

XVI. NEUROPHYSIOLOGY*

W. S. McCulloch
J. A. Aldrich
M. A. Arbib
F. S. Axelrod
M. Blum
J. E. Brown
J. D. Cowan

Herta von Dechend
Rachel G. Fuchs
R. C. Gesteland
M. C. Goodall
K. Kornacker
J. Y. Lettvin

Diane Major
L. M. Mendell
N. M. Onesto
W. H. Pitts
J. A. Rojas
A. Taub
P. D. Wall

A. RELIABLE COMPUTATION IN THE PRESENCE OF NOISE

This report is essentially an abstract of a paper that has been submitted for publication to the Philosophical Transactions of the Royal Society of London.

A theoretical study of the problem of constructing reliable automata from components of low reliability has been made. It is shown that information theory can be applied to this problem so that a computation capacity may be defined for modules computing probabilistic logical functions, which corresponds to the capacity of a noisy communication channel.

It is proved that definite events may be realized with arbitrarily high reliability, by networks assembled from modules and connections of low reliability, provided that the resulting networks are sufficiently redundant. If the assumptions are made that modules are sufficiently complex, and that modular malfunctions are independent of modular complexity, then the module redundancy of such networks need only be greater than a certain minimum whose value is determined by the computation capacity of modules comprising these networks.

A further result is a proof concerning errors in the pattern of modular interconnection. It is shown that if the frequency of errors of interconnection is less than a certain function of computation capacity and module redundancy, then with high probability, such errors may be corrected, and automata may be constructed, to function with arbitrarily high reliability despite errors in their interconnection patterns.

The functional organization of these automata is shown to be diffuse. Any one function computed by an automaton is computed by many modules, and any one module computes a diverse mixture of many of these functions. The resultant multiple diversity of function is closely connected with the high reliability exhibited by such automata.

J. D. Cowan, S. Winograd

(Mr. S. Winograd is now at the IBM Thomas J. Watson Research Center, Yorktown Heights, New York.)

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B. COGNITIVE SYSTEMS

Work on inductive logic has been summarized and written up in mimeographed notes entitled "Cognitive Systems and Logical Induction." It is shown how the limitations of Bayesian induction can be overcome by going to a universal logic (formalized language or associative system) and handling the axioms and rules probabilistically. This idea is worked out in terms of Post¹ normal systems on binary symbols employing an analogy with many-particle quantum mechanics. Shannon communication is then the special (Bayesian) case of such a theory when the Post system is a Boolean algebra.

Realizability of this theory is considered in terms of a quasilinear threshold (Pitts-McCulloch) net with three values and probabilistic thresholds.

A complimentary principle arising in the general theory has been published.² It answers partly, at any rate, a celebrated paradox of Hume's Treatise of Human Nature (1739).

The author believes that this theory will have applications to the problem of epigenesis in biology.

M. C. Goodall

References

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2. M. C. Goodall, Nature 194, 998 (1962).

C. STATUS OF OTHER RESEARCH

1. Rat Vision

J. E. Brown has succeeded in recording from single fibers in the optic nerve of rat. This is a resumption of work begun three years ago by R. Burde and then dropped. Mr. Brown has now found at least one fiber that is concerned with moving boundaries but indifferent to changing average flux in its receptive field. He reports what Burde also saw, that the description of what a fiber sees in its receptive field seems to be in part a function of the state of consciousness of the rat, and, perhaps, the state of attention. Certainly, barbiturates seem to have a profound action on the activity found in n. opticus, but whether from general suppression of population groups or general change in function cannot yet be told.

2. Olfaction

R. C. Gesteland and J. A. Rojas have prepared a paper on crude groups of olfactory fibers. A new finding has recommended the possibility of an additional mode of study.

Butyric acid – and some related chemicals – have the property of giving a completely positive, or initially positive, but diphasic Ottoson potential. This suggests a grouping of some odors not only by chemical similarity but by site of action. The question will be studied in detail. It is now possible to distinguish olfactory and N_V fibers in the mucosa by the shape of the transient. Furthermore, recording from N_V fibers in the nerve bundle itself is rather easy and confirms the functional separation observed in the mucosa. In general, we suspect that, at least in the frog, Beidler's view of the function of N_V fibers is not applicable.

3. Dorsal Roots

In the course of playing with dorsal rootlets in cat to record from certain myelinated fibers, and using our platinum-plated probes, Dr. Henneman, Rojas, Brown, and I noted discharging units showing triphasic action potentials, 5-10 msec long. These responded to peripheral stimulation of skin and/or muscle, and we believe them to be the unmyelinated fibers of the dorsal root. If this proves to be the case (we shall know in a few weeks), it will become possible for the first time to study these fibers easily. There is an enormous number of them and our knowledge about what they do and where they go is very limited.

4. Cerebellum

F. S. Axelrod has been recording from various kinds of cerebellar cells in the frog. There is a complex projection system from the limbs into cerebellum and it is hard to decide what function of limb movement and position and skin sensation is taken by the cells. The preparation is quite stable and permits of long recording from the same neurons.

5. History of Science

Some of our work has been in the history of science, concerned, in particular, with the reasons behind the divorce of psychology and physics in the latter half of the nineteenth century. This material will be presented elsewhere as part of an introduction to our new approach to nervous physiology.

J. Y. Lettvin

D. PHOTOGRAPHIC METHOD FOR THE STUDY OF VISION FROM A DISTANCE

We describe in this report an instrumental method for the measurement of the state of refraction of an animal (or human) eye from a distance. This technique, which makes use of flash photography, has an important advantage over other methods of measuring

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accommodation in that it does not require that the eye under study be carefully positioned with relation to the optic axis of an instrument. It is only necessary that the eye be located within a volume determined by the depth of field and the field of view of a camera. In some situations we may also require that the eye fixate on a point near or coincident with the camera.

In Fig. XVI-1 we show an arrangement by which light from a point source is caused to appear to emanate from the central region of a camera lens of wide aperture. This light is assumed to be imaged by an eye of unknown refractive state located a few meters away. Since the retina is an imperfect absorber, a reflection or "light reflex" will pass back through the lens of the eye, returning in the general direction of the camera (dotted lines of Fig. XVI-1). If the eye is within a few diopters of the best focal adjustment, we may reasonably expect that all or most of the light reflex will pass back through the aperture of the camera lens to expose the film or plate when the shutter of the camera is opened. If the camera is adjusted to focus sharply objects that are in a plane containing the eye, we record an image of the pupillary aperture, that is, the eye will appear to be illuminated from within (see Fig. XVI-2).

The interesting effect occurs when, in the arrangement of Fig. XVI-1, the camera

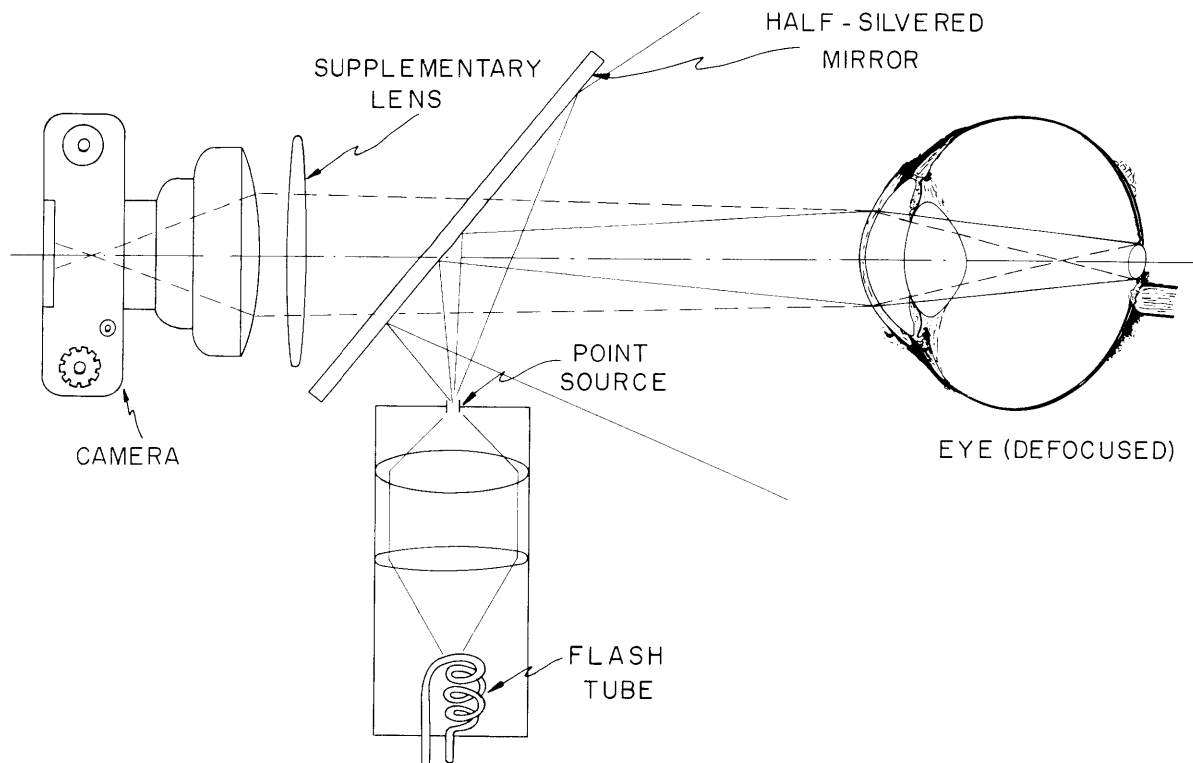


Fig. XVI-1. Arrangement for illumination by point source of light centrally positioned with respect to a wide-aperture camera lens.

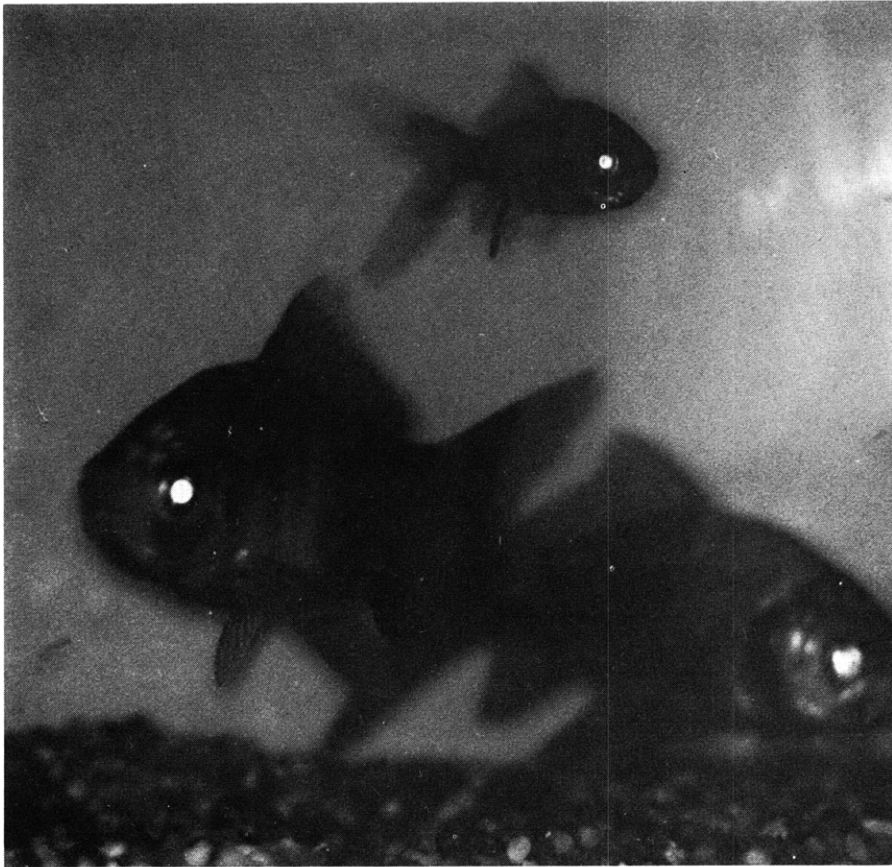


Fig. XVI-2. Light reflexes from goldfish eyes.

is purposely defocused, for example, by the addition of a supplementary lens of one-tenth the dioptral power of the camera lens. Ordinarily, we expect the image of a defocused point source of light to be an extended blur of uniform intensity. In outline, this blur will exhibit congruence with the aperture stop, the scale of proportionality being determined by the extent of defocus. Figure XVI-3 illustrates this effect; this picture was taken with a lens having a hexagonal aperture stop. In the present instance, however, the greatest part of the light reflex passes through the camera lens entirely within the confines of the aperture stop, that is, as if occluded by a stop of smaller size. The blurred image resulting from the reflex will therefore be more concentrated than the defocused image of a diffuse reflector similarly positioned in the plane of the eye. This blur is, in fact, a reproduction in miniature of the cross section of the light reflex as it enters the camera lens. Measurements of the size and shape of the blur image thus enable us to determine the angular divergence of the light reflex as it leaves the eye; these data, together with knowledge of the size of the eye, the pupillary aperture, and the reflective properties of the retinal surface, should suffice to determine the refractive



Fig. XVI-3. Photograph illustrating blur images of defocused light sources. (The lens used to take this picture has a hexagonal aperture stop.)

state of the eye.

There are at least three different ways in which we can defocus the camera to obtain useful information about the state of refraction of the eye. (i) We may alter either the power or the focal adjustment of the camera lens from that which would sharply focus the light reflex. This simple method has the advantage of yielding information concerning astigmatic, as well as spherical, focal errors of the eye, but has the disadvantage that the intensity of the spot will vary greatly with the refractive error of the eye. (ii) We may defocus the camera by means of a circular or astigmatic supplementary lens with the advantage that the blur is concentrated into a line image of variable extension; the variation of exposure with the refractive state of the eye is thereby greatly reduced. These data are better suited to microdensitometer analysis. Furthermore, a smaller

area of film is exposed by each individual eye within the field of view of the camera. A disadvantage of this method is the difficulty of determining a spherical refractive error in the presence of appreciable astigmatism. (iii) The camera may be defocused by using a conical supplementary lens (an "axiconic"). The resulting blur will be in the shape of the circumference of a circle. The angular distribution of intensities about this circumference will give an indication of the axis and the degree of astigmatism relative to the spherical error. Since the size of the circle is invariant, the photographic exposure will be little affected by the refractive errors under study. A disadvantage of this method is that it does not give complete information, since it gives no indication of the absolute magnitude of the refractive errors.

For preliminary experiments we have concentrated our attention on method (ii). For this purpose, we have employed an untrimmed 2-diopter ophthalmic-quality cylindrical lens; this is placed in front of the 58-mm (17.2 diopter) f 1.4 lens of a 35-mm single-lens reflex camera. This combination produces good quality line images of point sources of light as long as their images are located within 10 mm of the center of the 24 mm × 36 mm film plane. A refinement of some importance which we have employed is the use of a symmetrical occluding wedge, carefully centered and axially positioned to lie in the same plane as the virtual image of the point light source. The function of this wedge is to block those rays that diverge in directions that are orthogonal, or nearly so, to the axis of the cylindrical lens; these would otherwise register falsely on the film as weakly diverged rays. A subsidiary effect of this occluding wedge is to alter the form of the linear blur image, which now exhibits two maxima, as illustrated by the sequence of photographs of an artificial eye, shown in Fig. XVI-4. The spacing of these maxima provides indication of the divergence of the light reflex. Figure XVI-4a shows the blur image corresponding to the best focal adjustment of this "eye," a 13-mm f 1.5 movie-camera lens set at f 2. (A piece of white paper attached to the end of a micrometer barrel comprised the retina.) For Fig. XVI-4b we moved the micrometer 0.1 mm from best focus; in Fig. XVI-4c, 0.55 mm.

Using the same apparatus, we photographed a young adult male human subject with good vision and not requiring glasses, in various states of accommodation. Figure XVI-5a shows this subject looking at the camera (and light source); Fig. XVI-5b shows the same subject concentrating his gaze on the tip of a pencil approximately 8 inches in front of his eyes. The difference in the focal adjustments, as indicated by the separation of the maxima in light intensities of the two cases, is evident. A third photograph (not shown), taken with the subject fixating on a point behind the camera, indicated an intermediate degree of dispersion.

In its present form the instrument described in this report has two possible applications to physiology. (i) The study of animal vision. The possibility of studying the animals in their natural state (that is, fish swimming freely, etc.) should be of great

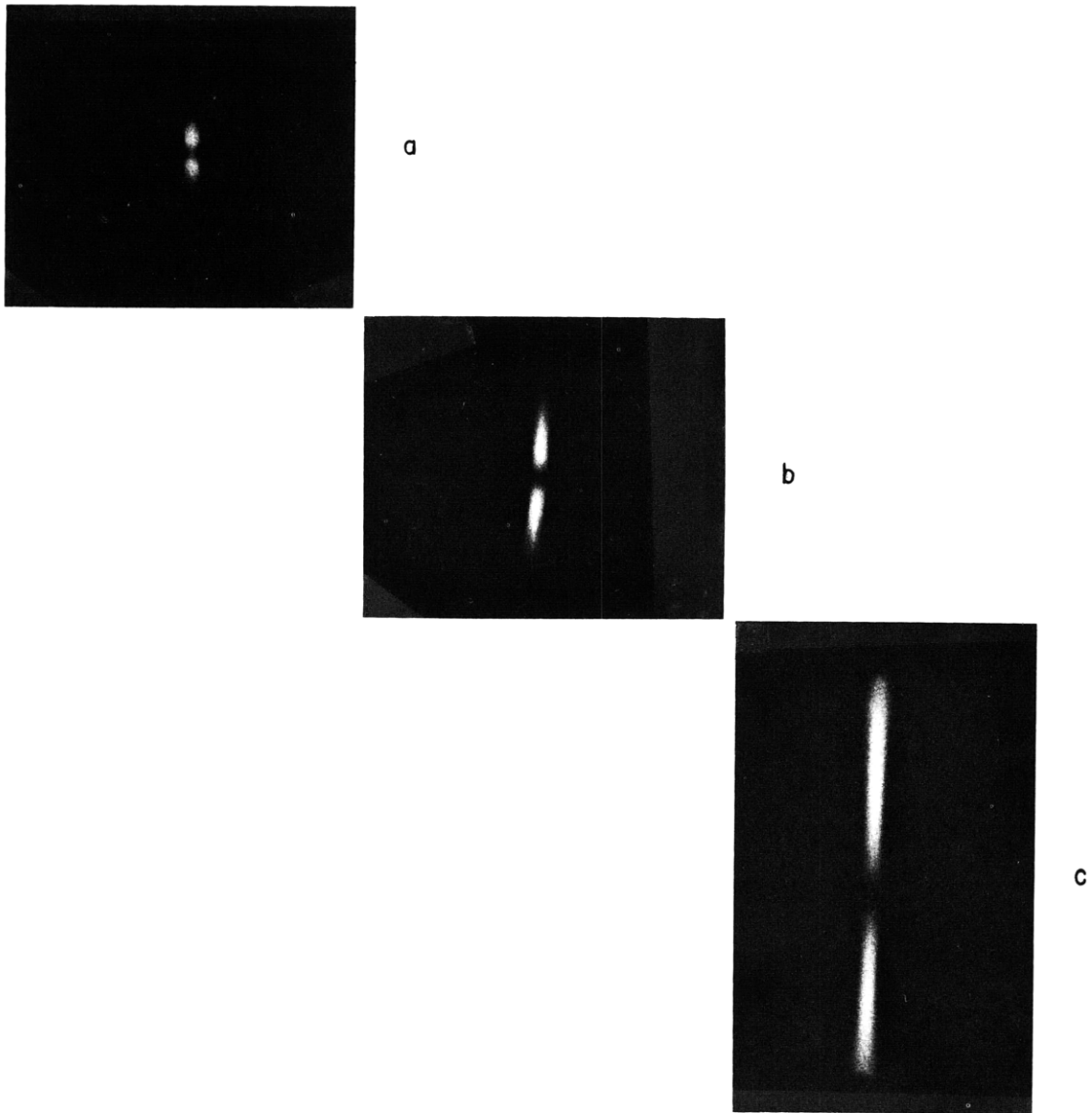
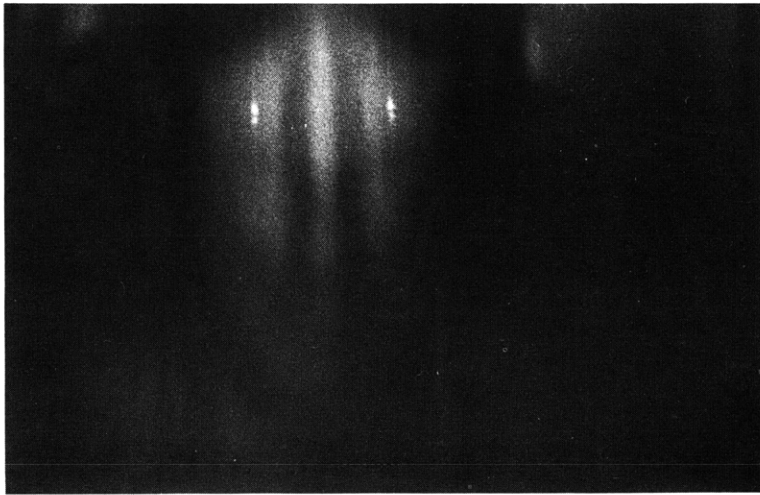
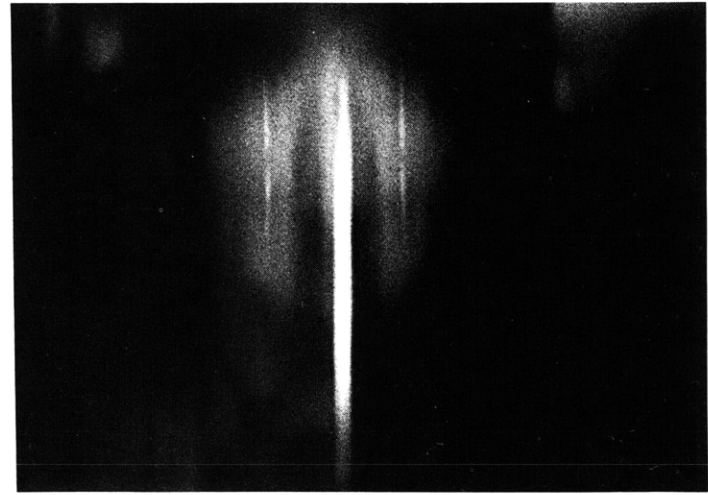


Fig. XVI-4. Photographs of artificial eye with various focal adjustments. (a) Best focus. (b) 0.10-mm defocus. (c) 0.55-mm defocus. Camera was purposely defocused with a 2-diopter cylindrical lens.



(a)



(b)

Fig. XVI-5. Photographs of human subject. (a) Subject fixating on camera, 1.3 meters distant. (b) Subject fixating on pencil, 0.2 meter distant. Camera was defocused with 2-diopter cylindrical supplementary lens.

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importance. Our first animal experiments will be with fish because there exists little reliable experimental data, either from behavioral experiments or from direct retinoscopic observation, concerning their visual capabilities.¹ (ii) As an instrument of mass retinoscopy, as for example, for the rapid determination of defects of far-vision in groups of children. Simple modification of the present apparatus, utilizing the known chromatic aberration of the human eye, should also enable one to determine the sign of the refractive errors.

B. Howland, H. C. Howland

(Mr. Bradford Howland is a staff member of Lincoln Laboratory, M.I.T. Mr. Howard C. Howland is from the State University of New York on Long Island, Oyster Bay, New York.)

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