# Andy Phung

Optoelectronics is the perfect marriage of materials science and electrical engineering. By exploiting the optical properties of certain materials, such as quantum dots or semiconductors, one can create novel components and devices capable of interacting with and utilizing light to perform certain tasks.

For instance, consider the active-pixel sensor, which is typically composed of a large array of light-to-electrical current converters exploiting the photoelectric effect (photodiodes) and MOS field-effect transistors to amplify the normally faint generated electrical currents. These sensors replaced the now-inferior charged-coupled device (CCD)-based sensors as the imaging and video industries moved towards high-definition images and video, as the power consumption rates of these CCD sensors were simply too high with larger arrays of pixels.

However, optoelectronic devices are not limited to just the detection of light or applications that require the usage of light. Just as we have built entire quantum computers to enable efficient computation with qubits and quantum algorithms, we can build computers that exploit the properties of light and use optoelectronic components for faster computation.

Instead of using electronic transistors to build logic gates that scale to circuits as traditional computers do, optical computers utilize optical transistors. Systems such as cavity quantum electrodynamics systems and systems of dye molecules have been used to mediate the photon interactions that are required to build a transistor, as photons cannot interact due to not possessing any electric charge. With a functional and sufficiently small transistor prototype, one can theoretically scale up to logic gates and circuits and integrate these optical computers with traditional electronic devices via optoelectronic components.

With all-optical computation at speeds close to the speed of light, the hardest problems in theoretical computer science, such as the traveling salesman problem with applications in vehicle routing and scheduling, can be solved in a reasonable amount of time using only classical (non-quantum) algorithms. However, the fastest optical transistor prototype is only slightly faster than commonly used silicon transistors—speeding up these prototypes will require advances in optics and materials engineering. Fortunately, we can turn to nature to make solving certain problems with light feasible.

Ising machines emulate and exploit the natural process of finding a stable configuration of spins in a ferromagnetic system to solve problems. Spins are, for our purposes, particles that can be either spin up or spin down. Simply put, spins can influence other spins in a system to change their state, which causes multiple chain reactions from the initial spin configuration until a stable configuration is reached. Since this natural process is essentially a type of optimization known as combinatorial optimization, these Ising machines can be used to solve combinatorial optimization problems.

The most successful implementations of these machines utilize an optoelectronic component called a degenerate optical parametric oscillator (DOPO), which are oscillators that can be in one of two states. In a DOPO-based Ising machine, DOPOs are first placed in an optical cavity and coupled to each other to allow them to influence each other. After then, the problem to be solved can be encoded as a configuration of spins through a programmable module. Once the coupled DOPOs reach a stable configuration, the states of the DOPOs can be read and decoded to obtain the solution to the problem.

DOPO-based Ising machines offer significant speedups compared to traditional algorithms and machines, which enable them to feasibly solve even the hardest (NP-hard) combinatorial optimization problems. Examples of such problems include the previously mentioned traveling salesman problem, scheduling project activities with the critical path method, and managing inventory with the knapsack problem.

Although successful prototypes have been constructed and tested, they currently are not as space-efficient as they could be, and scaling up will prove to be difficult unless the architectures of these DOPO-based Ising machines are improved on a fundamental level.

Being able to solve problems similar to the problems mentioned above quickly and efficiently will likely be crucial to scaling up many of the operations that the U.S. Navy and Marine Corps carry out regularly. Moreover, greater computing capabilities in general will likely be required for many of the resource-intensive projects that the U.S. Navy and/or the Marine Corps will take on in the future. For instance, further improvements to the Aegis Ballistic Missile Defense System may utilize a more advanced satellite tracking system requiring faster onboard computers.

I personally see much potential in optoelectronic-based and optical computing and consider both parts of the next frontiers of computing. I will likely end up pursuing these frontiers in the future, as both what I have learned about optoelectronics from the NAVAL Horizons program and past research I have conducted on optical computing and other forms of unconventional computing have permanently caught my attention. “Stand on the shoulders of giants”—I wish to build on the inspiring work of others in these frontiers with those who will choose to do the same.

However, advances in this direction are naturally not possible without the necessary funding or scientists who can contribute perspectives from other fields. As a department employee at the Office of Naval Research, Dr. Placencia from “Optoelectronics with Dr. Dio Placencia” is responsible for offering research grants to professors working in promising fields. By doing this, Dr. Placencia is essentially fostering innovation and potentially motivating these professors to take different directions within their fields by allowing them to bypass the grant application process and get straight to research.

The new innovations resulting from these grants along with programs such as NAVAL Horizons are instrumental to inspiring high school students and undergraduate students to enter the same fields. As a student who was inspired to enter computer science by the many innovations from the past decade, I wholeheartedly believe that reaching, educating, and inspiring students like myself is key to keeping the cycle of innovation and advancement moving.

It is indirectly because of the work of those at the frontiers of technology and people like Dr. Placencia that I have been able to get to where I am now. Thus, I have been aiming to impact as many STEM-oriented students as possible as part of my lifelong journey on the frontier of technology. Although I am not able to reach many people through spreading local opportunities and teaching what I can right now, I hope to become able to mentor motivated students as a professor or research scientist and offer exciting opportunities to those who wish to grow, just as the Office of Naval Research has done by fully funding the PhDs of Dr. Placencia and many others.

And with more students entering STEM fields and collaborating with researchers from fields outside of their own, we can reach greater heights in the most promising fields of today, such as autonomous systems.

From searching the ocean for wreckage with autonomous boats and submarines to mapping the seafloor to monitor the spread of invasive seagrass to robot-based search and rescue, intelligent autonomous systems are highly applicable in the U.S. Navy and Marine Corps. These systems primarily utilize feedback control systems and path planning algorithms for autonomous navigation, methods such as synthetic aperture radar for remote sensing, and a combination of traditional computer vision algorithms and machine learning models for detection and classification.

Autonomous systems powered with AI and other algorithms are powerful, but we will always be fundamentally limited by the power of our computers—developing faster and more compact onboard computers is essential to advancing autonomous systems. For this, we can turn to the emerging computers of today.

Neuromorphic chips aim to efficiently host computational models of neural systems, which are similar to neural networks, with a network of physical neurons. These chips provide more freedom as to what types of neural models can be utilized, and could also speed up inference times immensely with a parallelized architecture. Optical neural networks integrated with cameras could also serve a similar purpose for computer vision tasks, such as the aforementioned wreckage search operations. The previously mentioned DOPO-based Ising machines, which could be made practical in the next few decades with advances in optoelectronics, would be capable of extremely fast routing and scheduling computations that may be crucial to scaling up operations in the future. Moreover, these new paradigms of computation would have many applications outside of the U.S. Navy and Marine Corps.

After such computational methods are made practical, it will be up to those working on the frontier of AI to develop new algorithms and paradigms that are closer to the biological brain by continuing to take inspiration from other fields. For instance, we have yet to see any neural model that can parallelize the execution of subtasks as much as the human brain can.

Many of our most significant and impactful discoveries came from the work of those at the intersection of multiple fields, and it is no different now—by exploring the intersections of the physical sciences, engineering, and computer science, we can continue advancing the frontiers of computing and technology for a better world.