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SCIENTIFIC AMERICAN DIGEST

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MACHINES THAT THINK

THE article published below describes a purely mechanical device which can think and learn; likewise its startling performance. The construction of this thinking machine is one of several recent attempts made by some of the psychologists to test their suspicion that, when science has finally learned what thought is—if it ever does—it will turn out to be some purely mechanical process, nothing more. Perhaps the majority of scientists incline at present toward this suspicion. It must at once be said in warning, however, that no single "thinking machine" experiment, and no series of such experiments, has yet *proved* what thought is. Any such claim or inference would be premature and out of place at the present time.

The idea that thought is purely a mechanical process is only a *hypothesis*. Experiments with thinking machines are justified because in science it is always worth while to explore fully the possibilities of anything which seems at all suggestive. Those of our readers who do not care about philosophical problems such as the nature of thought will find that the performance of a thinking machine like the one described at least provides good entertainment.

The question—what is thought?—is really a part of a still larger philosophical question which occupies the minds of many scientists today—what is life itself? Is it too something purely mechanical? Are we and the other animals on the earth simply machines—elaborate and very complex it is true, but machines none the less? The behavioristic psychology, which the author mentions, falls in with that interpretation. We believe we choose our conduct, that is, that we have free will, but behaviorism asserts that our immediate environment "chooses" it for us. Whatever we do, no matter how trifling, is the resultant of a whole complex of stimuli received by us from without. Thus our conduct is determined ("determinism").

Science is divided roughly into two camps, the mechanists and the vitalists. The vitalists, who are in the minority, believe that life is not merely mechanical but is something over and above the mechanical processes which we see. This is allied to the familiar belief in a soul or a spirit, and is a kind of scientific mysticism. The mechanists, two parties of whom, the bio-physicists and the bio-chemists, are tunneling into the mountain of our ignorance from opposite sides, with remarkable success thus far, maintain that beliefs like this rest merely on gaps in our present knowledge and that the two tunnels eventually will meet, revealing fully what life is and, with it, probably what thought is. They believe that life and thought will prove to be ordinary phenomena governed by the laws of physics and chemistry, like other common phenomena.

Neither side can prove its case at present and so the reader must patiently wait.—*The Editor.*

By THOMAS ROSS

THE fundamental ideas of the behavioristic and gestalt psychologies justify attempts to construct and develop machines of a new type—machines that can think. Such machines are entirely different from the integraphs, tide calculators, and the like, to which the term "thinking machine" is sometimes applied, for, unlike the latter, they are not designed to perform with mathematical regularity but can "learn" to vary their actions under certain conditions.

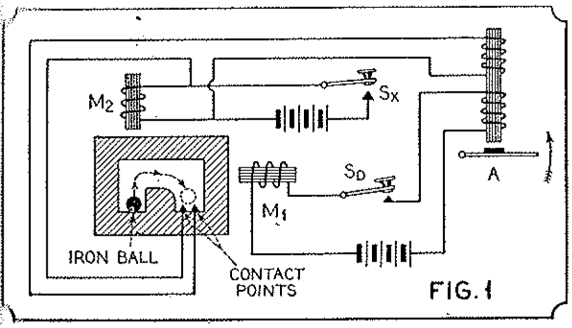
Several mechanisms have been designed and built to illustrate the "conditioned reflex," regarded by behaviorists as the basic element of mental activity. These mechanisms exhibit in simplified form the type of activity studied by the Russian psychologist and physiologist, Pavlov, in his well-known experiments with dogs. This experimenter observed that, while the taste of food normally caused the mouths of the dogs to water, most sounds and sights would not evoke this response; yet that, when one of these "neutral stimuli" was presented before or at the same time that the dogs were allowed to taste the food, the response came to be called forth by it just as by the actual taste. The salivary responses of the dogs had become conditioned to the neutral stimulus. In like manner, stimuli that are originally neutral in the machines are able to acquire power to produce the responses of the originally "dominant" stimuli.

An electrical device which parallels the effect of the conditioned reflex within limits is illustrated in Figure 1. When the switch, S_D (representing a sense organ sensitive to a dominant stimulus), is closed, the metal arm (response lever) A, is moved by the electro-magnet in the circuit with the switch. At the same time, the magnet, M_1, is also energized, but produces no observable effect. Closing the other switch, S_X, only raises the iron ball to the top of the chamber in the "memory cell" before conditioning has taken place, as only the magnet M_2 is energized by closing the switch at this time. However, if both switches are closed simultaneously, the response at the lever A is evoked and the iron ball in the memory cell is also first raised past the obstructing shoulder by M_2 and then drawn over on to the contact points by M_1. Conditioning occurs when this change takes place in the memory cell, for afterward closing S_X causes current to pass through the iron ball and then through the separate coil around the core of the magnet which originally operated the response lever, A, thus producing the same effect as was originally produced by closing S_D.

OF the mechanisms somewhat similar to this which have so far been constructed, some have been equipped with more than one part corresponding to S_X and, of course, such machines could be made with more than one receptor for dominant stimuli and any desired number of responses. (A device of the type which has more than one neutral stimulus receptor and which, though very simple, exhibits reactions which parallel a wide variety of psychological phenomena has been designed and constructed by Robert G. Krueger and Professor Clark L. Hull of Yale University.)

Since it is possible to parallel the conditioned reflex as it is observed in the laboratory, the idea suggests itself that machines embodying this principle can be made to move about and learn from stimuli encountered during their movement, just as animals do. For example, it should be possible to make a machine capable of learning its way through a simple maze. A machine of this sort, together with the type of maze it is designed to be used with, is shown in the photograph, Figure 2.

Figures 4 and 5 show the mechanical features of a machine of the same type, without connecting wires, and Figure 6 shows all of the electric circuits. In these diagrams, all parts having similar functions are marked with the same letter, while numerical subscripts are used to designate individual parts. Each lettered part has a vital function which



An electrical memory cell that demonstrates, within its limits, the basic element of mental activity

will be made clear in the following explanation:

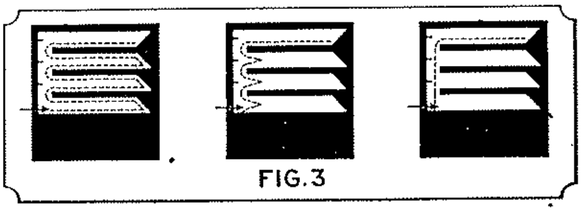
The inset in the lower right hand corner of Figure 4 shows a typical memory cell of the sort used in the maze learner. (Subscripts such as A_1, H_1 and so on, are omitted, as this is a generalized description equally true for all four of the memory cells used in the machine.) Parts A, B, and C are the three points of a single-pole double-throw switch. The movable pole, B, is made of spring brass under a slight tension so as to bear upward against the downward protruding tip of the wire rest, and bears on its free end a piece of soft iron. As will be seen from the drawing, a notch in a pivoted beam can be placed over the wire of the movable pole in such a manner that this pole is held rigidly away from both A and C.

When the machine is operated, there comes a time (different for each cell) when the electromagnet D is energized to act upon an iron disk on the pivoted beam, with the result that the notched end of the beam is raised so as to free the arm B. At the same time, the circuit which includes D, the pivoted beam (the beam is of brass), and the copper jaws X, is broken at X. The freeing of the switch arm B is the "sensitization" of the cell, for, after this operation, B is ready to be drawn aside to either A or C by the action of the magnets H seen in the plan view of the base.

Once contact has been established between either A or C and B, this contact remains unbroken until it is manually disturbed in resetting the machine. The formation of such contact by successive energization of D and H is the process which, in this machine, is equivalent to conditioning.

Obviously, such a memory cell could be operated by hand switches like those used in connection with the cell in Figure 1, but its potentialities are not limited to this. By embodying four such cells in a mechanism which possesses a limited degree of freedom of movement and which is provided with the necessary sources of energy under the control of these cells, it is possible to demonstrate that the resulting mechanism is capable, in a restricted sense, of exhibiting spontaneously intelligent behavior.

The moving member of the machine is an arm, like the boom of a derrick, which carries at its tip the *sensory* switches of the apparatus. Up and down movement is provided for by a pivot in the center of a vertical disk, while horizontal swinging is allowed by a pivot on the axis of a vertical cylinder which bears the disk carrying the arm, as shown in Figure 5. The movements made possible by these two pivots enable the machine to move its sensory tip, when placed as shown in Figure 3, through the slots of a cut-out maze. (Sliding contacts, indicated by the parts marked E and G, serve to carry electricity between parts which move relative to one another.)



Paths of the sensory tip of a "thinking machine"

Henceforward the explanation can be followed to best advantage by re-

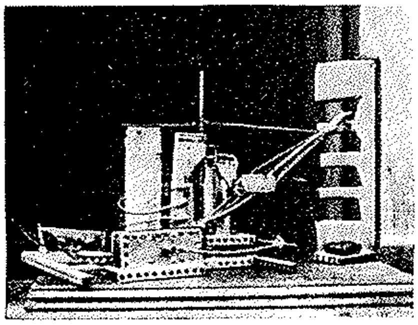
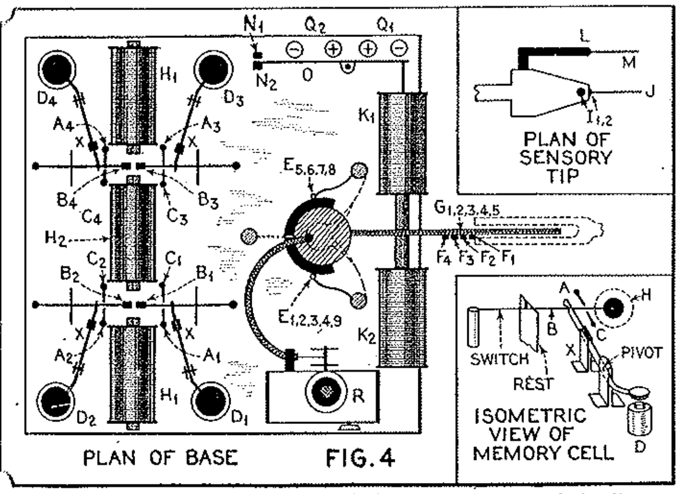


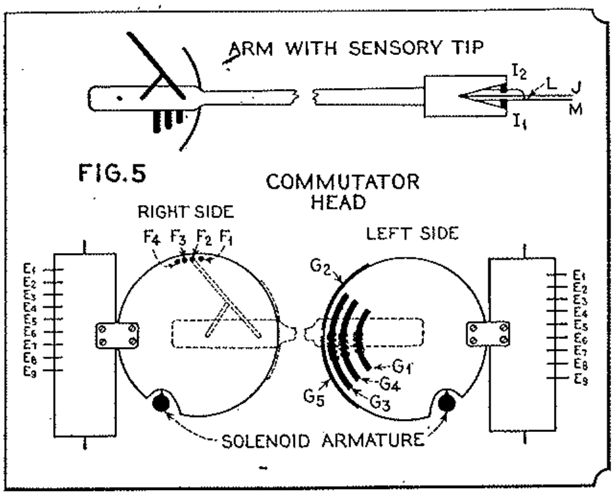
Figure 2: **An experimental model of a machine that "thinks." The four-slot upright maze is at right**

ferring to Figure 6 when circuits are designated and to Figures 4 and 5 when mechanical features or single units are named, for wires have been omitted from Figures 4 and 5 for the sake of clarity and spatial relationships have been disregarded in order to represent the circuits of Figure 6 with the maximum of simplicity. For instance, the switch arms B and the magnets H are shown widely separated in Figure 6 and represented in their true relationship in Figure 4.

The sequence of operations for the machine as a whole follows: The machine is set up with its sensory tip at the point indicated by the arrow in Figure 3. The battery Q_2 is then connected, with polarities as indicated, but nothing then happens because the sliding contact E_6 is so formed that no current can flow while the sensory tip is to the extreme left.

Next, Q_1 is connected, causing current to flow through the circuit Q_1, K_2, N_2, O. Immediately the action of the solenoid K_2 upon the iron armature con-





Details of the various parts of the "memory cells" and actuating mechanisms

nected to the vertical disk, on which the "boom" with the sensory tip is mounted, causes the sensory tip to be moved to the right.

When this motion has begun, E_6 moves into a position to carry current which passes through the circuit Q_2, E_6, G_1, F_1, E_1, D_1, X. Thereupon, sensitization of the cell, including the part B_1, takes place as explained in the paragraph devoted to that function.

At this time, it is to be noted, the first connection X is broken, and, for the time being no more current can flow from Q_2. The motion of the sensory tip to the right, however, continues until the switch tongue J strikes the end of the lowest passage of the maze. The sloping end of the passage causes J to make contact with I_2 and current flows through the circuit Q_2, E_6, G_1, J, I_2, G_3, E_7, H_1, K_1.

The energization of the conditioner magnet H_1 (this magnet is in reality two magnets connected in series, as shown by Figure 4) causes B_1 and A_1 to be thrown permanently into the circuit just designated, in such a manner as to shunt out the parts I, J, and H for that position which the tip of the sensory arm now occupies and for all other positions in which the switch-point F_1 is connected to G_1 by the brush (which is common to the sliding contact and the line of switch points).

THUS, the machine is conditioned to withdrawal from the lowest passage of the maze. The flow of current through K_1 not only causes withdrawal from the passage, by acting upon the armature on the disk, but also throws the switch O from its contact at N_2 to a new contact at N_1. Thus it not only prevents K_2 from acting against K_1 but also establishes the new circuit Q_1, O, N_1, R, E_9, G_5, M, L, G_4, E_8, K_1.

The electromagnet R thereupon releases a clockwork mechanism, which, through suitable mechanical coupling, acts to raise the arm bearing the sensory tip. The circuit just named is regenerative in such a way that, once established, it will persist even after Q_2 is isolated from its own circuit by E_6. Therefore, the arm continues to be raised until M is caught on one of the pegs protruding from the left hand side of the vertical passage of the maze. This breaks the circuit at L and M, causing R to lose its energy and bringing the arm to a stop in its upward progress. Simultaneously, K_1 releases O from N_1 allowing it to resume contact with N_2.

Now everything is as it was, except that the first memory cell has been conditioned to withdrawal and the machine is ready to "explore" a new passageway with its sensory tip. In the new position the switch-point F_2 is ready to carry current from Q_2 through the second memory cell, and conditioning takes place with a cycle of operations similar to that just described, but involving only the *heretofore unused memory cell.* Finally the machine comes to a stop with its sensory tip bearing against the upward slope of the last passage. Here conditioning takes place which causes it to remain, for in this case H_2 is brought into play, as may be seen from the wiring diagram. Now the path traced by the sensory tip looks like the line shown in the first diagram of Figure 3. We may take the fact that the machine stops with its tip in this position to indicate that the machine "likes" to have the tongue J deflected upward and "dislikes" to have it deflected downward or left in neutral.

When the machine is next placed with its sensory tip in the starting position, it will move so as to trace a path like that shown in the second diagram of Figure 3. Mechanically, the reason for this is that the conditioning of the memory cells furnishes a path through which current can flow to the solenoids K from Q_2 whenever E_6 will allow current to flow. As the points F allow only one memory cell to be connected at a time, the entry or withdrawal response must be appropriate to the passage to which the sensory tip is opposed.

A behaviorist observing the way in which the machine would react on first and second explorations of the maze might say that the beginnings of the entry movements on the second trial served to recall, through kinaesthetic stimuli, the experience of exploring each passage in question on the first trial. In this sense the points F become terminals of kinaesthetic, or muscle-sense receptors.

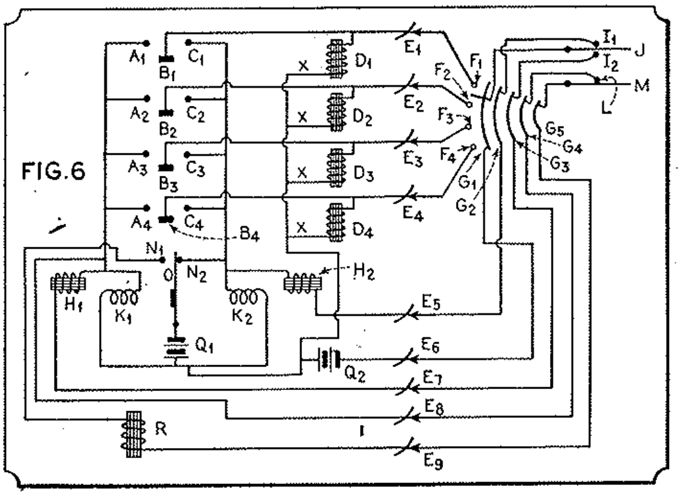
Further refinement of the mechanism would make possible a machine which would drop out all excursions into blind alleys, as shown in the third diagram of Figure 3 but the significance of such refinements was not considered sufficient to justify the difficulty of construction which would have been added to the most recently constructed model.

Inasmuch as it is possible to design a machine to learn its way through a maze, using only such a simple approximation of the conditioned reflex as is used here, it appears possible that machines exhibiting behavior that may truly be described as intelligent may be realized when the manifestations of conditioning are more closely duplicated. Therefore the author of this article is bending his efforts toward the invention of a small and efficient memory cell to be used in mechanisms for testing the following conception of thought:

Thought is minimized action. A series of events in the environment of an intelligent creature causes the creature to make a series of adjustive movements. At the same time, various events of the series become conditioned as stimuli for succeeding movements of the creature. Each response may become conditioned to any of several preceding stimuli, and also to the simultaneous stimuli produced by the creature's own movements. For these and similar reasons, there is crowding of responses when the series of events in the environment is re-initiated. This means that some responses will be virtually eliminated, others decreased, and still others (particularly the terminal ones) retained practically unweakened. Therefore, less time is required for the creature to recall the approximate response to the terminal event of a series than is required for the terminal event to occur after the initial event.

The awakening of a retained sensory impression when its response is made is memory in the common sense of the word. Thought, then, appears as a means of "trying" different actions and anticipating their results through a process of automatic recall.

The problem of thought being thus analyzable—and elementary learning machines have been successful—it appears that, as Professor Hull remarks, "at a not very remote date the concept of a 'psychic machine' may become by no means a paradox."



Circuit diagram of the parts of a "thinking machine"

Do you believe in birth control? In an early number this question will be discussed—without gloves.—Ed.