COULD COMPUTER PROGRAMS MATCH THE ABILITIES OF OUR BRAINS?

THE HUMAN BRAIN IS ONE OF THE MOST INTRICATE SYSTEMS IN NATURE. RECREATING ITS BEHAVIOUR USING COMPUTER PROGRAMS IS NO EASY TASK, BUT IT CAN BE DONE – BY USING ARTIFICIAL INTELLIGENCE HARDWARE THAT MIMICS THE DEEPLY COMPLEX NETWORKS OF NEURON CELLS IN OUR BRAINS. **DR PAVEL BORISOV** AND **PROFESSOR SERGEY SAVEL'EV**, AT **LOUGHBOROUGH UNIVERSITY**, UK, ARE EXPLORING HOW NEW ADVANCES IN TECHNOLOGY CAN HELP TO CREATE AN ARTIFICIAL BRAIN

TALK LIKE AN ARTIFICIAL INTELLIGENCE RESEARCHER

ARTIFICIAL INTELLIGENCE (AI) - systems that can take in data from their surroundings and use it to take action to achieve their goals, without any input from programmers

ARTIFICIAL NEURAL NETWORKS - computing systems inspired by biological networks of neurons and synapses which can mimic the behaviour of our brains

MEMRISTOR - a resistor that can remember how much electrical current has flowed through it in the past. Memristors are promising new components of artificial neural network hardware

NEURONS - nerve cells in our brains that communicate with each other by exchanging electrical or chemical signals

SYNAPSES - links between neurons through which signals propagate

WEIGHT - a connection strength between artificial neurons

Our brains are incredibly good at handling large amounts of complex information and applying previously learnt information in new situations. This is important for tasks like recognising familiar faces in a crowd or understanding words spoken by people with unfamiliar voices.

Computer programs that can perform these actions as well as us are extremely useful, but very challenging to build. Computers may be far better than us at remembering numbers and solving calculations, but not all information can be represented by numbers. This means regular computer programs cannot carry out many tasks as well as we can.

"If we write a computer program to detect a circle of a certain radius in the middle of a monitor, it will do it extremely fast," says Professor Sergey Savel'ev, a theoretical physicist at Loughborough University. He is working on understanding if a brain can be implemented on an electronic chipset. "But the program will become confused if the radius of the circle is different, if it isn't in the centre of the screen, or the image is noisy." To overcome this problem, scientists are now developing more advanced programs that can better mimic the processes occurring in our brains.

WHAT ARE NEURAL NETWORKS?

Your brain contains millions of neurons, which constantly talk to each other by exchanging signals across connections named 'synapses'. As we learn new information, the neural networks in our brains can alter connection strengths between other neurons, allowing the system to deal with new information more effectively in the future.

Scientists have recreated these systems in computers, using artificial neural networks. "Biological neurons are connected by synapses, while artificial neurons are connected by 'weights'," says Dr Pavel Borisov, an experimental physicist and Sergey's colleague at Loughborough University. "These simulated neurons can deal with input and output signals from other neurons."

As these programs experience new data, new weights will be assigned within the neural networks, so the output signals of particular artificial neurons will be processed in slightly different ways. For example, a neural network could be trained to recognise cats by showing it thousands of pictures of cats. Once trained, the system can then work out whether new, unfamiliar images contain cats.

Yet, even as neural networks become more advanced, they are still not nearly as effective as our brains. They work by filtering useful information out of useless data, rather than reproducing human thinking ability in understanding concepts. After all, we do not need to see thousands of pictures of cats just to recognise one!

HOW CAN MEMRISTORS IMPROVE NEURAL NETWORKS?

Improving neural networks further will require more advanced physical hardware. One way forward is to develop circuits that can actively change themselves as they encounter new information, something made possible through devices called memristors. These are related to the electrical resistors you have probably learnt about in physics, but can change their resistance depending on how much current has flowed through them in the past. Essentially, this gives them a 'memory'.

"Memristors can be used to replace weights in the software algorithms, so instead of storing all those numbers in the program, we can use each memristor's electric resistance to represent that weight," says Pavel. "That way, we don't need a special memory or a processor to sum up all the weights." In their research, Pavel and Sergey explore the exciting possibilities presented by this technology.

WHAT HAS SERGEY DISCOVERED SO FAR?

As our eyes take in new visual information, they convert it into electrical signals, which pass into an area of the brain called the visual cortex. The brain encodes the information onto short electrical pulses called 'spikes', which are sent on to be processed by other neurons, allowing the network to alter its synapses in response to the new information.

To recreate this behaviour in artificial neural networks, Sergey and Pavel use two types of memristor. "Volatile memristors return to the same state when electric power is off, so they aren't memorising what they learnt," Sergey says. "However, they can transform information into a series of electrical spikes, allowing artificial neurons to communicate."

In contrast, non-volatile memristors retain their memory when turned off and have a resistance that depends on the intensity and polarity of voltage spikes, making them more effective as artificial synapses. Sergey is combining these two types of memristor to better mimic the real visual cortex. He develops models to simulate memristor devices and artificial neurons in neural networks, then collaborates with Pavel to experimentally create these thin film devices and perform numerical analysis on spiking neurons.

HOW IS PAVEL'S RESEARCH IMPROVING MEMRISTOR DEVICES?

Pavel is developing new memristor devices by using fabrication techniques that are applied inside a vacuum chamber. This involves bombarding a solid disc of material with argon ions (a gas plasma), turning the thin top layer of the disc to gas. This gas settles on a solid, flat, glass-like substrate, forming a film just 100-500 atoms thick. By mixing the argon gas with oxygen, Pavel's team has fabricated memristors featuring a thin, slightly conductive oxide film, sandwiched between two metal electrodes.

"To understand if our memristor is working, we apply different voltages between the electrodes and measure the resulting current," Pavel says. "A proper memristor should demonstrate very distinct electric resistance values when the applied voltage is, for example, increased and then decreased, and the resistance should depend on the way the voltage was changed in the past."

Through this approach, Pavel has developed niobium oxide and silicon oxide films which can produce and control fast current spikes, in a similar way to biological neurons. The next step will be to connect these compact memristors into an advanced, low-power neural network.

COULD THESE DISCOVERIES BE APPLIED IN REAL LIFE?

For Pavel, the hope is to create prototypes of compact devices which can run neural networks using multiple built-in physical memristor elements that can operate without needing online access to a web server or external power grid. "These could include medical sensors to monitor heart or breathing rhythms, or engineering sensors to monitor the safety of buildings," he says.

For Sergey, the ultimate goal is to create an artificial visual cortex. "This device will be able to learn by itself and won't require any additional training or programming," he says. "This will allow it to adjust its performance depending on conditions in its environment, such as light intensity and the velocity of nearby objects."

Such a system could be used in robots, drones and self-driving cars, helping them navigate unfamiliar environments while remaining in contact with a central control system. In the future, it could even lead to implants to restore the sight of visually impaired people, although this is still some way off.

DR PAVEL BORISOV

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FIELD OF RESEARCH

Thin film devices

RESEARCH PROJECT

Developing thin films to act as memristors in modern neural networks

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)

PROFESSOR SERGEY SAVEL'EV

Department of Physics, Loughborough University, UK

FIELD OF RESEARCH

Modelling complex systems

RESEARCH PROJECT

Developing neural networks which can mimic the brain's visual cortex

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)

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ABOUT ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) is a large family of techniques, including neural networks, which enables computers to solve problems independently of human programmers. AI takes in information about the world, which could be gathered using sensors or by monitoring a person's online activity, then extracts useful information from this data and acts on it.

AI can be used in a diverse array of tasks, from allowing automated vehicles to navigate to suggesting relevant adverts for online shoppers. As this is still a new technology, some people are worried that it could transform our lives in negative ways we cannot yet predict. But for researchers such as Pavel and Sergey, the opportunities presented by AI are incredibly exciting, and could be used to solve some of the world's most complex problems.

HOW DOES AI TIE IN WITH OTHER FIELDS OF RESEARCH?

As the potential applications of AI are so diverse, most fields of research can benefit from, and contribute to, advances in AI.

For Sergey, the tools used by physicists for modelling complex systems can fertilise the development of a new generation of intelligent systems, while AI can help physicists to shed light on many unsolved problems in electromagnetism, hydrodynamics, condensed matter and quantum physics. For Pavel, developing high-performance memristors involves understanding of solid-state physics, material chemistry and neuroscience.

Due to this diversity, it is no surprise that many scientists working on developing AI technology are also fascinated by completely different fields. The ability to communicate and collaborate closely with researchers from other subjects is therefore an essential skill for any scientist working to further improve AI.

WILL COMPUTERS EVER BE ABLE TO REPLICATE THE HUMAN BRAIN?

As technology continues to advance, people are concerned that AI could one day become even more powerful than our own brains, an idea widely explored in science fiction. Sergey and Pavel both believe this is unlikely.

Since every brain is unique and constantly evolving as it responds to new information, Pavel says there simply is no way to recreate this in computer code. "It's like replicating a thunderstorm; you can be close, but never exactly there," he says.

However, Sergey believes the human brain is not the only, or even the best, intelligent system that exists. "We can create intelligent systems with quite different thinking abilities to us, possibly outperforming us in some respects, while still being less efficient than us in other thinking abilities," he says. Artificially mimicking the brain's behaviour more closely could lead to breakthroughs in ways to treat mental health issues, again highlighting the diversity and importance of AI applications.

EXPLORE CAREERS IN ARTIFICIAL INTELLIGENCE

- With a career in AI, you could find yourself designing robotic systems, programming virtual assistants or protecting computers from cyber-attacks. Almost all companies use some form of AI these days, providing a world of career possibilities for those with the skills to design and programme them.
- This article from Infosec discusses careers available in the field of AI: **resources.infosecinstitute.com/topic/ai-and-machine-learning-career-paths-trends-and-job-prospects**
- Prospects provides information about careers in machine learning, a branch of AI: **www.prospects.ac.uk/job-profiles/machine-learning-engineer**
- C3 AI is an AI software provider. Visit their website to explore the type of AI applications they develop and the careers available: **www.c3.ai**

PATHWAY FROM SCHOOL TO ARTIFICIAL INTELLIGENCE

- "Mathematics is the key subject needed in AI research and applications," says Sergey. Skills in computing are also essential.
- As AI can be applied to any field, take subjects depending on your interests. For example, biology-inspired AI systems require a knowledge of biology and neuroscience, while quantum AI systems require a background in physics and quantum engineering.

HOW DID PAVEL BECOME A PHYSICIST?

I grew up in a family of two engineers, and most of my relatives worked in engineering and manufacturing. That meant that anything related to physics and maths had a special appeal to me when I was at school. I was more interested in physics than computers when I was young, but the physics and technology of computer components were always interesting to me, and I also had a parallel interest in human biology. That's what fascinates me the most about neural networks – the overlap between electronic devices and the brains of living organisms.

Research into electronic devices that can act as a human brain intensified in 2008, when the experimental discovery of a memristor was reported. I remember reading that paper and thinking that this would be a huge field of research.

Previously, I have worked on magnetic materials that can be influenced by both magnetic and electric fields. My research was the first to demonstrate the electric switching of a pure magnetic effect, the so-called exchange bias. I also developed an innovative technique for measuring the magnetoelectric effect, and synthesised and studied thin films of magnetic materials which were previously only investigated as bulk crystals. In the field of memristor devices, I'm proud of our work on artificial neurons made from niobium oxide films. In the future, the hope is to expand our research on memristive devices towards larger neural networks and sensors, and to demonstrate them in practical experiments.

PAVEL'S TOP TIPS:

1. Follow where your curiosity leads you.

2. Develop strong resilience when dealing with difficult calculations or failed experiments. Without it, you may become disappointed and give up too early.

HOW DID SERGEY BECOME A PHYSICIST?

SERGEY'S TOP TIPS:

1. To love science and to be interested in your studies are two key ingredients.

2. To challenge yourself and others is also very important during your studies. In the end, solving problems nobody can solve will really motivate you in future.

My mother and father were both chemists, so I started to think about a career in research quite early on. One of my first motivations was to understand the physics of life and the brain, but I spent a long time working in the field of superconductivity. I was excited to return to the subject I was interested in as a teenager with a different level of understanding, and with the goal of emulating the brain using electronic devices.

I always liked interdisciplinary research that went beyond standard physics. Currently, I am collaborating with the Loughborough School of Sport, Exercise and Health Sciences, developing new models to understand brain images. I like to use my mathematical skills in new fields of study. This allows me to enjoy collaborations with scientists across the world.

I am proud of my development of novel theoretical methods in studying random noise in the dynamics of small, interacting particles and complex systems like neurons. Noise is any disturbance that interferes with data transmission or communication. Such research is important now because devices are becoming smaller and smaller, and noises are affecting their performance. This research has helped me a lot in the analysis of memristive devices, where nanoparticle diffusion is very noisy, and random noise plays a key role in the performance of memristors.