Brain-like Computation with Percolating Networks of Nanoparticles

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Self-assembled networks of nanoparticles have recently emerged as important candidate systems for brain-like (or neuromorphic) information processing.[1] The essence of the approach is to take advantage of the intrinsic dynamical properties of these networks to implement brain-inspired approaches to computation.[2]

Our percolating networks of nanoparticles (PNNs, Fig 1(a)) are self-assembled via simple deposition processes that are completely CMOS compatible, making them attractive for integration. The key to our approach is to terminate the deposition at the onset of conduction (the percolation threshold) when the electrical properties of the network are dominated by tunnel gaps between groups of particles.[3] The memristive tunnel gaps (Fig 1(b)) turn out to have neuron-like properties, which means that PNNs can be viewed as networks of neurons.[4]

Both the structural and dynamical properties of PNNs have been shown to be brain-like[2] and, in particular, avalanches of neuron-like spiking events have been shown to be critical.[1] Criticality is a key feature of the biological brain that has been related to optimal information processing capability. We have explored brain-like computation with PNNs in two regimes, beginning with simulations[5,6,7] that allow us to understand the processes and refine parameters, and then moving to experimental demonstrations[8]. At low voltages, the devices are amenable to reservoir computation and we have successfully demonstrated time series prediction, non-linear transformation and spoken digit recognition.[5,8] In the high voltage regime, the spiking behaviour of the 'neurons' has been exploited to perform Boolean logic and MNIST classification[6], and, most recently, optimization tasks[7].

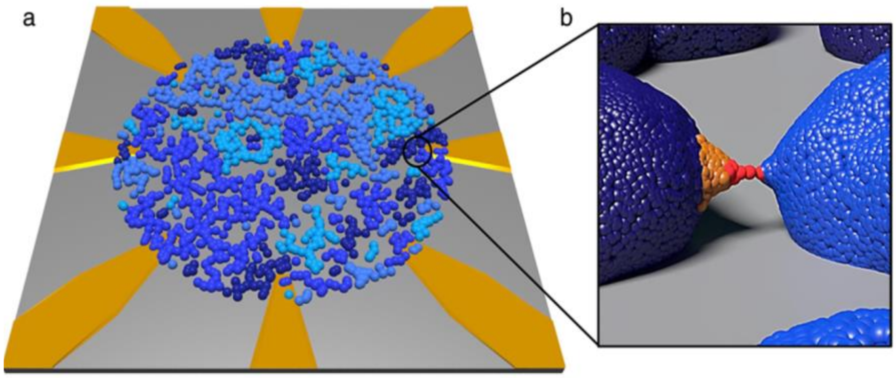

Figure 1. *(a) A percolating network of nanoparticles in a multiple contact geometry. The different shades of blue represent groups of particles that are in contact with one another. (b) The zoomed region shows a schematic of the growth of an atomic filament within a tunnel gap when a voltage is applied, leading to neuron-like spiking.*

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[3] A. Sattar et al, Phys. Rev. Lett. **111**, 136808 (2013).

[4] R. K. Daniels, et al Neural Networks **154**, 122 (2022), Phys. Rev. Applied **20**, 034021 (2023).

[5] J. B. Mallinson et al, Nanoscale **15**, 9663 (2023).

[6] S. J. Studholme et al, Nano. Lett. **23**, 10594 (2023).

[7] S. J. Studholme et al, to be published (2024).

[8] J. B. Mallinson et al, to be published (2024).