Quantum Brain and Cognition

In this Chapter we present several aspects of the current research in quantum brain.

5.1 Biochemistry of Microtubules

Recent developments/efforts to understand aspects of the brain function at the sub-neural level are discussed in [Nan95]. Microtubules (MTs), protein polymers constructing the cytoskeleton of a neuron, participate in a wide variety of dynamical processes in the cell. Of special interest for this subsection is the MTs participation in bio-information processes such as learning and memory, by possessing a well-known binary error-correcting code $[K_1(13,2^6,5)]$ with 64 words. In fact, MTs and DNA/RNA are unique cell structures that possess a code system. It seems that the MTs’ code system is strongly related to a kind of mental code in the following sense. The MTs’ periodic paracrystalline structure make them able to support a superposition of coherent quantum states, as it has been recently conjectured by Hameroff and Penrose [HP96a], representing an external or mental order, for sufficient time needed for efficient quantum computing [II07b, II07d].

Living organisms are collective assemblies of cells which contain collective assemblies of organized material, including membranes, organelles, nuclei, and the cytoplasm, the bulk interior medium of living cells. Dynamic rearrangements of the cytoplasm within eucaryotic cells, the cells of all animals and almost all plants on Earth, account for their changing shape, movement, etc. This extremely important cytoplasmic structural and dynamical organization is due to the presence of networks of interconnected protein polymers, which are referred to as the cytoskeleton due to their bone-like structure [HP96a, Dus84]. The cytoskeleton consists of MT’s, actin micro-filaments, intermediate filaments and an organizing complex, the centrosome with its chief component the centriole, built from two bundles of microtubules in a separated T shape. Parallel-arrayed MTs are interconnected by cross-bridging proteins.
(MT-Associated Proteins: MAPs) to other MTs, organelle filaments and membranes to form dynamic networks [HP96a, Dus84]. MAPs may be contractile, structural, or enzymatic. A very important role is played by contractile MAPs, like dynein and kinesin, through their participation in cell movements as well as in intra-neural, or axoplasmic transport which moves material and thus is of fundamental importance for the maintenance and regulation of synapses (see, e.g., [Ecc64]). The structural bridges formed by MAPs stabilize MTs and prevent their disassembly. The MT-MAP ‘complexes’ or cyto-skeletal networks determine the cell architecture and dynamic functions, such as mitosis, or cell division, growth, differentiation, movement, and for us here the very crucial, synapse formation and function, all essential to the living state. It is usually said that microtubules are ubiquitous through the entire biology [HP96a, Dus84].

MTs are hollow cylinders comprised of an exterior surface of cross-section diameter 25 nm (1 nm = 10^{-9} meters) with 13 arrays (protofilaments) of protein dimers called tubulines [Dus84]. The interior of the cylinder, of cross-section diameter 14 nm, contains ordered water molecules, which implies the existence of an electric dipole moment and an electric field. The arrangement of the dimers is such that, if one ignores their size, they resemble triangular lattices on the MT surface. Each dimer consists of two hydrophobic protein pockets, and has an unpaired electron. There are two possible positions of the electron, called α and β conformations. When the electron is in the β-conformation there is a 29° distortion of the electric dipole moment as compared to the α conformation.

In standard models for the simulation of the MT dynamics [STZ93], the ‘physical’ DOF—relevant for the description of the energy transfer—is the projection of the electric dipole moment on the longitudinal symmetry axis (x-axis) of the MT cylinder. The 29° distortion of the β-conformation leads to a displacement $u_n$ along the x-axis, which is thus the relevant physical DOF.

There has been speculation for quite some time that MTs are involved in information processing: it has been shown that the particular geometrical arrangement (packing) of the tubulin proto-filaments obeys an error-correcting mathematical code known as the $K_2(13, 2^6, 5)$-code [KHS93]. Error correcting codes are also used in classical computers to protect against errors while in quantum computers special error correcting algorithms are used to protect against errors by preserving quantum coherence among qubits.

Information processing occurs via interactions among the MT proto-filament chains. The system may be considered as similar to a model of interacting Ising chains on a triangular lattice, the latter being defined on the plane stemming from filleting open and flattening the cylindrical surface of MT. Classically, the various dimers can occur in either α or β conformations. Each dimer is influenced by the neighboring dimers resulting in the possibility of a transition. This is the basis for classical information processing, which constitutes the picture of a (classical) cellular automaton.