

In vitro experimental and theoretical studies to restore lost neuronal functions: the Brain Bow experimental framework

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NOWADAYS, neurological disorders that disrupt connections between brain and body thus causing paralysis affect millions of people worldwide. Such a number is likely to increase in the next years and current assistive technology is still limited. The possibility of controlling motion of a limb by thought is becoming reality owing to the advent of Brain Machine Interfaces (BMIs), which aim to extract motor intents from cortical signals and convey them downstream externally, therefore recovering motor capabilities in patients with impaired functional connectivity between the central and peripheral nervous system [1-3]. Development of these devices has already had a profound impact on the quality of human life, and will continue to do so while research in this field intends to remedy serious neuronal disabilities. However, most modern BMIs are designed to restore the lost motor functions by acting only in one direction, namely from the brain to the body.

The ultimate goal of our studies is development of a new proof-of-concept bi-directional BMI: a neuromorphic chip for brain repair that will reproduce the functional organization of a damaged part of the central nervous system [4]. To reach this ambitious goal, we implemented a multidisciplinary ‘bottom-up’ approach in which in vitro neuronal networks are the paradigm for development of an in silico model to be incorporated into the neuromorphic device. In this study we present the overall strategy and focus on the different building blocks of our research framework: (i) the experimental characterization and modeling of ‘finite size networks’, which represent the smallest and most general self-organized circuits capable of generating spontaneous collective dynamics; (ii) the induction of lesions in cultured neuronal networks and in an animal whole-brain preparation with special attention paid to the impact on the functional organization of the circuits; and (iii) the first production of a neuromorphic chip implementing a real-time model of neuronal networks. We provide a dynamical characterization of the finite size circuits with single cell resolution and show that a neural network model based on Izhikevich neurons is able to replicate the experimental observations. We also demonstrate that optical and ischemic lesions resulted in changes in the dynamics of the neuronal circuits in in vitro neuronal networks and in the whole-brain preparation, respectively. Finally, we present the implementation of a neuromorphic chip that reproduces the network dynamics in quasi-real time (10 ns precision).

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This work was supported by the European Union's Seventh Framework Programme (ICT-FET FP7/2007-2013, FET Young Explorers scheme) under grant agreement n° 284772 BRAIN BOW (www.brainbowproject.eu). [§]These authors contributed equally to this work.

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