. More than twice as many, 39 stores, were sited in ZIP codes from the more affluent half. Yet there has been no popular outcry alleging that Target unfairly discriminates against poor people in its more location decisions.

There are two main reasons why the concerns about Amazon are justified: rigidity and dominance. Rigidity has to do with both the online retailer’s decision-making process and with the result. Amazon decides which ZIP codes are in its service area. If a customer lives just across the street from the boundary set by Amazon, she is outside the service area and can do little about it. By contrast, someone who lives in a ZIP code without a Target store can still shop at Target—though it may take longer to get there.

It also matters how dominant a retailer is in consumers’ minds. Whereas Target is only one of many physical store chains, Amazon enjoys market dominance as a web retailer, and hence attracts more attention.

While their rigidity and dominance may cause greater concern about online businesses, we also are better able to detect their discrimination than we are for brick-and-mortar shops. For a traditional chain store, we need to guess how far consumers are willing to travel. And the likely areas a store serves may not map neatly into geographic units for which we have statistics about race or income. In short, the analysis is messy and requires much effort.

In contrast, it would have taken journalists at Bloomberg only a few hours to develop a map of Amazon’s service area and correlate it with income or race. If Amazon had done this internally, they could have performed the same analysis in just minutes—and perhaps noticed the problems and fixed them before same-day service even began.

As we find more and more uses for data-driven algorithms, it is not yet common to analyze their fairness, particularly before the rollout of a new data-based service. Making it so will go a long way to measuring and improving the fairness of these increasingly important computerized calculations.

This is an excerpt of an article that originally appeared at The Conversation. Read the original by scanning this page with the Decoder or at http://umicheng.in/fair-algorithms.

Vortex-induced vibrations can shear power lines, topple buildings and smash bridges to bits. Generations of engineers have dedicated their careers to fighting them. But a group of Michigan Engineers is using them to generate electricity. They’re working to harness alternating vortices in the slow-moving river and ocean currents that are common around the globe.

In 2016, they tested VIVACE, their first commercial-scale device, in the St. Clair River. (Watch a video of VIVACE’s deployment by scanning this page with the Decoder in the One Cool Thing app. See p. 10 for details.)

The 12-ton device was inspired by fish, who squeeze between the vortices created by their schoolmates to swim more efficiently. VIVACE uses similar vortices to push four 12-foot high cylinders from side to side, generating enough energy to power up to four homes.

Lead researcher Michael Bernitsas, the Mortimer E. Cooley Collegiate Professor of Naval Architecture and Marine Engineering, launched U-M startup Vortex Hydro Energy in 2004 to commercialize the technology.

“We have a good device,” Bernitsas said, “but taking principles from schools of fish and turning them into mechanical devices takes time.”
A jazzy tune flows through the air as State Street meets East Liberty, where the town meets the campus, melting into each other seamlessly. As the late afternoon light shifts from the Michigan Theatre to the State Theatre, students, townies, and visitors alike flood the streets and add to the beat of a saxophonist, Ahmid Alexander, as he plays a song off of Miles Davis’ “Kind of Blue.”
In the escalating struggle between the individual and the state, technology favors the powerful. That’s why this Michigan computer scientist and his team of researchers revel in righting the balance.

STORY BY: RANDY MILGROM
PHOTOS BY: JOSEPH XU
ILLUSTRATION BY: STEPHEN ALVEY
Halderman's real-world security contributions began while he was a PhD student at Princeton. In the early 2000s, Halderman was part of a group working to expose security flaws in new electronic voting machines. These had been too quickly purchased and too haphazardly installed after the 2000 “hanging chad” U.S. presidential election recount prompted Congress to appropriate more than $3 billion to “modernize” the U.S. election system. Machine manufacturers strenuously resisted research probes and critics’ warnings, and computer science and engineering departments around the country clamored to examine them.

In early 2006, an anonymous insider offered Halderman’s faculty advisor Edward Felten the opportunity to inspect a Diebold-manufactured machine, and Halderman was dispatched to retrieve it. This required a drive to New York City for a meeting in a dark alley with a man in a trench coat, who slipped Halderman a black canvas bag— which Halderman (as if he were in a B-movie) immediately transported to an undisclosed location.

In fairly short order, Halderman and his team would demonstrate that the voting machine inside the bag was no more secure than a typical home computer. They readily hacked it and infected it with malicious code that stole enough votes to change the intended outcome of a simulated election. The resulting paper convinced election officials in several jurisdictions that the machines simply weren’t trustworthy enough to be useful.

Asked now why he was the one sent to retrieve the machine, Halderman laughs. “I don’t know… I had a car?”

But he also was willing—and learning at that time to “overcome that mental block; that little taboo to even think about breaking a rule. It’s not something decent people do.” (This is to be very clearly distinguished from his research group’s strict “commit no crimes” policy, which is audaciously followed.)

Effective security work requires following one’s curiosity and understanding that, “it’s not your job to make everyone happy. Some people are going to be unhappy that you’re even asking the questions.”

Not long after Halderman arrived at Michigan, he and his students had asked enough questions to be embroiled in his most public election hack yet. In the fall of 2010, Washington, D.C., officials had invited the public to participate in mock voting to test its upcoming internet-based election—the nation’s first. As Halderman has since joked, “It’s not every day you can hack an election without going to jail.”

In less than 48 hours, Halderman and his students had hacked the system and stolen votes. Election officials learned they’d been had only after hearing “Hail to the Victors” when the voting page was displayed. And the D.C. online voting plan was summarily scrapped.

“We’re going to be leaders not by playing the academic game but by doing the work that matters.”

Halderman says, extending his lean frame along the length of the couch in his office. The place is packed with artifacts emblematic of security—people are going to be unhappy that you’re even asking the questions. He arranges and admires the stuff as he settles in to his office on North Campus.
I think people are very easily scared,” Halderman says quietly. “They had their job, and I had mine,” he says. “And the only reason I don’t believe it is that there are a lot of mortals. Ask Halderman what he and his group do to prevent spying information and thereby affects public opinion – this was an especially disquieting incident.

Bernhard describes Halderman’s attitude: “The world’s on fire all the time, so you may as well have fun while you go through it.”

This makes Halderman laugh out loud. “But I don’t believe ultimately that the world is going down in flames,” he says. “And the only reason I don’t believe it is that there are a lot of people working very hard, including us, to make sure it doesn’t.”

**SEEING BETTLEBAUM EASIER SECURITY**

One example of this hard work, which Halderman says he’s most proud of, is Let’s Encrypt – the results of an ongoing mission to secure literally every website on the Internet.

HTTPS, the foundational protocol of the web, was first made more governmental use of computer security problems in	

Still, Halderman’s characteristic calm was momentarily punctured as he explained that his passion for his students – and when he paused to consider the craven use of his persona to manipulate, and to invoke hate and fear. For Halderman – whose more expansive notion of “digital democracy” contemplates how computer technology impacts access to information and thereby affects public opinion – this was an especially disquieting incident.

**FINESSE ON THE SCALE**

Certainly there are basic maneuvers anyone can and should perform to harden his or her computer security. Two-factor authentication. Reasonable password practices. But that’s for mere mortals. Ask Halderman what he and his group do to prevent spying. Two-factor authentication. Reasonable password practices. But that’s for mere mortals. Ask Halderman what he and his group do to prevent spying.

“People in power see this first and foremost as a threat to their legitimacy,” Halderman says.

But it has remained complicated and expensive for many websites to obtain HTTPS status through the existing certificate authorities. So be-

**DIGITAL DEMOCRACY IN 2016**

Though Halderman says he spends so little of his time on election-related work that it’s “almost a hobby,” his long experience and world-class renown nonetheless landed him among the handful of experts overseeing the aborted 2016 U.S. presidential election recount process.

And the recount was not completed due primarily to partisan wrangling – something Halderman’s come to expect. In Estonia, the party out of power called the electronic voting system a “tool of the devil” while the party in power called Halderman a “communist” for exposing its flaws. In Australia, his colleague was threatened with loss of her university job merely because she joined Halderman in identifying its system’s weaknesses.

“Not to lose our ability to question the machines that got them elected,” Halderman says. “People in power see this first and foremost as a threat to their legitimacy.” Though a truncated process, Halderman and Bernhard gathered enough evidence to support the integrity of the 2016 presidential election – though not enough to definitively rule out a cyberattack. They also found the system more vulnerable to attack than they had suspected, and they’re continuing to advocate for improvements in a U.S. electronic voting system that is “lower on the list [among systems worldwide] that got them elected,” Halderman says. “People in power see this first and foremost as a threat to their legitimacy.” Though a truncated process, Halderman and Bernhard gathered enough evidence to support the integrity of the 2016 presidential election – though not enough to definitively rule out a cyberattack. They also found the system more vulnerable to attack than they had suspected, and they’re continuing to advocate for improvements in a U.S. electronic voting system that is “lower on the list [among systems worldwide] than we should be, given what’s at stake in our elections.”

No matter the results, Halderman believes this work may have motivated the racist, anti-Semitic, threatening messages that were posted under his name on a Michigan Engineering-based computer science lecture, late in the evening on February 7, 2017.

The attack was a “spoof” – the email header was forged so that the messages appeared to have originated from Halderman – opposed to a “hack,” which would have required an actual security breach and takeover of his account. In a brief public statement nearly immediately following the incident, Halderman said the “spoofed” emails “appear to be a cowardly action by someone who is unhappy about the research that Matt [Bernhard] and I do in support of electoral integrity.”

Over the next several days Halderman largely tried to go about his business around town, considering his next move – FBI and FBI and FBI and other investigations into the identity of the perpetrator). He sought to use the incident as a teachable moment for students in his cryptography classes by lecturing about the importance of both identifying a troll and not responding emotionally, because that’s precisely what the attacker seeks.

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Six months within its public launch in December 2015, Let's Encrypt had become the world's second largest certificate authority. And today, based on reasonable metrics, it's already become the world's largest.

Another security-enhancing invention: A very fast Internet-wide scanning methodology that was jump-started when Halderman asked then-PhD student Zakar Durumeric to "probe every computer on the Internet and come back with the set of public keys used for cryptography on all of them."

This seemed a nearly impossible task, especially for a first-year graduate student – like the Wizard of Oz telling Dorothy to return to the Wicked Witch's broomstick. Yet when Halderman next heard from his student – a mere two weeks later – "he was on a path to the solution."

Durumeric used existing tools in ways that eventually led to the creation of a new one called ZMap, enabling researchers to map the entire public Internet Protocol space in just hours.

The few prior attempts to accomplish anything similar were all extremely expensive and time consuming – epic undertakings featuring clusters of computers and experienced researchers who nonetheless completed just a portion of the intended task. ZMap reduced the cost and time by orders of magnitude, which Halderman credits in part to having built it with this specific application in mind, rather than repurposing something never meant to traverse the entire Internet.

And it takes a "sharper" rather than a "sequential" approach.

"We ask questions as fast as the network will go and let the responses come back whenever they do," Halderman says. "But that's okay; we'll get that information later."

Halderman links ZMap to a weather satellite for Internet security, continually gathering vast amounts of data. That information has transformed a largely anecdotal method of discovering and repairing Internet security problems into an empirical science so that problems can be more efficiently identified and solved.

Before ZMap, an attack on a widely-used form of cryptography – the Diffie-Hellman key exchange – "was gekke, but now a monumental encyclopedia that cryptographers had believed was virtually unbreakable!"

The key to the paper, which Halderman calls "one of the most satisfying things I've ever done," involves the Diffie-Halman key exchange, which, ironically, was the algorithm widely advocated as a defense against mass surveillance. As Halderman explains in the Freedom to Tinker blog, Diffie-Hellman users must first agree on "a large prime number with particular form." But standardized primes had become commonplace, which left Diffie-Hellman vulnerable to being "cracked" with just one enormous calculation.

Halderman concludes he "can't prove for certain" that this is what the NSA does. But that "enormous" calculation, conservatively estimated, "would cost an equally enormous amount to complete. And among the Snowden trove are budget documents that make it clear that such an NSA is investment is both affordable and likely. Halderman says he's "been told" that NSA officials are not exactly pleased with his work.

"It's a bit of a whol to digest," Halderman says. But by 2015, Halderman and a sizable group of collaborators – including several Michigan students and a number of colleagues from a handful of other institutions – published the revolutionary "Legatum" paper, based in part on the Snowden disclosures, that answered the question everyone had been asking: How did the NSA break so much encryption that cryptographers had believed was virtually unbreakable!

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Into The Storm

The most turbulent region of a hurricane holds secrets about its potential for destruction. Michigan Engineering's newly launched satellite system can help us understand how these storms intensify in a warming world.

STORY BY: Wade Craig Moore
**The rain has always been a problem because it’s this big interfering signal.**

Alumnus Jeff Masters flew into the eyewall of Hurricane Hugo and lived to blog about it. He is co-founder and meteorology director of Weather Underground, one of the most popular weather outlets.

Chris Ruf, professor in the Department of Climate and Space Sciences and Engineering, is principal investigator on the Cyclone Global Navigation Satellite System. He has been studying ways to improve hurricane-measurability since grad school. He stands at the CYGNSS Spaceflight Operations Center in the Space Research Building.

Cyclone soldiers

Masters had an uneasy feeling about Hugo’s eyewall as they approached. No other plane had been in this storm yet, so nearly nothing was known about the vortex that was about to swallow them. They were entering at an unusually low altitude -- as close as they could safely get to the water -- to carry out the Hurricane Energetics Experiment. As far back as 1989, researchers were studying the mechanisms of intensification, as well as how the air and sea intermingled in the storm’s most turbulent altitudes.

As the plane approached the eyewall, winds were reading only 60 mph. In retrospect, those readings may not have been accurate. Here’s an excerpt from Masters’ blog:

> We hit the eyewall. Darkness falls. Powerful gusts of wind roar at the aircraft, slamming us from side to side. Torrential rains hammer the airplane. Through my rain-streaked window, I watch the left wingtip flex down a meter, then up a meter, then down two meters every which way.

> And why some grow suddenly stronger, as Matthew did in 2016. But hurricanes still harbor secrets. Scientists need more than satellite systems to probe storms, so they scatter the signals most of the time. The cost of evacuating a mile of coast is about $1 million per mile. If you make a better hurricane forecast and end up evacuating less coast, or the right part of the coast, you’ve saved a million.

> “Hurricane track forecasts have been steadily improving, so we’re much better at telling you where we think a hurricane will go than we were 20 years ago. But forecasts of intensity have not improved anywhere near as much. The general consensus on why is because of our inability to measure what’s going on in the middle of the storm. If you can’t track the wind through the rain, you can’t track the storm’s kinetic energy, and you can’t track its evolution. What we’re hoping, in the end, is that our ability to forecast a hurricane’s strength will be much better thanks to CYGNSS.”

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**Hurricanes, cyclones and typhoons:** These monster storms, which have locally different names, transform heat from the ocean into winds of up to 200 miles per hour. They form when a low-pressure atmospheric disturbance meets a warm ocean. Air rushing toward the low-pressure zone veers into a vortex due to the Earth's rotation. These winds pull water vapor into the sky, where it condenses into storm clouds and rain. Condensation releases heat, which the storm converts to winds that stoke the cycle.

**Eye:** The lowest-pressure zone, drawing winds in. Skies are often clear. On land it's calm. On water, waves more than 50 feet high crash together from all directions.

**Eyewall:** The zone with the fastest change in pressure, where the most intense rain and winds reside. Updrafts within it carry water vapor skyward. "Hot tower"cumulonimbus clouds can stretch nine miles high, poking into the stratosphere.

**Hurricane Hunter Aircraft:** Operated by NOAA, these data-gathering missions have been the only way scientists and weather forecasters can get critical information about a storm approaching land. They penetrate the eyewall repeatedly to measure the maximum surface winds.

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**THE SATELLITES**

**GPS satellites:** The nation's 24 navigational satellites regularly ping the ground with data about their locations encoded in microwave radio signals. The nodes fly at around 12,000 miles up—a significantly higher than CYGNSS's 310-mile low-Earth orbit.

**CYGNSS observatories:** Eight microsatellite observatories, each about the size of a swan with its wings extended, function like radio receivers. They pick up the stream of GPS satellite signals that continually bounce off the ocean.

**Delay Doppler Mapping instrument:** This is the key sensor on each CYGNSS microsatellite. Within it, the antenna points up, collecting signals directly from GPS satellites. Two antennas point down, picking up GPS signals reflected off the ocean surface. The mapping instrument compares the reflected signals with the direct signals and creates Delay Doppler Maps that show how the GPS signals scatter over time, and in relation to the motion of the satellites.

**Delay Doppler Maps:** When the moon reflects off still water, we see its crisp mirror image. But in a choppy lake, that image is distorted, revealing the water and wind conditions. Likewise, in CYGNSS Delay Doppler Maps, smoother, calmer conditions yield stronger, more focused signals. Rougher, windier conditions lead to more diffuse signals. The CYGNSS wind speed retrieval algorithm gives the exact relationship, generating 32 wind measurements per second across the globe.

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**THE STORMS**

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Cape Canaveral Airforce Station at 3 a.m. Checklists hundreds of items to around 40,000 feet, then drop the rocket and payload. After falling to the belly of an L1011 Stargazer aircraft. The aircraft would carry them houses the mission control rooms.

"If everything is under control, you’re doing it wrong," he shared. Ruf believed in the philosophy of embracing chaos and uncertainty, rather than trying to control every variable. "The value of uncertainty is that it forces us to think in new ways, to explore the unknown." He was always looking for opportunities to push the boundaries of what was possible, and he believed that the unpredictable was where the most exciting discoveries were made.

"It was like a whole new world opened up to me," Ruf said. He was amazed by the beauty of the cosmos and the vastness of the universe. "Each launch was like a new adventure, a new chapter in our story of exploration." He was proud of the team he had assembled and the work they were doing, and he was excited for what the future held.

The launch of CYGNSS was a pivotal moment for Ruf and his team. It was a testament to their ingenuity and perseverance, and it opened up new avenues of research and discovery. Ruf knew that this was only the beginning, and he was looking forward to what they would achieve next.

"We’re just scratching the surface of what we can do," Ruf said. "There’s so much more out there waiting for us. We just have to keep pushing and exploring until we find it."
ARE WE FIGHTING CANCER WRONG?

IT'S NOT USUALLY THE INITIAL TUMOR THAT KILLS. IT'S THE WAY IT SPREADS.

STORY BY: Kate McAlpine
ILLUSTRATION BY: Stephen Alvey
hemotherapy. Radiation. Surgery. Doctors go after the tumors that they can see. But the seeds that cause cancer to spread? Those are thought to be single cells or clusters of cells, traveling through the bloodstream. It’s hard to eradicate them with such blunt instruments.

Researchers call them metastatic cells, cancer stem cells or stem-like cancer cells. Not everyone is on board with what exactly these cells are. “The controversial points include: Are cancer stem cells a fixed cell population, or is ‘stemness’ a state that any tumor cell can go through?” said Max Wicha, the Madeline and Sidney Forbes Professor of Oncology at U-M and a pioneer in cancer stem cell research.

He is working closely with engineers to answer this and other questions about cancer stem cells. Together, oncologists and engineers at Michigan are seeking to target these cells, shutting down cancer’s deadliest weapon: its ability to colonize other parts of the body.

WHY CANCER IS SO DIFFICULT TO FIGHT

Chemotherapy is a form of our usual go-to for exterminating unwanted colonists: we poison them. Antibiotics destroy bacteria without bothering our own cells because bacteria are very different from human cells. But cancer cells are human cells.

Cancer cells divide more often than normal cells, so conventional chemotherapy drugs go after particular stages in cell division. Cancer cells are more likely to be caught in these states. Still, the collateral damage can be devastating.

To make matters worse, stem-like cancer cells evade even this weak targeting because they don’t divide as often as typical cancer cells. They also seem to be tougher against radiation, with an enhanced ability to repair damage to their DNA. Cancer stem cells’ resistance to treatment may help explain why cancer has a tendency to come back. The scans show that the tumor has shrunk, but the cells left behind may be the most likely to spread to other areas of the body, or metastasize.

And then there’s the immune system. Previously assumed to be a hapless bystander, now researchers believe that it is complicit in allowing cancer to spread (see Metastatic Decay on p. 54).

Even so, oncologists at Michigan convey a sense of optimism. They have unprecedented tools at their disposal. Collaboration with engineers enables researchers to isolate and study cancer stem cells as well as the conditions that make a cell metastatic.

New devices are proving themselves in the clinic to inform patient care. One device offers a better measure of success for the clinical trial of a new breast cancer treatment than the usual yardstick of medical imaging.

Many of these researchers have come together to build a model for how metastasis occurs in humans – from an initial breast cancer tumor, through a simulated bloodstream, to a bone-like environment. The more they know about cancer and how it spreads, the better they will be at stopping it.

PERIL AND PROMISE: CANCER STEM CELLS

Cancer stem cells were first reported in 1994, in the highly regarded journal Nature. John Dick at the University of Toronto is credited with identifying them in leukemia, or cancer of blood cells. While ordinary leukemia cells divided frequently and were susceptible to chemotherapy, these other cells grew slowly, and his group noted that it was necessary to attack these cells specifically to avoid a relapse.

“Nobody really paid any attention to it, but we did because it seemed to me very logical, suggesting that cancer wasn’t just a disease of mutations but a disease of stem cells,” said Wicha.

Wicha teamed up with Sean Morrison and Michael Clarke, two professors of internal medicine and developmental biology at U-M, to run an experiment implanting human breast cancer cells into mice. They found that some cells formed tumors and others didn’t. For the cells capable of forming new tumors, they identified protein markers on the surfaces of the cells.

“And as soon as we published our study in 2003, within the next year, other groups started looking at stem cells in other kinds of cancer and found that virtually all cancers have these stem cells,” said Wicha.

Evidence is mounting behind the stem cell theory, but researchers are still puzzling the question of whether stem cells are born or made. One of Wicha’s recent studies, published last June in the journal Lab on a Chip, showed that cancer cells rely in part on the cells around them for the signals that allow them to turn into new tumors.

Euisik Yoon, a professor of electrical engineering and computer science, and his group led the work. They develop chips for capturing and growing single cancer cells. While computer chips are covered with elements like...
THE GIZMO CLUB

Around about 2002, Mark Burns, now the Anthony C. Lembke Department Chair of Chemical Engineering, and Daniel Hayes, the Stuart B. Podos Professor of Breast Cancer Research, got talking about how they could bring medical professionals and engineers together to find technological solutions to clinical problems.

The concept they piloted sent engineers down to the med school to hear presentations by doctors about problems they faced when trying to treat patients. Often, the problem would resonate with some of the engineers and then they would discuss potential solutions with the clinicians outside of club.

"Bringing people together from different disciplines is so crucial in this day and age. Current problems are very complex, and it’s really hard for one person, no matter how intelligent they are, to understand all aspects of that problem," said Burns. "At Michigan, you’re surrounded by so many other experts that you have this tremendous confidence they are bringing the same high-level knowledge and information to the table."

Sometimes, these ideas turned into proposals, grants and results. Other times, they fizzled.

"If an idea came up, it was a tremendous effort to get a project going," said Burns.

The missing piece, as Burns saw it, was seed funding to start a project immediately while excitement was high. The early results could then legitimate a proposal for a larger project funded by an agency like the National Institutes of Health.

In a sense, the Gizmo Club was a precursor to two initiatives at U-M. One is the BioInterface Institute, headed by Gizmo alum Joerg Lahann. The institute, started in 2012, holds workshops that bring in clinicians to discuss problems on a certain theme – such as capturing rare cells from a medical sample – with an audience of engineers. Discussions of potential engineering solutions are built into the program, and seed funding is available for the most promising ideas.

Or, if medical doctors and engineers come together in some other way, they can still be funded through MCubed, an idea that Burns co-launched in 2012. If three faculty from at least two different schools or colleges around an idea, they can test it out in a matter of weeks rather than months or years. Faster results mean faster progress.

THE CONTROVERSIAL POINTS INCLUDE: ARE CANCER STEM CELLS A FIXED POPULATION, OR IS ‘STEMNESS’ A STATE THAT ANY TUMOR CELL CAN GO THROUGH?

The controversial points include: are cancer stem cells a fixed population, or is ‘stemness’ a state that any tumor cell can go through?

"They also boost cancer drug resistance." Stemness and drug resistance seem to give off signals that encourage the cancer cells to form tumors. Marginaly more likely to divide and form a tumor, but those with company or nothing at all.

Beyond the walls, it was possible for cells to get a foothold, allowing the cells outside can influence whether the cancer cell is in a stem-like state.

"Cancer-associated fibroblasts boost cancer stemness," said Yoon.

The cancer cells surrounded by other cancer cells were only forced to – just a slight depression to keep it in place – ensuring that only the cells with signaling pathways – for instance, chemicals secreted by a fibroblast and picked up by a cancer cell – that encouraged cancer cells to get moving or to land in a blood vessel. These signals eventually lead the cells to become more metastatic. They showed that a single signaling molecule made a difference in how aggressively the cancer cells behaved. And that particular variation was not well targeted by the current drugs.

"New possibilities for anti-cancer drugs that target communication between tumor and non-tumor cells came into view," said Takayama.

Engineers also develop ways to tell stem cells from the cancer cells. One of the first differences engineers see: the stem cells, or those that make the disease more aggressive. These might also serve as targets for new drugs yet to be developed.

To make microfluidic techniques widely available at U-M, Nagrath is designing chips that can capture and handle cancer cells in different ways, for different purposes. One of her recent projects with Nithya Ramnath, an associate professor of radiology and biomedical engineering who studies metastasis. Together, they began use to Takayama’s microfluidic chips to determine how cells leave tumors and land elsewhere.

"We proposed an idea – a really bold idea – that we take cancer cells from these patients through blood samples," said Nagrath.

"We culture the cells, and we treat these cultures with the same drugs that he’s administering to the patients in the clinic.

Capturing the cells gave Nagrath’s group the ability to find out which genes were active in the cancer cell, which tells Ramnath which drugs are likely to be effective. They saw the patient’s cancer develop a mutation that made it resistant to the first chemotherapy drug. Then, that mutation disappeared when they began targeting that mutation in the cancer.

This patient, a 42-year-old man, died after the cancer spread to his brain. Still, Nagrath said technology like the one she and her colleagues are developing will help.

A variety of drugs are available to attack lung cancer’s various forms, but pancreatic cancer is not as well understood. Working with Diane Simecka, Lauren J. Greenfeld Professor of Surgery, Nagrath is capturing cells from the blood of pancreatic cancer patients looking for the genetic markers that make the disease more aggressive. These might also serve as targets for new drugs yet to be developed.

To make microfluidic techniques widely available at U-M, Nagrath is

Above, the courtyard chip with a cancer cell isolated in the middle, surrounded by the bed of cells that exchange chemical signals through narrow channels (seen in the schematic at left). Because the cancer cell has nothing to hold onto, only stem-like cells survive in the courtyard. Signals from the cells outside can influence whether the cancer cell is to a stem-like state.

"So the dilemma is, should we develop a mutation resistance drug or develop a new drug with a different mechanism of action," said Nagrath.

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Yoon used his chips to test how genes affect cell mobility and their ability to grow into spheres that represent tumor precursors. This patient, a 42-year-old man, died after the cancer spread to his brain. Still, Nagrath said technology like the one she and her colleagues are developing will help.

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One hot topic in managing the immune system’s role in cancer is whether drugs used to fight cancer can be repurposed to target cancer. Nagrath is working with Wicha on a clinical trial of a new drug combination to treat breast cancer—specifically targeting cancer stem cells.

“If you treat tumors with conventional chemotherapy, most cells die, so the treatment is monitored by watching for tumor shrinkage,” said Nagrath. “Cancer stem cells therapy are targeting only a few cells, so tumor size is not an indicator of successful therapy.”

Anne Schott, a professor of medical oncology, and Monika Burness, a lecturer in hematology and oncology, are currently running a clinical trial based on Wicha’s research showing that the arthritis drug tocilizumab can help treat an aggressive form of breast cancer, known as HER2 positive because the cells have HER2 receptors on their surfaces. Two drugs attacking the HER2 receptor, killing most of the cancer stem cells, but Wicha’s work suggests that some stem cells are left behind. These have receptors for interleukin-6, an immune signaling molecule. Interleukin-6 stimulates an immune response that the sponges help to reduce.

To populate the initial tumors, Nagrath and Yoon will join forces with Wicha’s tissue engineering group. They are handling the emulated bloodstream. This end-to-end system captures cancer cells from patient blood samples as well as from mice. These can then be grown in human-scaled scaffolds. Tocilizumab binds to interleukin-6, preventing it from reaching the cells. Together with Yoon, he explored how to keep the interleukin-6 receptors on cancer cells. Then, when they’re in the bloodstream, blood cells called neutrophils can detect something’s wrong and mount a suicidal attack, spewing a web of DNA and proteins at the offending cell. The highs are armed to kill bacteria and yeast, but if left unchecked, they can damage healthy cells as well. However, evidence suggests that when cancer cells are exposed to these neutrophils, they become more likely to form metastases. They are better at surviving in the bloodstream and invading new tissues. When a cell arrives in the bone tissue, it is still in the stem-like state. One of Luker’s big questions is—can the cells be kept from dividing once they arrive?

In experiments with mice, Shea and his colleagues found that the sponges reduced the number of metastatic cancer cells that landed in the liver by 64 percent, those in the brain were 75 percent fewer than in mice without the sponges. It’s an early detection system—it delays metastases and informs therapy decisions.

One of the questions on Shea’s mind is whether or not the cells captured in the sponges are cancer stem cells. To find out, he’s working with Wicha, a U-M oncologist. “The hypothesis is maybe we’re catching the worst cells and that’s why our animals are doing better,” said Shea. “An alternative hypothesis is the cancer cells being captured are not necessarily stem cells, yet the environment at the metastatic site turns them into stem cells.”
Flying on hydrofoils means more speed and more risk for the America’s Cup. With the boats and technology moving faster than ever, can these Michigan alumni help their team find the engineering solutions it needs to win in 2017?
The technology and teams have become so competitive that a mere one percent advantage in speed is enough to win. Secretive experimentation and creative problem-solving are a moat in this battle. In the last America’s Cup, using hydrofoils was allowed for the first time, which sparked a race in foil development and control. The hydrofoils add underwater wings that lift the hulls out of the water, practically eliminating drag – and introducing unprecedented speeds. “The hydrofoils act as underwater wings that lift the hulls out of the water, practically eliminating drag – and introducing unprecedented speeds. It’s a high-stakes engineering challenge where millions of dollars and the future of the America’s Cup rest on the line.”

For testing, the crew used an AC45 – a slightly smaller and simplified version of the 50-footers they’ll race in the June 2017 America’s Cup. Its sleek carbon-fiber body looks more spacecraft than sailboat and is networked with advanced sensors – including the kind used by missiles and drones – to America’s Cup catamarans. “I’m using specific geometric algorithms, like neural networks and NURBS topologies, to make a database for the simulations that we run. Then, we tie all that back together and solve a group of equations that figure out how fast the boat will go.”

Ricardo Bencatel (Former U-M Aerospace Postdoc) Control Dynamics Analyst and Control Systems Developer

After completing 50 percent of his PhD under U-M Aerospace professor Anouck Girard, he remained at Michigan for his postdoctoral research. At that time, he was brought on to apply his expertise with automated control systems – the kind commonly used on drones – to America’s Cup catamarans. First America’s Cup with this team

**AMERICA’S CUP (AC45) CATAMARAN:**
- **Close: 5 people 80 mph/128 kph (100 percent)**

**WE HAVE LIFTOFF**
Pedaling the Civil War and modern Olympics, the yachts that race for sailing’s most prestigious trophy, the America’s Cup, have evolved over 165 years. For decades, trains remained familiar to the average sailor: narrow decks, fabric sails and hulls that splashed through the sea at predictable speeds. Then in 2011, a radical mutation in that evolutionary chain occurred. As teams prepared for the last America’s Cup, New Zealand did something unprecedented by equipping its 72-foot catamaran with hydrofoils. “Once that was discovered, we followed suit quickly and managed to engineer our boat to foil well and still be legal,” says Ferguson. “We won the 2013 cup handily.”

The successful application of foils to the 72-footers provoked a collective reevaluation as to what was possible. The sport launched into a rapid technological arms race. International teams of engineers began working in isolated unions to solve new problems. Their calculations and designs have led to new ways of moving massive objects across the water at higher speeds, and with the humans on board unharmed.

Hydrofoils have been used on engine-powered ferryboats for decades. Steady thrust from an engine and heavy V-shaped foils makes this type of flying much more predictable and easy to control. In 2009, an experimental hydrofoiling sailboat, Hydroptère, set a

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Scott Ferguson (BSE NAME ’85) Design Coordinator and Manager of Wing (sail) Design

“I manage the entire group of designers. I remain having a focus in the wing because that’s my specialty in the past.”

First America’s Cup with ORACLE TEAM USA

Bryan Baker (BSE NAME ’03) Design Team - Performance Prediction

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**DAGGERBOARDS**
**RUDDERS**
**HYDROFOILS**

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**THE MICHIGAN ENGINEER 50**

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fast foils, but when you go out and race them, they're really hard to waterline. This balancing act is in constant flux as helmsmen jockey keep the craft soaring at an optimal height – only a few feet above the pop out of the water or go sideways really quickly,” says Baker. Start to go sideways, and if you fly too high too quickly, you can literally with the extreme side forces against the sail. “If you fly too high, you relatively lightweight catamarans requires different solutions to contend variable. Boats played by the rules of hydrostatics and buoyancy. Flying new avenue of dynamics. In traditional sailing, height was never a thin hydrofoils can resist more pressure than those exerted on the wings they’re controlled, are the team’s most highly safeguarded secrets. The helmsman and crew are in control of the whole thing.” These constraints have forced teams to innovate and experiment with new foil shapes and materials. The resulting components, and how they’re controlled, are the team’s most highly safeguarded secrets. The thin hydrofoils can resist more pressure than those exerted on the wings of a fighter jet. Micro-adjustments in design and control impact lateral, vertical and heave stability – all of which add up to controlled flight, not nose-diving or launching. From an engineering and design perspective, it’s opened up a whole new avenue of dynamics. In traditional sailing, height was never a variable. Boats played by the rules of hydrostatics and buoyancy. Flying relatively lightweight catamarans requires different solutions to contend with the extreme side forces against the sail. “If you fly too high, you start to go sideways, and if you fly too high too quickly, you can literally pop out of the water or go sideways really quickly,” says Baker. Stable, controlled flight on the water is not easy. Crews fight to keep the craft soaring at an optimal height – only a few feet above the waterline. This balancing act is in constant flux as helmsmen jockey for position amid unpredictable waves and wind. It’s a fine line between speed and stability. “On paper, you can design some really fast foils, but when you go out and race them, they’re really hard to control,” warns Baker.

**SPASHDOWN**

With only one second warning, a two-meter thick wall of water washes over the bow at nearly 50 mph. "It’s like concerts," says Tom Slingsby, ORACLE TEAM USA’s tactician and sailing team manager. "When you have a big splashdown, we often call them a ‘stuff’. If you’re when you get something a little wrong. It happens all the time in testing when you’re pushing right to the limit. We had a big stuff two days ago as we were going through a maneuver and we washed out the rudders that steer the boat.” It’s a consequence that has come with the speed of flying on foils. “We have a phenomena that happens in the water which is called cavitation, and we have ventilation occur,” explains Baker. It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities where the pressure is relatively low. From the sailor’s perspective, a visual cue is when a sheet of air bubbles envelops the submerged foils. “When that happens, it’s no longer creating flow through the water and loses all its lift characteristics. The boat comes down fast.” Probably the scariest and most dangerous scenarios is when this happens on the daggerfoil and the wind keeps pushing the wing forward – causing the boat to go bow down,” explains Baker. It’s like the wings being chopped off an airplane.

Sailors wear helmets and protective padding. They’re also now equipped with portable air canisters, since the death of Artemis Racing—causing the boat to go bow down,” explains Baker. It’s like the wings being chopped off an airplane.

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A DIFFERENT KIND OF DRONE

The pursuit of control has led to unprecedented experiments not only with the physical design but also advanced modeling software and control systems. One such experiment involved automated systems commonly found in drone technology. In early 2016, through a series of serendipitous connections and recommendations, automated flight expert Ricardo Bencatel was recruited to do something that had never really been done before. At the time, Bencatel was finishing his postdoctoral research at U-M’s Aerospace Engineering Department and had been collaborating on an experimental project with the Italian team, LuSa Rossa. However, when the Italians withdrew from the 2017 Cup in response to rule changes, Ricardo and his advisors at Michigan were approached by ORACLE TEAM USA.

Although automated controls are strictly forbidden in actual races, they can be used in interesting ways for experimentation and training purposes. The goal was to see if an automated system could fly the boat better than a manned crew. If so, what could the crew learn from the computer to better prepare for the America’s Cup?

“In the last cup, foiling was new. Just doing it was a big advantage,” says Bencatel. “In this cup, it’s about refining a way of handling something that’s already known. We’re trying to get some disruptive ideas and give us the advantage.”

The catamarans are covered in sensors that measure a variety of data, like the pitch, flight height and accelerations. That was all fed into Bencatel’s computer model to optimize this flight by leveling it off to keep it going steady — basically like an autopilot for an airplane, but in a completely different application. In sailing, the wind forces that provide thrust can also tip the boat over. There is a constant balance between what is known as the righting moment and the heeling moment. The side forces against the sail produce the heeling moment. In traditional sailboats, weighted hulls helped counteract these forces and keep the boat upright. With flying catamarans, the heeling moment is counteracted by the rudder and the hydrofoil on the leeward side (the side the wind is pushing to) and the rudder on the windward side (the same side the wind is pushing against). The rudder on the windward side actually creates inverted lift forces — pulling the hull back down into the water and keeping the platform level.

By nature, the AC45 operates under conditions that make it prone to rolling and tacking. An automated control system would have to sense and respond to these forces. The two main components of such a system were already on the boat. The sensors were already there to capture performance analytics. A joystick in the helmsman’s hand controlled the actuators. Bencatel’s mission was to connect the two. Doing so required a tedious programming loop.

He spent most of his time writing code for the controller and its analysis tools. “You go to the water and do tests and tuning,” says Bencatel. “Then you come off the water and you do analysis. And because this is an evolving problem and system, your analytical tools from the previous day are not enough for the new things you want to analyze. So you need to code the analysis tools. If everything goes well, you can identify the issue or bug in the controller code, go back, and correct it. Then you run simulations. And then back to the water.”

“We stuck with reasonably traditional controls in part because of the risk,” says Anouch Girard, Associate Professor of Aerospace Engineering at the University of Michigan and Bencatel’s advisor at the time. “We can try a lot riskier things on a quadrotor in my lab than on a boat that has six humans on board and costs $50 million. We haven’t yet pushed the boundaries of what we know how to do.”

“It’s very similar to aerospace — dealing with air flow, the technology,” says Bencatel. “In practice, the system will do unexpected things. Is that good or bad? Sometimes it’s a better way of controlling the machine than what humans might assume to do.”

One of the most exciting possibilities of the automation work was the possibility to figure out how to foil through turns and other maneuvers.

“I’m frankly amazed with what he’s able to do,” says Ferguson. “It’s not quite like taking your hands off the wheel of a car, but almost.” After months of experimentation, the autopilot was still not able to outperform the sailors, and the team was forced to move on due to time constraints. “We learn from things and modify our path,” says Ferguson. “The positive influence he’s had doesn’t change. There are great takeaways from every experiment.”

Bencatel stayed on with the team as a control systems analyst. “He’s been collaborating on an experimental project with the Italian team, LuSa Rossa. However, when the Italians withdrew from the 2017 Cup in response to rule changes, Ricardo and his advisors at Michigan were approached by ORACLE TEAM USA.”

Unfortunately, there isn’t more time. Design deadlines are only weeks away for the machine ORACLE TEAM USA will fly in June 2017 to defend the America’s Cup. “You begin to realize these are final decisions,” says Ferguson. “As the initial stages, you say ‘Let’s try this and if it doesn’t work we can try something else.’ Now when it comes to decision-making it gets a little bit tense at times.

This tension reflects the passion that drives the team. In this final phase leading up to the championship race, late nights blend into early morning, and the stakes of each day’s progress grow heavier. “Each day’s progress grow heavier. “Everybody here wants to succeed at this and win the America’s Cup,” says Baker. “Everybody’s working as hard as they possibly can to achieve that goal.”

In the months leading up to the 35th America’s Cup, five international teams will have competed for the chance to take on the defending champions. The championship race will take place in late June in Bermuda.
Lessons from Tony Fadell
A tech visionary who has reinvented industries tells us how it's done.

Story by:
Nicole Casal Moore

Photos by:
Marcin Szczepanski
Sometimes you have to trust your gut and go with it even when everything rational says no.


the early 1990s, at Apple spun off called General Magic, a band of prodigies set out to make “small, intimate life support systems.” They meant “life” in the day-to-day sense, rather than the opposite of death sense. This life support wasn’t intended to keep people breathing. But to the engineers at General Magic, who were thinking on societal scales, the idea seemed almost as profound.

“We have a dream of empowering the lives of many millions of people by means of small, intimate life support systems that carry people with them everywhere,” read the company’s mission statement. “These systems will help people to organize their lives, to communicate with other people, and to access information of all kinds.”

“They will change the way people live and communicate.”

This was about a decade after the launch of IBM’s first PC and eight years after Apple introduced the Macintosh. Personal computers had established themselves in American homes and offices. But robust handheld devices and smartphones were somewhere between a prototype and a glimmer in an engineer’s eye. And smartphones were somewhere between of IBM’s first PC and eight years after Apple’s leadership noticed this void.

Apple had less than 1 percent market share when the company brought its users the desktop metaphor and graphical interface we now take for granted.

“I knocked on their door until they hired me later that year,” Fadell wrote in the New York Times in 2013. “General Magic was a blazing startup. It was backed by some of the time’s largest electronics firms: Sony, Motorola, Philips and AT&T.

Analysts predicted that its programming language and operating system could become the standards of the burgeoning PDA industry. “I was working with the team that created the Mac – that had changed the world,” Fadell said. “We were all dead set on changing the world again. And everyone told us we could, so we just poured everything into it.”

The team worked 18-hour days. Some built tented bunk beds over their desks. Despite the pet rabbits that hopped around headquarters to spark creativity, it took them years longer than they expected to ship their first products.

But 1994 brought the release of the Sony MagicLink and the Motorola Envoy, both of which were based on a custom network by AT&T The much-anticipated devices flopped. But 1994 brought the release of the Sony MagicLink and the Motorola Envoy, both of which were based on a custom network by AT&T.

In 1991, Tony Fadell finished his computer science engineering degree at Michigan. With three startups already under his belt, the 22-year-old headed west to find work with his heroes – the “magnets” of Mountain View. Among them were the creators of Apple’s first computer to give it the desktop metaphor and graphical interface we now take for granted.

“Everything you thought you believed didn’t come true,” he said. “You have to process that and learn from it.”

In time, he and the team did. Many members went on to be highly influential in the tech sector. Forbes later dubbed General Magic “the most important dead company in Silicon Valley.” And when Fadell found himself leading Apple’s effort to build a smartphone in 2004, not only did he have a head start, he knew how to fill out the roster.

“At General Magic, we were making the predecessor to the iPhone 15 years too early,” Fadell said. “Sometimes you’ve got to go through a spectacular failure and turn it into a learning experience to be the phoenix from the ashes.”

Fadell is the iPod inventor, iPhone creator, and founder of Nest, the company that designed an iconic smart thermostat that’s at the center of the Internet of Things smart home revolution. When he came back to campus last fall, he opened up about what it takes to change the trajectory of an industry. Fadell spent time with the next generation of tech upstarts in the Center for Entrepreneurship and a software design course taught by one of his former instructors and business partners, Professor Elliot Soloway. Fadell was encouraging and candid as he divulged some of the lessons he’s learned in his 25-year career. “We’ll focus on five.

0.1/UNDERSTAND THAT YOU WILL FAIL

Twenty undergrads sat around a conference table smiling in swiveling chairs. They were part of an elite program in Michigan Engineering’s Center for Entrepreneurship called the Entrepreneurial Leaders Program. They all plan to start companies when they graduate, and they had prepared for this 10 a.m. meeting with a man who once stood in their shoes and went on to shake up Silicon Valley. Their heads were full of good questions.

“Sorry,” Fadell said before he called on anyone, “but you’re all going to fail.” He gave them an earnest smile.

“We didn’t learn to speak and walk without first failing. But you’ve got to just keep going. You’re either growing or you’re dying.”

As he described in his tale of General Magic, failure is often at the heart of eventual success. It’s an idea that might seem cliché, but Fadell breaks it open with a existential twinge.

“People give up because they don’t believe in their ability to adapt and change and take what they’ve learned and bet on themselves again. But you have to understand that that’s how the world works. Either you’re evolving or the system is evolving around you and you’re stagnant. That’s the difference between growth and death.”

Failures may look like low points in a career, he said. One of the most important character traits of a successful entrepreneur, though, is resilience – the ability to turn one into a springboard.

0.2/GET COMFORTABLE BEING UNCOMFORTABLE

Apple had less than 1 percent market share when the company brought Fadell in to make a portable music player in 2001. The firm still had “computer” in its name. It was not in the business of making portable music players.

Fruit-colored iPods had pulled the company back from the brink of insolvency, but it was still more than $500 million in debt. Its newest strategy, as Walter Isaacson detailed in his Steve Jobs biography, was to think of the personal computer as the digital hub of the home – a place to store and edit photos and videos, and to make the most of this information superhighway called the Internet. The new iTunes application let users rip music and make mixes. But if you wanted to play the mixes from anything other than a burned CD or the computer itself, the mp3 players of the time left much to be desired. They could hold roughly one album and their tiny buttons were a pain to use with adult-sized fingers.

Apple’s leadership noticed this void.

Fadell had come to the conclusion on his own. A defeat in his off hours, he hated lagging around hundreds of CeD. “I started thinking there’s got to be a better way,” he said.

By this time he’d been working on handhelds for more than a decade. Since his days at General Magic, he had developed critically acclaimed palmtops for Philips Electronics called the Nino and the Veio – arguably two more iPho predecessors that matured before their time. More recently, he had launched his own startup, Fuse Systems, to improve upon the status quo in mp3 players. He was excited to be going out on his own, following his heart. But while he was able to secure initial investments, soon the money dried up. This was just after the dot-com bubble burst.

Then he got a call from Apple. Would he work with the company as a consultant to develop a music player to support iTunes? Fadell thought, “Why not?” It might buy him time and help pay some bills. That’s not how the story ends.

Fadell’s Fuse would eventually become the iPod – the technology that set Apple on a course to become Fortune 500’s top tech company in 2016, with $233 billion in revenue. But turning the crazy idea into a successful product took years of dealing with naysayers, sticking his neck out and even standing up to Steve Jobs.

He told the music player’s origin story to a small class of computer science students in Professor Elliot Soloway’s software design course.
It was a course Fadell himself had taken from Soloway more than 25 years previously, and one that taught him a lot about life in addition to engineering, he said. He and his professor went on to launch a company, working just down the hall from the spot Fadell stood that afternoon.

Though the students were mostly too young to have owned an iPod, the iPhone has been ubiquitous since they were in middle school. They listened intently.

After two months working as a consultant, Apple required Fadell to become a full-time employee if he wanted to stay on the project. He agreed to, and set out to build a team. In an inconvenient twist, the project had to stay secret to potential new employees until they were hired.

“I had to ask them to come to a company that was failing and just trust me. I couldn’t tell them what they’d be building. And then I had to trust that Steve would have the money to finish and properly market the product,” Fadell said.

He managed to pull together a team of 25 – many from his previous endeavors. They worked feverishly. “I knew if we didn’t ship as fast as possible, our product would be killed. There were a lot of factors working against us.”

They shipped on schedule just ahead of the 2001 holiday season. “We got an initial sales spike in the first quarter, but then no sales increases for two years because it didn’t work with the PC.”

Fadell knew he needed to confront Jobs about that. He had tried early on, but Jobs’ response was something like, “Over my dead body.”

The Apple founder had envisioned that the iPod could drive Mac sales. “This is the way you’re going to sell more Macs?” Fadell remembers asking. “To use it you have to buy a $2,300 machine? You think that’s what’s going to convert people?”

Jobs didn’t budge. “So I built a Skunkworks team,” Fadell said. He disregarded his boss and pushed ahead moving the iPod to PC, in secret.

“We didn’t know if Apple was going to live or die,” Fadell said. “Sometimes you have to trust your gut and go with it even when everything rational says no.”

He and his colleagues eventually convinced Jobs to reconsider. (They had to involve then-Wall Street Journal tech columnist Walt Mossberg.) Soon after the iPod was available for the PC, it was bringing in half of the company’s revenue. “Then Mac sales started rising.”

“Put yourself where you’re uncomfortable,” Fadell told the class. “If you are not uncomfortable every day you’re either not trying hard enough or you’re not listening and learning. Always have those butterflies in your stomach.”

As protection against one particular type of discomfort, innovators need thick skins, clarified Soloway, an Arthur F. Thurnau Professor of computer science and engineering.

“You have to be able to do things that people aren’t necessarily going to like,” Soloway said. “Yes, I like people to like me, so it’s hard for me to do that. But when you’re creating something absolutely new, you have to be prepared for that.”

You have to ask the hard questions, Fadell said. Understand that to be a leader, you’ll have to take some steps alone. And you might upset people along the way, including people who outrank you.

“Most successful entrepreneurs are unmanageable,” Fadell said. “They’re always cutting against the grain and stirring the pot. They have a good story for what they’re trying to change. Some might consider them disagreeable, but how they see it is the status quo isn’t good enough.”

03./PEOPLE MATTER A LOT.

For all Fadell’s talk of entrepreneurs being difficult, his friends describe him as kind and loyal, with palpable enthusiasm and sincere and wide-ranging curiosity. (He once watched a brain surgeon perform an 8-hour operation, standing so close he got blood on his shoes, he told the London Telegraph in 2013).

He has 8,000 people on his contacts list. And he can attest to the importance of a deep and broad network that can carry you through the low points and help you to the high ones.

We go through these habitual routines that we don’t even realize we’re doing. Break that down and ask why, why, why.
He mentioned this idea to every group of students he spoke with during his campaign visit. He told students to connect with their peers starting right then and there, because ‘they’re going to need each other.’

“The best thing you can do is get to know people who are and get to know them. You have to spend 50 percent of your career networking,” he said.

The bonds that matter are the ones that form in the worst of times.

“When things aren’t going so well, you see the character of a person and how much they’re dedicated to the mission,” Fadell said. “You want to work with them for the rest of your life.”

An example: Brian Sander was an engineer at General Magic in the 1990s. He was involved in hiring Fadell, whom he remembers as “one of the most dynamic kids just out of college” that he’d ever met. Fadell returned the favor a decade later when he recruited Sander to “one of the most dynamic kids just out of college” that he’d ever met.

Sander said, “He is very much a vision person. He understands how to synthesize vision toward and how much they’re dedicated to the mission,” Fadell said. “You want

“in the end it was clear that we needed to build a phone, and we needed to build a touchscreen company on top of it,” Fadell told VentureBeat. “That’s exactly what we did. We created a touchscreen company to build the multi-touch display. Then we needed a better operating system, so we brought a bunch of pieces of the Mac, a bunch of pieces of the iPod, and bolted them together.”

This was the second generation of Fadell’s.

“It was like Frankenstein,” Fadell said. “Not everything hung together. It had the basics, but it didn’t have the magic.”

The third try charmed.

It had taken the team almost three years to ship. That’s a long time to work on one project, Fadell says. Stretching like that can take trust and patience. Members of the iPhone group had succeeded together before, though, and that mattered.

“The team had been to hell and back many times. We had learned to deeply trust and push each other through harrowing and galvanizing, tough projects.”

04 / TUNE IN TO PROBLEMS.

In some ways, the iPhone and the iPod solved problems consumers didn’t know they had. With the advent of digital music, ripping CDs or stealing songs from Napster seemed so much like a fine way to pass your time. But then iTunes came into play with its ripped

mp3s. But then it came times > iPod. Music lovers no longer had to fumble with discs or worry about being said. A clunky process became easy, eventually instantaneous.

In the case of smartphones, those that came before the iPhone had small screens and smaller keyboards. It wasn’t fashionable to complain about their shortcomings, though. After all, they were computers that fit in your pocket. The iPhone and its clones made the experience of using such a small machine more pleasant and therefore more useful. It’s about always asking: Why can’t it be better? And not just living with the status quo.

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“Why do I have to unlock the door? How can this system be improved? Tune it into.”

And as you tune in, let your curiosity carry you.

Fadell left Apple in 2010 to spend more time with his family. After traveling for several months, they came back to Silicon Valley and set to work making their new home more intelligent. Energy efficiency was important to Fadell, so he went looking for a smart thermostat. That’s when he found his next venture. Later that year, Fadell founded Nest Labs – a home automation company whose first product would be a thermostat.

“I realized there was a problem there that no one else was focusing on,” he said.

Lots of programmable thermostats existed, but they required — programming, and then reprogramming as the seasons changed or your energy goals changed, or your lifestyle changed.

Fadell’s wishe was clear. Who would buy a $250 thermostat? He felt those uncomfortable butterflies that tell him he’s onto something. The thermostat would be his entry into the connected home future that could automate and improve our living spaces. He trusted his gut, and he braced for the future.

“Where is the most fun at the amusement park?” he quipped. “On the scariest ride, cause if it ain’t scary it’s not fun.”

He and his team had to teach themselves. That can be common in a new domain, he cautioned.

“It’s literally through experience,” Fadell said. “We go through these habitual routines that we don’t even realize we’re doing. Break that down and ask why, why, why. Why do I have to use this door handle? Why do I have to unlock the door? How can this system be improved? Tune it into.”

After months of development, the company released its spartan disk that could automate and improve our living spaces. But the first thermostat wasn’t cutting it. Too many people in the world have smartphones. That growth has spawned new industries and new ways of communicating. On the industry side, there’s the app store and everything in it. Go a step further and think about the industries within the apps, like Uber.

On the communications side, this is about more than making it easier to educate someone up the airport. Smartphones and the citizens journalism they enable have been found to be key in disseminating information about rapidly unfolding events. That’s the role they played in the Middle Eastern uprisings that became known as the Arab Spring, according to a 2012 U.S. Institute for Peace report. Protesters used their smartphones to tweet updates to the world. All this energy has led to increased international pressure and helped to solidify regime change.

Now Nest is on the cutting edge of the burgeoning Internet of Things, a network that will connect the physical world with the virtual to continue down the path of logistical life support.

These successes are built on more than great, problem-solving products made by resilient, loyal teams. A Michigan Engineering student asked Fadell whether he preferred building things or marketing them.

“‘They’re fundamentally the same,’” Fadell answered. “If you don’t know how you’re going to market what you’re building, then you don’t know what you’re building because you don’t know what it’s for.”

“Most people create the press release right before they ship it. One thing I learned from Steve was you make it at the start of the project. And the execution has to know the product upside-down. You live it. You breathe it. You see people’s eyes light up while you’re building it. You know it in resources.”

Once the product hits the market, and even beyond, you need to have patience. The iPod took two years to catch on. Now it’s essentially default, commodified by the iPhone. The iPhone’s arc is still rising.

Fadell knows his work has made a difference in the world, but he also says he’s not done.

“It’s success when you’ve created a culture that lives past you,” he said. “A legacy.”
A PLACE WHERE POURING REIGNS

“When molten metal is being poured, some people back away,” explains Chip Keough, U-M alumnus and founder of Joyce Works. “Others lean forward. I look for the ones who lean forward.”

Needless to say, Keough (BSE ME ’77, BSE Mat’ 77) himself is in the latter category. The victim of a childhood accident that left him with a limp, Keough said he feels more comfortable near the molten metal than he ever has away from it. “When molten metal is being poured, some people back away,” he said. “Others lean forward. I look for the ones who lean forward.”

For alumni John Tishman, the family business has a long history. Tishman Construction dates back to 1908 when his grandfather, Julius Tishman, purchased the tenement building where he lived. Under John L. Tishman’s management, the company erected the world’s first three buildings of 100 or more stories – the John Hancock Center in Chicago and the World Trade Center’s twin towers – as well as other national icons such as Madison Square Gardens and Disney’s Epcot Center.

Committed to arming the next generation of construction managers with the cross-disciplinary expertise that they need to make complex projects a reality, Tishman endowed the U-M Construction Industry Alliance Program. In honor of John L. Tishman’s legacy, Dan and Sheryl Tishman have provided a gift that will expand the scope and impact of the construction management program. Their gift will create a new professorship focused on construction management and sustainability. It will also provide scholarships for students and discretionary support for the construction management program.

“John was so enthusiastic about his founding and involvement in the construction management program,” said Kim Hayes, the Arthur J. Decker Collegiate Professor and Donald Malone Department Chair of civil and environmental engineering. “The impact of the gift on the University of Florida’s construction management program will be felt for many years to come.”

CHIPS FOR ENGINEERING FEELING THE IMPACT

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Materials science was a major opportunity for U-M alumnus Walden (Wally) Rhines and his family. Now, he hopes to extend the same benefit to some of today’s students by endowing the Frederick N. Rhines Fellowship Fund. Every year, one graduate student in the Materials Science and Engineering Department will receive funding from the new fellowship.

Rhines (BSE Met E ’68) will remember the university in part because of his father, Frederick Rhines, then a renowned materials science professor at Carnegie Institute of Technology (now Carnegie Mellon University), moved the family from Pittsburgh to the then-stylish town of Gainesville, Florida. He aimed to start a materials science program at the University of Florida.

“It was a big risk,” Wally explains. “Carnegie was the metals capital of the world at that time and my father had an endowed professorship. And it wasn’t all obvious what the University of Florida would become.”

But Frederick Rhines (BSE Mat’ 49) had gone into orbit just two years earlier, launching the Space Race and laying the groundwork for Florida to become a hub of space research. Frederick’s newly founded materials science department was there to provide the materials that helped make it happen. And today, that department, a hub of Florida materials science department is the largest in the nation. Wally Rhines parlayed his materials science degree into a career in computer science. His research formed the foundation for the technology you see today. Besides creating possible and he also helped develop the Speech & Spell, the groundbreaking educational tool that pushed electronic speech technology into the mainstream.

Rhines says his materials science degree was key to launching his career; it propelled him to head of Texas Instruments’ semiconductor business in the 1990s. In fact, all three of the largest semiconductor companies at that time were led by materials science PhD engineers.

“In the early days of semiconductors, many of the key problems involved around things like how to produce high-quality silicon,” he said. “My father used to tell me that if you’re not sure what’s going to be excelling over the next 50 years, materials science is a good bet because it’s foundational to all areas of engineering.”

That philosophy proved valuable to Wally, who told the CEO of Mentor Graphics, a company that provides software and other digital technology to automotive suppliers and others.

Now, Wally and his wife, Paula Rhines, are working to help students explore materials science by endowing the Frederick N. Rhines Fellowship Fund in the name of Wally’s father. Wally hopes it will open doors for other students in the same way U-M opened doors for him.

“Michigan was a big university before big universities were common, and it just had a wealth of great faculty. And they had a very diverse campus, which was also a plus. I’m pleased that we can express our gratitude by funding some of the education of future materials engineers.”

The Rhines’ gift benefited from the Bicentennial Opportunity Matching Initiative, in which the University matches 50 percent of donor-endowed gifts for student support over $50,000 as part of U-M’s bicentennial celebrations.
Before Kevin Fu decided to come to Michigan Engineering, the rising star in medical device security already had a distinct impression of how collaboration happens here. “Michigan has an excellent reputation in engineering, but my earliest interactions were with the U-M Medical School,” the associate professor of computer science engineering said. “I was pleasantly surprised when they reached out to me. Michigan was really breaking through silos.”

On that first project, Fu worked with Thomas Crawford, a physician at the Medical School, on a program to sterilize and reuse pacemakers in developing countries. The collaboration demonstrated two strengths of the University of Michigan: the high-level collaboration demonstrated two strengths of the University of Michigan: the high-level experts’ interest in working together. Instead of starting with a specific approach, Fu says, U-M researchers often start with a problem they are passionate about, and then work together to find a novel solution.

“It’s all about the people,” he said. For U-M, Fu is the right kind of person. The activity he drives both within and outside the university underscores why it’s vital to attract and retain the best faculty and students. The internationally recognized expert in medical device security examines how devices such as pacemakers and insulin pumps could be affected by hackers or malware. As more and more devices become vulnerable, Fu’s expertise is increasingly in demand by the media as well as Congress. He is co-founder of a healthcare cybersecurity startup in Ann Arbor, in addition to directing two entities at Michigan Engineering: The Archimedes Arbor, in addition to directing two entities at Michigan Engineering: The Archimedes Center for Medical Device Security, which provides resources to industry experts for implementing cybersecurity; and the Security and Privacy Research Group at U-M, which involves a diverse team of researchers working broadly on trustworthy computing.

Bringing in the best and brightest is central to the vision of Alex D. Gallimore, the Robert J. Vlasic Dean of Engineering. Under Gallimore, Michigan Engineering will pursue preeminence by inverting in people who will blaze trails and forge new partnerships, giving them the resources and latitude that they need to succeed.

“We focus on collaborative processes because, for the kind of complex and wicked problems we want to address, it depends on a group of socially conscious and intellectually engaged people coming together,” said Gallimore, who is also the Richard F. and Eleanor A. Thowner Professor of Engineering and an Arthur F. Thurnau Professor of aerospace engineering. “But it’s not enough to get the right people in the room. Different terminologies, ways of thinking and ways of working must be reconciled. Planning and communication are required to explore the problem, devise approaches, test solutions and prepare those solutions for implementation. Michigan is developing and iterating on frameworks that facilitate talented groups as they take on grand challenges.

One aspect leads to another. If you just get them in a room, you can fall short of the potential they can have.”

Michigan Engineering cultivates its strength in collaboration because this is the only way to address the complex problems that face the world: systems-level problems that no single expert can understand completely. Solutions can only be found when people come together.

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DRESS TO ASSESS

Pictured here with their surveying equipment is the entire Michigan Engineering graduating class of 1871. Devolson Wood was the only full-time engineering professor at that time, and surveying classes were held in the old University Hall’s former dorm rooms, which were heated by wood-burning stoves. Prof. Wood had lobbied the University Regents to no avail to create a separate department to accommodate growing demand for engineering. When he resigned in 1872 he was succeeded by the teaching trio of Ezra Greene, James Davis and Charles Denison. In 1874 Professor Davis established the nation’s first surveying fieldwork camp at Whitmore Lake, Michigan. By 1895 – when more than 50 engineering students graduated – a separate Engineering Department was finally and officially established.
Michigan Engineering professor Joseph B. Davis founded the camp in 1874 near Whitmore Lake, Mich., as a field camp where civil engineering faculty and students could teach and learn surveying. In the 1880s, what would eventually become Camp Davis was a roaming supply of tents and equipment that traveled in the back of a horse-drawn wagon to lakes and lands throughout southern Michigan including Simpson Lake (1887), Clear Lake (1897) and others. Professor Davis managed the camp for nearly 40 years – until 1912, when Professor Clarence T. Johnson replaced Davis as camp director. Four years later, U-M officially recognized the camp's founder, naming it "Davis Engineering Camp." Since then, it has been affectionately known as Camp Davis.

Camp Director Johnson would soon seek solace from Michigan's weather and bugs, touring the country for grander climes until he became enthralled by the beauty of an abandoned homestead ranch in western Wyoming, in the Hoback Valley where the Snake and Hoback rivers meet. Situated within the Bridger Teton National Forest, this little ranch was naturally shielded from excessive winds. It was a heavenly place – a singular spot where one could not only see Cream Puff Peak from the cabins but also smell the unforgettable scent of sage from the forest.

In August 1928, Johnson, who was from Wyoming (and formerly the state's engineer), met with Wyoming governor Frank C. Emerson, state engineer John A. Whiting (both Michigan Engineering graduates) and three other Michigan Engineering professors. They all decided that this spread of 120 breathtaking acres, just 30 miles south of Jackson, Wyo., was it.

A SEARCH FOR SOLACE

Michigan Engineering professor Joseph B. Davis founded the camp in 1874 near Whitmore Lake, Mich., as a field camp where civil engineering faculty and students could teach and learn surveying. In the 1880s, what would eventually become Camp Davis was a roaming supply of tents and equipment that traveled in the back of a horse-drawn wagon to lakes and lands throughout southern Michigan including Simpson Lake (1887), Clear Lake (1897) and others. Professor Davis managed the camp for nearly 40 years – until 1912, when Professor Clarence T. Johnson replaced Davis as camp director. Four years later, U-M officially recognized the camp's founder, naming it "Davis Engineering Camp." Since then, it has been affectionately known as Camp Davis.

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MORE THAN A MUSTACHE

Mortimer Elwyn Cooley – sometimes referred to as “The Grand Old Man of the College of Engineering” – was Michigan Engineering’s second dean and by far its longest-tenured. A beloved teacher and mentor, Cooley had a profound impact on Michigan Engineering for more than 40 years. He was as instrumental to its early growth and prominence as anyone.

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THE WORLD GETS PHOTOSHOPPED

Like mullens and cassette tapes, most computer software from the 1980s is long-gone today. But back in 1988, a young Michigan Engineering PhD student quietly created a program that endures to this day. It would turn countless industries on their heads: marketing, advertising, publishing and, of course, photography. It would completely change how we see the world. It also would create a brand-new word: Photoshop.

The PhD student was Thomas Knoll (BS EP ’82, MSE CICE ’84), son of Nuclear Engineering department former chair and alumna Glenn Knoll. Thomas wanted to make factory robots work better; he was writing computer algorithms to enable robots to recognize the edges of an object so they could more readily grab them.

One algorithm, called the Sobel Edge Technique, was the genesis of Photoshop, and it is still in the software today—in the “Find Edge” filter. But it wasn’t until Thomas’ brother John got involved that Photoshop began to take shape.

Working in California at special effects giant Industrial Light & Magic, John was frustrated with the difficulty of displaying graphics on his new Macintosh computer. So he asked Thomas to write a few basic image display tools. Back in Ann Arbor, Thomas was slogging through a single application. He did, and called it “Display.” It was then that the difficulty of displaying simple 80’s image data became a welcome dissertation, and the project was a welcome distraction from the drudgery of writing.

Soon, John asked if Thomas could bundle the tools he’d created into a single application. He did, and called it “Display.” It was then that the brothers realized “Display” was only a part of something bigger.

To read more about the Knoll brothers’ path to commercializing what would become known as Photoshop—and for a recent interview with Thomas about those early days—scan this page with the Decoder in the One Cool Thing app (see p. 10 for details).

REVVED UP

An “old rivalry between engineers and lawyers broke out again last night,” reported the student-run Michigan Daily in its coverage of a fracas that erupted near the Diag in the early morning hours of January 12, 1934.

The cause of the ruckus involved an experiment that required the running of six 1934 Chevrolet motors, around the clock, at 2,500 RPM. At about 4 a.m. that morning the Automotive Mechanics Laboratory—a rather crudely constructed wooden lean-to built off of the back of the old Engineering Shops—was situated just across South University from the Law School.

In 1935, the U.S. had built its first nuclear-powered submarine. Legos and Velcro were changing American lives. And at the Willow Run Laboratory, U.M. research physicist Chihiro Kikuchi was working to develop a solid-state maser, a device that amplifies microwave radiation.

Kikuchi was developing the device as part of Project Michigan, an army surveillance technology initiative that studied tiny amounts of radiation created by the Earth. The maser, they believed, could amplify these signals, making them easier to study.

Other researchers had tried using crystals as amplifiers, but their devices couldn’t amplify radiation at the short wavelengths needed for the project. Kikuchi was inspired to try a different approach when he realized that synthetic rubies were simply chromium-doped aluminum oxide, and thus very easy to come by. He borrowed one from the mineralogy department, and after hitting a calculation snag in determining the magnetic field and the crystal’s axis, Kikuchi used a different angle that simplified the equations and eased the analysis.

It worked. Kikuchi and three other Project Michigan scientists threatened arrests, “Fake arrest!” You have no jurisdiction!” and “Where are your warrants? Believed forth in true courtroom style.”

The motors were finally silenced—and the police “left for more pleasant pursuits—such as capturing murderers.”

NOT A PAJAMA PARTY

So what was such a rashchells structure doing in the middle of the Diag, anyway? During WWI, temporary facilities were needed to teach thousands of enlisted men how to repair engines. After the war the lab was shoved into that hastily constructed shed to make space for the new Physics Building. Notwithstanding the shed’s obvious nuisance value, as the 1934 raid amply demonstrated, it was nonetheless rebuilt in 1937 after a fire destroyed its southern half.

The lab was deployed again during WWII, but finally replaced in 1956 by the new North Campus automotive lab. In 1974, the facility was renamed in honor of Walter E. Lay—the Michigan Engineering instructor (and soon to become icon) who had been telephoned the first night of the ruckus.
Plenty of kids dream about running away and joining the circus. But Michigan Engineer Chris Gatti (BSE ME ‘05, MSE BME ‘07) has made it happen. The 35-year-old performer, who describes himself as “an academic by training but an acrobat at heart,” joined Cirque du Soleil in 2014, swinging and leaping his way across South America in a travelling show called Corteo.

While a move from engineering to acrobatics might seem like a stretch, gymnastics has always been Chris’ first love. He first went to the gym at age four and has never looked back.

“Gymnastics was a safe place for me. It was where I always wanted to be and where I belonged,” he said. “It was what I thought about all day in school and I didn’t want to be anywhere else on a Friday or Saturday night.”

Chris competed with the U-M gymnastics team during his time as an undergrad, but left competitive gymnastics after graduation to focus on engineering. He trained in his spare time during a stint as a research-an undergrad, but left competitive gymnastics after graduation to focus on engineering. He trained in his spare time during a stint as a research assistant at Rensselaer Polytechnic Institute.

But the itch to perform never left him, and in 2014 he sent a demo tape, scan this page with the Decoder on the One Cool Thing app to watch Chris’ demo tape, scan this page with the Decoder in the One Cool Thing app to Cirque du Soleil. It didn’t take long for his phone to ring (to engineering from Rensselaer Polytechnic Institute.

At the moment, he’s working on an algorithm-based tool to schedule circus artists into acrobatic sequences based on their availability, capabilities and medical limitations. Chris sees acrobatics and academics as two sides of the same coin.

“I see research as playful because you can be very creative,” he said. “You have these problems shown to you and there isn’t just one way to solve them, you can go off in one direction and that’s fine as long as you get a solution. So that creativity is a little like playing in the gym.”

For me, programming is like a sandbox where I can just play and learn and pick things up,” he said. “It’s what I do as a break on weekends, I like to sit down and program and see what I can come up with. It’s not necessarily work, it’s just fun.”

While a move from engineering to acrobatics might seem like a stretch, gymnastics has always been Chris’ first love. He first went to the gym at age four and has never looked back.

“There is a solution. So that creativity is a little like playing in the gym.”

Time for mental gymnastics as well. Computer science is a major focus for him at the moment. "For me, programming is like a sandbox where I can just play and learn and pick things up,” he said. “It’s what I do as a break on weekends, I like to sit down and program and see what I can come up with. It’s not necessarily work, it’s just fun.”

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Aisha Bowe knows how important it is for young people to have positive mentors. Growing up, she was inspired by her father, who earned his degree in electrical engineering at age 40. After graduation, she became a NASA mission engineer and aerospace engineer.

Today, Bowe (BSE AeroE ‘08, MSE ‘09) has channeled that inspiration into STEMBoard, a technology company that she co-founded in 2013. STEMBoard’s goal is to help historically underrepresented youth play a role in designing tomorrow’s technologies.

STEMBoard is collaborating with historically black colleges and universities to host STEM camps across the United States. It has also created HackIT, a week-long camp that combines technology with entrepreneurship to provide students in the Caribbean with a mini-incubator for launching new ideas.

Bowe’s advice for underrepresented minority students interested in STEM careers is to take a fresh look at their experiences and background. What they see as hardships may actually put them at an advantage.

“Some students may feel that they don’t have access to the same resources and connections as their peers,” she said. “But that can be a good thing because it gives them a unique perspective. Today’s challenges need a variety of perspectives to find answers. My mantra is ‘never let others define what is possible for you.’”

Professor Ping Cheng “Benson” Yeh's awakening came the day he caught students sleeping in his class. Determined to keep students engaged, Yeh (PhD EECS ’93), an electrical engineering professor at National Taiwan University, developed a platform called PaGamO. It gives instructors the digital infrastructure to turn almost any course into a multiplayer online game.

A territory acquisition game similar to Risk, PaGamO requires students to answer questions from a problem set uploaded by their instructors. Correct answers help them build their territory or successfully attack other players.

Yeh, who earned U-M’s Outstanding GSI Award in 2003, says his years at Michigan sparked a passion for finding ways to help students learn.

He launched PaGamO in 2013 as part of a Massive Open Online Course (MOOC); it now has more than 350,000 users worldwide, according to its website. In 2016, Yeh became the first academic to receive Taiwan’s Presidential Award for Innovation.

“We really get our students addicted to learning,” Yeh said in a video after the platform’s launch. “That’s the dream of every teacher and we’re doing it...I believe MOOC, and PaGamO are going to create the next paradigm shift for online education.”

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SHOW YOUR SCHOOL PRIDE

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MUGS

BRAIN HACKS

Back in the 1980s, a U-M research team borrowed this machine during the course of an experiment. Can you guess what they used it for?

A. To extinguish an underground fire in a coal mine
B. To build an instrument for studying subatomic particles
C. To measure seismic activity near the Earth’s core
D. To win a demolition derby

MYSTERY MACHINE

Michigan Engineering’s free One Cool Thing app delivers a new idea to your smartphone each day—world-changing technologies on some days, wacky gadgets on others. Can you guess which thing below is NOT an actual invention featured in One Cool Thing?

A. A chair that grows its own upholstery
B. A device that uses two coconut shells to make your bike sound like a horse
C. A smartphone app that translates your dog’s barking into English, Spanish or Arabic
D. A countertop machine that produces a continuous supply of wine

COOL THING OR RED HERRING?

ANSWERS:

MYSTERY MACHINE: Answer B

Between 1979 and 1981, a group of engineers from U-M; the University of California, Irvine; Brookhaven National Laboratory; Harvard and the University of Wisconsin built a device to measure the decay of subatomic particles called nucleons. It required a six-story high underground cavity, which they dug with this device in a salt mine near Mentor, Ohio. Called a Dosco machine, it belonged to the Morton Salt Company.

Scan this page with the Decoder in the One Cool Thing app to learn more about the project and see photos of the underground cavern (see p. 10 for details).

COOL THING OR RED HERRING?

Answer C

That’s right—A, B and D are actual inventions. You’ll find them and many more in our One Cool Thing app. (see p. 10 for details).
Matthew Johnson-Roberson reaches into the water to help out his robot creation. He is an assistant professor in Naval Architecture and Marine Engineering and Computer Science and Engineering. Johnson-Roberson is working on a system that couples a robotic arm with a stereo camera and cognitive abilities – so this is no factory floor bot. Developed with his research group, the system will allow the robot to grasp and manipulate objects in a variety of open-ended environments – like underwater in the ocean.

PHOTO: Joseph Xu
MADE IN MICHIGAN
LAUNCHED INTO SPACE
HOW A CONSTELLATION OF SATELLITES WILL HELP MICHIGAN ENGINEERS SEE FARTHER INTO THE EYE OF THE HURRICANE. PAGE 32

See CYGNSS in 3-D above the hurricane by scanning this page with the Decoder. See p. 10 for details.