Available online at www.sciencedirect.com

ScienceDirect

Physics of Life Reviews 4 (2007) 223–252

PHYSICS of LIFE reviews

www.elsevier.com/locate/plrev

Review

Corticonic models of brain mechanisms underlying cognition and intelligence

Nabil H. Farhat

University of Pennsylvania, The Moore School of Electrical Engineering, and The Mahoney Institute of Neurological Sciences, Philadelphia, PA 19104-6390, USA

Received 14 June 2007; received in revised form 23 August 2007; accepted 23 August 2007

Available online 15 September 2007

Communicated by L. Perlovsky

Abstract

The concern of this review is brain theory or more specifically, in its first part, a model of the cerebral cortex and the way it: (a) interacts with subcortical regions like the thalamus and the hippocampus to provide higher-level-brain functions that underlie cognition and intelligence, (b) handles and represents dynamical sensory patterns imposed by a constantly changing environment, (c) copes with the enormous number of such patterns encountered in a lifetime by means of dynamic memory that offers an immense number of stimulus-specific attractors for input patterns (stimuli) to select from, (d) selects an attractor through a process of "conjugation" of the input pattern with the dynamics of the thalamo–cortical loop, (e) distinguishes between redundant (structured) and non-redundant (random) inputs that are void of information, (f) can do categorical perception when there is access to vast associative memory laid out in the association cortex with the help of the hippocampus, and (g) makes use of "computation" at the edge of chaos and information driven annealing to achieve all this. Other features and implications of the concepts presented for the design of computational algorithms and machines with brain-like intelligence are also discussed. The material and results presented suggest, that a Parametrically Coupled Logistic Map network (PCLMN) is a minimal model of the thalamo–cortical complex and that marrying such a network to a suitable associative memory with re-entry or feedback forms a useful, albeit, abstract model of a cortical module of the brain that could facilitate building a simple artificial brain.

In the second part of the review, the results of numerical simulations and drawn conclusions in the first part are linked to the most directly relevant works and views of other workers. What emerges is a picture of brain dynamics on the mesoscopic and macroscopic scales that gives a glimpse of the nature of the long sought after brain code underlying intelligence and other higher level brain functions.

PACS: 05.45.-a; 84.35.+i; 87.85.dq; 87.18.sn; 87.19.II

Keywords: Brain; Cortex; Population dynamics; Nonlinear dynamics; Logistic map network; Symmetry-breaking; Parametric nonlinear coupling; Self-organization; Information driven annealing; Emergence; Edge-of-chaos; Order from chaos; Attractors; Immensity; Dynamic memory; Redundancy; Perceptual categorization; Cognition; Intelligence; Brain-code

E-mail address: farhat@ee.upenn.edu.

1571-0645/$ – see front matter
doi:10.1016/j.plrev.2007.08.001

Contents

1. Introduction

The term *Corticonics*, coined by M. Abeles in 1991 [1] to describe the neural circuits of the cerebral cortex, conjugates cortex in a manner similar to electron and electronics. Here *Corticonics*, echoing electronics, refers to the art of identifying salient anatomical and physiological attributes of cortical organization to be abstracted and used in devising algorithms and computational models of the cortex, *cognition* and *intelligence* that are more powerful than what is possible today with neural net and connectionist models. Simply put, intelligence is what the brain does in predicting and deciding what to do next to maximize the chances of an organism to survive in its environment; as long as my brain continues to predict and anticipate what will happen next I will survive. Present day neural nets and connectionist models of the cortex have not been very effective in duplicating higher-level brain function, especially the ability of the brain to process and attach meaning to dynamic input patterns. These are spatio-temporal signals furnished by sensory organs responding to the influence of a continually changing, complex, and uncontrolled environment or alternately due to dynamic probing and exploration of the environment by touch, taste, smell or vision, the latter via saccadic eye movement. The reason for this limitation is the simplistic transfer-function description of processing elements used in most present day neural net and connectionist models which, as will be appreciated below, may not adequately represent the way a cortical patch reacts to sensory information relayed to it by the thalamus or to inputs it receives from other parts of the cortex itself. The importance of being able to process dynamic sensory patterns is well recognized by some neuroscientists. For example Miguel Nicolelis wrote in [2] the following passage which is reproduced here verbatim because it happens to express eloquently the need for work and results being reported on or reviewed here:

> "The fact that sensory cues in the natural environment typically have intricate time-varying properties and that animals can perceive such sensory stimuli very rapidly suggest that the mammalian central nervous system is capable of processing complex time-dependent signals very efficiently. For example, speech and other vocalization signals have unique spectro-temporal signatures in which the timing and order of basic components (e.g. syllables, phonemes, motifs, etc.) play a critical role in distinguishing the meaning of different sounds. Thus, neural circuits have to decode the temporal structure of these signals in order to allow the subject to perceive and respond adaptively to them".