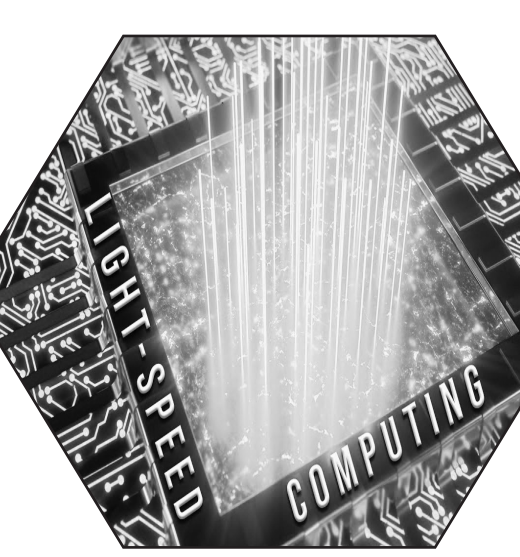
TRINITY MIRROR

IT matters

Optical computing to meet Gen X speed need

Increasingly complex applications such as artificial intelligence require ever more powerful and power-hungry computers to run. Optical computing is a proposed solution to increase speed and power efficiency but has yet to be realised due to constraints and drawbacks. A new design architecture, called diffraction casting, seeks to address these shortcomings. It introduces some concepts to the field of optical computing that might make it more appealing for implementation in next-generation computing devices.



Whether it's the smartphone in your pocket or the laptop on your desk, all current computer devices are based on electronic technology. But this has some inherent drawbacks; in particular, they necessarily generate a lot of heat, especially as they increase in performance, not to mention that fabrication technologies are approaching the fundamental limits of what is theoretically possible. As a result, researchers explore alternative ways to perform computation that can tackle these problems and ideally offer some new functionality or features too.

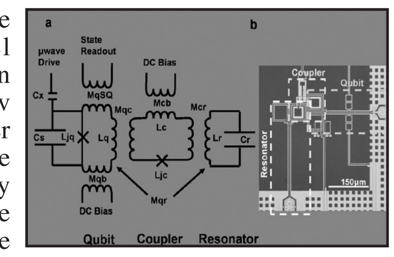
One possibility lies in an idea that has existed for several decades but has yet to break through and become commercially viable, and that's in optical computing. Essentially, optical computing leverages the speed of light waves and their ability to interact in complex ways with different optical materials without generating any heat. Add to this the fact that a broad range of light waves can pass through materials simultaneously without affecting each other and you can in theory produce a massively parallel, high-speed and power-efficient computer.

"In the 1980s, researchers in Japan explored an optical computing method called shadow casting, which could perform some simple logical operations. But their implementation was based on relatively bulky geometric optical forms, perhaps analogous to the vacuum tubes used in early digital computers. They worked in principle, but they lacked flexibility and ease of integration to make something useful," said Associate Professor Ryoichi Horisaki from the Information Photonics Lab at the University of Tokyo. "We introduce an optical computing scheme called diffraction casting which improves upon shadow casting. Shadow casting is based on light rays interacting with different geometries, whereas diffraction casting is based on properties of the light wave itself, which results in more spatially efficient, functionally flexible optical elements that are extensible in ways you'd expect and require for a universal computer. We ran numerical simulations which yielded very positive results, using small 16-by-16 pixel black-and-white images as inputs, smaller than icons on a smartphone screen."

Horisaki and his team propose an all-optical system, that is, one that only converts the final output to something electronic and digital; prior to that stage, every step of the system is optical. Their idea is to take an image as a source of data -- which naturally suggests this system could be used for image processing, but other kinds of data, especially that used in machine learning systems, could also be represented graphically -- and combine that source image with a series of other images representing stages in logic operations. Think of it like layers in an image editing application such as Adobe Photoshop: You have an input layer -- source image -- which can have layers placed on top, which obscure, manipulate or transmit something from the layer beneath. The output - top layer - is essentially processed by the combination of these layers. In this case, these layers will have light passed through them casting an image (hence the "casting" in diffraction casting) on a sensor, which will then become digital data for storage or presentation to the user.

"Diffraction casting is just one building block in a hypothetical computer based around this principle and it might be best to think of it as an additional component rather than a full replacement of existing systems, akin to the way graphical processing units are specialised components for graphics, gaming and machine learning workloads," said lead author Ryosuke Mashiko. "I anticipate it will take around 10 years to become commercially available, as much work has to be done on the physical implementation, which, although grounded in real work, has yet to be constructed. At present, we can demonstrate the usefulness of diffraction casting in performing the 16 basic logic operations at the heart of much information processing, but there's also scope for extending our system into another upcoming area of computing that goes beyond the traditional, and that's in quantum computing. Time will tell."

Coupling qubits for better quantum computing



Physicists from the University of Basel have succeeded in coupling two Andreev qubits coherently over a macroscopic distance for the first time. They achieved this with the help of microwave photons generated in a narrow superconducting resonator. The results of the experiments and accompanying calculations lay the foundation for the use of coupled Andreev qubits in quantum communication and quantum computing.

Quantum communication and quantum computing operate based on quantum bits (qubits) as the smallest unit of information - related to bits in a classical computer. Of the many different approaches currently being investigated around the world, one promising option is to use Andreev pair qubits.

These qubits are formed at interfaces between a metal and a superconductor in a process known as Andreev reflection. Here, an electron from the metal enters the superconductor, where it becomes part of an electron pair (a Cooper pair) - while a hole, which behaves like a positive particle, is reflected back into the metal. Based on this process discrete pairs of bound states are formed at the interface of these materials. They are known as Andreev bound states and can serve as the basis states of a qubit. These states are relatively robust to outside perturbations, and the coherence time - the time for which superposition is maintained - is relatively long. They can also be readily controlled and incorporated into modern electronic circuits. All of these factors are advantageous for developing reliable and scalable quantum computers.

The researchers have now achieved a strong quantum mechanical coupling between two Andreev qubits, each localized in a semiconducting nanowire. The results show excellent agreement with theoretical models.

"We coupled the two Andreev pair qubits at a large distance from one another at the two ends of a long, superconducting microwave resonator. This allows the exchange of microwave photons between the resonator and the qubits," explains Professor Christian Schönenberger from the Department of Physics and the Swiss Nanoscience Institute of the University of Basel, whose team carried out the experiments.

The microwave resonator can be used in two different ways: In one mode, the qubits can be read out via the resonator, providing the researchers with information on their quantum state. A second mode is used to couple the two qubits to each other, allowing them to "communicate" without losing microwave photons. The two qubits are then no longer independent of one another but rather share a new quantum state - which is vital for the development of quantum communication and quantum computers.

"In our work, we combine three quantum systems so that they can exchange photons between each other. Our qubits themselves are only about 100 nanometres in size, and we couple them over a macroscopic distance of 6 millimetres," says Andreas Baumgartner, one of the article's co-authors. "By doing so, we were able to show that Andreev pair qubits are suitable as compact and scalable solid-state qubits."

Smartphone-based microscope to reconstruct 3D holograms

Researchers have developed a new smartphone-based digital holographic microscope that enables precision 3D measurements. The highly portable and inexpensive microscope could help bring 3D measurement capabilities to a broader range of applications, including educational uses and point-of-care diagnostics in resource-limited settings.

Holographic microscopes digitally reconstruct holograms to extract detailed 3D information about a sample, enabling precise measurements of the sample's surface and internal structures. However, existing digital holographic microscopes typically require complex optical systems and a personal computer for calculations, making them difficult to transport or use outdoors.

"Our digital holographic microscope uses a simple optical system created with a 3D printer and a calculation system based on a smartphone," said research team leader Yuki Nagahama from the Tokyo University of Agriculture and Technology. "This makes it inexpensive, portable and useful for a variety of applications and settings."

In a recenty publication, the researchers demonstrate the smartphone-based digital holographic microscope's ability to capture, reconstruct and display holograms in almost real time. The user can even use a pinch gesture on the smartphone screen to zoom in on the reconstructed hologram image.

"Since our holographic microscope system can be built inexpensively, it could potentially be useful for medical applications, such as diagnosing sickle cell disease in developing countries," said Nagahama. "It could also be used for research in various field environments or in education by allowing students to observe living organisms at school and at home."

Digital holographic microscopes work by capturing the interference pattern between a reference beam and light scattered from the sample. The hologram is then digitally reconstructed, which generates 3D information that can be used to measure the sample's features, even those below the surface.

Although smartphone-based digital holography microscopes have been developed previously, available technologies either reconstruct the holograms on a seperate device or lack real-time reconstruction. This limitation arises from the restricted computing and memory capacity of most smartphones. To achieve fast reconstruction on a smartphone, the researchers used an approach called band-limited double-step Fresnel diffraction to calculate the diffraction patterns. This method reduces the number of data points, enabling faster computational image reconstruction from holograms.

"When I was a student, I worked on portable digital holographic microscopes, which initially used laptops as the computing system," said Nagahama. "With the rise of smartphones, I began exploring their potential as computing systems for broader applications and considered leveraging them for tasks like removing artifacts from observed images, which ultimately shaped the development of this microscope."

To help with portability, the researchers created a lightweight housing for the optical system using a 3D printer. They also developed an Android-based application to reconstruct the holograms acquired by the optical system.

The microscope generates a reconstructed image of the hologram on the image sensor of a USB camera built into the optical system. This hologram can be observed by the Android smartphone, which provides computational image reconstruction in real time. The reconstructed hologram is then displayed on the smartphone, where users can interact with it via the touchscreen.

Higher-order interactions can remodel complex systems

Networks, which include nodes and connections, can help researchers model dynamic systems like the spread of disease or how the brain processes information. Pairwise interactions between nodes can represent links between individuals -- how two neurons connect with one another in the brain, for example -- but scientists also study interactions involving three or more nodes.

These higher-order interactions reveal changes and phenomena beyond those found by looking only at pairs.

Yuanzhao Zhang, an SFI Complexity Postdoctoral Fellow, has studied how higher-order interactions affect a system at small scales. In new work publishedrecently, he reports on how higher-order interactions can reshape a system at larger, even global scales.

"We wanted to know how they change the entire landscape," he says.

Zhang and his colleagues found that higher-order interactions can lead to deeper "basins of attraction", which are collections of starting points that end up at the same state as the system moves forward in time.

If the system were a pendulum, the lowest point is an attractor, and every possible starting point is in the basin of attraction because they all eventually converge there. If the system were a brain working through a complicated math problem, then the thought processes that lead to a solution - hopefully the correct one - are in the basin of attraction.

A deeper basin means that the solutions are more stable -- that is, starting points get to the bottom faster or more quickly recover from small perturbations.

Surprisingly, though, Zhang and his group found that even though the basins get deeper, they become narrower.

What starting points do end up in the basin get there faster, but overall, fewer starting points lead to the bottom.

"If we start from a random point in the landscape, somehow we never reach [the basins of attraction]," Zhang says.

Higher-order interactions introduce a kind of nonlinearity that hasn't been well-studied.

The group found this behavior by testing a specific class of networks, but Zhang hypothesises that shrinking and deepening the basins is a more universal phenomenon among dynamic systems - and that higher-order interactions can lead to the formation of new basins.

"Once you introduce them, many new attractors that didn't exist before would appear," he says. The new work may be useful in probing complex interactions in real-world systems. "We want those deeper but smaller basins," Zhang says. Smaller basins would allow a brain to easily jump between different states to complete a complex task.

Deeper basins allow a friend in a conversation - or a person reading an SFI article online -- to keep their train of thought if they get momentarily distracted. "This stability allows the brain to recover faster from those small perturbations," Zhang says.