Chapter 3
Design for Information Processing in Living Neuronal Networks

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ABSTRACT

A neurorobot is a model system for biological information processing with vital components and the artificial peripheral system. As a central processing unit of the neurorobot, a dissociated culture system possesses a simple and functional network comparing to a whole brain; thus, it is suitable for exploration of spatiotemporal dynamics of electrical activity of a neuronal circuit. The behavior of the neurorobot is determined by the response pattern of neuronal electrical activity evoked by a current stimulation from outer world. “Certain premise rules” should be embedded in the relationship between spatiotemporal activity of neurons and intended behavior. As a strategy for embedding premise rules, two ideas are proposed. The first is “shaping,” by which a neuronal circuit is trained to deliver a desired output. Shaping strategy presumes that meaningful behavior requires manipulation of the living neuronal network. The second strategy is “coordinating.” A living neuronal circuit is regarded as the central processing unit of the neurorobot. Instinctive behavior is provided as premise control rules, which are embedded into the relationship between the living neuronal network and robot. The direction of self-tuning process of neurons is not always suitable for desired behavior of the neurorobot, so the interface between neurons and robot should be designed so as to make the direction of self-tuning process of the neuronal network correspond with desired behavior of the robot. Details of these strategies and concrete designs of the interface between neurons and robot are be introduced and discussed in this chapter.

1. INTRODUCTION

A neurorobot is a model system in which a living neuronal circuit is electrically connected to a robot body (Bakkum, 2004; Kudoh, 2007, 2011; Novellino, 2007). The neurorobot serves as a simple model for reconnection of brain and peripherals and reconstruction of biological intelligence. The neurorobot concept was pioneered by Potter and colleagues in 2003, who developed “Hybrot,” a contraction of hybrid robot (Bakkum, 2004). Hybrot is so to speak a kind of extension
of “Animat” reported by the same group in 2001 (DeMarse, 2001), in which a living neuronal circuit interacts with a computer-simulated environment. Although Hybrot replaced the simulated environment of Animat with a real robot body, both designs shared a common purpose: to elucidate mechanisms of biological intelligence, especially self-organization process of the intelligence during interactions between a neuronal network and the environment. Because the robot body is a mediator between neurons and environment, Hybrot exemplifies the field of “Embodied Cognitive Science,” which emphasizes the critical roles of a body on biological intelligence (Brooks, 1986; Pfeifer, 1999). Although the concept was foresighted, Animat, which simply connects neurons and the environment, could not deliver its intended behavior. It appears that “certain premise rules” should be embedded in the relationship between spatiotemporal activity of neurons and intended behavior—premise rules do not autonomously emerge from random interactions.

As a strategy for embedding premise rules, two ideas are proposed. The first is “shaping” (Chao, 2008), by which a neuronal circuit is trained to deliver a desired output. This strategy requires a supervisor to examine the output. The biological analog of the supervisor is the reward system.

The second strategy is “coordinating” (Kudoh, 2007, 2011). A living neuronal circuit is regarded as the central processing unit of the neurorobot. No supervisor is assigned, and the neuronal circuit is not manipulated by other components of the neurorobot. The desired behavior is generated by simple rules embedded in the connections between the neurons and robot body. The differences between the two strategies will be discussed later in this chapter.

To date, the characteristic features of biological intelligence have been scarcely replicated by artificial intelligence. The gap between artificial intelligence and real life has been often attributed to the frame problem and symbol grounding problem. However, embodied cognitive science offers appropriate solutions to these opt-expressed problems. In the context of embodied cognitive science, the premise rules for desired behavior are embedded in the relationships between sensors and actuators. The simple subsumption architecture of this approach can be remarkably adaptable and reliable in complex environments (Brooks, 1986). A neurorobot is realization of embodiment cognitive science by incorporating a living neuronal circuit into robot system. Originally, a neurorobot and its “small brain” constituted an effective model of biological intelligence, with the robot itself performing no useful work. Currently, it is recognized as a model of biological intelligence, especially in terms of embodied cognitive science. In addition, the system can be used for testing tube for such as regenerative neuromedicine and Brain-Machine Interface (BMI). The neurorobot system is simple and versatile enough to probe related neuroengineering technologies such as neuroelectrodes and BMI decoding algorithms.

This chapter introduces the concept of the neurorobot system and its use in various technologies. Predicted future works are also discussed.

2. OUTLINE OF A NEUROROBOT

A neurorobot consists of three principal components: a Living Neuronal Circuit (LNC), neuro-device interface, and robot body.

A LNC uses a reconstructed semi-artificial neuronal network in a dissociated culture system, or a slice preparation of a brain (Bakkum, 2007). In a broad sense, a local circuit in a whole living brain can constitute the LNC of a neurorobot (Kawato, 2008); however, such configuration is generally regarded as a BMI rather than a neurorobot model.

The interface includes hardware such as electrodes, an amplifier, A/D converters, and a computer to implement software such as programs for decoding neuronal activity and stimulating
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