XXIII. NEUROPHYSIOLOGY[*]

W. S. McCulloch
J. A. Aldrich
F. S. Axelrod
H. J. C. Berendsen
M. Blum
J. E. Brown
J. D. Cowan

J. R. Cronly-Dillon
R. C. Gesteland
B. Howland[†]
K. Kornacker
J. Y. Lettvin
R. Melzack

N. Onesto
W. H. Pitts
Paola M. Rossoni
A. Taub
L. A. M. Verbeek
P. D. Wall
S. Winograd

RESEARCH OBJECTIVES

The aims of this group can be stated best under five main headings:

1. Basic Theory

Our purpose is to develop the necessary logical and mathematical theory for an understanding of parallel computation such as the brain performs, and thus lay foundations for an attack on the problem of decision making in the presence of a redundancy of potential command such as that encountered in the reticular formation.

J. A. Aldrich, M. Blum, J. D. Cowan, N. Onesto,

L. A. M. Verbeek, W. S. McCulloch

(a) Computation in the Presence of Noise. An information theoretic model for probabilistic logical computation has been devised, and using this, we have shown that, in principle, there exists a nonzero rate for arbitrarily reliable computation in the presence of noise. Many-valued logical schemes have been used in an attempt to realize such rates, with negative results. The conclusions drawn are not that nonzero rates are unrealizable, but that more sophisticated structures are necessary (1, 2).

J. D. Cowan

References

1. J. D. Cowan, Many-valued logics and reliable automata, Symposium on Principles of Self-Organization, edited by H. von Foerster and G. Zopf, Jr. (University of Chicago Press, Urbana, Illinois, 1961).

2. J. D. Cowan, Toward a proper logic for parallel computation in the presence of noise, Proc. Bionics Symposium, edited by J. E. Steele (Dayton, Ohio, 1961).

(b) Multiple Error-Correcting Codes. Codes that correct many errors but do not correct few errors have been investigated. In these codes only received words that are a distance x from a transmitted word are decoded as the transmitted word ($np - n\epsilon \leq x \leq np + n\epsilon$, where n is the block length, p is the probability of error, ϵ is any positive number).

An example of n = 60, p = 1/3, k = 5 has been worked out in detail. The circuits for encoding and decoding this code can be realized by logically stable nets.

S. Winograd

2. Water Structure in Nerve

Our objective is to obtain information on the structure of water, particularly in nerve, and to investigate theoretically and experimentally the possibility that an organized water lattice prefers potassium to sodium. Measurements at ultrahigh frequencies on the dielectric properties of squid giant axons under various conditions (normal, poisoned, after stimulation) were carried out at the Marine Biological Laboratory, Woods Hole, Massachusetts, during the summer of 1960. The processing of the data has been considerably delayed by the necessity of solving a complex boundary problem, and is not yet completed.

H. J. C. Berendsen, W. S. McCulloch

3. The work that we plan this year will concern a variety of problems:

(a) Vision. We shall continue studying the visual system of the octopus, with an approach like that of Lettvin and Maturana's previous work on the frog.

J. Y. Lettvin

(b) Neuromuscular Transmission. We expect to continue the study of neuromuscular transmission in the heart of squilla, the mantis shrimp. This study, like that above, was commenced at the Naples Aquarium last year, and will be continued there.

J. Y. Lettvin

(c) Olfaction in the Alligator. We shall continue our present study of the primary olfactory units in the alligator, to determine the number of qualitatively distinct types and formulate general rules for predicting how the chemical nature of an odorant will influence the kind of response given by each type.

R. C. Gesteland, W. H. Pitts

(d) Olfaction in Insects. We shall continue studying the responses of the primary olfactory receptors of the cockroach (Periplaneta Americana) with the same objective as in study (c).

Paola M. Rossoni

(e) Artificial Models of Olfactory Receptors. We shall explore the possibility of making artificial olfactory receptors by measuring the impedance change in suitable electrodes produced by absorbed monomolecular layers of odoriferous substances. We outlined our plan for this research in Quarterly Progress Report No. 56, page 193, but other commitments prevented our making much progress with it during the past year.

R. C. Gesteland, W. H. Pitts

(f) Audition in the Frog. We shall pursue our study of the response of various types of cell in the cochlear nucleus of the frog to complex sounds.

F. S. Axelrod

(g) Group Theoretical Analysis of Invariants Computed by the Frog's Retina. The results of Lettvin and Maturana on the qualities of the visual signal abstracted by the retina and transmitted by the frog's optic nerve were qualitative and somewhat intuitive.

We plan to use the classical theory of continuous groups to provide an exact mathematical characterization of all transformations of primary visual inputs into outputs, showing the features that they have discovered in the transformations actually performed by the frog's retina. Besides its physiological interest, this study ought to give insight into ways of designing artificial models of retinas which should detect and follow discrete moving objects and ignore the general background — even when the whole background is itself moving.

<div align="right">J. Y. Lettvin, W. H. Pitts</div>

(h) Electrochemiluminescent Devices for Simultaneously Displaying the Results of Computing Machines with Many Independent Output Channels. The principles to be followed can be found under study (1). The devices glow with very low voltages, say, 1.5-2 volts.

<div align="right">R. C. Gesteland, W. H. Pitts, B. Howland</div>

(i) The Mechanism of Chemiluminescence. We hope to use the methods of arc polarography to elucidate the physical chemical mechanism responsible for chemiluminescence, partially in the hope of also throwing light on biological luminescence.

<div align="right">R. C. Gesteland, W. H. Pitts, B. Howland</div>

(j) Polarographic Methods for Measuring Ocean Currents. It is well known that the concentration of dissolved O_2 can be measured continuously, in almost any solution, from the amplitude of its polarographic reduction wave at a Pt electrode. It occurred to us during the summer that by using an auxiliary electrode and passing enough cathodic current through it to deplete the O_2 of the solution in its neighborhood, the measuring electrode should be affected only if it lay behind the auxiliary on some streamlines, and to a degree that would depend upon how much replenishment could take place by diffusion across streamlines in the time of flow between the two electrodes. This seemed to provide a method for measuring the field of flow both in velocity and direction. This is in fact true in KCl solution. We hope to make it work in the ocean, for which such a method is urgently needed and, at present, is unavailable.

<div align="right">R. C. Gesteland, W. H. Pitts</div>

(k) Color Vision. We expect to announce a new theory of color vision in vertebrates.

<div align="right">J. Y. Lettvin, H. R. Maturana, W. H. Pitts</div>

4. Basic studies are being carried out to determine the rules of connection in the sensory parts of the central nervous system. This group concentrates particularly on the skin and muscle sensory systems. Work is proceeding in the following areas:

(a) Tissue culture of nerve tissue to examine the anatomy and physiology of junctions between nerve cells and other types of cell.

(b) Metamorphosis. Skin sensory system analysis during metamorphosis in amphibia to determine the change of central pathways during change of behavior.

(c) Grafting. Skin sensory system analysis after grafting of additional structures such as an eye or leg.

(d) Terminations. Anatomy and physiology of terminations in frog skin. An analysis of what tissue breakdown products produce nerve impulses in damaged tissue. An analysis of the form of nerve endings to relate form and function.

(e) Central Maps. The topological organization of central cells in their relation to the skin and the method of transmitting the location of the stimulus.

(f) Pattern of Discharge. A study of the convergence of peripheral nerve fibers onto central cells and the relation of this convergence to the discharge patterns of central cells. The method of transmitting information on the nature of the stimulus.

P. D. Wall

5. Effects of Early Sensory Isolation[*]

There is considerable evidence that severe restriction of the early perceptual experience of animals produces profound disturbances of their perceptual, emotional, and intellectual development. The purpose of our investigation is to carry out a series of studies on the physiological mechanisms that underlie the highly abnormal behavior observed in animals reared in isolation. The focus of individual studies will be on three salient characteristics of the behavior of animals reared in isolation: (a) a frequent failure to perceive and respond to the appropriate environmental cues, including stimuli that are painful to animals that are reared under normal conditions; (b) an extremely high level of excited activity that pervades virtually all of the animals' behavior; and (c) a low capacity for learning new responses in problem-solving situations. The method of procedure for the first problem is to observe the behavior of restricted and normally reared animals from the same litter in response to brief burns and pinpricks and simultaneously to record responses evoked at the midbrain, thalamus, and cortex.

R. Melzack

A. ALLIGATOR OLFACTION

Use of microelectrodes like those recently described by Wolbarsht, and others (1) has resulted in a substantial improvement in our ability to record from single olfactory receptor cells. Using a sharpened wire with a diameter of approximately 4μ where it protrudes for various lengths from a rounded glass shoulder, we can record from a receptor on most penetrations. The electrodes easily penetrate the overlying cartilage and the membranes dorsal to the basement side of the mucosa without any other surgical intervention. The olfactory receptors fire irregularly, even when stimulated, at rates that are in agreement with Ottoson's (2) recently published data on the refractory period of the receptors (or their fibers) to direct electrical stimulation.

R. C. Gesteland, W. H. Pitts

References

1. M. L. Wolbarsht, E. F. MacNichol, Jr., and H. G. Wagner, Science 132, 1309 (1960).

2. D. Ottoson, Acta Physiol. Scand. (Stockholm) 47, 160 (1959).

B. FROG AUDITION

Most auditory cells in the dorsal auditory nucleus of the frog as seen by microelec-
trodes show more activity in response to complex sounds (the human voice, sounds made
by other frogs) than the maximum obtainable from pure tones of any frequency and inten-
sity.

F. S. Axelrod

C. ELECTROCHEMILUMINESCENCE

We have confirmed the remarks made in Quarterly Progress Report No. 59,
page 149, on the special advantages of our method for observing the motion of liquids by
making a survey of other methods, particularly those given in recent conferences on the
subject. We are preparing a detailed account of it.

A totally different application of the phenomenon is a direct method of representing
the results of computers whose elements operate within low voltage ranges, say 0 to
10 volts, or less (which will be true if they depend on transistors) as a visible graph.
The method depends upon a simple experiment. Let us take a wire of high resistance
(we used 1-mil platinum) with a potential +V at one end, the other grounded, with a sec-
ond electrode of constant potential, and immerse the pair in a luminol solution that was
prepared according to the recipe that we have given for obtaining a glow confined to the
anode surface itself. As we vary V, the potential at all points of the wire varies mono-
tonically with V, and the distance X from the lower end at which a critical potential h
is first obtained will move up and down the wire. Suppose that the potential h divides
those voltages that are large enough to produce a visible glow from those that produce
none, and that this boundary is sharp. For a given V, the wire will be lighted from the
point X to the top, and will be dark below. As V increases and decreases, the lighted
segment will lengthen and shorten correspondingly. This has, in fact, been observed.

Now suppose that we have an equally spaced parallel array of such wires, like the
vertical lines on a sheet of graph paper, and that we connect one end of each to an inde-
pendent source of voltage V(n), and immerse the whole array in the solution. As the
voltages V(n) change, the array will exhibit a "bar graph" of lighted segments of differ-
ent lengths, the nth bar measuring V(n). If the array is closely spaced, n can be taken
as a continuous independent variable x. Naturally, the vertical scale on a graph of this
kind is not linear in the applied voltages, but it can probably be made nearly logarithmic,
and, in any case, it can be calibrated. Also, there will be error from flows of current
in the medium along the wires and from one to the next; but it seems possible to reduce
this error to acceptable limits with suitable geometry.

The advantage of the method, if it is technically feasible, is that the applied voltage

may be as small as 2 volts and capable of augmentation if desired by reducing the amount of KCl added to decrease conductivity. Also, the system is fast enough to display a new graph every millisecond.

One can go a step farther and adjoin another array of wires perpendicular to the first (like the horizontal lines on graph paper), suitably partition the solution, and arrange connections at the nodes so as to obtain a glow only where the sum of the voltages in the wires intersecting at a node exceeds h. This would provide a simultaneous two-dimensional display that could be used for many purposes.

This study, thus far, is entirely preliminary, and we do not now wish to imply anything about the utility of the method.

B. Howland, R. C. Gesteland, W. H. Pitts