Chapter 2. System

2.1 An Autonomous System and a Heteronomous System

Information is treated in a *system*. Intuitively, *life information*, *social information* and *mechanical information* are each related to a living thing, human being, and information processing machine, respectively. All of three are regarded as systems in *fundamental informatics*.

Then what is a system? It is a functional entity composed of multiple components or elements. The essential point is that these components are not independent but mutually dependent and related, and they cooperate together to function as a whole system. It is not unusual that the operation of the whole system becomes radically different from the simple addition of each component's operation. Therefore in order for us to analyze such systems as living things, human beings and information processing machines, we must pay good attention to the *interrelations* among components, in addition to individual operations of each components. This must not be overlooked.

The essence of a system is the continuous *operation* and the accompanying structural *change*. Looking from the *outside*, a system is doing its function every moment by yielding some outputs in response to the inputs coming from an environment. However, if we look at it from the *inside*, what a system does is only to keep its operation and to keep changing itself, based on components' operations and interrelations.

By noticing the way of operation and change of a system, we can acknowledge a rule which governs the system. We must examine the rule to analyze the system. Naturally the function of a system depends on the properties of components – a cerebral nerve system is different from a software system, because the component of the former is a nerve cell while that of the latter is a program module. Nevertheless, if the rules governing them are identical, we can build up an integrated model for the both to analyze their operations/changes or inputs/outputs. This is an advantage of a systems theoretical approach.

Systems are classified into two types: autonomous systems and heteronomous systems. First we must make clear what autonomy is. Usually someone is called autonomous when he/she regulates his/her activities on his/her own. That is, autonomy means the ability to determine self-regulating rules (nomos). This enables one to behave based on one's own values, not as a means or a tool of others. Naturally it is connected to the concept of social independency which requires people to act independently according to their belief and free will. Therefore in a democratic society it is often said "An individual must be autonomous".

However, such social independency is not necessarily coincident with the concept of the autonomous system in fundamental informatics. The autonomy discussed here means that the rule, which governs the operations/changes of a system, is formed *inside* of a system. In other words, it represents the *closedness* of a system, where the system driving rule is determined by itself. Namely an autonomous system in fundamental informatics has little to do with so-called free will, or behavior based on independent judgment. Rather, it is *a closed system* driven by self-referential recursive rules.

As stated in Chapter 1, life information (the widest definition of information) brings about *significance* to a living thing, which is obtained through recursive try and error experiences. And the description of this *significance* using human-use symbols corresponds to the semantic contents of social information (narrower definition of information). Furthermore mechanical information comes into being from concealment of the semantic contents. This suggests that a living thing or a human being has much to do with an autonomous system. Then could we assert that an information processing machine like a computer is a *heteronomous (not autonomous)* system? We are going to examine this issue in this chapter.

● **Supplements and Applications**

Is there on earth a truly autonomous machine? In fact, many machines seem to advocate a kind of autonomy as a selling point. With the changes of an environment, these machines execute different functions. Let us take a simple example of a room with automatic illumination. The lights are turned on automatically when someone enters the room, and turned off as soon as everyone leaves. Could we think, however, of such a illumination system as an autonomous machine? It looks certainly operating automatically depending on the way human beings use the room. But as a matter of fact, it only follows the external rule constantly which was determined by a system designer. Such a system operates in pre-determined manners in response to various input, therefore it is nothing but *a heteronomous machine* no matter how flexible it may look.

Then we should consider *a learning machine* which develops its functions as time goes on. A learning machine does not necessarily follow an external rule exactly. In a sense we might say that it creates a self-regulating rule on its own. Therefore a learning machine is sometimes called an autonomous machine by engineers.

Let us consider a very simple example: a Japanese word processor with transforming function from hiragana to kanji which has a kind of learning capability. Assume a user input “かんじ” in hiragana. The candidates of transformation into kanji are “感じ”, “漢字”, “幹事”, “監事”, etc., and the word processor predicts user’s intention and transforms it based on past results. If the user is writing a financial report, the word processor probably learns to transform it into “監事” which means *an auditor* in Japanese. That is, this word processor forms an internal rule to transform “かんじ” into “監事”.

Despite that we can hardly call such a word processor an autonomous machine. What it actually does is that it simply exchanges the priorities of transformation programs based on past results. In short, the word processor can be thought to operate following the priority exchange rule (higher level rule) which has been determined by a designer beforehand. We might call the rule *a learning rule* whose level is conceptually higher than ordinary external rules.

The operation principle of learning machines is like this, although most of them are more complex than a word processor. A human being designs a learning rule, depending on which a learning machine adjust its internal parameters. Consequently, a learning machine never operates in a way beyond designer’s anticipation. A learning machine cannot be regarded as a true autonomous machine, because it is given from outside a learning mechanism for choosing functions adapting to working environment.

Generally speaking, the realization of a true autonomous machine is considered very difficult. On the other hand, it would be interesting that a human being who is in essence autonomous, often looks *having lost his/her own autonomy*.

Imagine that you go to a fast food shop and ask a part-time shop keeper “Take-out in a hurry, a couple of hamburgers and coffees”. Then the shop keeper might say “Thank you, two sets of hamburger and hot coffee -- OK?” and ask you “Is this for here or to go?”. You will probably get irritated as you already told it. But the trouble is not because the shop keeper did not understand your words. The shop keeper only follows the rule in a manual that first repeat customer’s order and then ask whether the client wants to eat inside the shop or not.

Such *a manual-sticking person* is not rare. They behave faithfully as told in a manual like a rule-driven machine, so they often look heteronomous being who has no free will. However, we must not forget that even such a manual-sticking person still keeps one's essential autonomy, because he/she is living in a self-created mental world and has the ability to think of anything.

2.2 A Computer System

As a typical information processing machine is a computer, we need to comment on its structure and the way of operation. In general, a human-made machine is a heteronomous one whose way of operation is determined by a designer, so as to give desired output for any input. This basic property is the same for any machine, from a sewing machine to an automobile or a computer. Especially a computer is worth noticing, because it is expected to reveal an essential feature of heteronomous machines. Through the analysis of a computer, we will be able to obtain a clear image of what a heteronomous (nonautonomous) system is.

A computer is, unlike an ordinary machine, *a logic machine* where logical functions are concentrated. An ordinary machine executes physical operations based on some logic: sewing cloth, moving by wheels, etc. Here logical and physical functions are usually closely interrelated to constitute an integrated whole. For example, in the case of a pedal-operated sewing machine of old times, the logic to realize complex movements of a needle is skillfully integrated into a structure of total mechanism which is composed of various parts like gears, cams, etc. Although being a remarkably ingenious machine, it is lacking in flexibility to implement added or deleted functions.

In order to increase flexibility and to provide a machine with diverse functions, it would be preferable to concentrate logical functions, and if possible, to make it separate and independent as a logical machine unit. A computer is nothing but such a machine. With it, all physical functions are executed under the control of a computer. For example, an electronic sewing machine of today has a micro computer unit which gives detailed instructions how to move a needle.

A logic machine, a computer, is conceptually separated into two parts: hardware and software. The hardware part, being connected to physical functions, constitutes the bridge between the physical *pleroma* world and the informational *creatura* world. Being a fixed part of a logical machine, hardware like memory or logical circuits entails basic operations while belonging to the physical world. On the other hand, the software part completely belongs to the informational creatura world, which realizes logical functions to process mechanical information. The essential point of a computer is that the software part is quite easy to change. Specifically, software is a set of *programs* which have detailed instructions for hardware operations.

The *hardware* part is composed of logical circuits for logical operations and memory devices for storing the results of such workings. Both are realized as electronic circuits which process discrete binary symbols of 0 and 1. Logical operations, based on Boolean algebra, calculate and/or transform binary symbols by the use of three operations NOT, AND, OR. Any complex processing carried out by a computer can be reduced to the combination of these three simple operations. Furthermore, all of the three can be realized by NAND circuits which actually constitute most of computers.

The s*oftware* part is comprised of procedures to designate the way of hardware operations. More specifically, it designates what kind of, and in what way logical operations should be executed. Mostly the software part has a multi-layer structure, of which the highest layer constitutes a user (human) interface and the lowest layer is directly connected to the hardware part. When a user modifies a program, it causes new logical development, resulting in hardware operation changes.

The original meaning of the word "program" is "to write (gram) in advance (pro)". The operation of a computer executed at present simply follows the logical procedure (program) written by a user beforehand. That is, the operation rule of a logic machine is determined from the outside, and there is no ambiguity no matter how complex it may be. In short, a computer system is in principle a heteronomous machine, even if it has some feeling of autonomy.

● **Supplements and Applications**

Why does a computer give us the impression of autonomy, although it is essentially a heteronomous machine? One of the reasons is that a computer operation often depends on real-time input data given every moment. In such a case, its operation and output fluctuate greatly. That is, the computer looks like operating autonomously in response to various input data, since its actual operation depends input data as well as its programs which have been given beforehand. This, however, brings about a sort of *inadaptability* peculiar to digital society.

Let us take an example of a web page which displays the guide of Chinese restaurants in a town. By clicking the button of some restaurant – say, "Dragon&Tiger King", we jump to the advertisement page of the restaurant, where we can get related information and make reservation on the page. We feel as if we *converse with a computer* in such a real-time application.

However, we must notice that this "conversation" is radically different from ordinary human conversation. In the "conversation" with a computer, basic *interpretation* of input words were mostly done beforehand by a human being, although the meaning of words are interpreted at every moment in ordinary real-time human conversation. More precisely, in this case a web designer specified in advance the detailed operations how to show users the related information of Chinese restaurants in the town and how to let them make reservations.

Like this, a computer attains pseudo autonomy based on the combination of *multiple time structures*. Despite that, it also brings about a kind of *inadaptability* because of time lags in a conversation with a computer. Namely a computer can never handle new type of inputs except for those foreseen by a designer. This makes a great difference between an experienced human guide and a computer. For example, we can no longer obtain useful data from the Web if Dragon&Tiger King has already gone out of business. But an experienced guide may introduce us the restaurant where the chef who used to work in Dragon&Tiger King is now working.

In other words, it can be said that this indicates the difference in processing *mechanical information* and *social information*. A computer never recognizes the symbol Dragon&Tiger King to be the name of a Chinese restaurant. Rather, it is simply interpreted to be the data to jump to a certain related web page. Seen from the inside of the computer, the *meaning* of a symbol is completely determined by the formal relation with other symbols, and the original meaning "Dragon&Tiger King as a Chinese restaurant" is totally concealed and ignored. The processing of mechanical information has such a complex time structure. On the other hand, human face-to-face conversation is composed of social information processing. Suppose that an experienced guide listens to the client's question "How can I make reservation at Dragon&Tiger King?". The guide may answer "It was already closed, but I know the restaurant in which the former chef of Dragon&Tiger King is working. You can enjoy the same taste there". Here we can see that the meaning of the word "Dragon-Tiger King" is interpreted in real-time.

The formal relations among symbols, no matter how precisely we may specify at length, have essentially nothing to do with the meaning or significance originated from life information. This is obvious if we imagine the following case, when we try to read a text in a foreign language we do not know at all by using a dictionary written in the language. The meaning of any symbol in the text is all described in the dictionary, but we will never be able to understand the text because the explanations of symbols themselves are written in unknown language.

2.3 Organization

What on earth is the difference between a living thing and a machine? We might say that the former is an autonomous system with operation rules generated inside, while the latter is a heteronomous system with operation rules given from the outside. But this does not always allow us to judge which of the two an object belongs to.

First, let us notice the discrepancy as *a physical substance* between a living thing and a machine. The argument is expected to illuminate the essential difference as *an information system*, which is the main subject of this text.

Suppose there is a "moving object" before our eyes. What is the standard for judging whether it is living or not? It is not appropriate to judge from the stuff. Although animals are made from protein or high molecular compound and a machine is mostly composed of metal and silicon, we could easily imagine a machine constructed using high molecular compound. Strictly speaking, there is no stuff or material which can be found only in the body of living things. Accordingly, if all properties of an object can be reduced to physical and/or chemical characteristics of its stuff, there should be no essential difference between living things and machines. But if we regard a living thing as *a system*, we can have another argument. As stated before, the characteristics of a system are determined not only by the properties of each component, but also by the interrelations among components. This view is supported by modern science. Hence a new question comes into being: what are the unique characteristics or relationship among components of a living thing. We call the characteristics peculiar to living things "*organization*" hereafter. So if organization is found in the moving object, it is considered a living thing.

An obvious feature of a living thing is that it always tries to survive and keep one's own life in a changing environment. A living thing is said to be an open system, since it lives by taking in nutrition and energy from its environment and putting out waste matters. And it is also an equilibrium system, because it maintains itself as stable as possible like a homeothermal animal that controls its body temperature. Namely a living thing can be physically modeled as *an equilibrium open system*. We call it "the first generation bio-model", in which *homeostasis* is attained as a feature of organization.

Note that, however, such a homeostatic feature can also be seen in a machine which has feedback facilities, not only in living things. An air conditioner equipped with thermostat is simply a good example. The cybernetic theory proposed in the mid-20th century provides the theoretical basis for such electro-mechanical systems. In other words, homeostasis may be necessary but not sufficient condition for organization.

Another obvious feature of a living thing is that it organizes itself and creates a diverse morphology – its own physical shape. If we think of the development process from a fertilized egg to an imago, we can acquire clear understanding. Since the entropy of a physical system increases with time and approaches to an equilibrium state, the emergence of morphology of a living thing is an extremely interesting phenomenon. We can obtain "the second generation bio-model" by regarding this self-forming feature as essential organization of living things.

Based on this model, we can look at a living thing as *an inequilibrium open system*, because a certain morphological order is attained in spite of physical instability. There are flows of substance and energy in which micro fluctuations and subtle interrelations of components are amplified and entrained to achieve a kind of regularities and macro morphological orders. Such self-forming or self-organizing feature surely constitutes peculiar characteristics of living things. We can observe these phenomena in firing patterns of animal's brains as well as morphology.

Nevertheless we can hardly take the self-forming or self-organizing feature for organization of a living thing. This is because there are many examples of inequilibrium open systems in the natural world which have nothing to do with living things.

● **Supplements and Applications**

Bénard cells, or *Rayleigh-Bénard convection*, is well known as a typical natural phenomenon of self-organizing. This convection occurs when we put high viscosity fluid like rapeseed oil into a flat container and heat it uniformly from below. At first heat is conducted gradually from the bottom to upper layers, and the heated surface layer shows ordinary subtle turbulence. But if we keep heating beyond some critical point, suddenly appear a number of cells on the top plane. Each cell, looks like a hexagon seen from above, composes a hexagonal prism where a kind of *convection* is observed: upward flow at the center and downward flow at the periphery.

In Bérnard Cells, a macroscopic order is formed through the entrainment of microscopic turbulent movements of molecules, which is considered to be a typical example of *dissipative structure*. Here the system, although in a state far from equilibrium, surely maintains a sort of formal order through a dynamical process. We could say that most of life phenomena have something to do with such an inequilibrium open system, and various research efforts based on mathematical approach have actively been made since the end of the 20^{th} century.

But a Bénard cell does not continue long time and disappears when left alone. If conditions are met, convection currents like a Bénard cell can appear even in the atmosphere, but they are naturally temporary phenomena which have no successions. Life phenomena, on the other hand, are characterized by a remarkable dynamics which has long been succeeded since the birth of life of 4 billion years ago, when considering generic inheritance of evolution. For that reason we should not directly connect the two phenomena. Nevertheless, such a self-organizing system is very important as a physical basis supporting a life phenomenon.

The important point concerning self-organizing systems is that, because of *nonlinearity*, we cannot analyze its macroscopic dynamic behavior by simply superimposing the microscopic dynamic behaviors of its components. This has opened the way to a new area of physical science which is fundamentally different from the 19^{th} century classical physics where the analysis of the world is aimed at by superimposing analyses of microscopic phenomena.

A nonlinear system is often called *a complex system*, and its mathematical properties have widely been investigated since the 20th century. Especially in the late 20th century we made a great progress in the theories related to *chaos* and *fractal*, the latter means self-similarity. In order to give an example of fractal figures, just imagine that we divide a line segment into three equal parts and depict an equilateral triangle with its base of the central part. If we continue to making up such triangles, we can draw a mysterious line termed *Koch curve*. And well-known *Koch Snowflake* can be obtained by linking such curves so as to make it closed. Keeping our eye on a part of Koch Snowflake, we can see a similar curve however we enlarge it: the characteristic of a fractal figure. Koch Snowflake is a mysterious figure that has the finite area and infinite perimeter.

Chaos is a mathematical phenomenon closely related to fractal. Despite its ordinary word usage, chaos does not mean the state of complete disorder. We can recognize a comparatively simple regularity in the depth, although the chaotic condition looks like a quite random behavior. Imagine we keep throwing a coin and obtain a series: head, tail, tail, …, etc. This looks like a completely random phenomenon. But the fact is, this series can exactly be obtained by calculating recursively the values of a certain function. Namely chaos theory connects, in a sense, two kinds of phenomena which previously considered separated: accidental events occurring statistically and deterministic events caused by functional calculation.

In general, nonlinear mathematical models are very interesting which have much to do with life phenomena. Nevertheless they concern only physical science areas, or the problems of the pleroma world. They are related to the physical pattern that carries information, but not directly to the informational arguments for significance or meaning.

2.4 Autopoiesis

We must note that a living thing has more essential characteristics in addition to homeostasis and morphology. That is nothing but the ability to create itself, and we call this function of self-reproduction "*autopoiesis*". Here "auto" and "poiesis" each represent "self" and "production", respectively. The autopoiesis theory was proposed by Chilean biologists/philosophers Humberto Maturana and Francisco Varela. We employ the concept of autopoiesis as organization in *the third generation bio-model*. Incidentally, it was science philosopher Hideo Kawamoto who named the first, second and third generation bio-models.

For example, a cell is not what was designed by others but continues recurrent self-creation: produce itself based on its state of being. The components of a cell, various proteins and nucleic acids, reproduce themselves recurrently while functioning interdependently. We can see there *a dynamic process network* to keep producing components, and conversely, the components to keep producing the process network. Therefore we may say that *components reproduce components*, or the process network is recursively interdependent.

In short, the organization of the third generation bio-model, autopoietic system, is given by *a dynamic process network reproducing components recursively*. The important point is that the third generation bio-model is, unlike the first (homeostatic) or the second (self-organizing) generation model, *closed*. Namely an autopoietic system is nothing but an organizationally closed system which constitutes a circle.

This is the point easy to be misunderstood. Based on physical scientific view, a living thing is obviously an open system. In fact, any protein of a cell takes in nutrition from its environment. However, the organization here does not mean physical or materialistic relations but abstract topological relations. We must not forget that an autopoietic system has a *structure* as well as organization. The structure, unlike the organization, is physical and concrete existence which can be seen and occupies certain space. The organization might be considered an invariable mathematical relation on which the variable structure stands. Therefore a cell as a physical structure may look an open system, but the organization, the basic reproduction mechanism, can be said to be a closed system.

Let us compare an autopoietic system with a homeostatic system and a self-organizing system. The observer's position of the latter is *external*, and he/she describes the operation dynamics, input/output etc. from the *outside* of the systems. So they are seen as open systems. On the other hand, the position of the observer of the former, who describes the self-reproduction dynamics of a living thing, is found in the *inside* of the system: the observation and description of an autopoietic system are done *internally*.

This *shift of a viewpoint* is critical to the understanding of the essential characteristics of a living thing. A living thing survives acting in and recognizing its environment, which results in the self-reproduction. Consequently, in order to grasp the self-reproduction mechanism of living things, we must shift our viewpoint from the outside to the inside of the system and describe its behaviors of recognition and actions.

Owing to the shift of a viewpoint, we can move from physical science or the world of pleroma to information studies or the world of creatura. Information studies must discuss problems related to *semantic contents* of information which a living thing brings about through its actions. What is essential there is sense-making functions rather than physical or chemical functions. Accordingly we choose an autopoietic system as a bio-model in *fundamental informatics*.

It is true that a self-organizing system also creates a kind of order by itself. But its order is different from the order created by an autopoietic system, because the former is related only to physical or chemical phenomenon that appears in an objective world. However, the order of the autopoietic system is, so to speak, a subjective one that is formed through the recognitive operations of the system.

● **Supplements and Applications**

The autopoiesis theory has a unique academic position: it was originated from ordinary science but epistemologically a little apart from it, which makes the theory difficult to understand. Let us introduce the birth episode of this theory. An inspiration came to Maturana when he was engaged in the research of color recognition of a *dove's neural (nervous) system*. If we irradiate dove's eyes with light of variable wavelength and examine the active patterns on its retina, we cannot find any clear correlation between wavelength and retinal activities. This is because retinal activities are not determined by the physical wavelength of the light irradiated. Rather, they are determined by the *color experience* the dove has had until then.

Thus, Maturana found out that it is impossible to analyze the activities of a neural system by the conventional scientific approach where a living thing is assumed to perceive an object in the external world. The neural system is closed and regulated by internal mechanisms, and the external world can only give some stimuli to trigger the activities of a neural system. Biological perception does not directly represent the external object, but something to be utilized in a recursive way how a living thing should act in a given environment.

The intuition of Maturana has much to do with the theme of fundamental informatics which is the relation between *information and its semantic content*. As stated before, a living thing (human being) cannot receive a piece of information like a physical package. Rather, a living thing generates life information internally in response to outer stimuli. So the semantic content that appears is tightly connected with *the activities for the living*. Let us take the example of book reading. The joy and impression of reading the same book are quite different from person to person, reflecting each reading experience. At any rate, we can never go out of our own world.

The autopoiesis as well as its organization, if we think in that way, does not look very strange. There are four well-known characteristics of an autopoietic system – *autonomy*, *individuality*, *self-determination of boundary*, and *absence of inputs/outputs* – which are said to be difficult. But they are understandable by noticing that an autopoietic system is a closed system operating recurrently.

First, autonomy here does not mean to determine some rules consciously or intentionally for oneself. Rather, it looks so because closed recursive operations cause habitual activities. Then, individuality is a reasonable result of organization that ensures oneself as a unit. And its boundary is naturally determined through its own operations, as we can see the membrane of a cell. Finally, we could never have inputs nor outputs for a closed system. For example, in the thinking process, words and images are going around only in our mind.

The autopoiesis theory is obviously one of the most important theories related to our recognition, consciousness, action, and society. Nevertheless, the application and theoretical development since its advocacy in the 1970s-80s have not been straightforward: in short, current state is not integrated and there are theoretical differences among influential researchers. Although basic concepts are more or less common, technical terms are not used in a uniform way.

Maturana and his student Valera are known as the founders of the theory, but their original directions were not necessarily the same. The former was a neurophysiologist and the latter was a theoretical biologist. Maturana intended, starting from the problems of recognition and observation, to make the autopoisis theory a *comprehensive general theory* including human social activities. Varela, however, preferred to limit the applicability of the concept of autopoiesis to the biological field, and intended to renovate *theoretical biology*. On another side, Varela tried to construct another independent general theory including social human activities based on *autonomy*, which is a central concept of autopoiesis theory.

A theoretical sociologist Niklas Luhmann, on the other hand, succeeded in building up his famous "*functionally differentiated social theory*" by adapting the concept of autopoiesis to theoretical sociology. Because of his theory, the concept of autopopiesis has greatly become popular, and many application efforts are being made in the related fields of social science and the liberal arts. In Japan, for example, science philosopher Hideo Kawamoto is engaged in the research of bodily actions based on autopoiesis theory.

2.5 A Psychic System

Fundamental informatics, in an effort to investigate the significance of information, approaches to the problems of life and cognition through autopoiesis theory instead of conventional physical science. Here what is examined is the dynamics of mind or consciousness which is modeled as a *psychic system (or mind system)* in the autopoiesis theory.

The psychic system is an autopoietic system whose component is thinking. That is, as "*organization"* we can find the recursive process that *thinking reproduces thinking*. The thinking here means a sort of *communication to express oneself* which is composed of various symbols – especially words – for images or concepts. Once a series of thinking is described, it begins to circulate in human society. Hence the psychic system is nothing but a system for *observing and describing the world*. Conversely, no other system can become an observer/describer than a psychic system. The results of observation/description are memorized, spoken out, or written on some media. And they constitute the "*structure" of a psychic system*.

Let us reflect roughly how we keep our thinking in everyday life. Our living body is always exposed to *external stimuli* which include not only artificial signals from a TV or cell phone but natural wind or sun light. On receiving some stimuli through sensory organs, our living body, especially our cerebral nerve system, is so perturbed that may yield *raw information* (*life information*). Since our psychic system is always interacting with our cerebral nerve system, thinking is generated by the use of raw information as material. And the description of thinking results in the production of *social information*. Furthermore this social information will in time influence the way raw information appear.

Through such processes, life information is transformed into social information with semantic content that may circulate in human society. Namely at least two autopoietic systems, a cerebral nerve system and a psychic system, are concerned in our *interpretation of information content*.

Incidentally, when two or more autopoietic systems interact closely with each other, we call it "*structural coupling*". Precisely speaking, the operations of two autopoetic systems are functionally interdependent, if they are in a state of structural coupling. We may also say these autopoietic systems are in a state of structural coupling with their each environment, because an autopoietic system is closed and therefore it cannot make any distinction between its environment and other systems.

Through the transformation process from life information into social information (including the feedback from the latter on the former), the structural coupling is done based on *brain cells* that are under external stimuli all the time. They affect the structures of *a living body system* and *a psychic system*, and the variation of such brain cells brings about the description of semantic information contents.

Note here that the operation of a psychic system itself does not necessarily need external stimuli. It is sure that our psychic system gets highly activated on receiving external stimuli such as TV broadcast of a sports match. Nevertheless, if we think of a dream, we can easily understand that our brain cells can also get excited and our thinking can be activated without any external stimuli. For a psychic system, in principle, there is no distinction between reality and illusion.

In other words, this means that the act of observation and description being done by our psychic systems does not presuppose absolute reality of an *objective* world. Rather, closure of a psychic system brings about human *subjective* world. Then, how could we execute social communication with others? We are going to argue this problem hereafter.

● **Supplements and Applications**

Mind is a difficult theme to discuss academically. As stated above, we analyze it as an autopoietic system in *fundamental informatics*. But in everyday vocabulary, the word "mind" is used in diverse contexts, and it is hard to articulate and fix its meaning. Compared with the related English words of "heart" and "spirit", it has general impression and rational connotation.

Psychology and psychoanalysis have proposed various mind models. Here we confine our discussion to the related fields of ICT or brain science developed recently. The research of *artificial intelligence* or *cognitive science* is an approach to simulate psychological functions mainly by the use of a computer model. Especially the ability to understand language has been investigated. That is, there is a belief that "*the machine with a mind*" is such a machine as can speak like a human being which, for the time being, is too hard to realize.

In brain science and neuroscience, minimal invasive instrumentation technologies which do not hurt the brain, such as positron emission tomography and nuclear magnetic resonance imaging, have remarkably developed since the end of the 20th century. For that reason, people are recently becoming highly interested in the approach to investigate the mystery of mind through scientific analysis. There the dominant way of thinking is the belief "*Mind is the brain*": the states and functions of mind will eventually be clarified by the research of the brain. As a matter of fact, there seem to be a project to realize *a computation model of mind*, by applying experimental results to a computer program.

The way we look at the world has certainly much to do with the state of excitements of our brains. Nevertheless it may also have to do with other organs than the brain. Furthermore, we must ask a more essential question: whether or not we can analyze the fundamental aspect of our mind by scientific measurement of the brain or computer calculation. Here we come across the issue of "*qualia*" which is well known as a hard problem to solve.

What is qualia? – It is inherent qualitative experience that we individuals have subjectively, through stimuli from sensory organs. Imagine the instant that we get up in the morning and open a window. We see the high sky with bright sunlight, where we have the qualia of brilliant blue color. At the moment, some part of our brains was on fire. However, we may not have the same qualia again, even if the state of firing of brain cells could be restored completely (which is virtually impossible). The experienced "blue" is closely related to the scenery, breeze, smell of the air etc. outside the window, and above all, is dependent on the feeling of oneself. Basically, one's own experience can never be repeated. The heart and/or spirit, as they have much to do with feelings and emotions, cannot be fully discussed while neglecting personal experience. The physical scientific approach based on brain science, if it is unable to discuss qualia, is useful at most only for limited functions of mind.

Let us consider this problem from the viewpoint of fundamental informatics. The autopoietic system model of mind does not neglect subjective personal experience. When we are looking up the blue sky, corresponding thinking is generated based on the stuff of *raw information* because our psychic systems and cerebral nerve systems are structurally coupled. Namely, *social information*, or the description by oneself, comes into being as *a first person expression* such as "What a beautiful blue sky!". Although the expression itself is commonplace, the generated thinking corresponds to the qualia – unique, individual and unrepeatable experience.

On the other hand, just imagine a brain scientist who monitors by instruments the brain state of the person watching the same "blue". In the psychic system of the brain scientist, thinking is also generated recursively. But his/her observation results are described objectively as *a third person expression*. The brain scientist is not interested in qualia. Rather, he/she describes the brain state of the person physically, as a spectacle of *the objective world*. In this way, an approach of fundamental informatics is able to make clear the position and range of the mind research based on brain science.

2.6 A Social System

It is basically a psychic system that interprets the semantic content of information. Then how can we explain from the viewpoint of *fundamental informatics* the *information transmission* in a society? As stated before, since a psychic system is closed, the semantic content of information (*social information*) cannot be completely conveyed like a parcel. What can be conveyed is only a symbol (*mechanical information*), and therefore misunderstanding can occur. Nevertheless, human society would collapse if no semantic contents were transmitted at all. Here we must turn our attention to a *social system*.

When noticing transmission of information content, it would be clear that the communication within a social group such as a community has a tendency of closure. For example, the people in a nation state communicate with each other using national language, hence the meaning of words is circulating within that language community. This causes the difficulty to learn the language spoken in a foreign state far away. Even in the same state, the employees of a company often share unique customs or values, and such semantic content does not always pass outside the company.

A social system in fundamental informatics is defined as an autopoietic system whose components are "communications". Namely, in that system, the process that *a communication recursively generates a communication* operates as "*organization*". Here note that a social system is considered not as an assembly of human beings as physical entities but as an assembly of communications as events. (Incidentally, it was a theoretical sociologist Niklas Luhmann that defined a social system as an autopoietic system whose components are commnunications. But the treatment of information in his theory is different from that of fundamental informatics as stated later.)

A communication is a kind of *event* generated by the sense-making effect of information, where for instance the remarks of social group members are used as stuff. In a meeting, participants actively exchange opinions, and there appears a chain of remarks: a remark is repeatedly produced in response to the previous remark. We can see continuous generation of communication there. Here the *structure* of a social system is composed of related documents such as the minutes of a meeting or memorandums of participants, which change themselves with the generation of communications.

The information transmission in fundamental informatics is nothing but *stable operation of a social system*, or continuous generation of communications. This is because, as long as communications are continuously generated, we can regard the semantic content of information is successfully transmitted to such extent that ensures stable operation of the social system.

It is certain that a psychic system is closed and nobody is able to peep in what is going on inside of others' mind. A remark in a meeting, however deliberately we may make, could be misunderstood by other participants. Moreover, nobody is able to precisely grasp the difference in information content interpretation between the speaker and listeners. Despite that, if the difference is too great, communications would be suspended. Hence we may believe that the information has been successfully transmitted for the time being, if opinions were actively exchanged and a conclusion has been obtained.

In other words, the transmission of information contents between psychic systems cannot avoid a sort of *relativity*, which has much to do with the properties of a social system. Let us take an example of the following simple conversation. A person spoke to others "I was born in a house on the side of the river". One listener may imagine a pure rapid water stream of a few meters in width, on the beach of which are found many round stones. Another listener may imagine scenery with a dirty narrow stream fed by waste water of a big city. And the other listener may have a spectacular vision of a great river as wide as several tens of meters with small houses along its side. This difference, unless speaker's main topic is related to the river, does not cause a problem that prevents continuous generation of communications. However, just think of the case the speaker proposes to have a barbecue party on the riverside the next day. Now the difference in images of the river can cause confusion among people about the way to prepare the party, and the communication may be suspended.

● Supplements and Applications

The conversation between human beings can be modeled by continuous production of communications in a social system, based on information content interpretation in psychic systems. Then, how about the "conversation with a *computer*"? As stated in Section 2.2, it is very difficult for a human being to communicate with a computer in a true sense. A computer is a stubborn and inflexible being. When we are asking a question through the Web, sitting in front of a PC, we feel like having a real time answer as a response. But actually it is an output syntactically and automatically made by a computer, chosen from the response examples for the input, that were prepared *in advance* by a designer or a manager of the computer system. Because of the time difference concerning interpretation of information content, we can hardly call it a real time interactive communication.

Nevertheless, the conversation *via the Web* is naturally possible. When we exchange views in an electronic bulletin board, send/receive mails to/from friends, give comments on others' blogs, such actions make operations which can be said interactive communication in a social system using web media. However, we should pay attention since we sometimes find it difficult to discriminate the above two (the conversation *with* a computer and that *via* a computer) while manipulating a PC or cell phone. As a matter of fact, when we are using a computer we often feel as if we were communicate with it in real time. The typical example is *a computer game*.

In a computer game, attractive characters move around vividly on the screen responding to the bodily actions of a player (user), and a dramatic story like treasure hunting or monster slaying is unfolded. However simple the story itself may be, the player feels involved in *the real-time game space* because the characters' reactions change quickly and dynamically depending on the player's skill. Of course the player knows by reason that he/she is doing nothing but tracing one of the tracks predefined by game designers. Nevertheless, the player cannot help feeling oneself is making a thrilling adventure. There occurs a reversal phenomenon that a *game computer* rather than a human being has the ability to *control the time flow*.

A so-called *on-line game* is a new type of computer games which has also elements of *real-time communication among human beings* via the Net. In that, several players make up a team and cooperate, while chatting with each other when necessary, in order to find treasures or fight with monsters. It takes as long as several weeks, even months, to finish one game. Such on-line game is very popular in Korea, and it has also become popular in Japan since the 2000s.

In a usual computer game, it is only one player's psychic system that concerns. But in on-line game, the operations of many psychic systems of the team members take part in, and based on which a social system operates. Note that the player's self in that *society* is "the self for the game" which is quite different from the one in everyday life. A weary middle-aged man can become an exquisitely beautiful lady, and a reserved girl can change into a brave medieval knight. They chat with others via the Net as such game characters.

A sense of solidarity of team members is very strong, because they fight together with enemies as comrades-in-arms. If a player improves one's skill and become a team leader, he/she will win a sense of achievement and the respect of other players. That also brings about a sense of responsibility, and one cannot stop playing even though being tired out, because one's absence may invite the victory of enemies. Thus, a player tends to spend days playing a game, sitting in front of one's PC for 10 hours or even 20 hours a day, without sleeping or bathing, only with taking snack foods. In the worst case, they become *game addicts* who approach to ruin.

This is the tragic case where human beings get caught in *the time flow* of a computer game as *a social system* altogether. Generally speaking, a computer game has the merit to relieve us from everyday routines, but we must not forget that it has also such a dangerous trap.

2.7 *A Hierarchical Autonomous Communication System (HACS)*

The academic target of *fundamental informatics* is naturally the study of information, and it aims to investigate the related phenomena of generation, transmission and storing of information. Certainly it has some biological, psychological and sociological aspects, but its methodology is not the same as that of biology, psychology or sociology. Autopoiesis theory had started from biology and then it was refined and prevailed mainly through its application to theoretical sociology. However, as fundamental informatics is distinct from these two fields, we must reexamine the related concepts to be adapted for the study of information. Hence in this lecture we are going to introduce a "*Hierarchical Autonomous Communication System (HACS)*" as the central concept.

The psychic system and social system, as stated in Sections 2.5 and 2.6 respectively, are both composed of not *matter* but events like *thinking* or *communication*. This is a prominent feature, as we consider the fact that the component of a cell is protein or nucleic acid. Although the operation of a psychic system or social system causes materialistic change in the *structure* such as brain cells, notebooks, minutes, etc., the *organization* of the system belongs completely to the non-materialistic *creatura* world. Moreover, we are able to regard thinking as "communication to express oneself". Accordingly, the psychic system and social system can be redefined as an integral concept of "*an autopoietic system with components of communication*".

Another important point from the view of information study is the existence of an *observer* who is structurally coupled to an autopoietic system. Any system keeps its behaviors implicit to us and remains unknown, unless such an observer describes how it is like, using the *social information* which circulates in a human society. For example, the society (troop) of chimpanzees is likely to exist in itself without human beings. However, it is not until a psychic system of a human researcher becomes structurally coupled with chimpanzee society and describes by human symbols – in documents or research papers – that the state of chimpanzee society can rightly be recognized by human beings. We cannot neglect the process of observation and description by human mind in fundamental informatics. It should be emphasized here that the psychic system structurally coupled to the system in question is observing/describing, not from outside but from inside, staying as close as possible to the system's viewpoint. The researcher of chimpanzees strives to exclude one's own subjectivity and observe/describe the communication activities in a chimpanzee troop from the standpoint of the chimpanzees.

An autopoietic system discussed in fundamental informatics is *a complex system* which is structurally coupled with a psychic system as an observer and describer. That psychic system is, as we might put it, a spokesman of the system. The only exception is a psychic system which *stands alone*. Otherwise, we must repeat structural couplings for ever. Our human psychic system has the ability of *self-observation* and *self-description* – we human beings can reflect what kind of thinking is circulating in our minds.

Another noteworthy characteristic of an autopoietic system in fundamental informatics is that it has the hierarchical or asymmetric properties. There is a common saying that an autopoietic system is closed and unrelated to the hierarchical properties. But as for such a complex system stated above, we can rightly acknowledge a sort of hierarchy.

Let us think of a social group like a company or enterprise. The psychic system of an employee there is naturally closed, and he/she keeps thinking autonomously. Likewise the social system of the company is generating communications autonomously. But what is important is that, from the social system's viewpoint, each employee looks as if working in a *heteronomous* way. They are each engaged in their charged input/output operations under the constraints such as regulations and enterprise ends. However, from the viewpoint of an individual employee, these constraints are felt like a kind of environment or background conditions: he/she is not very much conscious of these constraints in their everyday lives.

As such, most of the system investigated in fundamental informatics is an autopoietic system that is structurally coupled with a psychic system and having communications as components. We are going to call such a system "*HACS*" hereafter.

● Supplements and Applications

It would be better to articulate the conceptual relations between an autonomous system, autopoietic system and HACS, to prevent misunderstanding. An autopoetic system has the property of autonomy, so it is included in autonomous systems. And HACS is nothing but a kind of autopoietic system whose components are communications. Hence the following relation holds:

Autonomous System ⊇ Autopoietic System ⊇ HACS

As stated above, the opposite concept of an autonomous system is a heteronomous system. Then what is the opposite concept of an autopoietic system? – We call it an *allopoietic system*. The word "allo" means "others", and an allopoietic system is the kind of system that is created by something other than oneself, and creates something other than oneself. Ordinary machines like automobiles or computers are all allopoietic systems. In general, a lower level HACS often looks like a heteronomous allopoietic system from the viewpoints of upper level HACS. For example, when we see from the company's standpoint, employee's psychic system behaves as if it were a sort of allopoietic system like an information processing machine.

Note that such an asymmetric relation merely shows the way of operations of an upper level HACS, and it does not affect the autonomy of lower level HACS, psychic systems. Thinking communication itself is generated autonomously. Despite that, there is possibility that the *constraints* given by a social system might have indirect influence on the operations of social members' psychic systems, resulting in some *limits of choices and freedom* of activities. Suppose that a company forces its employees to work like machines under strict rules. That may improve efficiency, but will cause the resignation of creative employees.

By the way, let us comment on *privacy*, which is recently one of the biggest issues in information society. With the rapid development of ICT, it has become possible to memorize all actions of people on database. Not only basic personal information such as one's name, address, employment, family etc., but also almost all details of people's everyday life can be registered: one bought what goods, visited where, met who, saw what web page, etc. Moreover, people scarcely know that *they are always watched*. Should people's privacy be protected in such an information society? And what is the reason for the protection?

Taking notice of hierarchical properties of HACS, we can consider these problems. From the viewpoint of social systems (upper level), it is efficient to collect the detailed data of people's everyday lives. A mail-order web site, for instance, can introduce to clients some merchandise matched with clients' need, which decreases the sales promotion cost. There may be an opinion that it would be also convenient for users or people.

Nevertheless, what would happen if a life insurance company could procure and maintain people's medical examination results? The data of clients would be very valuable for the insurance company (an upper level social system) – valuable enough for the company to make a great profit. But it would be disadvantageous from the viewpoints of clients (lower level psychic systems). If someone is slightly related to a fatal disease, he/she might be refused to make a contract. People sign an insurance contract because their future is basically unpredictable.

As such, the protection of privacy is able to be discussed from fundamental informatics perspective. It is true that privacy may naturally be restricted to a certain extent for security reasons like crime prevention. In spite of that, if most of data related to people's everyday lives are grasped by a social group, the freedom or choices of people's activities is likely to be infringed. Moreover, it may even introduce social distinction in various aspects such as job employment, school entrance, marriage, etc.

2.8 A Robot

A living thing, especially a human being, is an *autonomous system*, and an information processing machine like a computer is a *heteronomous system*. But it is sometimes not an easy task to discriminate between the two by their outward appearances. For instance, an email-base automatic inquiring system being able to respond kindly to users' questions may feel like a human counselor. Moreover, it is important that, as stated before, there is a viewpoint from which a human being looks like an information processing machine with input/output functions.

Precisely speaking, we should notice that the two are quite different in the way of giving output (action). The output (action) of an information processing machine depends totally on *the input series* until the instant. But the output (action) of a human psychic system depends not only on the input series but also on *the way to process the input series (the way the system operates)* until the instant. And actually, we hardly know the alteration mechanism of the processing manner. This corresponds to the fact that we cannot strictly repeat our experiences.

Nevertheless, *robot research* keeps advocating the dream to create a human-like machine. In Japan the robot research is flourishing and the technological level of industrial robot research in particular is considered at the highest in the world. It is something like a symbol of advanced science & technology. Many Japanese people have friendly feelings towards robots and the very few have hatred or antipathy. With the recent advent of an ageing society, the development of *service robots* for nursing care or housework is in the limelight. Several products or specimens have already realized such as those for self-supporting walking, or for room cleaning. In addition, so-called *pet robots* are also being developed which tries to communicate with lonesome elderly people.

But this is a very difficult challenge. Unlike an industrial robot, a home-use service robot must operate safely and surely for non-professional people in diverse environments changing in various ways. Moreover, the ability to understand human words, which is a classic aporia, is strongly required for a pet robot. Having a small talk with elderly people without making them bored is not an easy task. On the other hand, we are able to develop pretty easily a robot (computer system) who can answer fixed type questions. For example, in order for a robot to answer a question such as “When did the Honnoji Incident happen?”, we only need a syntax analysis program to interpret fixed type questions like “When (where/how/why) did something happen?”, and a knowledge database of historical events. However, the ability to respond in an appropriate way to elderly people’s reminiscent talk requires a radically different approach.

If we regard a robot as an open system and provide it with knowledge propositions and programs to handle them, it becomes a typical heteronomous system. But a human-like robot is rather a *pseudo-colosed* robot which acquires knowledge more or less *autonomously.* Suppose that a robot, having no knowledge at the beginning, tries to recognize objects such as a table, sofa, plant pot etc. while moving around in the room and listening repeatedly to the words of an elderly person, gradually understanding his/her direction like “Bring me the plant pot besides the sofa”. The robot becoming smarter little by little through trial-and-error is likely to be felt by elderly people as if it were a real pet, and would not make them bored.

Experimental research of such a robot with advanced learning functions has already been begun (for example, *a communication robot* by Tadahiro Taniguchi). The important point is that a robot creates *internally* the concept of a symbol system based on its bodily action experience. Naturally such a symbol system is too primitive to be called language, and the robot is still a heteronomous system because the learning algorithm itself is designed by human beings. Nevertheless, we might be able to say that we can see there a kind of pseudo-autonomy.

● **Supplements and Applications**

People’s evaluation or impression of a robot is quite different between Japan and Western countries. It is often said that an average Japanese immediately imagines “*Astro Boy* (Tetsuwan Atomu)”, a famous SF comic/animation by Osamu Tezuka, when hearing the word “robot”. The Astro Boy is a cute child robot with extraordinary power and speed, who speaks human language to fight against enemies together with human beings. In fact, many Japanese robot researchers confess that they had admiration for Astro Boy in their younger days. Although Astro Boy is now an old work, the admiration for robots can also be found among Japanese young generations. In fact, new robot development is one of the most popular themes for the students majoring in engineering.

On the other hand, there seems to be common thinking in Western countries that a robot, especially a humanoid robot having a human-like appearance, is a sort of repugnant creature. Not a few people have a fixed image such as the horrible monster created by Dr. Frankenstein in the novel of Mary Shelley, or a rebellious slave robot in the famous drama *R.U.R.* of Karel Čapek.

When looking into the deep psychology of people, this difference is considered to be related to religious or cultural background. God created *everything* in Judeo-Christian tradition. Therefore, creating human-like existence is likely to cause a sense of blaspheme against God. That leads to the fear of the tragedy that we would be punished by the hands of what we created. In Japan on the other hand, we can find the completely different traditional world view; animistic one that everything is *born spontaneously* and has its own spirit, or Buddhist one that everything *enters Nirvana*. As the boundary between artifacts and nature is ambiguous, the idea that *a new existence* created by us should also be respected in its own way is widely accepted by people.

Because of this religious and cultural background, there is a saying that Japan will lead the 21st century international market of service robots or pet robots, in addition to industrial robots. Particularly as for the pet robot for entertainment, Sony, one of Japanese major electrical machinery manufacturers, already offered a "*robot dog AIBO*" for sale in the late 1990s. The AIBO, which moves around responding to human voices and actions, attracted much attention of the domestic and overseas mass media, and became temporarily a social phenomenon. For foreign researchers of Japanese culture, the question why Japanese people have so much affection for such an impractical automatic machine seems to have been an interesting theme.

Nevertheless, it would be too simple to affirm that a pet robot is quite easily accepted in Japan whereas hardly in Western countries because of the difference in the cultural and religious background. In fact, the sales of this robot dog in Japan had gradually decreased and now it is not sold any more. Such a complaint from its buyers has often been heard that it looks funny and cute at first but soon become boring. Probably because of this experience, since then, we do not hear that another product of this kind has been put on sale and become popular, although there had been many projects to develop similar pet robots. In brief, a pet robot needs *something* to attract our minds, whether in the East or the West. Without that, it will inevitably become boring before long.

How to realize a *charm* in an entertain robot is a delicate issue. In the case of a doll, a static existence, human beings could have imagination enough to invent some kind of charm in it. But in the case of an active robot, it is likely to become boring soon because of repetitive actions. The AIBO had a kind of learning ability and was able to grow a little. But it had to have more advanced *pseudo-autonomy* to keep interests of people.