THE SYSTEMS VIEW OF LIFE

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Part 1 - Machines, Organisms and the Self-Organization of Systems

The first obvious difference between machines and organisms is the fact that machines are constructed, whereas organisms grow. This fundamental difference means that the understanding organisms must be process-oriented. For example, it is impossible to convey an accurate picture of a cell by means of static drawings or by describing the cell in static forms. Cells, like all living systems, have to be understood in terms of processes reflecting the system's dynamic organization. Whereas the activities of a machine are determined by its structure, the relation is reversed in organisms - organic structure is determined by processes.

Machines are constructed by assembling a well-defined number of parts in a precise and pre-established way. Organisms, on the other hand, show a high degree of internal flexibility and plasticity. The shape of their components may vary within certain limits and no two organisms will have identical parts. Although the organism as a whole exhibits well-defined regularities and behavior patterns, the relationships between its parts are not rigidly determined. As Weiss has shown with many impressive examples, the behavior of the individual parts can, in fact, be so unique and irregular that it bears no sign of relevance to the order or the whole system. This order is achieved by coordinating activities that do not rigidly constrain the parts but leave room for variation and flexibility, and it is this flexibility that enables living organisms to adapt to new circumstances.

Machines function according to linear chains of cause and effect, and when they break down a single cause for the breakdown can usually be identified. In contrast, the functioning of organisms is guided by cyclical patterns of information flow known as feedback loops. For example, component A may affect component B; B may affect C; and C may "feed back" the influence to A and thus close the loop. When such a system breaks down, the breakdown is usually caused by multiple factors that may amplify each other through interdependent feedback loops. These factors may amplify each other through interdependent feedback loops the factors that were the initial cause of the breakdown is often irrelevant.

This nonlinear interconnectedness of living organisms indicates that the conventional attempts of biomedical science to associate diseases with single causes are highly problematic. Moreover, it shows the fallacy of "genetic determinism," the belief that various physical or mental features of an individual organism are "controlled" or "dictated" by its genetic makeup. The systems view makes it clear that genes do not uniquely determine the functioning of an organism as cogs and wheels determine the working of a clock. Rather, genes are integral parts of an ordered whole and thus conform to its systemic organization.

The internal plasticity and flexibility of living systems, whose functioning is controlled by dynamic relations rather then get rigid of mechanical structures, gives rise to a number of characteristic properties that can be seen as different aspects of the same dynamic principle-the principle of self-organization. A living organism is a self- organizing system, which means that its order in structure and function is not imposed by the environment but is established by the system itself. Self-organizing systems exhibit a certain degree of autonomy; for example, they tend to establish their size according to internal principles of organization, independent of environmental influences. This does not mean that living systems are isolated from their environment; on the contrary, they interact with it continually, but this interaction does not determine their organization. The two principal dynamic phenomena of self-organization are self- renewal-the ability of living systems continuously to renew and recycle their components while maintaining the integrity of

their overall structure-and self- transcendence-the ability to reach out creatively beyond physical and mental boundaries in the processes of learning, development, and evolution.
The relative autonomy of self-organizing systems sheds new light on the age-old philosophical question of free will. From the systems point of view, both determinism and freedom are relative concepts. To the extent that it depends on it through continuous interaction its activity will be shaped by environmental influences. The relative autonomy of organisms usually increases with their complexity, and it reaches its culmination in human beings.

This relative concept of free will seems to be consistent with the views of mystical traditions that exhort their followers to transcend the notion of an isolated self and become aware that we are inseparable parts of the cosmos in which we are embedded. The goal of these traditions is to shed all ego sensations completely and, in mystical experience, merge with the totality of the cosmos. Once such a state is reached, the question of free will seems to lose its meaning. If I am the universe, there can be no "outside" influences and all my actions will be spontaneous and free. From the point of view of mystics, therefore, the notion of free will is relative, limited and - as they would say - illusory, like all other concepts we use in our rational descriptions of reality.
To maintain their self-organization living organism have to remain in a special state that is not easy to describe in conventional terms. The comparison with machines will again be helpful. Clockwork, for example, is a relatively isolated system that needs energy to run but does not necessarily need to interact with its environment to keep functioning. Like all isolated systems it will proceed according to the second law of thermodynamics, from order to disorder, until it has reached a state of equilibrium in which all processes - motion, heat exchanged, and so on - have come to a standstill. Living organisms function quite differently. They are open systems, which mean that they have to maintain a continuous exchange of energy and matter with their environment to stay alive. This exchange involves taking in ordered structures, such as food, breaking them down and using some of their components to maintain or even increase the order of the organism. This process is known as metabolism. It allows the system to remain in a state or non-equilibrium, in which it is always "at work." A high degree of non- equilibrium is absolutely necessary for self-organization; living organisms are open systems that continually operate far from equilibrium.

At the same time these self-organizing systems have a high degree of stability, and this is where we run into difficulties with conventional language. The dictionary meanings of the word "stable" include "fixed", "not fluctuating", "unvarying," and "steady," all of which are inaccurate to describe organisms. The stability of self- organizing systems is utterly dynamic and must not be confused with equilibrium. It consists in maintaining the overall structure in spite of ongoing changes and replacements of its components. A cell, for example, according to Weiss, "retains its identity far more conservatively and remains far more similar to itself from moment to moment, as well as to any other cell of the same strain, than one could ever predict from knowing only about its inventory of molecules, macromolecules, and organelles which is subject to incessant change, reshuffling, and smiling of its population." The same is true for human organisms. We replace all our cells, except for those in the brain, within a few years, yet we have no trouble recognizing our friends even after long periods of separation. Such is the dynamic stability of self-organizing systems.

The phenomenon of self-organization is not limited to living matter but occurs also in certain chemical systems, which have been studied extensively by the physical chemist and Nobel laureate Ilya Prigogine, who developed a detailed dynamic theory to describe their behavior. Prigogine has called these systems "dissipative structures" to express the fact that they maintain and develop structure by breaking down other structures in the process of metabolism, thus creating entropy - disorder - which is subsequently dissipated in the form of degraded waste products. Dissipative chemical structures display the dynamics of self-organization in its simplest form, exhibiting most of the phenomena characteristic of life - self-renewal, adaptation, evolution, and even primitive forms of "mental" processes. The only reason why they are not considered alive is that they do not reproduce or form cells. These intriguing systems thus represent a link between animate and inanimate matter. Whether they are called living organisms or not is, ultimately, a matter of convention.

Self-renewal is an essential aspect of self-organizing systems. Whereas a machine is constructed to produce a specific product or to carry out a specific task intended by its designer, an organism is primarily engaged in renewing itself. Cells are breaking down and building up structures, tissues and organs are replacing their cells in continual cycles. Thus the pancreas replaces most if its cells every twenty-four hours, the stomach lining every three days; our white blood cells are renewed in ten days and 98 percent of the protein in the brain is turned over in less than one month. All these processes are regulated in such a way that the overall pattern of the organism is preserved, and this remarkable ability of self-maintenance persists under a variety of circumstances, including changing environmental conditions and many kinds of interference. A machine will fail if its parts do not work in the rigorously predetermined manner, but an organism will maintain its functioning in a changing environment, keeping itself in running condition and repairing itself through healing and regeneration. The power of regenerating organic structures diminishes with increasing complexity of the organism. Flatworms, polyps, and starfish can regenerate almost their entire body from a small fraction; lizards, salamanders, crabs, lobsters, and many insects are able to renew a lost organ or limb; and higher animals, including humans, can renew tissues and thus heal their injuries.

Even though they are capable of maintaining and repairing themselves, no complex organisms can function indefinitely. They gradually deteriorate in the process of ageing and, eventually, succumb to exhaustion even when relatively undamaged. To survive, these species have developed a form of "super-repair." Instead of replacing the damaged or worn-out parts they replace the whole organism. This, or course, is the phenomenon of reproduction, which is characteristic of all life.

Fluctuations play a central role in the dynamics of self-maintenance. Any living system can be described in terms of interdependent variables, each of which can vary over a wide range between an upper and a lower limit. All variables oscillate between these limits, so that the system is in a state of continual fluctuation, even when there is no disturbance. Such a state is known as homeostasis. It is a state of dynamic, transactional balance in which there is great flexibility; in other words, the system has a large number of options for interacting with its environment. When there is some disturbance, the organism tends to return to its original state, and it does so by adapting in various ways to environmental changes. Feedback mechanisms come into play and tend to reduce any deviation from the balanced state. Because of these regulatory mechanisms, also known as negative feedback, the body temperature, blood pressure, and many other important conditions of higher organisms remain relatively constant even when the environment changes considerably. However, negative feedback is only one aspect of self-organization through fluctuations. The other aspect is positive feedback, which consists in amplifying certain deviations rather than damping them. We shall see that this phenomenon plays a crucial role in the processes of development, learning, and evolution.

The ability to adapt to a changing environment is an essential characteristic of living organisms and of social systems. Higher organisms are usually capable of three kinds of adaptation, which come into play successively during prolonged environmental changes. A person who goes from sea level to a high altitude may begin to pant and her heart may race. These changes are swiftly reversible; descending the same day will make them disappear immediately. Adaptive changes of this kind are part of the phenomenon of stress, which consists of pushing one or several variables of the organism to their extreme values. As a consequence the system as a whole will be rigid with respect to these variables and thus unable to adapt to further stress, which consists of pushing one or several variables of the organism to their extreme values. As a consequence the system as a whole will be rigid with respect to these variables and thus unable to adapt to further stress. For example, the person at high altitude will not be able to run up a staircase. Furthermore, since all variables in the system are interlinked, rigidity in one will also affect the others, and the loss of flexibility will spread through the system.

If the environmental change persists, the organism will go through a further process of adaptation. Complex physiological changes take place among the more stable components of the system to absorb the environmental impact and restore flexibility. Thus the person at high altitude will be able to breathe normally again after a certain period of time and to use her panting mechanism for adjusting to other emergencies that might otherwise be lethal. This form of adaptation is known as somatic change. Habit-forming, and addiction are special cases of this process.

Through somatic change the organism recaptures some of its flexibility by substituting a deeper and more enduring change for a more superficial and reversible one. Such an adaptation will be achieved comparatively slowly and will be slower to reverse. Yet somatic changes are still reversible. This means that various circuits of the biological system must be available for such a reversal for the entire time during which the change is maintained. Such a prolonged loading of circuits will limit the organism's freedom to control other functions and thus seduce its flexibility. Although the system is more flexible after the somatic change than it was before, when it was under stress, it is still less flexible than it was before the original stress occurred. Somatic change, then, internalizes stress, and the accumulation of such internalized stress may, eventually, lead to illness.

The third kind of adaptation available to living organisms is the adaptation of the species in the process of evolution. The changes brought about by mutation, also known as genotypic changes, are totally different from somatic changes. Through genotypic change a species adapts to the environment by shifting the range of some of its variables, and notably of those which result in the most economical changes. For example, when the climate gets colder an animal will grow thicker fur rather than just running around more to keep warm. Genotypic change provides more flexibility than somatic change. Since every cell contains a copy of the new genetic information, it will behave in the changed manner without needing any messages from surrounding tissues and organs. Thus more circuits of the system will remain open and the overall flexibility is increased. On the other hand, genotypic change is irreversible within the lifetime of an individual.
The three modes of adaptation are characterized by increasing flexibility and decreasing reversibility. The quickly reversible stress reaction will be replaced by somatic change in order to increase flexibility under continuing stress, and evolutionary adaptation will be induced to further increase flexibility when the organism has accumulated so many somatic changes that it becomes too rigid for survival. Thus successive modes of adaptation restore as much as possible the flexibility that the organism has lost under environmental stress. The flexibility of an individual organism will depend on how many of its variables are kept fluctuating within their tolerance limits; the more fluctuations, the greater the stability of the organism. For populations of organisms the criterion corresponding to flexibility is variability. Maximum genetic variation within a population provides the maximum number of possibilities for evolutionary adaptation.
The ability of species to adapt to environmental changes through genetic mutations has been studied extensively and very successfully in our century, together with the mechanisms of reproduction and heredity. However, these aspects represent only one side of the phenomenon of evolution. The other side is the creative development of new structures and functions without any environmental pressure, which is inherent in all living organisms. The Darwinian concepts, therefore, express only one of two complementary views that are both necessary in understanding evolution. Discussion of the view of evolution as an essential manifestation of self-organizing systems will be easier if we first take a closer look at the relation between organisms and their environment.

Part 2 Independent Physical Entities in Physics and Microbiology and Symbiosis

As the notion of an independent physical entity has become problematic in subatomic physics, so has the notion of an independent organism in biology. Living organisms, being open systems, keep themselves alive and functioning through intense transactions with their environment, which itself consists partially of organisms. Thus the whole biosphere - our planetary ecosystem - is a dynamic and highly integrated web of living and nonliving forms. Although this web is multilevel, transactions and interdependencies exist among all its levels.

Most organisms are not only embedded in ecosystems but are complex ecosystems themselves, containing a host of smaller organisms that have considerable autonomy and yet integrate themselves harmoniously into the functioning of the whole. The smallest of these living components show an astonishing uniformity, resembling one another quite closely throughout the living world, as vividly described by Lewis Thomas.

There they are, moving about in my cytoplasm.....They are much less closely related to me than to each other and to the free-living bacteria out under the hill. They feel like strangers, but the thought comes that the same creatures, precisely the same, are out there in the cells of seagulls, and whales, and dune grass, and seaweed, and hermit crabs, and further inland in the leaves of the beech in my backyard, and in the family of skunks beneath the back fence, and even in that fly on the window. Through them, I am connected: I have close relatives, once removed, all over the place.

Although all living organisms exhibit conspicuous individuality and are relatively autonomous in their functioning, the boundaries between organism and environment are often difficult to ascertain. Some organisms can be considered alive only when they are in a certain environment; others belong to larger systems that behave more like an autonomous organism than its individual members; still other collaborate to build large structures which become ecosystems supporting hundreds of species.

In the world of microorganisms, viruses are among the most intriguing creatures, existing on the borderline between living and nonliving matter. They are only partly self-sufficient, alive only in a limited sense. Viruses are unable to function and multiply outside of living cells. They are vastly simpler than any microorganism, the simplest among them consisting of just a nucleic acid, DNA or RNA. In fact, outside of cells viruses show no apparent signs of life. They are simply chemicals, exhibiting highly complex but completely regular molecular structures. In some cases it has even been possible to take viruses apart, purify their components, and then put them back together again without destroying their capacity to function.

Although isolated virus particles are just assemblages of chemicals, they consist of chemical substances of a very special kind - the proteins and nucleic acids that are the essential constituents of living matter. In viruses these substances can be studied in isolation, and it was such studies that led molecular biologists to some of their greatest discoveries in the 1950s and 1960s. Nucleic acids are chainlike macro-molecules that carry information for self-replication and protein synthesis. When a virus enters a living cell it is able to use the cell's biochemical machinery to build new virus particles according to the instructions encoded in its DNA or RNA. A virus, therefore, is not an ordinary parasite which takes nourishment from its host to live and reproduce itself. Being essentially a chemical message, it does not provide its own metabolism, nor can it perform many other functions characteristic of living organisms. Its only function is to take over the cell's replication machinery and use it to replicate new virus particles. This activity takes place at a frantic rate. Within an hour an infected cell can produce thousands of new viruses and in many cases the cell will be destroyed in the process. Since so many virus particles are produced by a single cell, a virus infection of a multi-celled organism can rapidly destroy a great number of cells and thus lead to disease. Although the structure and functioning of viruses is now well known, their basic nature still remains intriguing. Outside living cells a virus particle cannot be called a living organism; inside a cell it forms a living system together with the cell, but one of a very special kind. It is self-organizing, but the purpose of its organization is not the stability and survival of the entire virus-cell system. Its only aim is the production of new viruses that will then go on to form living systems of this peculiar kind in the environments provided by other cells.

The special way in which viruses exploit their environment is an exception in the living world. Most organisms integrate themselves harmoniously into their surroundings, and some of them reshape their environment in such a way that it becomes an ecosystem capable supporting large numbers of animals and plants. The outstanding example of such ecosystem-building organisms are corals, which for a long time were thought to be plants but are more appropriately classified as animals. Coral polyps are tiny multi-cellular organisms that join to form large colonies and, as such, can grow massive skeletons of limestone. Over long periods of geological time many of these colonies have grown into huge coral reefs, which represent by far the largest structures created by living organisms on earth. These massive structures support innumerable bacteria, plants, and animals; crustacean organisms living on top of the coral framework, fishes and invertebrates hiding in its nooks and crannies, and various other creatures that cover virtually all the available space on the reef. To build these densely populated ecosystems the coral polyps function in a highly coordinated way, sharing nervous networks and reproductive capabilities to such an extent that it is often difficult to consider them individual organisms.

Similar patterns of coordination exist in tightly knit animal societies of higher complexity. Extreme examples are the social insects - bees, wasps, ants, termites, and others - that form colonies whose members are interdependent and in such close contact that the whole system resembles a large, multi-creature organism. Bees and ants are unable to survive in isolation, but in great numbers they act almost like the cells of a complex organism with a collective intelligence and capabilities for adaptation far superior to those of its individual members. This phenomenon of animals joining up to form larger organismic systems is not limited to insects but can also be observed in several other species, including, of course, the human species. Close coordination of activities exists not only among individuals of the same species but also among different species, and again the resulting living systems have the characteristics of single organisms. Many types of organisms that were thought to represent well-defined biological species have turned out, upon close examination, to consist of two or more different species in intimate biological association. This phenomenon, known as symbiosis, is so widespread throughout the living world that it has to be considered a central aspect of life. Symbiotic relationships are mutually advantageous to the associated partners, and they involve animals, plants, and microorganisms in almost every imaginable combination. Many of these may have formed their union in the distant past and evolved toward ever more interdependence and exquisite adaptation to one another.

Bacteria frequently live in symbiosis with other organisms in way that makes both their own lives and the lives of their hosts dependent on the symbiotic relationship. Soil bacteria, for example, alter the configurations of organic molecules so that they become usable for the energy needs of plants. To do so the bacteria incorporate themselves so intimately into the roots of the plants that the two are almost indistinguishable. Other bacteria live in symbiotic relationships in the tissues of higher organisms, especially in the intestinal tracts of animals and humans. Some of these intestinal microorganisms are highly beneficial to their hosts, contributing to their nutrition and increasing their resistance to disease.

At an even smaller scale, symbiosis takes place within the cells of higher organisms and is crucial to the organization of cellular activities. Most cells contain a number of organelles, which perform specific functions and until recently were thought to be molecular structures built by the cell. But it now appears that some organelles are organisms in their own right. The mitochondria, for example, which are often called the powerhouses of the cell because they fuel almost all cellular energy systems, contain their own genetic material and can replicate independently of the replication of the cell. They are permanent residents in all higher organisms, passed on from generation to generation and living in inmate symbiosis within each cell. Similarly, the chloroplasts of green plants which contain the chlorophyll and the apparatus for photosynthesis are independent, self-replicating inhabitants in the plant's cells.

The more one studies the living world the more one comes to realize that the tendency to associate, establish links, live inside one another and cooperate is an essential characteristic of living organisms. As Lewis Thomas has observed, "We do not have solitary beings. Every

creature is, in some sense, connected to and dependent on the rest. Larger networks of organisms form ecosystems, together with various inanimate components linked to the animals, plants, and microorganisms through an intricate web of relations involving the exchange of matter and energy in continual cycles. Like individual organisms, ecosystems are self-organizing and self-regulating systems in which particular populations of organisms undergo periodic fluctuations. Because of the nonlinear nature of the pathways and interconnections within an ecosystem, any serious disturbance will not be limited to a single effect but is likely to spread thought the system and may even be amplified by its internal feedback mechanisms.
In a balanced ecosystem animals and plants live together in a combination of competition and mutual dependency. Every species has the potential of undergoing an exponential population growth but these tendencies are kept in check by various controls and interactions. When the system is disturbed, exponential "runaways" will start to appear. Some plants will turn into "weeds" and some animals into "pests," and other species will be exterminated. The balance, or health, of the whole system will be threatened. Explosive growth of this kind is not limited to ecosystems but occurs also in single organisms. Cancers and other tumors are dramatic examples of pathological growth.

Detailed study of ecosystems over the past decades has shown quite clearly that most relationships between living organisms are essentially co-operative ones, characterized by coexistence and interdependence, and symbiotic in various degrees. Although there is competition, it usually takes place within a wider context of cooperation, so that the larger system is kept in balance. Even predator-prey relationships that are destructive for the immediate prey are generally beneficent for both species. This insight is in sharp contrast to the views of the Social Darwinists, who saw life exclusively in terms of competition, struggle, and destruction. Their view of nature has helped create a philosophy that legitimates exploitation and the disastrous impact of our technology on the natural environment. But such a view has no scientific justification, because it fails to perceive the integrative and cooperative principles that are essential aspects of the ways in which living systems organize themselves at all levels.
As Thomas has emphasized, even in cases where there have to be winners and losers the transaction is not necessarily a combat. For example, when two individuals of a certain species of corals find themselves in place where there is room for only one, the smaller of the two will always disintegrate, and it will do so by means of its own autonomous mechanisms: "he is not thrown out, not out gamed, not outgunned; he simply chooses to bow out." Excessive aggression, competition, and destructive behavior are predominant only in the human species and have to be dealt with in terms of cultural values rather than being "explained" pseudo-scientifically as inherently natural phenomena.

Many aspects of the relationships between organisms and their environment can be described very coherently with the help of the systems concept of stratified order, which has been touched upon earlier. The tendency of living systems to form multileveled structures whose levels differ in their complexity is all-pervasive throughout nature and has to be seen as a basic principle of self-organization. At each level of complexity we encounter systems that are integrated, self-organizing wholes consisting of smaller parts and, at the same time, acting as parts of larger wholes. For example, the human organism contains organ systems composed of several organs, each organ being made up of tissues and each tissue made up of cells. The relations between these systems levels can be represented by a "systems tree".

As in a real tree, there are interconnections and interdependencies between all systems levels; each level interacts and communicates with its total environment. The trunk of the systems tree indicates that the individual organism is connected to larger social and ecological systems, which in turn have the same tree structure.

At each level the system under consideration may constitute an individual organism. A cell may be part of a tissue, also be a microorganism which is part of an ecosystem, and very often it is impossible to draw a clear-cut distinction between these descriptions. Every sub-system is a relatively autonomous organism while also being a component of a larger organism; it is a

"Holon," in Arthur Koestler's term, manifesting both the independent properties of wholes and the dependent properties of parts. Thus the pervasiveness or order in the universe takes on a new meaning; order at one systems level is the consequence of self-organization at a larger level. From an evolutionary point of view it is easy to understand why stratified, or multileveled, systems are so widespread in nature. They evolve much more rapidly and have much better chances of survival than non-stratified systems, because in cases of severe disturbances they can decompose into their various subsystems without being completely destroyed. Non-stratified systems, on the other hand, would totally disintegrate and would have to start evolving again from scratch. Since living systems encounter many disturbances during their long history of evolution, nature has sensibly favored those which exhibit stratified order. As a matter of fact, there seem to be no records of survival of any others. The multileveled structure of living organisms, like any other biological structure, is a visible manifestation of the underlying processes of self-organization. At each level there is a dynamic balance between self-assertive and integrative tendencies, and all act as interfaces and relay stations between systems levels. Systems theorists sometimes call this pattern of organization hierarchical, but that word may be rather misleading for the stratified order observed in nature. The word "hierarchy" referred originally to the government of the Church. Like all human hierarchies, this ruling body was organized into a number of ranks according to levels of power, each rank being subordinate to one at the level above it. In the past the stratified order of nature has often been misinterpreted to justify authoritarian social and political structures.

To avoid confusion we may reserve the term "hierarchy" for those fairly rigid systems of domination and control in which orders are transmitted from the top down. The traditional symbol for these structures has been the pyramid. By contrast, most living systems exhibit multileveled patterns of organization characterized by many intricate and nonlinear pathways along which signals of information and transaction propagate between all levels, ascending as well as descending. That is why I have turned the pyramid around and transformed it into a tree, a more appropriate symbol for the ecological nature of stratification in living systems. As a real tree takes its nourishment through both its roots and its leaves, so the power in a systems tree flows in both directions, with neither end dominating the other and all levels interacting in interdependent harmony to support the functioning of the whole.

The important aspect of the stratified order in nature is not the transfer of control but rather the organization of complexity. The various systems levels are stable levels of differing complexities, and this makes it possible to use different descriptions for each level. However, as Weiss has point out, any "level" under consideration is really the level of the observer's attention; The new insight of subatomic physics also seems to hold for the study of living matter; the observed patterns of matter are reflections of patterns of mind.

The concept of stratified order also provides the proper perspective on the phenomenon of death. We have seen that self-renewal - the breaking down and building up of structures in continual cycles - is an essential aspect of living systems. But the structures that are continually being replaced are themselves living organisms. From their point of view the self-renewal of the larger system is their own cycle of birth and death. Birth and death, therefore, now appear as a central aspect of self- organization, the very essence of life. Indeed, all living things around us renew themselves all the time. "If you stand in a meadow," Thomas writes, "at the edge of a hillside and look around carefully, almost everything you can catch sight of is in the process of dying." But for every organism that dies another one is born. Death, then, is not the opposite of life but an essential aspect of it.

Although death is a central aspect of life, not all organisms die. Simple one- celled organism, such as bacteria and amoebae, reproduce by cell division and in doing so simply live on in their progeny. The bacteria around today are essentially the same that populated the earth billions of years ago, but they have branched into innumerable organisms. This kind of life without death was the only kind of life for the first two- thirds of evolutionary history. During that immense time span there is no ageing and no death, but there was not much variety either - no higher life forms and no self- awareness. Then, about a billion years ago, the evolution of life went through an extraordinary acceleration and produced a great variety of forms. "Without sex there could be no variety, without death no individuality." From then on higher organisms would age and die and individuals would pair their chromosomes in sexual reproduction, thus generating enormous genetic variety which made evolution proceed several thousand times faster.

Stratified systems evolved along with these higher life forms, systems that renew themselves at all levels and thus maintain ongoing cycles of birth and death for all organisms throughout the tree structure. Since we too are born and are bound to die, does this mean that we are parts of larger systems that continually renew themselves? Indeed, this seems to be the case. Like all other living creatures we belong to ecosystems and we also form our own social systems. Finally, at an even larger level, there is the biosphere, the ecosystem of the entire planet, upon which our survival is utterly dependent. We do not usually consider these larger systems as individual organisms like plants, animals, or people, but a new scientific hypothesis does just that at the largest accessible level. Detailed studies of the ways in which the biosphere seems to regulate the chemical composition of the air, the temperature on the surface of the earth, and many other aspects of the planetary environment have led the chemist James Lovelock and the microbiologist Lynn Margulies to suggest that these phenomena can be understood only if the planet as a whole is regarded as a single living organism. Recognizing that their hypothesis represents a renaissance of a powerful ancient myth, the two scientists have called it the Gaia hypothesis, after the Greek goddess of the earth.

Awareness of the earth as alive, which played an important role in our cultural past, was dramatically revived when astronauts were able, for the first time in human history, to look at our planet from outer space. Their perception of the planet in all its shining beauty - a blue and white globe floating in the deep darkness of space - moved them deeply and, as many of them have since declared, was a profound spiritual experience that forever changed their relationship to the earth. The magnificent photographs of the "Whole Earth" which these astronauts brought back became a powerful new symbol for the ecology movement and may well be the most significant result of the whole space program.

What the astronauts, and countless men and women on earth before them, realized intuitively is now being confirmed by scientific investigations, as described in great detail in Lovelock's book. The planet is not only teeming with life but seems to be a living being in its own right. All the living matter on earth, together with the atmosphere, oceans, and soil, forms a complex system that has all the characteristic patterns of self-organization. It persists in a remarkable state of chemical and thermodynamic non-equilibrium and is able, through a huge variety of processes, to regulate the planetary environment so that optimal conditions for the evolution of life are maintained.
For example, the climate on earth has never been totally unfavorable for life since living forms first appeared, about four billion years ago. During that long period of time the radiation from the sun increased by at least percent. If the earth were simply a solid inanimate object, its surface temperature would follow the sun's energy output, which means that the whole earth would have been a frozen sphere for more than a billion years. We know from geological records that such adverse conditions never existed. The planet maintained a fairly constant surface temperature throughout the evolution of life, much as a human organism maintains a constant body temperature in spite of varying environmental conditions.

Similar patterns of self-regulation can be observed for other environmental properties, such as the chemical composition of the atmosphere, the salt content of the oceans, and the distribution of trace elements among plants and animals. All these are regulated by intricate cooperative networks that exhibit the properties of self-organizing systems. The earth, then, is a living system; it functions not just like an organism but actually seems to be an organism - Gaia, a living planetary being. Her properties and activities cannot be predicted from the sum of hr parts; every one of her tissues is linked to every other tissue and all of them are mutually interdependent; her many pathways of communication are highly complex and nonlinear; her form has evolved over billions of years and continues to evolve. These observations were made within a scientific context, but they go far beyond science. Like many other aspects of the new paradigm, they reflect a profound ecological awareness that is ultimately spiritual.

Part 3 - Evolution, Nature and the Emergence of Ecological & Environmental Knowledge

The systems view of living organisms is difficult to grasp from the perspective of classical science because it requires significant modifications of many classical concepts and ideas. The situation is not unlike the one encountered by physicists during the first three decades of this century, when they were forced to adopt drastic revisions of their basic concepts of reality to understand atomic phenomena. This parallel is further enforced by the fact that the notion of complementarily, which was so crucial in the development of atomic physics, also seems to play an important role in the new systems biology.

Besides the complementarily of self-assertive and integrative tendencies, which can be observed at all levels of nature's stratified systems, living organisms display another pair of complementary dynamic phenomena that are essential aspects of self- organization. One of them, which may be described loosely as self-maintenance, includes the processes of self-renewal, healing, homeostasis, and adaptation. The other, which seems to represent an opposing but complementary tendency, is that of self- transformation and self-transcendence, a phenomenon that expresses itself in the processes of learning, development, and evolution. Living organisms have an inherent potential for reaching out beyond themselves to create new structures and new patterns of behavior. This creative reaching our into novelty, which in time leads to an ordered unfolding of complexity, seems to be fundamental property of life, a basic characteristic of the universe which is not - at least for the time being -amenable to further explanation. We can, however, explore the dynamics and mechanisms of self- transcendence in the evolution of individuals, species, ecosystems, societies, and cultures.

The two complementary tendencies of self-organizing systems are in continual dynamic interplay, and both of them contribute to the phenomenon of evolutionary adaptation. To understand this phenomenon, therefore, two complementary descriptions will be needed. One will have to include many aspects of neo-Darwinian theory, such as mutation, the structure of DNA, and the mechanisms of reproduction and heredity. The other description must not deal with the genetic mechanisms but with the underlying dynamics of evolution, whose central characteristic is not adaptation but creativity. If adaptation alone were the core of evolution, it would be hard to explain why living forms ever evolved beyond the blue-green algae, which are perfectly adapted to their environment, unsurpassed in their reproductive capacities, and have proved their fitness for survival over billions of years.

The creative unfolding of life toward forms of ever increasing complexity remained an unsolved mystery for more than a century after Darwin, but recent study has outlines the contours of a theory of evolution that promises to shed light on this striking characteristics of living organisms. This is a systems theory that focuses on the dynamics of self-transcendence and is based on the work of a number of scientists from various disciplines. Among the main contributors are the chemist Ilya Prigogine and Manfred Eigen, the biologists Conrad Waddington and Paul Weiss, the anthropologist Gregory Bateson, and the systems theorists Erich Jantsch and Ervin Laszlo. A comprehensive synthesis of the theory has recently been published by Erich Jantsch, who regards evolution as an essential aspect of the dynamics of self-organization. This view makes it possible to begin to understand biological, social, cultural and cosmic evolution in terms of the same pattern of systems dynamics, even though the different kinds of evolution involve very different mechanisms. A basic description, which is still far from being understood, is manifest throughout the theory, examples being the interplay between adaptation and creation, the simultaneous action of chance and necessity, and the subtle interaction between macro- and micro-evolution.

The basic dynamics of evolution, according to the new systems view, begins with a system in homeostasis - a state of dynamic balance characterized by multiple, interdependent fluctuations. When the system is being disturbed it has the tendency to maintain its stability by means of negative feedback mechanisms, which tend to reduce the deviation from the balanced state. However, this is not the only possibility. Deviations may also be reinforced internally through positive feedback, either in response to environmental changes or spontaneously without any external influence. The stability of a living system is continually tested by its fluctuations, and at certain moments one or several of them may become so strong that they drive the system over an instability into an entirely new structure, which we again be fluctuating and relatively stable. The stability of living systems is never absolute. It will persist as long as the fluctuations remain below a critical size, but any system is always ready to transform itself, always ready to evolve. This basic model of evolution, worked out for chemical dissipative structures by Prigogine and his collaborators, has since been applied successfully to describe the evolution of various biological, social, and ecological systems.

There are a number of fundamental differences between the new systems theory of evolution and the classical neo-Darwinian theory. The classical theory sees evolution as moving toward an equilibrium state, with organisms adapting themselves ever more perfectly to their environment. According to the systems view, evolution operates far from equilibrium and unfolds through interplay of adaptation and creation. Moreover, the systems theory takes into account that the environment is itself, a living system capable of adaptation and evolution. Thus the focus shifts from the evolution of an organism to the co-evolution of organism plus environment. The consideration of such mutual adaptation and co-evolution was neglected in the classical view, which has tended to concentrate on linear, sequential processes and to ignore transaction phenomena that are mutually conditioning and going on simultaneously.

Jacques Monad saw evolution as a strict sequence of chance and necessity, the chance of random mutations and the necessity of survival. Chance and necessity are also aspects of the new theory, but their roles are quite different. The internal reinforcement of fluctuations and the way the system reaches a critical point may occur at random and are unpredictable, but once such a critical point has been reached the system is forced to evolve into a new structure. Thus chance and necessity come into play simultaneously and act as complementary principles. Moreover, the unpredictability of the whole process is not limited to the origin of the instability. When a system becomes unstable, there are always at least two new possible structures into which it can evolve. The further the system has moved from equilibrium, the more options will be available. Which of these options is chosen is impossible to predict; there is true freedom of choice. As the system approaches the critical point, it "decided" itself which way to go, and this decision will determine its evolution. The totality of possible evolutionary pathways must be imagined as a multi-forked graph with free decisions at each branching point.

The picture shows that the evolution is basically open and indeterminate. There is no goal in it, or purpose, and yet there is a recognizable pattern of development. The details of this pattern are unpredictable because of the autonomy living systems possess in their evolution as in other aspects of their organization. In the systems view the process of evolution is not dominated by "blind chance" but represents an unfolding of order and complexity that can be seen as a kind of learning process, involving autonomy and freedom of choice.

Since the days of Darwin, scientific and religious views about evolution have often been in opposition, the latter assuming that there was some general blueprint designed by a divine creator, the former reducing evolution to a cosmic game of dice. The new systems theory accepts neither of these views. Although it does not deny spirituality and can even be used to formulate the concept of a deity, as we shall see below, it does not allow for a pre-established evolutionary plan. Evolution is an ongoing and open adventure that continually creates its own purpose in a process whose detailed outcome is inherently unpredictable. Nevertheless, the general pattern of evolution can be recognized and is quite comprehensible. Its characteristics include the progressive increase of complexity, coordination, and interdependence; the integration of individuals into multileveled systems; and the continual refinement of certain functions and patterns of behavior. As Ervin Laszlo sums it up, *"There is a progression from multiplicity and chaos to oneness and order."*

In classical science nature was seen as a mechanical system composed of basic building blocks. In accordance with this view, Darwin proposed a theory of evolution in which the unit of survival was the species, the subspecies, or some other building block of the biological world. But a century later it has become quite clear that the unit of survival is not any of these entities. What survives is the organism-in-its-environment. An organism that thinks only in themes of its own survival will invariably destroy its environment and, as we are learning from bitter experience, will thus destroy itself. From the systems point of view the unit of survival is not at entity at all, but rather a pattern of organization adopted by an organism in its interactions with its environment; or, as neurologist Robert Livingston has expressed it, the evolutionary selection process acts on the basis of behavior.

In the history of life on earth, the co-evolution of, microcosm and macrocosm is of particular importance. Conventional accounts of the origin of life usually describe the build-up of higher life forms in microevolution and neglect the macro evolutionary aspects. But these two are complementary aspects of the same evolutionary process, as Jantsch has emphasized. From one perspective microscopic life creates the macroscopic conditions for its further evolution; from the other perspective the macroscopic biosphere creates its own microscopic life. The unfolding of complexity arises not from adaptation of organisms to a given environment but rather from the co-evolution of organism and environment at all systems levels.

When the earliest life forms appeared on earth around four billion years ago-half a billion years after the formation of the planet-they were single-celled organisms without a cell nucleus that looked rather like some of today's bacteria. These so-called prokaryotes lived without oxygen, since there was little or no free oxygen in the atmosphere. But almost as soon as the microorganisms originated they began to modify their environment and create the macroscopic conditions for the further evolution of life. For the next two billion years some prokaryotes produced oxygen through photosynthesis, until it reached its present levels of concentration in the earth's atmosphere. Thus the stage was set for the emergence of more complex, oxygen-breathing cells that would be capable of forming cell tissues and multi-cellular organisms.

The next important evolutionary step was the emergence of eukaryotes; single-celled organisms with a nucleus contained the organism's genetic material in its chromosomes. It was these cells that later on formed multi-cellular organisms. According to Lynn Margulies, co-author of the Gaia hypothesis, eukaryotic cells originated in a symbiosis between several prokaryotes that continued to live on as organelles within the new type of cell. We have mentioned the two kinds of organelles - mitochondria and chloroplasts-that regulate the complementary respiration requirements of animals and plants. These are nothing but the former prokaryotes, which still continue to manage the energy household of the planetary Gaia system, as they have done for the past four billion years.

In the further evolution of life, two steps enormously accelerated the evolutionary process and produced an abundance of new forms. The first was the development of sexual reproduction, which introduced extraordinary genetic variety. The second step was the emergence of consciousness, which made it possible to replace the genetic mechanisms of evolution with more efficient social mechanisms, based upon conceptual thought and symbolic language.

To extend our systems view of life to a description of social and cultural evolution, we will deal first with the phenomena of mind and consciousness. Gregory Bateson proposed to define mind as a systems phenomenon characteristic of living organisms, societies, and ecosystems, and he listed a set of criteria which systems have to satisfy for mind to occur. Any system that satisfies those criteria will be able to process information and develop the phenomena we associate with mind thinking, learning, memory, for example. In Bateson's view, mind is a necessary and inevitable consequence of a certain complexity which begins long before organisms develop a brain and a higher nervous system.

Bateson's criteria for mind turn out to be closely related to those characteristics of self-organizing systems which I have listed above as the critical differences between machines and living organisms. Indeed, mind is an essential property of living systems. As Bateson said, "Mind is the essence of being alive." From the systems point of view, life is not a substance or a force, and mind is not an entity interacting with matter. Both life and mind are manifestations of the same set of systemic properties, a set of processes that represent the dynamics of self-organization. This new concept will be of tremendous value in our attempts to overcome the Cartesian division. The description of mind as a pattern of organization, or a set of dynamic relationships, is related to the description of matter in modern physics. Mind and matter no longer appear to belong to two fundamentally separate categories, as Descartes believed, but can be seen to represent merely different aspects of the same universal process.

Bateson's concept of mind will be useful throughout our discussion, but to remain closer to conventional language I shall reserve the term "mind" for organisms of high complexity and will use "mentation," a term meaning mental activity, to describe the dynamics of self-organization at lower levels. This terminology was suggested some years ago by the biologist George Coghill, who developed a beautiful systemic view of living organisms and of mind well before the advent of systems theory. Coghill distinguished three essential and closely interrelated patterns of organization in living organisms: structure, function, and mentation. He saw structure as organization in space, function as organization in time, and mentation as a kind of organization which is intimately interwoven with structure and function at low levels of complexity but goes beyond space and time at higher levels. From the modern systems perspective, we can say that mentation, being the dynamics of self-organization represents the organization of all functions and is thus a meta-function. At lower levels it will often look like behavior, which can be defined as the totality of all functions, and thus the behaviorist approach is often successful at these levels. But at higher levels of complexity mentation can no longer be limited to behavior, as it takes on the distinctive non-spatial and non-temporal quality that we associate with mind.

In the systems concept of kind, mentation is characteristic not only of individual organisms but also of social and ecological systems. As Bateson has emphasized, mind is immanent not only in the body but also in the pathways and messages outside the body. There are larger manifestations of mind of which our individual minds are only sub-systems. This recognition has very radical implications for our interactions with the natural environment. If we separate mental phenomena from the larger systems in which they are immanent and confine them to human individuals, we will see the environment as mindless and will tend to exploit it. Our attitudes will be very different when we realize that the environment is not only alive but also mindful, like ourselves.

The fact that the living world is organized in multileveled structure means that there are also levels of mind. In the organism, for example there is various levels of "metabolic" mentation involving cells, tissues, and organs, and then there is the "neural" mentation of the brain, which itself consists of multiple levels corresponding to different stages of human evolution. The totality of these mentations constitutes what we would call the human mind. Such a notion of mind as a multileveled phenomenon, of which we re only partly aware in ordinary states of consciousness, is widespread in many non-Western cultures and has recently been studied extensively by some Western psychologists.

In the stratified order of nature, individual human minds are embedded in the larger minds of social and ecological systems, and these are integrated into the planetary mental system - the mind of Gaia-which in turn must participate in some kind of universal or cosmic mind. The conceptual framework of the new systems approach is in no way restricted by associating this cosmic mind with the traditional idea of God. In the words of Jantsch, "God is not the creator, but the mind of the universe." In this view the deity is, of course, neither male or female, nor manifest in any personal form, but represents nothing less than the self-organizing dynamics of the entire cosmos.

The organ of neural mentation - the brain and its nervous system - is a highly complex, multi-leveled, and multidimensional living system that has remained deeply mysterious in may of its aspects in spite of several decades of intensive research in neuroscience. The human brain is a living system par excellence. After the first year of growth no new neurons are produced, yet plastic changes will go on for the rest of its life. As the environment changes, the brain models itself in response to these changes, and any time it is injured the system makes very rapid adjustments. You can never wear it out; on the contrary, the more you use it the more powerful it becomes.

The major function of neurons is to communicate with one another by receiving and transmitting electrical and chemical impulses. To do so, each neuron has developed numerous fine filaments that branch out to make connection with other cells, thus establishing a vast and intricate network of communication which interweaves tightly with the muscular and skeletal systems. Most neurons are engaged in continual spontaneous activity, sending out a few pulses per second and modulating the patterns of their activity in various ways to transmit information. The entire brain is always active and alive, with billions of nervous impulses flashing through its pathways every second.

The nervous systems of higher animals and humans are so complex and display such a rich variety of phenomena that any attempt to understand their functioning in purely reductionistic terms seems quite hopeless. Indeed, neuroscientists have been able to map out the structure of the brain in some detail and have clarified many of its electrochemical processes, but they have remained almost completely ignorant about its integrative activities. As in the case of evolution, it would seem that two complementary approaches are needed: a reductionist approach to understand the detailed neural mechanisms, and a holistic approach to understand the integration of these mechanisms into the functioning of the entire system. So far there have been very few attempts to apply the dynamics of self-organizing systems to neural phenomena, but those currently undertaken have brought some encouraging results. In particular, the significance of regular fluctuations in the process of perception, in the form of frequency patterns, has received considerable attention.

Another interesting development is the discovery that the two complementary modes of description which seem to be required to understand the nature of living systems are reflected in the very structure and functioning of our brains. Research over the last twenty years [to the mid '80's] has shown consistently that the two hemispheres of the brain tend to be involved in opposite but complementary functions. The left hemisphere, which controls the right side of the body, seems to be more specialized in analytic, linear thinking, which involves processing information sequentially; the right side hemisphere, controlling the left side of the body, seems to function predominantly in a holistic mode that is appropriate for synthesis and tends to process information more diffusely and simultaneously.

The complementary modes of functioning have been demonstrated dramatically in a number of "split-brain" experiments involving epileptic patients whose corpus caloosum, the band of fibers that normally connects the two hemispheres, had been cut. These patients showed some striking anomalies. For example, with closed eyes they could describe an object they were holding in their right hand but could only make a guess if the object was held in the left hand. Similarly, the right hand could still write but could no longer draw pictures, whereas the opposite was the case for the left. Other experiments indicated that the different specializations of the two sides of the brain represented preferences rather than absolute distinctions, but the general picture was confirmed.

In the past, brain researchers often referred to the left hemisphere as the major, and to the right as the minor hemisphere, thus expressing our culture's Cartesian bias in favor of rational thought, quantification, and analysis. Actually the preference for the "left-brain" of "right-hand" values is much older than the Cartesian worldview. In most European languages the right side is associated with the good, the just, and the virtuous, the left side with evil, danger, and suspicion. The very word "right" also means "correct", "appropriate", "just", whereas "sinister", which is the Latin word for "left", conveys the idea of something evil and threatening. The German for "law" is *Recht*, and the French *droit*, both of which also mean "right". Examples of this kind can be found in virtually all Western languages and probably in others as well. The deep-rooted preference for the right side - the one controlled by the left brain - in so many cultures makes one wonder whether it may not be related to the patriarchal value system. Whatever its origins may be, there have recently been attempts to promote more balanced views of brain functioning and to develop methods for increasing one's mental faculties by stimulating and integrating the functioning of both sides of the brain.