Neural Networks 101 (2018) 15–24

Contents lists available at ScienceDirect

Neural Networks

journal homepage: www.elsevier.com/locate/neunet

Neural electrical activity and neural network growth

F.M. Gafarov *

Institute of Computational Mathematics and Information Technologies, Kazan Federal University, Kremlevskaya 35, Kazan, 420008, Russia
Laboratory of Neurobiology, Kazan Federal University, Kremlevskaya, 35, Kazan, 420008, Russia

A R T I C L E I N F O

Article history:
Received 4 July 2017
Received in revised form 31 January 2018
Accepted 1 February 2018
Available online 9 February 2018

Keywords:
Neurite outgrowth
Neural activity
Network activity patterns
Structural plasticity

A B S T R A C T

The development of central and peripheral neural system depends in part on the emergence of the correct functional connectivity in its input and output pathways. Now it is generally accepted that molecular factors guide neurons to establish a primary scaffold that undergoes activity-dependent refinement for building a fully functional circuit. However, a number of experimental results obtained recently shows that the neuronal electrical activity plays an important role in the establishing of initial interneuronal connections. Nevertheless, these processes are rather difficult to study experimentally, due to the absence of theoretical description and quantitative parameters for estimation of the neuronal activity influence on growth in neural networks. In this work we propose a general framework for a theoretical description of the activity-dependent neural network growth. The theoretical description incorporates a closed-loop growth model in which the neural activity can affect neurite outgrowth, which in turn can affect neural activity. We carried out the detailed quantitative analysis of spatiotemporal activity patterns and studied the relationship between individual cells and the network as a whole to explore the relationship between developing connectivity and activity patterns. The model, developed in this work will allow us to develop new experimental techniques for studying and quantifying the influence of the neuronal activity on growth processes in neural networks and may lead to a novel techniques for constructing large-scale neural networks by self-organization.

1. Introduction

During ontogeny, neural subnetworks in the developing brain evolve from the initial disconnected state to the connected matured state (Ko, Cossell, Baragli, Antolik, Clopath, Hofer, & Mrsic-Flogel, 2013; Quartz, 1999; White & Fitzpatrick, 2007). The formation of correct neural connectivity during the nervous system development is important for high-level cognitive and motor behaviors. It is widely accepted that topographic organization in the nervous system is generated by the patterns of gene expression (Ackley & Jin, 2004) and the patterns of electrical activity (Krubitzer & Kahn, 2003). According to the early ideas by Hebb (1949) new synaptic connections preferentially grow between active neurons. The connectivity is fixed not only during development but also in the adulthood and massive processes of synapse deletion and reorganization of the connectivity during ontogeny (Butz, Wrgtter, & van Ooyen, 2009; Chklovskii, Mel, & Svoboda, 2004). The electrical activity of neurons triggers secondary processes in the form of molecular signaling cascades which leads to the corresponding changes in the shapes of neurons, dendritic spines and axonal boutons configuration, receptor configuration, neurite branching, growth and guidance (Borodinsky & Belgacem, 2016; Lim, Stafford, Nguyen, Lien, Wang, Zukor, He, & Huberman, 2016; Neely & Nicholls, 1995). However, the fundamental mechanisms controlling the developmental process of realistic connectivity generation in neural networks remain unknown. A deeper understanding of the connections growth process in neural networks will give us information about early developmental stages of the brain.

Neuroscientists believe that information is stored in the connection weights of neural networks (Chklovskii et al., 2004; Quartz & Sejnowski, 1997). Despite considerable progress in neuroanatomy, electrophysiology and imaging (Stetter, Battaglia, Soriano, & Geisel, 2012) of the detailed mapping of neural connectivity is a difficult task. The relationship between the connectome (Sporns, Tononi, & Ktter, 2005) and cortical function remains unclear, so we need to discover the nature and purpose of the principles underlying cortical connectivity (Budd & Kisvrday, 2012). Each sensory stimulus causes a complex pattern of activity in the neural populations of multiple cortical areas. The relationship between sensory stimuli, and firing patterns they evoke defines the 'neural code' of the corresponding populations of neurons (Harris & Mrsic-Flogel, 2013). A precise understanding of local networks dynamics requires relating circuit activity with the underlying network structure.

* Correspondence to: Institute of Computational Mathematics and Information Technologies, Kazan Federal University, Kremlevskaya 35, Kazan, 420008, Russia.
E-mail address: fgafarov@yandex.ru.

https://doi.org/10.1016/j.neunet.2018.02.001