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Nanostructure of a metamaterial under a microscope.

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The Five Vs of Big Data

Florence Nightingale is best remembered for her life-saving sanitation reforms at nursing and battlefield hospitals. But she owed her success to her astute use of data as much as to soap.

In fact, Nightingale’s numbers undercut the 1858 declaration of London’s Chief Medical Officer of Health, John Simon, that death from infectious disease was “practically unavoidable.” Nightingale knew that wasn’t true. She had collected large amounts of data on patient mortality throughout the Crimean War in the 1850s. It was clear that, before her arrival and implementation of sanitary measures, more soldiers died from infectious diseases like typhoid and dysentery than from battlefield wounds. After sanitation was introduced, deaths from contagion dropped dramatically. This convinced her that large-scale medical reform was needed, as were formal nursing schools. But she also knew that the tables of data she collected during the war would not make the necessary impact on Great Britain’s government.

Before presenting her data to the press and politicians, she had to give the data value. In a letter to a friend, Nightingale said, “None but scientific men even look into the appendices of a report.” So, Nightingale chose to communicate through data visualizations—lots and lots of infographics. She even invented a new type of diagram in 1859, now known as the comparative polar-area diagram, in which she illustrated the dramatic reduction in soldier deaths after implementation of sanitary measures at Turkey’s Scutari field hospital. Her chart was widely recognized as an unsubtle rebuttal to Simon’s grim assessment.

Nightingale’s approach had veracity. Her infographics and illustrations resulted in new health laws, hospitals, and training facilities in Great Britain, and they are the foundation of many principles of modern medicine.

Although numerical data of the mid-19th century was small-scale compared to the terabytes of data scientists work with today, Nightingale recognized the same “Five Vs” of Big Data that we do now:

Volume: To draw meaning, there must be lots of data
Velocity: Data comes in quickly
Variety: Data is messy and arrives in many different types and formats
Value: Data’s use must be discovered and put to work
Veracity: Data must be trustworthy.

In an 1857 letter to a friend, Nightingale wrote, “Whenever I am infuriated, I revenge myself with a new diagram.” Data visualizations were her preferred method to harness and translate data and tell an important story.

Today’s scientists use data in a similar way: They deploy vast datasets to train machine-learning algorithms that will, for example, reveal important patterns for medical diagnoses, exoplanet discovery, and even novel lens designs. In this issue of Photonics Focus we tip our hat to the world of Big Data, and the increasing role of photonics to filter, organize, and give that data meaning.

While I believe that today’s data scientists are driven by a more measured objectivity than Nightingale’s famously righteous fury, their work certainly shapes the stories that today’s scientists, engineers, and medical doctors aim to tell.

Gwen Weerts, Photonics Focus Editor-in-Chief
RESEARCH PAPERS are written for other scientists. They’re not easy for nonscientists to understand—and let’s be honest, they’re not always easy for other scientists to understand, either. Academic writing is full of jargon, acronyms, and algorithms; in a word, it’s dry. And, although Eureka! moments happen often in movies, they’re rare in real science. Most scientific advances happen incrementally, and it can be hard to convey why they matter, and how they fit into larger research problems.

For these reasons, it’s important for scientists and engineers to learn to translate their scientific output into language that can be easily understood, which is the arena of science communication. Science communication translates research written for an audience of academic peers to a public audience. Recent issues of Photonics Focus included a series on “A scientist’s Guide to Social Media,” which focused on the modern outlets of science communication, but there’s another skill yet to master: the layperson summary.

The layperson summary—or significance statement, nontechnical summary, or plain-language summary—is written in accessible language, and briefly summarizes the research paper in terms that are understandable to an educated person without specialized training in the academic topic. It can be useful, for example, in communicating with the press or with nonspecialists in grant-funding agencies or organizations.

So, how do you write a layperson summary? Fortunately, like Snell’s law, there’s a formula for that.

PARAGRAPH 1: DESCRIBE THE HIGHEST-LEVEL PROBLEM THAT YOUR RESEARCH AIMS TO SOLVE.
In one to three sentences, describe the context of your research project. This might be the “Big Question” that got you interested in this field in the first place.

PARAGRAPH 2: BRIEFLY REVIEW THE DOMINANT METHODS USED TO SOLVE THIS PROBLEM NOW.
In three to five sentences, give credit where it’s due. Explain the other approaches to the same problem and note their shortcomings. This background will set you up for justifying the need for your new approach or tool.

PARAGRAPH 3: STATE YOUR THESIS AND METHOD.
In the first sentence of paragraph three, state simply the main thesis of your paper. Then, describe your experiment in the most accessible, simple way possible. This paragraph should be no more than five sentences long.

PARAGRAPH 4: STATE YOUR FINDINGS.
What is the result of your study? In three to four sentences, summarize your results, and be specific and honest about your findings. If your approach shows a “significant” gain, then give a percentage to contextualize just how significant it really is—and maybe use a metaphor to help your audience understand the magnitude.

PARAGRAPH 5: GET A QUOTE.
Quotes are a great way to bring personality and human interest back into the science. You might ask your lab leader for a quote about why the study is important, or to comment on a unique collaboration that took place. Alternatively, you could ask the editor who accepted your paper for publication for a quote about why it’s worthy of publication in your journal of choice.

PARAGRAPH 6: STATE SOME APPLICATIONS WHERE THIS RESEARCH MIGHT BE USED.
Wrap up your layperson summary in two or three sentences by suggesting how this research might someday be used and tie it back to your intro where you stated the high-level problem. This type of conclusion can be more challenging for basic research, which doesn’t have an application in mind, but researchers working on basic science can often imagine different arenas that will be interested in their findings.
Your completed summary should be 500–600 words. Writing a layperson summary of a research paper should be a normal part of the writing process and is a good final step before submitting a manuscript to a journal for publication. The exercise will ensure that your manuscript is clear and well-organized. If you can’t concisely summarize a paper’s methods and takeaways immediately after completing the paper, this lack of clarity is likely also reflected in your manuscript. Plus, it’s best to write your summary when the details are very fresh.

Once written, there are a few different things to do with it. First, excerpt a small part and share it on LinkedIn when your paper publishes. Some journals also publish layperson summaries alongside the research article, so find out if that’s an option. And finally, send your summary to your university’s communications office or corporate PR manager. Find out how they distribute research advances at your institution and ask if they’d be willing to share your summary via their public outreach channels.

Positive attention on your research can pay dividends. Your enthusiasm for the topic will be contagious, and you may find collaborators or future lab members as a result of your efforts. Also, funders like public acknowledgement, and you want to be on their good side. Likewise, research institutions love visibility, and are motivated to show that their research dollars are being put to good use; they’ll appreciate the publicity. And, if these reasons aren’t enough, research articles that are promoted online via press releases, article summaries, and social media are downloaded two to 10 times more than papers without promotion.

Science communication has a real, measurable impact—not just on downloads and citations, but on public trust in science. And no one will trust what they can’t understand.

GWEN WEERTS is Editor-in-Chief of Photonics Focus.

IT’S IMPORTANT FOR SCIENTISTS AND ENGINEERS TO LEARN TO TRANSLATE THEIR SCIENTIFIC OUTPUT INTO LANGUAGE THAT CAN BE EASILY UNDERSTOOD.
Learning the Language of Science: A personal journey

HAVE YOU EVER CONSIDERED how different life would be if you could not communicate with the people around you? How would you express your ideas, feelings, and experiences?

Well, this is my story with the added twist that, as a scientist, I must expertly speak, read, and write in my second language, English, which is the language of science. It's a personal and professional challenge that led all the way to Buckingham Palace in the UK, where, as a PhD student, I represented the University of Southampton Optoelectronics Research Centre upon being awarded the 2017 Queen's Anniversary Prize for Higher and Further Education.

I had the opportunity to speak for a few minutes with Prince Charles. He asked about my nationality and my research, and then remarked that my English was good! Slightly embarrassed, I only could answer that he was so lovely. I had worked very hard to earn that compliment.

Buckingham Palace was a long way from home. I was born and raised in Mexico City where Spanish is the only language needed to communicate. Nonetheless, by the time I graduated as an engineer from Mexico’s National Polytechnic Institute, I knew some English but could not hold a conversation for more than a few minutes. I worked professionally for more than 10 years, and still did not have to take up formal English language studies because all of my business relationships were in Spanish.

Then one day life caught me by surprise and our family moved to the UK to support my husband’s career. After two years, I decided to pursue a PhD degree in optoelectronics. The program was in English, however, and I didn’t have the level of proficiency the program required. Unable to get formal lessons, I studied English seven to 10 hours a day at home. I worked with internet sources, books from the public library, and I spent some money on books and practice tests. I was also lucky to know many people who were willing to help me learn and practice.

While proficiency in a second language can be an advantage in any profession, it is a must for scientists whose first language isn’t English. While my English proficiency was just enough that I could start my doctoral program, I had to greatly improve my skills. This required more than making an effort—it required conviction, commitment, discipline, and above all, time management.

For example, I learned to never waste time in pursuit of better skills in English, and to value the time of others who were willing to help me. I learned that living in a country where English is the official language can help one learn, but that scholarly communication in English is a separate challenge.
What’s more, I realized how expensive and sometimes inaccessible it can be to obtain formal instruction in English. With that, I came to understand the importance of networking to improve professional skills, including spoken and written English.

I remember that it took me months to prepare my first conference paper, including at least 10 revisions with my supervisor. My main difficulty was grammatical structure and the complexity of English. A common mistake the first time anyone tries to write an article in another language is to formulate ideas in our native tongue, and then try to translate. But different languages often employ differing grammatical structures. This is certainly the case with English and Spanish. My suggestion is to keep it simple. Try to write short sentences. Be concise and follow basic academic writing guidelines. You also can consult sources, such as “10 Simple Steps to Writing a Scientific Paper,” by Andrea Armani, a professor at University of Southern California (spie.org/10StepsArmani), or download the free SPIE eBook, How to Write a Good Scientific Paper by Chris A. Mack (spie.org/SciPaperMack2018).

Like me, many science and engineering students develop their English language skills alongside graduate studies. They learn that communication skills are not limited to technical jargon, but include speaking and writing for the public. We face the challenge of being in front of an audience, where we must explain our work and findings fluently, in English, when we may not be at all confident. I still feel intimidated every time I speak English in front of an audience. My advice: Prepare a talk beforehand, practice as much as possible, and, most importantly, remember to breathe.

The first time I presented research results at a conference, I was so nervous my mouth got parched, and I could not speak for what seemed like forever. Finally, I managed to breathe and said to the audience, “I am sorry, I think I need some water.” That gave me time to think, relax, and start over. The experience taught me to avoid taking on extra pressure pursuing perfection. No one is expecting that. I promise you that everyone in the audience will understand.

While working towards my PhD, important activities that helped with both learning English and boosting my confidence included being part of SPIE subcommittees, being part of the SPIE Career Lab mentoring program, and receiving recognition from awards, grants, and scholarships.

Of course, it is paramount that graduate students receive support and guidance in their scientific work from supervisors and colleagues. But this also applies to learning English. I have found that learning a second language is always a key that can open several doors. As supervisors or mentors, we can be the difference for those starting out in science careers. I am so proud of all my mentees who have succeeded in their endeavours.

Part of my success as a scholar and researcher is because of my hard work, but I will be forever in debt to those who helped me improve my English skills. Since I started my PhD, I have committed to assisting others in developing their career paths as my mentors and colleagues have helped me. I invite everyone to extend a helping hand to someone you know who is on their path to learning the language of science.

ANGELES CAMACHO is a researcher at the University of Southampton Optoelectronics Research Centre. She is part of the SPIE Career Lab mentoring program and leads outreach programs in Latin America.
Battlespace environments create unique AI challenges for US military defense

UNITED STATES Department of Defense (DoD) senior leaders believe that artificial intelligence (AI) will play a critical role in the future success of multidomain operations (MDO). These can cut across cyber, land, air, space, and sea and bring together resources from the Air Force, Army, and Navy, as well as international coalition partners. Two primary challenges in this cluttered and complex battlespace are the need to collect, analyze, and disseminate information, coupled with the ability to make decisions.

Led by the commercial sector, the recent explosion of AI, primarily based on machine learning (ML), began in the early 2000s with data from successful deployment of wireless networking and connectivity, and the widespread availability of computational resources. In the last decade, this explosion was further propagated by the confluence of AI algorithms focused on data conditioning, modeling, classification, and regression; large data sets focused on collection, storage, and retrieval; and fast and cheap computing on CPUs, TPUs, and GPUs.

The commercial sector landscape for AI, which used to be niche, now spans a wide range of applications, industries, and a complete technology stack. Applications include enterprise intelligence, enterprise functions, autonomous systems, and agents such as robots and drones. Industries utilizing AI now include agriculture, education, finance and investment, legal, logistics, materials, retail, and healthcare. The technology stack includes agent enablers, data science, ML, natural language processing, data capture, storage, retrieval, open-source libraries, and computing hardware.

The Defense Department can, and does, leverage these decades of commercial investment and know-how learned from applications. However, military domains are also distinct from commercial applications and pose unique challenges. Rapidly changing battle space situations are characterized by limited access to real data to train AI, and peer adversaries who employ deceptive techniques to inject confusion and chaos. These elements challenge AI algorithms that rely on labeled datasets, crowdsourced dataset labeling, and metrics to benchmark the dataset.

Moreover, these MDO information and decision challenges require convergence of capabilities across multiple echelons at speeds and scales beyond human cognition. It is a driving force for the military to adopt AI-enabled technologies that will address these gaps with the goal of incorporation into their operations. Unlike commercial applications focused on channel-to-market, military applications must also align with defense doctrine, organization, training, supplies and equipment, leadership, education, personnel, and facilities.

To achieve this vision in MDO environments the military must be successful in addressing large-scale technical challenges. These include distributed operations in complex settings; extreme resource constraints such as weak communications or computational power; learning in complex data environments with sparse and potentially compromised data samples or highly contested environments; and relying on rapidly adaptable teams of autonomous AI systems that interact and learn from high-level mission goals set by people. At the tactical edge, this will require AI that is reliable and safe, explainable, robust to multiple varying adversarial attacks, and adaptive to evolving environments and mission tasks.

With the widespread interest in AI and the applications to data, a practitioner has a vast array of tools across the technology stack that enable AI systems built for civilian applications. These commercial platforms also offer democratization of AI with entire support ecosystems built around the platforms, which has contributed to the acceleration of AI adoption.

The introduction of AI tools as canned algorithms represents a subtle but important shift. In the past, the utilization of AI usually required carefully schematized data to fit a custom-designed application. Now, data representations and schemata are more likely to be taken off-the-shelf and pipelined into these canned algorithms. While this makes AI more easily and widely applicable, it also obscures assumptions made in the design of the data schema, which can lead to unseen biases and oversights. That is why the results from an AI system can be difficult to explain and necessitates continued exploration of systems operation on a theoretical level.

In most applications, AI practitioners comment that the actual work focuses on conditioning and preparing the data, or even constructing the databases themselves, with the actual application of AI algorithms as a limited part of making these automatic methods succeed.

What is more, AI systems must contend with system test and evaluation, validation, and verification. Challenges
include lack of a well-defined performance space and lack of trust. Predictability and lack of transparency in AI systems (because learning models are often a black box) can create issues, too. For example, when AI-based systems, especially with their highly nonlinear behavior, collect and analyze data, they may inadvertently create information that is protected with no recourse for understanding information provenance.

Finally, for DoD applications, consequence of actions must be considered. AI systems used for warfare may conflict with the ethics of private companies that would otherwise develop these algorithms.

Despite many obstacles, AI tools are expected to be crucial to military operations, now and in the future, so these problems are worth solving.

Retired US General John E. Hyten, the recent vice chairman of the Joint Chiefs of Staff, agrees. He says, “If we go into a future where there are no lines on the battlefield, and we have ubiquitous all-domain command and control and logistics that go seamlessly from place to place, from service to service, and it all happens in enormous speed...I can’t figure out in my mind how to do that without artificial intelligence.”

The upcoming conference on Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications at SPIE Defense + Commercial Sensing will dive deeply into the questions raised in this article. The story was written by Conference Chairs Tien Pham and Latasha Solomon (both from the Army Research Lab), Conference Co-Chair Ravi Ravichandran (BAE Systems), and Program Committee member Danda B. Rawat (Howard University).

### Industry Updates

#### M&A

- Evaporated Metal Films Corp. and Optometrics Corp. were acquired by Omega Optical Holdings, LLC for an undisclosed amount effective December 9, 2021.
- Kestrel Labs., Inc. was acquired by Zynex, Inc. for $31M effective December 22, 2021.
- Pfizer Inc. to acquire Arena Pharmaceuticals for $6.7B. Closing date TBA.
- Vishay Intertechnology, Inc. to acquire Barry Industries, Inc. for $21M. The transaction was expected to close on December 31, 2021.
- Delta Electronics, Inc. to acquire Universal Instruments Corp. for $88.9M. Closing date TBA.
- Quidel Corp. to acquire Ortho-Clinical Diagnostics, Inc. for $6B. The transaction is expected to close in the first half of 2022.
- Basler AG to acquire Datvision Co., Ltd. and IOVIS for an undisclosed amount. The transaction was expected to close January 7, 2022.
- Entegris, Inc. to acquire CMC Materials, Inc. for $6.5B. The transaction is expected to close in the second half of 2022.
- Prolab Instruments GmbH was acquired by Bruker Corp. for an undisclosed amount effective January 19, 2022.
- Bruins Instruments was acquired by KPM Analytics for an undisclosed amount effective January 11, 2022.
- UCB S.A. to acquire Zogenix, Inc. for $1.9B. The transaction is expected to close by the end of Q2 2022.
- Blue Origin LLC to acquire Honeybee Robotics for an undisclosed amount. The transaction is expected to close mid-February, 2022.
- Fluidigm Corp. is changing its name to Standard BioTools Inc., pending closing of a capital infusion that is expected to close late Q1 2022.

#### Executive Updates

- Marko Gerlach was appointed CFO of 3D-Micromac AG effective December 10, 2021.
- Americo Lemos was appointed CEO of IQE effective January 10, 2022. He succeeds Drew Nelson who has stepped down.
- John Rood, current CEO of Momentus Inc. has also been appointed President. He succeeds Fred Kennedy who resigned effective January 21, 2022. The company’s current CTO Rob Schwarz has taken on the additional role of Interim Head of Engineering and Operations.
- T. Paul Rowland appointed Interim CFO of Enablement Technologies, Inc. effective January 17, 2022. He replaces Craig Mode who was CFO and Co-CEO.
- Nigel Hunton was appointed President & CEO of Intevac, Inc. effective January 19, 2022.
- Clive Jennings was appointed Executive Director and CFO of Dialight plc effective January 19, 2022.
- Michael Barthlow was appointed President & CEO of BT Federal effective January 18, 2022.
- Michael Egholm of Fluidigm Corp. has been appointed CEO pending closing of a capital infusion expected to close late Q1 2022, or on May 15, whichever is sooner. He succeeds Chris Linthwaite who will continue as an adviser through November.
- Chris Kastner current COO of Huntington Ingalls Industries, Inc. was named President & CEO effective March 1, 2022. He succeeds Mike Petters.
The Growing Demand for Ultrahigh-Density Optical Data Storage

DRAMATIC INCREASES IN DATA STORAGE CAPACITIES are urgently needed as they are being outpaced by exponential growth in data generation, driven by use of the internet, social media, and cloud computing. New, long-term data storage solutions that extend beyond traditional magnetic hard disk drives or tape, and solid-state drive (SSD) storage are a must to overcome this bottleneck.

Optical techniques are widely believed to hold the key to increasing data storage capacities. With requirements of petabyte (PB) to exabyte (EB) storage capacities on the horizon, current optical disc technologies are unlikely to represent a viable option for high-capacity long-term archival storage. To meet the requirements of massive data warehouses, where magnetic-based storage technologies are still used, optical data storage in the mid to high terabytes (TB)- or even PB-per-device will be required. Optical data storage is particularly promising because it allows for multidimensional data storage.

One approach to boosting data storage capacities is 3D or multilayer optical data storage. As the name suggests, it involves information being recorded and read out in 3D structures such as multilayer discs, cards, crystals, or cubes. The writing and readout of information is typically achieved by focusing one or more laser beams into the 3D medium. Due to the volumetric nature of the storage medium, the laser is required to pass other points before writing or reading the desired datum. This means that a nonlinearity is typically required for both the write and readout functions so that only a single local point at a given time is addressed.

At the University of Southampton, United Kingdom, 5D optical data storage technology has been demonstrated. It stores information by encoding data not only in three spatial dimensions, but also by two parameters relating to birefringence that are manipulated by the polarization and intensity of a femtosecond laser focused inside a glass medium. The method could see hundreds of TBs stored in an optical medium also suffers from lack of re writability and a requirement for high-power lasers. Still, if the difficulties can be overcome, this and other multidimensional optical data storage technologies have the potential to dramatically increase optical disc capacities by several orders of magnitude, especially for archival storage applications.

Optical data storage is also suited to multilevel encoding techniques in which storage capacity can be significantly increased by writing multiple bits per point using different discretized signal intensity levels. Multilevel data storage also increases the data readout rate as several bits are read out simultaneously, which is very important for big data sets. Multilevel encoding has been demonstrated in several polymers, but suffered from photobleaching resulting in partial erasure of the data. These techniques have also been rather limited in the number of bits that could be stored.

In an emerging technique from the University of South Australia and the University of New South Wales, data can be stored using unique properties of inorganic phosphors. The optical data storage mechanism entirely revolves around modifying the luminescence spectral fingerprint of nanocrystalline phosphors with the burning of spectral holes at different wavelengths and discretized depths.

These changes to the luminescence spectrum involve exposing the nanocrystalline phosphors to certain wavelengths of light, which allows dips in the spectrum to be created in the frequency domain. These dips can be discretized in depth to store multiple bits at multiple frequencies at room temperature.
This approach has potential to be rewritable and to use low-power lasers. The technology also doesn’t require cryogenic temperatures, instead allowing spectral hole burning at room temperature making data storage with this approach significantly more practical. By dispersing such nanocrystalline phosphors into 3D media such as glass blocks, storage capacities approaching hundreds of TBs to PBs can be predicted.

These examples represent some of the many state-of-the-art optical data storage techniques emerging in the literature. They showcase the potential of optical data storage in solving the massive data storage bottleneck that society faces. It remains to be seen which technologies reach the market and are economically viable, but with large companies such as Google and Facebook taking an interest in optical discs for archival data storage applications, the optical disc is set to make a comeback in commercial applications. If, indeed, tens- to hundreds-TB optical discs can be realized economically, consumer applications are likely to follow.

NICOLAS RIESEN is a senior research fellow at the University of South Australia, a founder of Modular Photonics Pty Ltd., and an affiliate of TOMdisc.
Shining Light on Bioelectricity

AN ALL-OPTICAL, multifunctional molecular device, created by researchers at the University of Southern California, Los Angeles, promises to shine a light—actually, two lights—on the role and functioning of bioelectric fields that flow through and between cells and are fundamental to activities like thinking, talking, walking, and keeping the heart pumping.

The triangle-shaped nanodevice consists of two modules: a photo-induced electron transfer dye, tetraphenylethylene (TPE) as a two-photon imaging agent; and the organic photoconductor, naphthalimide (NAI), as an electric field-modulator. The modules are connected by a long alkyl chain that curtails crosstalk interference—a key challenge in designing multifunctional molecules. In fact, the researchers note that design of such a device is made possible thanks to recent advances in computational design algorithms that speed experimentation.

For their device, the TPE fluorophore sensor module is excited by near-IR light and can read and report bioelectric fields, via fluorescent microscopy, with high spatial and temporal resolution. The NAI photoconductor can modulate resistivity of the bioelectric field with exposure to UV light and it is tunable. The modules can be operated together or separately.

The TPE and NAI modules were chosen for low overlap of their absorption and emission spectra and the alkyl tether enforces colocalization to reduce the possibility of bulk separation. While the new device is intended for basic research outside the body on bioelectric fields, knowledge generated could be applicable in areas such as wound healing and fighting diseases like cancer and heart disease.


Rising Above the Racket in Quantum

BUT FOR THE NOISE, the adoption of high-dimensional quantum states in quantum information protocols would enable better performance in applications ranging from secure quantum communications to fault-tolerant quantum computation. Indeed, development of universal protocols able to engineer these quantum states would be a significant achievement. But the work requires a high degree of precision in characterizing noisy experimental apparatus—a precision often lacking in practical scenarios.

Now, researchers in Europe report demonstration of an adaptive optimization protocol that can engineer high-dimensional quantum states with a high degree of precision. The team turned to an automated adaptive optimization protocol to engineer photonic orbital angular momentum (OAM) states. Given a target output state, the protocol performs an online estimation of the quality of the currently produced states. It relies on output measurement statistics to determine how to tune the experimental parameters to optimize the state generation.

The algorithm does not need a description of the generation apparatus itself. Rather, it operates in a so-called black-box scenario, tuning the relevant parameters by relying only on the measured agreement between produced and target state. The handles controlled by the algorithm are the rotation angles of a series of waveplates used to probabilistically generate arbitrary four-dimensional OAM states, driving the dynamics to obtain the desired outcome.

The researchers say the proposed dynamical learning protocol will be beneficial for several quantum information tasks that require finding values of experimental parameters under noisy conditions.

Sensing an Inside Job

WE ALL KNOW AN INSIDE JOB WHEN WE SEE ONE. For researchers seeking to fully characterize the physiological function of living cells, a good look inside the complex intracellular environment would be a key advance. Accordingly, various micro/nanoprobes for subcellular measurement have been developed. These often rely on dyes and quantum dot–doped photoelectric materials as sensors or calibration objects, combined with far-field super-resolution optical technology.

But these techniques lack an effective circuit to track internal and external interactions between photoelectric signals and molecules. The accuracy of results in long-term measurement also suffers from background fluorescence interference and bleaching.

To skirt these issues and get a better look at the complex doings of the intracellular microenvironment, researchers from Nanjing University have developed an in situ nano-wire probe. The multifunctional, biocompatible, portable, and reusable microfiber probe is based on a zinc oxide nanograting-integrated microfiber. It serves as a refractive index (RI) sensor for live, label-free sensing of intracellular RI distribution and real-time monitoring of cellular molecules.

The sensing area of the device is about 800 nm × 6 μm—much smaller than that of traditional fiber gratings. The use of nanowire gratings instead of fluorescent particles for long-term single-cell detection offers a more stable and reliable performance. To demonstrate the nanowire probe function, the researchers inserted it into single living cancer cells. The device's sensitivity enabled observation of changes in cell morphology and intracellular microenvironment during apoptosis.

Quantitative detection and analysis of the refractive indices naturally occurring in single living cells during apoptosis can help to advance understanding of cell life events and disease. The Nanjing researchers say with the design of different structures, real-time monitoring of temperature and substance concentration in cells may one day be possible, allowing exploration of the evolution of cell physiological processes.

(D. Li et al., Adv. Photonics, 2022, doi: 10.1117/1. AP.4.1.016001)

Which Way the Light Goes

YOU DON’T NEED A WEATHERMAN to know which way the wind blows, Bob Dylan famously wrote, but some optical fiber and a couple of mirrors can help you keep track of which way the light is going. And that’s important for quantum communication or optical computing. An international research team based at the Max Planck Institute for the Science of Light has succeeded in measuring and influencing the direction a light wave is oscillating. They do so by manipulating the polarization of a continuous laser wave with a special glass fiber that has mirrors attached at both ends. They can change the polarization of a continuous light wave that is oscillating in one plane into a wave that oscillates in a circular manner resembling the shape of a corkscrew. To do so, they send IR light down a two-meter-long glass fiber. At both ends of the fiber are special mirrors made of thin layers of tantalum pentoxide and silicon dioxide that reflect more than 99 percent of the light. Trapped in between these nearly perfect mirrors, the light starts to change its behavior. That is, above a certain threshold of optical power the polarization changes and the light polarization moves forward in either a clockwise or anticlockwise manner. The researchers control the direction by changing the power of the light. They note that it is technically possible to miniaturize these devices and integrate them onto an optical chip, which would allow generation and control of complex polarization states, for example, for telecommunications systems. Such devices could also work as highly sensitive sensors and improve the performance of optical neural networks used in AI or for quantum information processing.

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WHEN VALERIE THOMAS, IN THE LATE 1970S, invented the illusion transmitter—a type of 3D display technology—she was also a leader of the National Aeronautics and Space Administration’s (NASA) Landsat Earth imaging program. From a little girl in the US state of Maryland, she had defied the odds to become a scientist and computer-science innovator whose work helped shape one of the most successful and versatile satellite imaging programs that continues today.

Thomas’ patented illusion transmitter, which can reproduce an image at a remote site using a camera and parabolic mirrors, is also still in use at NASA, and has had applications in television technology as well as imaging for surgical procedures.

These accomplishments are but highlights in the distinguished career Thomas began in 1964 as a recent college graduate—and one of the few Black women who worked at the agency. No stranger to adversity, in a 2019 NASA oral-history interview, she described how in those early days she had “not seen a computer except in science fiction movies.”

Thomas was born in Maryland in February 1943. From an early age, she developed an interest in mechanics after watching her father at work repairing televisions, she said in a CTV News interview. Seeing the inner workings of a television, with all its wires and circuits, fascinated her. She wanted to know how everything worked together to produce an image on the screen. This was, in fact, her introduction to the world of optics where she would find success.

Being Black and female in mid-20th century America, however, Thomas’ path was far from ordained. She told Oprah Daily about how her curiosity for electronics began. At age eight, Thomas visited her local library and came across a book titled The Boy’s First Book on Electronics. Excitedly, she took the book home to show her father hoping they could work on the science projects within. Her enthusiasm was not reciprocated, and she returned the book never having started on any of its projects. The book’s discriminatory title and the lack of encouragement at home sent a clear message. Electronics were not for girls.

As time passed, Thomas’ career in science seemed even less likely. She attended an all-girls school that hardly taught science and mathematics. Instead, she was encouraged to learn sewing and hairdressing, as these were seen as more fitting skills for girls in the 1950s.

However, Thomas was not to be deterred from her passion for electronics. She enrolled at Morgan State University, a public historically Black research university, as a physics major—one of two women in her class. She excelled academically and was set on a path to being hired as a data analyst at NASA just two weeks after her college graduation. That path would lead to Landsat.

Originally titled the Earth Resources Technology Satellite when it began in 1970, Landsat is the longest-running satellite program at NASA. Operated jointly with the US Geological Survey, Landsat satellites capture images of Earth across multiple wavelengths, allowing researchers to track a multitude of changing conditions on the Earth’s surface and in its atmosphere. “It was very exciting because it was the first time that multispectral images of the
Earth were produced from satellite data," Thomas said in the NASA interview. Landsat images are free to the public, and program data is used across many different industries from agriculture to urban planning. And that is thanks to Thomas’ early development of Landsat digital media formatting.

As she described in the NASA interview, when Landsat first became operational, Thomas saw researchers were having difficulty trying to access the complex digital data stored on computer-compatible tapes. So, she tried to configure the data in a more accessible way. 

“The scientists had difficulty in understanding how the digital data on the tape matched the visual images represented on the hardcopy or computer screen. I had experience in decommutation of scientific data and printing the information in an easily understandable format.”

Thomas became the go-to person to consult on Landsat data. The program continues to provide useful data about Earth’s surface and atmosphere, making it one of NASA’s most important resources. In fact, Landsat 9 launched 27 September 2021 with the expectation that its data would be available by this issue of Photonics Focus.

In 1976, Thomas attended a scientific exhibition where she experienced a lightbulb moment that would lead to another career breakthrough. One of the exhibits featured a projection of a burning light bulb that looked extremely real. When Thomas examined the actual light bulb being projected, it was not only turned off, but unscrewed from the lamp. She wondered how this was possible.

In a 2021 interview with Revolt TV, she said, “When I tried to touch it, my finger went right through what appeared to be a bulb. That caused my mind to wonder, what is going on? How did that happen? I decided to go to the library to look for a book to explain that phenomenon.”

The trick? Concave mirrors being used to make a projection. Thomas was fascinated and wondered how she could develop this idea further. Her big breakthrough came the following year with her invention of the illusion transmitter. The device she invented, patented in 1980, expands on television technology. That is, it takes an image created with flat mirrors behind a TV screen and, using concave mirrors, turns them into 3D projections.

Thomas believed that visualizing moving images in this way would be far more interesting and realistic. Although 3D displays were not new, the difference with Thomas’ invention was that it did not require special glasses to see the projected images. Hers is one among a small percentage of patents owned by Black inventors; even fewer are owned by Black women.

And though the technology is used by NASA, Thomas’ illusion transmitter was developed on her own time, as her career soared at the space agency.

After success with Landsat, for example, she was asked to lead a team of some 50 scientists for the Large Area Crop Inventory Experiment (LACIE), which used Landsat data to predict wheat yields on a global scale. Completed in just five months, it demonstrates the vast capabilities of Landsat to address global issues like agriculture.

From LACIE, Thomas worked her way up to become the associate chief of Space Data Operations at NASA. During the rest of Thomas’ three-decade career at NASA, she was put in charge of managing more projects such as the Space Physics Analysis Network. The project improved connectivity between computer systems and became a key part of the early internet. Thomas also developed the Minority University-Space Interdisciplinary Network which enables minority students at different institutions to connect and work with NASA scientists.

Since retiring from NASA in 1995, Thomas has used her platform and success to inspire others, especially women and young Black students. She works with organizations like the National Technical Association, Science Mathematics Aerospace Research and Technology, Inc., Shades of Blue, and Women in Science and Engineering. Thomas, who received her masters and doctoral degree while working at NASA is now a substitute teacher at a high school in Baltimore where she inspires young students to develop their passion for science.

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Next-gen Imaging
Takes Pictures that Speak a Million Pixels

When Mads Frederik Christensen, a 19th-century photographer from Copenhagen, wanted to take pictures, he had to build his own camera, like all photographers of his day. A sepia-toned image from the time shows Christensen, with a bushy white moustache and up-turned collar, standing next to his device, a boxy affair about the size of a large microwave oven that sat atop a scaffolding equipped with castors so he could roll it around.

A century or so later, in 2012, Christensen’s great-great-grandson, David Brady, built his own boxy camera, this one capable of creating the world’s first gigapixel images. “It’s about the same size as the cameras that were used in the 19th century,” says Brady, who at the time was an electrical engineer at Duke University’s Fitzpatrick Institute for Photonics. Unlike his forebear’s camera, however, Brady’s machine contained an array of 98 microcameras, with microprocessors that can stitch the individual images together.

In a sense, the two cameras represent the evolution of imaging. Where Christensen relied on the methods of conventional photography, with a lens focusing light rays onto a chemically treated plate to capture a moment in time, Brady’s uses the power of computing to derive data from the incoming light and select the relevant information to reconstruct a scene. Without that power, such a gigapixel camera would be impossible.

Computational imaging has been growing in popularity and sophistication over the last two decades, allowing it to overcome the limits of optical systems. Digital cameras can capture all sorts of information—not only light intensity and color, but also a variety of spectral data, such as polarization and phase—and use computational methods to extract information about a scene and recreate an image from that information.

“The camera would capture all potential optical information, and then you could go back and create images from that later,” says Brady, now a professor at the University of Arizona’s Wyant College of Optical Sciences. With conventional photography, the number and type of adjustments that can be made after an image is taken are limited. Computational imaging, on the other hand, allows users to refocus a photo, construct a 3D picture, combine wavelengths, or stitch together separate images into one. It can correct for aberrations, generate sharp images without lenses, and use inexpensive instruments to create photos that once would have required expensive equipment, even pushing past the diffraction limit to take pictures with resolutions beyond what a camera is theoretically capable of.
WE’RE IN A PHASE
WHERE A NEW MEDIUM HAS EMERGED,
BUT IT’S STILL IN THE CONTROL
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AS IT GETS USED BY
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WHO KNOWS WHAT’S GOING TO HAPPEN?
“Computational imaging does well when you’re trying to do something that another camera could do, but you’re trying to do it cheaper, smaller, faster,” says Laura Waller, head of the Computational Imaging Lab at the University of California, Berkeley. “Computational imaging is very good when you’re trying to do high-dimensional things—not just 2D imaging, but 3D or hyperspectral,” which images a scene at multiple wavelengths.

The difference between conventional photography and computational imaging is in part a question of designing the optical imaging system and the image processing system to work together, taking advantage of the strengths of both, Waller says. In regular imaging, the picture captured is, more or less, the result. Tweaking the image in software—to fix the contrast, for instance—does not make it computational imaging. In computational imaging, the whole system is designed to get a particular result, and what the camera captures is just a step along the way that may not look at all like the final image. It may, in fact, just be a blur.

For instance, her lab developed DiffuserCam, a system capable of creating 3D images without the use of a lens. It consists of a bumpy piece of plastic—something as simple as a piece of Scotch tape would do—placed over an image sensor. In a camera with a lens, a point in a scene maps to a point on the sensor. In the DiffuserCam, the plastic diffuser encodes a pattern of varying intensities for every point in the scene. The computer then decodes the patterns to recreate the scene. This makes for a lightweight, inexpensive system not limited by the focusing abilities of a lens. In a 2017 paper, Waller’s team used the system to reconstruct 100 million 3D voxels from a 1.3-megapixel image of a plant’s leaves.

Such a system could be useful to perform fast processing for vision systems in autonomous vehicles, for instance. It also provides a way to do imaging at challenging wavelengths for lensed systems. “X-ray lenses are terrible and they’re very expensive and they waste a lot of light,” Waller says. “Electron microscopy lenses are even more difficult.” In fact, her group is teaming up with x-ray and electron microscopy specialists at Lawrence Berkeley National Laboratory to develop computational imaging systems for their studies.

In a different approach, Waller’s group can achieve resolutions beyond the diffraction limit of a microscope objective by taking several images of the same object from different angles and using the computer to stitch the images together. They’ve replaced the light source in a microscope with an array of LEDs, and by turning on specific LEDs at different times they can illuminate the object from various angles. That produces high-resolution images across a large field of view, avoiding a trade-off between size and sharpness. Focusing at multiple depths provides large, high-resolution 3D images that can be used for biological applications, from the high-throughput screening of blood samples to in vivo studies of activity inside the brains of mice.
than the diffraction limit. Ozcan estimates the instrument cost more than $1 million when it was purchased about a decade ago. He has the neural net compare images from that instrument with others from a confocal microscope, which might cost between US $200,000 and $400,000. “We have trained that neural net to basically boost up its resolution to mimic a more expensive microscope,” he says.

A similar trick could aid in biopsies, which rely on images of tissue samples stained with various contrast agents. Staining a tissue can be time consuming, and if a pathologist wants to look at a different stain, that requires starting again with a different bit of tissue. Ozcan uses computational imaging to create virtual stains. First, he trained a neural network to look at the autofluorescence from unstained samples and relate them to images of stained samples, essentially transforming a fluorescence microscope into a bright-field microscope. Then he had the computer compare images of samples treated with different stains. Eventually what he wound up with was a way to take an unstained tissue sample and turn it into images of any stain he wanted. He showed a panel of pathologists images of samples stained by pathologists and those created virtually, and they could not tell the difference.

One particular stain of kidney tissue is exotic and expensive, Ozcan says, and can take a person about three hours to create. Creating the stained image computationally takes only a minute or two. Ozcan and one of his colleagues, Yair Rivenson, have co-founded a company, Pictor Labs, to commercialize their virtual staining techniques.

Microscopy is especially suitable for computational imaging, Ozcan says, because microscopes generate a lot of image data quickly, without variations in lighting and angles that might be more difficult for the computer to sort out. It’s possible to generate, over the course of several days, a few hundred thousand pairs of images for the neural network to train on.

That’s not to say the technology is limited to microscopy. Just about any imaging technology could benefit from computational enhancement. In virtual and augmented reality, for instance, researchers are still striving to make high-quality, lightweight optics that can be worn close to the eye and don’t suffer from chromatic aberrations while projecting desired images. “That’s certainly not a solved problem yet,” Waller says.

Even consumer applications are benefiting. “If you look at cell phone cameras these days, they’re full of computational imaging,” she says. The Google Pixel phone, for instance, has more than one pixel under each microlens to provide the camera with directional information, which in turn allows it to measure depth. “They can do all these neat things, like making your background more blurred or finding your head so they can put a fake hat on you,” Waller says. “They’re trying to go for extra information or trying to make the camera small and cheap, which is something computational imaging is good for.”

It might seem that the benefit of having smaller, cheaper optics would be offset by the cost of added computing, but because computing technology has improved so much faster than camera technology, that’s not the case. Since their invention, digital cameras have increased from 1 to 10 megapixels, Brady says. “It’s improved by a factor of 10 over a time period where memory got like a million times cheaper and communication bandwidth got a million times faster.” The data produced by cameras with lens arrays capturing multispectral images that last several seconds is massive—as much as 10 terabytes a day, in some cases—but neural processors based on machine learning algorithms can handle that, he says.

That kind of computing power can overcome some of the limits of optics. “It’s just extremely difficult to make a single lens that can resolve more than 10 megapixels for physical objects,” Brady says. “But it’s also completely unnecessary. When you go to these parallel processing solutions, you change the structure of the optical design and then you can get to really arbitrarily large pixel counts.”

Brady is also now chief scientist at Aqueti, a company he founded based on technology licensed from his former lab at Duke University. The company makes security cameras outfitted with an array of lenses to capture high-resolution video of large areas, then allows users to move around the scene and zoom in on any area within the field of view, without any movement of the camera. A video on the company’s website shows a wide-angle view of a couple of city blocks, then zooms in on construction workers on a roof, or focuses on a distant clock tower.

He imagines all sorts of new uses for technology with such capabilities. “Let’s say you’re getting married. You set up the device at the wedding. It captures all aspects of the wedding and allows you to go back to relive it in virtual reality. Why wouldn’t you want to do that?”

It’s difficult to say what all the applications for computational imaging might be, Brady says. “The kinds of things you can see, the kind of resolution that you have is very unprecedented. Insanely high resolution really,” he says, on the order of being able to focus down to a millimeter from a kilometer away.

“We’re in a phase where a new medium has emerged, but it’s still in the control of the technologists. As it gets used by artists and photographers, who knows what’s going to happen?”

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METAMATERIALS ENABLE NEW KINDS OF DEVICES WITHOUT USING GLASS, THAT DON’T RELY ON CURVATURE TO GUIDE LIGHT, BUT NANOSTRUCTURES
FOR MILLENNIA, optical lenses have been smooth, curved, and made of glass.

But in 2016, Frederico Capasso at Harvard University made a lens that was none of these. Seen with a microscope, his “lens” looked more like an army of dominoes assembling for war.

In fact, each of these dominoes was a 600 × 400 × 85 nanometer pillar made from titanium dioxide—called a nanofin because of its notched shape—arranged on a silicon dioxide wafer. Together, they formed one of the thinnest and flattest lenses ever created, with an optical resolution that put many commercial lenses to shame.

The nanofin works because light is diffracted by structures that are roughly the same size as its wavelength. What’s more, such diffracted light waves will interfere with one another, leading to bright and dark splotches.

A material that interacts with light through geometry rather than chemistry is called a metamaterial. If the geometry is restricted to a surface—say through many light altering notches such as a nanofin—the surface is called a metasurface.

Capasso demonstrated that if these structures were carefully arranged and meticulously fabricated, they could actively engineer a wavefront. They could, for example, conform light to a tight focus making a lens, or split white light into several colors creating a spectrograph.

Today, the field of metamaterials is moving forward rapidly thanks to a bunch of pioneers and their bold algorithms. Increasingly, the designs are being generated by artificial intelligence using human prompts. That’s because we don’t really know how to go from a proposed application—such as a lens—to a design that works for it. In addition, metamaterials are complicated structures that we are just getting to know.

“These are a class of materials where you create nonconventional electromagnetic, photonic, or acoustic properties that do not exist in conventional bulk materials through engineered subwavelength features,” explains Ali Adibi, professor of photonics at Georgia Tech.

“Optics is usually glass,” says Ravi Hedge, professor at the Indian Institute of Technology, Gandhinagar. “Metamaterials enable new kinds of devices without using glass, that don’t rely on curvature [to guide light], but nanostructures.”

Metamaterials devices promise a broad range of revolutionary applications. They could be used to create flat lenses necessary for miniaturizing cell phones, microspectrographs that could reveal the presence of toxic metals and other chemicals in a volume, components for...
quantum computers, cryptography and security, digital electronics that rely on light instead of electrons, and cloaking materials that render objects invisible.

Since structure is more important for these materials than chemistry, most of them are made with silicon and other conventional electronic materials that we know very well how to etch intricate structures on using established processes. This has made metamaterials attractive to many device manufacturers, and metamaterials research is one of the hottest topics in science.

The number of possible metamaterials is infinite. You can craft any number of structures—pillars, bars, rods, spheres—on the nanoscale, and arrange them in any combination. Each design element can be made of slightly different dimensions and of different materials. They can be stacked, rotated, or made to intersect. Each structure has a unique electromagnetic response that can be precisely calculated.

But the reverse problem—calculating a design that gives the desired performance—turns out to be extremely challenging.

“Designing custom metamaterials is challenging because each device has many dimensions, and each dimension can have tens to hundreds of parameters,” says Jonathan Fan, a professor of electrical engineering at Stanford University. Suppose a device has 10 free parameters that can be altered, and that each of these parameters, called dimensions or degrees of freedom, can take any of 10 possible values. That gives a total of $10^{10}$ structural choices—an impossibly vast space to explore.

Many commercially available software packages can calculate the electromagnetic (EM) output response (also known as EM solvers) for a given input structure and incoming light wavefront. They rely on Maxwell’s Equations, and are highly accurate, but tend to be time consuming.

“Suppose each calculation requires five minutes,” says Adibi. “It would take $5 \times 10^{10}$ minutes to check the whole design space.” That’s roughly 95,000 years.

One approach, then, is to use mathematical techniques to reduce the number of dimensions of the problem. “All we are doing is intelligent search,” explains Adibi. Recently, he used such a method to design a reconfigurable metamaterial that changes shape when an electric field is applied. These designs can play an active role in devices, instead of the passive designs currently being explored. However, dimensionality reduction is not always a solution because the time required for the reduced dimensions can still be enormous.

That’s why metamaterial researchers are increasingly turning to data-driven approaches such as deep learning to tackle the inverse design challenge.

In this approach, small computational elements called neurons store two numbers called weight and bias. An input signal is multiplied by the weight and added to the bias. If it exceeds a certain threshold value, the neuron passes the signal to the next neuron it’s connected to where the whole process repeats with a different weight and bias. Typical deep learning architectures used in language and image processing contain billions of these neurons each with a weight and bias.

The power of deep-learning models is that they can learn the correct weight and biases for an application from examples. For instance, a sequence of metamaterial designs and their outputs can be fed to a neural network. The model’s output is compared to a regular EM solver and the result is fed back into the network. Over hundreds and thousands of examples, the deep-learning model twiddles its weight and biases until the output matches what was calculated using Maxwell’s equations. Once the model is trained, the neural network can calculate a response in a matter of seconds.

If this sounds really complex, it is. But it has been shown to work again and again for all sorts of applications ranging from self-driving cars and language translation, to image recognition. No one really knows how neural networks are able to learn so well. A leading theory is that they act as sieves for data, so that only the most common—and hence fundamental—pieces of information reach the other end. Because they
are modeled on the human brain, this paradigm is known as artificial intelligence (AI).

Hedge uses this approach in conjunction with a so-called evolutionary algorithm to calculate the best designs for a metamaterial color filter and color splitter.

“A color filter separates out a particular color from white light. A color splitter will separate out wavelengths of light like a prism and direct each color in a different direction,” he says. It could be useful, for example, in some types of solar cells where infrared, ultraviolet, and visible light can be used simultaneously.

Hedge first trains a neural network to learn the electromagnetic response of metamaterial structures from hundreds of examples. This deep learning model does what an EM solver does but in a fraction of the time. A set of randomly generated designs are checked with the model, following which the poorest designs are dropped. The remaining designs are tweaked and made to swap design elements with other structures. This imitates a computerized version of evolution and natural selection with the Darwinian goal of surviving the chopping block at the model. During thousands of such iterations, the model continually improves its performance to reach an optimal design.

While evolutionary approaches are powerful and effective, deep learning can also be used directly for inverse design.

At Northeastern University, associate professor of electrical and computer engineering Liu Yongmin creates chiral metamaterials that separate light according to its polarization. Chirality refers to the handedness of a molecule. DNA, for example, is right-handed, like most molecules in the human body. “Polarized light interacts with chiral molecules differently and can be used for medical diagnostic and analytic purposes,” he says. Yongmin uses specialized deep learning architectures to solve the inverse design problem. In one, called an autoencoder, the input structures and their EM responses are used by a neural network to learn a mathematical representation called a latent space, which is like a map of the design space. If a good design is located at one point of the latent space, nearby points must also be good. New metamaterials can be designed easily once the latent space has been generated.

Though impressive, deep learning cannot guarantee the perfect metamaterial design for a given application. That’s because the inverse design problem does not always have a unique solution. Multiple structures that are not identical
can produce the same output response. So, it’s possible that a design discovered using hours of laborious computation might not be the best device in terms of performance or the easiest to manufacture.

To understand why this might be the case, we need to imagine that every possible design—excellent, good, bad, and terrible—is placed on an imaginary landscape such that the elevation of each device is inversely proportional to its performance. The best solutions—devices that meet our criteria—are the ones that lie at the bottom of a pit. Translated into this landscape, the goal of the inverse design problem is to find the lowest point starting from some random location.

The problems that deep learning excels at solving have simple bowl-shaped landscapes with a clearly defined lowest point. The metamaterial design landscape, on the other hand, is more like the Appalachian Mountains with many peaks, valleys, crevices, and chasms. Each chasm gives us a device that produces the desired response, but there is no guarantee that we have reached the deepest point, or correspondingly, the best possible device.

At Stanford, Fan is pioneering a method that tackles this problem head on. Called GLOnets (global topology optimization networks), his approach uses neural networks to smooth out the mountainous landscapes of other neural networks. Fan’s group has used this method to design high-efficiency diffraction gratings and thin-film stacks.

He is also working towards making the neural networks physics aware. The idea is to incorporate physical equations—such as the wave equation—into the training for deep learning models so that their efficiency and performance can be further fine-tuned.
Fan advocates Metanet, an open database where anyone can upload and download metamaterial designs and their resulting responses. His vision is to have a platform that allows anyone to check or validate an idea for a design within a few seconds or minutes of conception. This will enable everyone to have access to plentiful training data for their models, in addition to the trained models.

“In the metamaterial community, it is difficult to compare algorithms as everyone solves their own problems. Without a standardized dataset, it is difficult to compare results and to coordinate research efforts,” he says. This sentiment carries across the community.

“We should share data,” Adibi says. He proposes that companies that develop commercial photonics software provide a common platform for data sharing.

The other crux in the community is being able to learn new physics from the models generated by deep learning. Neural networks are considered something of a black box, meaning that there is often no explanation for how the model arrived at a particular solution other than through laborious number crunching. As a result, the photonics community doesn’t learn anything new, even if all the inverse design problems have been solved. Only genuine scientific insights might advance metamaterials to the next stage in their evolution.

For example, the design elements of a successful model could be performing novel nonlocal interactions that could help in engineering better devices. “Explainable AI is necessary to tackle even more complex problems, such as heterogeneous metamaterials,” says Hedge. These are made from multiple materials and span a wider range of chemistries than the systems studied today. Their potential applications are also consequently more diverse.

“The whole relationship between inputs and outputs is in the neural network weights,” notes Adibi. “If you try to understand them, they may tell a lot about a hidden world we don’t understand well.”

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Ever since computers evolved beyond purely analog mechanical devices in the 1940s, they’ve operated by moving and manipulating electrons, whether in vacuum tubes, transistors, or silicon chips. The state of technology didn’t allow any other reasonable possibilities, and there really wasn’t any pressing need for some. But in a 21st-century world becoming ever more dependent on crunching ever more data at faster and faster rates to support artificial intelligence (AI) applications, a new approach is taking hold: Faster and more efficient computing using photons.

The basic idea of optical computing has been around for decades, but its new incarnation is more properly termed photonic computing. As Nicholas Harris, founder and CEO of Lightmatter, a photonics computing startup, puts it, “The word optical kind of harkens back to more of bulk optics, free space lenses and mirrors, that sort of thing. Photonics is more of an integrated platform: The word photonics is parallel to electronics.”

Simply defined, optical/photonic computing uses photons to calculate a desired function or mathematical operation.

The early attempts at optical computing technology, in the late 1970s and early 1980s, turned out to be not quite ready for prime time, mostly because, as Andrew Rickman of Rockley Photonics remarked in a presentation remarked in 2018 at SPIE Photonics West, “Photons behave differently from electrons.” That fact posed serious problems when Bell Labs researchers experimented with creating an optical transistor. “In the ’80s, Bell Laboratories was claiming that they had come up with an optical computing technology,” Harris says. “They were working on an optical transistor. Transistors are nonlinear, which means that you can do things like create logic statements—if this/then, that sort of thing. It allows you to write programs using those statements. That’s what digital computers are really good at. What they found is that you really couldn’t string together very many logic operations before you lost all your signal, and that there were a bunch of challenges in trying to build logic with optics.”
As Ryan Hamerly, a visiting scientist at MIT’s Quantum Photonics Laboratory, wrote in an IEEE Spectrum article: “Nonlinearity is what lets transistors switch on and off, allowing them to be fashioned into logic gates. This switching is easy to accomplish with electronics, for which nonlinearities are a dime a dozen. But photons follow Maxwell’s equations, which are annoyingly linear, meaning that the output of an optical device is typically proportional to its inputs.” Aside from the significant loss of signal, there was also the problem of storing optical data.

At the time, the realities of the technology couldn’t quite live up to the hype surrounding it, and it became clear that optical transistors weren’t going to be replacing the traditional silicon variety anytime soon. Work using optical systems to explore quantum computing concepts continued in the 1990s with bulky free-space components such as lenses and lasers mounted on large breadboards, impractical for any kind of application.

“My background is in physics,” Harris notes. “And I can tell you that you really don’t want to do nonlinear operations using optics or photonics. Running operating systems and more general-purpose computing is not likely to be done fully using optics.” Optical technology in the form of fiber optics may have revolutionized communications and the growth of the internet, but the computers and other devices it tied together still largely consisted of conventional microelectronics.

As the computing universe moves ever deeper into AI solutions for an increasing range of applications, however, photonic computing is presenting unique possibilities. It turns out that integrated photonics, in which photonic devices are incorporated on a microchip, is just the thing for the massively parallel processing needed for artificial intelligence systems (AI), machine learning (ML), and deep learning neural network calculations, offering far greater speed and computing efficiency while using far less power than electrons.

Lightmatter has developed a photonic chip called Envise, specifically designed for AI. “It isn’t the type of computing that you would do to run an operating system or a video game,” Harris explains. “It’s for running neural networks. The computation that you’re doing a lot of the time there is linear algebra, a lot of adds and multiplies. We’re able to do those adds and multiplies using integrated photonic components.” As a very broad mathematical tool used in modeling all sorts of real-world phenomena from rocket launches to financial transactions, linear algebra is also at the heart of deep learning algorithms. Those depend on a linear algebra operation called matrix multiplication, which lends itself quite well to the analog linearity of photonics. “AI is the first market we’re going after because it’s a very exciting market, and it has huge implications for humanity.”

Renewed enthusiasm for dedicated AI processor chips was spurred in 2017 when Google announced its development of a deep learning processor called the tensor processing unit (TPU). Harris says, “It basically had an array of these matrix processors, 256 × 256 multiply-accumulate units. And with that, they were able to accelerate a lot of the core computations in deep learning. What we’re doing is similar to Google’s TPU work. We’ve replaced their electronic compute core with a photonic compute core. It saves a ton of power and allows you to run a lot faster.”
Indeed, a major selling point for photonic computing is its greatly reduced power consumption. The proliferation of large data centers and cloud computing is demanding ever more of the world's energy while also contributing significantly to accelerating climate change. According to Harris, photonics can play a major role in changing that.

"If you look at all of computing, the fastest growing segment is AI, and the energy footprint of the computing field in total is going to be something like 20 percent of the entire planet's energy consumption by 2030."

“So, let’s say that AI gets to 10 percent of that. You’re talking about two percent of the entire planet’s energy consumption just on this specific type of program that you might run. What we’re trying to do is reduce that environmental impact. Our technology allows you to run the same programs faster but using significantly less energy.”

A key part of Lightmatter’s Envise chip and other integrated photonics is a highly miniaturized version of a device called a Mach-Zehnder interferometer (MZI), which splits and recombines a collimated laser beam at the nanoscale. Large arrays of MZIs perform the matrix multiplication at the core of most deep-learning AI algorithms. “There’s been a lot of innovation that’s gone into the core compute element that goes into our processors,” says Harris. The Envise chip, which Lightmatter claims is anywhere from five to 10 times faster than Nvidia’s top-of-the-line A100 chip for AI, will be hitting the market this year, complete with a specially designed software stack that will allow plug-and-play compatibility with existing systems.

Lightmatter is only one of the players in what’s becoming a rapidly expanding photonics computing market. Others include Luminous, Optalysis, and Lightintelligence, each pursuing their own variations on the photonic computing theme.

Some companies such as Ayar Labs in California are focusing not on the processor core at the heart of the computer but how that core moves data in and out. Instead of transforming the CPU of the computer to photonics, the idea is to speed up communications within the system and its connections with the outside world. “We use some of these same underlying technologies, but we’re focused on solving different problems,” says vice president and managing director Hugo Saleh. “There’s a massive market opportunity here to open up these bottlenecks that have been preventing communication between chips. And this really ties into things like high-performance computing and AI.”

Just as fiber optics enables faster communications than copper wires for internet and cable, it can do likewise inside a computer, where billions of components must connect and communicate as fast as possible. “There’s something called SerDes [serializer/deserializer], which is the electrical signaling that goes from switch chip to a node,” Saleh says. “That electrical signaling rate now is getting very difficult,” he says, because it raises energy costs and introduces problems like heat that can mean difficult revisions to the engineering. “They went from 10 gig to 25, to 50 to 100, and they’re jumping through hoops to try and figure out how to keep driving that signaling rate higher and higher.”
And there’s a general consensus that the 100-gig generation is it.”

Ayar’s solution uses integrated optical input/output (I/O) chiplets that interface with larger chips to vastly increase data rates. Saleh says, “With an electrical wire, you can send one signal down at a time. With a fiber, you can send multiple frequencies down at the same time. In our case, we send eight colors of light all at the same time.” That means eight times the amount of information can be sent down the same optical fiber.

Just like the integrated photonics processor, optical I/O also offers a significant energy payoff. “We’re about a tenth of the energy required to move the data as electricity,” Saleh says. “If you’re talking about one chip, that’s not a big deal, but you start talking about someone like Google or Microsoft that has a million CPUs in a data center, and then they have tens of those data centers…” Doing the math, converting the world’s data centers to optical switching could mean a savings of up to five percent of the world’s energy.

“It’s really about more data, lower power, lower cost. All the key metrics that you think of in data center operation get improved by photonics,” he says. “This to me is the foundational technology that’s going to be required to enable the next wave of innovation that comes through the internet and beyond. When I hear things like ‘metaverse,’ AI and ML, for me, none of those things are possible without a complete transformation of the underlying infrastructure and how that infrastructure communicates.”

He makes an analogy with the US interstate highway system, which moves all major commerce. “[Photonics] opens up those freeways, those interstates, all the way into the core chip. We think it’s a wholesale transformation.”

Photonic computing isn’t a wholly limitless frontier, however: There are some inherent constraints. Because the calculations performed by photonic chips such as Envise are analog rather than digital, they can be somewhat less accurate than conventional transistors, and system noise can also be a problem. Photonic devices such as MZIs also tend to be larger and can’t yet be packed on a chip as densely as more traditional electronic components.

Although designers are working diligently to overcome such obstacles, it’s unlikely that all computers are going to go fully photonic anytime soon. “It’s not going to be in your cell phone,” says Harris. Optical computing, he predicts, will first be more of a high-performance AI accelerator for use by financial institutions, retail businesses, the military, and autonomous vehicle makers.

With AI systems striving for ever greater computer power, photonics computing technology offers a way around the inexorable technical limits of Moore’s law. Nicholas Harris offers an inside joke at Lightmatter: “Moore’s law? No problem.”

MARK WOLVERTON is a freelance science writer and author based in Philadelphia.
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#SPIEDCS
THE PAST TWO YEARS HAVE BEEN FRAUGHT WITH CHANGE. In both our professional and personal lives, we have needed to adapt to a world in which people are further away from each other and technology has taken charge of daily life. We are all sick and tired of seeing people on a screen from 7 am to 6 pm, and “work from home” has made it difficult to separate work from home.

Never has this been more apparent than when conferences moved to a virtual setting. “Going away to a conference” is hard to do when you are only going as far as your computer. So, attending a virtual technical meeting became about juggling one more thing, rather than a time to meet old friends and colleagues, and make new ones. And I have been completely out of touch when it comes to new products and technologies without exhibits and meetings with my industry colleagues.

As Photonics West 2022 approached, it was all my group at Vanderbilt University could think about. But navigating the pandemic has been all about timing. What felt safe yesterday could turn on its nose the next day or next week. When the omicron variant hit, we all kept our fingers crossed that the wave would pass, or at least start to fade, by the time of the meeting. It was close, but SPIE braved on, and on 21 January I landed in San Francisco ready to tackle being SPIE President at the Society’s largest meeting.

I was prepared to greet everyone and share my personal experiences with first timers and hang out with old friends. I brought nearly my entire team since none of us had been to a meeting since Photonics West 2020! Two years is a long time to go without sharing your scientific discoveries, especially for second and third year PhD students. And indeed I met and greeted many attendees and exhibitors and nearly everyone was thrilled to be there! We are a close knit community and this showed with everyone willing to do their part to make this conference a success. Early career professionals and students and even staff pitched in when needed and overall, everyone I spoke to agreed that the success of Photonics West portended to a positive outlook to 2022.

For the exhibitors present, the meeting provided opportunities for in depth interactions and meaningful conversations with technical conference and exhibition attendees which are vital to business in the coming year. I was pleased to meet exhibitors and attendees from not just the United States but also from France, Germany, Switzerland, The Netherlands, Japan, India, and more in the exhibit halls and exchange business cards while toasting to the return of Photonics West.

After a full and exhausting week, I am thankful for all who attended, and also understand why others chose not to. For me, it has once again become clear that in-person connection cannot be replaced, and I am proud of the Society’s efforts to support conferences that enable them. I look forward to the coming year and hope to see more of you at many more in-person meetings to come.

ANITA MAHADEVAN-JANSEN
2022 SPIE PRESIDENT
# SPIE Deadlines and Events

## March

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<td>Call for Papers opens for SPIE/COS Photonics Asia</td>
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<td>6-10:</td>
<td>SPIE Smart Structures + Nondestructive Evaluation, Long Beach, CA, USA</td>
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<td>9:</td>
<td>Abstracts due for SPIE Sensors + Imaging, including: Remote Sensing and Security + Defense</td>
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<td>Manuscripts due for SPIE Defense + Commercial Sensing</td>
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<td>Applications due for Eichenholz-SPIE Photonics Technician Scholarship</td>
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<tr>
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<td>SPIE Defense + Commercial Sensing, Orlando, FL, USA</td>
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<td>19-22:</td>
<td>Optics and Photonics International Congress (OPIC), Yokohama, Japan</td>
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<td>SPIE Advanced Lithography + Patterning, San Jose, CA, USA</td>
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<td>26-28:</td>
<td>Photomask Japan Digital Forum, Yokohama, Japan</td>
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<td>4:</td>
<td>Abstracts due for SPIE/COS Photonics Asia</td>
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<td>Manuscripts due for SPIE/RIT Photonics for Quantum</td>
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<td>15:</td>
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<tr>
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<td>SPIE/RIT Photonics for Quantum, Rochester, NY, USA</td>
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<td>Manuscripts due for SPIE Astronomical Telescopes + Instrumentation</td>
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<td>17-22:</td>
<td>SPIE Astronomical Telescopes + Instrumentation, Montréal, QC, Canada</td>
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<td>27:</td>
<td>Manuscripts due for SPIE Optics + Photonics</td>
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<td>10:</td>
<td>Manuscripts due for SPIE Sensors + Imaging, including: Remote Sensing and Security + Defense</td>
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<td>12:</td>
<td>Voting closes for the SPIE 2022 election</td>
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<td>21-25:</td>
<td>SPIE Optics + Photonics, San Diego, CA, USA</td>
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**SPIE Awards**

SPIE Awards honor the best in optics and photonics for significant achievements and contributions in advancing the science of light.

Honor someone in your community who has made a difference.

**Nominations are due 1 July 2022**

[spie.org/awards](http://spie.org/awards)

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**Family Care Grants**

SPIE believes that parents and care givers should have an equal opportunity in sharing their research and participating in conferences and symposia.

SPIE Family Care Grants are designed to supplement caregiving costs incurred by SPIE Members who are registered to attend a SPIE conference.

Learn more at: [spie.org/familygrant](http://spie.org/familygrant)
SPIE Awards Announced

**Early Career Achievement Award—Academic**

BHAVIN J. SHASTRI, for pioneering efforts in the field of neuromorphic photonics and his contributions to interdisciplinary research across nanophotonics, unconventional computing, and silicon photonics that pushed the frontiers of machine learning.

Shastri coined the term neuromorphic photonics and co-authored the first textbook in the field, in 2017. His research lies at the interface of nanophotonics, neuromorphic computing, and silicon photonics platforms, an area that promises to open new frontiers in machine learning for artificial intelligence and brain-inspired computing.

The SPIE Early Career Achievement Award—Academic is presented in recognition of excellence in academia and significant and innovative technical contributions in the engineering or scientific fields of relevance to SPIE.

**Early Career Achievement Award—Government/Industry**

LIONEL CLERMONT, for significant achievement in the field of stray light control, particularly his work on the ultrafast time-of-flight imaging characterization method.

Clermont, an optical engineer at the Centre Spatial de Liège, recently developed a disruptive approach for stray-light control in space instruments: time-of-flight (TOF) stray-light characterization, an advancement toward the development of higher performing space telescopes. He improved the design of a laser guide star system for adaptive optics by implanting an afocal configuration with controlled defocus, creating a thinner artificial star, and providing a better reference for the atmospheric turbulences that affect ground-based telescopes.

The SPIE Early Career Achievement Award—Government/Industry is presented in recognition of excellence in industry/government and significant and innovative technical contributions in the engineering or scientific fields of relevance to SPIE.

**Harold E. Edgerton Award in High-Speed Optics**

SPIE FELLOW MONA JARRAHI, for pioneering contributions to plasmonic time-domain spectroscopy and imaging systems including their scientific and industrial applications.

Jarrahi, a professor of electrical engineering and the director of the Terahertz Electronics Laboratory at University of California, Los Angeles (UCLA), has made significant contributions to the development of ultrafast optoelectronic devices and integrated systems for terahertz, infrared, and millimeter-wave sensing, imaging, computing, and communication systems.

The SPIE Harold E. Edgerton Award in High-Speed Optics is presented for outstanding contributions to optical or photonic techniques in the application and understanding of high-speed physical phenomena.

**Maria Goeppert Mayer Award in Photonics**

SPIE FELLOW SHIN-TSON WU, for seminal contributions to display and photonic device technologies that have led to widespread applications.

Wu, Pegasus Professor of Optics & Photonics at the College of Optics and Photonics (CREOL) of the University of Central Florida, is a leader in the field of display science and device technology. After nearly four decades of work in industry and academia he has obtained 191 patents from his work developing new liquid crystal materials, devices, and applications. His advanced LCDs and photonic devices have made a tangible impact on the global display and photonic industries.

The SPIE Maria Goeppert Mayer Award in Photonics is presented in recognition of outstanding contributions to the field of photonics and the development of innovative, high impact technologies.

See the entire list of SPIE Award winners at [spie.org/2022awards](http://spie.org/2022awards)
In Memoriam: Jack D. Gaskill

SPIE FELLOW AND PAST PRESIDENT JACK D. GASKILL, professor emeritus at the University of Arizona’s (UA) Wyant College of Optical Sciences (OSC) died 24 January at his home in Tucson. He was 86.

Gaskill joined UA in 1968 as an assistant professor of optical sciences. His career included publishing the book, Linear Systems, Fourier Transforms, and Optics, in 1978 and serving as associate director for academic affairs. He was also instrumental in establishing the Industrial Affiliates program at OSC.

Throughout his career, Gaskill recognized the importance of being involved with professional societies personally and for his students. He became a Fellow of SPIE in 1977 and served as editor of the SPIE journal Optical Engineering from 1985 to 1990. He was awarded the SPIE President’s Award in 1990, and then elected SPIE President in 1995, an experience he described as “one of his best.”

In a 2016 OSC interview, he said, “As President of SPIE, I was given opportunities to visit other universities and industrial companies that were involved in optics. I traveled throughout Europe and Asia, places I might not have visited otherwise. I also was introduced to some incredibly accomplished individuals that I might not have met otherwise.”

Upon retirement from OSC in 1999, contributions to the college by Gaskill and his wife Sandra led to establishment of the Jack D. Gaskill Undergraduate Scholarship. In 2015, colleagues, friends, and alumni established the Jack D. Gaskill Graduate Student Scholarship.

Gaskill was widely known for his poetry/limerick-writing skills and great sense of humor—he almost always began his lectures with a joke—and for his walk-on role in the 1984 film Revenge of the Nerds, which was filmed on the UA campus. An optics advocate to the end, his Arizona license plate proudly read “YAY.”

Read the full obituary at spie.org/GaskillObit

In Memoriam: John Greivenkamp

SPIE FELLOW AND PAST PRESIDENT John Greivenkamp, professor emeritus at the University of Arizona’s (UA) Wyant College of Optical Sciences (OSC) passed away on 29 January. He was 67.

After receiving MS and PhD degrees in optical sciences from UA in 1976 and 1980, Greivenkamp joined Eastman Kodak Research Labs in Rochester, New York, USA. He returned to OSC in 1991 as an associate professor of both optical sciences and ophthalmology and became full professor in 1997.


A passionate advocate of education, Greivenkamp received the 2017 SPIE Maria J. Yzuel Educator Award for his dedication to both formal and informal optics education, his passion for transferring knowledge to the next generation of engineers, and for inspiring all students to appreciate science.

“John’s commitment with SPIE spanned over a quarter of a century and encompassed everything that our society does,” said SPIE CEO Kent Rochford. “John’s deep involvement yielded insights and historical context that SPIE will sorely miss. But what I will mostly miss is his friendship.”

Read the full obituary at spie.org/GreivenkampObit
SPIE Announces 2022 Society Fellows

THIS YEAR, 58 SPIE MEMBERS become Fellows of the Society in recognition of their innovative technologies and scientific breakthroughs developed and generated across the optics and photonics enterprise in academia, industry, and government, as well as their long-term contributions to SPIE.

Of this year’s inductees, including the first SPIE Fellows from Egypt and Chile, half are from the United States whereas the rest hail from Australia, China, Germany, Japan, Malaysia, Poland, the Republic of Korea, Singapore, Spain, Switzerland, and Taiwan.

“SPIE Fellows represent the breadth of our global constituency as well as the technical range, diversity, and ethos of our Society,” notes Michelle Stock, chair of the SPIE Fellows Committee and TracInnovations’ director of business development and sales. “I’m delighted that we have continued to diversify our Fellow Membership geographically this year.”

See the complete list of the 2022 SPIE Fellows at spie.org/spiefellows2022

In Memoriam: Alan Paxton

SPIE FELLOW ALAN PAXTON of the US Air Force Research Lab (AFRL) at Kirtland Air Force base in Albuquerque, New Mexico, passed away in December 2021. Known for his expertise in laser physics, Paxton was cofounder of the SPIE Laser Resonators, Microresonators, and Beam Control conference, and served as its cochair for 12 years. An SPIE Member for more than 22 years, he also served as editor and author of several papers in the SPIE Digital Library, and was an SPIE Community Champion in 2019 and 2020.

“Alan was an outstanding scientist. At the same time, he was a very modest person,” said colleague Alexis Kudryashov, professor at the Institute of Geosphere Dynamics, RAS, and scientific director of Active Optics NightN Ltd. “He really played a great role in organizing our Laser Resonators Conference, inviting different interesting scientists, and he also did a lot of bureaucratic work— he was in charge of the preparation of the final program for many years.”

“Al has been an exemplary colleague and mentor in the uneasy but interesting world of our scientific community, and was indeed, a true gentleman scholar,” added Vladimir Iltchenko, photonics engineer at NASA Jet Propulsion Laboratory. “His passing is great loss for all of us, but what he has built will remain.”

Read more at spie.org/PaxtonObit

2022 Nick Cobb Memorial Scholarship

YONGHWI KWON is the 2022 recipient of the $10,000 Nick Cobb Memorial Scholarship, which recognizes an exemplary graduate student working in the field of lithography for semiconductor manufacturing. Cobb was an SPIE Senior Member and chief engineer at Mentor Graphics whose groundbreaking contributions enabled optical proximity correction for IC manufacturing.

Kwon is a PhD candidate in the School of Electrical Engineering at the Korea Advanced Institute of Science and Technology (KAIST). He plans to pursue research in computational lithography utilizing adaptive machine-learning techniques. He says his goal is to make a reinforcement-based standard cell layout generator that takes into consideration manufacturability, power, and area, with plans to create a company post-graduation.

“I am truly honored to receive the Nick Cobb Memorial Scholarship,” Kwon says. “Since Nick’s work on OPC is a fundamental basis of my work on computational lithography, this scholarship is especially meaningful. I am looking forward to presenting my research, as well as attending talks and presentations at upcoming SPIE conferences.”
Advanced Photonics Nexus Debuts

**Advanced Photonics Nexus** (APN), an Open Access journal co-published by SPIE and Chinese Laser Press (CLP), anticipates publication of its first issue in the second half of 2022. This latest SPIE-CLP publishing partnership focuses on original papers, letters, and review articles that reflect important advances in fundamental and applied aspects of optics and photonics.

*Advanced Photonics Nexus* is a sister journal of the highly selective *Advanced Photonics*. Like its sister publication, APN ensures fast-track publication of high-quality research submissions. Research areas covered include imaging systems, metamaterials, nanophotonics, optical fibers, quantum optics, ultrafast optics, biophotonics, and lasers.

Co-Editors-in-Chief are Xiao-Cong (Larry) Yuan, of Shenzhen University, Anatoly Zayats of King’s College London, and Weibiao Chen, director of the Shanghai Institute of Optics and Fine Mechanics.

“We are very grateful to the optics and photonics community for their support and trust in the Advanced Photonics journal, and we plan to develop this new venture, *Advanced Photonics Nexus*, to further serve researchers by providing rapid dissemination of their important results,” notes Zayats. “One of the meanings of the word nexus is a central or focal point. We hope that this new journal will be a focal point for our existing as well as new authors and readers across all fields of optics.”

Read more at [spie.org/APNexus](http://spie.org/APNexus)

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**AT THE 12TH ANNUAL SPIE STARTUP CHALLENGE** at Photonics West in January, VitreaLab and its laser-lit chip technology was announced winner of the competition’s $10,000 top prize. The company’s chip enables more power-efficient displays and is aimed at the 2D and 3D display market.

Quantopticon, a designer of simulation software for quantum photonic hardware manufacturers, received $5,000 for second place. Lumines took third place, winning $2,500, with their versatile platform for safer, more sensitive, and more reliable x-ray medical imaging.

The SPIE Startup Challenge showcases new businesses, products, and technologies that address critical needs within photonics, and is supported by Founding Partner Jenoptik, Lead Sponsors MKS Instruments, Hamamatsu, Edmund Optics, and Thorlabs; and Strategic Partners Alliance and NextCorps’ Luminate.

In addition, as part of the overall SPIE Startup Challenge program, four companies in the process of fundraising—Fastree3D, Raydiant Oximetry, Stratio, Inc., and UbiQD—presented their new technologies to prospective investors. All cash prizes for the Challenge awards were provided by Jenoptik.

“What I love about the Startup Challenge is that it brings the most promising technologies and connects them with investors,” noted Ian Tracey, founder of Anchored In, who served as one of the judges. “It allows us to take photonics technology to market and change the world for the better. I love the energy and the focus of these competitors, and there was such a wonderful variety of different technologies that they touched upon. It was really fantastic seeing them as they came on stage, to spot their energy and enthusiasm.”

Read more at [spie.org/Startup2022](http://spie.org/Startup2022)

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**2022 SPIE Startup Challenge: Winners showcase emerging photonics innovations**
SPIE AND THE UNIVERSITY OF ROCHESTER have established a $1 million optics graduate fellowship to provide financial assistance to select University of Rochester Institute of Optics graduate students. A $500,000 gift from the SPIE Endowment Matching Program will be matched 100 percent by University of Rochester.

Announced at SPIE Photonics West in January, this is the tenth major SPIE gift to universities and institutes as part of the Society’s program to expand optical engineering teaching and research.

“We are so grateful to SPIE for making this kind of investment in graduate education in optics,” says Institute of Optics Interim Director Thomas Brown. “Our alumni have had important leadership roles in SPIE through the years—this will be a huge help in preparing the next generation of leaders in the optics community. One of the fun things about gifts like this is that it allows us to invest in the best, to continue to search for future Nobel laureates, entrepreneurs, and engineers from all over the world to come to Rochester and be part of our growing family.”

“The SPIE Graduate Fellowship in Optical Sciences and Engineering will create transformative opportunities for PhD candidates at Rochester’s Institute of Optics,” says SPIE President Anita Mahadevan-Jansen. “Rochester has a long history of successful optics education and many of today’s leading optics researchers have emerged from its Institute of Optics. This endowed fund is a critical partnership between SPIE and the University of Rochester, one that will help ensure that pipeline of leaders continues for generations to come.”

Read more at spie.org/spiegradfellowship

SPIE Graduate Fellowship in Optical Sciences and Engineering

BONUS: Unscramble the letters to solve the final puzzle: What was the name of a pioneering Big Data Earth imaging program begun in the 1970s?
Reflections

This photo is a seldom seen application of schlieren imaging. It is a vibration pattern on the surface of a layer of molten paraffin wax in a shallow circular Pyrex vessel. The photo was taken with a color reflection schlieren setup where surface irregularities cause the light in the schlieren beam to be deflected by the changes in surface slope of the liquid. The “knife edge” filter array consisted of red, green, and blue filters.

Photo by: Andrew Davidhazy, Rochester Institute of Technology (Ret.)
davidhazy.org/andpph

Submit your own images of light properties and light-based technology to REFLECTIONS by mentioning @SPIEtweets or @spiephotonics. Submissions can also be sent by email to photonicsfocus@spie.org.
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