Encyclopedia of computational neuroscience:

The end of the second millennium

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Abstract

The authors describe mathematical and computational models in neuroscience as well as neuroanatomy and neurophysiology of several important brain structures. This is useful guide to mathematical and computational modelling of structure and function of nervous system. The book highlights the need to develop a theory of brain functioning, and it offers some useful approaches and concepts.

This fundamental volume unites under the same cover a brilliant and nicely illustrated introduction into neuroanatomy/neurophysiology and an encyclopedia of mathematical/computational models in neuroscience. The book contains two chapters: I) Three overviews: structural, functional and dynamical; II) Interacting systems in the brain: olfactory, hippocampus, thalamus, cerebral cortex, cerebellum, basal ganglia.

Consideration of neural organisation in the book is based on the triad: Structure, Function, and Dynamics and the authors consider each of these subjects separately in many details. There is important philosophical question about relations between Structure, Function, and Dynamics in this triad. In 1970s my supervisor Professor Albert Molchanov told that a biological "function" is the result of kinetic/dynamical development/realisation of "structure" and further, today's structure is a consequence/fixation of yesterday's kinetic (Molchanov, 1967)[1]. These relations might be realised on different hierarchical levels. Figure 1 gives a graphical representation of relations in the triad.

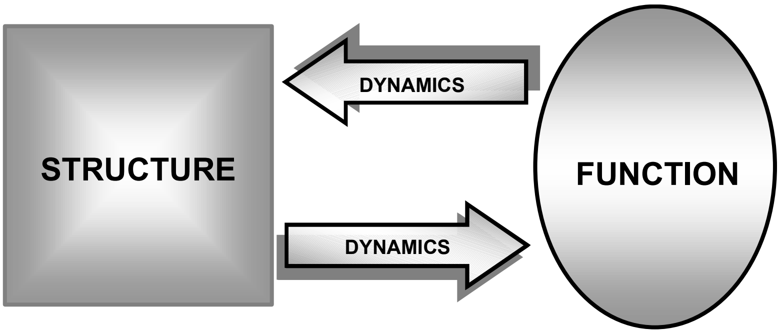

Figure 1

A functional overview presents mostly the schema theory, which is rooted in Immanuel Kant philosophy and was further developed in Jean Piaget's work. From a modern point of view schema theory is a "language" to describe different mental functions. Also computational and mathematical models of neural networks are particular examples of schemas to realise some definite function. For example, the authors consider in detail the schemas for reaching and grasping which are based on the cybernetic model with feedback loop. This is interesting to note that in 1970s the outstanding Russian physiologist academician Petr Anokhin developed the theory of "functional systems". The theory is still the basis for many neurophysiological studies (Sudakov, 1997). However it has not been reflected in the book at all.

[1] At that time scientists in the USSR understood the role of oscillations in biological and chemical systems and they studied the relations between "structure" and "function".

In the chapter “A Dynamical Overview” the methodology of neural network models is considered. The authors define deterministic models and consider attractors of dynamical systems: equilibrium point, limit cycle, and strange attractor. In principle one more attractor type exists in the phase space: this is a torus, which corresponds to quasiperiodic (envelope) oscillations. Computational models with multi-frequency dynamics seem to be very promising for modelling of information processing in brain structures (see, for example paper by Borisyuk et al., 1999 where the feature binding problem is described with using of multi-frequency oscillations).

Different models of a single neuron, neural population, and neural networks are considered as appropriate building blocks/modules to design particular computational models of brain structure or brain function. Several types of connection architectures between modules corresponding to different anatomical structures are studied. Note, that the authors do not mention an important type of connection architecture, the so called “neural network with a central element” (Kazanovich and Borisyuk, 1999). However, from the description of anatomy of different brain structures in the book it follows that the neural network with a central element is a very common architecture of connections between the brain structures.

A significant part of the dynamical review chapter is devoted to chaotic behaviour in neural systems. Neural models with chaotic dynamics, models with control of chaotic behaviour, and methods for analysing chaotic neuronal activity (e.g. EEG activity) are presented with many details. Nevertheless, the key question about the functional role of chaotic dynamics for the information processing in the brain is left open by the authors. They discuss the broad spectrum of opinions existing in the literature from the optimism of W.Freeman until the doubts of L.Glass. Probably the truth is as usual in the middle: chaotic dynamics naturally arises as a possible regime of the brain activity. Moreover, chaotic activity in the brain might be synchronised or partially synchronised and this is a possible basis for an information processing.

The authors study brain dynamics at many hierarchical levels and they discus some principles of neural organisation as a necessary component for the unborn brain theory. In fact the authors formulate two principles: 1) Principle of modular architectonics (nervous system is composed of building blocks); and 2) Principle of topographical order representation of sensory information in primary sensory cortices and a number of other structures (this is not clear how this principle might be used for auditory or olfactory sensory information). Also, indirectly and without clear formulation the authors discuss some other principles of the information processing in the brain: the principle of synchronisation of neural activity; the principal of spatio-temporal information encoding; the principle of flexibility of neural circuits (the same neural elements participate in the implementation of different functions); etc. Further progress in this direction seems to be extremely important because the list of principles is likely to be a foundation for the future development of theoretical ideas about brain functioning.

There are several limitations of the book such as some misprints, not carefully enough done organisation and systematisation of material. Nevertheless these limitations do not diminish the contribution of the book.

It is likely that the process of the book publication was too long and took more than 3 years. The majority of referenced papers are published before 1996. Computational neuroscience is a very rapidly developing field and during the last 3-4 years a huge amount of interesting and important papers have been published. We can say that the main results and achievements in the brain modelling at the last millennium are summarised in the book. Now it is the right time to write a new book, which will provide the concepts and ideas for the further development of computational neuroscience in the third millennium. Finally, the book highlights the need to develop a theory of brain functioning, and it offers some useful approaches and concepts.

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