From brain physiology to intelligent interfaces: lessons for neuromorphic technologies

Beatrice Mihaela Radu[1], Cristina Staicu[1,2], Felix Sima[2]

[1]University of Bucharest, Faculty of Biology, Department of Anatomy, Animal Physiology and Biophysics, Splaiul Independenţei 91-95, Bucharest, Romania
[2]Center for Advanced Laser Technologies, National Institute for Laser, Plasma and Radiation Physics, 077125 Măgurele, Romania
beatrice.radu@bio.unibuc.ro

The development of neuromorphic technologies increasingly relies on emerging hardware platforms, including memristive devices, spiking sensors, and adaptive neural interfaces [1,2]. Despite substantial progress, current implementations face critical limitations related to device variability, endurance, scalability, and the insufficient integration of physiological constraints into hardware and interface design [1,3]. The intrinsic complexity of neurophysiological properties, including spike timing–dependent coding, synaptic and homeostatic plasticity, neuromodulatory control, and multiscale feedback across neuronal and neurovascular loops, poses significant challenges for their translation into implementable neuromorphic architectures [4]. In parallel, the growing use of organ-on-chip and blood–brain barrier–on-chip platforms for drug testing highlights the need for neuromorphic devices and interfaces capable of interacting with physiologically relevant, dynamically regulated biological systems, particularly with respect to selective transport, adaptive regulation, and interface stability [5]. Within this context, the blood–brain barrier provides a reference model for interface architectures in which selective permeability, transporter-mediated exchange, and bidirectional signaling are dynamically co-regulated to maintain system stability while enabling controlled pharmacological access. Translating these principles to neuromorphic device and interface design underscores the need for adaptive, resource-aware interface layers capable of controlled signal and molecular transduction, supported by advances in emerging memristive and brain-inspired device technologies [6]. Addressing these challenges requires integrated device–system co-design strategies that align materials engineering, interface architectures, and biologically informed models to enable robust neuromorphic technologies and physiologically relevant platforms for drug testing.

References
[1] Indiveri, G., & Liu, S.-C. (2015). Memory and information processing in neuromorphic systems. *Proceedings of the IEEE*, 103(8), 1379–1397. https://doi.org/10.1109/JPROC.2015.2444094
[2] Li, Z., Huang, Y., Li, X., & Chen, F. (2023). Emerging memristive neurons for neuromorphic computing: Devices and applications. *Journal of Materials Science*, 58, 10875–10903. https://doi.org/10.1007/s10853-023-08976-x
[3] Kim, M. K., Park, M. S., & Hwang, C. S. (2020). Emerging materials for neuromorphic devices and systems: Challenges and opportunities. *Materials Today Physics*, 13, 100199. https://doi.org/10.1016/j.mtphys.2019.100199
[4] Bi, G.-Q., & Poo, M.-M. (2001). Synaptic modification by correlated activity: Hebb's postulate revisited. *Annual Review of Neuroscience*, 24, 139–166. https://doi.org/10.1146/annurev.neuro.24.1.139
[5] Staicu, C. E., Jipa, F., Axente, E., Radu, M., Radu, B. M., & Sima, F. (2021). Lab-on-a-Chip platforms as tools for drug screening in neuropathologies associated with blood–brain barrier alterations. *Biomolecules*, 11(6), 916. https://doi.org/10.3390/biom11060916
[6] Wang, J., Zhu, Y., Zhu, L., Chen, C., & Wan, Q. (2022). Emerging memristive devices for brain-inspired computing and artificial perception. *Frontiers in Nanotechnology*, 4, 940825. https://doi.org/10.3389/fnano.2022.940825