Neuromorphic Braitenberg vehicles

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Braitenberg vehicles [1] have played an important role in the history of cybernetics, embodied intelligence, and bio-inspired machines: bottom-up design from elementary sensors and actuators enable complex machine behaviors reminiscent of their animal counterparts. This research aims to revisit Braitenberg vehicles from a neuromorphic perspective (as can be seen in Figure 1). The key novelty is to design the behavior in terms of events rather than trajectories. This is achieved by keeping the continuous aspects of behavior by extracting these events from continuous neuronal dynamics.

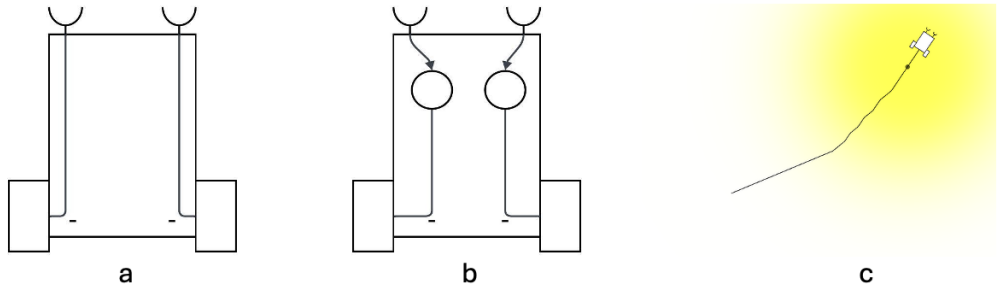

Figure 1: a) Braitenberg Vehicle 3. b) Neuromorphic Braitenberg Vehicle 3. c) Trajectory of the vehicle towards a source of light.

This architecture is scaled up to augment the reactive behavior of the machine with versatile and robust action selection mechanisms. This is achieved by a winner-take-all architecture whose active neuron selects the task to be performed [2, 3]. It generates a rhythm that produces a sequence of actions of variable duration. Reoccurring tasks (event behaviors) are inherently rhythmic: they consist of discrete patterns organized continuously in time and space. Additionally, the architecture can naturally capture the hierarchical structure of behavior, in which tasks can be decomposed into sub-tasks. This makes it scalable to generate deeper compositional behaviors, such as a vacuum cleaner tasked with cleaning a multi-floor building, where each floor is composed of multiple rooms.

A novelty of the proposed work is to introduce the distinction between “exteroception”, which concerns the regulation of the outer environment, and “interoception”, which concerns the regulation of the inner environment. Although this distinction is omnipresent in biology [4], it is generally not present in embodied machines. We discuss this topic through the Braitenberg setup, where going towards sources of light is an exteroceptive task, while returning to a charging station to replenish its battery is an interoceptive task. The proposed architecture reconciles both tasks in a rhythmic, complementary and asymmetrical manner. This way, we highlight the value of machines that organize their interaction with both environments on the basis of event-based exteroceptive and interoceptive internal models.

[1] V. Braitenberg, MIT press, 1986.

[2] R. Schmetterling et al., IEEE CSL, 8, 1235-1240, 2024.

[3] Y. Huo et al., NCE, 6 (1), 014018, 2026.

[4] B. Toussaint et al., NEUROSCI BIOBEHAV REV, 159, 105608, 2024.