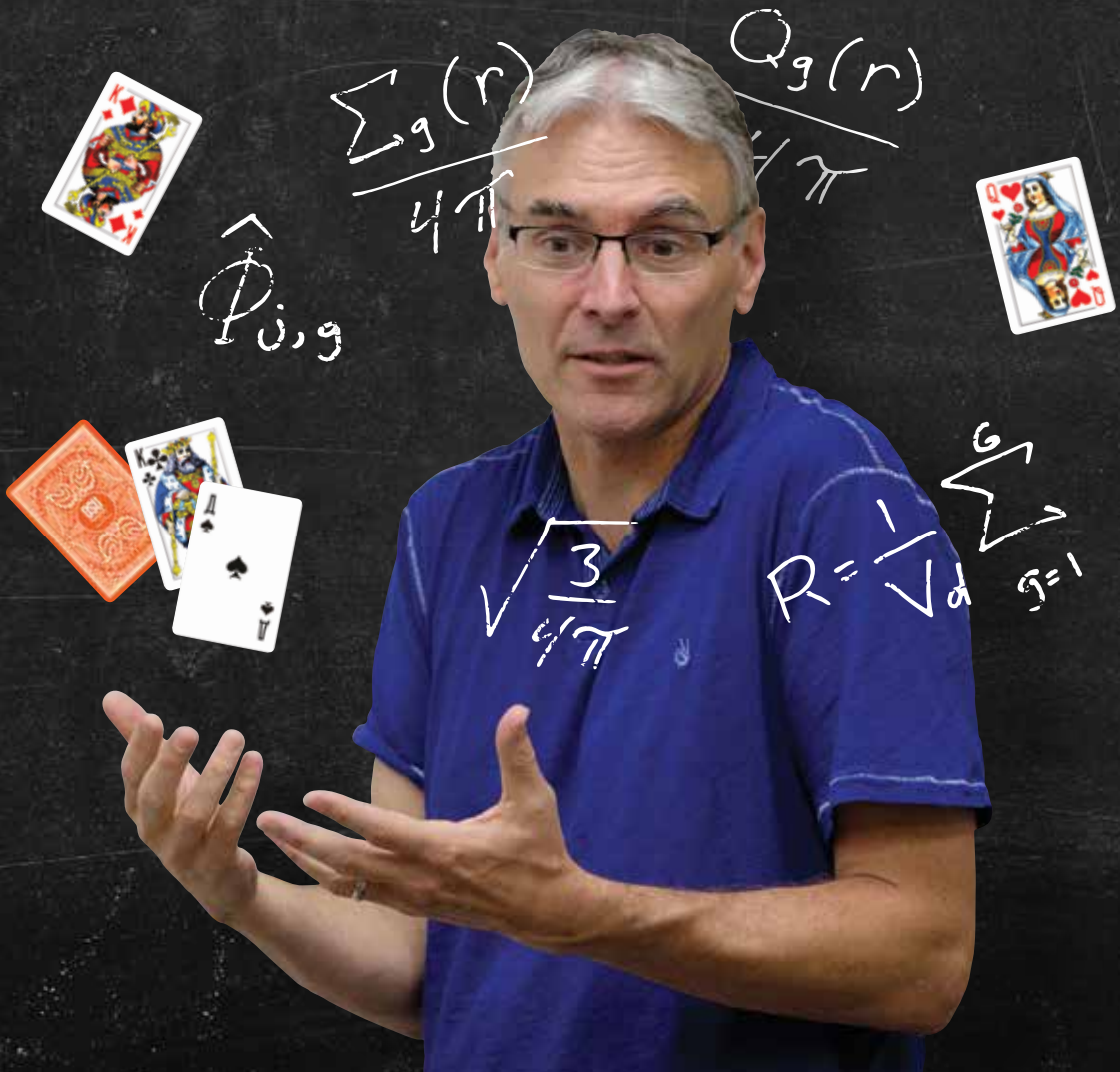


Momentum!

Fall 2016



Advances in data science
and engineering

Oregon State
UNIVERSITY

Momentum!

Fall 2016

02

Computational thinking:
A skill worth developing

04

Beyond encryption

06

Moving at the speed of lidar

FRONT COVER

Todd Palmer, professor of nuclear engineering, uses the Monte Carlo data modeling method to find a lower cost fuel replacement for a nuclear reactor in Uzbekistan. Born out of the card game, solitaire, Monte Carlo simulations use probability to model physical and conceptual systems. Palmer's research shows how Uzbekistan could have avoided the cost and risk associated with physically replacing and testing the fuel. (See story on page 10)

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08

Teaching robots to think
for themselves

10

Taking the gamble out of
nuclear fuel supplies

BACK COVER

A three-dimensional lidar point cloud of a damaged building in Concepcion, Chile, taken after the 2010 earthquake. (See story on page 6)

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Big data, big innovations

As electronic devices get smaller and smaller and computing power continues to exponentially increase, data scientists and engineers are finding new ways to collect, interpret, and convert "big data" into world-changing applications. An imagined future that used to be the stuff of blockbuster movies is becoming increasingly possible — even probable — thanks to the progressively synergistic relationship between the human brain and computers. Researchers are developing algorithms that enable self-driving cars, robots that "think," new technologies for deep space and undersea exploration, and myriad other innovations.

Advances in data science and engineering are also shifting the paradigm of how humans think and teach, conduct scientific research, and refine findings. In this issue, we look at several exciting College of Engineering research projects that involve new ways of harnessing big data, and we fill you in on how we are preparing our students to continue this breathtaking trajectory as their careers unfold:

- A powerful approach to problem solving called computational thinking is one aspect of the evolving human-computer synergy, and we are making concerted efforts to introduce this idea to students throughout our curriculums. We spoke to several industry leaders who have

strong ties to the university about the relevance of this approach, and we share their thoughts in the first article.

- In an age when we rely on global connectivity and instant access to information, data security is more important than ever before. Mike Rosulek and Attila Yavuz have found an algorithmic solution that allows for significantly faster data transfer while keeping personal and confidential information secure.
- Current lidar technology can gather upwards of a million data points per second, which can be translated into impressive, high-resolution images that are used in countless applications. Processing that amount of data, however, is extremely time-intensive — even with today's computing power. Michael Olsen developed an ingenious way to speed up this process while achieving more accurate results.
- Geoff Hollinger also has made an inspiring leap forward in the computer-human partnership by using a coactive learning algorithm to teach an underwater robot to make human-like decisions in planning and navigating routes.
- Todd Palmer is applying Monte Carlo algorithms to the problem of finding a reasonably priced fuel replacement for a nuclear reactor in Uzbekistan.

These stories represent a fraction of the research that has been made possible or greatly enhanced by recent advances in data science and engineering.

Go Beavs!



Scott A. Ashford, Ph.D.
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Computational thinking: A skill worth developing

by Gregg Kleiner

Startups and established companies are racing each other at breakneck speeds to use artificial intelligence (AI) to create new products and services. Engineers are teaching machines to learn, solve problems, and improve operations in industries

as diverse as healthcare, life sciences, automotive, manufacturing, entertainment, energy, and financial services.

“For as long as we have been designing computers, AI has been the final frontier,” said Jen-Hsun Huang, Oregon State engineering alumnus and cofounder, president, and chief executive officer of NVIDIA, the world leader in visual computing.

“Building intelligent machines that can perceive the world as we do, understand our language, and learn from examples has been the life’s work of computer scientists for over five decades.”

As humans are teaching computers to think, humans are learning to think differently. The emerging term for this is “computational thinking,” and it is a hot topic when it comes to educating future generations of engineers, scientists, artists, and pretty much anyone who is faced with solving problems.

The College of Engineering is developing ways to ensure that all engineering graduates are well versed in computational thinking, and industry insiders are excited about these efforts.

Brian Cripe, program manager for big data

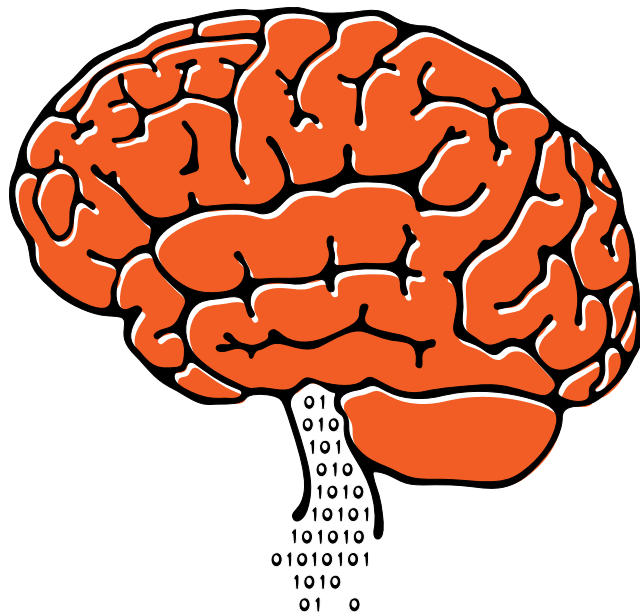
analytics at HP, indicated that computational thinking is an invaluable business skill.

“As a way of thinking about almost any problem, it’s a very powerful approach,” Cripe said. “I’ve worked with a wide variety of people at HP, and it’s one of the factors that distinguishes the really strong leaders or contributors from the others — the ability to stand back and abstract the problem, break it down, and then think

about it beyond the details. Not everybody does that.”

Computational thinking helps a person logically and efficiently approach a problem using some of the same techniques that computers use to process information and solve problems. These techniques include:

- Decomposition: breaking down a complex problem or system into smaller, more manageable parts.
- Pattern recognition: looking for similarities among and within problems.



“We need to find a way to systemize our decisions and use it to our advantage. Knowing there’s a science behind what we do intuitively every day...can help harness this important skill.”

- Abstraction: focusing only on the important information and ignoring irrelevant detail.
- Algorithms: developing a step-by-step solution, or the rules to follow to solve a problem.

Doug Fisher, a senior vice president and general manager in Intel’s Software and Services Group, believes that computational thinking can impact all of life.

“Developing this in engineering is a no-brainer, but we should also explore applying it beyond engineering,” Fisher said. “Almost everything we do can be broken down into threads of computation.

That’s because you are basically executing parallel processing, computation, and decision algorithms in every basic task. For example, when driving, should I reduce my speed in traffic, and if I do, is the car in the outer lane going to move across into my path?

To me, computational thinking is a valuable skill we use all the time, but we don’t recognize that is what we are really doing. We need to find a way to systemize our decisions and use it to our advantage. Knowing there’s a science behind what we do intuitively every day leads to the importance of developing a curriculum that can help harness this important skill.”

Fisher pointed out that computational thinking involves the ability to break down complex problems into manageable chunks and arrive at solutions that can be applied to similar situations in the future.

“Oftentimes, you see people solve problems with solutions that are so specific to that exact problem that they can’t be utilized in the next problem,” he said. “Having the ability to think about how you decompose a major issue, how you modularize that issue, how you validate your assumptions, and then how you do it in a way that ensures that others can utilize and reuse it — that’s really the heart of computer science in a lot of ways. When you want to solve a real-world problem, having the ability

to break that problem down into computational components is a vital skill set we should help everyone develop, regardless of discipline.”

Jon DeVaan, a former vice president at Microsoft and chair of the OSU Foundation Board of Trustees, concurs.

“Every engineer is going to use computers to do some aspect of their work, and taking any large problem and subdividing it over and over to reduce it to smaller, more solvable bits is a really great skill to have, no matter what you’re doing,” he said.

Although computational thinking is an emerging term, DeVaan is glad to hear that the college is looking at ways to implement it into the curriculum.

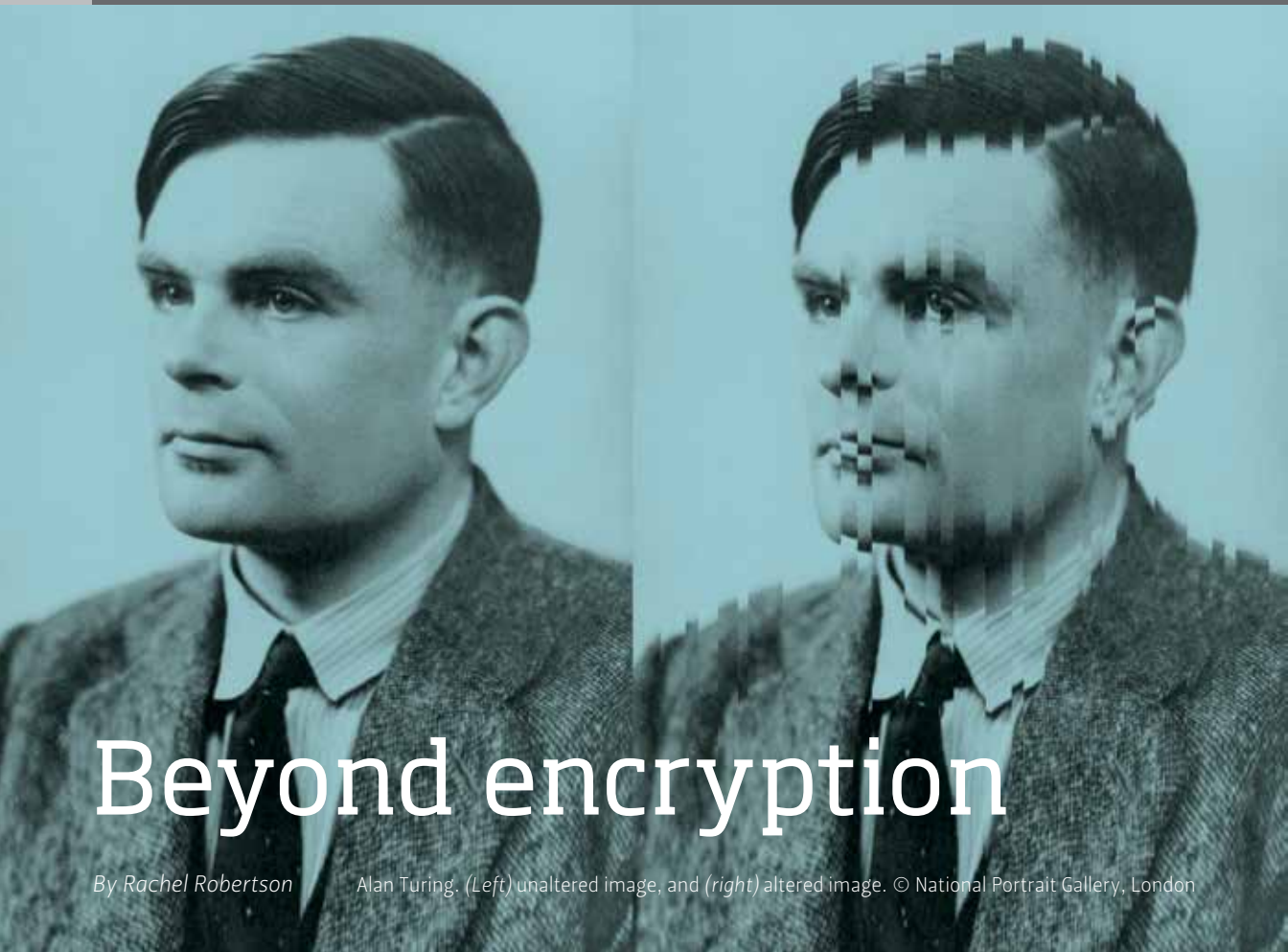
“Oregon State seems better than most universities at overcoming silos and getting people to really work together by looking at problems in a cross-functional way, and this kind of thinking complements that,” he said.

Mary Coucher, vice president of IBM’s Greater China Group Technology Partnerships, believes that computational thinking is applicable to all engineering disciplines.

“The students would definitely benefit, because it is all part and parcel to how they have to think when solving problems,” said Coucher, who is also on the OSU Foundation Board of Trustees, even though she lives in Shanghai. “At IBM, we are very focused on cognitive computing and I think this is along the same lines,

so it’s important for a company like ours.”

As the computer age continues to impact every aspect of life, committees at the College of Engineering are strategizing about how to best develop and implement coursework on computational thinking across all of the engineering disciplines. And they are probably applying computational thinking to the problem. **M!**



Beyond encryption

By Rachel Robertson Alan Turing. (Left) unaltered image, and (right) altered image. © National Portrait Gallery, London

Although data science and data engineering aim to improve our lives, and have done so in many ways, the threat of misuse of our private data and intrusion into our personal affairs is very real.

Vast amounts of information travels nearly instantaneously between giant server farms and our home computers and handheld devices. We rely on this transfer of data for banking, shopping, buying airline tickets, making dates, and countless other daily activities. Institutions and businesses collect, analyze, and store these data to better serve customers, improve health, perform political functions, and much more.

Unencrypted data in particular are vulnerable to attacks that can lead to significant consequences, such as the 2014 hack of Sony's computer system, which exposed company and personal secrets and destroyed information. An attack on an individual could be as benign as leaked email addresses, but can lead to identity theft and major financial headaches. If medical or genomic databases are breached,

sensitive personal information such as health status and predisposition to disease could be revealed.

"We need techniques that protect these data, and cryptography traditionally serves as the backbone of security systems to protect the information," said Attila Yavuz, assistant professor of computer science.

Data in secure systems are encrypted using permutation and substitution operations again and again until it becomes nearly indistinguishable from random data. Decryption reverses the steps to unscramble the data.

"We are only in the first stages of a society centered around massive data," said Mike Rosulek, assistant professor of computer science. "I don't think we yet understand all the implications of generating and storing it all. I hope it doesn't take a catastrophic breach to make people realize that cryptographic precautions are necessary."

Cryptography has come a long way since Alan Turing cracked the Enigma codes during World War II.

Advances have made it possible to perform the operations on encrypted data without decrypting it first and without leaking critical information.

"We call it the privacy versus data utilization dilemma," Yavuz said. "When we use strong encryption, accessing and analyzing these data become very difficult. Unless we can break this trade-off, it is really difficult for us to achieve both secure and usable information. So our objective is to fill this gap and create a system where we can search and analyze without compromising the data-analytics functionalities."

Yavuz is currently working with Robert Bosch LLC to provide more security for data collected from their medical devices. His research has demonstrated that his dynamic searchable algorithms can make encrypted queries on an encrypted dataset in two to 10 milliseconds per search, without decrypting it. The ultimate goal of his research is to integrate the algorithms into Bosch's telemedicine database so that practitioners can remotely access patient data while keeping it secure.

In contrast to Yavuz's work, which advances applied cryptographic techniques for a specific purpose, Rosulek's research focuses on theoretical cryptography — finding solutions that can be used to support any kind of computation on encrypted data.

Over the last couple of years, Rosulek has been working on what is known as "garbled circuits." They are not physical circuits, but a cryptographic domain where the computations on encrypted data are performed.

"You can think of a garbled circuit as a sealed box," he said. "This box is like an isolation or containment chamber with gloves attached to it, so the scientist can reach in and manipulate what is inside. But the garbled circuit is a black box so the operations being performed are not visible."

The idea for garbled circuits was first introduced in the 1980s, but it wasn't until the early 2000s that people began implementing the techniques with real data, and in the last decade researchers have been working on finding ways to make these

operations more efficient.

"Most modern processors have specialized hardware for cryptographic computations, so the computational cost is under control," Rosulek said. "The bottleneck is the amount of information that has to be exchanged between the parties that are doing the computation. The improvements we make are new, clever ways to encode these encrypted data with all the guarantees of a garbled circuit."

In two recent publications, Rosulek and colleagues demonstrated that, compared to other approaches, their new algorithms were 33 percent faster and had 33 percent less overhead in the amount of communication required for the computations.

"We also proved that by looking at all the known techniques, you can't do better than our most recent work," he said. "So we have shown that

our techniques are optimal until someone invents something totally new. It's been fun, because it's spurring people to think of different ideas."

The challenge of protecting private data is not likely to diminish. The amount of data in the world is doubling every two years and, according to the International Data Corporation, will reach 44 zettabytes (44 trillion gigabytes) by 2020. Much of

that will be personal information collected by the millions of smart devices in our homes and cars, or even attached to our bodies.

"One should never forget that it's vitally important for us to be able to secure our information, because in the future, that will be the single most valuable thing that mankind will possess," Yavuz said. "Researchers and every individual should realize the importance and value of the information that they have at their hands and try their best to keep it secure." **MI**

Cryptography has come a long way since Alan Turing cracked the Enigma codes during World War II.

Moving at the speed of lidar

By Steve Frandzel



Michael Olsen operates a robotic total station to establish control for lidar scans.

Lidar is a light detection and ranging technology that creates high-resolution, three-dimensional (3-D) representations of unparalleled accuracy and detail. It has become an invaluable and versatile tool for gathering information in dozens of fields, including forestry, archaeology, agriculture, and even crime scene investigation.

When Michael Olsen, associate professor of geomatics, aims and fires his lidar scanner, the tripod-mounted device collects a million points of data every second. From those data it creates a 3-D image of the targeted landscape, vegetation, and built environment. An average scan lasts about three minutes and yields an astonishing amount of raw, unstructured data.

Geomatics engineering involves taking geospatial measurements like these — on, above, and below the earth's surface — to support engineering

analyses. Lidar has made collecting the data easy, but the greater challenge is to develop tools that extract the information contained in the raw data.

Olsen's work involves teasing out meaningful information that engineers can use to build roads, inspect buildings for defects, evaluate coastal erosion or landslide hazards, or for scores of other applications. For example, civil engineers routinely use terrestrial (ground-based) lidar to design and inspect highways, bridges, public transportation, and other infrastructure.

"With terrestrial lidar, we can sample terrain and structures down to the level of millimeters," said Olsen. "Its accuracy is remarkable compared to what we used to get."

Firing nanosecond laser pulses at a rate of up to a million bursts every second, lidar measures the time it takes for each pulse to bounce back from whatever

it hits, then calculates the distance. Terrestrial lidar can be stationary (moved manually from place to place) or mobile (mounted to a vehicle). Airborne lidar has become commonplace and is the primary tool used to make topographic maps. Other lidar systems operate in space or underwater.

The elemental output of every lidar scan is the point cloud — visually stunning and sometimes ghostly images. Every scan, as represented by the point cloud, comprises tens of millions of data points, each of which corresponds to a point on an object in the physical world. "It doesn't just give you a bunch of numbers on a spread sheet or a bunch of code," Olsen explained. "You can visually see the data. That helps people understand the results in an intuitive sense."

On its own, though, a point cloud has no inherent meaning. "If we scan the room we're sitting in, the system will generate a 3-D point cloud, but it won't know that this is a door, that's a wall, that's a chair, that's a rug," explained Olsen.

Currently, rigorous geometric techniques are needed to segment and classify point clouds, enabling users to distinguish, categorize, and identify objects in a scan. Sometimes it takes days of computer processing, and sometimes it has to be done manually, the same way a photographer might manipulate an image in Photoshop. "It's tedious work," said Olsen.

Olsen has developed a solution that simplifies and accelerates the data processing component and produces more accurate spatial and structural representations from lidar images. Two-dimensional (2-D) image files are one-tenth the size of 3-D point cloud files, so Olsen and Hamid Mahmoudabadi ('16 Ph.D. Civil Engineering) segment and classify a 2-D panoramic image created by the lidar system — an image that usually gets ignored and then lost in subsequent processing.

"We take that initial data structure and create 2-D maps and apply proven software algorithms

to extract information from them," said Olsen. "Then we kick it back to a 3-D image where all of the objects have been divided out, categorized, and identified. The processing time with our approach is much shorter and more efficient, and the results are more accurate when compared to a commonly used technique for point cloud segmentation."

In one particularly robust validation of his segmentation method, Olsen applied both his new system and conventional segmentation to a lidar scan of the trophy case in Kearney Hall on the Oregon State campus. It was a challenging proposition because of the distorting effects from the glass front panel, but Olsen's technique handled it with ease.

"When we started with the 2-D panorama and applied our algorithm, it pulled out and identified each of the plaques and trophies as distinct objects," said Olsen. "The older approach applied to a 3-D point

cloud didn't work as well. With our new technique, we were very satisfied with the accuracy and the dramatically faster processing time."

Using Olsen's technique, lidar interpretation processes that normally take hours to compute can now be done in a matter of minutes with improved results and fewer errors.

Olsen's next step is to adapt his streamlined segmentation technique to mobile lidar, which scans large swaths of territory in a

very short time and is far more efficient than the painstaking process of taking individual scans, picking up the equipment, setting it at another location and repeating the process. Mobile lidar is also safer because surveyors and engineers don't have to stand near dangerous roadways to conduct stationary scans. "Right now, we're applying our algorithm to a single scan at a time," Olsen said, "but I think we'll be able to figure out a way to stitch together the multiple images that mobile lidar creates along highways. If we succeed, I think it will be the first time that's been done." **MI**

"It doesn't just give you a bunch of numbers on a spread sheet or a bunch of code. You can visually see the data."

Teaching robots to think for themselves

By Steve Frandzel



Graduate student Thane Somers services a robotic surface vehicle. The boat pictured does not travel under water like a torpedo-shaped AUV used in field trials, but it was used to test Geoff Hollinger's algorithm designed to train AUVs to learn human preferences.

Researchers at the College of Engineering are fusing human problem-solving skills with the number-crunching power of machines to guide robots and significantly change the way scientists gather data.

"We're building systems in which computers and people collaborate to make decisions," said Geoff Hollinger, assistant professor of mechanical engineering. Hollinger and his research team have trained autonomous underwater vehicles (AUVs) to plan routes that balance data collection goals with risk in a way that mirrors the priorities of their human operators.

"The scientist brings specialized knowledge and experience to the table, while the robot is capable of processing and evaluating large quantities of data," said Hollinger.

AUVs are a mainstay of oceanographic research. The robotic vessels — many of which are torpedo-shaped — navigate independently and monitor numerous environmental variables, such as temperature, salinity, and water quality. Some

models can cruise for weeks at a time, surfacing periodically to transmit data and check their position. Scientists operating AUVs rely on algorithms — sets of rules that organize data collected by the robot's sensors — to balance the scientific goals of a vehicle's mission with the many risks it encounters.

Ideally, an AUV can continuously plan and re-plan its route through unforgiving aquatic environments without human intervention, all the while weighing the relative importance of its data-gathering objectives against an array of threats. Ocean currents can push the slow-moving vehicles off course, forcing them to expend precious battery power for corrections. They can run aground or surface in a shipping lane and be demolished by passing vessels.

Unfortunately, the current generation of automated route-planning systems still struggle to evaluate the tradeoffs and consequences of their decisions. To teach AUVs to emulate human decision-making, Hollinger's team adapted and built on the "coactive learning" model, in which a person repeatedly makes

small adjustments to computer-generated routes until the computer's solutions resemble those of the human's. But that approach has its limits, explained Hollinger. People aren't particularly good at choosing the best travel plans for AUVs because, unlike computers, people are easily overwhelmed when bombarded with information.



"If I try to plan a route that's both safe and hits all of the hot spots I want to look at, I'm not going to do it well, because there's no way for me to evaluate all of the possible trajectories and choose the optimal one," said Hollinger.

People are, however, quite good at knowing what they prefer.

Consider a hiker crossing a high mountain meadow and hunting for some particular wildflowers on her way back to camp. Sunset is approaching. Sticking to the trail leading straight across the field is the quickest option and might turn up a few of the desired blooms along the way, but the hiker wants a bigger payoff. She prefers to meander through the field, even if it eats up valuable

daylight: more flowers, but more risk that she'll wind up searching for camp in darkness or get caught out in a dangerous late-day storm. She's abundantly aware of the risks and, in this relatively simple scenario, is probably equipped to make good choices and tweak them on the fly as conditions change to satisfy the competing objectives of gathering flowers and safety.

Why not teach a robot to learn from a human's reliable — though potentially flawed — preferences and task it to sort through the risk levels of nearly every possible route?

To test that strategy, the researchers created a simulated underwater landscape, represented by a color-coded map portraying the potential risk and reward of traveling throughout the imaginary area. Next, the researchers instructed the computer to plot a course that favors a high volume of information and downplays risk. The map, whose

dotted black line shows the computer's proposed route, was presented to a human expert who moved a single point on the path to reflect his preferences. The process was repeated a total of

16 times, each time with a different risk/reward map and computer-proposed route. After 20 such sequences, the routes the computer produced steadily began to echo the human's route-planning preferences. What's more, although most of the human modifications made sense, some were inconsistent, yet the computer seemed up to the task.

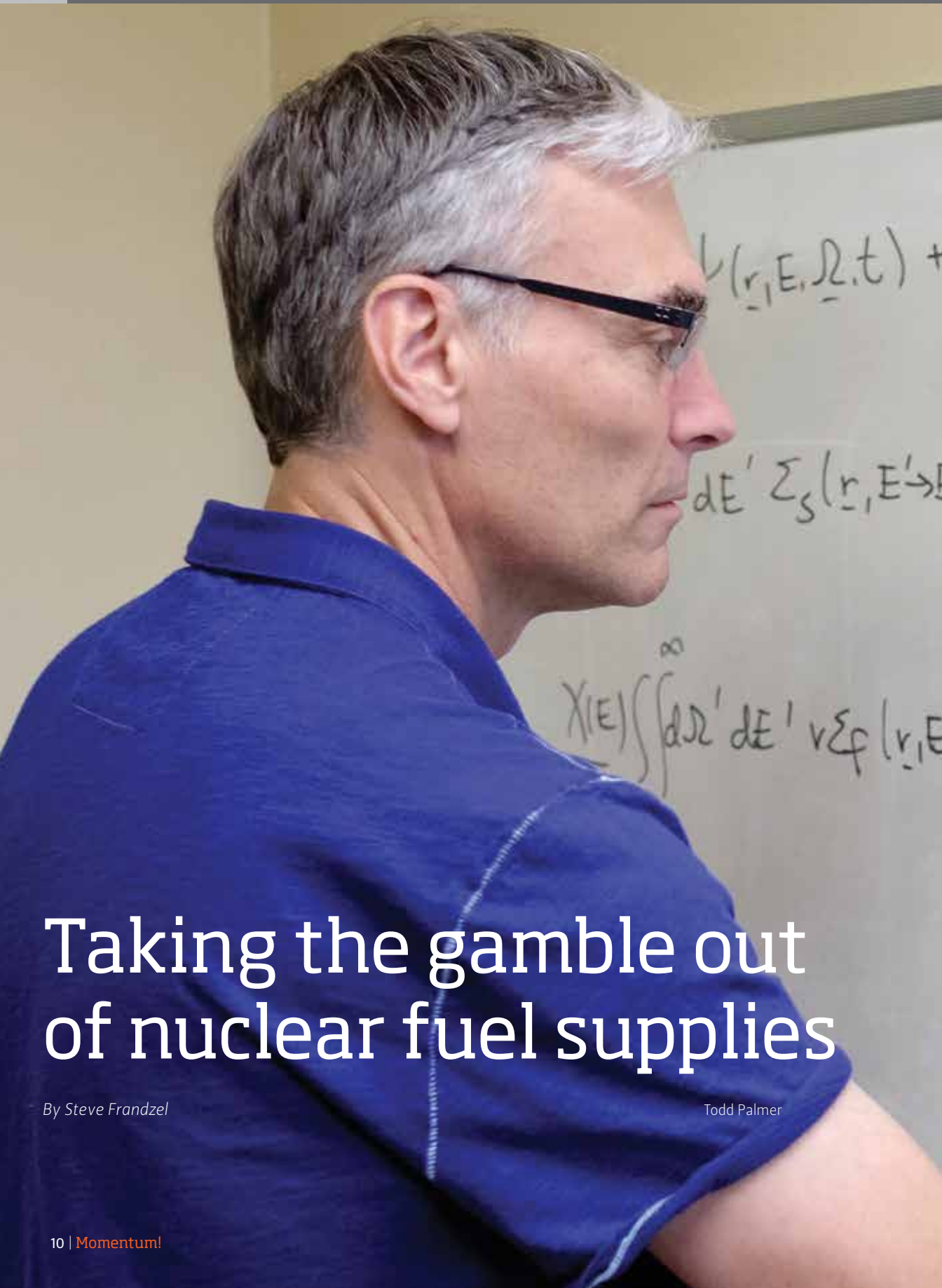
"With each change, the computer learned more about the human's underlying preferences and was also able to smooth over out-of-the-ordinary changes, which humans are bound to make," Hollinger said.

The researchers conducted field trials using a 6-foot-long AUV in a reservoir east of Los Angeles. After the AUV mapped water temperature and depth, the route

planning algorithm was put through its paces. In one test, the researchers wanted the AUV to follow a route that combined a depth of about six meters and water temperatures near 27 degrees Celsius. The preference for depth was weighted more heavily than the preference for temperature, and the AUV sailed off to follow computer-planned and human-planned trajectories. Just as in the simulated trials, the results were strikingly similar — evidence that the algorithm had adopted human preferences and adjusted its solutions appropriately. Promising results were also recorded after missions that sought maximum depths and minimum temperatures.

"We showed that it's possible to design systems for autonomous navigation that capture the essence of a human's priorities," said Hollinger. "Rather than have robots do the dull, dirty, dangerous work, we want a human-robot team that can accomplish something neither could accomplish alone." **MI**

"We're building systems in which computers and people collaborate to make decisions."



Taking the gamble out of nuclear fuel supplies

By Steve Frandzel

Todd Palmer



When the high price of Russian-made nuclear fuel jeopardized the future of important research, Oregon State engineers fashioned a solution using techniques whose roots can be traced to a game of solitaire played 70 years ago.

For decades, scientists around the world have conducted experiments at the research reactor operated by the Institute of Nuclear Physics in the capital city of Tashkent, Uzbekistan. Their work includes tests to investigate various facets of nuclear security and is funded by the United States Department of Energy.

Unfortunately, Russia is the sole supplier of the particular uranium-based fuel that powers the reactor, and it has priced Uzbekistan out of the market.

"Russia has a monopoly on this type of fuel," said Todd Palmer, professor of nuclear engineering. Uzbekistan recently announced that it will decommission the reactor, which means that researchers are losing a reliable and inexpensive testing venue that can complete experiments on short notice. Many Uzbeks are losing their jobs, and their country's prestige in the scientific community

will take a hit as a result. Although research reactors in the United States are capable of filling the gap, most of them are booked many months in advance.

Long before the decommissioning, Palmer and his colleagues were considering another option: replace the current plate-type fuel — so called because of its flat, rectangular shape — with plentiful and cheap pin-type fuel made in South Korea, which is configured in long, cylindrical aluminum rods. He likened the change to yanking a car's engine and slotting in another. "Hopefully, you'll get the same performance and the brakes and safety systems still work," he said.

But physically replacing the fuel assembly without knowing the outcome is risky business that would entail enormous political commitments and many millions of dollars. So to test the potential solution, Palmer simulated the fuel substitution using a technique called the Monte Carlo method, which relies on probability to model physical and conceptual systems.

Instead of producing a single answer, Monte Carlo simulations produce a range of possible outcomes

“ Monte Carlo simulations produce a range of possible outcomes and their likelihoods.”

and their likelihoods. “It’s the most mathematically simple, physically intuitive approach for solving very complicated problems that cannot be solved analytically,” said Palmer.

The Monte Carlo method

The Monte Carlo method was born out of a simple card game. In 1946, the visionary mathematician and Manhattan Project veteran Stanislaw Ulam was playing solitaire while recovering from a serious illness. He casually wondered what his chances were of winning a game and figured out that simulating the play 100 times and counting the number of wins made far more sense than trying to calculate the odds using a purely mathematical approach.

“This was already possible to envisage with the beginning of the new era of fast computers,” Ulam said in 1983, “and I immediately thought of problems of neutron diffusion and other questions of mathematical physics.”

The name Monte Carlo refers to the casino where Ulam’s uncle supposedly gambled away large sums.

Today, Monte Carlo simulations turn up in any field where probability and statistics play a role: physical sciences, finance, biology, computer graphics, artificial intelligence, petroleum reserves management, investing, election forecasting, climate modeling, sports, and more. It’s been used

to determine the most efficient process for boarding commercial airliners.

At its most basic level, Monte Carlo simulation predicts the outcome of flipping a coin thousands or even millions of times. Marginally more interesting is estimating the value of pi by simulating random dart throws at a circle inscribed within a square board, counting the number of hits inside the circle, then finishing with some middle school-level geometry operations. Things get notably more difficult when using Monte Carlo to approximate the odds, for example, of winning a baseball game.

Let’s say a team is down a run in the bottom of the ninth inning, with one out and a runner at first base. Is there a greater chance of scoring if, 1) the runner tries to steal second; 2) the batter tries to bunt the runner to second; or 3) the batter swings for a hit? At least a handful of variables must be quantified and plugged into the Monte Carlo software, such as the runner’s success rate for stealing against the opposing pitcher, the catcher’s record of throwing out base runners, and the hitter’s batting average and bunting ability. Even weather could play a factor. As the number of variables grows, confidence in the solution increases and the margin of error decreases. The simulation will produce a distribution of many thousands of data points from which the Monte Carlo algorithm will determine the most likely outcomes.

Using Monte Carlo in nuclear research

Where Monte Carlo simulations really shine is in addressing messy problems involving loads of variables and many possible outcomes — and where the stakes are high. Nuclear scientists use them to model the production and flow of energy in reactors and weapons, discover how radiation travels through and interacts with its surroundings, or assess the reliability of pumps, pipes, and other structures in nuclear plants.

A Monte Carlo simulation for a commercial nuclear reactor, for instance, calls for something in the neighborhood of two billion individual pieces of data to produce trustworthy results. The price of such fidelity is time, and Monte Carlo simulation is the tortoise of the data science world.

“Of all the algorithms, it’s easily one of the slowest ways of solving these types of problems,” said Palmer. Intricate simulations that incorporate the element of time, such as the rate of fuel depletion within a reactor core, can gobble up weeks of uninterrupted computer processing. The high-speed computers that make Monte Carlo simulation possible at all originated at the dawn of the atomic age in tandem with nuclear engineering, which is a point of pride for Palmer.

“The development of modern computers is more closely connected to nuclear engineering than with any other discipline,” he said. “The two sprang from the same well, and I feel a strong familial kinship to that.”

Scientists of the Manhattan Project, who faced mathematical challenges of mind-boggling complexity, relied heavily on mechanical tabulating machines, which frequently broke down from overuse. At the time, a “computer” was a human being. Roomfuls of human computers, mostly women, worked out calculations all day. Half a dozen of them later became the first programmers of ENIAC, the world’s first general purpose electronic

computer, which secretly went into service in 1946 and soon after was enlisted by the nuclear scientists who created the hydrogen bomb.

A potential solution

For the Uzbekistan reactor, a time-tested Monte Carlo algorithm (also with roots in the Manhattan Project) provided a clear answer to the original proposition: the reactor would indeed perform just as well and as safely with the alternate fuel supply from South Korea.

“Based on what we have found, we could say with confidence that it would work in the real world,” said Palmer.

Even so, Uzbekistan will close the reactor. Fuel costs may well have been a factor in the decision, but the advanced age of the reactor, which opened in 1959, may also have been a consideration. Palmer had hoped

to brief someone at the Department of Energy about the advantages, to science and the United States, of keeping the reactor running, but events overtook his plans.

“As scientists and engineers, we tend to stop after the calculations are made,” he added. “But a policymaker has to take that information and ask ‘what does this mean?’ and then make decisions based on the answer. It’s not just numbers.”

In addition to applying Monte Carlo simulations in his work, Palmer is also seeking ways to improve the

algorithms themselves, particularly in the development of radiation source detectors. Placed at a border crossing, these detectors could conceivably pinpoint radioactive cargo hidden in vehicles trying to sneak across a frontier, but they must be exquisitely sensitive in order to pick up the tiny amounts of radiation that slip through shielding material that smugglers are sure to use to avoid discovery.

“To design detectors, you need simulations,” he said. “We want to be able to complete these simulations as fast and accurately as we can to design the detectors as well as possible.” **MI**

A Monte Carlo simulation for a commercial nuclear reactor, for instance, calls for something in the neighborhood of two billion individual pieces of data to produce trustworthy results.

Todd Palmer with graduate students Lara Peguero, Anthony Alberti, and Douglas Woods.



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