VII Cybernetics and Psychopathology

It is necessary that I commence this chapter with a disavowal. On the one hand, I am not a psychopathologist nor a psychiatrist, and lack any experience in a field where the guidance of experience is the only trustworthy one. On the other hand, our knowledge of the normal performance of the brain and the nervous system, and *a fortiori* our knowledge of their abnormal performance, is far from having reached that state of perfection where an *a priori* theory can command any confidence. I therefore wish to disclaim in advance any assertion that any particular entity in psychopathology, as for example any of the morbid conditions described by Kraepelin and his disciples, is due to a specific type of defect in the organization of the brain as a computing machine. Those who may draw such specific conclusions from the considerations of this book do so at their own risk.

Nevertheless, the realization that the brain and the computing machine have much in common may suggest new and valid approaches to psychopathology and even to psychiatries. These begin with perhaps the simplest question of all: how the brain avoids gross blunders, gross miscarriages of activity, due to the malfunction of individual components. Similar questions referring to the computing machine are of great practical importance, for here a chain of operations, each covering a fraction of a millisecond, may last a matter of hours or days. It is quite possible for a chain of computational operations to involve 10^9 separate steps. Under these circumstances, the chance that at least one operation will go amiss is very far from negligible, even though, it is true, the reliability of modern electronic apparatus has far exceeded the most sanguine expectations.

In ordinary computational practice by hand or by desk machines, it is the custom to check every step of the computation and, when an error is found, to localize it by a backward process starting from the first point where the error is noted. To do this with a high-speed machine, the check must proceed with the speed of the original machine, or the whole effective order of speed of the machine will conform to that of the slower process of checking. Furthermore, if the machine is made to keep all intermediate records of its performance, its complication and bulk will be increased to an intolerable point, by a factor which is likely to be enormously greater than 2 or 3.

A much better method of checking, and in fact the one generally used in practice, is to refer every operation simultaneously to two or three separate mechanisms. In the case of the use of two such mechanisms, their answers are automatically collated against each other; and if there is a discrepancy, all data are transferred to permanent storage, the machine stops, and a signal is sent to the operator that something is wrong. The operator then compares the results, and is guided by them in his search for the malfunctioning part, perhaps a tube which has burnt out and needs replacement. If three separate mechanisms are used for each stage and single misfunctions are as rare as they are in fact, there will practically always be an agreement between two of the three mechanisms, and this agreement will give the required result. In this case, the collation mechanism accepts the majority report, and the machine need not stop; but there is a signal indicating where and how the minority report differs from the majority report. If this occurs at the first moment of discrepancy, the indication of the position of the error may be very precise. In a well-designed machine, no particular element is assigned to a particular stage in the sequence of operations, but at each stage there is a searching process, quite similar to that used in automatic telephone exchanges, which finds the first available element of a given sort and switches it into the sequence of operations. In this case, the removal and replacement of defective elements need not be the source of any appreciable delay.

It is conceivable and not implausible that at least two of the elements of this process are also represented in the nervous system. We can hardly expect that any important message is entrusted for transmission to a single neuron, nor that any important operation is entrusted to a single neuronal mechanism. Like the computing machine, the brain probably works on a variant of the famous principle expounded by Lewis Carroll in *The Hunting of the Snark:* "What I tell you three times is true." It is also improbable that the various channels available for the transfer of information generally go from one end of their course to the other without anastomosing. It is much more probable that when a message comes in to a certain level of the nervous system, it may leave that point and proceed to the next by one or more alternative members of what is known as an "internuncial pool." There may be parts of the nervous system, indeed, where this interchangeability is much limited or abolished, and these are likely to be such highly specialized parts of the cortex as those which serve as the inward extensions of the organs of special sense. Still, the principle holds, and probably holds most clearly for the relatively unspecialized cortical areas which serve the purpose of association and of what we call the higher mental functions.

So far we have been considering errors in performance which are normal, and pathological only in an extended sense. Let us now turn to those which are much more clearly pathological. Psychopathology has been rather a disappointment to the instinctive materialism of the doctors, who have taken the point of view that every disorder must be accompanied by material lesions of some specific tissue involved. It is true that specific brain lesions, such as injuries, tumors, clots, and the like, may be accompanied by psychic symptoms, and that certain mental diseases, such as paresis, are the sequellae of general bodily disease and show a pathological condition of the brain tissue; but there is no way of identifying the brain of a schizophrenic of one of the strict Kraepelin types, nor of a manic-depressive patient, nor of a paranoiac. These disorders we call *functional*, and this distinction seems to contravene the dogma of modern materialism that every disorder in function has some physiological or anatomical basis in the tissues concerned.

This distinction between functional and organic disorders receives a great deal of light from the consideration of the computing machine. As we have already seen, it is not the empty physical structure of the computing machine that corresponds to the brain—to the adult brain, at least—but the combination of this structure with the instructions given it at the beginning of a chain of operations and with all the additional information stored and gained from outside in the course of this chain. This information is stored in some physical form—in the form of memory—but part of it is in the form of circulating memories, with a physical basis which vanishes when the machine is shut down or the brain dies, and part in the form of long-time memories, which are stored in a way at which we can only guess, but probably also in a form with a physical basis which vanishes at death. There is no way yet known for us to recognize in the cadaver what the threshold of a given synapse has been in life; and even if we knew this, there is no way we can trace out the chain of neurons and synapses communicating with this, and determine the significance of this chain for the ideational content which it records.

There is therefore nothing surprising in considering the functional mental disorders as fundamentally diseases of memory, of the circulating information kept by the brain in the active state, and of the long-time permeability of synapses. Even the grosser disorders such as paresis may produce a large part of their effects not so much by the destruction of tissue which they involve and the alteration of synaptic thresholds as by the secondary disturbances of traffic—the overload of what remains of the nervous system and the re-routing of messages—which must follow such primary injuries.

In a system containing a large number of neurons, circular processes can hardly be stable for long periods of time. Either, as in the case of memories belonging to the specious present, they run their course, dissipate themselves, and die out, or they comprehend more and more neurons in their system, until they occupy an inordinate part of the neuron pool. This is what we should expect to be the case in the malignant worry which accompanies anxiety neuroses. In such a case, it is possible that the patient simply does not have the room, the sufficient number of neurons, to carry out his normal processes of thought. Under such conditions, there may be less going on in the brain to load up the neurons not yet affected, so that they are all the more readily involved in the expanding process. Furthermore, the permanent memory becomes more and more deeply involved, and the pathological process which occurred at first at the level of the circulating memories may repeat itself in a more intractable form at the level of the permanent memories. Thus what started as a relatively trivial and accidental reversal of stability may build itself up into a process totally destructive to the ordinary mental life.

Pathological processes of a somewhat similar nature are not unknown in the case of mechanical or electrical computing machines. A tooth of a wheel may slip under just such conditions that no tooth with which it engages can pull it back into its normal relations, or a high-speed electrical computing machine may go into a circular process which there seems to be no way to stop. These contingencies may depend on a highly improbable instantaneous configuration of the system, and, when remedied, may never—or very rarely—repeat themselves. However, when they occur, they temporarily put the machine out of action.

How do we deal with these accidents in the use of the machine? The first thing which we try is to clear the machine of all information, in the hope that when it starts again with different data the difficulty may not recur. Failing this, if the difficulty is in some point permanently or temporarily inaccessible to the clearing mechanism, we shake the machine or, if it is electrical, subject it to an abnormally large electrical impulse, in the hope that we may reach the inaccessible part and throw it into a position where the false cycle of its activities will be interrupted. If even this fails, we may disconnect an erring part of the apparatus, for it is possible that what yet remains may be adequate for our purpose.

Now there is no normal process except death which completely clears the brain from all past impressions; and after death, it is impossible to set it going again. Of all normal processes, sleep comes the nearest to a non-pathological clearing. How often we find that the best way to handle a complicated worry or an intellectual muddle is to sleep over it! However, sleep does not clear away the deeper memories, nor indeed is a sufficiently malignant state of worry compatible with an adequate sleep. We are thus often forced to resort to more violent types of intervention in the memory cycle. The more violent of these involve a surgical intervention into the brain, leaving behind it permanent damage, mutilation, and the abridgment of the powers of the victim, as the mammalian central nervous system seems to possess no powers whatever of regeneration. The principal type of surgical intervention which has been practiced is known as prefrontal lobotomy, and consists in the removal or isolation of a portion of the prefrontal lobe of the cortex. It has recently been having a certain vogue, probably not unconnected with the fact that it makes the custodial care of many patients easier. Let me remark in passing that killing them makes their custodial care still easier. However, prefrontal lobotomy does seem to have a genuine effect on malignant worry, not by bringing the patient nearer to a solution of his problems but by damaging or destroying the capacity for maintained worry, known in the terminology of another profession as the *conscience*. More genei:ally, it appears to limit all aspects of the circulating memory, the ability to keep in mind a situation not actually presented.

The various forms of shock treatment—electric, insulin, metrazol—are less drastic methods of doing a very similar thing. They do not destroy brain tissue or at least are not intended to destroy it, but they do have a decidedly damaging effect on the memory. In so far as this concerns the circulating memory, and in so far as this memory is chiefly damaged for the recent period of mental disorder, and is probably scarcely worth preserving anyhow, shock treatment has something definite to recommend it as against lobotomy; but it is not always free from deleterious effects on the permanent memory and the personality. As it stands at present, it is another violent, imperfectly understood, imperfectly controlled method to interrupt a mental vicious circle. This does not prevent its being in many cases the best thing we can do at present.

Lobotomy and shock treatment are methods which by their very nature are more suited to handle vicious circulating memories and malignant worries than the deeper-seated permanent memories, though it is not impossible that they may have some effect here too. As we have said, in long-established cases of mental disorder, the permanent memory is as badly deranged as the circulating memory. We do not seem to possess any purely pharmaceutical or surgical weapon for intervening differentially in the permanent memory. This is where psychoanalysis and other similar psychotherapeutic measures come in. Whether psychoanalysis is taken in the orthodox Freudian sense or in the modified senses of Jung and of Adler, or whether our psychotherapy is not strictly psychoanalytic at all, our treatment is clearly based on the concept that the stored information of the mind lies on many levels of accessibility and is much richer and more varied than that which is accessible by direct unaided introspection; that it is vitally conditioned by affective experiences which we cannot always uncover by such introspection, either because they never were made explicit in our adult language, or because they have been buried by a definite mechanism, affective though generally involuntary; and that the content of these stored experiences, as well as their affective tone, conditions much of our later activity in ways which may well be pathological. The technique of the psychoanalyst consists in a series of means to discover and interpret these hidden memories, to make the patient accept them for what they are and by their acceptance modify, if not their content, at least the affective tone they carry, and thus make them less harmful. All this is perfectly consistent with the point of view of this book. It perhaps explains, too, why there are circumstances where a joint use of shock treatment and psychotherapy is indicated, combining a physical or pharmacological therapy for the phenomena of reverberation in the nervous system, and a psychological therapy for the long-time memories which, without interference, might reestablish from within the vicious circle broken up by the shock treatment.

We have already mentioned the traffic problem of the nervous system. It has been commented on by many writers, such as D'Arcy Thompson,[1] that each form of organization has an upper limit of size, beyond which it will not function. Thus the insect organization is limited by the length of tubing over which the spiracle method of bringing air by diffusion directly to the breathing tissues will function; a land animal cannot be so big that the legs or ether portions in contact with the ground will be crushed by its weight; a tree is limited by the mechanism for transferring water and minerals from the roots to the leaves, and the products of photosynthesis from the leaves to the roots; and so on. The same sort of thing is observed in engineering constructions. Skyscrapers are limited in size by the fact that when they exceed a certain height, the elevator space needed for the upper stories consumes an excessive part of the cross section of the lower floors. Beyond a certain span, the best-possible suspension bridge which can be built out of materials with given elastic properties will collapse under its own weight; and beyond a certain greater span, *any* structure built of a given material or materials will collapse under its own weight. Similarly, the size of a single telephone central, built according to a constant, non-expanding plan, is limited, and this limitation has been very thoroughly studied by telephone engineers.

In a telephone system, the important limiting factor is the fraction of the time during which a subscriber will find it impossible to put a call through. A 99 per cent chance of success will certainly be satisfactory for even the most exacting; 90 per cent of successful calls is probably good enough to permit business to be carried on with reasonable facility. A success of 75 per cent is already annoying but will permit business to be carried on after a fashion; while if half the calls end in failures, subscribers will begin to ask to have their telephones taken out. Now, these represent over-all figures. If the calls go through n distinct stages of switching, and probability of failure is independent and equal for each stage, in order to get a probability of total success equal to p, the probability of success at each stage must be $p^{1/n}$. Thus to obtain a 75 per cent chance of the completion of the call after five stages, we must have about 95 per cent chance of success per stage. To obtain a 90 per cent performance, we must have 98 per cent chance of success at each stage. To obtain a 50 per cent performance, we must have 87 per cent chance of success at each stage. It will be seen that the more stages which are involved, the more rapidly the service becomes extremely bad when a critical level of failure for the individual call is exceeded, and extremely good when this critical level of failure is not quite reached. Thus a switching service involving many stages and designed for a certain level of failure shows no obvious signs of failure until the traffic comes up to the edge of the critical point, when it goes completely to pieces, and we have a catastrophic traffic jam.

Man, with the best-developed nervous system of all the animals, with behavior that probably depends on the longest chains of effectively operated neuronic chains, is then likely to perform a complicated type of behavior efficiently very close to the edge of an overload, when he will give way in a serious and catastrophic way. This overload may take place in several ways: either by an excess in the amount of traffic to be carried, by a physical removal of channels for the carrying of traffic, or by the excessive occupation of such channels by undesirable systems of traffic, like circulating memories which have increased to the extent of becoming pathological worries. In all these cases, a point will come—quite suddenly—when the normal traffic will not have space enough allotted to it, and we shall have a form of mental breakdown, very possibly amounting to insanity.

This will first affect the faculties or operations involving the longest chains of neurons. There is appreciable evidence that these are precisely the processes which are recognized to be the highest in our ordinary scale of valuation. The evidence is this: a rise in temperature within nearly physiological limits is known to produce an increase in the ease of performance of most if not of all neuronic processes. This is greater for the higher processes, roughly in the order of our usual estimate of their degree of "highness." Now, any facilitation of a process in a single neuron-synapse system should be cumulative as the neuron is combined in series with other neurons. Thus the amount of assistance a process receives through a rise in temperature is a rough measure of the length of the neuron chain it involves.

We thus see that the superiority of the human brain to others in the length of the neuron chains it employs is a reason why mental disorders are certainly most conspicuous and probably most common in man. There is another more specific way of considering a very similar matter. Let us first consider two brains geometrically similar, with the weights of gray and of white matter related by the same factor of proportionality, but with different linear dimensions in the ratio $A{:}B$. Let the volume of the cell bodies in the gray matter and the cross sections of the fibers in the white matter be of the same size in both brains. Then the number of cell bodies in the two cases bears the ratio $A^3{:}B^3$, and the number of long-distance connectors the ratio $A^2{:}B^2$. This means that for the same density of activity in the cells, the density of activity in the fibers is $A{:}B$ times as great in the case of the large brain as in that of the small brain.

If we compare the human brain with that of a lower mammal, we shall find that it is much more convoluted. The relative thickness of the gray matter is much the same, but it is spread over a far more involved system of gyri and sulci. The effect of this is to increase the amount of gray matter at the expense of the amount of white matter. Within a gyrus, this decrease of the white matter is largely a decrease in length rather than in number of fibers, as the opposing folds of a gyrus are nearer together than they would be on a smooth-surfaced brain of the same size. On the other hand, when it comes to the connectors between different gyri, the distance they have to run is increased if anything by the convolution of the brain. Thus the human brain would seem to be fairly efficient in the matter of the short-distance connectors, but quite defective in the matter of long-distance trunk lines. This means that in case of a traffic jam the processes involving parts of the brain quite remote from one another should suffer first. That is, processes involving several centers, a number of different motor processes, and a considerable number of association areas should be among the least stable in cases of insanity. These are precisely the processes which we should normally class as higher, and we obtain another confirmation of our expectation, which seems to be verified by experience, that the higher processes deteriorate first in insanity.

There is some evidence that the long-distance paths in the brain have a tendency to run outside of the cerebrum altogether and to traverse the lower centers. This is indicated by the remarkably small damage done by cutting some of the long-distance cerebral loops of white matter. It almost seems as if these superficial connections were so inadequate that they furnish only a small part of the connections really needed.

With reference to this, the phenomena of handedness and of hemispheric dominance are interesting. Handedness seems to occur in the lower mammals, though it is less conspicuous than in man, probably in part because of the lower degree of organization and skill demanded by the tasks which they perform. Nevertheless, the choice between the right and the left side in muscular skill does actually seem to be less than in man even in the lower primates.

The right-handedness of the normal man, as is well known, is generally associated with a left-brainedness, and the left-handedness of a minority of humans with a right-brainedness. That is, the cerebral functions are not distributed evenly over the two hemispheres, and one of these, the dominant hemisphere, has the lion's share of the higher functions. It is true that many essentially bilateral functions—those involving the fields of vision, for example—are represented each in its appropriate hemisphere, though this is not true for *all* bilateral functions. However, most of the "higher" areas are confined to the dominant hemisphere. For example, in the adult, the effect of an extensive injury in the secondary hemisphere is far less serious than the effect of a similar injury in the dominant hemisphere. At a relatively early age in his career, Pasteur suffered a cerebral hemorrhage on his right side which left him with a moderate degree of one-sided paralysis, a hemiplegia. When he died, his brain was examined, and he was found to be suffering from a right-sided injury, so extensive that it has been said that after his injury "he had only half a brain." There certainly were extensive lesions of the parietal and temporal regions. Nevertheless, after this injury he did some of his best work. A similar injury of the left side in a right-handed adult would almost certainly have been fatal and would certainly reduce the patient into an animal condition of mental and nervous crippledness.

It is said that the situation is considerably better in early infancy, and that in the first six months of life an extensive injury to the dominant hemisphere may compel the normally secondary hemisphere to take its place; so that the patient appears far more nearly normal than he would be had the injury occurred at a later stage. This is quite in accordance with the general great flexibility shown by the nervous system in the early weeks of life, and the great rigidity which it rapidly develops later. It is possible that, short of such serious injuries, handedness is reasonably flexible in the very young child. However, long before the child is of school age, the natural handedness and cerebral dominance are established for life. It used to be thought that left-handedness was a serious social disadvantage. With most tools, school desks, and sports equipment primarily made for the right-handed, it certainly is to some extent. In the past, moreover, it was viewed with some of the superstitious disapproval that has attached to so many minor variations from the human norm, such as birthmarks or red hair. From a combination of motives, many people have attempted and even succeeded, in changing the external handedness of their children by education, though of course they could not change its physiological basis in hemispheric dominance. It was then found that in very many cases these hemispheric changelings suffered from stuttering and other defects of speech, reading, and writing, to the extent of seriously wounding their prospects in life and their hopes for a normal career. We now see at least one possible explanation for the phenomenon. With the education of the secondary hand, there has been a partial education of that part of the secondary hemisphere which deals with skilled motions, such as writing. Since, however, these motions are carried out in the closest possible association with reading, speech, and other activities which are inseparably connected with the dominant hemisphere, the neuron chains involved in processes of the sort must cross over from hemisphere to hemisphere and back; and in a process of any complication, they must do this again and again. Now, the direct connectors between the hemispheres—the cerebral commissures—in a brain as large as that of man are so few in number that they are of very little use, and the interhemispheric traffic must go by roundabout routes through the brain stem, which we know very imperfectly but which are certainly long, scanty, and subject to interruption. As a consequence, the processes associated with speech and writing are very likely to be involved in a traffic jam, and stuttering is the most natural thing in the world.

That is, the human brain is probably too large already to use in an efficient manner all the facilities which seem to be anatomically present. In a cat, the destruction of the dominant hemisphere seems to produce relatively less damage than in man, and the destruction of the secondary hemisphere probably more damage. At any rate, the apportionment of function in the two hemispheres is more nearly equal. In man, the gain achieved by the increase in size and complication of the brain is partly nullified by the fact that less of the organ can be used effectively at one time. It is interesting to reflect that we may be facing one of those limitations of nature in which highly specialized organs reach a level of declining efficiency and ultimately lead to the extinction of the species. The human brain may be as far along on its road to this destructive specialization as the great nose horns of the last of the titanotheres.

This is a section of doi:10.7551/mitpress/11810.001.0001

Cybernetics or Control and Communication in the Animal and the Machine

By: Norbert Wiener

Citation:

Cybernetics or Control and Communication in the Animal and the Machine
By: Norbert Wiener
DOI: 10.7551/mitpress/11810.001.0001
ISBN (electronic): 9780262355902
Publisher: The MIT Press
Published: 2019

Funding for the open access edition was provided by the MIT Libraries Open Monograph Fund.

The MIT Press

First MIT Press paperback edition, February 1965

This book was set in ITC Stone Serif Std and ITC Stone Sans Std by Toppan Best-set Premedia Limited. Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Names: Wiener, Norbert, 1894-1964, author.
Title: Cybernetics ; or, Control and communication in the animal and the machine / Norbert Wiener ; forewords by Doug Hill and Sanjoy Mitter.
Other titles: Control and communication in the animal and the machine
Description: [Second edition, 2019 reissue]. | Cambridge, MA : The MIT Press, [2019] | "Reissue of the 1961 second edition." | Includes bibliographical references and index.
Identifiers: LCCN 2019005612 | ISBN 9780262537841 (pbk. : alk. paper)
Subjects: LCSH: Cybernetics. | Control theory. | System theory.
Classification: LCC Q310 .W47 2019 | DDC 003/.5--dc23 LC record available at https://lccn.loc.gov/2019005612

10 9 8 7 6 5 4 3 2 1