Research on optical computing system architecture for simple recurrent neural networks

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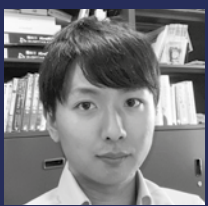
Impact Objectives

- Cross-disciplinary research to pioneer new computing technologies
- Explore optical computing to improve the performance of computer systems

Photonic device-based computing systems of the future

***Associate Professor Satoshi Kawakami** discusses the inspirations behind his latest work conducting cross-disciplinary research to pioneer new computing technologies*



How did you become involved in optical computing?

For some time now, I have been working to solve a wide range of problems related to optical computing in a bid to drive this field of research forward. Part of my background has been concerned with the miniaturisation of semiconductors and the fact that this appears to be coming to an end. It is no exaggeration to say that without miniaturisation there would have been none of the developments in information technology we have seen over the past 50 years, but the cessation of semiconductor miniaturisation means the loss of a powerful and reliable means of improving the performance of computer systems. About seven years ago I began collaborating with a researcher from a laboratory that was home to a very promising optical integration technology. From there, we started studying how to establish optical devices as computer systems and, as they say, the rest is history. It is my view that to take up this mantle and drive it forward, we need to realise the potential of optical computing.

You are based within the Constructive Electronics Laboratory at Kyushu University in Japan. Can you talk about the 'bottom up' approach taken to the research underway in the Laboratory?

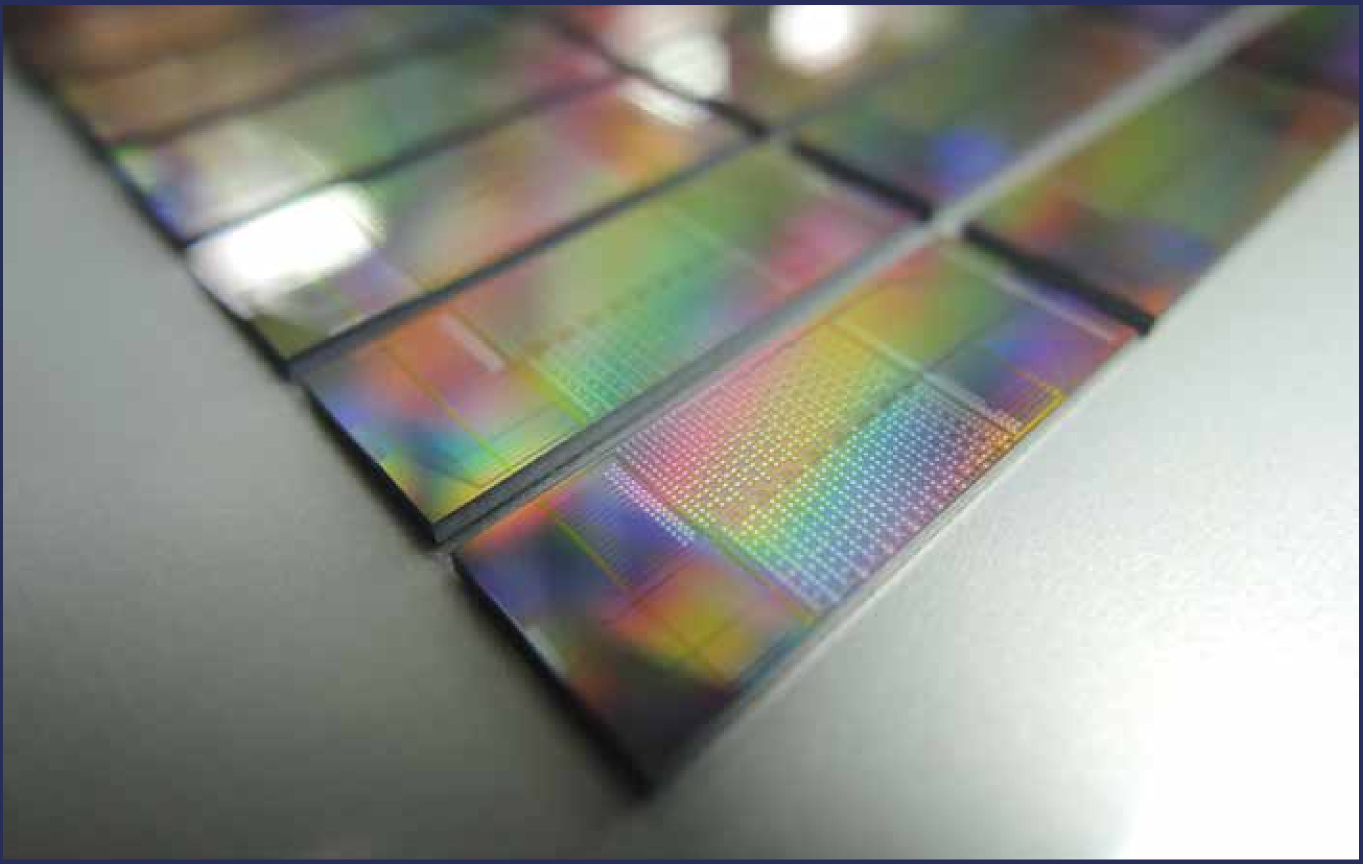
To solve the post-Moore era problems described below collaboration is essential. Therefore, I work closely with researchers who have various excellent device technologies (optical, superconducting, quantum, spin devices, etc.) and work across each technology layer. Our laboratory is operated by associate professors with different technical layers. Specifically, Dr Yajima is a device specialist while I specialise in computational architecture. The bottom-up approach is based on device technology and explores what it can be used for, whereas the top-down approach looks at what technology can be used from the application. Both are essential, but our lab focuses on the bottom-up approach.

Can you tell us about the value of collaboration and how it contributes to your work?

Collaboration is very important for our investigations. Conducting research across technology layers is essential in the development of computing technologies in the post-Moore era and this informs our approach. I am an expert in electric circuits and computer architecture, not in photophysics or devices. Thus, it is important to forge collaborations with academics from different fields and disciplines so that we can all contribute from different viewpoints and areas of expertise. By doing this, we aim to deepen our understanding of each other's technical layers and build optimal computer systems.

Finally, what are your research plans for the next couple of years?

For optical computing, we will consider further computational applications. There are many promising technologies other than the optical devices currently under consideration, such as reservoir computing. We intend to examine how these core technologies can be further developed into computer applications. While the focus of my current research is on optical computing systems, the main driver is in advancing computing, so any emerging technologies that could help us to achieve this are part of my research plans. ▶



Driving computing technology forward

*A team based within the **Constructive Electronics Laboratory** at **Kyushu University** is conducting research on optical computing system infrastructure. The findings will help pioneer new computing technologies in the post-Moore era and drive forward photonic device-based computing*

Moore's Law explains how every two years the number of transistors on a microchip doubles. This means that, in turn, we can anticipate that every two years the speed and capability of computers also increases. For the past 50 years or so, this has proved to be the case and Moore's prediction has been used in research and development across the semiconductor industry. However, it is now widely considered that one day Moore's Law will cease to apply - with some academics believing that this has already happened.

Indeed, some researchers are engaged in projects which seek to advance computing technology in what they refer to as the 'post-Moore' era. To achieve this, it is considered necessary to conduct research in different arenas of computing technology, ones that do not rely on the continuing miniaturisation of semiconductors. Unfortunately - and as is so often the case with these types of things - as one problem is overcome, such as the use of novel devices and their increased importance, another new challenge presents itself, such as the notion that a novel device that can operate at the speed of light has pitfalls like a lack of stability.

It is with these issues in mind that a cross-disciplinary team has come together to investigate optical computing system infrastructures, with a view to driving computing technology forward in a way that negates the need to comply with Moore's Law. If research endeavours such as these prove to be successful, then it is fair to say that the entire world will be affected in many ways, and we will need a new term to describe what comes after the digital age.

PHOTONIC DEVICE-BASED

Associate Professor Satoshi Kawakami is an expert in electric circuits and computer architecture. Based within the Constructive Electronics Laboratory at Kyushu University in Japan, he forms part of a team who is conducting cross-disciplinary research (materials, devices, circuits, architectures and algorithms) to pioneer new computing technologies in the post-Moore era.

It is the team's belief that photonic device-based computing systems are very valuable to the field and that such systems can help to provide higher performance at the same time as lowering both power and energy consumption. 'In the present and future society, it is unrealistic to think that the flow of digitalisation can be controlled and there is no doubt that the amount of information processing will continue to

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increase,' explains Kawakami. 'Therefore, the continuous improvement of computer systems with higher performance and lower power consumption/energy consumption will be essential to realise a sustainable advanced information society.'

COMPUTER SYSTEM ARCHITECTURE

The team's research interests include computer system architecture with emerging technologies. As mentioned above, these interests stem from the belief that semiconductor miniaturisation will come to an end soon, at which point novel devices will become extremely important in terms of driving computing technologies forward at a similar pace to that which has gone before. We have already seen that with mainstream applications, such as Artificial Intelligence (AI) and Big Data processing, that high precision is not always a precursor and/or requirement for the field of computing.

Due to the fact that high precision is not always required for existing technologies, it follows that new and emerging technologies may be able to provide such a wide range of benefits above those which already exist, that any shortfalls they might have can be absorbed through the possibilities and potential of said technologies. It is these which fuel Kawakami's belief that the focus should be on optimisation between the system hierarchy, as opposed to across it. 'Devices are an important layer that supports the foundation of the system, and their improvement will undoubtedly have a direct impact on high performance and low power consumption,' explains Kawakami. 'However, in order to create further breakthroughs, it is necessary to maximise the advantages of devices and hide their disadvantages at the system level and for this purpose, collaboration with higher system layers is expected.'

IMPROVING ENERGY EFFICIENCY

One thing that we can all agree on is how computers have become indispensable to our society. From personal computers, home appliances, cars and aeroplanes, through to medicine, finance and AI, dramatic improvements mean not only faster processing speeds, but adding new and novel applications. 'Large-scale language models such as ChatGPT, which has been the focus of much attention recently, have achieved language construction capabilities similar to those of humans by increasing the number of parameters,' outlines Kawakami. 'This increase in parameters has been made possible by recent improvements in computer performance. Thus, increased computer performance will be a driving force for innovation in all applications.'

In addition to improving performance, reducing power consumption is also an important goal. The more ICT devices are used in society, the greater the impact on carbon dioxide emissions. Improving the energy efficiency of computers is important for global environmental issues and is something that Kawakami and the team always hold in the centre of their minds throughout the course of their investigations.

SIMPLE RECURRENT NEURAL NETWORKS

One of their current research projects is looking at optical computing system infrastructure for simple recurrent neural networks. Optical computing that utilises nanophotonic devices is one of the most promising alternative computing approaches to support the continuous improvement of computing performance and low power consumption. The recent development of high-density integration technology for optical devices (nanophotonics) has enabled ultra-small size, ultra-low energy consumption and large-scale integration of optical devices. This provides momentum for the application of optical technology to information processing, which has mainly been applied to information and communication technology.

Although this optical computing research is in its infancy, it is still limited to proof-of-principle and optimisation of specific performance metrics (low latency) in the field of optical properties/circuits. 'It is important to establish a computer infrastructure that makes the most of the characteristics of optics by breaking away from discussions that have been confined to the field of optical devices and circuits,' highlights Kawakami. 'We want to re-examine the ideal state of optical circuits from the perspective of the entire system, including electrical memory and interfaces.'

Ultimately, if Kawakami and his team prove to be successful in their research endeavours, they will help to usher in a new era that moves away from the tenets of Moore's Law. It is no exaggeration to say that tasks and applications that would boggle the mind today could well be commonplace tomorrow - with the possible result that a new law will need to be coined; one that moves at an even faster pace than those that have gone before.

Project Insights

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