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Yoeri van de Burgt, Francesca Santoro, Benjamin Tee, Fabien Alibart. Editorial: Focus on organic materials, bio-interfacing and processing in neuromorphic computing and artificial sensory applications. *Neuromorphic Computing and Engineering*, 2023, 3 (4), pp.040202. 10.1088/2634-4386/ad06ca . hal-04348640

HAL Id: hal-04348640

<https://hal.science/hal-04348640>

Submitted on 16 May 2024

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EDITORIAL • OPEN ACCESS

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To cite this article: Yoeri van de Burgt *et al* 2023 *Neuromorph. Comput. Eng.* **3** 040202

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EDITORIAL

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RECEIVED
9 October 2023ACCEPTED FOR PUBLICATION
25 October 2023PUBLISHED
7 November 2023

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Editorial: Focus on organic materials, bio-interfacing and processing in neuromorphic computing and artificial sensory applications

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Artificial intelligence (AI) and deep learning rely on artificial neural networks that are typically executed on conventional von Neumann architecture-based computers, mostly operating in a sequential manner. In contrast, the human nervous system is a massively distributed, parallel, and interconnected system, with superior functionality and performance in data processing and adaptive learning compared to digital computers. Neuromorphic computing and engineering aims to replicate some of the functionalities and architectures of the human brain and nervous system with dedicated materials and devices. Realizing computational primitives of biological neural networks at the device and circuit level is the first step towards efficient neuromorphic computing systems that are able to sense, perceive, analyze, interpret and act upon a dynamic, real-world environment. Such neuromorphic approaches cover aspects associated to computing of complex time-dependent signals as well as signal encoding from sensory units in a bioinspired way.

Organic electronic materials present an attractive option for such systems, offering the potential for biocompatible and relatively cost-effective neuromorphic devices with low-energy switching capabilities and excellent tunability. Tunable organic electronic materials and devices may serve as attractive alternatives to traditional memristive devices, particularly in specific neuromorphic applications like online learning, where synaptic weights are trained on-chip for real-time predictions. The distinctive properties of organic materials may introduce novel and alternative switching mechanisms that exhibit reduced stochasticity while still maintaining low energy consumption and a wide dynamic range, ultimately leading to improved training and inference accuracy. These distinctive features of organic electronics could also be a unique opportunity to provide neuromorphic engineers with new hardware implementations of bio-inspired mechanisms. At the same time organic materials operate with ions and can be biocompatible, which opens up opportunities at the interface with biology. In this special issue we focus on organic materials, bio-interfacing and processing in neuromorphic computing and artificial sensory applications.

Despite recent advantages for organic neuromorphic systems for in memory computing, one of the main challenges remains the stability and in particular the state retention. In our special issue Felder *et al* [1] introduce a method to overcome this issue by 'reminding' the neuromorphic devices at certain times. This way the classification accuracy can remain high with a simple action.

Using a similar network of organic ECRAMs, which is traditionally implemented for in-memory computing, the same authors show in Felder *et al* [2] that it is also possible to run spiking neural networks. They demonstrate that their non-ideal devices that 'forget' their state, are actually 'reminded' by the spikes, and thus keep the high classification accuracy.

Mimicking spiking behavior is an important step towards artificial systems operating at the interface with biology. In Hosseine *et al* [3] the authors show a biologically realistic spiking synaptic circuit on a biocompatible flexible substrate.

On the other hand, for temporal systems such as many biological signals like ECG it can also be beneficial to use reservoir computing. This type of architecture uses a non-linear transformation of input signals to allow them to be linearly separated. In software this concept is well understood but in hardware many

practical issues arise. Fortunately, in Cucchi *et al* [4] the authors present a very practical hands-on tutorial to start implementing reservoir computing in hardware.

Another alternative approach to synaptic crossbar arrays of ECRAM devices, is to grow conductive dendritic polymeric fibers *in situ* to reproduce the interconnections in between nodes in a neural network. Scholaert *et al* [5] show that such dendritic objects have non-linear current–voltage responses that could be advantageously used to classify spiking signals, such as spiking activity that would be produced by biological neural cells.

However, true organic neuromorphic systems operating at the biointerface are not yet available and more research is certainly needed to achieve this ambitious goal. In Bruno *et al* [6] the authors give a perspective of how some of the challenges towards this goal can be overcome including organic material design to interface cell, tissues and organs and potentially bridge to more sophisticated inorganic computing units for closed-loop control sensing and actuation.

Finally, in Field *et al* [7] a tantalizing concept is introduced that states that any system with morphological degrees of freedom and locally limited free energy will eventually evolve toward a neuromorphic morphology that supports hierarchical computations. These hierarchies occur throughout biology, from the architectures of intracellular signal-transduction pathways to the large-scale organization of perception and action processing in the mammalian brain.

Data availability statement

No new data were created or analysed in this study.

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