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THE SECOND CYBERNETICS

Deviation-Amplifying Mutual Causal Processes

By MAGOROH MARUYAMA

Since its inception, cybernetics was more or less identified as a science of self-regulating and equilibrating systems. Thermostats, physiological regulation of body temperature, automatic steering devices, economic and political processes were studied under a general mathematical model of deviation-counteracting feedback networks.

By focusing on the deviation-counteracting aspect of the mutual causal relationships however, the cyberneticians paid less attention to the systems in which the mutual causal effects are deviation-amplifying. Such systems are ubiquitous: accumulation of capital in industry, evolution of living organisms, the rise of cultures of various types, interpersonal processes which produce menial illness, international conflicts, and the processes that are loosely termed as "vicious circles" and "compound interests"; in short, all processes of mutual causal relationships that amplify an insignificant or accidental initial kick, build up deviation and diverge from the initial condition.

In contrast to the progress in the study of equilibrating systems, the deviation-amplifying systems have not been given as much investment of time and energy by the mathematical scientists on the one hand, and understanding and practical application on the part of geneticists, ecologists, politicians and psychotherapists on the other hand.

The deviation-counteracting mutual causal systems and the deviation-amplifying mutual causal systems may appear to be opposite types of systems.

But they have one essential feature in common: they are both mutual causal systems, i.e., the elements within a system influence each other either simultaneously or alternatingly.

The difference between the two types of systems is that the deviation-counteracting system has mutual negative feedbacks between the elements in it while the deviation-amplifying system has mutual positive feedbacks between the elements in it.

Since both types are systems of mutual causal relationships, or in other words systems of mutual feedbacks, they both fall under the subject matter of cybernetics.

But since the *deviation-counteracting* type has predominantly been studied up till now under the title of cybernetics, let us consider its studies *the first cybernetics*, and call the studies of the *deviation-amplifying* mutual causal relationships "*the second cybernetics*."

The deviation-counteracting mutual causal process is also called *morphostasis*", while the deviation-amplifying mutual causal process is called "*morphogenesis*." (For a technical treatment of the subject, see my article "Morphogenesis and Morphostasis," Methodos, IS, no. 48,1960)

Though the second cybernetics as defined here is lagging behind the development of the first cybernetics at the present moment, the germination of the concept of deviation-amplifying mutual causal process is not entirely new. The concept was formulated in some fields even before the advent of cybernetics and was applied fruitfully. The field of economics is a good example.

For many years the economists had claimed that it was useless to try to raise the standard of living of the lower class, because, they argued, if the income of the population in the lower class should increase, they would produce more children and thus reduce their standard of living to the original level; the poor stay poor and the rich stay rich. This was a morphostatic model of mutual deviation-counteracting between, the income level and the number of children. This theoretical model led the policy makers to the action of laisser-faire policy. On the other hand, it was also known that "the more capital, the more rapid the ratio of its increase"; in other words, the poor become poorer and the rich become richer - This was a morphogenetic model of deviation-amplifying process.

Subsequently J. Tinbergen and H. Wold have given more elaboration and mathematical sophistication to the theory of mutual causal process in the theory of economics [1]. More recently G. Myrdal has pointed out that, while in the economically well-developed countries the regional, social, and hierarchical differences in economical level tend to decrease, in the economically underdeveloped regions the difference between the poor and the rich increases. In an economically well-developed society, transportation, communication, education, insurance systems, and welfare programs equalize the economical level throughout the society. In an economically underdeveloped society, on the other hand, under the laisser-faire policy and free play of market forces, the few privileged people accumulate more wealth and power while the living standard of the poor tends to fall. Low standard of living, poor health, and low efficiency in work aggravate one another. Racial or social discrimination, and other social, psychological and cultural factors may be added in the "vicious circle." Likewise, between nations, world free trade is profitable for rich countries and detrimental for poor countries. This morphogenetic reformulation of the economic theory affects the public policy toward the direction of planned economy within economically underdeveloped countries and controlled international trade pi.

Myrdal l2) further points out the importance of the direction of the initial kick, which determines the direction of the subsequent deviation amplification in the planned economy. Furthermore, the resulting development will be far greater than the investment in the initial kick. Thus, in the economically underdeveloped countries it is necessary not only to plan the economy, but also to give the initial kick and reinforce it for a while in such a direction and with such an intensity as to maximize the efficiency of development per initial investment. Once the economy is kicked in a right direction and with a sufficient initial push, the deviation-amplifying mutual positive feedbacks take over the process, and the resulting development will be disproportionally large as compared with the initial kick.

We find the same principle of deviation-amplifying mutual causal relationships operating in many other happenings in the universe. Take, for example, weathering of rock. A small crack in a rock collects some water. The water freezes and makes the crack larger. A larger crack collects more water, which makes the crack still larger. A sufficient amount of water then makes it possible for some small organisms to live in it. Accumulation of organic matter then makes it possible for a tree to start growing in the crack. The roots of the tree will then make the crack still larger.

Development of a city in an agricultural plain may be understood with the same principle. At the beginning, a large plain is entirely homogeneous as to its potentiality for agriculture. By some chance an ambitious farmer opens a farm at a spot on it. This is the initial kick. Several farmers follow the example and several farms are established. One of the farmers opens a tool shop. Then this tool shop becomes a meeting place of farmers. A food stand is established next to the tool shop. Gradually a village grows. The village facilitates the marketing of the agricultural products, and more farms flourish around the village. Increased agricultural activity necessitates development of industry in the village, and the village grows into a city.

This is a very familiar process. But there are a few important theoretical implications in such a process. On what part of the entire plain the city starts growing depends on where accidentally the initial kick occurred - The first farmer could have chosen any spot on the plain, since the plain was homogeneous. But once he has chosen a spot, a city grows from that spot, and the plain becomes inhomogeneous. If a historian should try to find a geographical "cause" which made this spot a city rather than some other spots, he will fail to find it in the initial homogeneity of the plain. Nor can the first farmer be credited with the establishment of the city. The secret of the growth of the city is in the process of deviation-amplifying mutual positive feedback networks rather than in the initial condition or in the initial kick. This process, rather than the initial condition, has generated the complexly structured city. It is in this sense that the deviation-amplifying mutual causal process is called "morphogenesis."

Aspects of Causality

A sacred law of causality in the classical philosophy stated that similar conditions produce similar effects. Consequently, dissimilar results were attributed to dissimilar conditions. Many scientific researches were dictated by this philosophy. For example, when a scientist tried to find out why two persons under study were different, he looked for a difference in their environment or in their heredity. It did not occur to him that neither environment nor heredity may be responsible for the difference - He overlooked the possibility that some deviation-amplifying interactional process in their personality and in their environment may have produced the difference.

In the light of the deviation-amplifying mutual causal process, the law of causality is now revised to state that similar conditions may result in dissimilar products. It is important to note that this revision is made without the introduction of indeterminism and probabilism. Deviation-amplifying mutual causal processes are possible even within the deterministic universe, and make the revision of the law of causality even within the determinism. Furthermore, when the deviation-amplifying mutual causal process is combined with indeterminism, here again a revision of a basic law becomes necessary. The revision states:

> A small initial deviation, which is within the range of high probability, may develop into a deviation of very low probability or more precisely, into a deviation which is very improbable within the framework of probabilistic unidirectional causality.

Not only the law of causality, but also the second law of thermodynamics is affected by the deviation-amplifying mutual causal process. Let us return to the example of the growth of a city in an agricultural plain - The growth of the city first increases the internal structuredness of the city itself. Secondly, it increases the inhomogeneity of the plain by its deviating from the original prevailing condition. Thirdly, the growth of a city at a spot may have an inhibiting effect upon the growth of another city in the vicinity, just as the presence of one swimming pool may discourage an enterpriser from opening another pool right next to it, and just as the presence of large trees inhibits with their shades the growth of some species of small trees around them. A city needs a hintergrund to support it, and, therefore, cities have to be spaced at some intervals. This inhibiting effect further increases inhomogeneity of the plain.

This gradual increase of inhomogeneity is a process against the second law of thermodynamics. In a few words, the second law of thermodynamics states that an isolated system spends with a great probability most of its time in high-probability states. Hence, if an isolated system is in an improbable state, it will most probably be found in the future in a more probable state. Under the assumption of randomness of events, homogeneous states are more probable than inhomogeneous states. For example, uneven distribution of temperature is less probable than even distribution of temperature. Under the assumption of the second law of thermodynamics, an isolated system in an inhomogeneous state will most probably be found in a future in a more homogeneous state. The second law of thermodynamics is in this sense a law of decay of structure and of decay of inhomogeneity.

Evolution

Any process such as biological growth which increases structuredness and inhomogeneity was against the second law of thermodynamics and was an embarrassing problem for scientists. This embarrassing question was temporarily ignored by the argument that an organism is not an isolated system. But what process and principle make it possible for an organism to increase its structure and to accumulate heat was never squarely answered. Now, under the light of deviation-amplifying mutual causal process this mystery is solved.

The process of evolution, or in other words phylogenetic morphogenesis including the pattern of behavior, is deviation-amplifying in several ways.

First, there is deviation-amplifying mutual process between the mutations and the environment. For example, suppose that some mutants of a species can live at a lower temperature than the "normal" individuals. Then the mutants may move to an environment which is colder. Further mutations occur - Some of the mutants are unfit for the low-temperature environment and die off. But some other mutants are able to live in a much colder climate than their parents. They move to a still colder environment. The cold climate eliminates any new mutants that are unfit for cold climate. The "average" individuals of the survivors are then fit for cold climate. The chances of the species, or at least some members of the species, to move to a still colder environment are now greater than before. Thus the selection of, or accidental wandering into, a certain type of environment and the direction of survivable mutations amplify each other.

Not only the organism may move into a new environment, but it may also create its own environment. Homo sapiens is a typical example. A "civilized" man lives in an environment which he created, and which is relatively free from the bacteria of certain diseases such as typhoid. His resistance against typhoid decreases as a result of living in such an environment. The decreased resistance necessitates him to make his environment more germ-free. This decreases his resistance further.

Secondly, there is interspecific deviation-amplification. For example, a species of moth has predators. Because of the predators, the mutants of the moth species which have a more suitable cryptic coloration (camouflage) and cryptic behavior than the average survive better. On the other hand, those mutants of the predators which have a greater ability than the average in discovering the moth will survive better. Hence, the cryptic coloration and the cryptic behavior of the moth species improve generation after generation, and the ability of the predators to discover the moth also increases generation after generation.

Thirdly, the intraspecific selection has a deviation-amplifying effect, for example many animals prefer supernormal (above-average) members of its species to normal members for mating and for carrying on other cooperative activities. By giving more responses to supernormal stimuli than to normal stimuli, the members of blic species amplify, by favoring supernormal mutants, the deviation in the direction of super-normality. The deviation in turn may increase either the number and the intensity at the members' responses to the supernormal stimuli, or the level of the supernormality of the members' characteristics.

The response to supernormal stimuli may he inborn or culturally conditioned. For example, an oystercatcher (Haematopus ostralegus) prefers a large artificial egg given by an experimenter to its own egg, and tries to sit on the large egg even though the egg may be as large as the bird's body [a]. This response is inborn. On the other hand in homo sapiens, what is considered "supernormal" often depends on the culture. In the contemporary American culture, female legs which are more slender and longer than normal are supernormal stimuli, while in Polynesia obese young girls used to be supernormal stimuli. In this way, culture may influence the direction of the evolution of the human species while, at the same time, the evolution influences the culture. We may say that "cultural selection" rather than natural selection is the mechanism of human evolution since much of man's environment is man-made. But the matter is not very simple because certain cultures like ours, with medical science and technology, make it, possible for constitutionally "unfit" individuals to "survive." Perhaps fitness should be defined not in terms of the capacity of the individual without tools, but in terms of the tools which he can mobilize.

In any case, roan is responsible for his own evolution because of his capacity to create his own culture which is his environment and to choose his criterion of supernormality. Incidentally, to "create" is no longer a concept which violates the law of physics. As we have seen, creation ex nihilo, or rather almost ex nihilo, is scientific ally possible because the secret is no longer in the Prime Mover or in the Creator, but in the process of deviation-amplifying mutual positive feedback network.

Fourthly, the effect of inbreeding is deviation-amplifying for purely statistical reasons - Marriage between close relatives produce individuals in whom certain characteristics are extremely amplified. In fact, if people were to practice intra family marriages only, each family would develop into a separate species because there is no interbreeding between families. In a more extreme case, if the reproduction were always sexless, i.e., if an individual produced its offspring without any help from another individual, then each individual's descendants would develop into a separate species. In fact, "species" would he non-existent.

Many times cooperation between individuals facilitates life [4], and therefore the existence of species facilitates the life of the individual. The sexual reproduction, as compared with asexual reproduction, acts as a stabilizer of the species.

Here we have seen that mating may amplify the deviations or stabilize the species. This is not a contradiction. Whether mating is deviation-amplifying or deviation-counteracting depends on whether the inbreeding component or the interbreeding component is predominant. S. Wright [5] has made this relationship clear. When the mutation rate is high as compared with the population size, random matings will produce more inbreeding than interbreeding, and the deviation-amplifying effect is predominant. On the other hand, when the population size is large as compared with the mutation rate, random matings will produce more interbreeding than inbreeding, and the deviation-counteracting effect is predominant. The direction of deviation in a small population with a high mutation rate is unpredictable since it depends on the initial kick which is random. But once the deviation started, it is systematically amplified in the same direction.

When the mutation rate is neither too high nor too low as compared with the population size, neither inbreeding nor interbreeding predominates. The result is neither deviation-amplifying nor deviation-counteracting, but a combination of both which results in random drift. At one time, a random initial kick produces a deviation in a certain direction. Deviation-amplification takes over and this deviation is amplified consistently in the same direction. But this does not last very long. Soon, deviation-counteracting takes over, and the population becomes fixed at a certain point of deviation. After a while, another random initial kick produces a deviation in a new direction. Deviation-amplification takes over again and the population drifts consistently in this direction for a while. But soon, deviation-counteracting takes over and the population becomes fixed at a new point in the new direction of deviation. Then another initial kick starts a deviation in a new direction. The process repeats itself with unpredictable drifts.

The maximum speed of evolution is found, not in one colony with a high rate of mutation and a small size of population, but in the interaction between colonies which have a moderate mutation rate. When the mutation rate is too high as compared with the population size, the mutant characteristics may amplify themselves at a speed beyond the possibility of finding a new environment and new intraspecific and interspecific ecological conditions which are suitable for the mutant characteristics, and beyond the possibility of allowing other variations of mutants, which have characteristics greater in survival value, to develop. The species may become extinct, or it may reach the limit of mutability and become fixed there, or the mutant characteristics may become so dominant and homogeneous as to become deviation-counteracting.

A moderate mutation rate produces a more viable and changeable evolution. Moreover, when there are occasional exchanges of immigrants between colonies, the introduction of a new strain, which has proved to be viable in one colony, into another colony has the same effect as producing viable mutants, and tends to favor evolution.

This seems to be true of human cultures also. When there is enough separation, not necessarily geographical, between cultures to allow them differentiation and variety, with enough exchange between them to allow mutual enrichment and new combinations, the human civilization seems to progress most efficiently.

As we have seen, evolution is deviation-amplifying in several ways. For this reason we called evolution "phylogenetic morphogenesis." But more traditionally, "morphogenesis" is used for ontogenesis, i.e., for the development of the embryo into an adult individual. Is the new usage of the word "morphogenesis," meaning deviation-amplifying mutual causal process, in any way contradictory to the traditional usage? By no means so. As we see in the following, the development of the embryo also involves deviation-amplifying mutual causal process.

There is one basic difference between ontogenesis and phylogenesis. Mutation and natural selection, which are the basis of phylogenesis, are absent in ontogenesis. In fact, while phylogenesis has the randomness of mutation, ontogenesis lacks this randomness and seems to be based on a strictly detailed, deterministic planning. But this detailed planning is generated within the embryo by a deviation-amplifying mutual causal process in a deterministic scheme.

A model of information storage

Biologists have been puzzled by the fact that the amount of information stored in the genes is much smaller than the amount of information needed to describe the structure of the adult individual. The puzzle is now solved by noticing that it is not necessary for the genes to carry all the information regarding the adult structure, but it suffices for the genes to carry a set of rules to generate the information.

This can be illustrated by a model:

Let us imagine, for the sake of simplicity, a two-dimensional organism. Let us further imagine that its cells are squares of an equal size. Let us say that the organism consists of four types of cells: green, red, yellow, and blue. Each type of cell reproduces cells of the same type to build a tissue. A tissue has at least two cells. The tissues grow in a two-dimensional array of squares. Let us give a set of rules for the growth of tissues:

1. No cells die. Once reproduced, a cell is always there.

2. Both ends of a tissue grow whenever possible, by reproducing one cell per unit time in a vacant contiguous square. If there is no vacant contiguous square at either end, that end stops growing. If there are more than one vacant contiguous squares at either end, the direction of the growth is governed by the preferential order given by Rules 3, 4, and 5.

3. If, along the straight line defined by the end cell and the penultimate cell (next to the end cell) there are less than or equal to three cells of the same type (but may be of different tissues) consecutively, the preferred direction is along the same straight line. If that direction is blocked, follow Rule 5.

4. If, along the straight line denned by the end cell and the penultimate cell, there are more than or equal to four cells of the same type (but may be of different tissues) consecutively, the preferred direction of the growth is a left turn. If a left turn is impossible, make a right turn.

5. If, when a straight growth is preferred, the straight growth is impossible because the square ahead is already occupied, do the following:

If the square to which the straight growth would take place is filled with a cell of the same type as the growing tissue, make a left turn. If the square ahead is filled with a cell whose type is different from that of the growing tissue, make a right turn.

6. The growth of the four types of tissues is timewise out of phase with each other: green first, red second, yellow third, and blue last within a cycle of one unit time.

..	..	35	34	33	32	..	..	..	..	..	..	..	..	..	..	..
..	..	36	43	42	31	..	..	..	..	..	..	..	..	..	..	..
..	..	37	44	41	30	..	..	..	..	..	..	..	..	..	..	..
..	..	38	39	40	29	28	27	26	..	..	..	..	..	..	..	..
..	..	..	..	15	14	13	12	25	..	..	..	..	..	..	..	..
..	..	..	..	16	23	22	11	24	..	..	19	18	17	16	..	..
..	..	..	..	17	24	21	10	23	22	21	20	..	..	15	..	..
..	..	..	..	18	19	20	9	8	7	6	12	11	10	14	..	..
..	..	..	..	..	..	8	7	6	5	5	13	16	9	13	12	11
..	..	..	..	..	..	9	14	13	4	4	14	15	8	..	..	10
..	..	..	..	..	..	10	11	12	3	3	3	6	7	..	..	9
..	..	..	..	..	..	2	1	1	2	..	1	5	5	6	7	8
..	..	..	..	..	..	3	11	12	13	14	1	4	4	..	..	..
..	..	..	7	6	6	4	10	9	16	15	2	3	3	..	..	..
..	..	..	6	5	4	3	2	8	17	2	1	1	2	..	..	..
..	..	..	9	6	13	12	1	7	18	3	..	..	..	..	..	..
13	12	11	10	7	14	11	1	6	5	4	..	..	..	..	..	..
14	23	22	21	8	9	10	2	3	4	5	16	15	14	..	..	..
15	24	25	20	..	..	..	..	..	..	6	17	20	13	..	..	..
16	17	18	19	..	..	..	..	..	..	7	18	19	17	..	..	..
..	..	..	..	..	..	..	..	..	..	8	9	10	11	..	..	..

Fig. 1

Rules 2, 3, 4, and 5 can be diagrammed together as in Figure 1. Using these rules, we can compute the growth of the tissues when the locations of the initial tissues are specified. For example, let us say that, in Figure 2, only the squares marked by 1's are filled with cells of the types indicated by the colors. At the end of the second unit time, the squares marked by 2's are filled. And at the end of the nth unit time, all squares marked by numbers less than n are filled. At the end of the 44th unit time, all tissues have completed the growth, and the organism has attained its full differentiation.

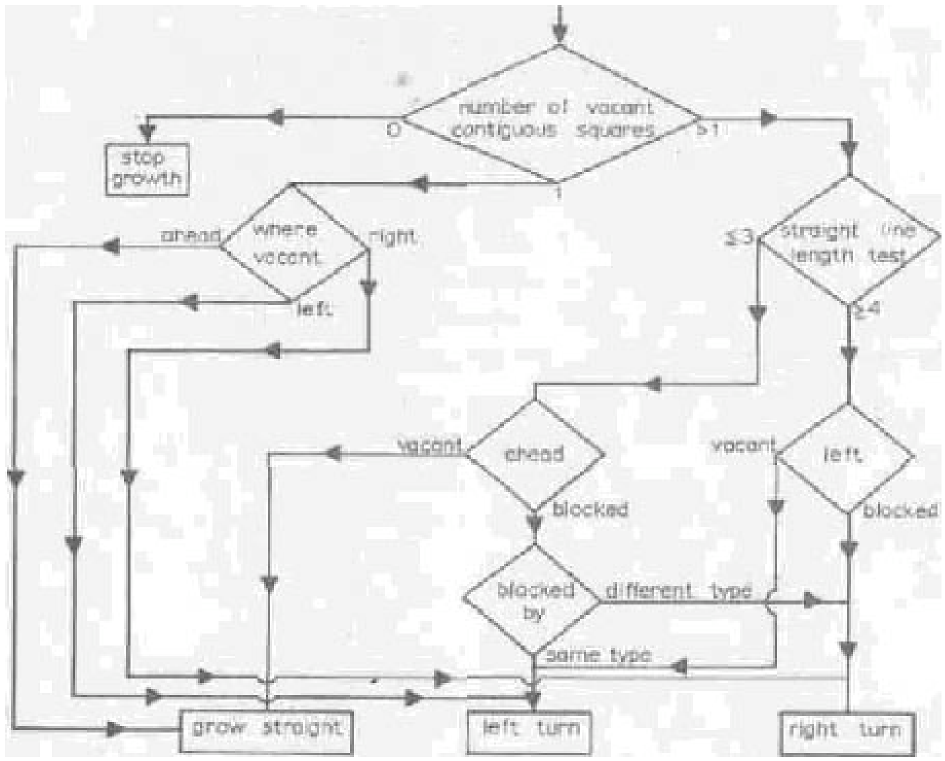

Fig. 2

In this example we started with four tissues of the minimum length, one tissue of each of the four types. But already the result is a fairly complex structure. If we start with a slightly larger number of tissues at the beginning, the resulting pattern becomes disproportionately more complex.

The amount of information to describe the resulting pattern is much more than the amount of information to describe the generating rules and the positions of the initial tissues. The pattern is generated by the rules and by the interaction between the tissues. In this sense, the information to describe the adult individual was not contained in the initial tissues at the beginning but was generated by their interactions.

Besides generating information, this type of process has two additional features. First, it is strictly deterministic. When the locations of the initial tissues are identical in two embryos, the resulting adults, no matter how complex, will be exactly identical.

Secondly, it is in most cases impossible to discover the simple generating rules after the pattern has been completed, except by trying all possible sets of rules. When the rules are unknown, the amount of information needed to discover the rules is much greater than the amount of information needed to describe the rules. This means that there is much more waste, in terms of the amount of information, in tracing the process backwards than in tracing it forward. A geneticist would waste much time and energy by trying to infer the characteristics of the embryo from the characteristics of the adult organism. It would be more profitable to perform experiments in embryonic interference and embryonic grafting. The same is true also for the study of other deviation-amplifying mutual causal processes such as history or mental illness.

Since information is generated by the interaction between various parts of the embryo, it is not necessary for each part of the embryo to contain information regarding the body part it is destined to become. It partly receives the information from other parts of the embryo and from its relationships to them. For example, in the embryo of certain species, if the part which would become an eye is transplanted at an appropriate stage of the embryonic development into the part which would become skin, the eye-tissue becomes skin. It receives information for its growth from its surroundings.

We have discussed mainly the structure-generating aspect of the interaction between the parts of the embryo. But the interaction has also a structure-stabilizing aspect. Let us look at the example of the grafted eye tissues again. When they were grafted on skin tissues, the skin tissues made the would-be-eye tissues into skin tissues, against the possibility that the would-be-eye tissues might become an eye. This process is "morphostasis" in the traditional terminology.

Thus, the usage of the words "morphogenesis" and "morphostasis" in the sense of deviation-amplifying mutual causal process and deviation-counteracting mutual causal process, respectively, does not contradict their traditional usage in the sense of ontogenetic structure-generation and structure-stabilization. The new usage not only extends the old usage, but gives a functional definition in terms of deviation-generating and deviation-counteracting, and in terms of positive and negative feedback networks.

Positive and Negative Feedback networks

Let us now examine more closely what is meant by positive and negative feedback networks. Let us first emphasize that the presence of influences in both directions between two or more elements does not necessarily imply mutual causation. If the size of influence in one direction is independent of the size of influence in the other direction, or if their apparent correlation is caused by a third element, there is no mutual causation. Only when the size of influence in one direction has an effect upon the size of the influence in the other direction and is in turn affected by it, is there a mutual causation.

For example, Eisen Iron Co. makes iron from iron ore. Dexter Tool Co. manufactures tools made of iron. Dexter buys iron from Eisen, and Eisen buys tools from Dexter. There is some mutual relationship between the two companies. But suppose Dexter buys iron from several companies. When Eisen's output drops, Dexter's purchase of iron from other companies increases. When Eisen's output goes up, Dexter's purchase of iron from other iron companies decreases. The amount of tools Dexter can supply to Eisen does not depend on the amount of iron Dexter buys from Eisen. Furthermore, Dexter has other customers besides Eisen. Whether Eisen buys no tools or 10,000 tools from Dexter does not matter much to the operation of Dexter. In this- case, though there is traffic of merchandise in both directions between Eisen and Dexter, the amounts of traffic in two directions have no mutual causal relationship.

Suppose that, suddenly, some ship industry develops in the vicinity, and both iron and tools are in great demand. Consequently, both Eisen's output and Dexter's output increase simultaneously. But this simultaneous increase was not caused by a mutual causal relationship between Eisen and Dexter, but by a third element which is the ship industry.

On the other hand, if the amount of Dexter's output depends on the amount of Eisen's output and varies with it either in the same or opposite direction, and the amount of Eisen's output depends on the amount of Dexter's output and varies with it either in the same or opposite direction, then there is a mutual causal relationship between Eisen's output and Dexter's output.

Mutual causal relationships may be defined between more than two elements. Let us look at the following diagram. The arrows indicate the direction of influences. + indicates that the changes occur in the same direction, but not necessarily positively. For example, the + between G and B indicates that an increase in the amount of garbage per area causes an increase in the number of bacteria per area. But, at the same time, it indicates that a decrease in the amount of garbage per area causes a decrease in the number of bacteria per area. The – between S and B indicates that an increase in sanitation facilities causes a decrease in the number of bacteria per area. But, at the same time, it indicates that a decrease in sanitation facilities causes an increase in the number of bacteria per area.

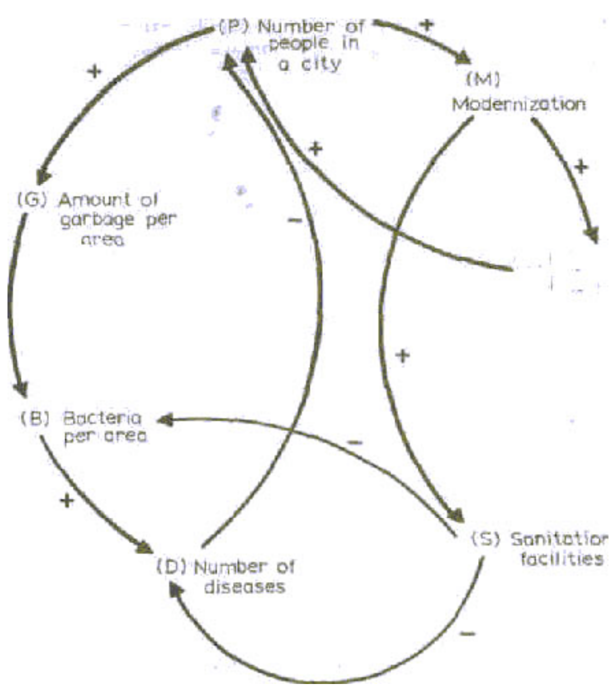

Figure 3

As may be noticed, some of the arrows form loops. For example, there is a loop of arrows from P to M, M to C, and C back to M. A loop indicates mutual causal relationships. In a loop, the influence of an element comes back to itself through other elements. For example, in the loop of P-M-C-P, an increase in the number of people causes an increase in modernization, which in turn increases migration to the city, which in turn increases the number of people in the city. In short, an increase in population causes a further increase in population through modernization and migration. On the other hand, a decrease in population causes a decrease in modernization, which in turn causes a decrease in migration, which in turn decreases population. In short, a decrease in population causes a further decrease in population through decreased modernization and decreased migration.

Whatever the change, either an increase or a decrease, amplifies itself. This is so when we take population as our criterion. But the same is true if we take modernization as a criterion: an increase in modernization causes a further increase in modernization through migration and population increase; and a decrease in modernization causes a further decrease in modernization through decreased migration and decreased population. The same holds true if we take the migration as the criterion.

In a loop, therefore, each element has an influence on all other elements either directly or indirectly, and each element influences itself through other elements. There is no hierarchical causal priority in any of the elements. It is in this sense that we understand the mutual causal relationships.

Let us take next the loop P-G-B-D-P. This loop contains a negative influence from D to P. In this loop, an increase in population causes an increase in the amount of garbage per area, which in turn causes an increase in the number of bacteria per area, which in turn causes an increase in the number of diseases, which in turn causes a decrease in population. In short, an increase in population causes a decrease in population through garbage, bacteria and diseases. On the other hand, a decrease in population causes a decrease in garbage, bacteria and diseases, and thus causes an increase in population. In this loop, therefore, any change in population is counteracted by itself. Likewise, any change in the amount of garbage per area is counteracted by itself. The mutual causal relationship in this loop is a deviation-counteracting mutual causal relationship. Such a deviation-counteracting process may result in stabilization or oscillation, depending on the time lag involved in the counteraction and the size of counteraction.

Let us further consider the loop P-M-S-D-P. This loop has two negative influences. An increase in population causes an increase in modernization, which in turn causes an increase in sanitation facilities, which in turn causes a decrease in the number of bacteria per area, which in turn causes a decrease in the number of diseases, which in turn causes an increase in population. This is therefore a deviation-amplifying loop. Two negative influences cancel each other and become positive in the total effect.

In general, a loop with an even number of negative influences is deviation-amplifying, and a loop with an odd number of negative influences is deviation-counteracting. Besides the three loops mentioned above, there is another loop P-M-S-B-D-P, which is deviation-amplifying because of the two negative influences contained in it. The system shown in the diagram contains several loops, some of which are deviation-amplifying and some of which are deviation-counteracting. Whether the system as a whole is deviation-amplifying or deviation-counteracting depends on the strength of each loop. A society or an organism contains many deviation-amplifying loops as well as deviation-counteracting loops, and an understanding of a society or an organism cannot be attained without studying both types of loops and the relationships between them. It is in this sense that our second cybernetics is essential to our further study of societies and organisms.

Not only are there deviation-amplifying loops and deviation-counteracting loops in the society and in the organism, but also under certain conditions a deviation-amplifying loop may become deviation-counteracting, and a deviation-counteracting loop may become deviation-amplifying. An example is the principle of diminished return. An increase in investment causes an increase in capital, and an increase in capital makes more investments possible. Before the profit reaches a certain level the effect of income tax is negligible. But, as the profit becomes greater, the influence of income tax becomes greater and eventually stabilizes the size of the capital.

A culture may follow a similar process. Sometimes one may wonder how a culture, which is quite different from its neighbouring cultures, has ever developed on a geographical background which does not seem to be in any degree different from the geographical conditions of its neighbours. Most likely such a culture had developed first by a deviation-amplifying mutual causal process, and has later attained its own equilibrium when the deviation-counteracting components have become predominant, and is currently maintaining its uniqueness in spite of the similarity of its geographical conditions to those of its neighbours [g].

The second cybernetics is useful also in such fields as psychiatry. In many cases, interpersonal conflicts are generated by mutual deviation-amplification between persons and are later maintained at the deviated (but not necessarily deviant) pattern. Mutual amplification may occur within a person, for example, between loss of self-confidence and poor performance in a neurotic person. The established pattern, no matter "how" deviated, is not necessarily "pathological" if it enables a constructive life. But, if the pattern results in a reduction of conflict-free, constructive energy, then a therapy becomes necessary. The therapy aims at breaking the stabilized unsatisfactory pattern and at initiating a new deviation-amplification in the direction of developing a satisfactory pattern.

The second cybernetics will be useful also in the technological fields such as in the design of a machine which invents. A trial-and-error machine is inefficient because it has no directivity. But it has a great flexibility. A deviation-amplifying inventing machine, on the other hand, works in the direction specified by the initial kick, and, for this reason, is efficient. It is not built for any specific direction, because the direction is a variable which is specified by the initial kick. In this sense it is flexible. But in another sense it is not flexible because once the direction is set, it will persist in that direction. A machine that incorporates randomness, deviation-amplification and deviation-counteracting may be both efficient and flexible. It can search for all possibilities. It can try to amplify certain ideas in various directions. It can stay at a relevant idea (which may change from time to time during the invention) and bring back to it other ideas for synthesis. In fact, openness to strange hunches, ability to elaborate on them and to bring them back to a synthesis are what is found in the process of human creative minds [7].

The elaboration and refinement of the second cybernetics belong to the future, and we may expect many fruitful results from them.

- ***Magoroh Maruyama*** **(June 1963)**

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