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Chapter 1

Introductory Chapter: Cognitive and Computational Neuroscience - Principles, Algorithms, and Applications

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1. Cognitive and computational neuroscience: principles, algorithms, and applications

The term "computational neuroscience" was introduced by Schwartz [1] through the organization of a conference in California in 1985. Cognitive and computational neuroscience evaluates the different brain functions (e.g., attention, emotion, perception, learning, consciousness, anesthesia, cognition, and memory) in terms of the information processing procedure of the brain [2]. This topic is an interdisciplinary issue that links the diverse backgrounds of neuroscience, cognitive science, psychology, mathematics, biomedical engineering, computer science, robotics, and physics. Therefore, the main idea of this book is to present a general framework for the researchers from diverse fields.

2. Related works

Cognitive and computational neuroscience has many medical and engineering applications such as rehabilitation [3], psychology and psychiatric disorders (e.g., depression, chronic addiction, post-traumatic stress disorder, dementia, attention deficit hyperactivity disorder, and autism) [4], brain-computer interface [3, 5], human-computer interaction [6], neurofeedback [7, 8], marketing [9], robotic [10], and decision-making [11]. Research in cognitive and computational neuroscience is categorized into four main topics, including experimental neuroscience (e.g., electrophysiology, neuron, synapse, synaptic plasticity, memory, conditioning, learning, consciousness, vision, neuroimaging), theoretical neuroscience (e.g., models of neurons, single-neuron modeling, spiking networks, network dynamics, behaviors of the brain networks, mathematical models of the brain activity, sensory processing, connectivity analysis), dynamical systems (e.g., synchronization, oscillators, pattern formation, chaos), and computational intelligence (e.g., neural networks, graph theory, reinforcement learning, pattern recognition, evolutionary computation, information theory, statistics, and signal processing).

Suitable brain signals and images are usually used according to invasive or non-invasive acquisition techniques. Therefore, non-invasive techniques, such as electroencephalography (EEG) [12, 13], event-related potentials (ERPs) [14, 15], magnetoencephalography (MEG) [3, 16], functional magnetic resonance imaging (fMRI) [17], positron emission tomography (PET) [18], transcranial direct current stimulation (tDCS) [19], and transcranial magnetic stimulation (TMS) [20], are generally preferred.

This section presents a detailed discussion of previous related works on different methods based on epilepsy and seizure detection along with different machine-learning approaches. In one study, Hosseini et al. [21] proposed a qualitative and quantitative analysis of EEG signals for epileptic seizure recognition. Hosseini et al. [22] proposed an approach for seizure and epilepsy recognition using chaos analysis of EEG signals. Hosseini [23] proposed a hybrid method based on higher order spectra (HOS) for recognition of seizure and epilepsy using EEG and electrocorticography (ECOG) signals.

Several studies have been proposed for the presentation of functional models, conceptual models, bio-inspired frameworks, signal processing approaches, image processing approaches, and electrophysiology studies based on cognitive processes, including emotion, stress, and attention. In one study, Hosseini et al. [24, 25] proposed a labeling approach of EEG signals in emotional stress state using self-assessment and psychophysiological signals. Hosseini [26] and Hosseini et al. [27–29] presented an HOS approach for emotional stress detection using EEG signals. Hosseini et al. [30, 31] designed an emotion recognition system using entropy analysis of EEG signals. Hosseini et al. [32] proposed an improved model of the behavioral calcium channels in the hippocampus CA1 cells during stress.

In another study, Hosseini et al. [33] proposed an emotional stress recognition system using psychophysiological and EEG signals. Hosseini et al. [34] proposed different features including fractal dimension, wavelet coefficients, and Lempel-Ziv complexity of EEG signals for emotional stress recognition. Hosseini et al. [35] presented a cognitive and computational framework of brain activity during emotional stress. Hosseini et al. [36] presented a cognitive and computational framework of the brain activity in emotional stress state. Hosseini [37] proposed attention and emotion recognition systems based on biological images and signals. Hosseini and Naghibi [38] proposed a computationally improved model of brain activity in the visual attentional state. Hosseini proposed [39] a computationally bio-inspired model of brain activity in the selective attentional state and its application for estimating the depth of anesthesia.

This chapter attempts to introduce the different approaches, principles, applications, and theories in cognitive and computational neuroscience, from a historical development, focusing particularly on the recent development of the field and its specialization within psychology, computational neuroscience, and engineering.

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