Lighting up the future of brain-inspired computing

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Nowadays we are experiencing a boom in Artificial Intelligence (AI). Being a buzzword with science fiction references until recently, AI in the last couple of years tends to become a commodity. Even the least tech-savvy around us have used some sort of AI software, such as OpenAI's ChatGPT, Google's Gemini or Microsoft's Copilot. This progress has been facilitated by machine learning algorithms combined with advanced hardware architectures. One hundred years after the first patent on field effect transistor (FET) was filed, we now use tens of billions of transistors in the latest CPUs (central processing units) or even hundreds of billions of transistors in GPUs (graphic processing units) and recent neuromorphic systems, such as Intel's Hala Point[1] and IBM's North Pole[2].

There is no doubt that AI will be widely adopted in the coming years by several industries to optimise transport and logistics, energy management in buildings, automation and anomaly detection in industrial settings, to give some examples. AI can also assist in minimising waste, improving resource efficiency and even monitoring the impact of climate change across land, oceans and air, and guiding interventions for mitigating it. All these advancements will contribute towards reaching several of the 17 Sustainable Development Goals (SDGs) that were established by the United Nations in 2015[3].

However, we cannot turn a blind eye to the negative effects of excessive use of AI regarding SDG 7, which refers to ensuring there is affordable and clean energy available for all. Apart from using AI for increasing the environmental sustainability of several sectors, we should also strive to make AI itself more sustainable. This need has become more imminent in the last decade with the rapid and widespread proliferation of data centres, which are said to be responsible for 1-2% of global electricity usage[4]. Apart from the financial aspects of this energy utilisation, there is also a significant environmental cost associated with the carbon dioxide emissions of data centres, which is expected to double by 2030, and AI is considerably to blame for this increase.

Neuromorphic computing, inspired by the way the human brain works, tries to emulate with electronic devices the dense neural network of the brain and its trillions of connections via synapses with the ultimate aim to reduce the latency and power consumption of incumbent electronics. Despite lacking a standardised benchmarking tool to monitor energy consumption of AI usage and of a direct one-to-one comparison with the cognitive operations performed by the human brain, a rough estimation shows that we are still orders of magnitude away from the power efficiency of the brain. As an example, the adult brain with approximately 86 billion neurons in *ca.* 1200 cm^3 consumes 20 W to perform normal everyday cognitive functions like responding to

[1] https://newsroom.intel.com/artificial-intelligence/intel-builds-worlds-largest-neuromorphic-system-to-enable-more-sustainable-ai
[2] https://research.ibm.com/blog/northpole-ibm-ai-chip
[3] https://sdgs.un.org/goals
[4] https://www.technologyreview.com/2025/03/03/1112758/should-we-be-moving-data-centers-to-space/

different stimuli, creating thoughts and completing inference tasks[5]. For comparison, Intel's Hala Point with its 1.15 billion artificial neurons fitted in a chassis the size of a microwave oven consumes a maximum of 2,600 W of power to operate[1].

Could this be an indication that we are looking at the problem from the wrong angle? We have been riding the wave of digital technologies for several decades that we have let ourselves, as scientists and technologists, be swept by it. We try to emulate the brain with switches and 2- or 3-terminal clocked devices, while each neuron is a multi-terminal biochemical "device"; the brain operates in an analogue, asynchronous fashion; it's a soft matter immersed in a liquid electrochemical rather than a purely solid state "dustless" environment. What if the answer lies in re-inventing our electronics by using completely unconventional materials and novel architectures?

Organic materials are undoubtedly the closest to emulate the chemistry of the brain. They have been proposed as best candidates for implantable electronics mainly due to their biocompatibility. If organic neuromorphic chips were used in tandem with implantable probes and polymer-coated microelectrodes, we could speak of a truly neuromorphic system that can directly tackle certain issues with brain and neurodegenerative diseases. Apart from organic materials, other mixed ionic-electronic conductors, such as perovskites, certain metal oxides or polyoxometalates and organometallic complexes can be also considered. Electrical signals in the brain are being propagated via ion channels (such as Na^+ and K^+), the dysfunction of which leads to serious neuronal disorders. In fact, studying these mechanisms through artificial systems that are akin to the actual ion and electron transporting channels could also contribute to our better understanding of the brain function.

Finally, inspired by the field of optogenetics, where synapses are modulated by light signals, we could move towards photonic or optoelectronic synaptic and neural circuit architectures rather than purely electrical circuitries. Neuromorphic functionalities are easier to control optically (as long as the right materials are chosen), thanks to the unique properties of light (wavelength, polarisation) that add extra degrees of freedom, while light allows for both spatial and temporal patterning and fast switching between states. Photodetector type of devices can offer analogue / multi-bit memory operation and low cross talk, as the stimulation can be spatially confined. Long- and short-term memory is also attainable within the same device merely by changing the mode of operation. Due to photocurrents being created with close to zero applied bias, such devices hold promise for ultra-low power consumption, something which is the Holy Grail of neuromorphic computing.

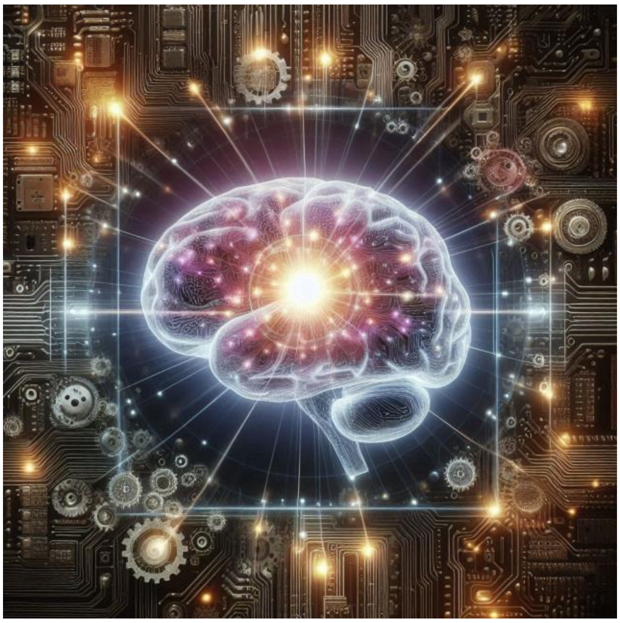


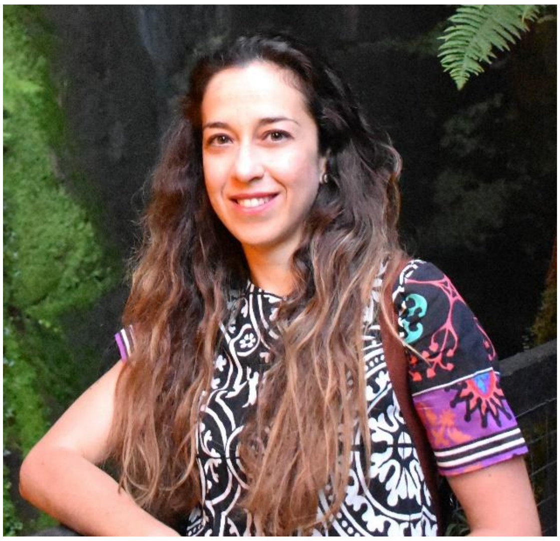
Figure created with Bing Image Creator.

[5] Marković, D., Mizrahi, A., Querlioz, D. *et al.* Physics for neuromorphic computing. *Nat Rev Phys* **2**, 499–510 (2020). https://doi.org/10.1038/s42254-020-0208-2

It becomes evident that to achieve this, an interdisciplinary effort spanning many scientific fields is required. Computer scientists and electrical engineers alone do not suffice to solve these problems. Technological innovation has been driven by diversity in research environments, not only in disciplines, but also skills, gender and cultures. A recent report compiled by The Alan Turing Institute in the United Kingdom[6], exploring how the gender gap shapes scientific knowledge and technological innovation, shows that women in AI are by far a minority. Although this refers mostly to AI from the computer science/machine learning perspective, having more women developing electronic devices and AI hardware is indispensable for lighting up the space of brain-inspired computing and leading to a brighter future for all of us.

Short bio

Dimitra Georgiadou is Professor of Flexible Nanoelectronics and UKRI Future Leaders Fellow in the School of Electronics and Computer Science at the University of Southampton, UK. Dimitra earned her PhD in Chemical Engineering/Organic Electronics from the National Technical University of Athens (NTUA), Greece. Before joining the University of Southampton, she was an Industrial Fellow at the Department of Materials and Marie Skłodowska-Curie Fellow at the Department of Physics of Imperial College London, UK. Her research interests are the fabrication and optimisation of nanoscale opto/electronic devices, including RF diodes, OLEDs, photodetectors and memories, by applying novel materials concepts and alternative patterning techniques, which are compatible with flexible substrates. Her group focuses on creating more efficient, sustainable, and intelligent systems to be applied in neuromorphic computing and the Internet of Things.



[6] https://www.turing.ac.uk/research/research-programmes/public-policy/public-policy-themes/women-data-science-and-ai