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Stability of arbitrary structures and its implications for heredity and evolution

The axiom of arbitrary structures in biology and its implications for the multiplicity of structures

Arbitrariness was one of the keywords in the theory of linguistics developed by Saussure (1972), but its proper understanding was hampered by a number of factors. This was due to the distortion which the original edition (Saussure, 1916) had suffered until it was rectified by the discovery, made only from 1957 on, of the original material of his lecture courses given during 1907-1911. For examples of arbitrariness in various structures, see Sibatani (1990). Since modern structuralism was primarily based on the theory of Saussure, I employ, for developing structuralist ideas in biology, the concept of arbitrariness as an axiom and follow its logical consequences, the procedure also taken by Ikeda (1988) in his recent book on biological structuralism.

Axioms are not dogmas, as is well known in mathematical systems. The "structure" in the present context means the relationship between components of the system, or laws or rules governing them. If a structure or a set of rules is arbitrary, which means that it has emerged without any particular ground in preference to other feasible alternatives, then we must envisage the problem concerning the multiplicity of possible structures even with respect to the system containing the same set of components, let alone those having additional components. Given the arbitrariness and multiplicity of structures, the question of their stability immediately comes to the fore.

However, we have to accept that, unlike entities and phenomena, laws or rules are, by definition, *invariant*. As noted by Saussure (1972) himself, arbitrariness also means necessity, because components of the system, once bound by the structure, however arbitrary it may have been at the outset, are nevertheless unable to disobey the rule. Furthermore, as may be seen in the analysis of Castoriadis (1975), there is a motive of original-

ity with what may be conceived as the arbitrary (or unmotivated) structure. Saussure (1972) dealt with the dialectics between the binding by necessity for a synchronic relationship among components and, by implication, the freedom in generative processes for a diachronic evolution of the structure. This important point should always be kept in mind when dealing with plausible mechanisms for emergence of a new structure.

Reverse-reductionism

In this research program I wish to introduce, into biology, some of the principles accepted in human sciences. This attitude may be called reverse-reductionism. It does not intend to deny the importance and usefulness of reductionism (atomistic or physical) in biology. However, without getting involved in the controversy concerning the primacy of self-sufficiency of reductionism in biology, I wish to try to find out, in biological processes, some structures equivalent to what is found to be useful in studying human sciences (see Sibatani, 1990). This is therefore neither bottom-up reductionism nor top-down holism. It is simply an attempt to reverse the dehumanizing of biology through the monopoly of reductionism.

I wish to stress that this is by no means the same as anthropomorphism in biology, which I understand is a metaphor rather than a recognition of the categorical equivalence between human and non-human systems. Instead, I wish to examine whether the same type of structure maybe found equally in both purely biological structures and those underlying human mind or brain activities including language (see for example, the genetic code *versus* language — Sibatani, 1985, 1989). In other words, I am trying, in contrast to the tradition of underestimating biological processes among biologists, to overestimate them quite deliberately; the effectiveness of this attitude is now supported empirically in different fields of biology (Albrecht-Bühler, 1986; Seyfahrh, 1987). The rather sweeping designation of reverse-reductionism here is a reflection of my eagerness to see what will result from this venture. Of course, the view obtained through such an exercise should be tested against the reality of biological processes, and that will ultimately decide whether the present pursuit is worth continuing.

Structure and its configurations

Structure may take up multiple configurations within the range of its own rules (Ikeda, 1988). We may have a transformation between configurations, but not between structures. A structure should never change but new structures could simply emerge, though probably only very rarely. For instance, traffic rules were traditionally defined in two dimensions, and have materialized in two configurations: the left-side and the right-side traffic. They are mutually incompatible but transition from the one to the others has taken place in recent history (once in Sweden and twice in Okinawa). However, the three-dimensional traffic rule has come into effect only after introduction of aviation, but it cannot be transformed or reduced into a two-dimensional one. Hence these two sets of rules represent separate independent structures. This suggests the way in which a new structure may come into existence. The three-dimensional traffic rule obviously has an additional component, the third dimension in which vehicles can move.

Structure is heritable through dynamic processes

In biology, developmental genes must always co-operate, during the course of ontogeny, to produce a functional organism. In *Drosophila*, about 50 so-called developmental genes in five groups controlling the mode of gene expression and cellular interaction are integrated to work together in a well-organized order (Ingham, 1988). We thus see that those genes are bound by a perpetual and integrating structural relationship. A diversion from such a binding relationship on the part of any gene would lead to a failure to produce a functional organism, resulting in a lethal mutation. Thus, the hidden or deep-seated, hardly visible structure holding the genes together must be dynamically maintained over many generations through interactions among the component genes to produce the functioning organisms. Moreover, such a structure must survive unscathed upon speciation which usually need not bring about any drastic change in the body plan. Although such a structure remains largely invisible, it should be much more stable than a genome, a cell, a multicellular eukaryotic organism or even a gene reproduced over many generations.

Therefore, structure seems to be dynamically and integrally maintained through interactions of its components (possibly inclusive of many

entities and processes other than genes) defined and bound thereby (Saussure's synchrony). In this sense, certain structures (in our sense), other than DNA, must also be recognized as hereditary.

A given structure logically anticipates all of its possible configurations at its emergence

Once a structure is defined, it logically determines all of its possible configurations whether they are categorically realizable or have already materialized. Many configurations of a given structure thus wait for their actual materialization in evolution. Ikeda (1989) has clearly defined two separate aspects of evolution. One is the change in configuration of a given structure. The other is the emergence of a new structure. While all the events of the former may be conceived as anticipated at the outset, how a given configuration actually comes to materialize in the course of history and of evolution cannot be predicted. This corresponds to contingent processes in evolution. Furthermore, there could be many different possible courses to produce a certain configuration through transformation. The actual course taken may signify a phylogeny, but from the viewpoint of structures and configurations, actual phylogenetic lineages are as contingent as the events which have come to bring about these transformations. Any two configurations may be logically close to each other but may materialize only at remote places and separate times. In an extreme case, an identical configuration may be produced more than once within the framework of a given structure, although the complexity of most structures may make it highly improbable that such a logically possible course actually takes place. Obviously, we have to override, in our thinking, the principle of parsimony, which has recently been repudiated by Hall (1988) on an experimental basis.

By contrast, the emergence of a new structure cannot be anticipated in principle. Above all, the structure is arbitrary so that any modification of the rule or addition of a new component in the rule does not logically follow from the existing structure; hence an emerging structure is irreducible to any existing biological structures or else physical laws.

In this context, variation of forms in a given phylum or any other higher taxa may represent configurational changes within a given structure, whilst the emergence of higher taxa charged with independent rules or relationships among their components or loaded with newly substantiated components, must be visualized as emergence of a new structure. Most evidently, emergence of organisms, emergence of eukaryotes or multi-

cellular organisms and emergence of language during the course of organic evolution may be regarded as events which definitely introduced new structures. Obviously, such an emergence cannot be explained or predicted in terms of preexisting structures.

Quiescent genes and cryptic phenotypes

I will now turn to the reality of biological processes. I can enumerate a large number of quiescent genes and cryptic phenotypes for given taxa, pointing to the existence of invisible structures beneath the surface characters (including active genes) of an organism (also see Sibatani, 1989). Among quiescent (or quasi-quiescent) genes one may count the haemoglobin gene in non-leguminous higher plants (Bugosz *et al.*, 1988); enamel protein genes in birds (Kollar and Fisher, 1980); quite a few non-functioning genes for sugar utilization in bacteria (Cairns *et al.*, 1988; Hall, 1988). Since these quiescent genes are not inactivated like pseudogenes, they are either protected by an unknown mechanism from inactivation by genetic drift (Kimura, 1983) while being maintained in a really non-functional state; or else they may be either functioning very weakly, or in some other ways than the ones known to us. In both cases, we will again decline to think according to the principle of parsimony (see above). The presence of such quiescent genes points to a structure which binds the existing genes, hence it is more essential in heredity than the presence and functions of individual genes. Certain features appear repeatedly but discretely in taxa belonging to different groups, suggesting that they share a common generative mechanism, which may or may not be expressed in individual taxa (see, for example, Garcia-Bellido, 1983).

On the other hand, there are many examples in which organisms belonging to a given taxon suddenly exhibit an unusual character, often observable in other related organisms, which are so well co-ordinated that it is inconceivable that they are obtained by a single mutation, and which even occur simultaneously in many individuals so that the hypothesis of mutations is excluded from the outset. Among these I shall count the cactus growing into the form of ordinary plants in humid environment (Sibatani, 1989); occasional emergence of atavism in various organisms such as horns in horses or hind limbs in seals (Ohno, pers. comm.); brood-parasitic behaviours in the chick of various non-parasitic birds (Alvarez *et al.*, 1976). These examples, together with others to be described below, again clearly indicate the existence of invisible structures which organize individual processes and, when a favourable

situation arises, suddenly materialize its hidden capacity, which is there without undergoing actual use.

"Hyponica" tomatos

Recently, a new plant technology called *Hyponica* has been developed in Japan, which involves nothing like gene manipulation (Nozawa, 1985). The effect must be fully environmental, as in the aforementioned case of the cactus. It is a water/air-controlled cultivation from seedlings, using an electronically regulated, ordinary mixture of inorganic salt solutions recycled to the root for optimum utilization of nutrients, without any hormone treatment. Various, mostly annual plants, including tomato, melon, cucumber and many other broad-leaf vegetables as well as some cereals, can be quickly grown, often into a tremendous size. For example, a tomato plant typically grows in eight months to a stem diameter of 20 cm at the base, the supraterrrestrial part spreading over 10 m in diameter, and bearing 10,000 fruits, all of excellent quality in respect of size, content of nutritional material (sugar, vitamins, etc.), colour, flavour and texture. Moreover the plant, which is never pruned, inclusive of its parts in the shade, can vigorously grow all the time as long as the space allows, over any number of years (i. e. it is no longer an annual plant), eventually to 6 m high, thus actually growing like a tree, in a remarkably healthy state, tolerating high temperatures (50-60 °C) at the top part of a green house, and totally resistant to microbial diseases and infestation of insect pests. In these points the "*Hyponica*" plants are quite unlike super-animals produced by gene manipulation, which show various defects in high frequencies even if they grow into giants (Webster, 1989). Induction of those "new" or previously unobserved characters in "*Hyponica*" plants is totally due to environmental effects (mainly due to the removal of mechanical hindrance of root growth by the soil with all its chemical and biological involvements). The plants used are ordinary varieties, having never been conditioned or selected over generations to show such new characteristics.

These observations would indicate that organisms are much more than what they appear, concealing many different abilities, and such hereditary endowment having never been used to the full in their history of existence. This would mean that the structure specifying a species is something much more than the total sum of the ordinarily manifested traits of the species. In other words, organisms show only a part of their real

ability determined or allowed by their hereditary or innate endowment. Incidentally, the same holds well with human beings as evidenced by the extended performances of those people who suffer from inborn physical deficiencies.

Obviously, those abilities of *Hyponica* plants could not have been acquired through mutation and natural selection. The structure allowing their manifestation must have been there cryptically all the time from the very beginning of higher plants, but never having had a chance to find the space/time adequate to unfold its full generative capacity.

Cave fish

A Mexican fish, *Astynax mexicanus* is known to occur in two typical forms: one lives in rivers and has normal eyes; the other one (the so-called Anoptichthys) living in caves is totally blind. Although adults of the latter population have only rudiments of the eyes concealed internally, the eye starts being formed almost normally at early stages of embryogenesis, and only later becomes suppressed (Peters and Peters, 1973). This is another example of crypticism but complementary to the preceding ones, in the sense that the apparently negative characteristics are generated through a secondary arrest of a normal positive process which is well maintained in spite of its apparent abortive course. Crosses of those two populations give fertile hybrids, but the parent characters do not clearly segregate in the F₂. An intermediate population is known, which is blind but with eyes that have degenerated to lesser extents, and which are extremely variable and often exhibit in bilateral asymmetry. All these findings may be explained by a polygene model (Peters, 1988), but we must keep in mind that, in spite of the recent progress in molecular genetics, virtually nothing is known about the molecular basis of polygenes. The presumably recent isolation of the cave population is inferred from the good cross-fertility of the river and cave populations, so the genetic change into blindness must have occurred very rapidly. This has led to the interpretation that the evolution of the cave population could not be due to the result of natural selection but to the high mutation pressure due to the unusually high rate of mutagenesis in the polygene system involved (Peters, 1988). Moreover, eye formation in this and related cave fish is known to be enhanced by light (Peters, Scholl and Wilkens, 1975). Thus, whether genetically controlled or environmentally induced, variable features governing eye formation are primarily generated by the underlying structure and peripherally modified to become innate or envi-

ronment-dependent. In the light of recent findings in bacteria (Hall, 1988), the whole phenomena may be viewed from a new angle of directed or anticipatory genetic changes.

Bird songs and migration

Two impressive examples of the variation between the innate and environmentally induced nature of a complex ability as encountered in different taxa may be found in singing and migration of birds. As for a bird's ability to sing, there again seem to be two extremes with respect to the extent to which the ability is innately endowed. Thus, in his classical work Sauer (1954) reported that, in complete sound isolation from the egg stage, and even under deprivation of auditory perception, the common whitethroat (*Silvia communis communis*) developed its male songs completely innately, and that the functional songs for courtship and territoriality which the experimental birds later developed were the derivation of its autonomously generated early songs which may be regarded as a kind of self-expression (Portmann, 1960). Sauer's work did not make use of modern spectrographic recording techniques and hence should be interpreted with caution, but the main fact still remains that for this species, the male bird could innately develop the ability to sing, without auditory exposure to its own songs or those of other conspecific birds.

It is known further that, in a number of birds other than the common whitethroat, the autonomously acquired ability to sing in general can be fully developed without acoustic perception (Eibl-Eibesfeldt, 1976). At the other end of the spectrum of innate *versus* acquired ability, there are canaries. They acquire new songs each year, and this remarkable ability seems to be due to another remarkable ability of its brain to co-opt newly dividing cells in the zone overlying, and then migrating into, the higher vocal centre of the avian brain to compensate for the death of old nerve cells (Nottebohm, 1989). Between the extremes of innate self-expression on the one hand and post-natal acquisition and elaboration of expressibility through various social or physiological activities on the other, there seem to be, among birds, many intermediate stages which mix innate and acquired abilities to articulate their songs. As is admitted by Eibl-Eibesfeldt (1976), the acquisition of songs by learning seems to be, in some species, obviously limited by the species-specific pattern. Behind the ability of a bird to learn songs, we have to assume the existence of complex innate framework (structure) which enables them to learn relevant songs, as in the case of human learning of native languages (Chomsky,

1968). This view is favourably supported by the work of Hultsch and Todt (1989) who discovered that the learning ability of a nightingale had been underestimated: the young birds seem to be able to memorize songs to which they are exposed quite readily. This would suggest that they simply "learn" the songs through allowing the preexisting structure to materialize, the tutor's songs serving only as the trigger to unleash manifestation of existing configuration of the innate structure. This point would be verified if learning a particular "dialect" only in part would lead the bird to develop the rest itself.

Situations concerning migration of birds again appear to be similar to bird songs. We have a whole spectrum among different bird species, from a completely innate migrator to an obligatory learner for long-distance traveling behaviour (Sutherland, 1988).

Eusocial behaviour — independent evolution or preexisting structure?

Lastly, I wish to discuss some aspects of eusocial behaviours. The most well known neo-Darwinian theory of eusocialization is that of Hamilton (see Grafen, 1985) using the concept of kin selection and inclusive fitness. This theory is concerned with the evolution of eusocial and altruistic behaviours of the non-reproducing workers, which, without mediation of inclusive fitness, could not readily be explained in terms of natural selection of the replicates of the "altruistic" gene in the progeny population. However, the theory has not enjoyed full support from the experimental evidence. To mention a few rather powerful incompatible lines, firstly there are collaborating workers of a swarm in three wasp species, which have been shown to have low relatedness of productive females that take up the role of workers (Queller, Strassmann and Hughes, 1988). In a leaf-cutter ant, there are foraging specialists among unrelated co-foundresses, but their various features are contrary to the predictions made from the neo-Darwinian social competition theory (Rissing *et al.*, 1989). There is also a species of ponerine ant which has lost the queen — caste but whose workers are all potentially reproductive, but become egg layers only if mated, in a short season, by numerous males who encounter only a sample of workers to mate. There is no evidence for the genetic relatedness of the workers because a large number of males and fertilized females are present in a nest, without overlap between successive generations (Peeters and Crewe, 1985).

It becomes evident, by these comparisons, that the evolution of euso-

cial behaviours cannot always be explained by inclusive fitness. In socio-biology it has become a cliché to state something to the effect that eusocial behaviour has evolved independently at least 13 times in different monophyletic groups of Hymenoptera through the mechanism of kin selection of the gene for altruistic social behaviour of the workers. Similar expressions are often made to explain parallel appearances of some trait. Again, using the structuralist way of thinking, our argument may take an entirely different line. The eusocial behaviour has been based on the deep-seated structure, or heredity in the broad sense, for certain insects or any other animals including mammals, in which the behaviour might have emerged originally as the spontaneous surface phenomenon generated from an arbitrarily originated deep-seated structure.

It is well known that in some species of birds or hymenopterans, abilities discussed above are genetically controlled in the sense that they are innate and appear without imprinting in young animals, whereas in other species they must be environmentally induced, by their congeners or conspecifics. It appears as though the structure eliciting such behaviours is there already before they started showing such behaviour. The behaviour may have appeared in appropriate niches without gradual accumulation, but by a kind of postadaptation, i. e., quite perfect from the beginning without practice, however strange this might seem.

Conclusion: towards the origin of structure

The way of seeing does not, of itself, lead to the immediate solution of the problem. It simply means a reorientation of our scientific thinking, which is here about ontogeny, heredity, behaviour and evolution. We are still largely ignorant how to approach the problem scientifically. Just as we largely do not know how various functional macromolecules have appeared in primaevial organisms in the first place, we do not know how such a perfectly working structural relationship could have emerged. The problem of emergence of a structure also applies to the emergence of a language (or languages). The ability of using and understanding the language — Saussure's (1972) *langage* or the language faculty of Chomsky (1986) — must have preceded the actual emergence of the language. It may help if we could identify some very simple structure on which we can start analysing its properties and its emergence.

The language may be viewed to have arisen as a means of self-expression (Mathesius, 1961) rather than of communication. Drunken persons tend to euphorically shout without much verbal message to convey. Hu-

man utterances of joy, agony, pain or sexual ecstasy may also belong to the category of self-expression. These facts suggests that self-expression may well have preceded information transmission in human utterances. A structure, the existence of which we can only infer, may have emerged, all at once in its simplest but already perfect form in the sense of synchronicity of Saussure (1972), for some end other than what we envisage today. Hence the historicism of neo-Darwinism to explain the teleonomy is declined at the very root by structuralist thinking. Instead, I wish to focus on the point that all the surface phenomena have been logically defined in terms of this or that configuration of a structure, once the structure comes into existence.

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