Coding and decoding of information in bi-directional neural interfaces

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Several researchers have proposed to study learning and memory by connecting nervous tissue, kept alive *in-vitro*, bi-directionally to an external device, i.e. an actual physical body. For instance, Reger & al. (2000) connected a lamprey brain, isolated and kept alive *in-vitro*, bi-directionally to a mobile robot. The robot was presented light stimuli and the brain reacted to them inducing the robot to follow or escape the light source. Similar experiment were performed by DeMarse & al. (2000), who interfaced a neuronal network cultured on a micro-electrode array to a computer-simulated animal, moving inside a virtual world. Following this approach, and with the aim of establishing general interfacing techniques and computational methods (Martinoia et al, in press), we interfaced a mobile robot with a population of neurons, extracted from rat embryos and cultured on a micro-electrode array. One peculiar feature of this preparation is the possibility to stimulate and/or record from multiple sites at the same time. A neural preparation which is provided with a body is the ideal framework to address two related issues: (i) design of coding and decoding schemes to translate sensory signals into patterns of stimulation, and recorded firing patterns into motor commands; (ii) characterization of the input-output behavior of the neural preparation, as perceived by its robotic body.

With this application in mind, here we review mathematical and computational tools which allow to study coding, decoding and characterization of input-output behavior. We first address general technical issues related to stimulation and recording from a neural preparation; then we discuss the notions of time-dependent firing rate and of neural code. We then introduce a number of mathematical tools (taken from dynamical systems and information theory), that allow to provide precise definitions to the notions of coding, decoding, and transferring information. We finally provide examples of application of these techniques, from the literature and from our specific application.