1. CONTEMPORARY VIEW OF BRAIN FUNCTION

The brain plays a most particular role among all of our organs: in contrast to other organs, it does not process metabolic products, but rather a "substance" that did not become the subject of systematic scientific investigation until this century, namely *information.* As late as in the eighteenth century, the brain was considered to be a gland whose secretions were distributed throughout the body along the nerve pathways. The structure of the brain as a complex intertwined fabric of multiply networked cells exchanging signals with one another was first recognized during the past century, principally through the research of Golgi and Ramón y Cajal.

With this modern point of view, the specialization of the brain into areas, so-called cortices, responsible for particular activities, such as vision, hearing, or the movement of muscles, was soon discovered. Countless experiments and studies have extended and refined this picture in many respects; the invention of the computer has augmented this refined view of the concrete "machinery" with an equally refined view of its abstract task, the processing of "data." According to our present understanding, these data are represented on at least two distinct functional levels, differing in their time scales. One level is characterized by rapid changes (on the scale of milliseconds to seconds), the other by much slower processes (taking seconds to years).

The "fast" level consists of the instantaneous activity state of single neurons. The corresponding patterns of activity encode data that can change continuously and are presumably responsible for the contents of our short-term memory as well as for our immediate sensations. Our sensory receptors determine a part of these activity patterns through incoming nerve bundles by imprinting their activity more or less completely onto some subset of the neurons. The remainder of these changes is determined by the interactions among the neurons themselves, which can be either " excitatory" or " inhibitory" in nature.

The connection pattern, which determines the rapid activity changes in a decisive way, is not static, but can gradually evolve. It thus constitutes the second, "slow" level and codes those data which change either gradually or not at all. In particular, our long-term memory belongs to this level. Changes on this level concern the effectivity of the connections between neurons and take place primarily at the *synapses*, the neural "contacts," whose capacity to change and adapt forms the basis for the brain's learning ability. According to a hypothesis going back to Hebb (1949), the efficacy of a synapse changes depending on the correlation between the activity of the *presynaptic* neuron, *i.e.*, the neuron that triggers the activity of the synapse, and the *postsynaptic* neuron, *i.e.*, the neuron that is affected by the synapse. This hypothesis has been experimentally verified at individual synapses (Kelso et al. 1986). Changes on the fast and the slow level are thus coupled in both directions: The rapidly varying activity states of neurons gradually mold and change the network of connections between neurons, and these gradual changes in turn exert a back-reaction on the activity states of the neurons themselves.

According to our current understanding, the coupled, nonlinear dynamical processes for neuron activities and synaptic strengths form the basis for the functioning of the brain. This concept departs completely from the way sequential computers work. Thus, although the reaction time of a neuron (typical timescale 1 ms) and the signal propagation velocity along a nerve fibre (typical value 10 m/s) are extremely slow by the standards of modern computers, nature more than compensates for this disadvantage by the massive parallelism of the neural network. The underlying strategies of information processing must be significantly different from those of present-day computers. For example, only a few dozen sequential processing stages can possibly be involved in the observed, rapid formation of complex percepts, such as the visual recognition of a scene in a fraction of a second. This represents an important constraint on what can be considered as possible brain algorithms.

Since an individual neuron plays a minor role in what is happening globally, a high level of error tolerance results. A further property is the nearly complete lifting of any distinction between data and algorithm: an algorithm is embodied in the unfolding of the system dynamics and, hence, is determined by the synaptic strengths as well as by the instantaneous neuron activities. At the same time, the synaptic strengths also determine which activity states can be attained and thus determine which memories can be recalled. Interestingly enough, in programming languages used for artificial intelligence such as LISP, the rigid distinction between data and program has also been relaxed.

The framework provided by the coupled dynamics of neurons and synaptic strengths is still enormously broad. Obtaining concrete insights into the capabilities and properties of such information-processing systems requires the identification of important paradigmatic classes of such systems and of the problems that they can solve. The following chapters give an overview of some important and typical models of neural networks. However, it is reasonable to begin with a brief (and hence by necessity very fragmentary) sketch of the biological background. The reader may obtain more thorough information on this subject in the books by, for example, Creutzfeld (1983), Kandel, Schwartz (1985), and Brooks (1981).