Meetings

Bionics

The unities underlying the behavior of animals, men, and machines were brought into clearer focus at a national symposium held 13–15 September 1960 in Dayton, Ohio. The meeting, under the sponsorship of the Wright Air Development Division of the United States Air Force, was attended by approximately 700 persons. Thirty invited speakers reported new developments concerning methods of information handling used by living systems and artificial models of such systems. The magnitude of the recent advances so impressed the participants that they virtually demanded that such a meeting be made a regular event. This report is based entirely on my notes; I apologize for any errors of fact or interpretation, and for not mentioning many talks because of lack of space.

At the start, H. E. Savely of the Air Force Office of Scientific Research pointed out three aspects of living systems which are worthy of study for incorporation into artificial systems: (i) the extreme sensitivity of certain receptor organs—for example, the ability of certain fish to detect a change in the electric field in the water around them of as little as 0.003 μv/mm; (ii) the ability of even simple living brains to integrate the activity of many sensor and effector organs; (iii) the ability to retrieve information rapidly in the central nervous system; and (iv) the ability to store information at molecular levels, even for periods of generations, as in the chromosomes. An example of the successful use of a living system as a prototype for an artificial system is the application in an optical ground-speed indicator for airplanes of the simple principle in the beetle's visual system that provides information on velocity.

H. E. Savely cautioned (i) that as long as we lack fundamental understanding of the laws of organized complexity, it may not be possible to duplicate the living system; (ii) that nature is limited simply to building on and modifying pre-existing systems and that the living system therefore may not provide the most economical approach to a particular information-handling problem; and (iii) that it is common for the physical scientist to think that he can take a quick look at some biological system, work out the principles in a very short time, and then apply them to the design of some artificial system. Not only is he mistaken in this belief but he is very much like Brer Rabbit attacking the Tar Baby. The harder he attacks the problems of biology the more deeply does he become enmeshed, so that he soon finds himself unable to drop them.

An analysis of the relatively simple servomechanism controlling the size of the pupil of the human eye was presented by Lawrence Stark, now of the Massachusetts Institute of Technology. This paper and one other were the only reports dealing directly with the information-handling mechanisms of living systems—evidence perhaps of the difficulty of such an approach. The other talks dealt with the design of artificial systems. E. E. Loebner of RCA Research Laboratories pointed out that man, because he has few outputs (muscles), has built only a few information inputs into the gear he controls, to match his few outputs. This restriction on the number of inputs has been carried over into equipment not under human control. It would often be preferable to give such equipment multiple inputs, such as man has in his sense organs.

The general logical operations that a computer must perform in order to behave like an organism were described by Peter M. Kelly of Aeronutronics. It must take inputs from a sensory field, code them into groups, act on them by some internal logic, code the outputs, and carry out responses in terms of this output code. The coding of the sensory input to the internal logic can be fixed in advance—that is, preorganized. It is also possible to design machines which are self-organized—that is, capable of learning how to code their sensory input and their output so as to achieve the desired responses to particular sensory situations. Kelly, and also Walter Reitman of Carnegie Institute of Technology, discussed the design of such machines and gave examples of existing machines in which the two types of design are used. (Could it be that when we intuitively judge one type of organism to have more "consciousness" than another, the distinction in physical terms is that it has a greater capacity for self organization?)

W. P. Tanner of the University of Michigan argued that the human being is not completely preorganized so as to give a fixed response for a particular sensory input but is capable of self-organization. Therefore, the human being subjected to psychophysical tests should not be considered to have a sensory threshold but should be treated as a computer which is testing the statistics of the test situation and making decisions which optimize some aspect of that situation. Tanner is analyzing such performances of human beings in auditory test situations.

The problem of designing a machine which can differentiate or recognize one out of all possible sensory functions was discussed by Seymour Papart of the National Physical Laboratory, Teddington, England. The problem is simplified by the fact (i) that the input functions possible are only a portion of all functions, and (ii) that as the number of dimensions of the input functions increase, the chance of separating any two input functions increases, even with a simple machine. He has roughly estimated that one human being during his lifetime could learn up to 10^8 particles of information. This much learning could be handled by any of the systems of self-organization described at the symposium. (Compare this estimate with the estimate of 10^{15} made some years ago by W. S. McCulloch and of 10^{13} to 10^{15} made by H. von Foerster.)

Artificial devices which recognize patterns, including one device capable of recognizing cancerous cells under the microscope, were mentioned by P. Metzelaar of Space Technology Laboratories. Some machines have given performance superior to the human—for example, a checker playing program for the IBM 704 computer. Other machines have been designed that can predict the future of a sequence from its past. Metzelaar suggested that if the design problems can be solved, the future machine will do preliminary pattern transformations on its sensory inputs in order to reduce the amount of information that must be handled and stored. It will also be able to consider its sensory input in either gross outline or fine detail and know which type of consideration is needed, decide how to divide its attention among its different sensory inputs, and know which of various recognition mechanisms it should use.

In a talk that was as remarkable for its witty asides as for its lucid exposition, A. Novikoff of Stanford Research Institute briefly described integral geometry and illustrated its use in the design of pattern-recognizing devices. One theoretical device is able to distinguish patterns, regardless of their rotation or translation in the visual field, by differences in the frequency with which the lines of the pattern were intersected by a line segment, of fixed length, repeatedly placed in random orientation and position on the visual image (a "randomly tossed" curve).

Visual Systems

J. R. Singer of the University of California described a visual system which, by means of radial scanning, can recognize a two-dimensional object regardless of the visual angle it subtends or of its rotation in the visual field. However, this system requires that the object be centered in the visual field, so it is unlikely that the visual systems of living organisms, at least of vertebrates, use the same principle.

A different type of artificial visual system, designed by L. D. Harmon of Bell Telephone Laboratories, can recognize the convexity of a moving target. It consists of seven similar photocells, six tightly packed around the central one. The output of the central photocell produces inhibition at an artificial neuron; the output of the others, excitation. The neuron responds only to the passage of targets with radii within a particular size-range, according to the threshold setting. This system may correspond to the convexity detectors in the frog's eye, previously reported by Lettvin, Maturana, McCulloch, and Pitts.

E. E. Loebner demonstrated an artificial visual system consisting of a matrix of photoconductors, each connected in series with an electric energy source and an electroluminor. When light hits a photoconductor, this permits current to flow through the luminor and causes the luminor to emit light. By appropriate connections and interconnections of these elements it is possible to reproduce many of the functions of the vertebrate retina, including all four detection functions found in the frog retina by Lettvin *et al.* It is possible that some of the circuits used in the model may be recognized in the living retina.

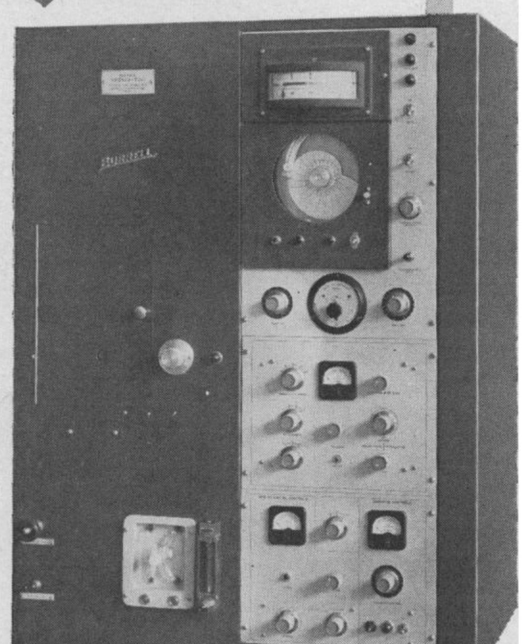
A machine capable of distinguishing among the spoken names of the digits ("one," "two," and so on) was described by W. C. Dersch of International Business Machines Corporation. At least one of the principles on which it operates is known not to be used in the human auditory system. L. A. de Rosa of International Telephone and Telegraph Corporation presented a theory of the operation of the auditory system, explaining that its frequency discrimination is produced by an autocorrelation process rather than by mechanical filters. W. A. van Bergeijk of Bell Telephone Laboratories has built an artificial neuron network which he considers analogous to the spiral innervation of the cochlea and has measured signal loss as a function of simultaneous firing of several branches of the neuron. No similar measurements have been made on the actual nerve for comparison. He has also built an analog of a branching sensory nerve of the skin and has found that the analog and such nerves have comparable recruitment functions.

Artificial Neurons

The highlight of the symposium was a group of talks by W. S. McCulloch and other mathematicians from his laboratory at the Massachusetts Institute of Technology and by K. K. Maitra of RCA Research Laboratories, on the general problem, "How simple can a neuron be and still, by proper interconnection . . . perform all the known functions of the brain?" They started with the very simple McCulloch-Pitt neuron, which consists of a device that has many inputs which can carry either excitation or inhibition. It possesses a polar threshold such that the output is in one or the other of two states, depending on whether the algebraic sum of the inputs does or does not exceed the threshold value.

M. Blum considered the general question of what logical functions could be performed by simple networks of such neurons. He showed that if the number of inputs (such as signals from different sense organs) to a neural net is large, the number of logical functions which the net can perform approaches one-quarter of the totality of logical functions. This should certainly be enough to perform the limited number of logical functions which are known to be carried out by the brain.

A. N. Verbeek showed how to produce reliable computation with a "noisy," unstable neuron having four sources of trouble: variations in the signal strength of the inputs, faulty connections, variations in internal threshold, and inability to propagate its output signal. He used triplet networks made up of three of the simple neurons, all the inputs to the triplet going in parallel to two of the neurons and their outputs going to the third neuron, whose output was the output of the triplet. Signals from each input were connected in parallel to each of many triplets. Each of these performs the logical operation, and the output of all the triplets goes to a neuron which acts as a majority decider, taking the outputs, comparing them, and deciding which is correct according to the output signals of the



majority. If each neuron is capable of producing an error 5 percent of the time, the upper limit of the probable error of such a net can be made less than one in 1 million by a combination of just 30 such redundant triplets. This work is of great significance, since up to now the only theoretical method of increasing reliability has been to put many elements in parallel wherever one element has been used in the original net. Von Neumann has shown that to achieve a reliability of one error in a million by this older method with neurons which produce an error 5 percent of the time would require a net of about 20,000 neurons.

Cowan presented the mathematical logic he has developed for dealing with the behavior of nets of neurons carrying on logical computations in the presence of noise. He was able to represent a general noisy computation scheme and to calculate the amount of signal that came through.

K. K. Maitra presented an extension of the work of Verbeek in the design of nets which reliably perform logical operations even though the neurons and connections of the net may be unreliable. He developed a simplified mathematical symbolism for describing the manipulations of each triplet network. He was able to show that where a certain logical function is desired from the triplet, this function can be achieved with the greatest reliability by making the triplet from a combination of neurons each having a particular logical function, determined by a process he could specify. In a similar way he was able to show that if triplets are combined into triplet networks and these in turn into larger triplets, and so on, a minimum probability of error is found in networks made by three or four orders of such tripletting. When instead of tripletting the triplets he duplexed them, this gave increasing reliability with increasing order of duplexing up to any arbitrary level of reliability. Thus, it is possible in theory to design networks with unreliable neurons which will give any desired reliability of performance.

In a delightful summarizing talk, H. von Foerster of the University of Illinois pointed out the importance of this work on reliability. It permits the achievement of increased reliability in a system not by increasing the reliability of the components and connections but, more economically, by multiplexing unreliable components.

At the end of the symposium a final question was presented to McCulloch. He was asked, in effect, whether the people working on information processing would not some day, like the nuclear physicists today, have cause to regret the social consequences of their work. McCulloch replied that he was convinced that it was in man's nature to develop both the socially good and the socially bad consequences of any invention. He fully expects that the world will be booby-trapped by the use of these and other sciences, but it is his firm hope that by making available information-handling devices of great capacity man will prevent the detonation of that booby trap through misinformation.

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Forthcoming Events

March

19–25. Caribbean Region, American Soc. for Horticultural Science, 9th annual, Miami, Fla. (E. H. Casseres, Londres 40, Mexico 6, D.F., or W. H. Krome, Box 596, Homestead, Fla.)

20–22. American Physical Soc., Monterey, Calif. (W. A. Nierenberg, Univ. of California, Berkeley 4)

20–23. Institute of Radio Engineers, 1961 intern. convention, New York, N.Y. (E. K. Gannett, IRE, 1 E. 79 St., New York 21)

20–24. American Surgical Assoc., Boca Raton, Fla. (W. A. Altemeier, Cincinnati General Hospital, Cincinnati 29, Ohio)

20–24. National Health Council, forum and annual meeting, New York, N.Y. (NHC, 1790 Broadway, New York 19)

20–24. Western Metal Cong. and Exposition, 12th, Los Angeles, Calif. (A. R. Putnam, American Soc. for Metals, Metals Park, Ohio)

21–23. American Meteorological Soc., general meeting, Chicago, Ill. (E. P. McClain, Dept. of Meteorology, Univ. of Chicago, Chicago 37)

21–23. American Physical Soc., Division of High-Polymer Physics, 21st, Monterey, Calif. (D. W. McCall, Bell Telephone Laboratories, Murray Hill, N.J.)

21–23. American Power Conf., 23rd annual, Chicago, Ill. (W. C. Astley, Philadelphia Electric Co., 900 Sansom St., Philadelphia 5, Pa.)

21–24. American Assoc. of Anatomists, 74th annual, Chicago, Ill. (O. P. Jones, Dept. of Anatomy, Univ. of Buffalo, Buffalo 14, N.Y.)

21–30. American Chemical Soc., 139th, St. Louis, Mo. (A. T. Winstead, ACS, 1155 16th St., NW, Washington 6)

23–25. American Orthopsychiatric Assoc., 38th annual, New York, N.Y. (M. F. Langer, AOA, 1790 Broadway, New York 19)

23–25. Quantum Electronics, 2nd intern. conf., Berkeley, Calif. (J. R. Singer, Dept. of Electrical Engineering, Univ. of California, Berkeley 4)

23–26. International Assoc. for Dental Research, 39th annual, Boston, Mass. (D. Burrill, IADR, 311 E. Chicago Ave., Chicago 11)

24–29. National Science Teachers Assoc., Chicago, Ill. (R. H. Carleton, NSTA, 1201 16th St., NW, Washington 6)

26–29. American Assoc. of Dental