A CMOS Approach to Emulate Neuro-Glia Interactions in Cognitive Processing

Yilda Irizarry-Valle and Alice C. Parker, IEEE Life Fellow

University of Southern California, Los Angeles, CA, 90089

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Our central goal in the BioRC research [1] is to demonstrate electronic circuits that mimic the intelligence, learning and memory capabilities of the brain through the use of analog electronic circuits forming neuromorphic systems of networked neurons.

Neuromorphic engineering is a leading future technology for the invention of smarter computers, specialized hardware for large-scale networks, and prosthetic devices inspired on brain computational processing. An ambitious multidisciplinary approach is taken towards discovering what makes the brain outperforms in terms of power, robustness, and sensory computations. The current research is on unraveling the computational processing between the two major cell types in the brain, neurons and glial, for the design of custom bio-inspired and biomimetic circuits. We focus on cognitive processing and investigate the fundaments of sub-cellular events involved in sensory computations, combined with high level observations on the integration/coordination of information across different regions in the brain. We explore the limitations of current technologies and investigate through circuit simulation on the capability of neuro-glia computations in cognitive functions. This sets the basis to further evaluate and explore the limitations of embedding biological computations using current technology. It also allows for testing biologically inspired circuits that share biophysical properties similar to the computations performed in the brain.

Sensory information, e.g. visual information, enters brain via different neuronal pathways, carrying different features and with different delays, where further processing creates a conscious scene. Using neuromorphic circuits, our research aims to contribute to a better understanding of the role of astrocytes, a subtype of glial cells, in the integration of neuronal activity leading to a conscious episode [2]. We emulate subcellular mechanisms that support the communications between astrocytes and neurons. Astrocytes modulate neuronal activity by their release/uptake of transmitters, not by firing action potentials; rather their excitability is due to intracellular calcium waves, elicited by neurotransmitters from surrounding neurons. These nonlinear Ca^{2+} waves represent the coding mechanism through which astrocytes "make decisions" to feed back to neurons [3]. A single astrocyte can span over 100,000 synapses. Astrocytes do not usually behave as an individual unit; instead they form a syncitium, i.e. a network of astrocytes, to sense and influence massive amount of neuronal activity. At the syncitium, astrocytes communicate with each other by means of the propagation of calcium waves via gap junctions. Groups of neurons that cannot directly communicate may "talk" to each other through the astrocytic syncitium. These properties of astrocytes make them a good prospect for the binding of neuronal information.

We model the biological mechanisms, using CMOS neuromorphic circuits, through which astrocytes play a role in the synchronization of neuronal activity. Synchronization is fundamental in conscious processing, and recent experiments have shown that single astrocytes are capable of inducing *slow inward currents* (SICs) with a high degree of correlation into extrasynaptic NMDAR channels of adjacent dendrites, causing synchronized events in adjacent neurons [4], a mechanism that we have emulated. By circuit simulations, we have seen that our hypothesis on the changes of the excitability of neurons is dependent on the arrival of slow inward current events which greatly influences the amplitude of excitatory postsynaptic potentials. This work suggests, for real biological circuits, the possible implications of phase synchronization on the firing of neurons and the way the astrocytes interact with each other that could potentially elicit synchronization at different locations in a group of unrelated neurons. This is a first step to demonstrate more complex interactions between neurons and astrocytes.

Our research aim is to capture the essential dynamics of networks of astrocytes interacting with neurons using neuromorphic circuits with minimum circuitry. To the best of our knowledge, the BioRC Biomimetic Real-time Cortex group is the first to emulate neuro-glia interactions using CMOS technology.

References:

[1]A. C. Parker, The BioRC Biomimetic Real-Time Cortex Project, Univ. of Southern California, 2013 [Online]. Available: http://ceng.usc.edu~parker/BioRC_research.html

[2] J. Robertson, “The Astrocentric Hypothesis: proposed role of astrocytes in consciousness and memory formation”, *Journal of Physiology*, pages 251- 255, 2002.

[3] G. Carmignoto, “Reciprocal communication systems between astrocytes and neurons”, *Progress _eurobiology*, 62(6):561-581, 2000.

[4] T. Fellin, O. Pascual, S. Gobbo, T. Pozzan, P. Haydon, and G. Carmignoto, “Neuronal synchrony mediated by astrocytic glutamate through activation of extrasynaptic NMDA receptors,” *neuron*, vol. 43, pp. 729 - 743, 2004.