Book Reviews

Internal Workings of the Brain

The Cerebellum as a Neuronal Machine. JOHN C. ECCLES, MASAO ITO, and JÁNOS SZENTÁGOTHAI. Springer-Verlag, New York, 1967. 343 pp., illus. $17.

Brain function is commonly viewed in relation to the phylogenetic level of brain structure, and higher levels of function are commonly attributed to more recently developed regions of the nervous system. The phylogenetically new cerebral cortex is thus seen as the seat of higher mental processes, and phylogenetically old subcortical structures are commonly thought to mediate more elementary, lower-level aspects of behavior. The notion that older structures mediate lower functions is based in part on the assumption that older structures remain static as newer structures evolve. This assumption may be warranted for some parts of the brain, but it is certainly unwarranted for the cerebellum, an ancient structure which is at the same time modern. The cerebellum, a brain center which functions in the control of movement, appeared in fish and became highly developed in reptiles, but its evolution did not then terminate. On the contrary, the cerebellum developed apace as the vertebrate brain evolved to its very highest form, for, as the authors of *The Cerebellum as a Neuronal Machine* point out, "With each further evolutionary development of the brain this same cerebellar organization seemed to be a necessary adjunct. . . ." The cerebellum has certain regions related primarily to the vestibular apparatus and others related primarily to the cerebral cortex, but in spite of these differences, all cerebellar regions are remarkably similar in structure and intrinsic organization: the histological appearance of the cerebellar areas associated with phylogenetically new and old parts of the brain is virtually the same. "Essentially, the cerebellum is constructed of stereotyped and relatively simple neuronal arrangements which we can regard as 'neural machinery' designed to process the input information in some unique and essential manner."

The Cerebellum as a Neuronal Machine deals with the operation of these "simple neuronal arrangements." The scope of the monograph may be likened to that of a treatise which explains the operation of a computer in terms of the basic structural elements of which it is composed, together with the physical connections and functional interactions between these elements. Such a treatise is necessarily (and by intent) limited, for at this level of description a computer that composes music might appear identical to one that dispenses summonses for traffic violations. In limiting their attention to the internal workings of the cerebellum, the authors necessarily omit much that is important: topics such as the important functional differences between the various subdivisions of the cerebellum, and problems related to the role of the cerebellum as an element in that larger neuronal machine, the nervous system as a whole.

Design of the Machine

The anatomical chapters with which the monograph begins reveal that the cerebellar computer is constructed of eight kinds of components: two kinds of input axons, five kinds of intrinsic cellular elements, and one kind of output neuron. Though few in kind, cerebellar elements are vast in number: a cubic millimeter of the granular layer of the cortex contains 2.4×10^6 granule neurons, a cellular density exceeding that of any other part of the nervous system. The neuronal components of the cerebellar cortex are arranged in a highly ordered pattern. Indeed, the geometrical precision with which the elements of the cerebellum are oriented along the axes of a Cartesian coordinate system is reminiscent of the latticework of conductors and ferrite cores in memory units of present-day digital computers. The aim of Eccles, Ito, and Szentágothai has been to synthesize cerebellar anatomy and physiology so as to achieve a formulation of the functional interrelations of these geometrically arranged input, intrinsic, and output elements. Many of the data presented were obtained by the three authors in their own laboratories (in Australia, Japan, and Hungary, respectively), and the separate chapters are in large measure the individual work of one or another of the authors. Szentágothai deals with anatomical matters, Ito describes the processing of the cerebellar output, and Eccles analyzes the processing of input and the interactions between the intrinsic elements lying within the cerebellar cortex.

One of the most striking features of the functional design of the cerebellum is the extent to which its operation depends on neuronal inhibition. Of the five kinds of elements whose cell bodies lie in the cerebellar cortex, four are inhibitory, that is, they act to reduce the excitability of the neurons on which their axons terminate. Only the granule cells (the most numerous of the five kinds of elements) are excitatory, and it is by way of these granule cells that excitation received from one group of input fibers is relayed to other cortical elements. The remaining intracortical neurons act to control and focus the consequences of this excitation—and they do so entirely by means of inhibitory action. Most surprising, perhaps, is the fact that the entire output of the cerebellar cortex, transmitted exclusively by axons of Purkinje cells (P-cells), is inhibitory. The output of the cerebellar cortex via P-cell axons must be distinguished from the final output of the cerebellum, for the cortical output via P-cells is transmitted to the rest of the brain by neurons lying in nuclear masses below the cerebellar cortex—neurons called nuclear cells (N-cells). The synaptic endings of P-cells on N-cells are inhibitory, P-cell axon terminals releasing a synaptic transmitter which makes N-cells less excitable. The fact that N-cells are inhibited by P-cells means that the final output of the cerebellum is, so to speak, a negative image of the output of the cerebellar cortex. An increase of impulse frequency in P-cells results in a decrease of impulse frequency in N-cells, and a reduction of impulse frequency in P-cells results in an augmentation of N-cell activity. N-cell axons terminate in many different regions of the brain and, in contrast to the terminations of P-cells, all synaptic endings of N-cells are excitatory; P-cells communicate by *inhibiting* or *disinhibiting*, whereas N-cells communicate by *facilitating* or *disfacilitating*.

Though P-cells communicate only with N-cells, N-cells receive a second input from other elements outside the cerebellum, and this input is excitatory rather than inhibitory. To the engineer, the N-cell may seem analogous to an electronic gate: the inhibitory P-cell input closes the gate to an excitatory input coming to the N-cell from outside the cerebellum. When the excitatory input is present and the inhibitory input absent, there will be an output from the N-cell. Even without the excitatory input, however, N-cells are "spontaneously" active, and the existence of this activity shows that N-cells have a pacemaker mechanism which generates impulses even without extrinsic sources of driving. To continue the analogy between N-cell and electronic gate, this pacemaker activity may be said to provide a third input to the gate, a "clock" input. The existence of the "clock" input provides a carrier frequency, and the frequency of impulse output discharged along from the N-cell axon is modulated down or up by the inhibitory and excitatory inputs reaching it from the cerebellar cortex and the rest of the brain, respectively.

Methodological Scheme

The preceding formulation of some of the operational features of the cerebellum was reached by Eccles, Ito, and Szentágothai through correlation of electrophysiological and anatomical data. An anatomico-physiological approach was the key to establishing the special importance of inhibition for information processing in the cerebellar cortex. Thus, physiological studies demonstrated the existence of an inhibitory process capable of blocking the excitatory synaptic action of input fibers on granule cells, and anatomical studies allowed the origin of this inhibitory action to be assigned to a special type of cell (the Golgi cell), because only this cell had terminations situated in such a way as to mediate the observed inhibition. Combined electrophysiological and anatomical data were also essential in assigning inhibitory functions to two other intracortical cerebellar neurons, the basket cell and the stellate cell. Thus, electrophysiological observations showed the existence of inhibitory synaptic action on both the somata and dendrites of P-cells, and the topographical arrangements of the basket and stellate cells conformed exactly to the requirements for cells having these respective inhibitory actions. These examples of the juxtaposition of anatomical and physiological findings are but a few of many that could be cited, for the ingenious combination of functional and structural data to yield principles of cerebellar operation is one of the outstanding features of the monograph.

This review would be misleading if it left the reader with the impression that *The Cerebellum as a Neuronal Machine* is directed primarily to the communication engineer, and it should be emphasized that the book will not make easy reading for those without a specialized background in electrophysiology and neuroanatomy. To be sure, the authors interpret their results in general operational terms, but the actual data on which their conclusions are based are those of physiology and anatomy. The reader without knowledge of the significance of neuronal hyperpolarization or depolarization, of potential field distribution in a volume conductor, or of the Golgi, Nauta-Gygax, and other histological techniques, for example, will have difficulty following the experimental results presented and will in general be unable to understand how the authors reach their conclusions. Those without a background in neurobiology might do well to preface their study of the monograph by a reading of Eccles's recent paper "Circuits in the Cerebellar Control of Movement" [*Proc. Nat. Acad. Sci. U.S.* **58**, 336 (1967)], in which notions of cerebellar organization are presented in terms that can be grasped by the nonspecialist. Finally, this review would do the authors an injustice if it were to suggest that they believe that the problems of cerebellar organization (even in the limited sense in which they have dealt with these problems) are now solved: they readily admit that the weight of evidence in support of several of their conclusions is not yet overwhelming, and add that there remain many important aspects of cerebellar architecture for which they are unable to propose a physiological role. Eccles, Ito, and Szentágothai have assembled a body of evidence and have constructed a model. Their model has gaps, but it is without doubt the best presently available, and it surely represents a great advance over the models of only a few short years ago. Furthermore, the very gaps in the model point toward future investigations which will add new chapters to what Eccles sometimes refers to as "the cerebellar story." Indeed, it seems possible that the cerebellum may turn out to be the neurophysiologist's Rosetta stone, its new and old parts revealing new and old neural codes. Future studies may decipher these codes, and may reveal how the cerebellum serves as a communication link for parts of the brain which speak the different languages of vision, audition, and kinesthesis, allowing these different languages to be translated into the language of muscular control—and of behavior in general.

EDWARD V. EVARTS
Laboratory of Clinical Science, National Institute of Mental Health, Bethesda, Maryland

Nuclear Physics

Many-Body Description of Nuclear Structure and Reactions. Course 36, International School of Physics "Enrico Fermi." C. BLOCH, Ed. Academic Press, New York, 1966. 605 pp., illus. $26.50.

The Varenna summer school was an exceptional one, and this volume of papers presented there contains many new developments, systematically and logically developed. Thus it is worth what it costs, even though the amount is a bit staggering.

Here those who do not read Russian can become acquainted with the methods of A. B. Migdal, who applies the Landau theory of Fermi liquids to nuclei. His article, "The method of interacting quasiparticles in the theory of the nucleus," is, in fact, pedagogically an improvement on his book on the same subject in Russian. Migdal's methods are of wide use in the U.S.S.R. The new feature of his work, it seems to me, is the use of density-dependent interactions, although such interactions were used by T. H. R. Skyrme and others many years ago, in somewhat different contexts. Otherwise, much of the theory is a reformulation of familiar methods in unfamiliar language, that of Green's functions. The question of origin of the P_2 force is not adequately handled in Migdal's lectures here; the reader is referred to later work, for example, that of Krainov and Malov published in *Yadernaya Fizika* **6**, 252 (1967) for a better treatment of this question. Although I do not care personally for the formula-